AVIATION ENGINEERING

50

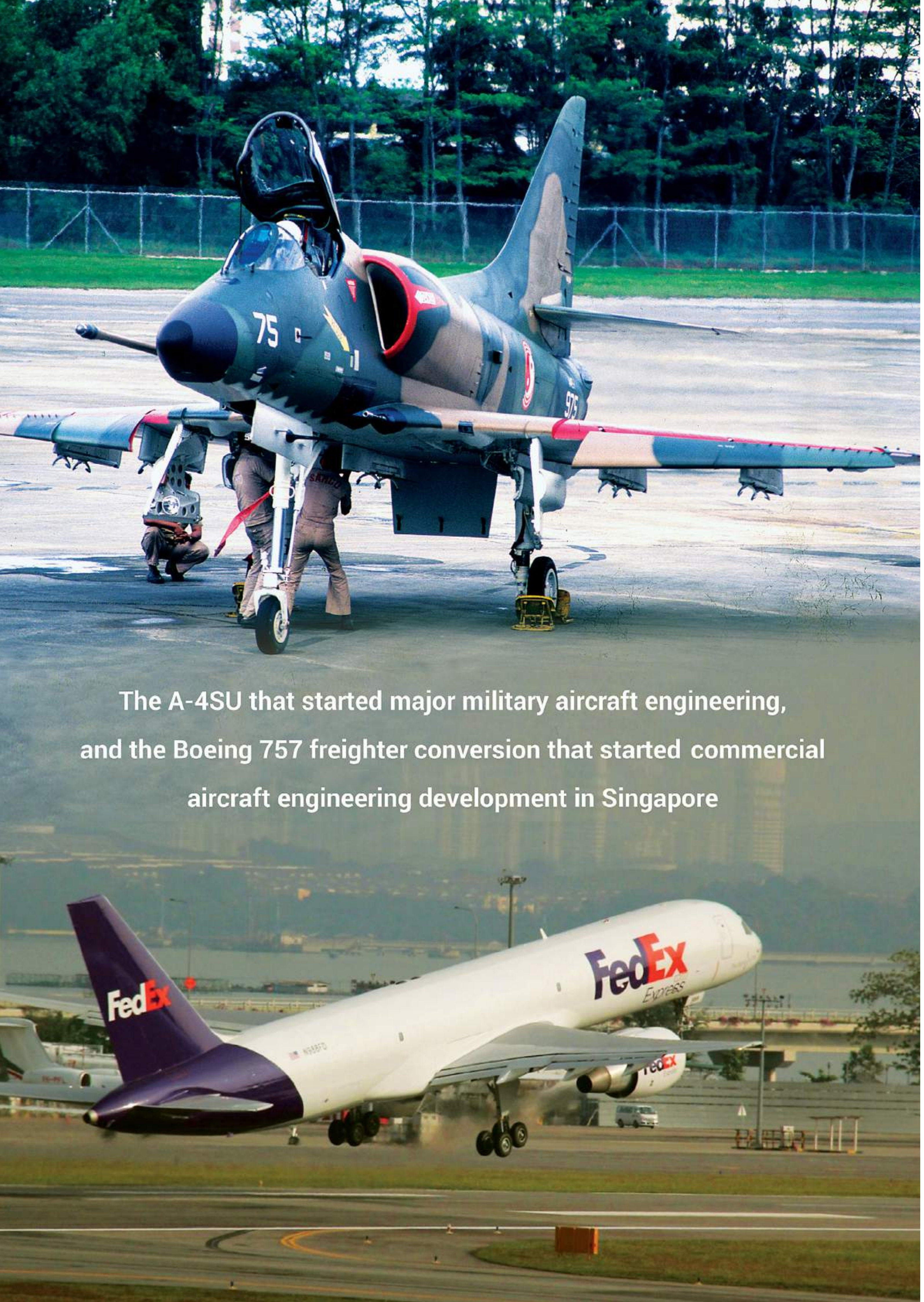
> *"DTC IS THE SECRET-EDGE WEAPON OF THE SAF"*

DR NG ENG HEN
MINISTER FOR DEFENCE

DEFENCE
TECHNOLOGY
COMMUNITY
50th ANNIVERSARY

ENGINEERING SINGAPORE'S DEFENCE — THE EARLY YEARS

DTC IS THE SECRET-EDGE WEAPON OF THE SAF



The A-4SU that started major military aircraft engineering, and the Boeing 757 freighter conversion that started commercial aircraft engineering development in Singapore

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FOREWORD

The journey of Singapore's Defence Technology Community (DTC) parallels that of the Singapore Armed Forces (SAF) – indeed both were co-dependent and iterative processes which fed off each other's success. Pioneers in both communities recognised very early on the stark limitations of a small island with no geographical depth and limited manpower. But despite this realisation, they were undaunted and shared a common resolve to mitigate Singapore's vulnerabilities and constraints, and build a credible SAF through sheer will, commitment and the harnessing of the powers of technology. In Dr Goh Keng Swee's words, "we have to supplement the SAF's manpower with new technology, as manpower constraints will always be there. Our dependency should be more on technology than manpower. And we must develop indigenously that technological edge." As worthy and important as these ideals were, it was an arduous journey for the DTC. With poor standards of general education, let alone engineers or scientists, how could Singapore develop such capabilities?

This book series chronicles the last 50 years of that ascent that begun in 1966. The DTC has indeed come a long way from its humble beginnings and with it, a transformation of the SAF's capabilities. Today, both the SAF and the DTC are respected professional bodies and the requests from advanced economies to collaborate reflect the standards which we have achieved. Our closely-knit community of defence engineers and scientists stands at the frontier of technological progress. Indeed the DTC is the secret-edge weapon of the SAF.

As the DTC celebrates its 50th anniversary, we want to thank especially its pioneers who were committed to achieve the unthinkable and were not daunted by severe challenges along the way. Their efforts and beliefs have spawned world class agencies such as DSTA and DSO, and the family of Singapore Technologies (ST) companies.

More hearteningly, the virtuous effects extend into mainstream society too. Today the defence cluster of DSTA, DSO, MINDEF, the SAF and ST employs the largest proportion of scientists and engineers in Singapore – almost one in every 12! It is not an overstatement that these entities have been the main receptacles to maintain the science and technology capabilities in our nation, providing life-long careers in the process.

Beyond defence, the DTC has also positively impacted our society in a variety of ways: in producing mass thermal scanners to combat the 2003 SARS outbreak, in designing and building the iconic Marina Bay Floating Platform to host the National Day Parades and sports events, in breaking new ground and old mindsets when we built the underground storage for munitions, in forming the nucleus to start the MRO (maintenance, repair and overhaul) industries to service airlines in Singapore and globally.

The stories that are told in this book series should lift the spirits of Singaporeans, old and young. They celebrate what pioneers and successive generations of committed scientists and engineers have accomplished over the years. But they also give hope to our future, as they will serve as reminders during difficult times to overcome challenges and continue to keep Singapore safe and secure for many years to come.

Dr Ng Eng Hen
Minister for Defence
Singapore

MESSAGE

The Defence Technology Community (DTC) has steadily evolved over the last 50 years. We started off as a small, three-man technical department in the Logistics Division in 1966 supporting defence equipment procurement and there was much work to be done. The Army then was largely equipped with second-hand vehicles and surplus equipment left by the British. The Republic of Singapore Navy (RSN) had two boats, one steel and the other wooden. Recognising the need to overcome the immutable challenges of geography and resource constraints facing Singapore, we extended our scope to include conceptualisation, development and upgrade of defence systems. These efforts leverage the force multiplying effects of technology to meet the unique challenges and operational requirements of the Singapore Armed Forces (SAF), beyond what could be had buying off-the-shelf.

This four-book "Engineering Singapore's Defence – The Early Years" series covers the entire spectrum of the DTC's work in the land, air and sea domains to deliver cutting-edge technological capabilities to the SAF. It chronicles our 50-year journey and documents the largely unheard stories of our people – their challenges, struggles and triumphs, their resolve and ingenuity, and their persistence in overcoming the odds. These stories include:

- The upgrading of the French-made AMX-13 light tank to the AMX-13 SM1 configuration by the DTC, the Army and ST Engineering, laying the foundation for the design, engineering and production of the Bionix, Bronco and Terrex armoured fighting vehicles for the Army.
- The integration of the RSN's missile gunboats and missile corvettes which built up the DTC's confidence to move on to specify and acquire best of breed systems to integrate into new ships like the frigates. It also laid the foundations for ST Engineering's capabilities to design and build ships for the RSN and some other navies.
- The conversion of old US Navy's A-4 Skyhawk aircraft into the A-4SU Super Skyhawk for the Republic of Singapore Air Force, building up ST Engineering's capabilities to undertake further aircraft upgrades such as for the F-5E Tiger fighter aircraft, and to undertake servicing and repair of commercial aircraft.
- The system-of-systems integration efforts to evolve the island air defence system, building on legacy systems left by the British to seamlessly incorporate new weapons, sensors, and indigenously developed command and control systems to extend the range and coverage of Singapore's air defence umbrella, and the build-up of the DTC as a system-of-systems to deliver cutting-edge capabilities and systems to the SAF, and to meet the technology requirements of the nation.

While not exhaustive, these stories provide us with a glimpse of the "dare-to-do" and enterprising spirit that our DTC personnel and forerunners possess.

There is no end to change and transformation. Singapore and the SAF will continue to face many challenges in the years ahead. However, with the capabilities and expertise developed over the years in its more than 5,000-strong personnel, and its established linkages with renowned R&D partners locally and around the world, I am confident that the DTC will remain steadfast in delivering the critical technologies and innovative solutions for the SAF and the nation. May the stories in these books inspire our current and future defence engineers and scientists to continue to push boundaries and think creatively to deliver capabilities that will safeguard our sovereignty for the years to come.

Ng Chee Khern

Mr Ng Chee Khern
Permanent Secretary (Defence Development)
Ministry of Defence, Singapore

PREFACE

What this book is not. This book is not a history book per se. It will not go into detail just for historical accuracy and the coverage will not be to present information from a time domain consideration. The information included only relates to the issues covered.

This book captures and shares with the readers the experiences that led to the build-up of aviation engineering capabilities in two Singapore organisations which are important parts of Singapore's collective history in celebration of Singapore's 50th Anniversary in 2015, and the Defence Technology Community's (DTC) 50th Anniversary in 2016. The two organisations are the Republic of Singapore Air Force (RSAF) and ST Aerospace.

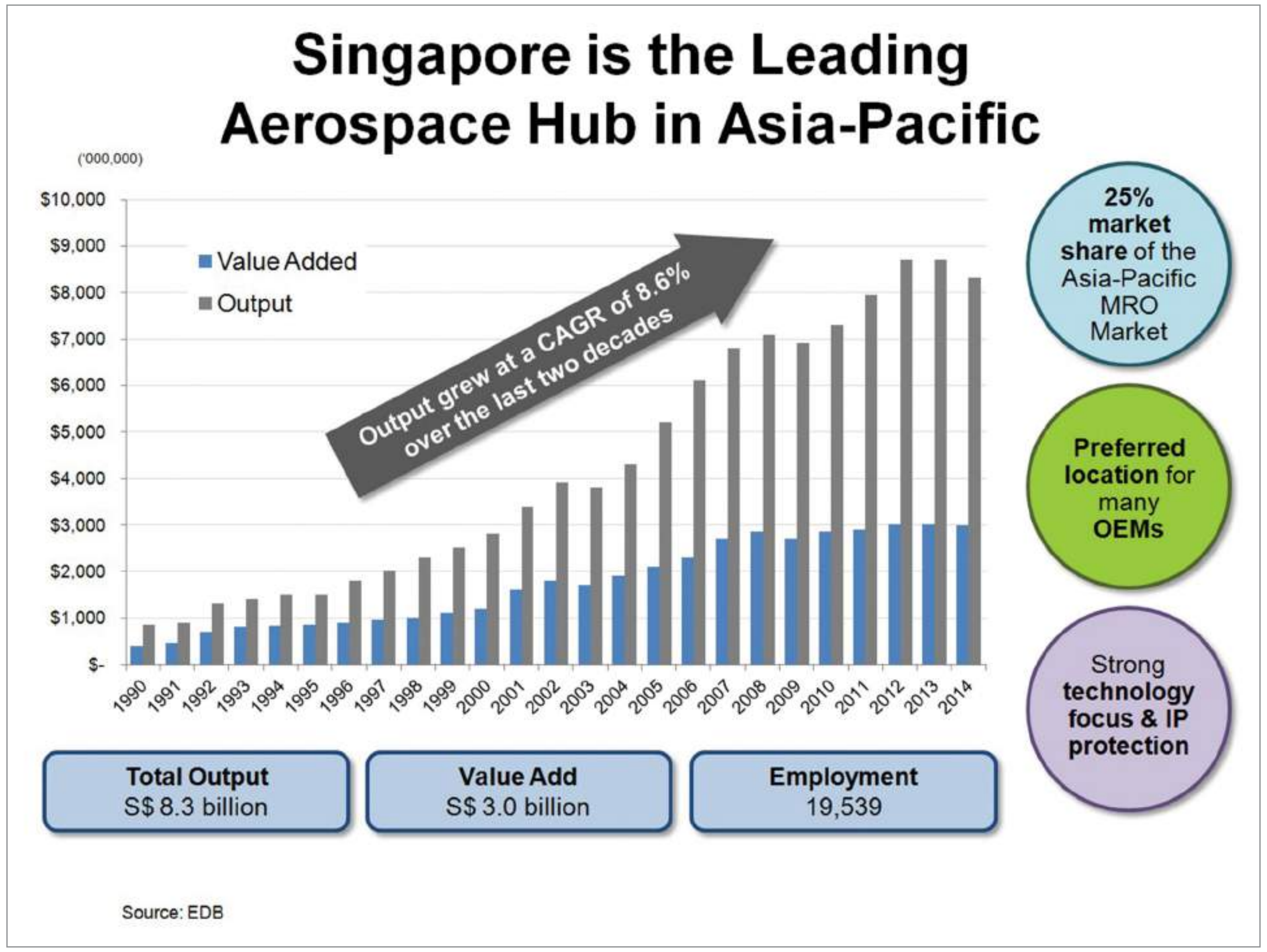
This book is a combined effort by a team of people who were personally involved with the experiences shared herein over much of the period covered by it. Some are still very actively involved in the two organisations mentioned! Their valuable support to make the book possible is recognised and deeply appreciated.

Aviation has always been important to Singapore.

As an island state, air connection with the world is important for the efficient and rapid transportation of people and high-value goods. Recognising this, Singapore has focused much attention on aviation, aviation infrastructures and aviation industries to ensure they remain a competitive segment of Singapore's economy. As a leading air transportation hub, Singapore has more direct flight connections to countries in Asia and beyond than most other countries.

Defence has always been a priority to Singapore. It assures not only Singapore's survival from military threats but also its economic viability to investors. One important dimension of defence of Singapore is the Singapore Armed Forces (SAF). Speed, flexibility and immediacy of response is important for the armed forces of a small nation like Singapore. Having a capable air force is key to this. In the formative years of the build-up of Singapore, the interest in aviation manifested itself through national defence and air transportation. Two institutions of Singapore that resulted were the RSAF and Singapore Airlines (SIA). Today, the RSAF is a leading air force, amongst air forces globally, and SIA has attained a recognised leadership position and image amongst airlines internationally.

Over the years, another dimension of aviation, the aviation industry of Singapore, has also grown to become an important component of Singapore's economy and of the global aviation maintenance, repair and overhaul (MRO) industry.



Growth of Singapore's aviation industry
(Source: EDB)

From an economic point of view, the aviation segment has experienced a compounded annual growth rate (CAGR) of about 8.6% over the last 20 years. It provides employment for some 19,500 people and contributed a total annual output of S$8.3 billion to Singapore's economy with a value-add of S$3 billion in 2014 (according to the Singapore Economic Development Board. This value excludes airline operations cost, military aviation expenditure, and airports operating and fuel cost).

This aviation segment of the industry has traditionally been focused on MRO. Its significance is reflected in that Singapore currently has some 25% of the MRO business in Asia-Pacific. This includes the MRO business of major local companies such as ST Aerospace and SIA Engineering Company, many of the leading global commercial aviation original equipment manufacturers (OEMs) with significant operations in Singapore, and other aviation MRO and engineering companies. 90% of the aviation business in Singapore is currently in MRO with 10% in manufacturing.

In recent years, emphasis has been placed on expanding the scope of this segment of business to new products development and high value-add manufacturing. Some of the more visible illustrations of this outcome were the opening of the Rolls-Royce plant in Seletar Airport during the 2012 Singapore Airshow, which assembles the Trent 900, Trent 1000 and Trent XWB engines as well as produces the Trent Wide Chord Fan Blade. This was followed in the 2016 Singapore Airshow by Pratt and Whitney's launch of its manufacturing facility for its Geared Turbo Fan parts such as Hybrid Aluminium Fan blades and the High Pressure Turbine Disks. These not only add to the high value-add manufacturing segment of the economy but also the diversification in the aviation manufacturing segment. From an overall perspective, the hope is to achieve a more balanced MRO versus manufacturing portfolio without diluting the MRO market share in the coming years.

Focus of this Book

In the Singapore context, aviation engineering covers a very broad scope which includes defence and commercial aviation engineering (each includes development engineering), manufacturing and MRO engineering, and research in aviation engineering.

This book focuses on the build-up of aviation engineering experience and capabilities in two organisations, the RSAF and ST Aerospace. The growth of engineering capabilities in these organisations share a common origin and, while they continue to share joint interests in areas relating to aviation engineering for defence, ST Aerospace has, in addition, significant interest in commercial aviation engineering. Their scope of engineering work is broad, and covers important sub-sets of the aviation engineering activities in Singapore.

Through this book, we hope to capture and share with all Singaporeans some important and interesting aspects on the development of these two Singapore organisations; the experience they went through and how they evolved to what they are today. These include stories of the aviation engineering group behind the RSAF, a leading and well-respected air force globally and, the other, a commercial aviation maintenance and engineering company from Singapore with global reach and significance in the commercial aviation world, which started as the aviation depot for the RSAF and has a continuing responsibility and commitment to support Singapore's defence needs.

The aviation engineering work of these two organisations covers engineering in support of MRO: upgrading of aircraft, engines and components; engineering design and development work for upgrade of aircraft; programme management; system acquisition; new products development and applied research for both commercial and military aviation.

Military Aviation Engineering

This write-up on the build-up of military aviation engineering expertise in Singapore will focus on the period from 1972. Although Singapore became an independent nation in 1965 and the RSAF started off as the Singapore Air Defence Command (SADC) in 1968, it was only in 1972 that the RSAF assumed responsibility for its own military aviation engineering with the formation of an Air Engineering Department in HQ SADC.

The set-up of the local military aviation industry to support the RSAF was an integral part of the masterplan to ensure that the RSAF would be well supported not only through its internal logistics and engineering capabilities, but also by a complementary defence industry operating on strictly commercial business lines. ST Aerospace started out in 1975 as the aviation depot for the SADC's first fighter jet, the Hawker Hunters, and subsequently undertook the refurbishment and upgrading of the A-4 Skyhawk aircraft during its early days to support the growth of the RSAF.

As the RSAF evolved from its early years' focus on training of pilots and build-up of enabling capabilities to build up an operational air force, the demands of support from its industry partner, ST Aerospace, increased. Besides undertaking more complex MRO, ST Aerospace stepped up to the requirements of the RSAF for advanced military technologies and engineering capabilities to upgrade its fleet of aircraft over the years.

Starting with its first major engineering undertaking, the upgrade of the RSAF's old Skyhawk fleet to the A-4SU Super Skyhawk, ST Aerospace grew its engineering capabilities to become a full-spectrum aviation engineering company over the last 40 years, with both engineering hardware and software competencies. Despite the A-4SU being the first major upgrade programme for Singapore, and a very significant one in scope and complexity, the upgrade was a resounding success through the efforts, initiatives and capabilities of the engineering team.

Through this and many other subsequent upgrade programmes on various RSAF's aircraft platforms to meet new mission requirements, many engineering skills and capabilities were built up in the RSAF and ST Aerospace. Besides delivering cost-effective solutions to meet Singapore's defence requirements over the years, the engineering knowledge and experience gained by its engineers have been also useful and necessary to support new aircraft acquisition programmes for the RSAF and through-life support of the upgraded aircraft.

This successful outcome was achieved through the partnership between the defence engineers in the RSAF, the Defence Science and Technology Agency (DSTA), the DSO National Laboratories (DSO) and ST Aerospace. Under this partnership, engineers played complementary roles to provide the skill sets and capabilities needed to support the RSAF's fleets of aircraft efficiently and cost effectively through their life cycles. This capability provides one of the pinions that enabled the RSAF to become a leading air force.

Commercial Aviation Engineering

Meanwhile, in the late 1980s, the possibility for growth into commercial aviation MRO surfaced. In 1982 the "aviation companies" of the Sheng-Li group of companies, under the name "Singapore Aerospace" was listed in the Stock Exchange of Singapore. Following the listing, it leveraged its aviation MRO capabilities to support regional air forces. In the late 1980s it ventured further into commercial aircraft maintenance with the set-up of wholly commercial MRO companies in Singapore and overseas.

In 1997 Sheng-Li decided to delist four listed defence-related companies undertaking aviation, electronics, automotives and shipbuilding engineering in its group and re-list them as ST Engineering on 28th August 1997 as each was, on its own, deemed too small and might benefit from leveraging as a group. The aviation company of ST Engineering is ST Aerospace.

In addition to its support of the RSAF, ST Aerospace grew rapidly from 2000 and expanded its network of companies in Singapore and globally to the US, Europe and China. Its commercial airframe business became recognised as the largest commercial aircraft MRO group in the world in a survey by Aviation Week & Space Technology in 2002, just 12 years after it started commercial aircraft MRO, and has remained so ever since.

ST Aerospace also grew its components and engines business on the back of its Power-by-the-Hour (PBH) programmes, which was one of the early pioneers of this business concept in the early 1990s. And, in recognition of the emerging significance of low-cost carriers (LCCs), it built up business models, including Total Aviation Support, to address the requirements of LCCs. Beyond its recognised lead position in commercial aviation MRO for legacy and freight airlines, it is also a major player in the Low Cost Carrier (LCC) market.

Leveraging its military aviation engineering capabilities, it went into commercial aviation work which has more engineering contents, starting with the Section 41 Termination work on the Boeing -747 -200/300 and Passenger-to-Freighter (PTF) conversion. It established a strong reputation for good performance in the commercial aviation industry through these two major early initiatives. Following this it went into engineering design and development of PTF for the B757, and now the Airbus A330.

Engineers and engineering capabilities enabled the Singapore Ministry of Defence (MINDEF), the RSAF and ST Aerospace to achieve many successful outcomes on both its military and commercial aviation engineering initiatives. This contributed to the RSAF becoming a leading air force and ST Aerospace becoming a global aviation services company within a short span of 40 years.

Chapter 1 will share the beginnings of this journey. Chapter 2 elaborates on the early initiative of the RSAF and ST Aerospace into MRO and engineering work, and Chapter 3 on some of the major milestones that were achieved over the years in military aircraft upgrading, in acquiring capabilities on surveillance, rotary and unmanned aircraft, and going into commercial aviation MRO and engineering development work. As a result of the work undertaken, many capabilities were acquired and developed, and some of these are detailed in Chapter 4 titled Processes and Products – Processes as in capabilities that could be leveraged and applied on future engineering and maintenance undertakings and Products as in delivered end products like an aircraft component such as a mission computer or part of an aircraft like the EC-120 and even an aircraft, albeit unmanned.

From where they were in the early days of Singapore, the efforts of engineers have enabled the build-up of capabilities in both military and commercial aviation engineering to support the operations of the RSAF and ST Aerospace today. The book will endeavour to capture the challenges that were overcome in the journey of both organisations over the years.

What the future holds is anybody's guess. However, while both the RSAF and ST Aerospace are in better positions than where they were in the early days, the challenge may be steeper in the years to come because of the naturally higher expectations and more demanding external environment. The outcomes that have been achieved are results of the efforts and contributions of engineers and other stakeholders of the RSAF and ST Aerospace during this period. Hopefully this book will encourage future engineers to strive to do even better in the years to come.

Mr Tay Kok Khiang
Editor, Aviation Engineering

Chapter One

WHERE WE WERE

Section 1.1
How it all started

As summarised in the preface, this book is about the journey of two organisations in Singapore, the Republic of Singapore Air Force (RSAF) and ST Aerospace, as they went about building their aviation engineering capabilities over the last 40-plus years. Today, these capabilities support a leading air force and are the basis of a leading global independent commercial aviation engineering and maintenance, repair and overhaul (MRO) company.

Chapter 1, "Where we were" is to provide some historical perspective of the two organisations. In this first section, titled "How it all started?", the objective is to share with the reader some snapshots of the origin of the two organisations.

This book is not intended to be a history book; the snapshots are to provide some context for the following chapters of this book. For those interested in a fuller historical documentation of the different aspects of these two organisations, there are various books and reports written over the years which might give a more detailed treatment.

The Republic of Singapore Air Force

When Singapore became an independent nation on 9th August 1965, it was immediately evident to the Government there was a need to quickly build up the Singapore Armed Forces (SAF) as the ability to defend itself was integral to Singapore's survival and future as a nation. The British Government had already announced the withdrawal of its troops east of the Suez by the "mid-seventies". As a result of deteriorating economic conditions back in the United Kingdom (UK), the British Labour Government announced on January 1968 that the withdrawal would be brought forward to end 1971. The air component of the SAF, the Singapore Air Defence Command (SADC), was set up on 1st September 1968, three years after Singapore gained independence.

The SADC formed its first flying squadron, 150 Squadron, in 1969 with the delivery of eight Cessna 172Ks propeller driven trainer aircraft. In the same year, 130 Squadron was formed with the arrival of 16 Strikemaster jet training aircraft. Both 130 and 150 Squadrons were assigned under Flying Training School (FTS) and initially operated from the Royal Air Force's (RAF) airbase at Tengah (RAF Tengah) but later moved to RAF Changi following the arrival of the SADC's first Hunter fighter aircraft at RAF Tengah. In the same year, 120 Squadron was formed with the delivery of eight Alouette III helicopters at RAF Seletar. In the build-up years, the maintenance of these aircraft was contracted to Hawker de Havilland (Australia). The SADC's local technicians were part of the composite work force that worked on the fleet to gain hands-on experience.

The RAF handed over RAF Seletar to Singapore on 16th April 1969. This was followed by the handover of the radar station at Bukit Gombak, HMS Simbang (naval base at Sembawang) and RAF Changi. The RAF's final parade to hand over RAF Tengah to the SADC was held on 15th September 1971.

The RAF's final handover parade at Tengah Air Base in 1971

Thus, the SADC became fully responsible for its own operations, including maintenance support of the aviation assets that it took over from the RAF. Besides its training aircraft and helicopters, these included the surveillance radar at Bukit Gombak, the Bloodhound surface-to-air missile at Seletar and the initial Hawker Hunter fighter aircraft at Tengah.

The Air Engineering Department of the SADC was formed in 1972 and this was the start of military aviation engineering and maintenance in independent Singapore.

As Singapore developed and the demands on the SAF for Singapore's defence increased, the SAF grew to meet the challenge. In 1975 the SADC was renamed the Republic of Singapore Air Force (RSAF) to reflect its emergence as an air force.

In the early years, the operations of the SADC comprised:

Changi Air Base

Changi Air Base started with the operations of the SF 260 Marchetti (which replaced the Cessna 172Ks), the Strikemaster training aircraft, the Alouette III helicopters, and later added the Skyvan and C-130B Hercules transport aircraft.

Changi Air Base was the training, transport and helicopter base.

Strikemaster fleet on line in Changi Air Base

Tengah Air Base

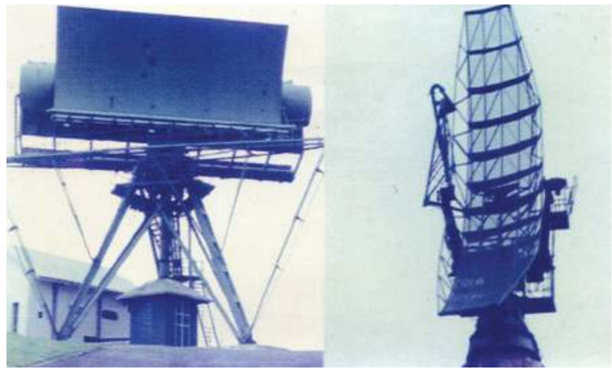
Tengah Air Base operated the Hunter fighter aircraft fleet, the first air defence and ground attack aircraft of the RSAF. A few years later the Skyhawk fleet which was initially being built up in Changi Air Base was transferred to Tengah Air Base.

Hunter aircraft towed into hangar at Tengah Air Base

Tengah was the fighter aircraft base. It was the only operational airbase then with both the main fighter fleets of Hunter and Skyhawk aircraft operating from it.

Bukit Gombak

Bukit Gombak housed the air surveillance radars. With the handover from the RAF in August 1971, it was renamed Air Defence Radar Unit (ADRU). ADRU operated the Marconi long-range search radars, the S316L/S and the S319L, and two HF 200 Height Finders. Later came the TPS 43 radar.



Marconi S316 and Plessey HF 200 radars on Bukit Gombak

AN/TPS 43DX, the RSAF's first 3D radar

ADRU provided air surveillance and controlled the Bloodhound air defence missiles in Seletar.

Manpower Resources, Engineering Manpower

The suddenness of the British pull-out caught Singapore by surprise. The SADC was in its very early days and by 1971 it had only a smattering of engineering manpower, thinly spread throughout its operations. Many of its technical manpower were still under training overseas or had just returned from training.

As mentioned, the SADC's Air Engineering Department was formed only in 1972. Up till the handover by the RAF, the whole engineering responsibility was undertaken by the RAF with British officers and SNCOs (senior non-commissioned officers).

People Then

Just to give a feel on the dependence on "expatriate" management then, in Tengah Air Base all the Engineering Units, even the General Workshop, were managed by expatriate SNCOs. Real control of operations at each work centre was under the RAF "Flight Warrant Officer" for that work centre, which operated under the RAF's concept of operations.

Singaporean officers were hard to come by. In a typical operating base under the RAF managed airbases, the command structure and manning was British officers at the Wing and Squadron levels, and Singaporean engineers (where available) at the Flight level. At the Flight level, the SNCOs were from the UK (seconded from the RAF or ex-RAF servicemen on contract) and the junior ranks from the SAF Technical School which trained Singaporean technicians. In the early 1970s, polytechnic graduates and those from technical schools were also first enlisted as full-time National Servicemen (NSFs) aircraft technicians. Quite a sandwich!

Build Up of Engineer Workforce

As mentioned, the engineering organisation of the RSAF started with the Air Engineering Department of the SADC in 1972. It was responsible for engineering and maintenance matters pertaining to aircraft and other weapon systems operated by the SADC, the "Air Wing" of the SAF. The first Head of Air Engineering was from an airline as there was no aviation expertise within the armed forces.

Up to 1968 some of the early engineers who later served in the SADC had joined the Ministry of Interior and Defence, Logistics Division first. They came in as army officers. They were later transferred to the SADC, which was formed only in 1968. Others were recruited directly into the SADC.

Some engineers from the initial cadre were sent to the UK for the one-year graduate level Applied Engineering (Mechanical) and Applied Engineering (Electrical) courses at the Royal Air Force College in RAF Cranwell. This was to equip the new engineers to undertake engineering duties upon their return to the SADC. Unlike this pioneer batch, later batches of engineers were put on the job soon after they were recruited and thus had to learn on the job. The SADC could no longer afford the luxury of lengthy structured training programmes overseas as there was a pressing demand for engineers to be deployed as quickly as they were recruited in view of the announced withdrawal of the RAF.

Thereafter, the exceptions were the small number of engineers who were sent together with technicians overseas for specific aircraft trade specialisation courses (known as “type courses”) whenever a new aircraft type was acquired. Most of the technical personnel would return to serve in the field, in the airbases and squadrons, but some of the experienced officers (largely technical officers) and technicians were deployed to staff the newly established Air Engineering Training Institute which was inaugurated in November 1972 in recognition of the need to ramp up the number of technicians trained because of the planned expansion of the RSAF.

In 1972, the RSAF inducted its hitherto single largest group of 14 military engineers, fresh after graduating from the University of Singapore. Most were born in 1949. National Service (NS) was approved by Parliament in 1967 and those who were born in 1949 were 18 years old and due to be inducted for NS in 1967. However they were (according to the policies then) allowed deferment from conscription to go to university first. They were deployed to the units on operational appointments although some were on staff appointments at the Air Engineering Department, HQ RSAF.

Between 1972 and 1976, more engineering graduates in small numbers each year were recruited from the University of Singapore and overseas universities, as well as a small number of returned Colombo Plan scholars who were deployed to the RSAF by the Public Service Commission (PSC), the agency that managed government scholarships. The make-up of the engineers was largely from mechanical, electrical and electronic engineering disciplines with the occasional aeronautical engineers which was not common in those days. The concerted push to build up the number of engineers (and technical officers), albeit at modest levels then, and engineering capabilities continued.

So, how was engineering learnt/practised?

Mostly from real-time experiences in operating the fleet of aircraft and air assets in operations then.

MRO experience was gained through solving problems, faced in operations of the aircraft and equipment, on a real-time basis, as and when they occurred! Complex technical problems there would always be in operating any fleet of aircraft, even today. In the case of the SADC, there was another complication from operating used (pre-owned) aircraft and equipment. Singapore was a new nation then and while building up a defence capability was important, the national economy was in its very early days and affordability was an important consideration in the selection of aircraft and equipment types for the SADC.

So, in addition to the normal problems associated with operating any fleet of aircraft or weapon system, there were many situations where the lack of manufacturers support, unavailability of engineering and maintenance data, low level of knowledge due to the very inexperienced staff, and ageing equipment problems further complicated the problems faced by the early engineers.

In several of the situations, with the old aircraft came inherent problems for which the aircraft were "retired" and the RSAF had to “re-learn” lessons on these inherited problems (some examples on this aspect will be illustrated in later parts of this book) after the introduction of the assets into service and find solutions which the previous owners had left unsolved or could not find good solutions for.

Opportunities for learning and building up of engineering experience were, however, very rich as a result.

Standards and Control, Strive for Excellence

The build-up of an air engineering organisation in MRO is not just about building engineering capabilities to recover the assets when they break down. Nor is it just about building up the requisite number of engineers. In the case of aviation MRO, especially, there are some things then and today which have not changed, and that is the culture of maintaining high standards through rigorous control of all maintenance activities. The RSAF understood that and continued to build on this requirement over the years.

The need for higher standards and controls is integral to aviation, both military and commercial. Serious failures in aviation could likely be catastrophic and are usually highly profiled! This naturally led to a requirement for tighter controls, a culture of compliance and adherence to higher standards. This covers the whole gamut from training, qualification and certification of people approved to work on aircraft and associated equipment; controls on suppliers and parts purchased; design, testing and certification of the aircraft and its components; and documentation and traceability. Compliance is expected and mandatory.

While compliance has always been a requirement, it is not sufficient by itself. To really do well, the organisation in aviation MRO has to strive to excel in each of the matters that affects the quality of its work. This is in view that the weakest link determines the strength of the chain.

For both military and commercial aviation, all servicing and repairs have to be strictly in compliance with the requirements of the relevant national aviation authorities(NAAs). The NAA for military aviation are the Air Force itself and the aircraft and equipment manufacturers or what is commonly designated as the "Original Equipment Manufacturers" (OEMs). For commercial aviation the authorities are the civil aviation authorities (CAAs) and the OEMs (who themselves have to meet the CAA’s requirements). Deviations from the requirements, like the very tight tolerances called for in the maintenance manuals, have to be formally “approved” by the OEM of the equipment and the military or civil aviation authority concerned.

The repairable limits in the manufacturer’s approved structural repair manuals are very tight and many repairs cannot be done due to these tight limits. Defects above allowable repair limits have to be relayed to the OEM for recommendations. This is still the practice for civil aviation today. For the RSAF, the approving authority is HQ RSAF. However, in the early days HQ RSAF did not have the right level of manning by experienced personnel to discharge this responsibility and had to depend more on external inputs.

There were advisors and consultants aplenty who had worked with the RSAF and ST Aerospace over the years. They were experienced, capable and highly-committed people within the scope of their specialisations and had contributed to the build-up. But these advisors and consultants could not undertake the responsibility meant for the leaders of the organisation. The organisation had to develop its own capabilities to make major and critical decisions.

In the early days, the RSAF quickly learnt that depending on the OEMs to come up with a repair above the repair limits in the Technical Manual was not the solution as it took too much time, time which the RSAF could not afford as it had training and operations to conduct and limited assets to depend on. To improve on the lead time to a decision, following the induction of more graduate engineers and the gradual build-up of experience, repairs above Technical Manual limits were proposed by the RSAF engineers and sent to the OEMs for endorsement instead of asking them for solutions as was previously done. Such initiatives of the engineers got much faster responses from the manufacturers.

It was also more meaningful to the young engineers then as this was the opportunity to put their engineering education into practice. Most of the repair schemes proposed were approved by the OEMs, sometimes with slight modifications or suggestions. The only problem was that much of the learning had to be self-taught through interpreting the Technical Manuals and exercising one's best engineering judgement.

Air Engineering Department in HQ SADC was also in the build-up stage. As such, it was not well-manned and lacked experienced engineers to deal with engineering problems. The engineering manpower resources then were "fairly distributed" between HQ and operating units. The engineers available at HQ were also more focused on overall policy matters and longer term matters affecting the build-up of the SADC, including provisioning and purchasing of materials. As a result, engineers in the field had plenty of autonomy.

Needless to say, the number of engineers and experience level have increased significantly since the 1980s, especially following the period known as the “A-4 Crisis” in 1985 (see Section 3.1). But this was how it was at the beginning.

Quality Assurance

Quality is always of paramount importance for aviation as it has always been for the RSAF in the early days and for the SADC then. However in the early days, the primary focus was on conduct of training operations, and, quality assurance started as an assurance against discontinuation of flying.

The quality function was exercised through the Quality Assurance (QA) Branch in HQ SADC. Its focus was primarily to follow up on special investigations on serious defects, in relation to aircraft and weapon systems incidents and accidents, especially those with safety implications. In a sense it acted as an independent advisor to HQ SADC, providing a second opinion on adequacy of actions recommended by or decided at the airbases.

When QA was started, it was led by an expatriate officer (a Captain) on contract to the SADC and four expatriate staff from Airworks Services. In 1975, SADC technicians were posted in to replace the Airworks Services expatriate staff. A Singaporean engineer (of about the same experience as the batch of 14 engineers mentioned earlier in this chapter) took over as the SADC's Head of Quality Assurance. QA then became a wholly Singaporean responsibility.

Amongst its functions, QA was responsible for assessing and endorsing "Technical Orders" issued by the air bases. Such Technical Orders were issued to undertake special maintenance actions in response to problems experienced during operations. QA would follow up on these and convert those that it endorsed to Special Technical Instructions (STIs, for one time compliance) or Servicing Instructions (SIs, for periodic compliance).

QA also provided engineering direction on matters that was not part of the regular activities of aircraft maintenance. One such area was quality of aviation fuel which was not a specific field of knowledge for technical personnel trained to maintain aircraft.

In 1978, Air Engineering Department decided it was necessary to exercise more control of the increasing level of engineering and maintenance activities in the field as the fleet of aircraft and flying operations were growing rapidly. Decisions on engineering policies and major engineering decisions were then centralised and controlled through QA in HQ RSAF. (Before that, controls of engineering matters were largely left with the airbases.) This control of engineering policies and practices from HQ was also formalised through the issue of the Air Force’s "Air Engineering Staff Instructions".

At a later stage, as HQ RSAF was more developed and engineering branches were set up in HQ RSAF, the roles of QA and the Engineering and Systems Branches of Air Engineering Department were rationalised. QA then reverted to its assurance role.

Learning from Others

Over the years, the Air Force has always been willing to learn from other more established air forces. From an air engineering perspective, in the initial years most of the learning was from the RAF. This was followed by a period when the Republic of China Air Force (ROCAF) provided the lead. There were also various periods which saw senior seconded personnel from the US Navy (USN), the US Air Force (USAF), the Royal Australian Air Force (RAAF), the Royal New Zealand Air Force (RNZAF) and the Israeli Air Force serving as exchange officers or advisors in the Air Force.

In the initial years, the SADC was organised and operated according to the RAF’s practices due to the extensive influence of the RAF in the RSAF's formative years. Almost all its aircraft and weapon systems were then of British origin.

As the RSAF grew, the fleet was expanded to meet the growing need for more and different aircraft types to meet its evolving operational needs whilst keeping costs affordable. To the jet trainer fleet of Strikemasters was added the American-made T-33 trainers. The helicopter fleet was expanded with the Bell 212 and UH-1Hs. The Skyvan light transport aircraft was joined by the much larger and more versatile used C-130B Hercules. The fighter aircraft fleet was expanded with the acquisition of the A-4 Skyhawks acquired from Davis-Monthan "Bone-Yard" where retired US Services aircraft were stored. The transition of the fleet, from a largely British-made aircraft to American aircraft types entailed much adaptation in maintenance practices, tooling, documentation practices and concepts.

In view of this, the ROCAF was invited to help after the British withdrawal as they were one of the more experienced air force in Asia and they operated many US-made aircraft. For example, the ROCAF operated one of the largest fleet of F-5 aircraft then. ROCAF officers and SNCOs were inducted into the SADC airbases to provide the necessary experience in support of the rapid build-up of the SADC.

In later years, the Skyhawk operations also saw exchange officers from the RNZAF and the C-130 operations had exchange officers from the RAAF and the USN/USAF. (The RNZAF and RAAF had good operating experience on the A-4 and C-130, respectively.)

Although the foreign air forces involved contributed in many ways to the build-up of the RSAF, the most important consideration was their relevant aircraft-type experiences. They also assisted in introducing the RSAF to different operating concepts and their experiences as an air force. Bridging the technical experience and manning gaps were beneficial but not the only consideration.

The assistance of the foreign air forces and navy (USN) through loan/secondment of their experienced staff were very helpful to the RSAF Air Logistics Organisation over the years. Some acted as advisors in HQ RSAF, while others were seconded to the operational units in the airbases.

ST Aerospace, the Air Force Depot

Origin of ST Aerospace

When the SAF was being built up, the Government took a strategic decision to build up a complementary “depot” to support each of the Services; the Air Force, the Navy and the Army, as well as in electrical and electronics engineering. The thinking was that each would complement the respective Service's need for industry support.

ST Aerospace, which was to be the "industrial arm" of the SADC for aviation support work beyond the RSAF's immediate operational requirements started a few years later after the formation of the SADC. It began as an aircraft MRO named Singapore Aircraft Maintenance Company (SAMCO) in September 1975 and was incorporated in 1976.

Lockheed Aircraft Services Singapore

Prior to the set-up of SAMCO, Lockheed Aircraft Services Singapore (LASS), a Singapore subsidiary of the US Lockheed Aircraft Services Company, provided technical support to the SADC. LASS was started in the 1970s to support the US Armed Services aircraft operating in Asia during the period of the Vietnam War. It supported the SADC's depot maintenance needs but the biggest job it did for the SADC was the refurbishment of the A-4B Skyhawk aircraft, including the first upgrading of its avionics. The main avionics upgrade for the A-4 was done much later during the A-4 upgrade to A-4SU. LASS work included the addition of outboard pylons, split spoilers and 30mm Aden guns. The A-4B fleet comprised some 32 Skyhawks. LASS also upgraded the Hunter fleet with improved weapons carrying capabilities by adding a centreline station and capability to be armed with 4 AIM-9 Sidewinder air-to-air missiles on its wing pylons.

LASS also developed the unique twin-seat configuration TA-4S which had separate front and back cockpits. This was driven by necessity as although there were many single cockpit A-4Bs available, there were no twin-seat A-4Bs produced and the RSAF needed them for training new pilots.


The only Hunter aircraft to have AIM-9 missiles and centreline MERS carriers

Unlike other twin-seat TA-4 Skyhawk trainer variants developed by the OEM, McDonnell Douglas with tandem cockpits covered by a single, large clamshell canopy, RSAF'S TA-4S (its designation after the conversion by Lockheed as detailed in Section 1.1) had a distinct, stepped aft cockpit with a separate windshield and canopy for the instructor pilot. This unique "double bubble canopy" provided better over-the-nose visibility for the rear instructor pilot during landing, and perhaps might have been influenced by Lockheed's experience with its own stepped-cockpit trainer versions of the SR-71B and U-2CT spy planes of the Cold War era.

The manner in which the TA-4S was built was also novel. Instead of a purpose-built twin-seat cockpit section, the TA-4S was constructed from an A-4B with a second, 28-inch long cockpit "plug" inserted between the original cockpit and centre fuselage. While not as structurally refined as Douglas' new TA-4F and TA-4J designs, this was a cost-effective approach that maximised the re-use of components from "donor" A-4B airframes, including structural members, cockpit systems/components, and canopy. Two A-4B airframes were used to build a TA-4S trainer aircraft. The second airframe was used to "cannibalise" the canopy, cockpit systems and components, and structural items mentioned earlier. A subsequent refinement to the aft canopy transparency shape was to increase the bulge laterally, to provide better forward vision for the aft crew member (looking forward from the extreme left and right side of the canopy).

LASS had under its employment some Singaporean aircraft technicians and engineers amongst its staff in Singapore. It operated from Seletar Air Base (SAB). At the end of the Vietnam War on 30th April 1975, LASS withdrew from Singapore. Many of these Singaporean staff of LASS continued their aviation careers in Singapore under SAMCO, when it started in April 1976.

Build-Up of SAMCO

SAMCO took over the hangars vacated by LASS in SAB. While the designated role of SAMCO was to be the depot for the RSAF, it also sought to delve into "commercial work" beyond its support for the RSAF. It won its first "major" commercial contract in September 1980 with the USN to perform Depot Level Maintenance work for one of its KC-130R Hercules on layover in Singapore. This was ST Aerospace's first significant non-RSAF contract then and that this programme is still ongoing today speaks plenty of its ability to retain customers and its performance as an MRO provider.

To facilitate a quick start at SAMCO, some of its senior management were seconded from the SADC. The first Managing Director of SAMCO was the first Head of Air Engineering of the SADC. The first Production Manager of SAMCO was also from the SADC.

When SAMCO was set up, Hunter depot maintenance capability and some depot-type work were transferred from the SADC to SAMCO to enable it to build up its experience. Up till then Hunter depot maintenance was performed within the SADC by Tengah Air Base's Aircraft Servicing Flight. SAMCO's first major engineering programme was the A-4C Skyhawk refurbishment and restoration programme. When it was decided to further expand the RSAF, the decision was to acquire more A-4 Skyhawks. However there were no more A-4B aircraft available. The only A-4s available in adequate numbers was the A-4C. They were retired earlier than the A-4Bs but due to the low humidity in Davis-Monthan Air Force Base they were in good condition. So A-4C it had to be.

First Major Refurbishment of Aircraft by SAMCO

As this was the first major refurbishment undertaken by SAMCO, it was a significant task. SAMCO was barely into its fourth year of operations when the first A-4C carcasses were delivered to its facility at Seletar Airport on August 1980. This programme gave SAMCO its first experience in major refurbishment and modification work. The first refurbished A-4C, designated the A4S-1, rolled out of SAMCO on 24th January 1982.


Early A4S-1 Skyhawk converted from A-4C

Besides the A-4 aircraft airframe work for SAMCO, the refurbishment programme introduced new capabilities and high value-added work to its sister companies; overhaul of the A-4's J-65 engines for Singapore Aero Engines Overhaul Limited (SAEOL), and repair and overhaul of electrical, avionics and mechanical components at Singapore Aero Component Overhaul (SACO) and Singapore Electronics and Engineering Limited (SEEL). This was the start of ST Aerospace's aircraft engines and components business which complemented its aircraft MRO and engineering capabilities.

In later years, the military engines and components experience enabled ST Aerospace to extend its capabilities to commercial engine and component MRO and modification work. This extended ST Aerospace's commercial aviation business. Although ST Aerospace evolved the Maintenance-by-the-Hour (MBH) concept on commercial engines and components businesses to meet the preferred business model for low cost carrier (LCC) airlines, without these starting MRO experience on military engines and components, ST Aerospace might not have been able to do so.

Trainer with Twin-Radome Cockpits

SAMCO further enhanced its structural modification capabilities through work on the building of the TA4S-1. As mentioned earlier, the first TA-4S, developed from the A-4B was designed and built by LASS. This capability and tooling were transferred to SAMCO which extended the development work done in later years to meet the need for significantly more twin cockpit aircraft to meet its training and new operational needs. Although the essence of this conversion process was retained, ST Aerospace development of the TA4S-1 was a more complex conversion since it combined the avionics (described in the following section) and re-engine upgrades simultaneously with the twin-seat conversion. In addition, when more TA-4S were needed for new operational requirements, further structural development work had to be undertaken as there were then insufficient A-4C carcasses available.


Handbuilding the TA4S-1 at SAMCO

This write-up will not go into details of the engineering efforts that went into developing the number of TA4S-1 needed by the RSAF in later years except to recognise the significance of the TA4S-1 in the capability build-up period. The TA-4 was, and is even today, the only twin-radome trainer aircraft in aviation, one for the front cockpit and another for the back cockpit.

Though a major engineering undertaking and many major changes were made to the aircraft and its systems, the TA-4SU (designation for the upgraded TA4S-1) were very successful aircraft which never had a single loss despite its demanding usage as a trainer aircraft over its life cycle. It also became the platform for operational development in the RSAF and later, the Fighter Lead-in Trainer in Cazaux, France, where the RSAF trained until the fleet of TA-4SU was retired in 2012 due to expiry of structural life.

Build-up of Singapore Aircraft Industry, later re-named Singapore Aerospace, then ST Aerospace

With the maturing of the various MRO capabilities in support of aviation, a decision was taken to combine them under a single company, Singapore Aircraft Industry (SAI). SAI was formed on 25th February 1982 as the holding company of SAMCO, SAEOL and the aviation electrical shops of SEEL. When the company was listed, it had an annual revenue of S$70 million. The intention to build several other companies within SAI, including for manufacturing (SAM, Singapore Aerospace Manufacturing), spares or warehousing (SAW) and components (SACO) was also laid out. The announced intention then was "to build a repair and overhaul company to serve the ASEAN and West Asian Gulf State".


TA4S-1 on landing roll

The first Managing Director of SAI was from MINDEF.

SACO was launched on 9th August 1982, a 50:50 joint venture (JV) of the Aviation Division of SEEL and the Component Overhaul Shops of SAMCO. SAEOL was incorporated in January 1977 through a joint venture between SAI and Singapore Airlines (SIA) to repair and overhaul "small" engines, which then were the military engines and the aged JT8D engine. Subsequently SIA sold its shares in SAEOL to SAI as it had no commercial interests in the JT8D engine.

SAI was renamed *Singapore Aerospace (SA)* in *January 1990*.

SIA's first B747 hangar converted for military aircraft use

SAI took over SIA's first B747 hangar in Paya Lebar in 1983 to do military work as SIA had moved to Changi Airport and the RSAF had moved from Changi Air Base to Paya Lebar Airport. The hangar reverted to commercial use in later years when, in January 1990, its first wholly commercial aircraft maintenance company, Singapore Aviation Services Company (SASCO) was formed.

ST Aerospace's growth in aviation engineering and MRO is covered in Chapters 3 and 4.

Building Up Engineering Development Capabilities in ST Aerospace

The growth into military engineering development work was not easy. Although there were good engineers in MINDEF, the RSAF and ST Aerospace, experience level was low when the A-4SU upgrade programme was started in the early 1980s. However, the combined team of ST Aerospace's management and engineers worked closely together with the RSAF and the Defence Technology Group (DTG) in MINDEF (predecessor of the Defence Science and Technology Agency, DSTA) to overcome each major problem as they surfaced. Following the successful design and certification work, and committing the design to production, presented various difficulties as resources were very limited then. The combination of capabilities, commitment and determination saw the team through the A-4SU programme and, subsequently, many other successful military aviation engineering initiatives. Some of these are covered in Chapters 3 and 4.

In later years, post 1990, ST Aerospace extended its engineering capabilities to commercial aviation work as it endeavoured to go into commercial aviation MRO. This is explained under Section 3.6. From thence, it went into developmental engineering work on commercial aircraft like Passenger-to-Freighter (PTF) Conversion (see Sections 4.5, 4.8.3 and 4.8.4) and other aviation related products. ST Aerospace has since established itself as a leading player in PTF conversions, a major commercial aviation engineering development activity, complementing the aircraft OEMs in delivering cost-effective solutions to the market.

In summary, up to 1984, the activities of the RSAF and ST Aerospace were in building up basic MRO and engineering capabilities to support the RSAF's flying training requirements. 1985 to 2000 was time spent in building up the RSAF post the A-4 Crisis, the build-up of RSAF's engineering and operational capabilities and the operationalisation of the RSAF. Besides the engineers in the RSAF, ST Aerospace played an important supporting role in the recovery and subsequent operational build-up of the RSAF. Thereafter, the combined capabilities in the RSAF and ST Aerospace were, on the military side, focused on the continued build-up of new capabilities for the RSAF as the RSAF transformed to what it is today.

For ST Aerospace, in addition to the important role it played in support of the RSAF build-up since its formation in 1975, in parallel from 1990, it was trying to foray into the commercial aviation market for commercial passenger airliners.

Section 1.2
Some History of the Early Engineering Work in Support of the RSAF

From within the RSAF and ST Aerospace

This section presents some snapshots of the build-up of the RSAF engineering organisation and engineering work undertaken in the early days.

The Fleet Build-Up

By 1976, there were no less than six types of fixed and rotary wing aircraft in the RSAF's fleet: Hunter and A-4 Skyhawk fighter aircraft, SF-260 basic trainers, Strikemaster jet trainers (augmented by a few earlier model Jet Provost trainers, purchased second-hand from another air force), Skyvan light transport aircraft and Alouette III light helicopters. A year later, the UH-1H, Bell 212 helicopters and Lockheed C-130B heavy transport aircraft were added to the fleet. The Hunters and Skyhawks were surplus aircraft acquired from the RAF and USN respectively. The Hunters were acquired in flying condition from the Hawker Siddley Aircraft Company in the UK. The company had earlier acquired surplus stocks from the RAF, Netherlands and Belgian air forces before refurbishing them for re-sale to world-wide customers. The initial aircraft were ferried to Singapore by Hawker Siddley Aircraft pilots. The first batch of A-4B Skyhawks were acquired from the USN's mothballed fleet in non-flying condition and Lockheed Aircraft Services was contracted to set up a re-manufacturing line at Changi Air Base to refurbish and assemble the old airframes to flying condition and to add additional avionics systems such as new communication and navigation systems. When the RSAF made its second buy of A-4s (A-4C this time), it was refurbished by SAMCO. This was the foundation of ST Aerospace's A-4 capabilities.

In view of the decision to undertake the major A-4 upgrade to the A-4SU in the early 1980s, ST Aerospace made its first significant recruitment of graduate engineers, 10 engineers in total, to undertake the task. They were complemented by highly experienced consultant engineers from overseas. Over the years, the focus on building up of engineer manpower and skilled technicians enabled ST Aerospace to successfully discharge its responsibility as the prime contractor for the modification and upgrade programmes of the RSAF.

In parallel, the RSAF also built up its engineering capabilities following the A-4 Crisis. This was followed by an increase in aviation engineering capabilities in DTG to manage the major acquisition programmes. The integrated engineering resources under the RSAF, DTG and ST Aerospace are the foundation for engineering initiatives in military aviation in support of the RSAF today.

Establishing Engineering Capabilities in the RSAF

The bulk of the engineering work in the 1970s to early-1980s was technical support and sustenance of the fledging RSAF fleet[1].

The early aircraft engineers were deployed to either the airbases in Tengah, Changi and Sembawang (Paya Lebar Air Base was established later in 1981 following the decision to move Singapore's international airport to Changi) or to Air Engineering Department in HQ RSAF in MINDEF at Tanglin.

In the airbases, the engineers took charge of hangar maintenance of aircraft or workshops performing servicing and repairs of mechanical, electrical, electronic and armament and weapon system components. Besides the engineers, there were also technical officers. These technical officers were experienced technical specialists who were commissioned as officers. They were usually polytechnic diploma holders or had gone on to complete their polytechnic diploma in engineering in the course of their service with the RSAF. The technical officers usually start their service on flight line servicing of aircraft because of their aircraft experience. Those with more experience might see themselves in similar appointments as the engineers in the hangars and workshops as their experience and professional capabilities were recognised by the RSAF.

Because the Air Force was in its early years and engineering capabilities were limited, when its aircraft were acquired, the focus was on ensuring operational support was not compromised. The need for a more comprehensive acquisition package which would have given the RSAF an in-depth engineering capability in the aircraft was not recognised then. Technical training on the aircraft and its systems was thus limited to maintenance work.

The RSAF had to rely mostly on overseas OEMs for the bulk of component overhauls and repairs, due mainly to decisions at the time not to invest in high cost support equipment and associated tooling and training. There were also no plans to develop the ability to indigenously support, modify and upgrade the aircraft during its life cycle. The "smart buyer and smart user" approach had yet to come.

The engineers in the airbases provided management oversight over the technicians in what was largely scheduled and unscheduled maintenance tasks according to prescribed procedures in maintenance and repair manuals provided by the OEMs. They were also the first line of defence to engineering problems experienced during maintenance. Because of the lack of sufficiently deep engineering knowledge on the aircraft and its systems, serious problems were usually addressed in consultation with the OEMs. Urgent dialogues with OEMs were done via the old faithful telex machine, and normal dialogues by post. So there were issues with responsiveness of OEM's support and aircraft recovery time.

In later years, with new aircraft acquisitions starting with the F-5, the services of technical representatives from the OEMs were sometimes acquired for specific periods. These "Tech Reps", as they were affectionately called, were stationed in the airbases and provided the important direct links to the OEMs. They became valuable and most sought-after technical resources whenever unique and abnormal problems surfaced.

Though many of the Tech Reps were knowledgeable, one of their biggest advantages to the RSAF was their knowing where at their respective OEMs, thousands of miles away, the relevant knowledge or capabilities reside. Resolution of new and unique problems and

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[1] Support of air defence systems is addressed in one of the series of four "Engineering Singapore's Defence – the Early Years" books titled "Engineering System-of-Systems".

development of maintenance and repair procedures beyond maintenance manual limits provided a valuable learning experience to the RSAF engineers. Over time it allowed the engineers to "stretch beyond the book". Eventually, rather than approaching the OEMs on what to do, the RSAF engineers took the initiative and began to propose technical solutions which were evaluated with their local Tech Reps for their inputs before applying the proposed solutions to fix the problems. The RSAF engineers soon found that this initiative was more satisfying and at the same time yielded a faster "fix" for the problems. Time was always the essence in getting an unserviceable or grounded aircraft back into the air. The enthusiasm of the engineers never waned.

At Air Engineering Department, HQ RSAF, engineers were deployed to look after specific aircraft types ("airframes"), engine types, or systems such as armament, airborne communications, radar, electrical and aircraft instruments systems. Major problems and issues faced by the airbases would be managed by engineers from HQ RSAF who would work with their counterparts in the airbases in developing solutions. OEMs were consulted when required. Problems which were unique to our operating environment might require further investigation by the OEM, before an agreed solution was developed. A characteristic of the early days of the RSAF aircraft engineering activities was the heavy reliance on the manufacturers for know-how and support.

An aircraft and its systems and components are maintained in accordance with maintenance schedules which consist of inspections and maintenance actions at specific intervals prescribed by the aircraft and component manufacturers. These maintenance schedules and maintenance requirements are developed based on the manufacturer's design considerations, modified by operational experience and engineering analysis of defects experienced. The objective is to ensure that an aircraft and its systems can be operated with acceptable reliability and in a safe manner, yielding the expected performance and with minimum unexpected in-flight failures. If there are impending failures, these should mostly be detected during scheduled maintenance inspection or by specific measurements of the system performance parameters.

The aircraft maintenance requirements are continually updated by the OEM based on inputs from operators of its aircraft all over the world, including the RSAF.

In addition, the aircraft and component manufacturers put out ad hoc "service bulletins" (SBs) requiring a one-off inspection and maintenance action, or repeated maintenance actions, or a modification action, usually to fix a problem detected during service and one which is likely to have fleet-wide implications. It is not just a simple process of complying with the requirements as there would be so many SBs that such an approach would ground the fleet.

Besides those SBs with safety of flight implications, others may be optional, to improve on a certain condition, or if there is an operating requirement. Technical and operational judgement are needed to evaluate each SB to decide when might be a right time to carry out the inspection, maintenance or replacement, or if it should be implemented at all. Evaluation of SBs and modification proposals is to determine its applicability to the operators' fleet and immediate safety implications, if any. These maintenance concepts generally apply to both military and civilian aircraft support.

From time to time, aircraft failures and other anomalies might occur, some of which might have been experienced by other air forces and hence known by the OEM. Some however might be unique to the RSAF and likely caused by the local operating environment or operational usage. In the latter category, consultation with the OEM would usually be the norm, but as the RSAF's engineers gained experience, they were able to analyse the failures and develop enhanced inspection procedures and local "fixes" for the problems. The study of problems and failures in aircraft systems and components by our engineers during the 1970s and early 1980s eventually developed into the science of failure analysis and reliability engineering that is rigorously practised in the RSAF today.

Defence Industry Role, Complementary to the RSAF's Role

The roles and set-up of the defence industry have been explained in Section 1.1. Initially, the defence industry was to undertake "Depot Level Maintenance" work (or MRO work in the commercial aviation world).

The RSAF would perform maintenance tasks which were directly related to the immediate generation of aircraft availability within the airbases. These included "before flight" and "after flight" servicing of aircraft in the flight line, rectification tasks to recover and turn around unserviceable aircraft (usually by the following day), scheduled maintenance tasks involving short aircraft downtime, and operational level workshop repairs on engines, mechanical, electrical and electronic components. Major aircraft scheduled maintenance which required extensive aircraft downtime (from several weeks to several months) and component and engine overhauls and repairs would best be farmed out to an "outside contractor" as these would not directly influence the near-term aircraft sortie generation.

With the formation of SAMCO in 1975, the build-up of depot level capabilities was started in earnest. In the beginning, some of these initial capabilities were actually transferred from the RSAF to help SAMCO build up its capabilities in the interests of the RSAF in the longer run. Besides performing heavy scheduled maintenance of aircraft and component overhaul and repair, SAMCO engineers also worked with their counterparts in the OEMs to jointly develop engineering repair schemes and modification proposals to fix problems and defects found during scheduled maintenance, or to improve reliability and maintainability of systems and components.

For a specific repair, a technical proposal would be submitted and discussed with engineers from the RSAF before the solution was mutually agreed and implemented. Sometimes, RSAF engineers may have a different perspective of the technical solution that might be more suited to meet its operational requirements or on risks and cost trade-off. This was thus the beginning of engineering development activities in both the RSAF and local industry.

Pioneering Efforts

The lack of technical know-how on the early RSAF's fleet was no impediment to RSAF engineers in carrying out their tasks. The "can do" spirit was very evident during the pioneering days as there was usually no one else whom the engineers could immediately turn to, apart from the related aircraft maintenance manuals. The situation could be critical if a problem resulted in a precautionary fleet-wide grounding of all aircraft. The pioneering spirit meant that the engineers earnestly worked to find solutions to problems which were not normal and which the engineers were not fully equipped or trained to do. The simple purpose was to fix the problem and get the aircraft flying again.

There was however no compromise on flight safety standards, for safety in aviation was paramount and well understood even in the early years.

When there was an OEM Tech Rep resident in Singapore, his expertise and experience would be the first for our engineers to draw on but for more complicated problems, he might not be able to help. As necessary, the RSAF might seek to communicate with the OEM directly on critical and important matters, especially those affecting safety or operational capabilities.

However not all OEMs were responsive. Some wanted to be funded separately to research our queries and provide response. This started to make our engineers realise the importance of having the right level of technical data and engineering training so they would not be over dependent on the OEMs. Besides delays in arriving at the right answer, it might also be operationally unacceptable. The availability of adequate engineering data, and the ability to interpret and use the data, allowed a deeper understanding of the system from the design perspective, and thus enable the RSAF to be less reliant on the OEMs to solve operational problems except for very major issues.

Nevertheless, despite the lack of engineering data in the earlier days, the RSAF's engineers were resourceful enough to be able to handle not only the support of operations but a number of projects involving modifying the aircraft to perform special roles during the pioneering days. The following two projects are cited as illustrations to give some insight on what were done even with limited OEM-level data and the lower level of engineering experience in the RSAF then.

The First "Smoke Modification"

The first fighter aircraft in the RSAF's history was the Hunter aircraft. Even in those days, as it is now, Singapore's National Day was a big event for the SAF. And a fly-past was a must! As it does even today, a fly-past always draws excitement from the crowds who gather to witness National Day celebrations. And the first fighter aircraft must surely be one of the key components of the SADC's contribution to the SAF contingent at the National Day Parade. For the Hunter Squadrons, National Day, and in fact any major exercise like the Five-Power (the UK, Australia, New Zealand, Malaysia and Singapore) Air Defence Exercise, were times when it had to be at its best.

A self-imposed "requirement" for the Maintenance Flight that maintains the Hunter aircraft, called Aircraft Servicing Flight (ASF) later renamed Hunter Maintenance Flight (HMF), was that every aircraft would fly. Even aircraft on longer term scheduled maintenance would be recovered to meet this objective. The technical workforce would throw everything it had onto the aircraft to ensure its recovery in time for the event. And the Squadron would always have a pilot to fly the last aircraft recovered. Such was the spirit.

On the way back to Tengah Air Base, the whole fleet, every aircraft, would fly over the airbase in a single formation to celebrate the success of the event for the whole base. Some 36 to 40 plus Hunters, depending on the number of aircraft in the fleet then would blank out the sky during such an event. Pride and simple joy for the people behind the action!

One day, it was decided that it would be nice to have the Hunters emit smoke during the National Day fly-past. Today, many aircraft flying in air displays have smoke emitting capabilities but in the early 1970s this was uncommon.

Today, the RSAF might look for some special off-the-shelf configurable smoke modification to buy and install on the aircraft but back then there was no such thing. The acquisition process was not so well defined in those days and it would not have been possible to meet the timeline as the objective date – by National Day – was fixed. In any case, the cost would have been too prohibitive! So it fell on the Maintenance Flight behind the Hunter Squadrons to make it possible.

The system was conceptualised based on the configuration of the Hunters. Fortunately, the Hunters had a fuel storage system which facilitated the modification. There was a front fuel tank in its forward fuselage, and fuel was also stored in the wetted wings and two smaller tanks in the rear fuselage. The Hunters also had large external fuel tanks ("Drop Tanks"). The fuel from the rear tanks and wings would be transferred to the front tank from which the engine would take its fuel. In order to create a separate storage tank for the smoke generating fluid, the rear fuel tanks on the aircraft were isolated. As the rear tanks were smaller, there remained sufficient fuel in the remaining tanks for the aircraft.

Diesel was used for the smoke generation. The diesel was stored in the isolated rear tanks and would be fed from the rear tanks, via a separate pipe line, to the end of the aircraft jet pipe (where the jet thrust from the jet engine was emitted) and be vaporised by the hot exhaust gas to create the thick white smoke. Later, dye would be added to the diesel in the rear tank to create the red smoke. This resulted in the colourful red and white emissions we see at air displays! The jet engine's exhaust temperature would not be high enough to cause spontaneous ignition of the diesel fuel, just to vaporise the diesel into highly visible smoke.

As it was an airborne system, engineering and safety came first. But, it had to be possible, to work reliably, and to meet the objective timeline for the National Day concerned.

The piping systems were designed from seamless copper pipes, to avoid risk of cracking at the seams. Brass pipelines were more common but brass had a problem with age hardening. The control valve to select and de-select release of smoke-generating diesel fuel had to be an aircraft certified valve. All wiring and mounting for the smoke modification components had to be of aviation standard.

There were many ground tests followed by airborne testing of the system. Much testing was also required on the inclusion of the red dye as it did not mix well with the diesel. Intermittent smoke emission would be unacceptable by airshow standards. To ensure proper vaporisation of the diesel, the engine of the aircraft must be flown at a certain engine throttle setting to get the jet pipe exhaust gas temperature right.

Finally, the "smoke mod" was successfully flown on its first National Day outing on 9th August 1974.

"Smoke mod" aerial display

In subsequent years, later aircraft like the A-4 Skyhawk, the F-5 Freedom Fighter and the F-16 Fighting Falcon were also modified to generate smoke for National Day fly-pasts. Each had its own unique smoke modification to do the task. The system for each aircraft type would be different for reasons related to the aircraft. But the very first smoke modification for Singapore was on the Hunter aircraft, and a totally homemade design-and-built system!

In those early days when the RSAF, or rather the SADC, was less structured, the underwriting of the modification was with the Air Base. Nevertheless, the responsibilities rested with the engineers on the ground. Self-control is, under certain environments, perhaps the most effective of controls. There would be no doubt as to accountability. This and the capabilities of the fledgling engineers enabled the RSAF to achieve many things in its early days.

Alouette III with underslung state flag

There was no other way in any case. The job had to be done. The people in place had to do what was necessary. The mission had to be accomplished. After all, this was the Air Force, albeit one in the making then!

Flying the Flag

The appearance of a large national flag carried by a helicopter during the National Day fly-past is always a proud moment to every citizen viewing the National Day Parade. The reader may not be aware of the engineering analysis that must be carried out before flight certification of the flag carriage is given by the engineering authority in the RSAF. The Alouette III was the first helicopter to have the honour to fly the state flag during the National Day Parade fly-past in 1970. Essentially, this fly-past configuration was treated as an underslung load carriage for the helicopter. The state flag was attached to a cable with a weight suspended at the end, in order to keep the cable taut during flight. The top end of the cable was attached to the underslung attachment hard point of the helicopter lower fuselage structure. In flight, the load was free to twist, orientate and swing about its vertical axis, and the flapping of the flag would cause drag.

The engineer had to assess the structure and hard point attachment, aerodynamics, load oscillation in forward flight, safe handling and manoeuvre boundary, weight and centre of gravity (CG) of the underslung flag configuration, and emergency manual release of the load (flag) to ensure that there was no transgression beyond the flight envelopes of the helicopter. It looked nice and seemingly easy to fly the flag but much effort went into ensuring that the flag would flutter nicely and safely in flight as it could be disastrous if the flag got blown up by the downwash of the propellers. Before each flight, the flag had to be inspected carefully as a smallest tear could result in the whole flag being torn apart because of the airloads. While we are used to seeing very heavy underslung loads like artillery pieces regularly lifted by the Chinook today, the carriage of a large Singapore flag presented a significant challenge because of its dynamics. Since then, every National Day must have a Singapore flag in the fly-past.

Enhancing the RSAF’s Support Capability

As the momentum of operations intensified, engineering and logistics challenges to support the expanding RSAF aircraft operations increased rapidly. To ensure a more integrated support of operations, in 1978, Air Engineering Department and Air Logistics Department (which included the provisioning and purchasing, and contract management functions, and the management of the RSAF supply bases) were merged and collectively called Air Logistics Department (ALD). The materials function, such as spares management, provisioning and purchasing, remained largely unchanged and was under the direct responsibility of Deputy Head Air Logistics (Materials), while the engineering support function under the former Head Air Engineering came under Deputy Head Air Logistics (Engineering). Both Deputies reported to a single Head Air Logistics. This change helped to foster a closer working relationship between the Technical and Materials (Supply) communities to ensure optimum support of the RSAF's aircraft and related support equipment, in order to achieve the maximum availability of aircraft and systems.

Civilian Engineers in the RSAF

Up to the late 1970s, engineers with an interest in a career in military aviation had to join the RSAF as military engineers. That meant that they became military personnel, in uniform, with an officer's rank, and would have to perform certain military duties (such as Duty Officer and Payroll Officer, to name a few) in addition to their professional engineering work. This scheme of service was unpopular with some engineers and somewhat limited the RSAF’s ability to recruit engineers as many were not prepared to assume a military career. Virtually all the engineering graduates (at least the male engineers) had experienced NS and many did not view a military career positively then. The SAF was in its early days and did not have the possibilities it now has to project itself as a plausible career option.

A complementary and hopefully more attractive scheme, administered by PSC, was introduced in 1979. This was the non-military Defence Engineering and Scientific Service. Most of the military engineers at the time were given an option to opt for this new civilian engineering scheme and many did so. The scheme also proved successful in recruiting an increased number of engineering graduates in subsequent years.

The First Supersonic Fighter

The acquisition of new F-5E/F supersonic fighter aircraft from the US in 1978 provided a great opportunity to send some of our engineers to the US to receive technical training on the aircraft type at Northrop Corporation, the manufacturer. Unfortunately, the RSAF did not seize upon this acquisition as an opportunity to jump start the build-up of its engineering capability through a comprehensive engineer’s training package on the design perspective of the aircraft and its systems as this was not the priority then. In addition, the need to have such capabilities then was not so obvious.

However, a number of engineers were trained in the US on the maintenance aspects of the airframe structure, mechanical and electrical systems, aircraft avionics, armament systems, and the General Electric (GE) J-85 gas turbine engine. The training at the manufacturer’s facilities, though maintenance-biased, nevertheless provided our engineers with some basic knowledge on the fundamental design of the aircraft and systems, and its maintenance philosophy.

In a way, the F-5E/F acquisition programme was an opportunity missed as it happened too early in the history of the RSAF. While our F-5 project team learnt from the US counterparts

F-5E in formation

the structured process of definitisation of spares, and support and test equipment, we did not recognise the need to define the other requirements needed to indigenously support and operate the aircraft and systems throughout its life cycle, which could be 20 to 30 years or more.

Thus, the need to define and acquire the necessary engineering data packages and proper engineers' training on the interpretation and usage of the engineering data was not considered. Such engineering data would have allowed the RSAF to know the aircraft sufficiently to be able to indigenously modify and upgrade it and to add new systems during its life cycle.

This lack of data was to pose significant challenges to the RSAF, Defence Materials Organisation (DMO) and ST Aerospace engineers in the years to come when they began to look at the upgrading of the F-5 aircraft. How they overcame the challenges to propose solutions would be addressed in Section 2.2.

Improving Aircraft Maintenance

As mentioned, the RAAF and RNZAF were amongst the foreign air forces which offered valuable technical assistance to the RSAF in the build-up of its engineering capability. Besides the "Exchange Officers" programme with the RNZAF and RAAF which has been mentioned, the RSAF had also benefited from other aspects of their engineering experience. For instance, in the late 1970s the RNZAF embarked on a review of all the scheduled maintenance requirements of their aircraft fleet. This concerned the maintenance schedules and tasks originally developed by the respective aircraft manufacturers. The RNZAF review was based on a document called Maintenance Steering Group-3 (MSG-3).

The MSG-3 document was developed by major civilian airlines in the US and civil aircraft manufacturers (such as Boeing, McDonnell-Douglas and Lockheed) in the late 1970s. The document presented a methodology and decision logic process for developing scheduled maintenance tasks and intervals acceptable to the aircraft manufacturers, airlines and civil airworthiness authorities. The concept was to recognise the inherent reliability of aircraft systems and components and avoid unnecessary maintenance tasks, thereby increasing efficiency and reducing aircraft downtime. The MSG-3 document was an evolution of the MSG-1 document developed for the Boeing B747, and MSG-2 developed for the McDonnell-Douglas DC-10 and Lockheed L-1011. This concept is referred to as Reliability Centered Maintenance (RCM) by US defence contractors and by the USAF.

The RNZAF reviewed the scheduled maintenance requirements of their entire fleet and progressively applied the MSG-3 (or RCM) concept to develop new improved maintenance schedules for their P-3C Orion, C-130, A-4 Skyhawk, Strikemaster and UH-1H aircraft. When the RNZAF briefed the RSAF about their Improved Maintenance Programme (IMP) and offered to train Singaporean engineers on the methodology, the RSAF sent a team of engineers for a three-week training programme. The Singapore team received training on the analysis process of aircraft systems and components, including the functional failures of each component and analysing failure modes and effects, and the development of the appropriate maintenance strategy and a complete RCM-based maintenance schedule.

Upon their return to Singapore, several working groups were formed, and the engineers led these groups and commenced the reviews for our Hunter and A-4 Skyhawk fighter aircraft, and UH-1H helicopter. The aircraft systems and components and the original manufacturers' scheduled maintenance requirements were reviewed together with in-service RSAF's maintenance and failure data collected over the years, and in consultations with the manufacturers, developed new and customised IMP for each of the RSAF aircraft types.

The RSAF's IMP took into account the relatively small fleet size of our aircraft types and our unique operating profile. For example, a generic scheduled maintenance programme developed by the manufacturer often has "heavy" and "light" inspection requirements at different intervals.

During the "heavy" inspection schedule, the aircraft down time for checks and maintenance can be significant. For a small fleet operator like the RSAF, having aircraft down for long periods for scheduled maintenance may not be preferred because of impact to operational availability of the equipment.

The IMP designed by the RSAF team enabled the scheduled maintenance packages to be "equalised" so that each inspection package would involve similar total work effort and downtime. The team eventually developed and implemented the new IMP for most of the RSAF fleet over a two-year period.

The newly acquired F-5E/F also had its scheduled maintenance packages developed to RCM principles by the manufacturer Northrop Corporation. The C-130B transport aircraft was a strong candidate for IMP development as its scheduled maintenance programme, based on USAF servicing manuals included "heavy" and "light" maintenance packages and the "heavy" checks were causing considerable downtime. Lockheed, the manufacturer, then developed and marketed a RCM-based equalised servicing package known as the SMP-515C. The RSAF adopted this maintenance package.

The work done by the team of RSAF engineers and technicians in developing the RSAF's IMP enabled more optimal planning and scheduling of the aircraft fleet for maintenance, more effective use of technician manpower in the airbases and improved overall efficiency and cost effectiveness within acceptable levels of aircraft and equipment operability and risk.

Chapter Two

PIONEERING SPIRIT

Section 2.1
Maintenance, Repair and Overhaul

To any air force or airline, MRO is a key activity to keep its aircraft safe for flying and to sustain its flying operations. Besides the user's technical organisation, the NAA also keeps a close watch on the MRO activities and compliance level of its charge in the interests of flight safety. In the case of commercial aviation, the NAA is the civil aviation authority (CAA), like the Civil Aviation Authority of Singapore (CAAS), the Federal Aviation Administration (FAA) in the US and the European Aviation Safety Agency (EASA). For an air force, the engineering organisation at the air force headquarters is the de facto aviation authority.

MRO is very important to an air force because it directly impacts its ability to generate flying operations. The number of sorties which an air force can generate is dependent not only on the number of aircraft it has, but also on the fleet's serviceability level at the beginning of the operation, the serviceability of the aircraft through each flight, and its ability to generate the next flight. The number of flights per aircraft per day (and night) is dependent on the aircraft condition and the effectiveness of its MRO. The outcome of MRO undertaken over the years affects the condition of the fleet and is of primary importance to flight safety and aircraft availability. It directly reflects an air force's capability as the number of aircraft an air force possesses is usually fixed.

For commercial operators like airlines, MRO is equally important. The same parameters (such as flight generation, fleet serviceability and reliability of aircraft) for the military operator serve as the final measure of the effectiveness of the airline's MRO policies and implementation. Airlines, freight operators and, LCCs value and place great emphasis on good MRO. Many of the LCCs, for instance, typically fly up to eight or more flights a day on each aircraft and aircraft's condition is the key enabler to achieve such an intense level of operation. ST Aerospace has gained the trust of many passenger and freight airlines over the years through its performance as an MRO, keeping their aircraft flying and flying safely. This enabled ST Aerospace to become the largest aircraft MRO company in the world.

The starting focus of both the RSAF and ST Aerospace was MRO. In undertaking MRO there is a lot of engineering involved, especially maintenance engineering, which makes the difference between one MRO and another. In the earlier stages of their development, most of the engineering undertaken was to overcome maintenance type problems or to improve on situations faced during maintenance. This section of the volume is not about MRO per se but to share on some of the engineering experiences that the RSAF and ST Aerospace had in their early years while undertaking MRO activities in support of aircraft operations, and the pioneering spirit that had enabled them to overcome the problems faced. The build-up of MRO experience over the years had also given both the confidence for their subsequent endeavours into engineering development work, and brought them to where they are today.

In the beginning, there were only maintenance and repairs in the Air Force (then SADC) and overhauls in the depot in ST Aerospace (then SAMCO) for the Air Force. Engineering activities were largely undertaken in support of maintenance needs. Maintenance at the unit level involved the daily servicing and turnaround inspection of aircraft, and short-term servicing which could be based on calendar duration (e.g. monthly) or flying hours (e.g. 50-hourly).

Engineering in MRO

Undertaking maintenance well is not just about conducting inspections and doing routine servicing according to some standard procedures. There are many situations in maintenance as well as repair and overhaul where sound engineering judgements are needed or where complicated engineering problems may arise. The significance of handling this well is equally important for a relatively small and complex military aircraft as it is for a large commercial airliner.

The following paragraphs will draw on some of the experience in maintenance in the early years which contributed to the build-up of the engineers and engineering capabilities in the RSAF and ST Aerospace.

A good example is the planning and execution of the higher order scheduled maintenance. These have to be carried out strictly according to the fleet's Maintenance Plan at specific periodicities although, within limits, small flexibilities may be allowed. The Maintenance Plan integrates the work that is done to monitor the condition of the aircraft and undertake preventive measures to minimise defects, especially serious ones, which may adversely affect the aircraft availability. As such, the Maintenance Plan seeks to integrate the periodic maintenance requirements of the aircraft based on its design with the operator's planned use of the aircraft, so as to optimise the availability of the aircraft for fulfilment of the mission.

Besides the development of the Maintenance Plan, its execution is equally important as the concern is aircraft airworthiness and safety of flight. A serious failure to implement an aircraft's scheduled maintenance requirement could result in a fleet-wide grounding. While this could happen to both military and commercial operators, the adverse experience of commercial operators might more likely lead to adverse publicity. There had been cases where airlines had their fleets grounded by their CAAs until they could show they were on top of the problem. In the case of airlines, restoring a mismanaged aircraft's servicing programme is not easy as this would be constrained by the availability of hangars and technical manpower, especially in the case of wide-body aircraft. An airline could lose its approval from its CAA if it did not manage its maintenance programme well.

First Initiative to Develop Local Maintenance Plan

An example on the development of a scheduled maintenance plan would demonstrate how engineering capabilities had helped the Air Force optimised its maintenance programme and operations. This case was from the 1970s, on the original Hunter aircraft's scheduled servicing plan which required scheduled maintenance to be done at 240, 480, 720 and 960 flying hours.

Originally, when the first 240-hourly servicing was due, the aircraft had to be sent back to the OEM in the UK for its servicing. This happened for the first few servicings. For cost and other reasons, the natural question was why the servicing could not be done locally. HMF, then called "Aircraft Servicing Flight", rose to the challenge and successfully completed the first scheduled servicing locally and in good time. This was followed by the 480- and 720-hourly servicings. Because the Air Force was increasing its flying rapidly, and the fleet was small as the two squadrons of Hunters were not fully delivered yet, the SADC was then onto its first 960-hourly "Major Servicing" soon.

The Servicing Programme from the RAF for the Hunter was there, and the RAF did have good maintenance documents, so the important thing was to simply perform the checks called for. But with each level of servicing, the Progressive Packaging of the maintenance requirements meant that the work got more complex and more demanding work had to be done. The 960-hourly servicing inspection was to restore the aircraft so it could continue onto the next 960-hourly cycle which could take four to five years to fly off.

Whilst Aircraft Servicing Flight (the engineering unit at the airbase) had proven that it could undertake the technical and engineering aspects of the servicing, a concern was the capacity of the workforce to handle the rapidly increasing workload as more aircraft were being introduced with commensurate increases in flying hours and the snowballing number of servicing which arose. This led to the SADC undertaking a complete review of the scheduled maintenance programme of the Hunter to develop a new Maintenance Programme which would enable it to achieve its flying commitments without compromising on the maintenance needs of the aircraft.

Structured Review of Scheduled Maintenance Programme

Maintenance and overhaul are not only about adhering strictly to prescribed servicing programmes. That is a given and a minimum requirement. The more important point is to make sure that the Servicing Programme is kept current and relevant.

Under-servicing is not acceptable. Servicing requirements have to be reviewed periodically to ensure it reflects the needs based on the age and condition of the aircraft, and their usage and operating environment. Such periodic reviews are as important as making sure the aircraft does not miss any servicing. Over-servicing is however wasteful of resources, incurs unnecessary cost and also imposes unnecessary limitations on operations and the potential of the aircraft assets.

Based on projections of the flying requirement and fleet size, a study was conducted to evaluate the possibility of extending the servicing cycle from a 240 hourly cycle (with the “Major Servicing” on its fourth servicing at 960 hours) to a 300 hourly cycle package (with the 1,200 hourly inspection as the Major Servicing) so that the aircraft would not be grounded for servicing too frequently. Studies of the rationale behind the maintenance schedule and findings from servicing done to date were examined to assess which of the tasks might not be needed or could be done less frequently, and which tasks would need to be done more frequently. The assessment was based on the criticality of the tasks being reviewed and the risks should there be failures.

A new servicing cycle was successfully designed and implemented after it was approved[1]. (The methodology was revalidated again in later years by an external party and endorsed.) Periodic reviews of servicing tasks, and appropriate adjustments based on experience in operations and findings during servicings, as well as assessment of the impact of such decisions subsequently became an MRO practice in the RSAF.

The amount of data to be reviewed was one of the major complications. This was in the days before computers were readily used or even available. All the maintenance data were in hard copies and not consolidated. In the early days, the retention of the maintenance documents was more for follow-up investigation purposes and not for engineering improvements.

Major Engineering Works on Top of Scheduled Maintenance

In addition to the scheduled servicing tasks performed during a periodic maintenance was the requirement to clear the deferred defects carried on the aircraft. In aircraft MRO certain defects which were acceptable to be deferred, including defects which had not reached its allowable critical limits, could be categorised as "deferred defects" so as not to affect the immediate utilisation of the aircraft. As a good engineering practice, these defects would normally be cleared by the next scheduled servicing and, at the latest, by the "Major Servicing"(the highest servicing level under the periodic servicing cycle).

The scheduled servicing which arose was therefore further complicated by the additional work to be done to clear the deferred defects. This made each servicing more demanding and difficult, but certainly more interesting as the "deferred defects" would usually include many first experiences for the Air Force and the deferred tasks were usually more technically challenging, which was why they were deferred.

Hence the higher scheduled maintenance was more demanding as the work packages got more demanding, and there were also major repairs that had been deferred during the earlier servicing to be cleared.

An example of a more demanding job in the higher servicing work package of the Hunter aircraft was the removal of the main-planes ("wings") of the aircraft for inspection of the joints between the wing and the fuselage. This task was called for during the 960 hourly servicing. This was a difficult task to carry out because of the tightness of the close tolerance bolts which held the aircraft’s wings to the fuselage. The approved extraction tools for this job often failed as the threads of the extraction tool frequently got stripped before the bolts could be extracted! After a few such failures, there were no more approved tools available. The lead-time for procurement of replacement extraction tools was long and the maintenance unit had to find alternative ways to get the job done. From aircraft MRO, the activity moved to tool manufacturing and other technically interesting work although this was not in the plan.

Another example, this time on clearing of major deferred defects during scheduled servicing was the replacement of the cracked main landing gear’s “pintle” housing, a major structural part of the aircraft’s wing to which the landing gears were attached. Unless the cracks had reached certain critical limits, such defects could be deferred and monitored periodically until they reached critical limits or when they could be replaced during the next scheduled servicing. Even for a manufacturer’s factory floor with all the structural rigs for assembly and build of the fuselage, that would still be a major job.

To a regular aircraft maintenance hangar, without the specialised jigs and fixtures, this was a very major undertaking as any slight movement of the wing structure after the cracked housing was removed would mean the whole wing would become warped and could not ever be restored. Recognising the technical risks and the fact that this would not be the last replacement of the said housing as the fleet was around the same age, the Aircraft Servicing Flight decided to take on the challenge. It was too costly to try to purchase a structural jig and the lead-time for such a procurement would also have been too long. The aircraft would meanwhile be sitting in the hangar for a long time before the structural jig arrived. Sending the wing back to the OEM in the UK would also be very costly and take a long time.

At that time, holding up precious hangar slots was one thing but reducing the number of aircraft in operations on a prolonged basis was an even bigger concern as the pressure from flying hours requirement to meet the build-up of the RSAF was pressing. Using its own initiative, the maintenance flight decided to build its own structural jigs. It procured I-beams used in building construction, built its own structure jig with the support of the

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[1] This was the first comprehensive review of an aircraft's scheduled maintenance programme by the RSAF’s engineers. The capability was later enhanced through the learning of MSG-3 methodology from the RNZAF mentioned under Chapter 1.

airbase general workshop, and replaced the landing gear housing successfully!

There were many other examples but the examples cited were to illustrate that MRO was not just about carrying out servicing inspections and checking for routine defects. A lot of engineering went behind the work that had to be done as part of the MRO activity.

Although there were experienced expatriate technical personnel present, they did not help much on the examples cited as they did not have the relevant experience. The expatriate staff comprised very experienced people in their own rights, but their experience was on the conduct of aircraft operations in an operating airfield. In their home system, they had the benefit of the full OEM support and proper depots. The RSAF then just did not have similar support nor the luxury of time and resources. But, the job had to be done!

Whilst the examples mentioned illustrated some of the typical heavy maintenance and repair works which the SADC had to contend with when it started in the early 1970s, on a day-to-day basis the maintenance personnel had to deal with many other serious aircraft problems, some of which had potential for serious accidents. Two such examples were the landing gear system and the Avon-207 engine of the SADC's first fighter, the Hawker Hunter.

The landing gear system of the Hunter was the cause of much angst with pilots and ground crew. Most of the failures on the landing gear system were related to the uncertainty of whether the landing gears were securely lowered and locked down (for landing). While an indication that a landing gear was not safely locked down might be a false alarm, it might also be a real problem in which case the landing gear might collapse on aircraft touched down. In addition, there were also instances where the landing gears could not be lowered at all. If all things failed, the pilot might be required to do a forced "belly landing" (i.e. land on its fuselage without lowering its landing gears) or an asymmetric landing without all the landing gears lowered. This could cause serious damages to the aircraft and risks to the pilot. Amongst the causes of the problem was that the landing gear control and indication system were complicated. The process of rigging each sub-system was prescribed in the manuals but because of the aircraft design, the rigging of one sub-system might adversely affect the other sub-systems. The OEM manuals did not include a procedure of rigging the whole system!

With wear and tear of the various linkages, including the stress that the system underwent with the impact of each landing, the variables involved were many. On top of that was the wear and tear on the indication system (to indicate the landing gears were fully extended and locked down) itself. Until it was brought under control by the SADC's engineers and technicians, hardly a week went by without an emergency call from an aircraft in the air due to landing gear problems. In some instances, they were false indications (which the pilot had no means of validating), but in others, there were real defects. There were instances of aircraft being landed with wheels not fully locked down. Fortunately, owing to the skill of the pilots, only the aircraft were damaged. In one instance, the only damage was to the external drop tanks and the potential of over-stressed aircraft structures!

The second example was from the Avon-207 engine on the Hunter aircraft. The engine was inherently very sensitive to airflow instability because of the various efforts over the years by the engine OEM to increase the power available from the engine. (This is not peculiar to only the Avon engine but is a common outcome on many other aircraft engines to meet operational demands.) This made the engine sensitive to airflow instability especially during changes in engine power setting (frequently in the case of combat aircraft). To reduce the risk, a bleed valve was built in to extract excess air at critical moments. The setting of the opening and closing of the bleed valve was another complication as it was in those days a very manual and tedious process. There was also the possibility of engine airflow surge with major downstream damage to the whole compressor of the engine if its bleed air system was out of calibration because of defects or normal wear and tear. The inlet fan blades of the Avon-207 engine were also built of aluminium alloy which did not take kindly to ingestion of foreign objects (for example, solid debris and even small birds), inducing secondary damage known as "Foreign Object Damage" (FOD). Each damaged engine, be it due to engine surge or ingestion of FOD, was a flight safety issue as the Hunter was a single engine aircraft. It was also a costly business to repair any damage on the engine because of the high cost of parts, especially the compressor and turbine blades. MRO engineers finally brought the problem down to a manageable level but it remained a critical problem as long as the aircraft continued in operations.

There were plenty more other defects that kept the engineers and technicians very busy. The examples cited were some of the more significant experiences on one aircraft type only as the purpose is to share some of SADC's experiences in MRO in its early days which helped to build up the maintenance and engineering experience of its personnel. The Hunter was the SADC's first fighter aircraft and fighter aircraft would usually be subjected to more rigors of operations and therefore had more potential for failures. However, each subsequent fleet type that was introduced had its share of technical challenges. Some of the very serious ones and how these were would be shared in Chapter 3.

Pervasiveness of Experience over the Years

Every aircraft type has its own particular set of challenges. This is especially so for military aircraft because of its complexities, the operating stress that the aircraft is put through and the lower level of redundancy (compared to commercial aircraft) that is included in its design because of the constraints of weight and size. Often, there might also be operations induced problems. The learning curve was just steeper in the early days of the Air Force as experience was low.

However, what could be said of aircraft technical and engineering issues on the Hunters that exacted the best of the engineer and technical work force then could also be said of the A-4 Skyhawks, the Super Pumas, the S-211 trainers, the C-130s Hercules, and the F-16s and F-15s fighters in the later years!

Some of the issues faced might be inherent to the specific type or series of aircraft concerned, some might be due to inadequate design or certification, whereas others could be due to usage. The problems were each challenging and interesting, and they might cover problems with the aircraft, the engines, the radar, its various systems or some critical components. Although older aircraft might be expected to have more reliability and wear and tear related problems, new aircraft presented interesting challenges as well as was learnt in later years.

Some issues emerged at the early stages of induction of the aircraft (infant mortality), others as they were put through their regimes. The nature of the problems might be different but they were equally serious in terms of technical risks, operational impact and cost.

Given that each of the problems could be different from the others and they could arise at any time in the operations of the aircraft, the important lesson to learn was to make sure the RSAF had the engineering competency to deal with them. Each problem, which could be operations induced, due to design or reliability inadequacy, or wear and tear, could have safety or operations impact on top of the incurrence of cost and engineering efforts. As the possibilities would be wide ranging, the only insurance that the RSAF could buy against such uncertainties would be the engineering capabilities and experience of its personnel.

Commercial Aviation MRO

Although its work in support of the RSAF was primary and the workload had been growing steadily since its start-up, it was clear to SA that it had to search beyond doing external military aviation work to do commercial aviation work for its growth. This was because its earlier attempt to expand through undertaking external military aviation work had revealed the potential to be limited. So in 1990, ST Aerospace ventured into the commercial aviation MRO market in view of certain opportunities that had surfaced then. This is explained in Endeavour into Commercial Aviation MRO from Section 3.5.1 to 3.5.3.

Similarities and Differences

Through its pioneering experience in Commercial aviation work, ST Aerospace gained important insights into the similarities and differences between commercial and military MRO and engineering activities. Commercial aviation MRO, from a Heavy Maintenance Visit's (HMV) perspective, has many similarities to military aviation MRO, and the engineering aspects in support of such MRO are largely similar. The responsible aviation authorities are however different (covered in the next Section). Except for the very large operators, the airlines and their MRO partners depended on the OEMs for answers to serious MRO defects and repairs. Large passenger and freight airlines usually have significant in-house engineering organisations. Responsiveness of the OEMs in commercial MRO is also different, so is spares support. There are good fundamental business reasons behind the differences; from the way the organisations (airline and air force) are structured, the concept of operations, commercial versus military concepts of priority, and commercial (business) considerations.

As an illustration, military operators stock their own spares for good reasons associated with their operational requirements. Many may also insist on providing their own spares, including consumables. Parts traceability is given more emphasis for reliability tracking reasons and repair history. In the later years, export control became an important factor for needing traceability.

Commercial operators are more flexible on open-market purchases and as such the commercial supply chain is better developed. Consequently, the lead-time for buying of parts is much shorter and there are well-oiled mechanisms to get spares in the shortest possible time, including loans from other operators. In a sense while military customers emphasise independence, commercial customers emphasise inter-dependence.

High work standards is a requirement from both military and civil aviation customers but because of the need to fly at an intense level to cover its cost and be profitable, the main emphasis of airlines is around minimising down-time. Down-time in HMV is, for instance, an important consideration to airlines and there is a price it would be prepared to pay for faster turnaround on HMVs. LCCs take this issue a big step further. For some LCCs, even the turnaround check by a technical crew is done away with and the pilot does the check himself, somewhat like in the old days for the military even when aircraft were much less reliable then.

So when ST Aerospace went into commercial MRO, there were many differences but no big surprises technically on the aircraft maintenance aspect. However, it quickly learnt that being able to perform the job was one thing but to be able to do it within the contracted schedule and making a profit was the challenge. The size of the aircraft platform presented a different set of problem. Man-hours per check were easily larger by a big factor compared to military aircraft. On the other hand, the contracted time to complete any job was but a fraction of that for military work. This lead to very high loading of manpower resources on most jobs to get them out on time. Any problem like cost escalation therefore had a larger impact for commercial MRO, and if it was not managed carefully could easily result in major financial losses.

Having the right level of costly trained manpower was essential to meet the customers' emphasis on turnaround time. But unless the volume of business was sufficiently high to support the manpower use efficiently on a sustained basis, the loss could be significant.

Planning assumed a new level of significance. Ability to load and unload manpower became key to both good performances in turnaround time and cost control. These difficulties were not insurmountable but they were not what ST Aerospace was familiar with at the beginning when it went into the civil aviation business. Nor were the issues easily manageable as work was scarce and not easily secured in the early days. The scale of its operations was another factor which was important for the company to be efficient and this was a problem faced in the early days as the work it could secure was sub-scale.

Being Customer Focused

The problem of scale was not over even when the bar was crossed. Each new facility had to go through the same set of problems during its built-up. Even established companies have to maintain their customer base and workload well as without that, they would run into the same issues of inefficient utilisation of costly manpower resources and operating losses. On a positive side, it made the whole company very customer focused. This was a value that pervaded through the company, not only in aircraft MRO, but also in its engines, components, engineering and spares businesses.

Importance of Approvals

Management, engineering and MRO manpower had to comply with CAA requirements. As the company had to have the flexibility of undertaking work for different airlines, it and its professional staff like Licensed Aircraft Engineers (LAEs) had to have the certification of their customers' CAAs. Some countries fortunately accept authorisation from some of the CAAs like the FAA and EASA.

For customers from countries like China and Japan there were certifications of the Civil Aviation Administration of China (CAAC) and Japan Civil Aviation Bureau (JCAB) respectively to be obtained as well. There were areas of differences in expectations from the different CAAs but generally the difference was about the areas of emphasis. The basic requirements on quality, for instance, were not different. Nevertheless, the annual audits and certification was still a process to go through and many of the companies within ST Aerospace including engines and components, had a busy schedule year round being audited by the various CAAs and the customers' Quality Assurance staff.

How to be Economically Viable?

In the early 1990s, ST Aerospace's was not an established player in commercial aircraft MRO. Without a market position, it was difficult to secure work, especially for large packages of work from major operators. Where work was obtained, the question was one of available resources to do the work. And on completion of the jobs, the concern was how to use the manpower that had come off the aircraft. More often than not, it was a case of feast and hunger from month to month.

Profitability of the commercial business was critical and during the early years there were many occasions when the company appeared to be fighting a seemingly losing battle.

The management and crew in each of its facilities were determined and flexible. They embraced the need for the company to be profitable. In the case of SASCO, the staff from Hong Kong and elsewhere was highly committed as this was their future since they had decided to "adopt" a new country. So, although it started with a grouping of people of many diverse backgrounds, they integrated well on a common interest and SASCO became known by customers for being the leader in many MRO activities including Section 41 termination work, PTF conversion and HMV.

Mobile Aerospace Engineering (MAE) in the US was also a greenfield set-up (like SASCO) and despite the difficulties it faced in its early years it became the launch centre of many important programmes for ST Aerospace in HMV and PTF over the years. Despite the very difficult years in the beginning when work was not visible and it was uncertain if MAE could be sustained, the management and staff worked together and maintained their focus on the customers. An obvious affirmation that MAE was able to achieve its objective was when ST Aerospace started to look for a second site in the US for expansion.

What was not anticipated initially was the benefit of having MRO facilities in different parts of the world to support major passenger and freight airlines. Many of these airlines were global companies and did not only operate within their countries of origin. The ability to support these airlines through MRO facilities in its network was a competitive advantage for ST Aerospace. This was validated by the number of ST Aerospace's larger customers which were supported by more than one of ST Aerospace's MRO facilities or by different MRO facilities within the group at different times as its requirement changed. This led to the decision to establish ST Aerospace as a global MRO.

Some Key Initiatives to Stabilise Commercial Aircraft MRO Business

From 2000, several initiatives were taken by ST Aerospace to stabilise its commercial airframe MRO business and to ensure it would be sustainable. Two of these initiatives are used to share the experience. These were the investment in Licensed Aircraft Engineer (LAE) training and in building up its PTF conversion capability.

The first initiative was through the set-up of its own in-house LAE training programme. Prior to 2000, ST Aerospace depended on ad hoc training slots made available by airlines which normally conducted their own in-house training for their aircraft engineers. Training programmes were launched by the airlines only when needed. The number of slots which ST Aerospace could secure was what the airline concerned could spare after meeting its own needs! This opportunistic arrangement was not satisfactory as the numbers of training slots made available were not sufficient for ST Aerospace, especially when it was poised for growth.

MRO depended on a large number of trained personnel and LAEs were core to commercial aviation MRO. Running its own LAE training programme ensured the projected numbers of LAEs were generated on time. Equally important was that it enabled ST Aerospace to maintain control over the quality of training and the culture it wanted its engineers to have.

These considerations led to the decision by ST Aerospace to train its own licensed engineers.

In 2006, ST Aerospace started to induct graduates with engineering degrees for its LAE training programme (Certificate in Aircraft Maintenance Programme (CAMP 6)). This raised the bar as, even today, LAEs do not have to be graduate engineers. In 2006, because of external economic conditions, some graduate engineers applied for the LAE training programme. ST Aerospace viewed this positively as better-equipped LAEs should be a strong competitive advantage for the company. Extending the window on academic qualifications also gave the company a larger pool of people to recruit from. It used to be difficult to get graduate engineers who wanted to do the hands-on work which LAEs had to do. Here was a situation where some graduate engineers might be prepared to do so! This was not so different from the RSAF's earlier experience in the mid 1980s when it first recruited graduate engineers for military aircraft work and got them to work in the field to gain hands-on experience during the initial years of their employment.

Another equally important initiative was to invest heavily in PTF conversion capability. SASCO held the record for having converted more MD-11s than any other facilities in the world. MAE achieved the same for B727 and was on track to achieve the same for MD-10 when the programme was discontinued. Today, ST Aerospace as a group is converting more B757s between MAE and STA Engineering than any other conversion houses in the world ever did on other platforms.

Besides PTF conversions based on the aircraft OEM's Supplementary Type Certificate (STC), an approval from the relevant CAA to modify an aeronautical product from its original design, ST Aerospace's Engineering Development Centre undertook its own design work to develop a STC for B757 PTF conversion. This was selected by FedEx as the replacement solution for its aging B727 freighters. Further downstream, ST Aerospace was selected by Airbus EFW as its partner for A330 P2F development. The B757 and the A330 P2F developments and conversions would be covered in Section 4.8.3.

The important perspective to draw is that from a very low base, in a very competitive field, the company managed to seize the opportunities that presented themselves and grew a business in commercial aviation MRO and PTF conversion which overtook its military business in revenue as the market was the global commercial aviation market.

The military and commercial aircraft MRO businesses shared many similar dimensions and each grew from a greenfield basis to become important components of ST Aerospace today. The common factor between the two businesses was that they were both started by doing MRO.

MRO in ST Aerospace is however not only about airframe maintenance, repair and enhancements through modifications and upgrades. That is today the most visible and is significant. MRO in ST Aerospace is about the whole spectrum of support to an operator and extends to engines, components (mechanical and avionics), engineering services and spares support.

Whilst aircraft MRO, upgrading and conversions, are areas where ST Aerospace has established a globally competitive position, the activities beyond direct aircraft MRO are equally important to the company and enable it to provide services to customers who need them, up to "total aviation support" (explained later in Section 4.7).

In these other areas, significant capabilities have been developed which are competitive with the best in the market. Narrow-body aircraft engines and components repairs, PBH services, and engineering development are some such areas.

They are also synergies between what ST Aerospace does for its military MRO business and what it does for its commercial MRO business. Whilst similarities between the two businesses in aircraft MRO lie mainly in basic maintenance practices, quality and safety considerations, among others in the case of engines and components, even some of the test equipment and processes may be similar. Some of these capabilities would be covered in Chapter 3.

Perhaps the most important thing that ST Aerospace had invested in since its pioneering days was embracing the interests of its customers, large and small, as its own. Many things contributed to its build-up over the years but what had significantly differentiates and distinguishes ST Aerospace from its competitors is its customer base.

Section 2.2
Engineering Development – Modifications and Upgrading

This section of the book focuses on the pioneering spirit of the engineers in building up the engineering development capabilities to deal with the modification and upgrade of specific systems of aircraft. This covers the period before 1980. Thereafter, it went into the major conversion programmes which has become a hallmark of the RSAF's upgrade programmes starting with the A-4SU upgrade. The same approach was undertaken for engines and components, although the extent of engineering initiatives was less in view of the nature of the business.

The engineering development work differs from the maintenance engineering work undertaken to address MRO problems described in the previous section of this chapter. At some point the level of engineering in MRO, such as for major repairs, may be significant but unless it involves a fleet-wide issue, it might just be dealt with as a specific repair task with significant engineering input. Where the problem becomes systemic, it might require a modification or upgrade of the aircraft (or engine or component) and this would have to be applied across the entire fleet. Besides overcoming systemic problems on the aircraft, modification or upgrade might also be done to enable the aircraft to have a new capability. In later years, post 1980, because of the transformation of the RSAF from a training air force to an operational air force, and the possibilities brought about by technology, the upgrade work it did became extensive conversion programmes.

The preceding section of this chapter discussed how the RSAF and ST Aerospace had built up its maintenance capability, starting from maintenance strictly in accordance with the OEM's prescribed technical manuals to the extensive MRO capability for both military and civilian aircraft today.

During its early years, through interactions with the OEMs of the various aircraft, engines and equipment on problems that arose during aircraft operations, the RSAF's engineers started to learn more about the design considerations of their aircraft and systems. Knowledge of the aircraft and systems was slowly accumulated and provided more in-depth understanding of the design and engineering of aircraft. This enabled the engineers to progress to the development of major modifications and, later, upgrading of aircraft and systems.

Over time, in the late 1970s, the RSAF started to become a "smart user" of its equipment and systems. Through interactions with the OEMs, our engineers began to understand the equipment and systems from the design perspective and they began to develop competencies and confidence in trying to support the systems more effectively. ST Aerospace started to initiate local modifications, repair schemes and engineering proposals to fix problems or to enable the aircraft to fulfil new operational requirements.

Up to around 1979, there was no specialist engineering group in ALD, RSAF, and engineers in Quality Assurance Branch in ALD took on the engineering responsibilities. The initial engineering capability build-up was through failure investigation with the assistance of local institutions providing specialist services such as metallurgical examination and chemical analysis. Previously, a failed component was usually sent to the OEM for failure investigation and analysis. The engineers from Quality Assurance Branch also worked collaboratively with ST Aerospace engineers in reviewing and approving engineering and modification proposals submitted by the latter to resolve problems found during routine maintenance or to address systemic reliability issues. The spirit was to indigenously do more in the repair and modification of the RSAF's aircraft fleet, improve fleet reliability and availability and minimise over dependence on the OEMs. This was in order to be more responsive to the RSAF's needs and to help reduce costs.

By 1980, the first Engineering Branch was formed in ALD and it was tasked to provide engineering services for airframe and engines, avionics and electrical systems, and armament systems and weapons. This Branch, initially staffed by engineers and technical officers, was also tasked to undertake new projects. The smart-user approach also meant that engineers started to develop solutions to problems indigenously. Consultation with the respective OEMs was still required as most background engineering data on the aircraft and systems were not available then, but the engineers started to gain confidence and competence in locally developed solutions. Where needed information and data were not released by the OEMs for whatever reasons, engineers developed engineering models to derive equivalent information so that the needed development could continue unimpeded.

By 1982, the RSAF and ST Aerospace made the leap to embark in several significantly larger programmes such as the fleet-wide structural repair and replacement of the A-4 wing rear spars, jet engine blades and vanes manufacturing, remanufacturing of the Bloodhound long-range surface-to-air missile wings and replacement of wing's core matrix structure, the C-130B aerial tanker conversion and the integration of new weapons to the F-5. In these early programmes, the engineers were still in the learning mode. In some projects technical consultants were engaged or an experienced foreign systems integration company was engaged in a tripartite partnership with ST Aerospace and the RSAF. The key emphasis then was to do as much of the work as possible in Singapore, by Singaporean engineers and learning in the process. Some of the projects that reflect this build-up of pioneering engineering capability in the RSAF and ST Aerospace are discussed in the following pages.

Aircraft Modification – C-130B Conversion to Tanker

In the mid 1970s the RSAF started to deploy its aircraft overseas for training and live firing exercises for extended periods because of the lack of training airspace and weapon firing range facilities in Singapore. Besides deployment overseas for exercises, the RSAF was also keen to deploy its aircraft to friendly countries which were willing to host the RSAF's training. This was the start of the capability build-up to ferry aircraft to countries like Thailand, Australia and New Zealand to support the RSAF's overseas deployment needs. As the RSAF's confidence grew, a requirement was established for aerial refuelling tankers to extend the range of overseas deployments, to carry out in-flight refuelling en-route during the ferry of fighter aircraft overseas to their training grounds. The availability of aerial refuelling would also reduce the operations and logistics tasks of the ferry mission and increase the efficiency of the deployment. Otherwise the aircraft would have to be staged through multiple cities and towns in relatively short hops along the way to the final destination. The aerial tanker can refuel a flight of aircraft "on-the-fly", cutting down the number of refuelling stops along the way and hence reducing the time taken and ferry support effort.

The RSAF already operated four C-130B transport aircraft at the time and hence it made sense to look at a tanker aircraft based on the C-130 airframe from the operations point of view. Lockheed, the OEM, had produced a tanker version of the C-130, known as the KC-130 for the U.S. military as well as a number of other countries. These were new-build aircraft, built as an aerial tanker. Lockheed was interested at the time to sell the new tanker aircraft, not to modify existing C-130 airframes into a tanker. This was however a costly solution and not preferred by the RSAF. As the C-130B aircraft fleet was adequate for the RSAF's projected needs (including the tanking role) at the time, the interest shifted to the feasibility of converting its existing C-130Bs into tanker aircraft as and when this role was required; in other words, a role change into aerial refuelling tanker configuration. As a small air force, the RSAF worked on the multi-role principle where possible. A project team, comprising engineers from the RSAF and ST Aerospace was formed in 1980 to perform this feasibility study. This perhaps marked the beginning of the transformation of the RSAF and ST Aerospace from a maintenance-oriented organisations to embrace engineering development and major modifications of aircraft. Together with others projects, this project marked the beginning of the pioneering work done by the RSAF and ST Aerospace in developing the capabilities and know-how to perform complex modifications and systems upgrades on aircraft in later years.

The project team worked with an experienced aerospace company to examine the feasibility of modifying the RSAF's C-130B. It was a learning and competency building experience for the RSAF and ST Aerospace in those days, and our engineers were very much in learning mode. The RSAF finally made the decision to go ahead with the tanker conversion project. The first two aircraft were modified at the supplier's facility and the RSAF and ST Aerospace engineers were attached over a period of one and a half years to participate in and learn from the system design phase, the build-up of the refuelling components and system, the structural modification of the C-130B airframe required to accommodate the refuelling system, and the ground and flight tests. ST Aerospace performed the work on the remaining two aircraft in Singapore, with oversight from the contractor. The project gave ST Aerospace important hands-on experience in major airframe structural modifications and system integration work.

Internal fuselage mounted fuel tanks for KC-130

KC-130 with external pods from which refuelling drogue is extended

Although conceptually similar to the Lockheed KC-130 tanker, the design of the RSAF C-130B tanker was different. The fuselage-mounted fuel tanks were of a different design. They were made up of four approximately 800 US gallon fuel tanks that were attached to a standard 20ft loading pallet that was loaded onto the fuselage as standard cargo. These were designed as two modules, each consisting of two tanks, stacked vertically. The entire pallet could be moved into the C-130B fuselage and secured via the internal cargo handling system. The total fuel carried by the tanker was about 3,200 US gallons, slightly less than the Lockheed tanker aircraft.

A fuel transfer and management system had to be designed and integrated with the aircraft fuel system. Fuel could be transferred from the internal cargo compartment mounted tanks to the aircraft wing tanks (which fed the engines) and vice versa. More importantly fuel had to be transferred via electrical fuel transfer pumps from the fuselage tanks, up through the upper fuselage, through the left and right wings and to the air refuelling pods, from where it would be dispensed to the receiving aircraft.

A removable pylon and air-refuelling pod was designed for attachment to each wing. The refuelling pod consisted of the hose reel and drogue assembly, as well as the fuel and hydraulic systems which reels out and trails the hose and drogue and controls the fuel flow. Structural modifications were made for the observer stations installed on each paratrooper door. The receiving fighter aircraft would engage the drogue (which is a conical-like basket) with its aerial refuelling probe to start the fuel transfer process. The refuelling pod, complete with the hose and drogue mechanism, was bought direct from Sargent Fletcher, the prime supplier of such equipment. The refuelling pods were mounted below the

C-130 outer wings, outboard of the number 1 and 4 engines. The appropriate areas in the wing structure had to be structurally modified and strengthened to take the increased loads of the refuelling pod and anchor the associated fuel pipes carrying fuel from the fuselage tanks. Finally, an aerial refuelling control panel was added to the flight engineer's station in the cockpit and the necessary electrical modifications carried out. During flight, the flight engineer controlled the deployment of the refuelling hose and drogue, and the fuel transfer to the receiving aircraft.

The RSAF A-4 and F-5 undergoing air-to-air refuelling from a KC-130

The nature of the project meant that there was valuable exposure to system design, safety assessment, airframe structural modification, systems integration, ground testing, quality control and the conduct of flight tests. One key lesson learnt was the realisation that there would always be integration problems no matter how thorough the design stage was, and effort and time had to be allocated for trouble-shooting problems that cropped up. This was part and parcel of good programme management.

Cost effectiveness was a key consideration on the solution adopted. This included cost effectiveness in using existing assets to their limits, and in having an easily reconfigured modification so that the limited aircraft assets could be flexibly utilised! It was through this and other pioneering projects in the early 1980s that the RSAF and ST Aerospace were able to build up local capability and grow the confidence to embark into more sophisticated and complex modification and upgrade programmes on the A-4, F-5 and later-generation aircraft like the F-16.

F-5E/F Weapon Integration

The early 1980s also saw the RSAF's engineers venturing into a challenging new field - certifying externally carried weapon (nominally called a "store") to the F-5E/F fighter aircraft. This discussion will focus on the effort of RSAF's engineers in carrying out aero-mechanical analysis, ground tests, flight tests and the necessary instrumentation of the F-5E for the task. This completely new effort provided a valuable learning experience for a team of relatively inexperienced engineers. It was through such projects and immersion of our engineers with consultants and overseas contractors that created windows of opportunity to learn as they work. This experience is relevant to the discussion on engineering capability build-up as this was necessary for the modification work on the various RSAF's upgrade programmes in later years.

Engineering

This section will start with a simplified explanation of the tasks involved in aero-mechanical certification for high performance aircraft. These would comprise aero-elastic flutter analysis, safe release and separation of the store, assessing aircraft handling qualities, flight performance evaluation and assessing the engine operating envelope (such as stall or surge characteristics) at high aircraft angles of attack during carriage of the store.

The following provides a simple illustration on the efforts required for aero-elastic flutter analysis, which constitutes one of many engineering activities that needs to be performed to provide an understanding (of the complexity) of safe aero-certification of external weapons or stores on high performance aircraft. Some simple explanation on the flutter phenomenon on aircraft might be useful. Fighter aircraft wings can be relatively stiff (like the A-4 or F-15) or flexible (like the F-5 or F-16). Aircraft with stiff wings are usually not susceptible to flutter. A flexible wing can bend or twist under the influence of air loads such as gusts or turbulence. Have you ever taken a commercial flight and looked out of the window and watched the wing bending up and down and perhaps even twisting when the aircraft flies into turbulence, and wondered if that wing will break off?

Although the wing structure is designed to withstand steady static air loads experienced, in an unsteady situation (such as gusts and turbulence) the dynamic air load may begin feeding into the elastic motion of the wing, causing its amplitude of bending or twisting to increase with increasing dynamic pressure or airspeed. This in turn will cause increased air load, further increasing wing bending or twisting (hence increasing the relative angle of attack) until structural failure occurs.

The dynamic coupling between the elastic motion and aerodynamic loading is called "aeroelastic flutter". Flutter involves the interaction of aerodynamic, elastic and inertia forces on the aircraft structure (in this case the wing) to produce an unstable oscillation that may result in structural failure. Catastrophic flutter failures have destroyed aircraft over the years.

The introduction of a new external weapon or store on the wing of a fighter aircraft alters the structural, inertia and aerodynamic loading of the aircraft structure. The aircraft will have to be investigated and flight tested to ensure that the new configuration (during carriage and release of the weapon) is free from flutter as well as structural divergence (the unstable oscillation discussed earlier).

To start the analysis, aircraft mass, stiffness and aerodynamic models are first developed for the aircraft and weapon. Flutter analysis is then carried out.

The mass and stiffness model generates the aircraft dynamic characteristics which are validated by ground vibration testing of the aircraft and weapon. The mass and stiffness model, and the aerodynamic model are used together to carry out the flutter analysis. The aircraft is finally flown through a series of flight tests, and the flight envelope gradually opened in order to validate these analytical flutter predictions. Thus the aircraft high-speed flight envelope is eventually established for the new weapon carriage configuration.

Importance of Purchasing Engineering Data Upfront

Since the RSAF did not have data on the F-5E (other than the aircraft loads and stress reports), engineers had to develop a structural dynamic model of the F-5E. In view of the lack of expertise in this area, an overseas company proficient in aircraft structural dynamic modelling was engaged to coach the RSAF's engineers. A low fidelity finite element model of the aircraft with lumped mass and stiffness distribution was developed with the help of the consultants. This included the wing, pylon and weapon characteristics since this was the area of interest. Together, the team carried out the analysis and subsequent ground vibration verifications. This was then followed by a flight test programme to check out the aircraft's flight envelope as the final verification of the analytical prediction. The whole programme provided a tremendous learning experience for the project team. Engineers had a first-hand understanding of the considerations and complexities of integrating an external weapon to a fighter aircraft. Besides the static structural loads assessment, engineers learnt that there was the aeroelastic behaviour of the airframe with the new store, which had to be modelled, analysed, and verified by ground test before they could use these models to open the aircraft flight envelope through flight test to validate the analytical prediction.

Certification and Flight Tests

There was also the issue of weapon release certification. The static and dynamic structural loading on the airframe upon weapon release had to be considered. If the weapon had a rocket motor, the effects of exhaust plume ingestion into the jet engine would have to be investigated. This was the first weapons qualification flight test experience for the engineers.

In order to carry out the flutter flight test and weapon release qualification, the aircraft had to be instrumented with appropriate sensors and a real-time telemetry package installed to transmit the monitored parameters. A ground station had to be built for the flight test engineering crew to receive real-time data from the test aircraft and analyse it in near real-time, whilst the test pilot was waiting in the air (within safe flight envelope) for further instructions before he could proceed to the next test point. A separate contractor was sourced to provide the instrumentation and telemetry package. While the contractor was responsible for providing the complete airborne and ground telemetry package, measurement sensors and the build-up of the ground telemetry station, the RSAF engineers had to install the airborne package and sensors on the F-5E as the contractor did not have experience on this aircraft.

The build-up of the instrumented F-5E presented a challenge. Normally, a flight test aircraft would be specially built and appropriately wired during manufacture. As and when required, this instrumented aircraft can be equipped with the airborne telemetry package and sensors. After the test, these can be removed and the aircraft reverted to its normal operational role. For the project, the engineers had to instrument an existing F-5E that was not designed and manufactured with instrumentation provisions.

Designing and retrofitting the mountings and wiring provisions of all the sensors were hence a significant task. There were "synchro" sensors which were installed to sense rotary movement of aircraft control surfaces, accelerometers which sensed vibration, position transducers which sensed linear movements such as engine throttle position, strain gauges which were a proxy for loads, and sensors measuring a host of other parameters.

The engineers decided to remove one of the two aircraft cannons to create space for the telemetry package. All sensors had to be wired to the telemetry package. As the instrumentation installation was designed after the aircraft was built, some of the sensor installation and wiring were less than elegant. For example, accelerometers installed in the aircraft tailplane (to measure vibration) had to be externally installed via a permanent adaptor plate bolted on the tailplane. The signals were carried via thin external wires from the tip of the tailplane to the fuselage. The wires had to be secured and taped (by "high speed" aluminium adhesive tape) on the tailplane surface. This was the only solution and good enough for a number of flights before the tape had to be replaced. This "band-aid" solution was certainly not elegant. However it reflected the resourcefulness of the engineers in working out a solution that was "safe to fly", practical and got the job done.

The F-5E/F weapon integration programme was successfully completed. More importantly, the project sowed the seeds for the establishment of a weapon integration and flight test capability in the RSAF and eventually ST Aerospace. This capability now extends to the F-16 and F-15 and the lessons learnt in instrumentation and operation of the F-5E flight test aircraft helped the RSAF flight test community define the requirements for new manufactured flight test aircraft when the F-16 and F-15 were acquired in later years.

Section 2.3
Service Life Extension Programme (SLEP)

A key engineering capability achieved by the RSAF was the implementation of the service life extension programme on various aircraft types. Some of the aircraft like the KC-135s, C-130s and A-4s were not new when we bought them. For the new aircraft that were bought (such as E-2C, S-211 and F-16), several of them had to be used beyond their intended service lives. Service lives of aircraft are typically designed to last about several thousands of flying hours (for the F-16, it is 8,000 hours) but if it is flown more severely than what it was designed to be, then fatigue problems may start to surface faster than expected. To monitor these usage patterns, the RSAF's engineers developed Aircraft Structural Integrity Programmes (ASIP) to collect information on aircraft usage so that timely preventive maintenance, inspections and modifications could be done to ensure continuous airworthiness of the aircraft. In addition, such ASIP systems could also allow additional flying hours to be authorised depending on the usage pattern. Some examples of what the RSAF had done for SLEP are as follows:

F-16 Falcon Up

This involved structural modifications on the F-16A/Bs. Through knowledge of the usage pattern, design data and experience, the RSAF was able to determine the requirements for the various proposed modifications by the USAF to upgrade the aircraft structures and decided on local implementation of the upgrading instead of depending entirely on the USAF and Lockheed Martin. Subsequently, considerable savings were achieved by engaging ST Aerospace to modify the aircraft. This also helped built up ST Aerospace's depot repair capability for the F-16s.

Falcon Up was the first F-16 project undertaken by ST Aerospace. As the USAF did not provide the detailed service bulletin (only engineering drawings were provided) needed for the modification, ST Aerospace had to develop the level-3 job cards from observing the first aircraft modification done by Lockheed Martin. Throughout the whole process, there were many evaluations and decisions made by the RSAF and ST Aerospace, such as to cold-work more rivet holes compared to those called out by the USAF since the structures were already open up for re-work. Some of the procedures were also modified along the way as experiences were built up. All these were eventually submitted for approval to the appropriate authorities in the RSAF. All modifications were successfully completed and no rework was necessary. There were many visitors (overseas operators who were planning their own Falcon Up programme) who came to visit throughout the period of modification from mid 1996 to mid 1999 to learn from RSAF's experience.

The RSAF also had the foresight to save cost earlier in the contracting phase by buying over the tooling for the modification to be loaned to ST Aerospace. This saved the RSAF $0.5 million. With the experience, ST Aerospace then went on to successfully support the Falcon Up modification for another country together with Lockheed Martin which reduced the cost for the country. With the organic capability built up through Falcon Up, ST Aerospace was able to take on more extensive project work on the RSAF F-16C/D.

E-2C SLEP

This involved the structural enhancement on the Wing Centre Section of the E-2C aircraft in order to extend the life of the aircraft beyond its intended design life. To ensure proper engineering analysis and decisions, a flight recorder was installed on the E-2C to collect the aircraft usage pattern so that the information could be compared with the designed usage to allow the aircraft to extend its service life. Extensive savings were derived from this project which won the Best Engineering and Development Centre (EDC) award in the RSAF.

S-211 SLEP

This was another in-house structural life extension programme for the S-211 aircraft, which increased the average service life from 5,500 hours to 8,000 hours. The requirement was scoped to support the flying operations till year 2009, resulting in a need to only upgrade 10 aircraft structurally. The project involved technical feasibility study of cold-working and other structural reworks for the S-211 aircraft to develop the final modification. In addition, Structural Health Monitoring Systems (SHMS), similar to ASIP, were also included as part of the S-211 upgrade. The SHMS involved the development and implementation of the PZT (piezoelectric) and CVM (Comparative Vacuum Monitoring) on the lead S-211 aircraft (A/C 349 and 340) to assist in the development of the maintenance policy for the upgraded aircraft. The project won the Best Suggestion Award at the MINDEF level in 2005.

A-4 and F-5 ASIP

With the aircraft upgraded through the conversion programmes, the RSAF was able to use the data collected from the mission computer to compute the usage pattern. This allowed the A-4 aircraft to be flown beyond its original service life. Similarly, for the F-5, inspections on the aircraft could be extended, as the actual usage pattern was deemed to be less severe than the design. This allowed savings in manpower resources and downtime of the aircraft.

Section 2.4
Managing Technologies

Building Up Engineering Capabilities at ST Aerospace

As the RSAF was building up its engineering capabilities through MRO, modification and upgrading of its aircraft to meet its operational requirements, a parallel build-up was ongoing at ST Aerospace.

While ST Aerospace's initial MRO capabilities were built up through the assistance of the RSAF in the early days, the approach on engineering capability built-up had to be different as the RSAF would not be building up capabilities of an engineering company. That was not the RSAF's core business. This section is about how the company, ST Aerospace built up its design, development and manufacturing capabilities to incorporate new technologies that became available for improving the capabilities of aircraft and their weapon systems to meet the requirements of initially the RSAF and, later, adapting the capabilities to serve the commercial aviation market. These capabilities also enabled ST Aerospace to go into new product development, some examples of which are shared in Section 4.8.

The Starting Organisation

In the eyes of many people, ST Aerospace is a global aircraft MRO company but its engines and components businesses, which have become quite significant, are not as visible. Perhaps this is because of the higher signature of aircraft over engines and components work, or the fact that ST Aerospace is recognised as the world's largest airframe MRO company since 2002.

Besides aircraft, engine and component MRO, an equally important and significant dimension of ST Aerospace is its engineering development capabilities. The company did not acquire the full-fledged engineering capability that it has today through acquisition of an existing engineering company, nor did it recruit large number of experienced engineering personnel from elsewhere. The capabilities were built up from undertaking progressively more demanding engineering work and learning from the work it did. Each step was on something that it had never done before and the approach was pioneering in any sense of the term.

Whilst its engineers were increasingly involved in engineering work for its maintenance and refurbishment activities, the most significant transition to engineering development activities was when it started to undertake upgrading military aircraft and, later, PTF conversion of commercial passenger aircraft to freighters and development of products. The first major aircraft upgrade that ST Aerospace delved into was a very significant programme in terms of programme size and technical complexity. That was the A-4SU upgrade. To undertake the task, ST Aerospace recruited a group of 10 young engineers and engaged the services of three very experienced senior engineers from Grumman to guide them.

In its early years, ST Aerospace's enthusiastic young engineers would work on the projects as nominated sub-contractors. Over the years, ST Aerospace painstakingly acquired the engineering experience and management capabilities to become the prime contractor of major programmes as this is very important to the retention of capabilities to support the upgraded aircraft over its life cycle.

The engineering organisation or EDC of ST Aerospace started in the late 1970s with a very simple structure — the Structural Engineering Group and the Systems Group were the two main groups of the organisation. Software engineering was not then considered a necessary skill to be developed until much later when the A-4 underwent its avionics upgrade in the mid 1980s.

Over time, the engineering organisation became more developed with the addition of various specialisations, including software which is today a critical core skill for any high-tech engineering company. Programme management was also recognised as an important capability as increasingly ST Aerospace was increasingly appointed as prime contractor for programmes of high complexity and value.

There were many reasons for this. The RSAF, as a very knowledgeable and operational air force, always wanted the best performing equipment available from the market. Many other users would just go for a system provided by one principal OEM which naturally would supply most of the subsystems and components, not necessarily the best or the most cost-effective in its class. To achieve its objective, the RSAF would need to appoint a prime contractor and system integrator to be responsible for integrating the equipment from various OEMs. That prime contractor and system integrator must had broad enough knowledge and capability to work with the various sub-systems and equipment OEMs. It must also be there in future years, providing life cycle support including continuous enhancements of the upgraded aircraft as and when newer technologies presented the opportunity, or simply to replace equipment which became not supportable. This discipline of the RSAF to keep its capabilities at the leading edge without incurring unnecessary cost of replacing aircraft frequently also led to its emphasis on Life Cycle Management LCM) as detailed in Section 4.1.

Most of the major systems upgrades also involved substantial work on the aircraft, its structures and retained installed systems. ST Aerospace, as the strategic industry partner of the RSAF became the natural choice as prime contractor responsible for programme management and system integration. To undertake this heavy responsibility, ST Aerospace had to not only build up all the necessary skills and capabilities associated with each requirement but also to sustain the capabilities and continue to add new ones over time on its own. Besides the engineering capabilities, ST Aerospace had to maintain the installed systems' "corporate knowledge" without which it would be difficult and costly to add new capabilities over time.

Recognising New Requirements to Develop

For brevity, the development of the various core engineering design and development capabilities which are normally found in most general engineering organisations will not be discussed here although they had to be built up and are as important as the company has to have the full repertoire of engineering skillsets.

This section will instead focus on those additional competencies in ST Aerospace which were necessary to enable it to support the RSAF's requirements. Besides the capabilities that are discussed in this section, some other capabilities which have become entrenched as "processes" of the company are covered under Chapter 4 and would not be covered here. These engineering capabilities had differentiated ST Aerospace from the other aviation companies, especially the MROs, and enabled it to undertake higher value-added jobs well, as well as perform its MRO business better.

Composites Capability

ST Aerospace realised very early on the potential of composites in aviation and started on a journey to build the capability to undertake design and development work with composites. Composite materials are basically a combination of two or more dissimilar materials in order to achieve better properties, or impart a new set of characteristics that neither of the constituent materials could achieve on their own. Engineering composites are typically built up from individual plies made of carbon, glass or aramid, among others, that take the form of continuous fibres either in a single direction (unidirectional) or woven into a fabric, and embedded in a host polymer matrix, such as epoxy, phenolic and polyester which are laminated layer-by-layer to build up the final material and structure.

Composite materials have tremendous applications and advantages in aerospace. These materials are light and yet offer high mechanical properties in the areas of strength and stiffness, and the fabric can be configured to provide the necessary compression or tension strength exactly where such characteristics are required in the design of a particular aircraft structure part. This behaviour and lay-up process of the fabric in the manufacturing of a structural part makes it possible for a structural part to be manufactured with lesser sub-parts, which results in weight savings, one of the key constituents that determine the performance, endurance and fuel consumption of an aircraft.

Composite Manufacturing, Made-to-Print

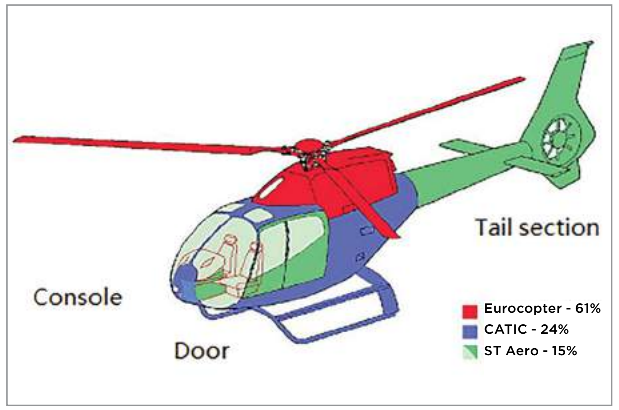
ST Aerospace's first initiative on composite work started in the early 1980s by going into composites manufacturing with aircraft OEMs under the RSAF's offset programmes for new aircraft purchases. The motivation was to introduce aerospace composites technologies to the local industries as composites were very new then. The items manufactured include the Super Puma helicopter composites sliding door and floor board, the Dauphin helicopter floor board and the S-211 jet trainer aircraft rudder and elevator. These items were manufactured by Singapore Aerospace Manufacturing (SAM), then a subsidiary of ST Aerospace.

In the late 1980s, ST Aerospace was involved in a fighter aircraft capability enhancement programme in which a new nose radome made of composite material was required to house a new system on the A-4. This requirement offered ST Aerospace the opportunity to design, manufacture and test the composite radome. With the help of an experienced consultant, ST Aerospace fulfilled the contractual requirement and at the same time built up the associated composites engineering design expertise and manufacturing capability. With this track record, SAM was subsequently engaged to fabricate the entire composite airframe for part of the Searcher unmanned aerial vehicle (UAV) acquired by MINDEF. As its experience grew, SAM competed in and won contracts to manufacture the composite nose landing gear door of the Boeing B777 aircraft and engine nacelle thrust reverser for the Airbus A340 aircraft.

Composite Design and Development, and Manufacturing through EC 120

In the early 1990's ST Aerospace entered into collaboration with Aerospatiale (later named Eurocopter and now, Airbus Helicopter) and China National Aero-Technology Import & Export Corporation (CATIC) to design and build a 1.5 ton helicopter (designated as EC-120) made almost entirely of composite material for the global market. This was at Aerospatiale's invitation as it wanted a three-party collaboration to enhance its proposal to China. At that point, ST Aerospace already had its EDC and SAM organised to do engineering design and manufacturing respectively for metallic aero-structures and components. Although the joint venture programme would be led by Eurocopter, the challenges in design and manufacturing effort faced by the young ST Aerospace's team of engineers was still massive. That was the first time the team was involved in the design and manufacture of primary structures made from composites. It was also the first time it was in an international collaboration with a major aviation OEM and a major industry player from China, the China National Aero-Technology Import & Export Corporation (CATIC). ST Aerospace understood the rare opportunity and decided to take on the challenge.

ST Aerospace took a 15% share of the joint venture and was responsible for the design and manufacture of the tail boom, Fenestron, cabin and cargo doors, and console and wind shields. The primary structures (tail boom and Fenestron) would be almost entirely made of composite material (see diagram below).



Work share on the EC-120

The project team was organised into an integrated product team (IPT). Representatives from the various engineering, manufacturing, test and quality assurance disciplines were involved in every aspects of the design phase. This was so that any design considerations that could have undesirable impact on manufacturing process, such as process limitations, tooling design, production quality and consistency, would be addressed and modified during the design phase. This would minimise any costly re-design efforts and schedule impact due to manufacturing complications during the production phase of the project. The design and manufacturing concepts were thoroughly tested during the prototyping stage and improvements made before final production decision was taken. In order to mitigate the challenges of ensuring that the different parts designed by the different parties of the partnership would fit properly during final assembly, Eurocopter organised a joint design office during the early stage of the design phase. The engineers from the three partners were co-located so that they could have regular sharing of their designs which might have impact on the parts under the responsibility of the other partners.

One of the key challenges in the manufacturing of composite structures was in the design of the lay-up and curing tooling. The tool had to be precise in shape and dimensions, provide consistency in results, be durable and function well under the combination of temperatures and pressure variations in an autoclave during the curing process without affecting the final form of the product. The manufacturing engineers undertook economic cost-benefit analysis on the choice of material to use for the tools against the available budget. While a metal tooling would be more precise and less subjected to wear, it would be more costly. The problem was however not cost but uncertainties about how many helicopters would be sold.

The engineers also had to learn how to work with new composite material, some with thickness as thin as 0.1mm without causing any tear or delamination during curing as this would result in the scrapping of an expensive part during manufacturing.

The design team also had to consider various types of composite materials to use in order to meet stringent weight, strength and manufacturing cost target set for each part. New knowledge in designing different fabric lay-up orientation (angles) and number of plies to provide the optimum mechanical properties at a targeted area of the composite structure had to be mastered in quick time in order not to cause delays to the other partners design efforts. This also included learning the art of adding reinforcement plies at locations where needed (example to allow bending in one direction, but not in another direction) and the ability to design integral parts, which was an advantage offered through the use of composite fabric, instead of assembly of multiple parts.

Another significant challenge faced by ST Aerospace was the ability to improve its efficiency in manufacturing composite structures. Manufacturing using composite fabrics is a laborious process. In order to make a sub-assembly, plies of composite fabric have to be cut, laid-up on the tool, checked, and compressed after a pre-fixed number of plies. The cycle repeats until all the plies in different orientation and thickness according to design have been completed and the lay-up tool is properly vacuum sealed for curing. After all the sub-assemblies have been manufactured, these have to be assembled to form the final assembly, which may need another curing cycle to bond the pieces together. The needed efficiency, and expertise, to do this work well are usually achieved by technicians who have been working with composite materials for a significant number of years, many of which are spent manufacturing the same part. Most of the technicians in Eurocopter had been working in the composite shops for more than a decade, with some more than 20 years.

In Singapore's work environment, it was difficult to maintain a team of trained and experienced staff with similar experience. As such, it was very challenging to improve the manufacturing efficiency of the EC-120 components under ST Aerospace work share to the level needed to meet the targeted performance to make the project financially viable. A lower cost base producer had to be found to undertake the serial manufacture of the parts upon production go-ahead.

ST Aerospace sub-contracted the production of its work share to manufacturing companies in China and Taiwan. To do this well, ST Aerospace had to develop expertise in sub-contract management. Under commercial aviation certification processes, ST Aerospace remained responsible for its sub-contractors and the quality of their products. This added a new dimension to its capabilities build-up, an important aspect when in later years it ventured into major commercial aviation PTF conversion programmes.

With the facilities and processes in place, ST Aerospace applied its knowledge and experience gained on composite structure design through the EC-120 helicopter programme to UAV, some 15 years later. In parallel, ST Aerospace also enhanced its capability in composite structure and airframe repair which was important for newer commercial airplane like the B787. Besides continuing to acquire maintenance processes certified and approved by the OEMs, ST Aerospace also worked with local research institutions like Agency for Science, Technology and Research (A*STAR) to improve the current processes, and to assess new techniques in composite design, inspection and repair for commercial MRO. In technology and engineering, for most matters, there is no major divide between commercial and military aviation.

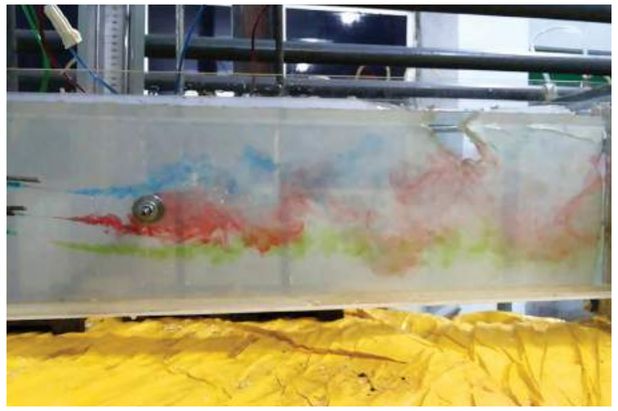
Recognising that composites repair and manufacturing would be an important technology to have in its repertoire as an aviation company, ST Aerospace invested in capabilities build-up over the last 20 years through training and gaining experience through undertaking programmes with much composite design and development contents. While academic training is important, the ability acquired by undertaking actual development programmes would lead to a more rigorous capability being acquired.

Aero-Science

Aero-science covers aerodynamics, aircraft flight performance, and aircraft stability and control. Aircraft manufacturers use various disciplines in the aero-science to help them develop better aircraft. As an MRO house set up initially to support the RSAF, the need for aero-science in ST Aerospace became apparent when the company was involved in the RSAF aircraft upgrade programmes.

The development of aero-science capability, as with many of the other engineering capabilities in ST Aerospace, began with the A-4 re-engine programme in the mid 1980s. A specialised aero-science group of two young mechanical engineers formed the nucleus of this group and their initial focus was to compute and evaluate the flight performance of the aircraft with the new engine. Their jobs included the establishment of a new flight envelope, aircraft take-off and climb performance, turn and manoeuvrability, range and endurance, and descent and landing characteristics.

Beside numerical predictions of these flight performances, the aero-science group was also important to the flight testing efforts to validate the upgraded aircraft performance. Measured data had to be matched against the predicted numbers before they went into the publication of the new flight manual for the upgraded A-4.



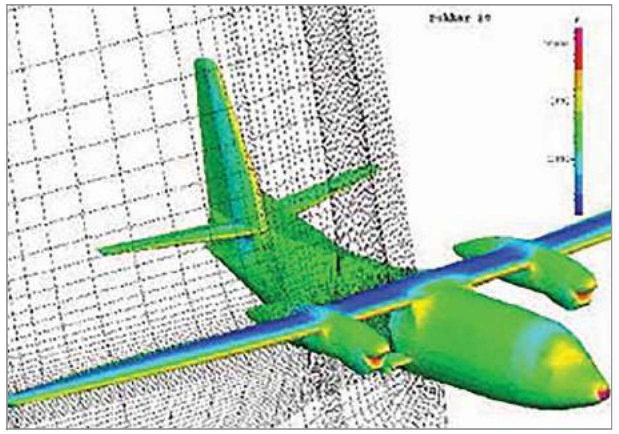
Water tunnel flow visualisation

When the flight test programme began, the prototype aircraft with the new engine experienced lateral-directional oscillation due to the cross flow effect of the bifurcated duct separating the flow from the two intakes situated on either sides of the A-4, just aft of the cockpit. General Electric (GE), the engine manufacturer, led an investigation team comprising Northrop, the programme technical consultants engaged by ST Aerospace and ST Aerospace's engineers, and used a water-tunnel test technique to visualise the flow phenomenon around and inside the aircraft intake ducts. The need for such investigations led to the setting up of a water tunnel test facility in ST Aerospace in late 1980s. This simple set-up became a valuable tool for all subsequent work requiring flow visualisation and enabled ST Aerospace to evaluate and assess aerodynamic effects for other aircraft modification and upgrade programmes.

Enhancing Aerodynamic Capabilities

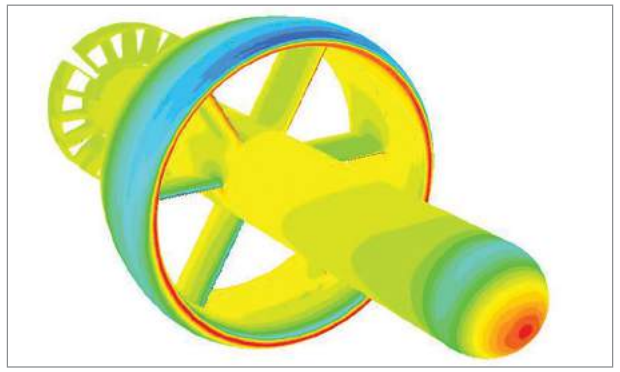
To further enhance its aerodynamics capability, ST Aerospace embarked on the development of a Reynolds Average Navier-Stokes Computational Fluid Dynamic (CFD) code with Defence Science Organisation (now known as DSO National Laboratories or DSO) and ALD now known as Air Engineering & Logistics Organisation (AELO). CFD uses computational techniques to numerically simulate the properties (such as velocity and pressure) of flows over the aircraft and to enable users to evaluate the flow behaviour and aerodynamic forces acting on the aircraft surfaces, without the need to conduct costly wind tunnel tests (there were no wind tunnels in Singapore then). The aerodynamic capability set up allowed ST Aerospace to assess the impact on aircraft aerodynamic and fight performance due to the introduction of new external stores to the aircraft.

Aircraft stability and control is another important aspect of aero-science in assessing and evaluating the effect of external systems on aircraft flight characteristics. ST Aerospace built up this aspect of engineering capability by working with DSO in modelling and simulating the separation of external stores like bombs or missiles when released from aircraft.



Pressure distribution over
a complete aircraft using CFD

When ST Aerospace embarked on the development of UAV systems after the turn of the new millennium, the engineering capabilities in aero-science came in very handy. The aerodynamic analysis capability was fully utilised for the design and development of UAV systems, and the stability and control capability was used for the development of ST Aerospace's flight control computer for the UAV. An example of ST Aerospace's aerodynamic analysis capability is the computational fluid dynamics (CFD) modelling of the pressure distribution it did of a Fantail UAV (a vertical take-off and landing, VTOL UAV) when it flies horizontally.



CFD computation of a Fantial UAV

Today, ST Aerospace has established the basic capabilities in all aspects of aero-science. The aero-science capability is an important part of ST Aerospace's engineering capabilities to support its system upgrade work as well as new products development.

Avionics Software

Software Capability Build-Up

The Engineering Software Department (ESW) within ST Aerospace's EDC was formed in the late 1980s. The key driver for this build-up was to enable ST Aerospace to undertake the important task of integrating the many electronic components that were being introduced into aircraft even in those days, an activity that could only become more important in the future.

Operational capability upgrades and technology insertions would require changes to the aircraft core avionics software, commonly called Operational Flight Programme (OFP). This was especially true with the introduction of the glass-cockpit. Information from the various aircraft sensors and avionics systems would all be piped in to the core computer(s) of the aircraft for weapon delivery and navigation computation. This information would be displayed on the glass-cockpit for use by the pilot.

OFP is usually large-scale. It is mission and safety critical in nature and requires real-time embedded execution. In view of the safety requirement and the nature of the operations, this aspect of the capability build-up involved not just the engineers' skill set and knowledge, but also the integration facility and software process, policy and governance.

To facilitate this capability build-up, the engineers were initially attached to the OEMs' facilities to understand the software design, implementation, integration and testing. Besides working with the aircraft and sub-system OEMs, local feasibility studies and development of further enhancements to aircraft and its systems enabled ST Aerospace to strengthen its software development capability.

The importance of having engineers to solve problems, especially major problems with safety of flight implications was, first, well-illustrated in the case of the A-4 Crisis in Chapter 3. This was validated again and again over many other occasions. As another illustration, this time using an electronic engineering application, was the upgrade of the F-16 as the aircraft mission computer was limiting the ability to add new operational capabilities. To replace the existing mission computer would have been a costly option and, more importantly, in terms of time and efforts because of the need to re-certify the existing on-board systems and weapons capabilities. This was addressed by adding another mission computer to handle those new requirements that could function on its own. Both the add-on mission computer and software were developed by ST Aerospace' s hardware and software engineers.

Meeting Customer's Regulatory Requirements

With the increasing importance of software to the operations and safety of its aircraft, the RSAF formalised its software configuration management organisation to govern and regulate the OFP software releases. Its role was to ensure that, besides quality and safety, all software released adhered to certain standards and configuration control. The committee of this organisation comprised the various stakeholders within the RSAF, engineering and operations, and the industry.

For each version of the OFP software release, the software changes, testing concept and status have to be presented to and approved by the committee before the approval for software release would be given. Through the experience built up from the early A-4 to the latest F-15 aircraft, the process has evolved from the early days of adhering to MIL-STD-2167A to today's comprehensive setup in accordance with DO-178C and IEEE 12207-2008.

To meet the needs of the RSAF software governance requirements, ESW in ST Aerospace had developed a set of software process handbooks since the early 2000s. The handbooks detail the activities to be performed during software planning, management, development and integration. This software process was assessed at Software Engineering Institute, Carnegie Mellon (SEI) Capability Maturity Model (CMM) Level 3 back in 2003 by a US rating company, the Process Group. The Process Group is an authorised assessor of the SEI CMM. These handbooks regulate the practice of all software engineers within ESW since then. Constant revisions are made to these handbooks to keep the process up-to-date and relevant.

Technologies, especially those related to software and hardware, have been evolving at an escalating rate since the days when the desktop PC was born. There was the Z80 from the 1970s to the current generation of multi-core processor. This means larger and more complex software can be packed within each avionics computer.

Real-time software partitioning, where software is divided into various packages that are housed within each core of the processor, has been introduced to better manage the interaction and execution of the various software modules and hence maintain better control of software safety. New software design, programming concepts and languages, and more development tool suites are introduced regularly into the market to make software development more efficient and better managed.

Unlike in the consumer products world where users and suppliers are quick to adopt new technologies, the decision process in aviation tends to be more cautious and deliberate. This is because some of the changes might have unforeseen impacts on other systems and might require the entire system to undergo full qualification, including flight testing. The cost of changing to newer technologies, and the concern of possible risks to safety, have resulted in a more cautious stance although the adoption of new technologies is inevitable.

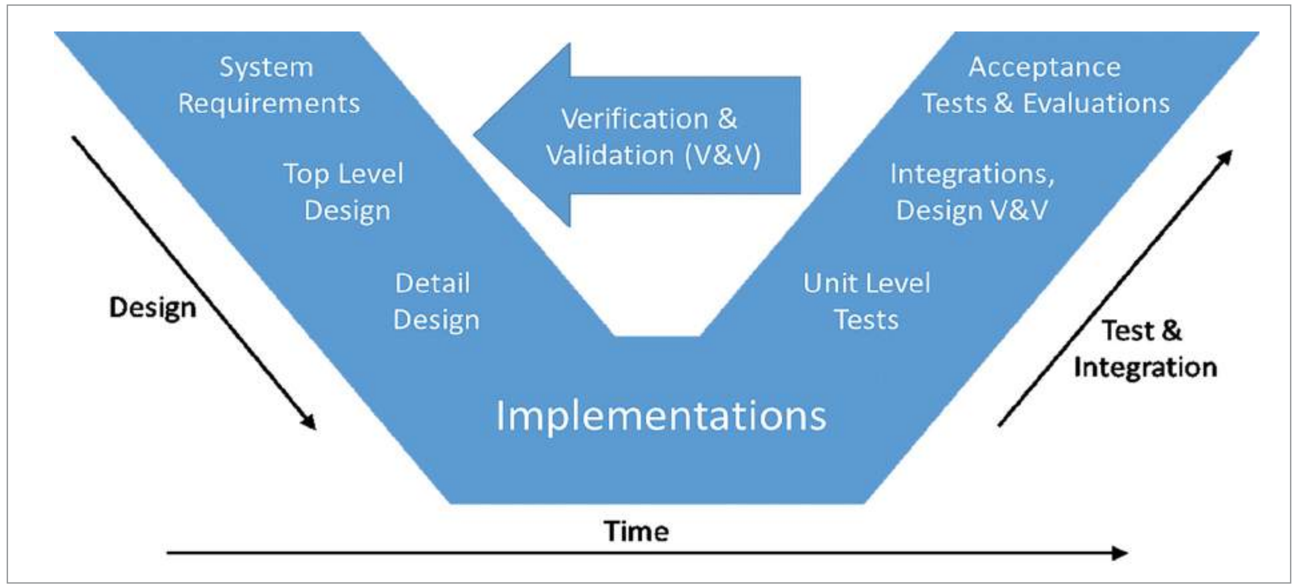
Other aspects in software development to watch out for are the ever-increasing security threat of malware and other malicious software, and the changes in the guidelines and standards for software development. The threat of malware and malicious software cannot be belittled and would have to be addressed and managed in software development and integration.

With lessons learnt and experience built up over the last few decades, software processes have been made more robust and stringent while emphasis on software safety has increased. These have resulted in more requirements being imposed and additional efforts being put into software development, testing and integration. Although the software capability attained locally has reached a high level of maturity through the hard work of the pioneer generations of software engineers, the work is never completed as efforts continue to be needed to keep the processes relevant with the evolving standards in the next bound of development.

System Integration

A system is an aggregate of subsystems cooperating so that it is able to deliver the desired overarching functionality. Systems integration is the process involving the optimal design of the interactions between the various subsystems, new and old. The integrated system is tested progressively to ensure it achieves the desired outcome in the intended operating environment.

An aircraft in service today, be it a military or commercial aircraft, will likely continue operating for many years to come. This is not only because of the very high cost of new replacement aircraft but because an aircraft in service can continue to meet the service requirements if it is kept relevant through the introduction of newer subsystems to enable it to better undertake its mission or meet new regulatory requirements. While system upgrades or updates are most common in the case of mission equipment and other aspects of an aircraft's avionics, in other cases it might involve a change in configuration to undertake a new role. A good example is the RSAF A-4 Skyhawk which had its systems upgraded in the 1980s to meet its intended role as the A4SU. Following that, over the next two decades, its systems continued to be modified repeatedly to meet each new mission requirements.



V-Model and V&V process of systems integration

We all know that an aircraft has to be highly reliable and avoid critical malfunctions during flight. Hence all systems incorporated in the aircraft have to undergo various stringent development tests and validation. This is especially true for sub-systems to be added to an in-service aircraft as the newly introduced equipment or sub-system might have adversely affected some existing functions. The systems integration activity has therefore to be done systematically and rigorously according to the V-model below.

The verification and validation (V&V) process is also required to be well documented. The approach is practised throughout the aviation community.

Design of sub-systems and components is undertaken through a top-down process starting from system requirements. Unit-level tests are conducted to ensure compliance to detailed design requirements prior to Integration. They can range from simple continuity tests of an electrical harness to complex tests for a computer software configuration Item (CSCI) of a complex weapon release algorithm.

When all sub-systems and components are ready, the activity proceeds to integration and V&V of the top level design. Integration is usually done on a System Integration Laboratory (SIL) that is representative of the aircraft concerned, where the sub-systems and components are to be hosted, from a systems integration perspective. While there is usually no simulation of engines and wings in the SIL, you can usually find actual mission computers, displays and controls of the aircraft. Depending on the sophistication of SIL, it may be possible to virtually fly and execute a complete mission to test the integrated system under the most stringent scenarios.

For systems integration involving flight controls, the integration facility might include the real aircraft control surfaces including rudder, ailerons and elevators, and the associated actuators. This type of integration facility is usually used during the aircraft development phase and is only found in the aircraft OEM premise.

Other V&V activities includes thermal measurements while "sun tanning" the aircraft, Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI) analysis to validate safety aspects of the top-level design.

In the final V&V against system requirements, three acceptance tests are executed sequentially followed by operational test and evaluation (OT&E). The three tests are system software acceptance test in the SIL, ground acceptance test (GAT) on aircraft while aircraft is on ground, and flight acceptance test (FLAT) on aircraft in flight.

ST Aerospace started the build-up of its airborne systems integration capability during the A-4 Skyhawk's first avionics upgrade, focusing on weapons delivery and navigation missions in the 1980s. This was extended over the subsequent years beyond attack avionics and navigation systems integration activities.

ST Aerospace's approach towards building systems integration capability was fortunately built with system, software and hardware capabilities under one roof, enabling the company to architect tailored solutions that would be difficult otherwise. Since ST Aerospace is also an aircraft maintenance house, the solutions offered also took into consideration the aircraft users' perspective like life cycle support considerations, and not only system performance.

On the development of the F-16 indigenous integration capability, in the 1990s ST Aerospace sent a team of software and system engineers to acquire the know-how from Lockheed Martin on both the SIL and OFP of the aircraft.

When the F-16 SIL was delivered to Singapore, indigenous integration of new systems on the newly purchased F-16C/D was undertaken successfully upon the arrival of the new aircraft in Singapore. After several new systems integrations efforts, it was clear to the engineers that the available processing, memory and data bus bandwidth of the avionics architecture of the aircraft was insufficient. A proposal was received to change out three on-board mission computers (of the four existing) and add a new data communication bus to address the problem. The approach would entail increased efforts and cost in re-hosting the baseline software and engineering risks.

Leveraging on its systems integration experience and the advantage of having system, software and hardware capabilities under one roof, ST Aerospace proposed to incorporate a specially configured mission computer to replace only one of the four existing mission computers that handled the less safety critical function of displays. This new mission computer, together with a new data bus, would handle the functions of the replaced computer with spare capacity to handle future additional requirements. The remaining three mission computers needed only minimal software changes. This approach enabled the baseline implementations to remain largely intact while accommodating future growth needs cost effectively.

New challenges, whether the result of new operation requirements or the introduction of new capabilities, have never failed to make a systems integration engineer's life exciting. To ensure the capability is maintained and built upon continuity, new engineers including some fresh from university are regularly inducted for training through actual work under the personal guidance of the more senior engineers to pass on their experience and knowledge.

The systems integration capability is an important sub-set of the overall engineering capabilities needed to support aircraft operators. While it started with the support of military aircraft which were the first users of complex integrated electronics systems in mission systems of the aircraft, similar systems are today increasingly prevalent in newer generation commercial aircraft.

With the rapid advancement in electronics hardware, systems would require upgrading in time or face obsolescence. The systems integration capability is thus an important "soft" asset to have. Although many other aspects in aviation are equally important, systems integration capability is of primary importance to aviation because of safety of flight concerns. In addition, the complexity of the various systems on board an aircraft and the interactions between them, as well as the long duration an aircraft remains in service makes it even more important not only to have a systems integration capability but also systems engineers with thorough knowledge of the systems installed.

Managing Technology Needs

The above technologies were part and parcel of the broad-based engineering capabilities that the company built up over the years. Complementing these were many other fields of engineering which were equally important in the make-up of an aviation engineering company.

ST Aerospace had taken the approach of investment in training, but more importantly, through actual work exposure on real engineering programmes to build up these capabilities. Where the areas of expertise were lacking, consultants and specialists in those fields were appointed. Working on engineering projects was a most effective means of acquiring not only the knowledge but also the experience.

A lot of effort was expended on ensuring the sustainability of capabilities built up. Without relevant and challenging work any capability will dissipate with time. In addition, the ability to ensure self-renewal through injecting new engineers and deploying experienced engineers gainfully were all part of the efforts in managing technologies, to enable the company to meet its obligations to the RSAF and its commercial customers.

Section 2.5
"Commercialisation"

The RSAF Commercialisation Journey

The Pioneering Move

While the build-up of the SAF has always included the defence industry to undertake the traditional depot activities, in the case of the RSAF and ST Aerospace, outsourcing of logistics and maintenance activities had over the years evolved beyond traditional depot tasks and is, today, much beyond what was originally envisaged. The journey has been a long and innovative chapter which contributed to the rapid growth of the RSAF.

This section will cover briefly the outsourcing of the traditional depots but will focus more on "commercialisation" of full support functions for the selected RSAF's squadrons, including flight-line operations. The term "commercialisation" has evolved to this broader and specific context which is well understood by both the RSAF and ST Aerospace. The term used to designate such programmes is *"Commercialised Programme"*.

Over the years, the engineering pioneers have been willing to change their mental models of how the RSAF could be supported, and to organise and run the business differently. Traditionally, the idea of commercialisation was abhorrent to the military. This might be due to the fact that it involved non-military personnel in operational tasks. Whilst the primary concern was operational effectiveness, there was also a concern of compromise to security and risks. Perhaps the foremost concern might be the ability to assure operational readiness and having full control of the means to undertake the mission, something which must never be compromised in fulfilling the sacred defence mission of the armed force.

In the case of the RSAF, serious considerations were given for commercialisation, weighing the benefits and potential risks it might involve. It was a test of the RSAF's willingness to think innovatively and manage the execution of its plan; a decision that proved revolutionary in shaping the Air Force's concept of operational logistics support as an important part of its core operations today.

Impetus

There were many reasons for the commercialisation direction that the RSAF undertook; the main impetus revolved around improving efficiency and operational readiness to achieve the RSAF's mission.

While cost-effectiveness was a key driver to control rising in-house support costs, an outsourcing strategy was an effective tool to enable the RSAF to concentrate its internal resources on its critical and core activities. It could also deploy its skilled resources to operationally more complex tasks and free up its valued human capital to support the build-up of critical operational capabilities. The pace, scope and depth of commercialisation, and strive for the right balance and optimal means of contracting were challenges that its engineering leadership boldly surmounted.

As early as the 1970s, the RSAF embarked on the commercialisation of various depot functions using different business strategies, ranging from open competition to limited and closed tenders, to strategic sourcing with specific defence partners, depending on the nature of the function concerned. The right partners were selected with the necessary expertise, resources and track record so that they could fulfil their long term obligations without disruption to the RSAF's operations. Even though extensively outsourced, the RSAF had retained the planning, control or technical expertise where required, so there would be no question regarding the ultimate ownership, quality management and deep professional knowledge.

Partnership with Strategic Partners

Apart from ST Aerospace, the other three Strategic Business Areas (SBAs) of ST Engineering, namely ST Kinetics, ST Marine and ST Electronics as well as other local industrial partners have also provided various integrated services to the RSAF over the years, improving and sustaining the RSAF's operational capabilities. To ensure that the services of such commercial entities remain uninterrupted during periods of crisis, these key partners were designated as Essential Firms under the auspices of Total Defence of Singapore.

With these in place, the RSAF went beyond just outsourcing MRO. In the 1980s, the Long Term Manpower Plan of MINDEF forecasted manpower constraints as a serious impediment to the SAF's plan to rapidly increase its overall combat capability. With a zero manpower growth policy imposed and the continuous drive for efficiency and effectiveness towards the latter part of the decade, there was an even greater impetus to expand the scope and scale of commercialisation.

In the mid 1980s, the RSAF took a cautious step forward to fully commercialise the operational support of the SF-260 squadron, the basic training aircraft for the RSAF then. Following the positive experience from this, in 1992 the commercialisation initiative was extended to the total support of the entire S-211 fleet even though it was then still facing serious technical issues since its induction into the RSAF as the RSAF was the lead operator of this new aircraft type. Operationally the S-211 was also a more critical fleet for the RSAF. The decision to effect the commercialisation of the S-211 fleet was indicative of the confidence of the RSAF that ST Aerospace had the wherewithal to handle the then problematic aircraft.

Shortly after, in 1993, the S-211 programme was slated for permanent deployment to Australia. This was a new experience for both the RSAF and ST Aerospace in operating its first Commercialised Programme overseas. Nonetheless, despite the move overseas and the build-up of a joint venture, and a transition to a composite workforce as required under the government-to-government memorandum of agreement (MoA), the technical problems on the aircraft were progressively resolved and flying operations grew rapidly to more than 7,000 hours per year to meet the RSAF's training requirements. The aircraft continued to meet its mission requirements until it was retired in 2008 due to expiry of its structural life. Aircraft supportability and obsolescence problems were well-managed.

Unmanned aerial vehicles serviced under commercialised programme

Beyond manned aircraft, a further step was next taken to commercialise the UAV operations and support. This was testament to the mutual confidence gained in the commercialisation concept, given that the UAV involved other key considerations. These included a more complex combination of organisations involved, namely the RSAF, the Army, ST Aerospace and ST Electronics (for the ground systems support), as well as the requirement for field deployment.

RSAF's Commercialisation Effort: The 3-in-1 Commercialisation Contract

Fokker 50

C-130

KC-135

Subsequent to the commercialisation of the S-211 and the UAV came the C-130 total commercialisation programme in 1997. This was another bold step forward - the "3-in-1" commercialisation contract for the C-130, Fokker 50 and KC-135 aircraft. These were all operational fleets, as opposed to the earlier commercialisation of the SF-260 and S-211 training fleets, and this "3-in-1" contract also amalgamated the maintenance support for all three transport class aircraft platforms with special operational missions. The main impetus for the merging of the contracts was the similarities of the maintenance concepts of these platforms and the synergy possible from combining the support of the three separate fleets. In view of the positive performances of the SF-260 and the S-211 commercialisation, the operations side of the RSAF was also supportive of taking this step involving their operational fleets. Ultimately, the merged programme ended up with better aircraft serviceability, enhanced operational readiness, significant reduction in Aircraft-on-Ground rates and improved aircraft availability. These aircraft types were also more demanding in support needs even in peace time as they were regularly on overseas operational duties and on call for operational tasking. Hence the improvements which came about from the commercialisation benefitted operations as well.

Moving on to helicopters, the Oakey Training Centre (OTC) was set up in Australia in 1998 under an MoA between the governments of Singapore and Australia to provide an overseas training facility for the RSAF's Super Puma air crew. Under the MoA, the entire maintenance operations and support of the OTC was commercialised to Bristow Defence Industries (BDI). This marked the first time where the support of a fleet of the RSAF aircraft in an overseas detachment was outsourced to an overseas company. The collaboration included ST Aerospace which provided the engineering expertise to support BDI as necessary, especially on areas where it had developed special capabilities as the RSAF depot for the Super Puma.

Evolution in the Approach of Commercialisation

In the early days of the RSAF's commercialisation of MRO, an input-based approach was adopted whereby the contractor was paid based on work done per man-hour. In 1994, the input-based approach was enhanced by introducing a strategic sourcing contractual framework whereby the contractor had to co-invest to ensure a shared vested interest. In addition, key performance indicators were introduced to monitor performance with Performance Bonus incentives to deliver better service beyond what was contracted.

During the early 2000s, Air Logistics Organisation (ALO) reviewed the strategic sourcing contractual framework and assessed that while it was better than the traditional input-based approach of the past, it did not incentivise the contractor to continue improving its efficiency and to enhance the reliability of the system.

Determined to strive for a progressive model which would inherently encourage self-improvement, the RSAF evolved from the input-based approach to an outcome-based approach which was governed by Performance-Based Logistics (PBL). Simply put, performance-based strategies buy outcomes not services. This concept was incorporated into both traditional depot work and the commercialised programmes.

The first PBL contract, the Advanced Jet Trainer (AJT) Commercialisation Contract for the MB-346 aircraft, was established between the RSAF and ST Aerospace in March 2007. It was a comprehensive contract which covered organisation, intermediate and depot level maintenance of the aircraft, engineering services as well as materials management. Through this PBL initiative, the RSAF achieved significant cost savings through leveraging the scale of the programme.

Riding on the success and effectiveness of the PBL framework, similar contracts were also awarded to Boeing and General Electric (GE) for spares support for the RSAF's F-15SG and AH-64D Apache. Besides ensuring better supportability while in-house capabilities were being built up, it also attempted to address reliability concerns that were dependent on the operating environment and usage.

In Conclusion

Today, many of the systems which the RSAF operate are supported commercially. Among these, the most comprehensive are the "Commercialisation Programmes" which see the whole logistical and engineering support functions outsourced. For all these programmes, contractors play a critical role in the overall capability of the RSAF, be it during peacetime or in operations. The RSAF ensures that they are well-integrated into and recognised as an integral part of the RSAF's operations. The success of this is attributed to:

a. Design and structuring of effective commercialisation contracts and programmes;
b. Strong alignment of culture and values between the RSAF and the contractors to drive continuous improvement, and
c. Contracting for desired outcomes and performance-driven objectives.

The best validation of the RSAF's Commercialisation Programmes is the fact that these programmes have been able to serve the requirements of the RSAF during training and as well as when the RSAF deploys operationally overseas. This has been tried and tested in many different scenarios including regular short and long term overseas deployments, be it for search-and-rescue missions, humanitarian missions such as the 2004 Asian Tsunami or the conduct of operations overseas.

Section 2.6
Values and Necessities

Working together, MINDEF, the RSAF and ST Aerospace managed to overcome the many constraints that were faced to develop the engineering capabilities that had supported the RSAF and enabled it to become a leading air force over a short 40 plus years. This is the outcome of all parties recognising the values to be observed and the necessity to maintain these values. Some of these are discussed in this section to ensure proper understanding of what were behind the outcomes.

The same focus on what were important to the build-up of engineering and logistics capabilities behind military aircraft, engine and systems support were also applied by ST Aerospace in its venture into commercial aviation MRO and engineering over the last 25 years.

Training Our Engineers

The reader would hopefully, by now, have a clearer view of the vital role our engineers played, be it in acquisition, operations and support, or in keeping the defence equipment and systems updated and relevant throughout their life cycle. Singapore is a very small country with limited resources. Whatever defence equipment Singapore acquires, others can easily do so in larger numbers if the buyer country has the financial and manpower resources. Maintaining the qualitative edge rather than quantitative edge is important. For that, MINDEF, the SAF, DSTA, DSO and the Singapore Technologies companies involved in supporting defence equipment employ a large number of talented and dedicated engineers, who are focused in the business of keeping our defence equipment in optimum condition, upgraded with advances in technology and new capabilities that emerges to meet the operational requirements of the RSAF.

Immersion of our engineers during the acquisition process has been RSAF's and DSTA's top priority over the years. In every new programme, ST Aerospace engineers are also trained at the OEM's facility alongside counterparts from the RSAF and DSTA. Structured and unstructured training for our engineers have since the mid 1980s been a contractual requirement, negotiated into the acquisition contract with the OEM. Such training equip our engineers with adequate knowledge of the aircraft and systems we operate not only from the maintenance perspective but, just as importantly, the design and engineering perspectives to enable them to support the aircraft through its life cycle.

An effective way to enable our engineers to learn and acquire knowledge and hands-on experience on a new system is to locate our engineers in the OEM's facility, with assigned responsibilities on defined parts of the work, under the guidance of the OEM's engineers. This is increasingly possible today as the RSAF and ST Aerospace engineers have good experience. An example is where engineers from the RSAF and ST Aerospace would be attached to the OEM and tasked to work on specific software modules being developed for the RSAF. OEM sometimes do not prefer this arrangement as more time and effort is required to supervise the customer's engineers, and yet the OEM is still contractually responsible for the parts of the work done by the Singaporean trainees.

This is respected and constructively managed in contracting so that the OEM is fairly compensated. The benefit to DSTA, the RSAF and ST Aerospace is enhanced training and experience for our engineers through these windows of opportunity.

Helicopter Engineering

Training of our engineers at the OEM's facility could sometimes be supplemented by tailored graduate-level short courses at an engineering school. In the mid 1990s, when the RSAF was rapidly expanding its helicopter fleet in terms of types and numbers, there was a need to build up the helicopter engineering competency in both DMO and the RSAF. Leveraging on two new helicopter acquisition programmes at the time, a helicopter engineering training programme was developed with the OEM, Eurocopter (now Airbus Helicopters), together with a reputable French engineering school, the Ecole Nationale Superieure d'Ingenieurs des Constructions Aeronautiques (ENSICA) in Toulouse. It was a 15-month programme, where engineers from DMO and the RSAF would spend an initial three months in a French language school in Toulouse, France, six months in Eurocopter and a final six months in ENSICA.

This programme provided a good foundation and practical exposure in helicopter engineering, although the three-month French course was barely sufficient and our engineers had to put in extraordinary effort to learn technical terminologies in French. The short course conducted in ENSICA was at post-graduate level and included options such as avionics integration, propulsion and stability and control. The foundational helicopter engineering competencies of the RSAF and DMO engineers were established through this programme which put them in good stead to undertake some of the more complex helicopter acquisition and upgrade programmes in the years to come.

Overseas Programme Offices

It is the practice of DSTA to set up a small project office at the overseas OEM's facility, especially for large and complex programmes. Such an office is termed the Resident Project Office (or RPO). Usually one or two engineers (sometimes more) from DSTA or the RSAF are rotated to the RPO for a 18-month tour. The RPO is established soon after contract signature and would last through the project implementation phase to the initial deliveries of the system concerned. Usually this is for about three years. The main focus of the RPO engineers is to maintain close interaction with their OEM counterparts on a day-to-day basis, and monitor progress, especially on the customisation and unique changes. As an example, during the Apache programme implementation the RPO that was set up at Boeing's facility in Mesa, Arizona allowed our engineers to be part of Boeing's Integrated Project Team's programme and technical meetings and to understand and influence the decision throughout the build process.

There was much interactions with the company's subject matter experts and our engineers quickly became more familiar with the helicopter and its systems. RPO attachments proved to be of great benefit for our younger engineers in speeding up the build-up of their competencies.

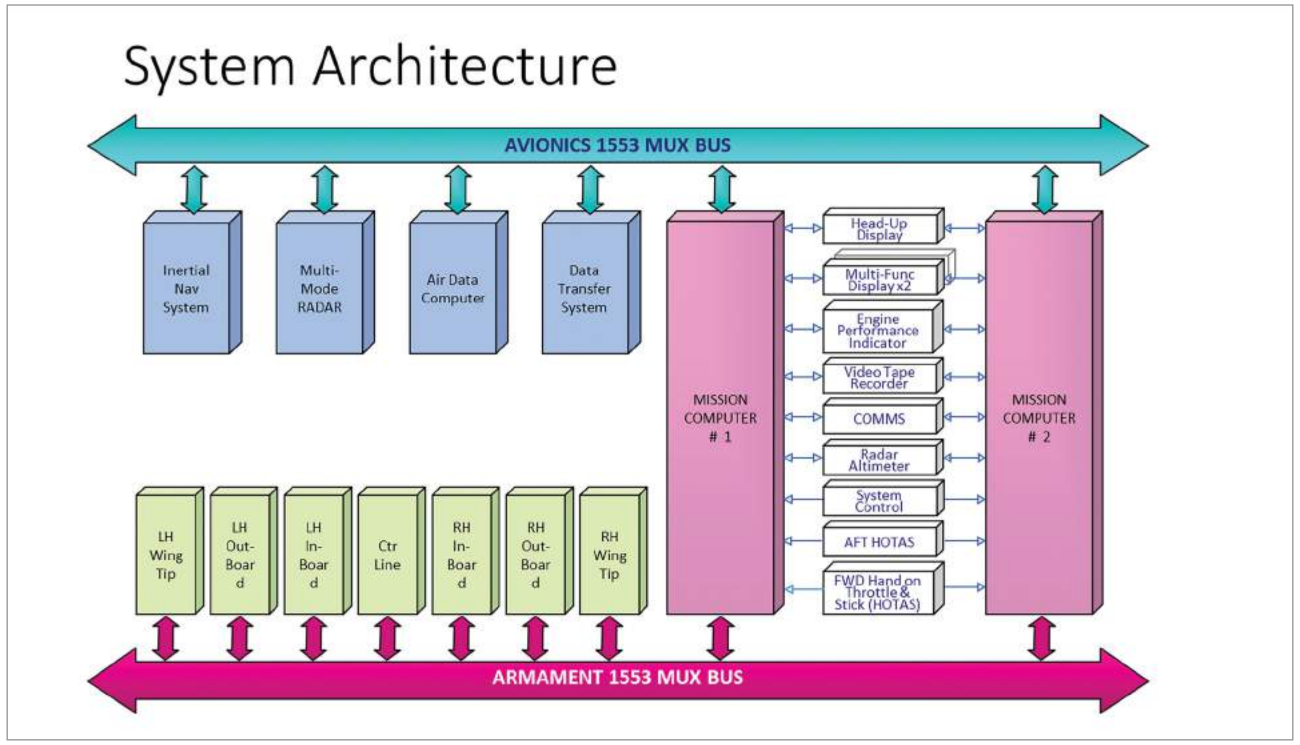
In-Country Capability

The RSAF has learnt from the days where aircraft operations and support relied almost entirely on the OEM. Those were the days when the RSAF had to go back to the OEM on technical problems which were beyond the normal recovery action in the OEM's maintenance manuals. The consequence of such total reliance meant that the RSAF would have little control on the resources and response time in formulating solutions to the problems it was facing. This would be operationally unacceptable today. Thus there is a mandatory requirement for an acceptable level of organic operations support and engineering capability in all acquisition programmes.

In working out the support posture for a new aircraft programme, the RSAF members in the project team define the spares and support equipment requirement based on a pre-established operating profile. Together with the OEM, the RSAF will define the level of repair to be done in the RSAF and ST Aerospace. Maintenance training is then defined for the RSAF technicians and ST Aerospace personnel.

Beyond maintenance, the RSAF's requirement also calls for the capability to modify and upgrade its aircraft fleet throughout its life cycle. Typically, the life cycle of a new aircraft can be 30 years or longer. During this period, modifications and upgrades may be carried out on the fleet to fix a reliability issue or technical problem, to add new systems to the aircraft to enable it to remain operationally viable in a changing threat environment, or to address an obsolescence issue. The key objective for the RSAF is to be able to develop and implement the modifications and upgrades indigenously. The RSAF had learnt important lessons from earlier acquisition programmes. For example, the lack of engineering knowledge (from the design perspective) on the F-5E/F and to a lesser extent the Super Puma helicopter later on had resulted in much difficulty faced when integrating new systems onto the aircraft some years later. It was the resourcefulness of engineers in the RSAF and ST Aerospace that created workaround, although sometimes with less than the ideal solutions. Time and significant effort were required to generate the needed engineering data that were not procured. The RSAF soon realised that to be able to modify and integrate new systems into our aircraft, it must have access to the necessary engineering data and the ability to understand and make use of them. Subsequent acquisition programmes had this important requirement explicitly stated in the conditions of tender which would be eventually negotiated into the contract.

For every new programme, DSTA, the RSAF and ST Aerospace would define together with the OEM the engineering data and reports and the necessary engineers' training to be acquired. OEM's do not readily provide a shopping list of available engineering data and reports. Engineer training is also not a standard package that the OEM typically



Schematic of the F-5 upgrade architecture

provides to other customers. In most cases, a non-recurring effort is incurred in order for the OEM to develop and propose solutions for this requirement. This task can be costly but is necessary. DSTA, the RSAF and ST Aerospace have to collectively work with the OEM to define, negotiate and tailor a package to meet our objectives for self-sufficiency.

This is more easily said than done. Sometimes there are issues on the release of such data, either for commercial proprietary reasons or security concerns from the foreign government on "know-how" transfer. Nevertheless, the project team from DSTA and the RSAF will negotiate for the best possible outcome. Where necessary they would have to reject offers that did not meet the specified requirements, and there had been major programmes where this was experienced.

In understanding the aircraft and equipment systems they operate, our engineers will be better able to investigate and analyse problems which are experienced during operation, and which might be unique to our operating environment. Engineers can then work out solutions or tweak the systems and extract its full performance potential. More importantly, when new systems upgrade is required in the future, our engineers will have the ability to undertake the effort entirely on their own when desired instead of being forced into certain directions by external factors. This gives the RSAF the qualitative edge.

Access to Software

A modern military aircraft with its state of the art combat avionics and weapons is a software intensive aircraft. The simplified diagram below illustrates the avionics architecture of the modernised F-5 combat avionics suite. At the heart of this is the OFP, the aircraft operating system software.

Engineers need to understand and have access to the aircraft OFP in order to integrate new systems in future. Since the avionics suite in the F-5E/F was upgraded by ST Aerospace, the RSAF and ST Aerospace possess the complete OFP and development tools in the SIL to modify and test new software modifications throughout the life cycle.

With new aircraft acquisition programmes there is the task of negotiating for the release of the aircraft OFP. The government of the country of manufacture may be reluctant to allow the OEM to release such software, as it is deemed to give the user country a significant technological jump and the ability to integrate new systems and weapons in future with little control or influence from the seller country's government.

The release of aircraft software has been a delicate and sensitive issue in the acquisition of advanced combat aircraft. Discussions and negotiations are usually carried out at a government-to-government level. While the release of software is important to Singapore in meeting the RSAF's objectives to indigenously support the aircraft and systems throughout the life cycle, concerns of the seller's government have to be taken into account. The software issue has posed serious challenges during the acquisition negotiation for new aircraft and systems. Both buyer and seller parties must be willing to work together and find a common ground and acceptable solution, taking into account each other's concerns.

Stakeholders

Typically, an aircraft acquisition programme includes many stakeholders. From the buyer side, the integrated project team comprise DSTA as the project management agency, the RSAF as the operator and maintainer of the aircraft and ST Aerospace as the industrial partner who will provide the heavy maintenance and modification and upgrade effort during the life cycle. When specialist investigations are required, such as some specific aerodynamics studies or advice on electronic warfare systems, the services of DSO are obtained.

From the seller side, there is the OEM's project team and usually some representation from the seller country's government in providing oversight on matters concerning national security and release. In some advanced fighter aircraft acquisition, the seller country requires a government-to-government transaction and the representation from the foreign government will be significantly increased to a full project team, mirrored by the OEM project team. The size of the seller team (government and OEM combined) attending regular programme and technical reviews can be large and unwieldy.

It would be interesting to understand the make-up of the Singapore integrated project team. The focus of this discussion is on the collaborative nature of the Singapore team. As mentioned, DSTA provides the core members of the project team, led by a programme manager or programme director in the case of a high-cost, high-impact and complex programme. Many are experienced engineers, veterans of successful past projects and some have served in the ALD and the airbases. This has been made possible through the deliberate effort over the years to cross-post engineers between the RSAF and DSTA to enrich their experience.

ALD provides specialist engineers to enhance the project team. These are engineers with disciplines such as aerodynamics, structures, avionics, sensors, electronic warfare, propulsion and weapons. In addition, the RSAF also provide specialists who would perform the detailed assessment and definition of the level of in-country support required, and the provisioning of the initial lay-in of spare parts and support equipment. Another important participant from the RSAF is Air Plans Department which provides the operations perspective through the participation of the RSAF pilots.

The final and a key pillar of the buyer integrated project team is ST Aerospace. As the industrial partner, the company provides the heavy MRO service for all the RSAF aircraft, the design and engineering support for modifications and upgrades. In any new aircraft programme, ST Aerospace is part of the equation and hence a key participant in the project definition phase.

Since ST Aerospace provides the deeper MRO services, the necessary support equipment and tooling for heavy airframe maintenance and component overhaul and repair has to be defined, procured and installed in the company's hangars and overhaul shops. The necessary maintenance training is also provided to ST Aerospace technicians. Much of the software and engineering data reside in ST Aerospace facilities although ownership rest with RSAF's. This is necessary since ST Aerospace is to develop and implement modifications and upgrades to the RSAF fleet. ST Aerospace is accountable to the RSAF for the secure access, control and safe keeping of all engineering data and software.

To ensure the knowledge and capabilities required to support the operational capabilities the RSAF require of its weapon systems, a lot of investments have to be made. They include investments on training the engineers who support the new systems, in engineering data and on equipment documentations. These capabilities enable Singapore to support its aircraft and weapon systems through their life cycles, including mid-life upgrades and capability enhancements. From the experience over the years in supporting an important operational fleet of aircraft at the leading edge, it is also realised that having the knowledge and means to overcome problems faced in operations are equally important. These are the values that must come with each capability inducted into operations to ensure the RSAF truly has a sustainable capability in its weapon systems.

Chapter Three

SOME MAJOR MILESTONES

Section 3.1
The A-4 Crisis

The first refurbished A-4C, designated the A4S-1, rolled out of SAMCO on 24th January 1982. Before that, in 1972, LASS was contracted to refurbish the first fleet of A-4Bs, including a basic avionics upgrade and installation of 30mm Aden cannons. This aircraft, designated the A4S, "S" for Singapore, was the first Skyhawk to enter service with the RSAF in 1974. The combined A-4 fleet (A4S and A4S-1) grew rapidly from 1982 and A-4 flying in Tengah Air Base was ramped up rapidly as the fleet grew. The aircraft were allocated into three squadrons; 142, 143 and 145 Squadron. The A-4 was then the backbone of the Air Force, as the RSAF's fighter trainer as well as its front-line operational aircraft. The only other fighter aircraft then was the F-5, an air-defence interceptor capable of supersonic flight and the older Hunter aircraft.

Although the A-4 had an operational role, the operational capability of the aircraft then was limited. Its primary armament was the 20mm guns. The A4S was upgraded with 30mm guns to increase its fire power. However that created a lot of problems with its secondary structures resulting in skin cracks due to the heavy vibration and stress induced by the larger-calibre guns during gun firing. So the A4S-1 kept its 20mm guns. The bomb carrying capability was limited because the aircraft could not carry many bomb loads and the CP741 Bombing System on the aircraft was difficult to learn, maintain and use. Its effectiveness and accuracy were therefore limited. The other weapon option was the 75mm rockets. The most important role of the aircraft then was to train pilots to fulfil the desired operational pilot establishment.

While this rapid build-up of flying was going on, the RSAF started a study in 1983 on the operational upgrading of the A-4. The considerations behind the initiative, the scope of the study, and the recommendations were approved. That and the subsequent decisions to upgrade later aircraft types led to upgrading programmes detailed under Section 3.2. The contract for the upgrading of the engine and avionics of the A4S-1 was awarded in February 1985.

A few months later, the Air Force experienced a number of Skyhawk crashes in a series of accidents that became known throughout the RSAF as the "A-4 Crisis" an RSAF - level crisis which, if not resolved, could have set the RSAF back many years and remembered to this day for the seriousness of the situation then, and the people who had faced the challenge and overcame it.

The Accidents that Happened

When the first A-4 aircraft crashed into the Straits of Malacca on 24th July 1985, it was on a routine check flight. Immediate checks were carried out on the fleet in areas that might reveal plausible causes for the crash. Nothing was found amiss in the investigations done and the precautionary grounding of the fleet was lifted. The next day, 25th July 1985, a second aircraft went down in the Straits of Johor.

From the investigation outcome, the whole fleet was checked again and progressively released for flying. A month later, on 26th August 1985, a third aircraft was lost in an overseas detachment in Central Luzon in the Philippines. And yet a fourth aircraft crashed into the sea off Tengah on 22nd October 1985.

Four aircraft losses from the same fleet within three months was a catastrophe that had never been experienced before by the RSAF, and never since. The Air Force was then only about 15 years old and while it was manned by capable leaders and dedicated air and ground crew, the problem was very significant and there was serious concern throughout MINDEF and the RSAF. It was a crisis in every sense of the word.

Everyone involved was put through a very severe stress test of their capabilities during this period; their confidence, their leadership and commitment. The cohesiveness of the Air Force as an organisation in the face of the difficult situation was also tested.

Each accident, especially one which is associated with damage or loss of aircraft or life would have already been a grave concern. Having four aircraft losses, as well as the loss of a pilot, compounded the concern - the level of which was more than four times that for an isolated accident. The overriding, concern was whether the fleet was safe to fly. Besides the Boards of Inquiry appointed for the accidents, the whole Air Force was involved in one investigation or another over a very long time. Any potential lead that might throw some light on the accidents was immediately followed up on. There was, however, very scarce information on what might be the cause of the accidents. The onset of the accidents was very sudden, and because of the nature of many of the accidents over water, recovery of debris was at best sparse and uncertain.

Besides time, capability development and money, the most important impact of the A-4 Crisis was on the morale of the Air Force. If it could not recover from such a critical situation, the impact would have been severe. That would have taken a big toll on how the Air Force would develop in future years and adversely affect its confidence in undertaking many of the transformations it went through over later years which brought it to what it is today.

What were the Options?

One option was to migrate to a new aircraft type. To evaluate and acquire a new aircraft type to replace the A-4 and rebuild the whole operational and logistics system would take many years. For a start, a new aircraft that could meet the requirement would have to be identified and acquired.

Acquisition of a fleet of such a size would involve a lot of "life cycle management" work as elaborated in Chapter 4, including cost trade-offs, logistics planning, supporting infrastructures and capabilities as the number of aircraft needed to replace the A-4 fleet would have to be sufficiently large to support a very heavy flying commitment.

A whole training programme would have to be developed for both aircrew and ground crew on the new aircraft. Some of the activities would include the re-training of pilots, engineers and engineering staff, starting with training of the trainers. The new fleet could also only be built up as quickly as the production capacity of the manufacturers of the new aircraft could deliver. Long leadtime items for manufacture of the new aircraft purchased could take two to three years to procure. Barring unforeseen circumstances, the replacement of the fleet and transition of the whole programme could take as much as eight to ten years, maybe more. That could have serious adverse ramifications down the line, possibly affecting even present day RSAF's capabilities.

The cost of such an effort was one thing; the loss in time would have been more serious. The loss of confidence would have been unacceptable as well, and the most important consideration. Meanwhile, while waiting for the new fleet to build up, what would the A-4 aircrew and the student pilots coming off flying training school on the Strikemasters and the T-33 fly?

Could the A-4 Upgrade be the way out?

Just prior to the A-4 Crisis, the Air Force had started a major programme to upgrade the fleet.

The engine upgrade could have helped overcome the A-4 Crisis but the RSAF could not have waited for the upgrade to be completed to address the immediate requirements presented by the Crisis. The A-4 Crisis started in July 1985. The first flight test of the A-4U (A-4C with F-404 engine) was in 1986! And the first A-4SU, which was the designation for the A-4 with F-404 engine and the Ferranti Weapon Delivery and Navigation System (WDNS), flew only in 1990. In any case, this was the first upgrade done by the RSAF and SA and, even if it was not, there was no certainty it would have been successful. Many upgrade programmes of other air forces over the years had illustrated that success should not be taken for granted.

The RSAF had no choice but to address the solution to the A-4 Crisis and pursue the A-4SU upgrade on parallel paths.

Confronting the Problem

As the options were limited and had serious implications, the problem had to be solved!

Since the accidents were mainly over the sea, much of the evidence were lost and it was difficult to find evidence to firmly determine the cause of each accident and the links, if any, between the accidents. As the fleet of aircraft was old, there were also many inconsistencies in built between aircraft and other issues which further complicated the investigation. Each lead, however insignificant, had to be followed through to determine if it might be related to the cause of the accidents.

From the investigation, available data and other information, it was concluded that the most probable cause of the series of accidents was the catastrophic failure of the Curtis Wright J-65 turbojet engines due to the separation of the Inconel 718 blades at mid-chord. The Inconel blades were introduced by the USN to overcome bird strike damage on the previous steel blades.

There were other areas of the aircraft that needed improvement, like chaffing hydraulic tubes, because of the way aircraft were built in the early days but these were not expected to be the cause of the multiple aircraft accidents.

So, while many precautionary checks and additional corrective actions were instituted to minimise the risk of something being missed, the most important action taken was on the J-65 engine. Based on the evidence and data available then, it was decided to reduce the approved life of the engine's inlet compressor blades (stages 1 to 3 compressor fan blades) so that they would be replaced before the projected onset of failure. Operations was reinstated, albeit at a lower level of flying to ensure it was sustainable, in view of complications due to the unavailability of critical parts. The fleet's supportable flying hours was reduced to 50% of what was being flown before the Crisis.

The reduced flying hours was the result of many factors. There were additional inspections introduced, spares of assured quality were difficult to procure, the engine OEM was no longer producing the required parts, the maintenance manpower was stretched by the additional work and flying supervision had to be enhanced among others.

To sustain even this reduced level of flying, the aircraft maintenance hangars had to go onto a 24-hour shift because of the additional checks imposed. The Skyhawk maintenance hangar was previously operating on a planned 1 ½-shift system. The engine bay in the base, as well as the engine depot at SAEOL, was also under pressure to inspect, test and certify the rebuilt engines. Every finding, big or small, real or perceived, had to be investigated and followed through. With the heightened sensitivities, anything out of the norm like reported abnormal sounds or vibrations would become the subject of intense investigations.

It was only in 1988, three years after the accidents that the RSAF decided to scale back on the additional maintenance work done on a precautionary basis. This decision was based on the outcomes from the additional inspections which affirmed that there were no other systemic problems which were not known. It was also a conscious decision on the balance of trade-off between doing more work and the risk of human errors creeping in as the technical crew was very stretched by the level of activity.

The A-4 Crisis was certainly a test on the engineering and logistics system of the RSAF. It was also an equally important test on the operations side of the RSAF and on the whole command. Although this book is on aviation engineering, for this section on the A-4 Crisis, it would be necessary to recognise the contributions from the operations side of the house which were also important in enabling the Air Force to recover from the Crisis.

In view of the reduced level of flying operations, the flying hours allowed for operational pilots as well as pilots under training programme had to be reviewed. Aircrew proficiency had to be maintained despite the reduced level of flying. In addition, the operational capabilities of the A-4 had to be maintained as it was an important operational asset then. The only other fighter in the RSAF was the F-5 which was a much smaller fleet, and the Hunters. Whilst safety was the first concern, there were other longer-term concerns like whether the Air Force build-up might be delayed. Opportunities for improving pilot generation capacity through training with external agencies like the USN were quickly staffed and taken up.

A real concern then was that any operations-induced accidents might further compound the problems at hand and affect the recovery. As a result, even safety envelopes for the flying of the aircraft had to be redefined to adopt a more defensive posture to minimise risks. As for technical problems, any operations issue was also addressed at higher levels to ensure the issue received the best attention possible.

What was equally important, as the RSAF worked closely to recover from the Crisis, was the morale of the people who were directly involved in the flying and maintenance of the aircraft. Despite a brave front, there were concerns to be managed. A lot of effort was expended at various levels to make sure all would pull together as a team. And they did.

If anything, this was the real test for the RSAF as an air force up to then!

So, over a period of several years, the RSAF successfully overcame the A-4 Crisis through its own engineering efforts and the resolve of the whole Air Force (both operations and logistics) and restored flying of the A-4 fleet of aircraft.

Following the recovery from the crisis, the A-4 operations continued uneventfully. Over time, the J-65 powered A-4s were seamlessly upgraded with the GE F-404 engine and designated the A-4U. This was followed by the second round of upgrading, this time the replacement of its aged electronics with the Ferranti WDNS. The A-4 with the F-404 engine and the Ferranti WDNS suite was named the Super-Skyhawk, the A-4SU.

Besides the engine and the attack avionics suite, there were also many other improvements made through the A-4 upgrade. They contributed to make the A-4SU a better aircraft although they were not related to the A-4 Crisis accidents.

Despite the scale and complexity of the upgrade, and it being the first major upgrade for all involved, it was a highly successful programme made possible through the combined efforts of DMO, the RSAF and ST Aerospace.

The successful recovery from the A-4 Crisis enabled the RSAF to continue on its operational development through various aircraft platforms to today, when it can proudly aver to be a leading air force. The A-4 aircraft served the RSAF in many capacities. It last served as the RSAF's advanced fighter lead-in trainer aircraft for the RSAF detachment in Cazaux, France, before retiring in 2012 after 38 illustrious years of service with the RSAF.

While the upgrade to the A-4SU was highly successful in terms of the enhanced capabilities that were realised, what might not have been obvious to external parties was that it produced an aircraft which was highly reliable. Since the days of the A-4 Crisis, the A4SU never saw a single loss attributed to technical failure, despite its intense utilisation over the next 16 years!

The A-4 Crisis was a huge success story for the RSAF. Confronted with a hidden technical problem which it inherited with a fleet of old aircraft it acquired, a problem which could possibly have brought many other organisations down, it overcame the problem, recovered from the crisis and rebuilt its operations successfully on its own.

Whilst the problem needed an engineering solution and the engineers stood up to the expectations of them, the A-4 Crisis was an RSAF-wide Crisis. The uncertainties were demoralising, not least to the pilots who had to continue flying the aircraft or to the Air Staff and above who had to endorse the recommendations to fly and the technicians who worked round the clock for three solid years.

The A-4 Crisis demonstrated the cohesion of the RSAF as an organisation, as a command. While the RSAF would continue to face difficult situations as it would always be at the leading edge, the A-4 Crisis was a watershed event in the history of the RSAF.

Engineering Transformation of the Air Force

The A-4 Crisis had another equally important impact on the RSAF. It was the impetus for the build-up of engineering capabilities in the RSAF. Up to then, a rhetorical debate within the Air Force was on whether there was a role for engineers in MRO. It became amply clear as a result of the A-4 Crisis that engineers were important in the overall make-up of technical resources supporting the RSAF.

Engineers were a scarce commodity in the Air Force in the early 1980s. At the height of the A-4 Crisis, there were only some 60 plus officers within the RSAF's ALO, including its senior management who held engineering degrees. This number included those experienced engineers deployed to undertake the A-4 upgrade programme just before the onset of the A-4 Crisis. Engineers in the operational logistics units at the RSAF airbases were scarce.

The Air Force was then largely manned, at the operating level by technical officers who were very experienced and competent. But for the next stage of the RSAF's evolution, including the full recovery from the A-4 Crisis and the future build-up of the Air Force, it was well accepted that more engineers would be essential.

Engineers play many roles in aviation. They are not only useful in research but also in the development of newer platforms and systems with improved performance, safety or creature comfort. They are equally important in MRO, finding solutions to operational problems, enhancing systems' reliability and aviation safety. If MRO could not achieve the outcome needed because of some fundamental problems which could not be solved through maintenance, engineers would be needed to develop modifications and upgrades to the aircraft or its sub-systems to address deficiencies or to introduce newer technologies for better system performance, reliability or cost effectiveness reasons. Such major modifications and aircraft fleet-wide upgrading will be addressed in Section 3.2.

The critical roles played by engineers was recognised during the A-4 Crisis when it was evident that the 60 plus engineers in the RSAF then would not be sufficient to enable it to proactively respond to another crisis of an equivalent scale and support the future Air Force.

Besides overcoming the A-4 Crisis, the Air Force also took several key decisions which transformed ALO and laid the foundations for the future. Previously, the primary focus of the RSAF was on achieving the operating levels to meet its training needs for more pilots and technicians. As the demand on flying hours was high and the RSAF was in its rapidly growing stage, that was then the most visible and pressing need.

Approval was sought for an establishment of 250 engineers. Initial approval was given for an establishment for 200 engineers as it was decided that some of the capability build-up proposed could be deferred as they were then sufficiently supported within MINDEF.

The upgrade of the A-4 further underscored the requirement for more engineers in aviation. The upgraded systems were of the latest technologies then and it was obvious that more engineers would be required to support the advanced systems introduced and to meet the future demands for more capabilities. These included the introduction of the E-2C and plans to purchase the F-16. This need for more engineers to support the Air Force's future requirements was recognised not only within MINDEF and the RSAF but also by companies in the defence industry like ST Aerospace.

Engineers in MRO

The question was how to induct the number of engineers needed to support the growth of the RSAF. Up to then, ALD had depended on recruitment of military engineers from graduates with NS liability and civilian engineers who came in as Defence Engineering and Scientific Officers (DESO) through PSC. Although the engineers were well-qualified, and many had contributed significantly to the RSAF over the years, the assurance on the ability to build up the needed numbers with the right level of experience based on such an opportunistic approach was, at best, uncertain. The PSC channel was also limited as it had to serve the whole Public Service. Service conditions and career advancements were also uncertain for both military and civilian engineers, and many engineers then were concerned if they would be recognised for their work on military systems.

To meet the approved establishment of 200 engineers by the Air Force, more options were necessary to complement the existing schemes for recruitment of engineers. The military engineer career scheme, the Air Engineering Officer (AEO) scheme, was then enhanced to enable the RSAF to reach out to engineers who were prepared to don the uniform as a career option. This provided the RSAF with two streams, military and civilian, from which to induct the number of engineers needed. From a professional engineering perspective, it was ambivalent whether the engineer was a uniformed officer or a civilian officer. As a military organisation, military engineers were deemed to be more easily integrated into the military command structure of the RSAF and could be more flexibly deployed. What was more important, however, was the quality and numbers of engineers that could be recruited into the RSAF. So both civilian and military engineers continued to be inducted, directly and through traditional sources. There was important work to be done!

Over the years, the requirement for engineers was reviewed periodically according to the sophistication of the fleet and technology advances. Today there are some 350 engineers in the Air Force. Another 300 more are deployed in various capacities such as in acquisitions, programme management, development and research in MINDEF. There are also some 400 more in ST Aerospace supporting both the military and commercial aviation business of the company.

Today we can look back with some satisfaction that engineers across the different groups have been built up over the last 30 years. The experience level of the engineers has been enhanced through reasonable retention rates and passage of time in supporting operations of the Air Force and its fleet renewal through the upgrading of existing aircraft and new acquisitions. The growth into the commercial aviation business by ST Aerospace also increased the career opportunities for aviation engineers and enhanced the robustness of the engineering organisation.

Following the successful recruitment of the earlier batches of military engineers after the A-4 Crisis, there were two important tasks at hand.

The first task was to get the fresh engineers a solid grounding of aviation engineering experience. Their ability to perform would be severely limited if they did not have a good grasp of the aircraft that they were responsible for, and its operating conditions and requirements. For new engineers, the best experience was to have them exposed to the aircraft systems and their operations. They had to gain hands-on experience and have direct responsibility for making engineering decisions, as well as understand safety requirements and the impact of their work if they were to perform the roles expected of them.

When the decision was first taken in 1986 that new engineers would have to spend their initial years doing field work at the RSAF's airbases, it was not popular as many young engineers, military and civilian alike, had different ideas about the engineering work they should be doing after graduating. Concerted efforts were put in to ensure they understood the benefits of gaining practical exposure and, over time, this was continually reinforced. Today, engineers see what their seniors have done successfully and accept field deployments as part of their training and career progression.

Engineering Organisation Structure

The second task was to create an organisational structure that would enable the RSAF to build up specialisation in various aviation engineering fields, as well as ensure operating aircraft systems were cared for. This led to the specialists and systems support functions and ALD was organised along these lines. This was essential as it provided for the development and retention of sufficient specialists and systems engineers to support the future needs of the RSAF. The assurance of a viable and interesting career was important to the retention of both military and civilian engineers. In later years, the organisation continued to evolve with the needs of the RSAF but the principles of having engineers on the ground for operational hands-on experience and specialisation continued.

In 1998, the engineering capability was further refined with the introduction of the Integrated System Engineering Team (iSET) concept to support every aircraft type in service. The multi-disciplinary team of staff with a joint purpose and mission to support the system from inception to disposal provided in-depth expertise, team knowledge and total ownership. The extended team not only included engineers but also material specialists so as to enhance the capability and responsiveness in coming up with holistic solutions to improve platform serviceability, availability and capability, and their common language was LCM.

Although the build-up of military MRO capabilities in the RSAF had started from a very low base, over the years it evolved with its changing needs to support its operations well. Much had been achieved in developing engineering solutions to difficult technical problems and ensuring the aircraft were supported at a high level commensurate with the operational requirements of the RSAF.

At ST Aerospace, there was a commensurate build-up of engineers and engineering capabilities to support the RSAF's requirements and later, the requirements of its commercial aviation business. The build-up of engineers and engineering capabilities in ST Aerospace is shared in Sections 2.4.

What were the lessons learnt?

Many important lessons were learnt from the A-4 Crisis.

From an organisational perspective, the most important lesson would probably be the importance of organisational strength and cohesion to overcome difficult situations that could arise at any time that could threaten the survival of the organisation.

From an engineering management's perspectives, the lessons were:

- The need to have capabilities to understand the aircraft and weapon systems in depth so as to be able to find solutions for problems that might surface in their usage to recover from such problems and to optimise their applications.
- The maturing of the RSAF would require a commensurate mature engineering group to overcome potentially disruptive experiences.
- The recognition that engineers were important manpower resources in the RSAF.

The A-4 Crisis might have been one of the most significant problems then but it was not the last. There had been others since, perhaps not as dire but no less significant. The A-4 Crisis was highly visible because of its implications then but over the years there were other engineering challenges that were as important. Some of these would be covered in later sections of this book.

Perhaps the most important lesson learnt was the recognition of the need to be prepared. So long as there was flying, there would always be the potential for major disruptions due to unforeseen circumstances. Any organisation could adopt a defensive stance and put in place all the necessary precautions but when this failed, the ability to recover would be the key. Through a good MRO programme, many problems could be prevented but when problem did surface, it would have to be the people who knew the equipment and understood the engineering who would find the solutions.

Manufacturing Engine Parts – Driven by Necessity

The following story, perhaps best illustrates the resourcefulness of engineers from the RSAF and Singapore Technologies (ST) in the 1980s. Faced with a critical shortage of spare parts and the potential of the entire fleet of aircraft being grounded, a team of engineers set out to examine the feasibility of manufacturing an equivalent of those few parts that could not be purchased from the market as those available came with documentations of dubious origin.

The first A4S aircraft operated by the RSAF were refurbished from USN's surplus of old A-4B. The early A-4 models, the "B" and "C" models, were significantly different from the later A-4s such as the "D", "E", "K" and "M" models. The most significant difference was the installed jet engine. The "B" and "C" models had the Curtis Wright J-65 turbojet engine while the later models had the higher thrust and more successful Pratt & Whitney J-52 turbojet engine.

Not long after the RSAF fielded the refurbished Skyhawks, Curtis Wright decided to exit the jet engine design and manufacturing business. By the early 1980s, J-65 engine spares were becoming increasingly difficult to obtain.

At this point, a short description about the turbine section of a jet engine (or gas turbine) and the engine cycle would be helpful to the reader. Turbine vanes and blades form a set of components that make up one stage of the turbine section of a jet engine. A jet engine usually has more than one stage in the turbine section.

The turbine vanes are a set of stationary airfoils that directs high-temperature and high-pressure gases, from the burning of the fuel-air mixture in the combustion chamber, to impinge on a rotating set of turbine blades that extract energy from the impinging gas flow. This energy is used to drive the jet engine compressor module which compresses air to be directed to the combustion chamber where the air is mixed with fuel and ignited to produce the high-temperature and high-pressure gases. In order to withstand the extremely harsh operating environment, turbine vanes and blades are manufactured from exotic high-temperature materials. Because the turbine blades are mounted on a rotating disk, they are subjected to more severe centrifugal loads compared to the stationary vanes. Hence the blades operate in an environment of high stress, vibration, and high temperature. This causes corrosion, fatigue and a phenomenon called creep, resulting in weakened blades and potentially leading to fractures and failures. It is for this reason that turbine blades and, to a lesser extent, vanes have finite operating lives and at the expiry of their lives, these blades and vanes must be replaced during engine overhaul, to ensure reliable and safe operation of the jet engine.

Thus jet engine blades and vanes for the J-65 engine were reasonably high-consumption spare parts which were continually sourced and procured. As the engine manufacturer was no longer in the business, the availability of spare blades and vanes in the market began to diminish. Soon, aircraft parts stockists who still had stocks of the blades and vanes were asking for high prices for the items. More importantly, there was also suspicion that the spares sold by stockists were bogus parts, notwithstanding the fact that they came with a certificate of conformance and other authentication documents.

There were a number of instances of premature blade or vane failures during operations and these parts were from such stockists. Clearly, to bridge the gap in supply in order to sustain the A4S operations, a temporary supply of blades and vanes must be found.

In view of the unavailability of critical parts to continue flying and the problem with dwindling and dubious parts from stockists, engineers in the RSAF decided to study the possibility of manufacturing the blades and vanes for the J-65 engine with one or more industrial partners. As the RSAF had no engineering data related to the jet engine this was going to be very difficult. With a local industrial partner, an ST company, the engineering team set about establishing the precise profile and dimensions of the blades.

Thus, the painstaking process commenced. The necessary engineering drawings were eventually generated. The blade and vane material was known and not considered "highly exotic" by the industry standards then. The material, a nickel-based alloy, was not proprietary and manufacturing processes for the material well established. This made the manufacturing task easier.

Next the RSAF engineers searched for an industrial partner locally and overseas who had the experience and know-how to be the manufacturing source. It was decided to start with the first-stage turbine blades because their consumption during engine overhaul was highest among the turbine section blades and vanes. They were forged and machined to final dimensions and tolerances.

The engineering team studied two processes, forging and investment casting, to manufacture the turbine blades. The forging process was selected as it allowed better control and a smaller grain size which would give better high-cycle fatigue[1] life for the blade.

Working with an overseas industrial partner, the RSAF team established that they were able to precision forge the blades as opposed to the normal forging process. Precision forging is a positive factor as it would yield the airfoil part of the blade in its final dimensions and tolerances without the need for final machining. Only the “fir tree” blade root part of the blade needed final machining. As the RSAF team lacked the necessary expertise and experience, a third party was engaged as consultant to assist the project team to develop jointly with the overseas industrial partner the process control, audit and inspection procedures. The team also decided to precision forge the blades at the overseas facility and then shipped the unfinished blades back to Singapore for final completion in Singapore. "Fir tree" blade root and the blade tip were machined to final dimensions and tolerances. The RSAF and ST engineers were also stationed at the industrial partner’s facility overseas to provide oversight on the project.

The next step was to define the qualification process for the blade and certify its use on our A-4 jet engines. The RSAF team had the benefit of a generic US military standard for qualification of jet engine components such as the turbine blade. The difficult task was to develop a test plan to qualify our blade. Again, an experienced consultant was engaged to work with the project team to define the qualification test plan. The plan called for a 150-hour test run at a variety of engine throttle settings in a jet engine test cell at ST Aerospace’s jet engine test facility. The purpose was to cycle the engine through an accelerated test that was equivalent to a much longer duration of normal operational usage. The accelerated testing actually took several months to complete and the blade was eventually qualified, installed and flown on A-4s.

The success of this project and the experience gained by the RSAF and ST engineers provided the confidence that it could, as a last resort should the availability of some parts become critical, find a temporary way out until a commercially-viable solution could be found. Other stages of the turbine blades and vanes were candidates for manufacture and this was later extended to compressor blades and vanes and the combustion chamber as these also came in short supply. New manufacturing techniques such as investment casting were explored with other overseas companies and adopted for those parts that did not require precision forging.

Learning Value

This project was a tribute to the pioneering spirit of the RSAF engineers in the 1980s. The RSAF was still in the build-up stage in its engineering capability and the engineers were very young and inexperienced. There wasn't the engineering capability it has today, but there was the “dare to do” and “can do” spirit. Perhaps the environment then had enabled engineers to take the plunge but there was simply no choice. Buying and installing parts of dubious nature was not an option as safety was paramount and well understood. Engineering considerations were also thoroughly thought through before decisions were made.

There were a number of valuable learning points for the engineers from the RSAF and ST to take away. First, from the study of the J-65 engine, the original materials used and alternative materials available, the engineering team had a good understanding of the suitability of the trade-offs for the different parts of the engine. For example, the considerations for material selection for the turbine section of a jet engine given the presence of high temperatures, thermal cycling and stress cycling. The engineers had an understanding of the properties of high-temperature materials and how their microstructures would change over time, and the resulting effects on fatigue properties and creep. The team also had a good understanding on thermal barrier coatings used to reduce thermal stresses on blades and vanes, and manufacturing processes such as precision forging and machining.

The spin-off benefit was the exposure of the ST company involved as one of the industrial partners of this project. Following this initiative, it embarked onto other manufacturing activities which used its precision engineering capability. Examples of such projects included the manufacture of fighter aircraft role equipment such as external fuel tanks, weapon pylons, bomb carriage and ejector racks.

If the original parts could have been bought, even at increased prices, it would still be a less painful way to bridge a very difficult period in sustaining its operations. It would also be in line with the RSAF's policy to stick with OEM parts. But that was not possible at that time. Although it was not even thought of then, in a sense the RSAF achieved the ability to be more self-reliant in the capabilities of its engineers to find acceptable solutions in times of need. In later years, many of the approaches to meeting its operational requirements were even more optimal than depending on external offers, although buying what could be bought off-the-shelf remained its first consideration.

Section 3.2
Conversion Programmes

Since the pioneering effort by the RSAF engineers and ST Aerospace in the early 1980s on programmes like the conversion of the standard C-130B transport aircraft into the KC-130B aerial refuelling tanker role, upgrade of the Hunter and A-4B Skyhawks to carry air-to-air missiles and more bomb stations increasingly complex modification and conversion programmes have been carried out by the RSAF, DSTA and ST Aerospace. A significant number of these involved the A-4 and F-5 platforms. The decision in 1985 to replace the legacy engine of the A4S-1 with a modern turbofan engine was the RSAF's first major undertaking. This was quickly followed by the replacement of the A4S-1 and TA4S-1 legacy avionics systems with a modern combat avionics suite, the first such system for the RSAF then.

A number of challenging upgrade programmes involving the F-5 followed – the conversion of a small number of F-5E fighters to RF-5E reconnaissance aircraft, carrying dedicated electro-optical sensors in a specially developed nose and pallet, and the F-5E/F avionics modernisation which also included the replacement of the legacy fire control radar. The Fokker 50 Maritime Patrol Aircraft (MPA) programme adapted a civilian passenger turboprop aircraft to provide a very cost-effective armed maritime patrol capability for the Navy. Some of these interesting programmes are discussed below.

Section 3.2.1
New Engine for the Skyhawk

The RSAF had operated A4S Skyhawks since 1972. In the late 1970s, the Skyhawk aircraft was the mainstay of the RSAF fighter fleet. Many RSAF pilots and technicians were trained on this venerable aircraft. The RSAF and ST Aerospace, in the process of refurbishing the aircraft, also established substantial depot

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[1] A high cycle fatigue environment is where the cyclic stress is low and deformation within the elastic range. The material has a finite fatigue life which is characterised by an S-N curve.

maintenance facilities and modification capabilities for the Skyhawk aircraft.

Despite its age, the airframe and engine were assessed to be supportable with adequate spare parts available from retired USN aircraft stocks and component OEMs. For the engine, many of the spare parts were still available from the engine manufacturer although production of the engine had ceased.

Curtis Wright, the manufacturer of the J-65 engine installed in the RSAF A-4 aircraft, was not a big player in the jet engine business. While the company was one of the largest aircraft and engine manufacturers in the US during World War II, its aviation business was in steady decline after the war. The J-65 engine, based on a British design (the Armstrong Siddley Sapphire turbojet), was the company's only jet engine product. The company decided to exit the business in the early 1960s after failing to make significant inroads into military jet engine sales as subsequent models of the Skyhawk operated by other air forces were all powered by the newer Pratt & Whitney J-52 turbojet engine.

Up to the mid 1970s, Curtis Wright was still providing spare parts for the J-65 engine. However, by the early 1980s, OEM parts were no longer available and the RSAF had to rely on aviation spares stockists and the USN for whatever excess engine spares available. It was only a matter of time before spares from the open market and the USN started to diminish and stockists began asking high prices for whatever spares that remained.

Non-OEM parts also started to surface in the market. The RSAF was the main operator of the A-4 with J-65 engine then and was on its own in trying to sustain J-65 engine operations.

The supportability of the RSAF's Skyhawk was soon adversely affected by engine spare parts availability. Consumption, of initially the first-stage turbine blades and vanes, was increased as a result of pre-mature failures of engine turbine parts, some of which were assessed to be caused by inferior-quality parts of uncertain origin, although they were purchased with OEM's certificate of conformance. Needless to say, the authenticity of the certificates of conformance was doubtful in many instances. Any possibility to procure J-65 parts which were claimed to be authentic was followed up quickly.

While the problem with the availability of engine parts was being addressed, the fundamental question was the ability of the J-65 powered Skyhawk to meet the operational requirements of the 1990's. Replacing the J-65 powered Skyhawk fleet was an option and there were then two aircraft available in the market that could potentially fulfil the role - a later version of the Skyhawk powered by the Pratt & Whitney J-52 engine (A-4M being the latest model) and the Brazilian-Italian produced AMX light strike aircraft.

The A-4M powered by the J-52 had substantially higher thrust than the J-65 powered Skyhawk and consequently, the former had markedly better performance in dash speed, climb rate and sustained turn, meaning, better sustained manoeuvrability. Production of the J-52 powered A-4M had ceased in the 1970s but it was technically feasible for McDonald Douglas, the manufacturer, to re-open the production line although at a significant start-up cost. A number of air forces including the USN were then operating different series of the J-52 powered Skyhawks including the A-4M and surplus of these models were available in the market.

The AMX was a newly-designed light attack fighter aircraft with modern combat avionics that mimicked advanced fighters like the F-16A/B. It was jointly produced by Aermacchi and Embraer under an Italian-Brazilian joint venture. The aircraft's maximum take-off weight was lower than the J-65 powered Skyhawk, thus it had a lower weapons carriage capacity.

A-4 in Black Knight colours with rear fuselage split for F-404 engine removal

The RSAF was faced with a number of issues on the future of its strike aircraft fleet. Would the RSAF want another Skyhawk, this time a refurbished J-52 powered aircraft that might again face obsolescence issues in the near future? Would the RSAF want to forgo its entire existing Skyhawk support infrastructure for a new replacement aircraft that would also entail new and costly investment in pilot and technical crew training and a whole new logistics support set up, with the new fleet and support infrastructure taking years to build up? What, if anything, could be done to its large fleet of J-65 powered Skyhawk to make it viable into the 1990s?

In 1983, the RSAF formed a study team comprising engineers and pilots to initiate a study on the solution to meet the projected operational requirements of the 1990s. The engineers were from a multitude of disciplines such as systems engineering, aerodynamics, structures, propulsion, avionics and armament systems[2]. The study team considered two options – upgrade and modernise key systems in the existing A4S in order to renew its operational life, or acquire a new aircraft.

Two years later, the study team concluded that an upgraded A-4S Skyhawk would be operationally viable going into the 1990s. Given a major modernisation, the aircraft with the necessary upgrades would still be a more cost-effective solution compared with the cost of acquiring an equivalent fleet of new fighter aircraft. The study team recommended to replace the A4S' old and unreliable J-65 jet engine with a modern engine and replacing the A4S' old bombing computer and gunsight system with a state-of-the-art WDNS to give vastly improved mission effectiveness and accuracy in weapons engagement and delivery. The RSAF accepted these recommendations. Thus, two major development programmes for the upgrading of the A4S were initiated at about the same time. The WDNS avionics upgrade programme eventually had a longer implementation period because of a problem with the original contract awarded. This merits an interesting and separate discussion. This section will focus on the legacy jet engine replacement programme while the upgrade and installation of the new WDNS system will be discussed in the subsequent section.

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[2] Most were either mechanical or electrical and electronic engineers in those days.

Engine Selection – Old Meets New

The core study team from the ALD was transferred to DMO in 1985 to focus its attention on the Skyhawk upgrade project. The DMO-managed project team included the RSAF engineers and pilots, and ST Aerospace as the industrial partner. The first task of the team was to conduct a market survey of the available engines.

With a good knowledge of the integration requirement of the A-4 systems and their operation, the system engineers had to draft a comprehensive "Request for Proposal" which included detailed design and interface data required for feasibility studies, the scope of work, functional design, test and acceptance requirement, and the integrated logistics support requirement for life cycle cost[3] assessment.

Three candidate engines were considered – the Pratt & Whitney J-52 turbojet, the Rolls Royce RB-199 turbofan and the GE F-404 turbofan. Production of J-52 engine had ceased but the manufacturer was willing to re-start the production line if selected. Although a well-proven jet engine, it was the oldest of the three, being a 1960s-era design. The RB-199 engine was an advanced three-spool turbofan powering the Tornado fighter aircraft. A "non-afterburning" version was proposed. The F-404-GE-100D was a "non-afterburning" version of the turbofan that powered the F/A-18 naval fighter aircraft. The last two engine designs were of the late 1970s era. They were also lighter engines. All three engines offered about 20% more thrust than the J-65 engine. The F-404 engine was eventually selected.

During evaluation of the candidate engines, the project team looked at the compatibility of the engines with the A-4 aircraft's sub-systems in order to assess the modification efforts required to attain compatibility as a reflection of the risks involved. The complexity of integrating a new engine to an existing airframe was quite different from that of a new airframe design.

The system engineers had to deal with constraints that a modern engine could impose on the A-4 airframe and vice versa. Some of the many engineering considerations that the project team faced are discussed below.

Engineering Considerations

The physical installation layout of the new engine and associated engine sub-systems was not just a matter of available space in the A-4 airframe. The differences in engine installation on the F/A-18 Hornet fighter aircraft and the maintenance concept of the F-404 engine compared with the J-65 engine on the A-4 presented challenges. Most modern engines like the F-404 adopt a "bottom access" for installation, removal and maintenance. This means that in a modern airframe installation such as the F/A-18, the lower fuselage has adequate access doors which can be opened and removed to facilitate engine removal and installation or maintenance work done on the engine and its sub-systems.

An older platform like the A-4 had an integral wing (below the fuselage) that did not allow for bottom access. Moreover, as with aircraft of that era, the A-4 was designed for the fuselage to be "split" and the rear fuselage and empennage (tail section) rolled back and removed via a special handling "dolly". This was to facilitate engine removal and installation (by sliding the engine rearward or forward on a separate engine dolly) as well as for major maintenance work on the engine sub-systems.

This was one of the mechanical interface constraints between a new engine and an old platform with different concepts of maintenance. Therefore, studies focused on the feasibility of adopting a rear installation and removal for the F-404 engine and opening new side fuselage access panels to allow acceptable access for in-situ maintenance tasks. This study further identified that a new rear engine mount had to be redesigned for the F-404 engine to interface with the A-4 airframe.


A-4C refurbishment – forward and aft fuselage

The original A-4 jet engine and airframe design had the entire engine "accessories" such as generator and hydraulic pumps mounted on an "accessory gearbox" which was in turn mounted on the engine, to form an integral part of the engine. Whenever the need arose to replace an unserviceable engine, all the accessories from the removed engine must be transferred to the new one.

All spare engines were configured without the accessories installed, hence the necessity to transfer the accessories from a removed engine to the new one.

In a modern fighter airframe and engine design, this accessory gearbox is no longer mounted on the engine. It is, instead, mounted on the airframe and driven via a drive shaft known as the power take-off (PTO) shaft that taps power from a small gearbox on the jet engine. This modern concept gearbox is aptly called the Airframe Mounted Accessory Gearbox (AMAG), on which all the accessories are mounted. Since an engine removal did not affect the AMAG and transfer of accessories, considerable man-hours were saved. The AMAG and its mounted accessories are regarded as part of the airframe. Not only must engineers find room in the A-4 airframe to install the AMAG and accessories, the layout must be optimised, taking into consideration the resultant aircraft's CG and its impact on aircraft longitudinal stability.

The engineers also had to consider the alignment of the PTO shaft between the new F-404 engine and the AMAG in the installation design. Airframes flex during aircraft manoeuvres. The installation of both the engine and AMAG had to be designed such that there was minimal deflection of the structural mounts, fuselage and wing. Finite element method was used to analyse the deflections and the results were correlated with static load tests.

The compatibility of the new engine with the airframe's existing side air intakes was a primary consideration. The new engine had a higher air mass flow rate. Engine operability and the effect of this increased air mass flow rate on the performance of the legacy airframe's air intakes and the external

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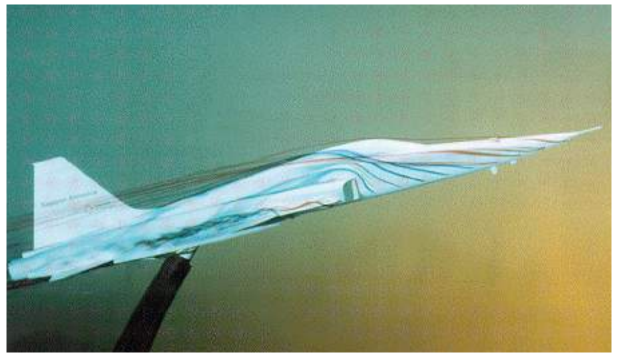
[3] Life cycle cost is an estimate of the entire operation and support cost of the aircraft or system plus the initial acquisition cost, based on a projected operating profile and useful life of the system. It reflects the expected total cost outlay in operating the system over the projected period, as opposed to the initial cost outlay of the project cost of a system.

aerodynamic flow field had to be considered. Given that the older model A-4B and A-4C aircraft did not have the air intake boundary layer diverter plates[4] that later models had, there was concern that at high angles of attack and side slip angles, low energy boundary layer air could be ingested into the engine compressor leading to the possibility of engine surge or stall.

ST Aerospace engineers used a water tunnel and an A-4 scale model to investigate the interaction of the external aerodynamic flow field and the engine intake airflow demand. The studies revealed that there was a possibility of some breakaway of the airflow along the forward fuselage, ahead of the air intakes at higher angles of attack[5]. This necessitated further water tunnel investigations during the design and development phase of the project to find a solution. Eventually, two aerodynamic vanes were designed and installed on the lower forward fuselage, ahead of the air intakes. These vanes generated vortices at higher angles of attack and in turn energised the low-energy boundary layer air flowing into the intakes, thus preventing a potential engine stall situation. The effective cleared flight envelope of the aircraft was hence raised.

In their evaluation of the proposals and from the preliminary feasibility analysis, some of which are discussed above, the engineers from DMO and ALD prepared the scope of work and responsibilities for ST Aerospace and the engine supplier which included, functional design requirements, acceptance test requirements, integrated logistics support requirements and the programme management plan. This became the basis for the contract's technical requirements.



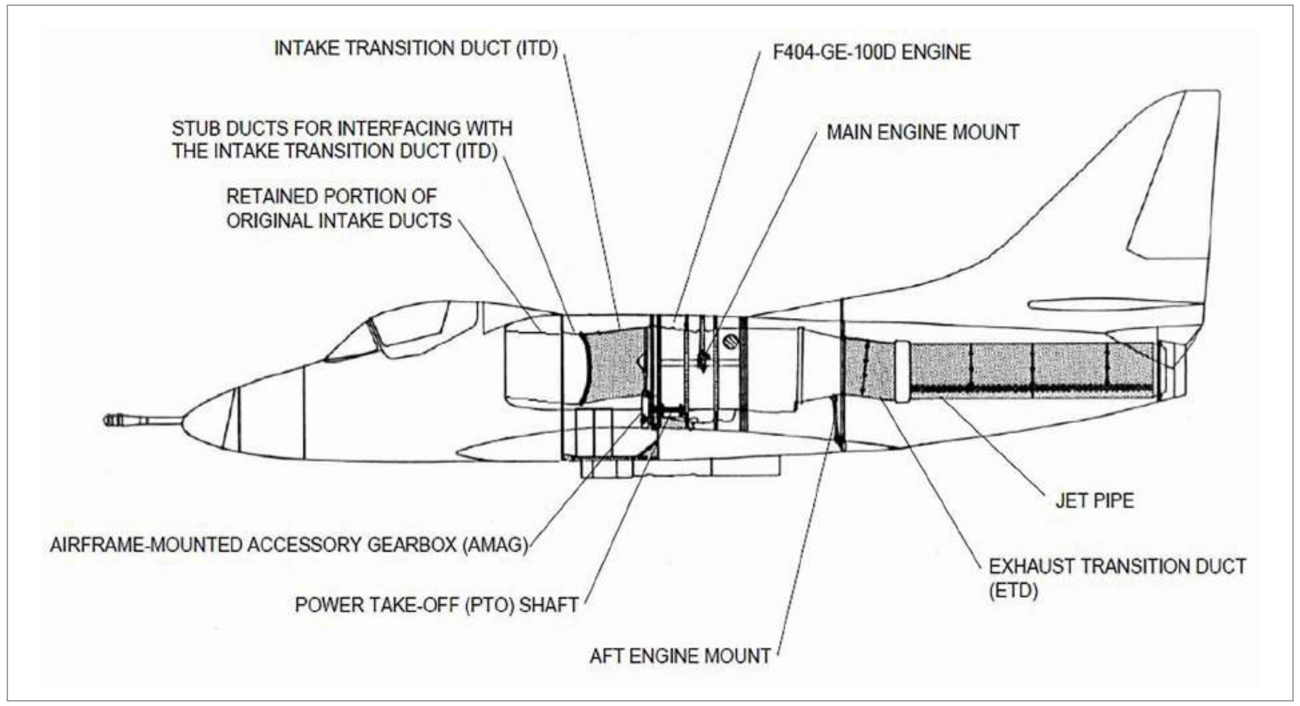
An F-5 undergoing a water tunnel test

Aerodynamic vane

Prototype Development

While the detailed design phase was being done in ST Aerospace, system engineers and specialist engineers from DMO and the RSAF maintained thorough oversight on the aircraft configuration and interface requirement to ensure that there were no conflicts among the various systems and sub-systems. The design was progressively reviewed for compliance with functional specification, reliability, maintainability, failure effects and adequacy of redundant features.

There was strict discipline imposed whereby all deviations, non-compliances and new requirements had to be submitted to the project team for review in order to control programme costs, schedule and safety impact. The changes on the airframe were significant, especially in the internal airframe structure and sub-systems. The main ones are described below.



Schematic of an A-4SU configured with F-404 engine installation

The F-404 engine had three mounts, two forward and one rear. The two forward mounts took the thrust of the engine. As the new engine produced 20% more thrust, a new fuselage frame had to be added and two existing fuselage frames reinforced. Together, these three frames bore the structural load from the engine thrust.

While the fuselage air intake remained the same, a new transition duct had to be designed and manufactured to interface the intake to the engine face. Similarly, a new jet pipe replaced the original and a new S-shaped exhaust transition duct was designed and manufactured to align and restore the original thrust line of the aircraft.

New structural mounts had to be designed and built on the wing to carry the AMAG. A modified version of the F/A-18's AMAG and PTO shaft were used. A new higher capacity solid-state variable-speed constant-frequency generator, two new hydraulic pumps and a new air conditioning system were also added.

The engine throttle control had to be re-designed and interfaced with the new engine's fuel control unit and finally, the new engine required new cockpit instrumentation for the different parameters monitored.

Flight Test

The prototype ground and flight tests took nine months. A total of 150 test flights were accomplished to test the system's functions and compatibility. More than 90 parameters were measured and tracked via a real-time data acquisition and telemetry system.

The test procedures were based on specific test points and flight conditions specified by our specialist engineers who participated with the flight test engineers and reviewed the results of each test before the test envelope was progressively expanded.

The A-4 engine flight testing was the opportunity for the RSAF to set up a formal Flight Test Centre. Staffed by a small number of test pilots, this centre was to further develop in the years to come with more pilots and flight test engineers trained in the US and UK.

The most interesting aspect of the test

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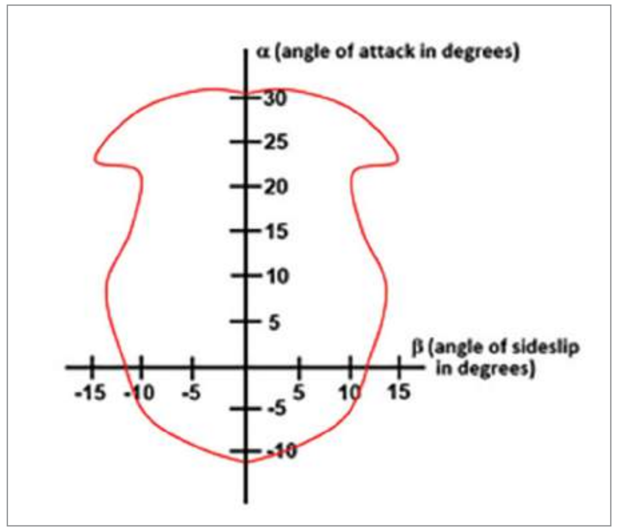
[4] A boundary layer diverter plate removes the "boundary layer" or "slow and turbulent flow layer" near the airframe surface and allows this boundary layer air to escape down a separate channel. Thus, only "clean" laminar flow air enters the intake.

[5] The aircraft angle-of-attack or "α" is the angle between the aircraft's reference line and the oncoming free air flow.

was the aerodynamic compatibility of the engine operating behind the modified A-4's air intakes. To explore this, the flight test pilot had to progressively bring the aircraft to greater angles of attack (known as "alpha" or "α") and angles of sideslip (known as "beta" or "β"). A series of rapid throttle transients – "slamming" of the throttle from engine idle to maximum speed - had to be executed to test engine response and operation under each "α-β" test point. Engine operability in the worst-case adverse airflow and intake conditions was finally explored with the aircraft being brought to a very high angle of attack and reaching stalling speed. Throttle transients were then executed.

For this series of tests, there was a risk of the aircraft getting into an unintentional and unrecoverable spin. A spin recovery parachute system was installed for these tests to improve the chance of recovery should a spin develop during flight test. The tail area of the Skyhawk was modified to accept the loads of the spin recovery system. The results of the engine operability flight tests demonstrated that the original A-4 intake with the newly designed inlet transition duct operated efficiently and with adequate pressure recovery over the full flight envelope of the aircraft. The F-404 also proved to be a "tolerant" engine in this aspect.



Typical alpha-beta manoeuvre envelope for subsonic fighter aircraft

During the flight test, an interesting problem associated with airframe intake and engine compatibility arose. In a specific flight test routine, when the engine throttle setting was rapidly retarded from cruise power to a lower thrust setting, a series of engine compressor stalls and slight aircraft yaw instability was experienced. While the problem did not repeat all the time, it occurred several times during the flight tests and thus affected the clearance of the engine operating envelope. The issue had to be investigated. It was an interesting challenge to the engineers to determine the root cause and find a solution quickly.

The eventual fix was a simple one. The A-4 has air intakes on both sides of the fuselage. These right and left fuselage air intakes are mated to an internal "bifurcated" intake transition duct which transitions the left and right intakes into a single round air inlet duct that eventually mates with the jet engine face. Engineers found that there was some instability in the airflow in the intake transition duct during rapid engine throttle retardation and this phenomenon triggered the engine compressor stall. After consultation with one of the original designers of the A-4, by then already retired, the solution; was a simple one. The fix was to keep the airflow from the right and left intakes separated all the way to the engine inlet face. This was done by extending the "splitter plate" of the inlet transition duct and not allowing the airflows of both the right and left intakes to merge. With this problem resolved, the flight test programme continued.

To the aircraft enthusiast or budding engineer, here is a more technical explanation. During rapid throttle retardation from cruise condition to a lower setting, the air mass flow going into the inlet duct was momentarily more than what the engine could ingest. This would cause some airflow instability in the inlet transition duct area, which in turn caused the air mass to oscillate between the right and left air intakes via the intake transition duct.

This oscillation of the air mass is known as "cross talk". The instability of airflow in the inlet caused a number of compressor stalls within the very short period when the engine throttle setting was retarded.

Production Go-Ahead

After the successful prototype flight tests, a thorough review of the test results by the project team and approval by an independent airworthiness panel, the first Weapon Systems Safety Advisory Board (WESSAB), it was time to get on with serial production of the A-4 fleet in ST Aerospace. WESSAB was set up by the RSAF to review all safety related issues during the project and became a practice continued for all subsequent major upgrades in MINDEF. The fleet of J-65 powered A4S-1 and TA4S-1 Skyhawks were re-manufactured with the F-404 engine as the new propulsion plant.

The re-engined Skyhawk was re-designated the A-4U/TA-4U. The emphasis was on production aircraft manufactured to the same tolerances and performance standards as the prototype. Hence, the focus by the project team during this phase was on quality. In-process and final acceptance procedures were worked out with ST Aerospace engineers. An RSAF technical team was stationed at ST Aerospace to carry out in-process audits and final acceptance checks of completed aircraft.

A "bird's-eye" view of A-4 Super Skyhawk modification production line at ST Aerospace Paya Lebar

Concurrently, ALD engineers defined the integrated logistics support requirements. Adequate spares and support equipment were acquired for the new systems added, based on a pre-determined operating profile and the level of in-country repair capability that the RSAF wanted. A comprehensive level of organic support capability, both in the RSAF and ST Aerospace, was established for the upgraded A-4.

The Rest is History

The Super-Skyhawk, the A-4SU served the RSAF from 1990 in many capacities until the retirement of the last TA-4SU from the RSAF's training detachment in France in November 2012. The F-404 engine gave the A-4SU a new lease of life, with very significant improvement in performance but equally importantly in reliability, maintainability and aircraft availability. The improvement in aircraft flight performance was also equally impressive: 35% increase in rate of climb, 40% increase in level acceleration and 15% improvement in maximum dash speed.

The success of the A-4/F-404 project, the first of the major upgrading projects by the RSAF, clearly demonstrated the capability and competence of engineers in the RSAF, DMO and ST Aerospace. The easier solution was to retire the A4S early and replace it with a fleet of new fighter aircraft.

Last A-4 detachment on flight line In Cazaux, France

Instead, the path of the F-404 re-engine and the WDNS upgrade was chosen. It was a major undertaking at a time when the in-country engineering experience was very low. The outcome was a highly successful and cost-effective programme which transformed the A-4 Skyhawk into an operationally viable aircraft which served the RSAF for a further 20 years.

The success of the A-4 Skyhawk re-engine programme attracted much attention in the early 1990s. The Institution of Engineers Australia, through the Institution of Engineers Singapore, invited the project team to present a paper on the Singapore A-4 re-engine experience and considerations. The paper was presented at the IEAust Conference in Melbourne in 1990/1991.

The A-4 re-engine, together with the attack avionics upgrade programmes, sowed the seeds for the transformation of the local aerospace scene in Singapore from an airframe maintenance-heavy industry to a full-fledged aerospace engineering industry a decade later that had the capability of undertaking major airframe modifications, full avionics and sub-systems integration, and weapons integration.

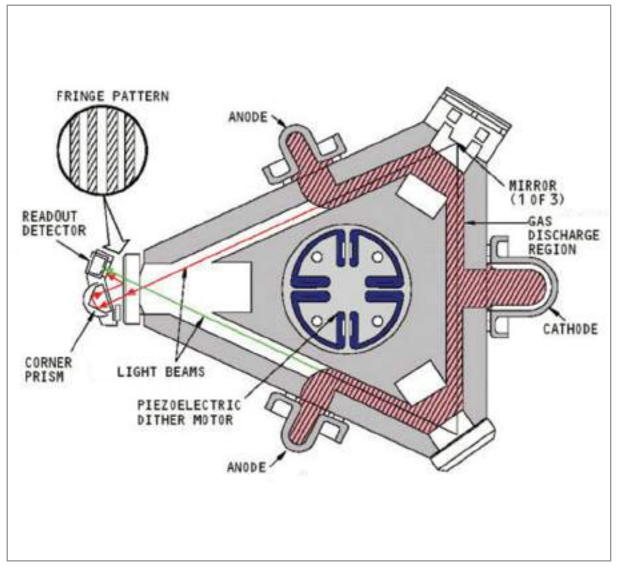

Three identical Ring Laser Gyroscopes arranged in Orthogonal axes

Section 3.2.2
A-4 Avionics Upgrade (1985) – First Major Avionics Upgrade Undertaken

The RSAF A-4 Skyhawk fighter aircraft avionics upgrade project achieved many firsts in Singapore's military aviation history – the largest fleet of operational aircraft to undergo a major avionics upgrade, among the first fighter aircraft in the world to integrate a ring laser gyroscope (RLG) in a strap-down inertial navigation system (INS), and the first project to include full technology transfer (systems engineering and software) through on-the-job attachment at a US company Lear Siegler Inc., which has since been acquired by Smiths Industries.

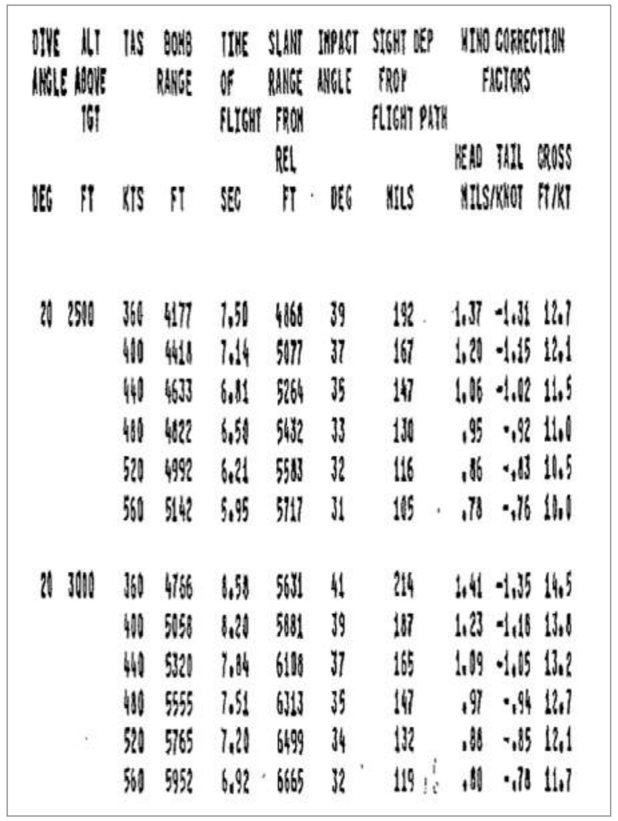
However, the Lear Siegler contract was cancelled shortly after contract signature in 1985, as full software release was not approved by the US government in a timely manner. Ferranti Ltd, a large defence company located in Edinburgh, Scotland and now part of BAE Systems, was then awarded the contract.

Young aviators born in the 1990s and later would be familiar with smart multi-function colour displays (MFCDs), head-up display (HUD) and helmet-mounted display (HMD) providing all vital information and cues that the pilot needs. It would be unimaginable to use old analogue instruments, gauges and the manual CP741 gyro gun-sight computer to perform air-to-ground bombing and air-to-air gunnery as in the pre-upgraded A-4. These were replaced by a "glass cockpit" with real-time software controlled WDNS. This comprised then state-of-the-art (mid 1980s) digital fire control computer, HUD, monochrome multi-function displays, INS with RLG (conventional gyroscopes using mechanical precession are less accurate and reliable), and other sub-systems common in modern fighters – all of which were qualified to Airborne Military Specifications.. A laser spot tracker was also installed in some of the upgraded aircraft within the nose instead of a more capable, but expensive radar.



Schematics of a Ring Laser Gyroscope

Previously, based on the weapon ballistic table flight manual, the pilot had to adjust the gun-sight marking and then perfectly execute the pre-planned flight profile based on the prescribed speed, dive angle and height to perform "eyeball" target bombing. Besides contending with cloud cover or changing wind condition, a one degree error in dive angle of 20 degrees at 3,000 feet height and 440 knots could mean a total miss of a few hundred feet on the ground. With WDNS, there was no need to follow a strict planned profile. The bomber just needed to fly according to the intuitive HUD symbols generated by the fire control computer in every computer cycle. It also provided him with multiple choices of bombing modes and weapons, besides basic air-to-air gunnery and missile firing solution, even without a radar.



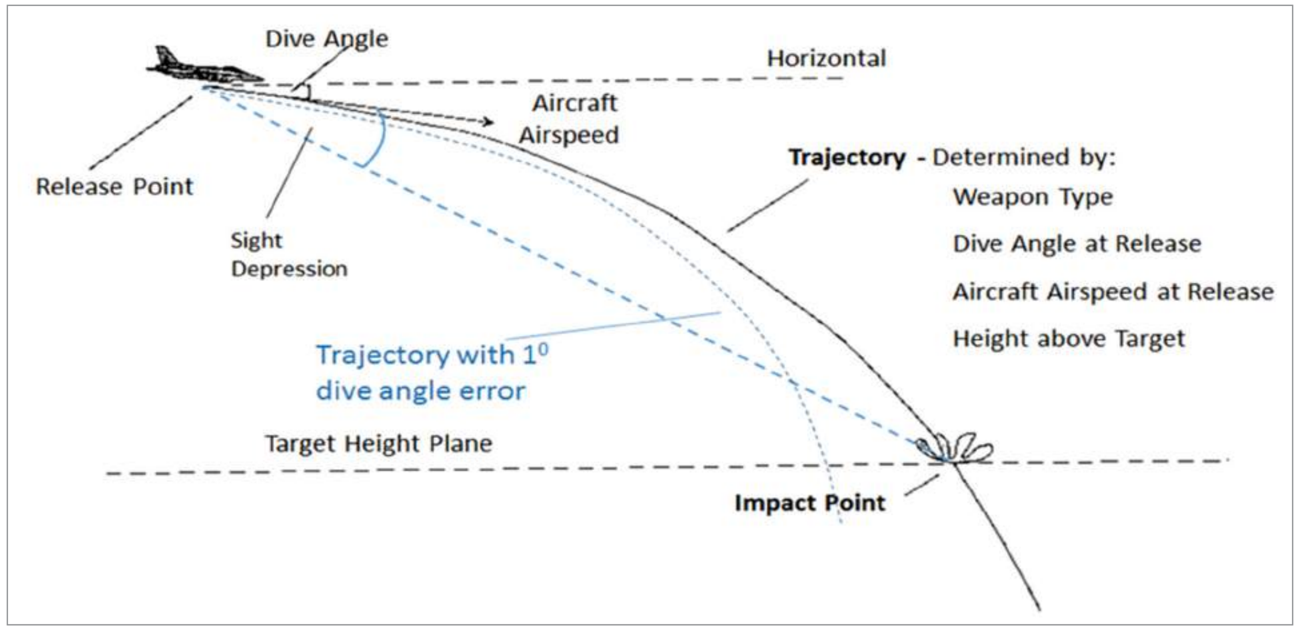
DIVE ANGLE	ALT ABOVE TGT	TAS	BOMB RANGE	TIME OF FLIGHT	SLANT RANGE FROM REL	IMPACT ANGLE	SIGHT DEP FROM FLIGHT PATH	WIND CORRECTION FACTORS		
								HEAD	TAIL	CROSS
DEG	FT	KTS	FT	SEC	FT	DEG	MILS	MILS/KNOT		FT/KT
20	2500	360	4177	7.50	4868	39	192	1.37	-1.31	12.7
		400	4418	7.14	5077	37	167	1.20	-1.15	12.1
		440	4633	6.81	5264	35	147	1.06	-1.02	11.5
		480	4822	6.50	5432	33	130	.95	-.92	11.0
		520	4992	6.21	5583	32	116	.86	-.83	10.5
		560	5142	5.95	5717	31	105	.78	-.76	10.0
20	3000	360	4766	8.58	5631	41	214	1.41	-1.35	14.5
		400	5058	8.20	5881	39	187	1.23	-1.18	13.8
		440	5320	7.84	6108	37	165	1.09	-1.05	13.2
		480	5555	7.51	6313	35	147	.97	-.94	12.7
		520	5765	7.20	6499	34	132	.88	-.85	12.1
		560	5952	6.92	6665	32	119	.80	-.78	11.7

Section of ballistic table for a typical bomb drop

In contrast with modern computing devices such as multi-core and graphics processor-equipped 4G smart phones that consume memories in gigabytes, the technologies back then, such as 16-bit processors and 128 kilobytes of memory, were considered luxurious. The market then was not populated with third-party commercial off-the-shelf (COTS) processor chips. Neither were commonly used operating systems such as Windows, VxWorks, Android nor popular languages like C/C++ or Java offered for modern day software programming, available. This made the programming of the mission and navigation tasks in the Ferranti-proprietary fire control computer quite an experience.

Given the very limited computing power and memory of the fire control computer then, besides careful real-time tasks scheduling per cycle, every software variable had to be assigned fixed memory location, while fixed-point arithmetic, instead of floating-point, had to be employed in the software computation codes. It was indeed quite an engineering feat that the fire control computer could process so many innovative algorithms in real-time without "crashing".

One example of such innovativeness was the extensive off-line curve-fitting of ballistic



Bomb trajectory and miss distance due to 1-degree dive angle error

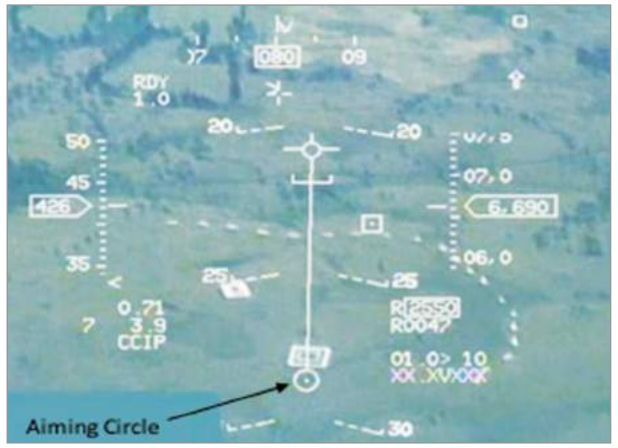
tables for each bomb, rocket or bullet. The curve-fitted ballistic parameters were then stored in the fire control computer and used to compute weapon trajectory precisely in a single computer cycle, compared to the 5 cycles for a typical numerical integration ballistic computation. The off-line tools capability was essential to subsequent generation of local aiming solutions for new weapons of similar categories.

The squadron flying the A-4SU Super Skyhawk performed exceedingly well and won top honours in bombing exercises against its newer F-16 and F-5 counterparts in the RSAF. It was the Best Combat Squadron in the RSAF from year 2000 until the aircraft's retirement.

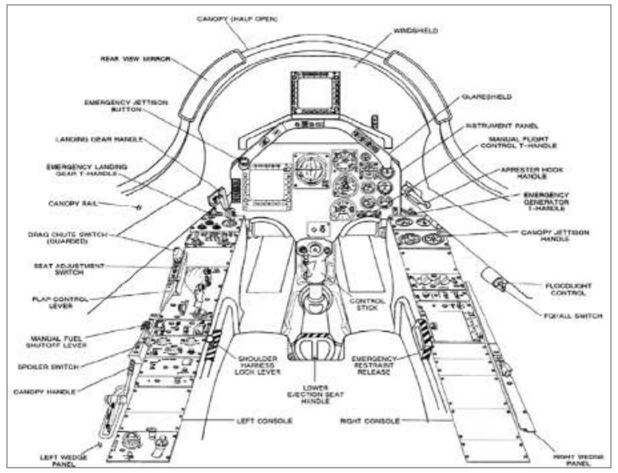
Another capability learned was how theoretical circular error probable (CEPs), or miss distances, were computed for bombing solution accuracy for each mode and profile, and how to certify that an aiming solution was accurate in actual flight tests conducted locally.

To deal with the shortcomings of not having a radar, the pilot had to perform a height fix or update at sea before an attack run and also manually overlay the HUD target symbol onto the actual target position in some bombing modes. It was also an eye-opener to learn how to project an air-to-air lead computing gun aiming circle on the HUD, based on own-ship manoeuvre and stadiametric ranging using target wingspan and manual range estimation, to track an air target. During live-firing flight tests, the target was a large banner towed by another aircraft. As expected, the air-to-air gunnery performance was a far cry from its ground strike accuracy but it was still acceptable operationally.

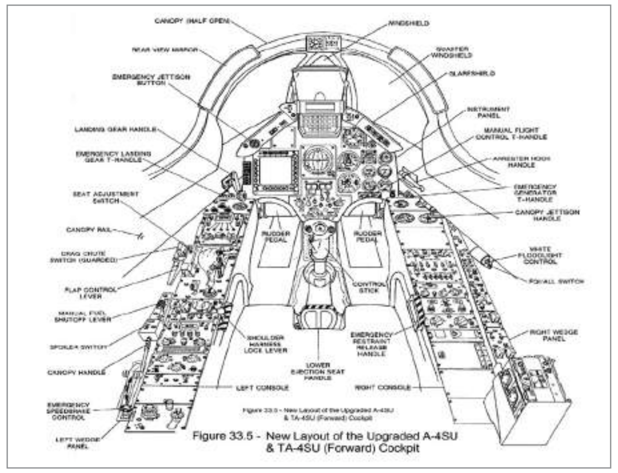
It was interesting to note that, unlike Singaporean engineers then, the two Ferranti's weapon aiming algorithm "gurus" were former fighter pilots, system engineers, algorithm engineers and flight test engineers, all rolled in one. They commanded the greatest respect in their company because of their knowledge.



HUD bomb impact point aiming circle based on sight depression angle



TA-4SU front cockpit



TA-4SU rear cockpit

For about 20 months, 12 engineers, six each from DSO and ST Aerospace, were involved in acquiring real-time OFP (which resided in the mission computer) and mission planning software (which resided in the ground mission planning station) technology through joint development work, under the close supervision of Ferranti's software team. It was the first project where Singapore's engineers were involved in OFP development from scratch in accordance with a military standard (MIL-STD-2167). Acquiring the entire WDNS algorithms and OFP capability had facilitated in-country OFP maintenance and future upgrades, and also the development of indigenous software upgrade solutions for other fighter aircraft.

During this long term overseas work attachment, several ST Aerospace and MINDEF system engineers were also involved in the avionics system integration design, integration laboratory design and testing work. These young engineers not only worked closely throughout the weekdays, they also socialised over the weekends. With such a conducive environment, it was not surprising that romance blossomed among some members of the team.

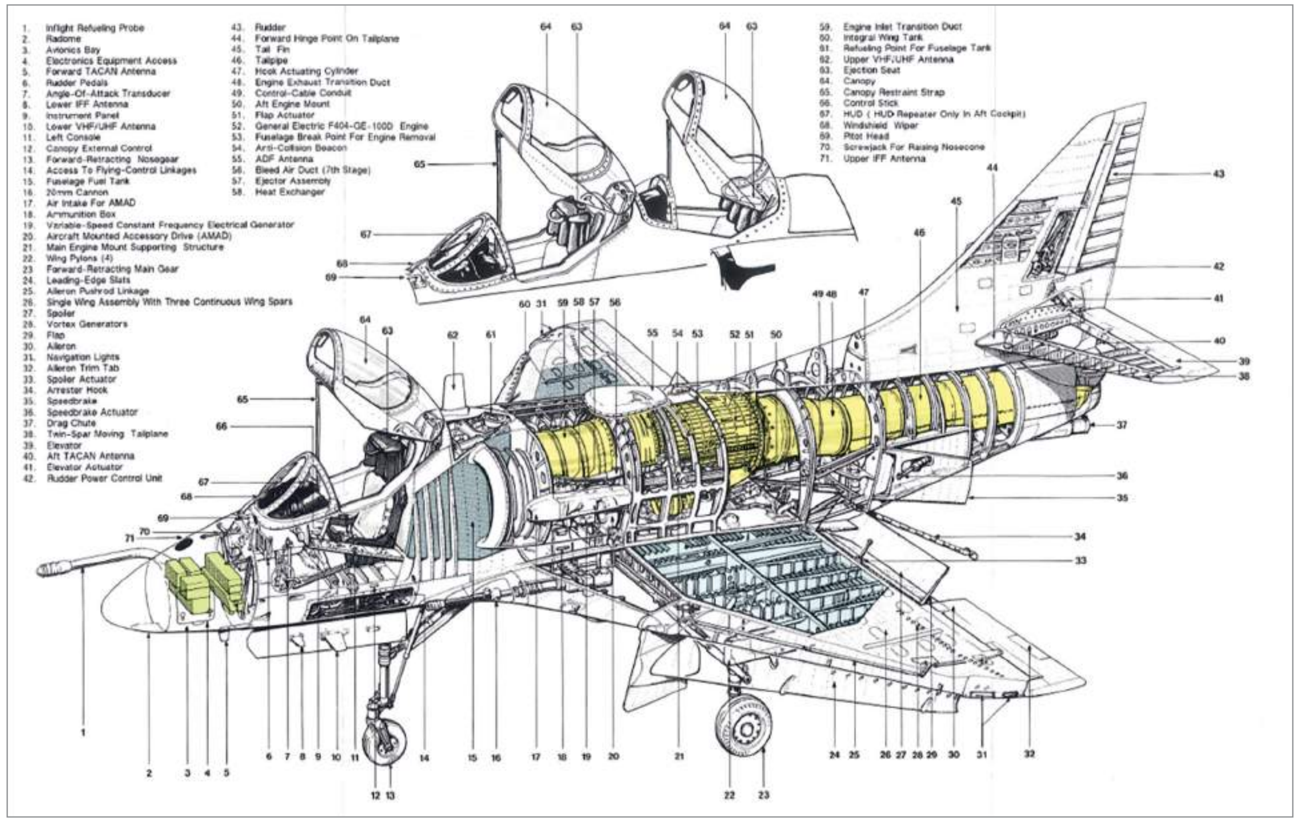
Strangely, at that time, a reverse "brain drain" occurred after project completion – two very senior Ferranti engineers stationed in Singapore for flight tests eventually migrated to Singapore and found related jobs in ST Aerospace.

The TA-4SU trainer was subsequently upgraded with several new capabilities by ST Aerospace – air combat manoeuvring and instrumentation (ACMI), additional mission computer, new data bus, multi-function colour display (MFCD), laser targeting pod and new stores. This proved that the technology transfer plan was well executed and the decision to attain self-sufficiency was correct.

The fact that A-4 upgrade projects won at least two prestigious Defence Technology Awards in the 1990s spoke volumes of the engineering prowess and "can do" spirit of the leadership and engineers involved, be they from MINDEF agencies, the RSAF or ST Aerospace.

The fleet of Super Skyhawks retired from operational service on 31st March 2005 but the aircraft continued as an advanced jet trainer for the RSAF and was finally withdrawn from service in 2012.

During National Day Parade in 2000 and Asian Aerospace 1990, 1994 and 2000, the RSAF Black Knights flew the "red-and-white" Super Skyhawks in aerobatic displays. Singapore



A-4SU internal profile (Above, twin cockpit of TA-4SU)

Polytechnic, Ngee Ann Polytechnic, Temasek Polytechnic and Nanyang Technological University each received an A-4SU Super Skyhawk as teaching aids for their aerospace programmes.

Section 3.2.3
F-5E/F WDNS Upgrade – Unleashing the Tiger

The F-5 Tiger fighters had served the air forces around the world very well since the 1960s. Its reliability and versatility were well known. The F-5E/F was in the service of the RSAF since the late 1970s. In the 1990s, a team of pilots, programme managers and engineers from the RSAF, DMO, DSO and ST Aerospace gave the RSAF F-5E/F fleet a new lease of life with a WDNS upgrade. The scale and complexity of the upgrade then, was the first in the world.

In addition to the upgrades seen in the A-4, the F-5E/F WDNS upgrade, commencing 1991, replaced the analogue gauges with digital colour displays, and added a modern multi-mode radar. The upgraded F-5E/F became the most advanced multi-role F-5 fighters in the world then with enhanced air-to-air and air-to-ground capabilities. The avionics was also comparable to those found on modern fighters such as the F-16 which were inducted into the RSAF fleet in the late 1980s. Thus, the upgraded F-5E/F also serve as excellent lead-in trainers for these advanced fighters.

A night view of the NVG compatible cockpit of the upgraded F-5E

The F-5 upgrade team faced many engineering challenges. One key decision for upgrading the F-5 was the selection of the replacement radar. The seemingly obvious and low-risk choice would be to go for mature and proven radars available then. However, the team took the bold step to select a multi-mode radar from FIAR that was still under development. The promise of improved radar performance and better immunity to electronic countermeasures offset the assessed risks.

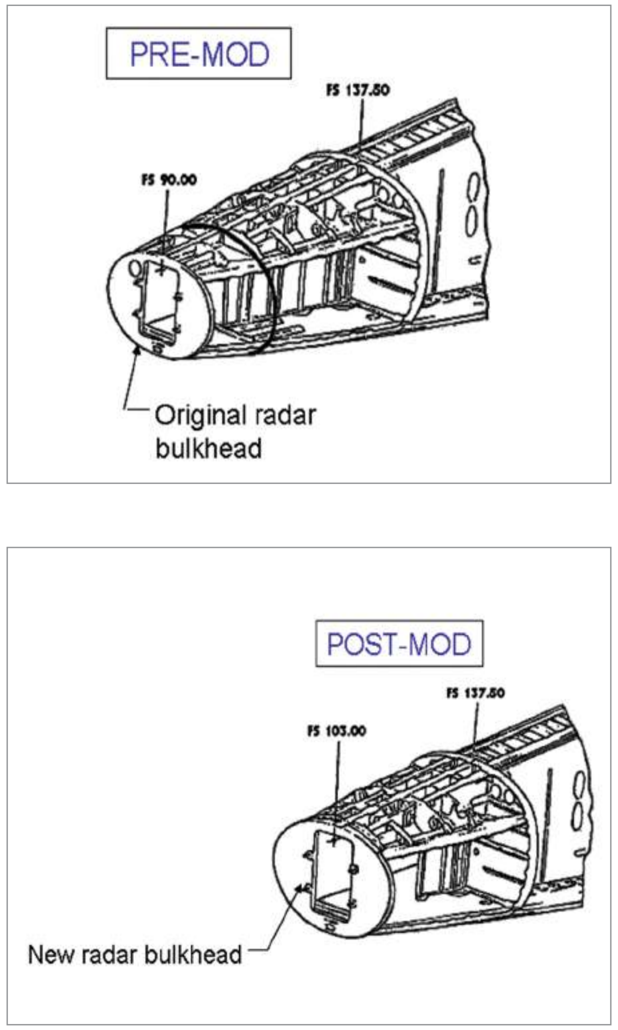
So a small team of the best radar engineers in the RSAF, DMO and DSO was assembled and spent some time at the radar OEM's facility to further assess the state of the radar's development and the remaining development tasks. The team assessed that the radar would yield the promised performance advantage over the other mature radar candidates in the market, but there remained significant risks in the remaining development.

It was anticipated that while the radar OEM should be able to deliver a better performing radar than what was available then, it would probably not be able to achieve its promised delivery date and a delay was likely. The RSAF's planning norms for the project thus factored in an internal specific period of delay in radar delivery. This bold decision enabled the team to specify and achieve better radar performance capabilities, such as detecting and tracking targets from a greater distance than any other radars in a similar class available at that time, and achieving the desired operational performance.

To incorporate the new radar upgrade, the radar bulkhead which supported the radar antennae was moved back by more than 1 foot. A new bulkhead and a larger nose radome to accommodate the larger radar antenna for increased detection range was installed.

Extensive engineering and operational trade-offs were considered. One of these was the removal of a gun to allow for more space for the new avionics equipment. The operational benefit was the vastly improved air-to-air detection range, giving the WDNS-upgraded F-5E/F an edge over its adversaries.

Teething issues were encountered with the new radar during the development and initial operational phase of the upgraded F-5E/F. One issue was the reliability of the new radar due to constant failures of a particular subsystem of the radar. The engineers from the RSAF, DMO and ST Aerospace worked tirelessly with the radar OEM to gather and analyse large quantities of data to establish the root causes of the issue. Such relentless efforts eventually enabled the root causes to be identified and solutions to be implemented.



Modified nose (bottom)
with bigger bulkhead to receive a new radar
with larger antenna and swing angle

Another engineering challenge was replacing the aging gunsight with a HUD to improve pilot's situational awareness. The HUD displayed all the critical information in the front field of view of the pilot. This allowed the pilot to navigate and engage the enemy with weapons while maintaining full awareness of his surroundings. The installation of the HUD mounting required the resizing of the instrument panel with all the associated structural support changes, including new shock mountings to isolate the vibration during gun firing.

The installation of the new HUD, the new instrument panel layout to accommodate the multi-function display (MFD) and resizing of shock mounts required evaluation of a safety concern: the ejection clearance profile of the pilot and the surrounding layout of the seat.

A ground simulation pull-up test of the pilot's seat (including the pilot) was conducted to ensure that the safety of the ejection clearance profile was not compromised. One of the outcomes of this exercise was the need to re-size the up-front control panel (UFCP) of the HUD, which violated the safe ejection clearance profile.

The aircraft cooling system was also enhanced with a new air-condition pack to provide better cooling for the radar and new avionics equipment. This approach was also subsequently adopted by ST Aerospace for its Brazilian Air Force's F-5 upgrade. Even the F-5 aircraft OEM, Northrop Grumman, adopted this approach when they developed their own F-5 upgrade package.

To achieve the required weapon aiming and navigation accuracy, the performance of the relevant new airborne equipment (i.e. HUD, INS, fire-control radar antenna array, gun) had to be validated and the installation of the respective mounting platforms (i.e. HUD mount, INS mounting tray, antenna pedestal and gun mount) had to be accurately bolted to the aircraft structure so that all were aligned to the aircraft common reference axis. This was achieved by alignment with design reference markers placed accurately in front of the aircraft on a harmonisation board. By sighting of these reference markers through a telescope placed on the corresponding mount, tray, and pedestal, they were mechanically and separately trimmed to achieve the desired accuracy. When all were aligned to the respective markers on the harmonisation board, the mounting accuracy of the WDNS system was assured.

As part of the capability build-up, a team of engineers from the RSAF, DMO, DSO and ST Aerospace was attached to the avionics and software OEM. In partnership with the OEM, several innovative design concepts were incorporated into the upgrade. As an example, two independent mission computers provided sufficient processing power and failure back-up which enhanced the reliability, survivability and mission success of the upgraded aircraft. The software development used object-orientated design methodology and Ada programming techniques to produce the OFP which was very modular in design, thus enhancing maintainability and growth potential to accommodate integration of future systems.

Having overcome the initial delays posed by all the teething issues and engineering challenges, the WDNS-upgraded F-5E/F with all the targeted enhanced capabilities was eventually delivered and went on to serve the RSAF well.

The success of the RSAF F-5E/F WDNS upgrade programme marked another significant milestone in the aviation engineering capabilities of Singapore. Like the A-4 re-engine and avionics upgrade programme, the F-5E/F WDNS upgrade programme once again proved that upgrading an existing platform was a very viable and cost-effective solution to meet the requirements of the RSAF despite the immense engineering challenges which had to be overcome.

The WDNS-upgraded F-5E/F aircraft won several accolades, including winning many air-to ground bombing competitions against other newer aircraft. It also won the Defence Technology Prize (DTP) in 1999. The engineering capabilities gained from the upgrade were important for subsequent work involving incorporation of several mission enhancing systems such as new stores, forward-looking infra-red (FLIR) and an additional mission computer to complement the existing mission computer which was heavily loaded as replacing the original computer with a new one would entail costly re-engineering and re-certification of many functions. All these follow-on upgrades were conceptualised and implemented indigenously by Singaporean engineers.

The experience and track record from this upgrade programme helped ST Aerospace to compete in and win international F-5 upgrade programmes from countries such as Turkey and Brazil, further elevating the reputation of Singapore's aviation engineering capability beyond its shores.

Section 3.2.4
Giving the F-5 an Eye in the Sky – F-5E to RF-5E Conversion

In the mid 1980's, the RSAF began searching for a replacement reconnaissance aircraft, a role that was then fulfilled by the Hunter FR.74A, a variant of the stalwart Hawker Hunter as the Hunter was approaching retirement due to supportability issues and cost of maintenance.

After an evaluation of the options available then, the decision was to replace the Hunter FR.74 A with the Northrop RF-5E Tiger-eye. This was a dedicated reconnaissance version of the F-5E fighter, and its palletised reconnaissance bay concept afforded greater options for reconnaissance payload types, and hence operational flexibility. Not least among the advantages of the RF-5E was that its airframe and systems were based on the F-5E – an aircraft already in the RSAF, thus affording commonality advantages in crew training, spares and logistics.

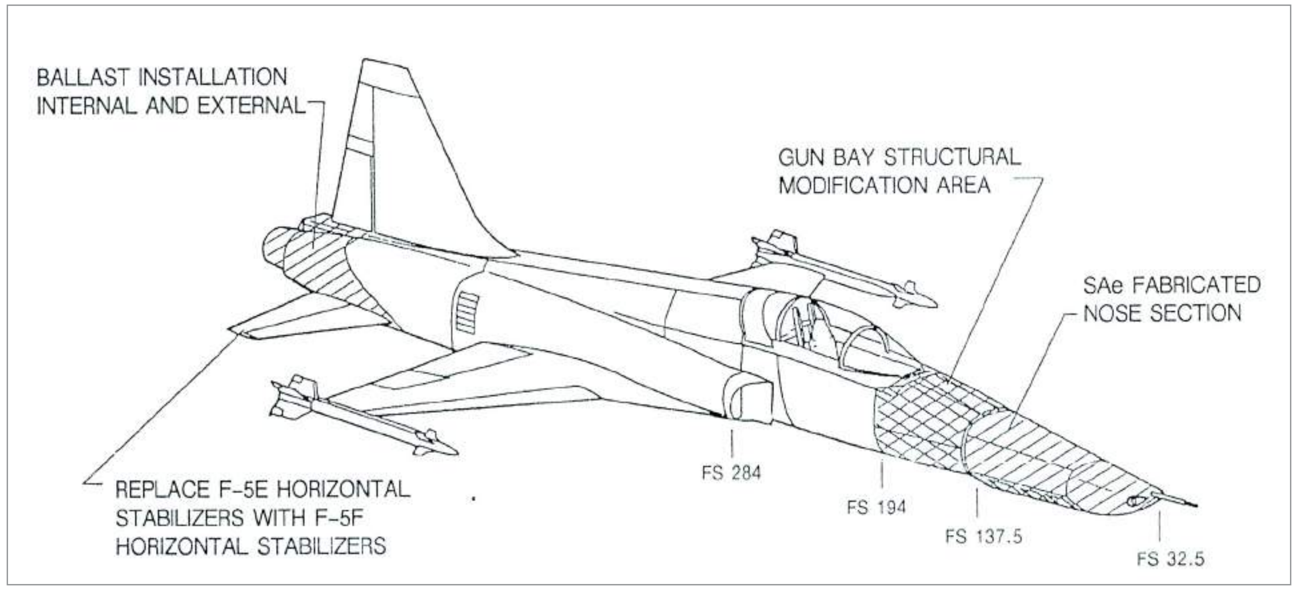
However, by the time of the decision was made in the late 1980s, Northrop Corporation, the OEM of the F-5 series, had already ceased production of the aircraft. The only way RF-5Es could be produced then would be through conversion of existing F-5E airframes.

Fortuitously, for the RSAF and ST Aerospace, Northrop's business case projected a very limited market for more RF-5E sales, and on this basis Northrop agreed to sell their RF-5E manufacturing capability to Singapore.

An agreement was struck with Northrop which saw the RF-5E engineering data package and production tooling transferred to ST Aerospace. The arrangement enabled RF-5E-unique parts to be built locally for the conversion programme. The F-5E airframes slated to become RF-5Es were converted in two distinct ways: some aircraft had the complete forward fuselage and cockpit section removed and replaced by the reconnaissance variant's forward fuselage and cockpit supplied by Northrop as part of the business agreement, while other aircraft had the radar and avionics bay section of the fuselage removed, and the new, locally-built, reconnaissance nose section grafted on.

A third F-5 squadron within the RSAF – 141 Squadron, an ex-Hunter unit – was formed to operate these aircraft.

This programme was notable for being the first occasion where major airframe sections were fabricated locally. From an aircraft structures consideration, it was probably the most extensive airframe modification ever undertaken on an RSAF aircraft, surpassing



Conversion concept from F-5E to RF-5E

the A-4 to TA-4 and F-5E/F conversions.

Several years after completion of the RSAF RF-5E programme, another RF-5 conversion opportunity materialised, this time for an overseas air force and a major F-5 operator. Agreement was secured from Northrop to work with ST Aerospace to support the requirement of its customer.

This local fabrication and modification capability was therefore unexpectedly put to good use again as the total number of aircraft converted ultimately produced more RF-5Es in total than was originally built by Northrop.

Section 3.2.5
Upgrade Capability Serving Overseas F-5 Users

Venezuela Air Force F-5A/B Upgrade – First International Fighter Upgrade Programme

In 1990, before the Singapore F-5 avionics upgrade was started, ST Aerospace was awarded its first international WDNS upgrade programme by the Venezuelan Air Force (VAF) for its fleet of F-5A/B aircraft. It was a rare opportunity for ST Aerospace engineers to be involved in a programme which went through the complete product cycle of design, development, prototyping, testing and production of a combat aircraft. More significantly, it was to upgrade the F-5A/B with an avionics suite similar to the early F-16 Fighting Falcon.

This programme fully capitalised on the diverse aircraft upgrade and system integration expertise of ST Aerospace. Working closely with the customer and designated sub-contractors who were experts in their respective areas, ST Aerospace successfully completed the programme and delivered the upgraded aircraft with greatly enhanced operational capabilities, on schedule and within budget.

As this was an international upgrade programme, ST Aerospace had to deal with cross-cultural perspectives and expectations that they had not encountered before. Learning to navigate the bureaucracy and financial system of a new country, communicating in a different language, being immersed in a new culture, living in a foreign land and working hard to fulfil its prime contractor's responsibilities was certainly an unforgettable experience for the team of engineers.

Nevertheless, through perseverance and innovation, and with the support of the customer and sub-contractors, the team overcame the challenges of the programme. One example of this is given in the following anecdote.

Our Very Own Bullseye

The flight test phase of the programme was exciting and challenging. ST Aerospace worked closely with the customer's team of pilots and technicians who supported the team well. The work was very hands-on and helped to instil a spirit of camaraderie – flight sortie planning with the pilots, helping out with weighing of practice bombs, and conducting systems environmental testing in the wee hours of the night followed by breakfast before sunrise.

The excitement went up a few notches during the weapons delivery trials. When the weapons delivery trials started, members of the test team comprising the customer and ST Aerospace engineers had to travel up to three hours each day to the test range to set up and man the observation tower.

Due to the rudimentary communications infrastructure at the test range, on many occasions the test aircraft had to act as the "re-broadcast" station between the team at the airbase and the team at the test site!

Activities that the team took on in the normal course of work included helicopter rides to the bombing range and taking care of the bomb scoring process – it was not easy to find the practice bombs in the mud! The team even took on the task of building a temporary bomb range and its own "bullseye". One day, due to the unavailability of the allocated bomb range during the wet season, the customer asked if the team knew how to construct its own target. This was to facilitate the flight testing of the accuracy of the new WDNS on the upgraded aircraft. The customer engineers had obtained permission from their authority to make use of a very large field (larger than the airbase itself) next to the airbase as the temporary bomb range. The team gamely took up the challenge. With the help of the customer, the team cleared the field, surveyed it and set out to work. The team then walked to the field with pails of white paint, brushes, a stick and a length of rope and started to improvise a test range. The scene remained vivid and was deeply etched in everyone's memories. It was an incredible feeling to be able to stand literally at the runway, contribute to the upgrade and witness the first flight of the F-5 with an F-16 chase plane in tow.

Constructing our bullseye

With its own bombing target closer, not only did the team save on travelling time, the customer could also carry out two to three flight test sorties a day through the wet season and this helped to shorten the weapons delivery trials period. The customer informed the team that after they left, the range target continued to be used by other squadrons at the air base.

A practice bomb hitting the bullseye

In addition to the technical outcome achieved with the upgraded fighter aircraft which met the contracted performance target, this programme demonstrated the "can do" spirit of our engineers. Major programme activities were carried out in Singapore and in the customer's country ranging from engineering design, prototyping, flight testing and production line set-up.

Besides the technical success of the upgrade, the most satisfying moment for the team was when the customer's senior management confided that this was their only successfully completed aircraft upgrade at that time!

Section 3.2.6
Brazilian Air Force F-5E/F Upgrade

Upon the successful execution of the RSAF F-5E/F and VAF F-5A/B upgrade programmes, ST Aerospace pursued other overseas business opportunities. In partnership with a system OEM, ST Aerospace targeted the upgrade of the Brazilian Air Force (BAF) F-5E/F aircraft in the early 2000s. It was another important opportunity for ST Aerospace to upgrade another foreign F-5 fleet after the successful the RSAF and VAF F-5 programmes.

The scope of work of the BAF upgrade was similar to the RSAF upgrade programme and thus ST Aerospace was very familiar with the work to be done, especially the nose bulkhead structural modification work. However, in this case the modification works on the aircraft were to be carried out by Embraer, the BAF's industry counterpart. ST Aerospace was to design and supervise the upgrade work to be carried out by Embraer. The key challenge faced by the ST Aerospace team of engineers and technicians was in supervising their Brazilian counterparts while adopting the Embraer's work system such as its process of work flow and logistics of parts.

This was difficult as Embraer's process was adopted from its commercial new aircraft production work, which was a build to-print work process typically adopted for manufacturing type of work. This process was not preferred for an aircraft upgrading type of work where timely on-the-spot decisions and appropriate quick design changes would be needed. Furthermore, aircraft to aircraft variations played a large role in defining different solutions for the same installations and a manufacturing process would hamper smooth and quick execution.

Nevertheless, the ST Aerospace team persevered as it was committed to the delivery of a successful programme for the BAF. The ST Aerospace team of engineers and technicians did well to execute and complete the programme in good time. The team also built excellent relationships during the time spent in Brazil and gained experience in working with the system hardware OEM and another foreign customer. Overall the team of engineers and technicians enjoyed their stay in Brazil for over the three years, from 2001 to 2004.

The Brazilians team came across as a very committed lot who clearly showed a high level of knowledge. They would dwell on an issue and seek clarification for as long as it took to understand the issue. One ST Aerospace engineer recalled that during one of the aircraft design reviews in Singapore, the review ended at 2am on the last day. The same engineer and his team then attended the system design review at the system OEM's site office immediately the week after and ended the last day of that review at 3am. It was such commitment by all stakeholders which ultimately delivered a fleet of upgraded F-5 aircraft that fully met the operational requirements for the BAF!

Section 3.2.7
Upgrading of the Hercules C-130

The C-130 is a proven, robust workhorse and the world's most versatile airlifter for more than 50 years. Thirty years ago, the SAF's NSFs and NSmen went for overseas training on the C-130. Thirty years on, our military personnel, humanitarian relief teams still rely on the robust and reliable workhorse to go overseas for training, mission and disaster relief operations.

Despite their age, the RSAF's fleet of C-130s has been kept in tip-top condition through good maintenance and restoration work over the years. In addition, much work has been undertaken to counter obsolescence and supportability issues, and to enhance the aircraft's capabilities. Similar to the Super Puma, the RSAF fleet of C-130's was also of mixed configurations, for example the autopilot system and auxiliary power units were different between the C-130Bs and C-130Hs. There was also a lack of uniformity in the two aircraft types' flight and maintenance manuals. Historically, the RSAF C-130B aircraft was maintained using Technical Orders (TO) developed by the USAF while the later C-130H aircraft was maintained using Technical Manuals (TM) developed by the aircraft OEM, Lockheed Martin. This non-standardised configuration was further complicated by various special operations installations. The mixed configuration presented both logistics and operational challenges to the RSAF. In addition, as the equipment aged, they presented reliability issues and the support of the aircraft became more complicated over time.

In 2007 the RSAF decided to embark on a modernisation programme that included fleet standardisation, modernisation and reliability improvements, as well as equipping to operate in civil airspace.

ST Aerospace was contracted to undertake the upgrading of the RSAF C-130s. After evaluating the various options to meet the RSAF's requirements, ST Aerospace proposed a cockpit suite comprising five "glass displays" similar to those for new airliners. The suite included displays for engines, flight management system, autopilot, weather radar, communication and navigation suite, safety and surveillance systems, as well as a self-protection system. The upgrade also included replacement of the older gas turbine compressors and air turbine motors (GTC/ATM) on the C-130Bs with an auxiliary power units (APU) and an environmental control system (ECS). The modernisation revitalised the legacy systems on the aircraft, enhancing not only its availability, but also ensuring its uninhibited operation in communications, navigation, surveillance (CNS) and air traffic management – civil airspace worldwide.

Several significant technical challenges were encountered during the course of the modernisation. To start with, as the TOs for the RSAF C-130Bs had not been updated for years following the retirement of the C-130B in the USAF fleet, it required much time and effort to verify the accuracy of the data and information in the TOs before they could be used in any part of the design. Besides the publications, the replacement of the legacy GTC, air turbine motors and ECS on the C-130B with the newer APU and ECS found on the later C-130H series aircraft was complicated. Although there was an approved Service Bulletin (SB) before by the aircraft OEM for the APU and ECS installation on the early series of C-130H aircraft, there was no SB available for the same upgrade on a C-130B aircraft. In other words, most of the A-kits (both electrical and mechanical parts) that were developed under the SB could not be used for this installation.

The need to re-fabricate a large portion of these electrical and mechanical A-kits also meant prolonging the downtime of the aircraft for modification. As the SB used the early series of C-130H aircraft data as the reference, the lack of adequate aircraft data, as well as the lack of on-site technical support from the originator of the SB further aggravated matters. Hence a significant portion of the SB kit could not be implemented and had to be re-designed. The installation procedures had also to be re-developed.

The upgraded RSAF C-130 with a modern glass cockpit, with the EIDS located at the centre of the five glass displays

The team had to adapt the original design so that the original contents of the SB could be carried out on the older C-130B aircraft. This was the first successful conversion of the legacy GTC, air turbine motors and ECS to the newer APU/ECS on the C-130B aircraft in the world.

The other technical challenge was the replacement of the 32 legacy analogue engine gauges with a digital Engine Instrument Display System (EIDS), an MFD for the engine operating parameters. As the aircraft engine parameters were not available, it had to be measured using an in-house designed analogue break-out box and then translated to the EIDS readings. The break-out box was also used subsequently to fine tune the transient behaviour of the EIDS display. Being digital, the new EIDS exhibited jitteriness in its readings which had been damped out by the inertia in the analogue gauges.

Another significant technical challenge was in the installation design of the self-protection suite. This was a requirement as the aircraft could be involved in peacekeeping missions in theatres of conflict.

To be able to effectively counter shoulder-launched portable missiles, flares would be fired from dispensers installed on the aircraft at appropriate sequence and timing. As the flares are incendiary in nature, the installation of the dispensers and prediction of the trajectory of the flares was critical as they could otherwise endanger the aircraft. The trajectory of the flares would also be affected by the dynamics of the aircraft and airflow so this needed to be defined and verified in a cost-effective manner.

As a trial-and-error approach would be costly and would also not be rigorous enough from an engineering point of view, this led to the development of analysis codes and tools which could compute the trajectory of the flare. This was accomplished by ST Aerospace through a step-by-step build-up from engineering first principles.

A rigorous model that captured aircraft dynamic manoeuvre effects was developed and validated. The flare dispenser orientation of the C-130 was thus determined analytically and safe separation was validated with only a few flight tests.

An RSAF C-130 dispenses flares during a test flight

Although ST Aerospace is well known for its track record of upgrading many aircraft types over the years, this very successful upgrade on the C-130 was not just another successful upgrade but an affirmation of its competence on the C-130 aircraft and understanding of the CNS and air traffic management requirements. In 2012, ST Aerospace was awarded a contract by the Royal Air Force of Oman (RAFO) to upgrade its fleet of C-130Hs with a modernised cockpit and a suite of avionics that meet civil airspace regulation requirements.

An upgraded RSAF C-130

Celebration during the handing over an upgraded C-130 to RAFO

Section 3.2.8
F-16

The RSAF advanced fleet of F-16 and F-15 aircraft is held in high regard by many other armed forces. Besides the operational capabilities of these aircraft, the RSAF is recognised for its logistics support capability that keeps the fleet at a high state of serviceability and operational readiness despite intensive utilisation. The RSAF, together with its industrial partner, ST Aerospace, is also recognised for its capability to continuously develop upgrades these aircraft, as with other aircraft in its fleet, indigenously to meet its evolving operational needs.

The build-up of this capability is the result of the painstaking efforts by the RSAF planners and DSTA and ST Aerospace engineers over the past decades.

Build-up of F-16 Engineering and Logistics Capabilities

The RSAF's fleet of F-16 and its logistics and engineering capabilities were built over a span of more than two decades. The F-16 programme started in 1985 with the purchase of a small fleet of F-16A/B and stationing these aircraft at Luke Air Force Base in Arizona, USA for a pilot training programme with the USAF. Even with a fleet size of only eight aircraft then, a robust support package was acquired and built up in Singapore. The focus then was not only to operate and gain experience on operations of an advanced fighter aircraft but to build the capabilities to support its operations at a high level. Hence a decision was taken to invest in a comprehensive support package that included an Avionics Intermediate Shop (AIS) which consisted of four automatic test stations to diagnose all the F-16A/B's electronic boxes, and a Jet Engine Intermediate Maintenance shop (JEIM) which allowed for tear down, blade and vane and other components replacement, and rebuilding of the F-16's jet engine.

This has been the RSAF's modus operandi, to ensure its weapon systems are kept at a high level of serviceability despite high usage and small fleet numbers. The overseas training programme included the RSAF's own engineers and technical workforce supporting the training of its pilots. Flying in the vast training air space in Arizona in the US and working with one of the most advanced air force in the world provided unique learning opportunities from the USAF's experience.

With this initial experience, the subsequent acquisition of F-16C/D aircraft in 1993 was structured to include the ability and the necessary tools to integrate unique third-party systems, systems that do not necessarily come from the USAF or the OEM Lockheed Martin in the aircraft. Thus the requirement for organic engineering capability was a key requirement in the follow-on acquisition of more F-16s.

After engaging the US Government and explaining our need to develop this capability in Singapore, the US Government agreed for

Lockheed Martin to release the specific aircraft engineering data and avionics software source codes for the indigenous maintenance and support of the F-16C/D aircraft during its life cycle.

More Cost-Effective and Tailored Engineering Solutions

With this major hurdle behind them, the F-16C/D project team came across another big surprise. Lockheed Martin had developed the avionics SIL internally for the development and testing of the entire F-16 software and had subsequently sold several systems of the same configuration to USAF and another country for their software maintenance effort. This was therefore, naturally, the system proposed for Singapore.

This was a very large and expensive software development station costing more than US$60 million then. It was a non-starter for the RSAF. However, this was the tool that Lockheed Martin had in its own manufacturing facility and it had already sold several of these. It was thus easier for the company to produce “one more of the same”.

At that time, the RSAF and ST Aerospace were already engaged in the F-5 avionics modernisation programme and had a software development station and SIL in ST Aerospace. A large team of engineers and software specialists, mainly from ST Aerospace, was supporting the F-5 upgrading programme. There was also the older A-4SU avionics upgrade software development facility used in that programme a few years earlier. A decision was taken to brief the USAF and Lockheed Martin on the capabilities already in place. The first reason was to ensure the USAF was aware that Singapore knew how to integrate modern avionics into a fighter aircraft, was able to manage the risks and already had similar capabilities. The second, and more important reason, was to convince Lockheed Martin and USAF that there could be a more cost-effective way to design and build a software development facility to meet Singapore's needs than just copying the SIL that was in Fort Worth. The capabilities on the A-4 and F-5 software development facilities were used to illustrate what Singapore could already do cost-effectively. Lockheed Martin subsequently re-proposed a software development facility (known as the F-16 Software Maintenance Facility, or SWMF) at a fraction of the cost of the original SIL.

Phasing in of Engineers through Actual Engineering Development

As Lockheed Martin developed and built the Singapore SWMF in its Fort Worth manufacturing facility, ST Aerospace software engineers were attached to Fort Worth to participate in its development and testing. This made good sense as the SWMF was to be transferred to ST Aerospace and its engineers would be operating and maintaining it. Singapore's understanding of the F-16 avionics and the operating system software had also enabled it to define the unique changes required on the F-16 to incorporate third-party systems.

Utilising Capabilities to Support New Operational Requirements

The SWMF was used extensively to modify, test and troubleshoot the core avionics software and, to some extent, as part of a rapid prototyping system for new capabilities to be tested by pilots in a laboratory environment. The SWMF with its software development, testing and debugging capabilities gave ST Aerospace engineers a platform to learn and hone their skills in avionics systems integration through various upgrade programmes.

The above is a testament of the engineering expertise that Singapore has achieved. Its engineers could routinely interact with the various avionics suppliers or aircraft OEMs to discuss the development of next generation solutions for military and commercial customers.

To be able to integrate and certify new external stores on the F-16, our engineers defined the requirements for an instrumented aircraft. An external store is anything that is external to the aircraft which would affect or be affected by the airflow over it. This investment in instrumented aircraft would enable future RSAF’s upgrades to be tested and certified and was an important part of the capabilities which were acquired for supporting the fleet through its life cycle.

The F-16C/D became a major capability of the RSAF when it was purchased in 1994. The purchase included continued basing of these aircraft in Arizona, US for the pilot training programme. As a reflection of the RSAF's high expectations, when the pilot training programme was being defined, the USAF counterpart initially did not agree to the planned requirement on flying hours. The concern was that the Utilisation Rate ("UTE" in the USAF’s parlance) was too high and that it might not be supportable.

The USAF finally agreed to the planned flying hours after understanding that, with its smaller fleet, the RSAF needed to use its assets more intensely. The flying hours planned for were achieved when operations started. This created a positive image of the RSAF, as well as the F-16C/D's ability to support a more demanding level of operations. Contracts for additional batches of F-16C/D were signed in 1997 and in 2000.

Section 3.2.9
F-15SG Capability Build-up

The most recent RSAF fighter acquisition was the Next Fighter Replacement Programme (NFRP). This was the acquisition of the most advanced fighter aircraft to date. A number of advanced fighters were evaluated. These were the Lockheed Martin F-16E/F (or Block 60), Boeing FA-18E/F, Eurofighter Typhoon, Dassault Rafale, Sukhoi SU-30 and the Boeing F-15E. An experienced project team comprising pilots and engineers from the RSAF and DSTA was formed for the project. Flying and technical evaluation of each candidate aircraft was carried out at the manufacturer’s facilities. An initial shortlist of six aircraft was reduced to two and from these two candidates a winner would be selected eventually.

For the final “shoot out”, the NFRP project team required that the aircraft be brought in for another round of flying evaluation in Singapore’s operating environments. The comprehensive evaluation was augmented by modelling and simulation, and analytical assessment using the Analytical Hierarchy Process (AHP).

The F-15E aircraft (later re-designated the F-15SG) was evaluated to be the most cost-effective aircraft for the RSAF's needs. Cost effectiveness has always been an important consideration for Singapore’s weapon acquisition programmes. More on this “value for money” guiding principle, modelling and simulation and the AHP process can be found in the chapter on LCM.

The F-15SG thus became the latest aircraft to be inducted into the RSAF. The next section focuses on the significant efforts of the F-15 project team in defining the capabilities to be acquired together with the aircraft, so as to ensure that Singapore could operate the aircraft at a sustained high utilisation rate as with the other RSAF aircraft, and be able to upgrade the aircraft as required to keep it relevant over its entire life cycle.

Setting Up Indigenous Capability

The operational lifespan of a new aircraft like the F-15SG could be as long as 25 to 30 years, depending on its structural design and usage. To be operationally viable, its on-board systems may require one or more mid-life upgrades due to advances in technology and equipment, change in operational scenarios, or obsolescence of the on-board systems and components. These considerations were the reasons for indigenous capabilities to be set up to support the aircraft over its life-cycle.

Build-Up of Local Engineering Expertise

The F-15SG programme initiated a build-up of local engineering expertise at ST Aerospace to maintain, repair and overhaul the aircraft, engines and systems, and the setting up of a capability to upgrade the aircraft systems in the years to come.

A review of ST Aerospace's and RSAF's readiness to undertake the task of maintaining and sustaining the F-15SG fleet and its advanced systems was done. It included the charting of the technical competencies of our local pool of engineers and technicians, as well as reviewing the existing engineering and test facilities to perform the expected engineering tasks such as aircraft maintenance, avionics component maintenance, and engine testing and calibration.

Building Up F-15SG Indigenous Modification and Maintenance Capabilities

The early A-4SU and the F-5E/F upgrade programmes, together with the knowledge of supporting aircraft operations over the years, provided valuable experience and built up the know-how and capabilities of the engineers from the RSAF, DSTA, DSO and ST Aerospace. Some of these engineers made up the F-15SG project team, and their experience enabled them to effectively define the indigenous capability required to be built up in Singapore, along with specific requirements for the manufacturer's engineering data, tools and test facilities to be set up.

Firstly, the aircraft would need to have the necessary provisions for future growth in capabilities to keep it relevant for future operational needs. The lesson learned from the A-4SU programme was the importance of providing for growth provisions in areas like memory and data-bus architecture in the mission computers of the aircraft. This would lead to more optimal approaches and solutions for future aircraft capability enhancements.

As such, during the selection process, the engineers defined specific on-board aircraft growth provisions such as CPU processing capacity, data-bus architecture and aircraft electrical power for the aircraft manufacturer to meet. As different suppliers may have different approaches and engineering setups to maintain their aircraft, test cases were defined in order to allow the aircraft manufacturer to propose the required software and system testing tools to be provided under the contract for future capability enhancements of the aircraft capabilities.

Secondly, the engineering data required would need to be extensive and sufficient to ensure that the RSAF would be able to maintain and perform modifications to the aircraft over time. A list of these engineering data, reports and documentation were defined as part of the contract in the areas of system specifications, aero-systems, structures, aerodynamics, EMI/EMC, software of key mission systems, development and integration tools and facilities.

Thirdly, a software development facility and a system integration laboratory (SDF/SIL) was acquired and set up locally, allowing ST Aerospace to perform software source codes modifications and testing to three of the key mission computers and store management system of the aircraft.

Having learned from operating our A-4, F-5, F-16 test rigs where hardware obsolescence and support by the OEMs over the long term was withdrawn, the self-sufficiency concerns were addressed by acquiring a complete set of design documents for all of the OEM proprietary hardware. This would ensure that ST Aerospace would have the basis to re-design and fabricate such new hardware if needed in the future. In addition, as prolonged usage of the test facilities was envisaged for testing and operations due to insufficient environmental provisions, the engineers also took care to understand and provide for adequate environmental and infrastructure provisions, and ensure that the cooling and humidity requirements, power needs and floor space were right from the beginning.

Fourthly, as with the F-16C/D, one F-15SG was specifically built with provisions to be reconfigured as a flight test instrumented aircraft to carry out work related to future integration of new systems. Engineers from the ALD's Aerodynamics Branch worked with their counterparts from Boeing to define the type of instrumentation required for the future flight test development work envisaged.

The designated flight test aircraft had to be uniquely designed and manufactured with wiring and other provisions for the instrumentation package which included a whole array of sensors, store separation cameras, and data acquisition and telemetry system.

For logistics and maintenance, the RSAF engineers specified the maintenance manuals and documentation for the overhaul of the aircraft. Support and test equipment, tooling and training to carry out the different levels of maintenance up to the heavy MRO work done in ST Aerospace were defined and acquired, taking into consideration, wherever feasible, the existing organic capability already established from past programmes.

In order to minimise investment costs, a survey was carried out to identify potential commonalities in the skill sets, test equipment and tooling that already existed at the repair and overhaul shops in ST Aerospace. This required detailed technical study into existing support equipment such as engine test cells and calibration tools, for possible adaptation for F-15 application. The survey also took into consideration the existing capabilities in ST Aerospace and RSAF's workshops which could or could be adapted to perform the F-15 maintenance tasks. Hence, only those additional unique support equipment and tooling which were needed were acquired.

Establishing the Expertise Requirement in ST Aerospace

As for the A-4SU and the F-5 upgrade programmes, capability build-up of F-15 aircraft systems and avionics modification would reside in ST Aerospace. Hence, there was a requirement to train engineers from ST Aerospace with a deeper knowledge of specific F-15SG systems in order to carry out the tasks expected in the future. These engineers were to work side by side with the Boeing engineers to learn the required skill sets. Some trainings were for up to three years. To ensure that the investments in the training achieved the outcomes intended, ST Aerospace had to specially shortlist the engineers to be sent. They had to have a good foundation in software development and system integration and also had competency in software modifications and system integration work.

Establish the Training Programme and Approach

A training programme was developed with Boeing for engineers from the RSAF, DSTA, DSO and ST Aerospace to effect the knowledge transfer. The training was under two categories – the first was an in-depth classroom training of the various F-15SG systems, in the areas of structure, propulsion, aircraft systems, avionics and aerodynamics. The second category was a training cum on-the-job training programme for ST Aerospace engineers to prepare them to undertake system and software modifications of the existing systems.

For the latter, specific system integration "use cases" relating to potential future aircraft modifications were developed with Boeing and formed the baseline syllabus for the OJTs. The progress of the learning and coding for the use cases were tracked at the regular programme management reviews to ensure that Singapore's requirements were met.

Establishing the Local Development Facility

Besides addressing the training needs, a dedicated SDF/SIL would need to be acquired and set up locally. A new facility was decided on instead of adapting an existing facility. All the requirements which might otherwise limit the capacity or capability of the laboratory were addressed from the onset.

Establishing a Build-up Period for ST Aerospace

The SDF/SIL was acquired and set up locally. Time was needed to commission the facility and to enable our engineers to familiarise themselves with the tools they would be using. Time was also needed to ensure that results of test cases were consistent and repeatable in our own system integration test rigs as were observed during testing at Boeing's facilities previously. This build-up period allowed engineers from ST Aerospace to practise and further enhance their skill sets. As Boeing's test philosophy and approach was different from the practices we developed over the years from our A-4 and F-5 programmes, our engineers also developed the critical test cases, processes and procedures for the F-15SG in order to meet the RSAF's safety standards and needs.

All these proactive and elaborate planning and considerations for setting up local capability was a result of our experiences from many of the systems integration programmes undertaken through the years.

Section 3.3
Surveillance Aircraft

Section 3.3.1
E-2C

Singapore's air defence in the 1970s and early 1980s was predicated on ground based radars. As an island with limited number of high points, these ground radars suffered from line-of-sight limitations and gave the SAF very short reaction times to incoming threats masked behind terrain and the earth's curvature. In the early 1980s, MINDEF acquired the Grumman E-2C Hawkeye airborne early warning and control (AEW&C) aircraft from the US. The E-2C was extensively used by the USN for over-the-water air surveillance. As an elevated sensor, the E-2C removed the constraint of ground-based radar limited by the height of its radar antenna.

The E-2C allowed for air and surface surveillance over larger areas and provided tactical control of air assets and complemented the land-based air defence system.

The RSAF gained its "eyes in the sky" capability with the arrival of the four E-2C aircraft in 1987. These formed the RSAF's 111 Squadron.

On 6th May 1988, 111 Squadron was officially commissioned by then Second Minister for Defence, BG (NS) Lee Hsien Loong. The RSAF was the first air force in the region to be equipped with an AEW&C capability.

The E-2C project was managed by a team of engineers from the then Special Projects Organisation. A Government of Singapore Programme Office was established in Long Island, New York to closely manage the programme. Around the same period, MINDEF had identified that command and control (C2) system was an important area that the local defence community had to build up its expertise in. C2 is an integral part of any armed forces and the SAF must be able to customise its C2 systems through local C2 development. MINDEF leveraged this opportunity to build up such a capability.

A team of 12 engineers from DSO were attached to the then Grumman Corporation to participate in the design, development, coding and testing of the E-2C's software.

This group of engineers was one of the building blocks for the build-up of real-time C2 software development in MINDEF. This significant investment would later pay off in the E-2C upgrade and Frigate C2 development for the RSN.

Need for Upgrade

The E-2C acquired in mid 1980s was in a configuration called "Group Zero" comprising mission computer and 10-inch monochrome displays. In the 1990s, the Group Zero system was found to be increasingly inadequate to cope with operational demands. The man-machine interface (MMI) was inefficient, requiring frequent operator actions, leading to heavy operator workload and distraction from actual mission execution. Lack of colour on the monochrome displays hindered quick information assimilation and situation awareness. The ageing mission computer, with limited memory and processing speed, was unable to cope with the addition of new software features required by the operators. In addition, due to age, the Group Zero mission systems faced technology obsolescence and increasing low reliability.

E-2C Upgrade

In the early 1990s, MINDEF looked into upgrade options for the E-2Cs. The obvious option was to go back to Northrop Grumman Corporation, the OEM and upgrade the aircraft to Group II which was the most current configuration then. However, this package did not introduce any significant upgrade of the computer system other than a slight increase in speed. It comprised mainly of an upgrade of the 10-inch monochrome display to an 11-inch colour display. There were also obsolescence issues on the mission systems to take care of but these were not addressed.

Alternatively, an in-country upgrade of the E-2C system was assessed to be feasible. Although there were higher risks associated with this option, this approach would address the key issues of enhancing the E-2C operator efficiency and effectiveness, and overcome obsolescence issues. This in-country development would also enhance the indigenous C2 capability in the DTC.

Even though the engineers had undergone software maintenance training, system design knowledge and documentation required for an upgrade of this scale was not available. The team had to look for other means to overcome the lack of technical documentation, mainly in the areas of message protocols and sub-system behaviours. The years of working on the first generation E-2C system, however, had built up the technical expertise and confidence of the engineers to develop the C2 mission system. There were two other major C2 projects being developed locally in the early 1990s. These were the Fokker 50 MPA and the mission C2 system for the Navy's Patrol Vessels. The DTC was then taking on more C2 development projects with increasing complexities and this gave them the confidence that the local upgrade of the E-2C was possible.

The in-country upgrade of the E-2C mission control system started in late 1993. The ageing computer system was replaced by a state-of-the-art suite of commercial-off–the-shelf (COTS) processors adapted to harsh military environments. Due to extensive use of COTS components, the new system was more power-efficient, lighter and dissipated less heat. The new system was also more reliable and easier to maintain and upgrade.

Millions of lines of software codes were rewritten and the software was redeveloped using open architecture standards and modern coding techniques to handle the real-time demands of the C2 system. This was another valuable learning experience in MINDEF's journey in opening up new horizons for the indigenous development of airborne C2 systems.

Major Elements of the E-2C Upgrade

Upgraded Operator Consoles

The old monochrome 10-inch display was replaced by a 19-inch high-resolution colour monitor. The modern larger colour display helped the operators to analyse information more quickly and accurately. The use of a standard keyboard and trackball reduced the workload and increased operational effectiveness of the operators as they were familiar with the use of such devices compared to the non-standard older input devices.

New C2 Software

The real-time C2 software was designed to handle the high volume of raw sensor data from all the existing avionics systems and a new Global Positioning System (GPS). With more processing power and information storage available, the software was then able to carry out split-second calculations in real-time.

The new software was also easier to maintain compared to the old code which was built using an older generation of programming language.

Upgraded Cockpit

The addition of a GPS and a cockpit display unit (CDU) was part of the avionics upgrade in the cockpit. The GPS enhanced the navigation accuracy of the E-2C while the CDU allowed the E-2C pilots to better appreciate the surrounding air situation.

The industry partner for the upgrade, ST Aerospace, was engaged to carry out the avionics hardware upgrade based on the conceptual design provided by the programme team. Then, ST Aerospace had little experience in ruggedising and integrating large-scale COTS computer systems required by the upgrade. There was significant learning effort by ST Aerospace in embarking on this project.

An example was the repeated failures of the mission computer when subjected to environmental qualification tests. Due to the large physical size of the mission computer there was only one in-country facility then which was suitable to conduct the tests, and every re-test as a result of a failure could only be carried after several months wait.

The success of the upgrade was due to a group of very dedicated members who persevered through tough times. There was a strong partnership between the E-2C operators, ST Aerospace, DSO and DSTA. The E-2C Upgrade was successfully accomplished and won the Defence Technology Prize in 1999.

The local development of the E-2C mission control system led to the build-up of significant indigenous technical expertise in the airborne C2 domain. This and other C2 development programmes undertaken locally since have nurtured the defence ecosystem's capability to build more advanced and sophisticated C2 systems.

Section 3.3.2
Fokker 50 Maritime Patrol Aircraft Conversion

Maritime air surveillance is an important capability for Singapore to safe-guard the sea-lines-of communications through the Malacca Straits and the South China Sea.

When the requirement for a MPA was established, there were several acquisition options:

(1) Buy an off-the-shelf MPA
(2) Modify a military transport aircraft to be an MPA
(3) Refurbish and upgrade a second-hand MPA
(4) Convert a civilian passenger aircraft to be an MPA

After extensive studies, it was decided to undertake the bold step of converting a civilian passenger aircraft for maritime patrol missions. The Fokker 50 was selected. It was a breakaway from the conventional mindset of using only military-qualified platforms for military applications.

The project team, led by DTC, assessed the feasibility of the Fokker 50 airframe to accept structural modification to install the mission systems and carry weapons. This involved the introduction of some major structural frames into the fuselage to carry the concentrated loads. A pair of "stub wings" (a short cambered wing protrusion from the fuselage) was introduced to carry the Harpoon anti-ship missile. Hard points were also introduced into the wing to carry search-and-rescue pods.

Further assessments were also made to ensure structural strength adequacy for increased fuel capacity and consequently increased maximum-take-off Weight (MTOW) for longer endurance flights. As a result of increasing the MTOW, an assessment of the engine performance was required to determine the impact on take-off distance and climb gradient to ensure safety.

To perform the maritime surveillance mission, the Fokker 50 was required to fly at low altitudes for extended periods. This operating profile differed from its original design as a passenger aircraft where the normal profile would comprise take-off, cruise at altitude and landing. There would be increased exposure to turbulence at low altitudes in the maritime surveillance role. The project team was keenly aware that this could affect the fatigue life of the airframe. An extensive study was done to identify the fatigue critical components and re-run the fatigue analysis using the new operating profile to establish the effects on the structure and design the appropriate maintenance actions.

For the maritime surveillance mission, the main sensor was the radar. In order to have a 360-degree radar coverage, the best place to install the radar was in the belly of the aircraft. Ground clearance was a challenge. The radar had to be embedded into the airframe as far as possible. Part of the radar had to penetrate into the pressurised cabin of the fuselage. This required design reinforcements in a sensitive part of the fuselage. A "pressure bucket"[6] was introduced to seal off the penetration. Fatigue assessments had to be carried out to ensure adequacy of the reinforcements to withstand the ground-air-ground pressurisation cycles during operation. Even then, the ground clearance was not enough. The radar antenna needed to be reshaped to reduce its profile so that it would not strike the ground in the event of a heavy landing with burst tyres. Analysis and testing were required to ensure the reshaped antenna was able to meet the operational target detection requirements.

To complement the radar detection with visual identification, an infra-red detection system (IRDS) was installed. This system also needed a 360-degree field-of-view in order for the radar to slew it to the target of interest. Naturally, the IRDS was also installed on the underside of the aircraft. It was located under the nose. When the radar was shining forward, the directed beam would impinge on the IRDS. The resultant electromagnetic interference would affect the performance of the IRDS resulting in "snowy pictures". A series of design improvements were carried out to "harden" the IRDS and overcome the problem.

An aircraft modification will never be complete

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[6] A reinforcement literally like an inverted bucket.

without an aerodynamic assessment. With the carriage of external weapons, and the addition of radar, IRDS and wing pods, the drag profile of the aircraft was significantly different from that of a passenger Fokker 50. A new set of flight performance charts had to be generated.

To deploy the Harpoon and search-and-rescue pods, store separation analysis was carried out to ensure that when these stores were released from the aircraft at various speeds, they would not tumble or float up and hit the aircraft. Drop trials were then performed to demonstrate the actual behaviour of the stores during separation. High-speed cameras captured the sequence of the drops and detailed analysis was carried out to chart the flight envelopes for launch and jettison of these stores. While the structural design and aerodynamic analysis were taking place, mission system integration activities were running in parallel. The mission systems were developed in a test bed to check out the system installation and interfaces before actual work on the aircraft.

A full-scale mock-up of the whole cabin area was simulated using an old Fokker 50 fuselage. Details of mechanical installation and system interface were checked out and operations were simulated to validate responses. This parallel activity saved many months in the programme schedule and it also allowed aircraft and system problems to be isolated and solved concurrently.

By the time the flying qualities of the modified aircraft had been validated, the mission systems were ready for integration to the platform. Through this approach, a prototype MPA was ready for testing in less than two and a half years from contract go-ahead which was a significant achievement.

Section 3.3.3
G550

Retirement of the E-2C was initiated around mid 2000s. The Gulfstream G550 commercial business jet was one of the platforms considered. Operating a commercial jet would provide us with a lower life cycle cost as compared to using a military jet. The G550 platform was selected from studies against several other commercial platforms. The team found that the G550 was the most optimal aircraft for the radar system and the required airborne early warning mission system.

The G550 aircraft would need to be modified extensively to carry the active phase array radar on both sides of its fuselage and the many mission systems on-board which needed to co-exist and interoperate with the aircraft systems.

The entire system comprising aircraft and mission systems had to undergo very rigorous airworthiness qualification tests. Airworthiness was a fundamental and cardinal requirement for this programme especially since there were significant modifications to the aircraft due to the intense integration work carried out on-board.

An Obese G550

In the beginning, bottom-up estimation of the combined weight of all the mission system components revealed that it exceeded the maximum allowable weight of the aircraft, or in aircraft parlance the Maximum Zero Fuel Weight[7]. We had an obese system to start with and one that could not take off from the runway.

With weight and space at a premium, the weather radar that came with the business jet was removed and replaced with a mission radar antenna to provide 360-degree coverage. Since the weather radar was required to apprise the pilot of bad weather along the flight path, the team came up with a solution to incorporate a weather mode in the front mission radar. It might sound easy but to design a radar to detect aircraft instead of weather in one mode and weather in another mode was not easy! One major difference is that in a weather radar, an aircraft is treated as clutter and in a surveillance radar, weather elements are treated as clutter!

The programme team scrutinised the weight of each critical component to ensure that the aircraft carried no unnecessary weight. It was important to choose the right material and components that went into the system, and to balance this with the system's performance.

Most of the existing systems including the galley and aircraft toilets were on the chopping block. Thankfully, none the essential items had to be removed.

The active phase array radar will be used as an example to illustrate the degree of detail the team went into. In this active phase array radar there is a transmit/receive module (TRM) for each antenna element. There are hundreds of these antenna elements forming the radar antenna. The team had to scrutinise the reduction of even a few tens of grams from each element as the net overall weight that could be reduced was significant.

The close scrutiny on the weights of each sub-system was very successful and the G550-AEW was delivered with a sufficient weight margin.

Good radar performance was critical. One of the most significant challenges was the massive ground clutter returns which created false alarms and receiver saturation that would cause degradation of the whole radar picture. The team and the contractor came out with a new and innovative radar signal processing mechanism that dealt with radar returns differently.

Apart from system performance, human factors was also an important aspect for the programme. Human factors engineering (HFE) experts studied and collated the anthropometric data specific to Asians. This was used in the design of the operator console and selection of chairs, taking into consideration ergonomics, maintainability and space limitations. For example, if a maintenance task would require three persons, space had to be allowed for it.

G550 before and after modification with airborne sensor

The G550-AEW was truly an extremely ambitious project that pushed technological and engineering boundaries. It involved the development of sophisticated and state-of-the-art sensors and mission suites integrated onto a business jet aircraft. The engineers leveraged their experience in delivering the F-50 MPA aircraft to overcome many technological challenges. The first G550-AEW system was delivered to the RSAF in February

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[7] With Maximum Zero Fuel Weight, we cannot trade off fuel to create room to carry more mission systems on board.

2009, thus marking the commissioning of another successful major programme. Apart from delivering the key operational capability, this programme further facilitated the build-up of substantial critical technologies in our local defence partners and industries. These achievements were possible due to the close collaboration and effective working relationship between the RSAF, DSTA, DSO and ST Engineering.

Section 3.4
Rotary Wing Evolution

Section 3.4.1
Vertical Lift in the RSAF

The helicopter is without doubt one of the most versatile and important air vehicles in the aviation world. Helicopters, or rotary-wing aircraft as they are sometimes called, can be used for a wide range of operations including humanitarian and disaster relief, fighting forest fires, emergency medical evacuation on land and at sea, reaching the most remote places quickly where no other vehicles might be able to access.

Unlike a conventional fixed-wing aircraft which most readers might be more familiar with, a helicopter is capable of forward, sideways, rearward movement and vertical flight, as well as hover. This gives the helicopter its unique capabilities. It uses lift generated by a set of rotating rotor blades or rotating wings. This set of rotor blades is attached to a rotating mast which supports the helicopter in flight and during hover. Power for the rotating rotor blades comes from one or more jet engines (more correctly known as turbo-shaft engines) driving a gearbox. When the helicopter's main rotor blades turn, it also produces a reaction torque which tends to turn the fuselage in the opposite direction. Hence in most helicopters, there is a small tail rotor assembly which produces enough propulsive thrust to compensate for this torque and keep the fuselage stable.

The first helicopters to be inducted into the then SADC were eight French-made SA 316 Alouette III light utility (general purpose) helicopters in 1969. A year earlier, a pioneer batch of technicians were sent to France for technical training on the helicopter. The RSAF's helicopter fleet and lift capability grew rapidly with the subsequent acquisition of UH-1B/H helicopters from the US and later the Super Puma medium-lift helicopters from France.

The UH fleet included UH-1H helicopters which were excess stock from the US Army inventory. Three new Bell 212s formed the main search-and-rescue helicopters for Singapore over many years. As the helicopters took on more operations, the UH-1B was subsequently added as the UH-1H was scarce then. One of the reasons was the UH-1H was then still an important helicopter for the US Army in the Vietnam War and it was difficult to get used UH-1Hs. On the other hand the UH-1Bs were readily available and came at a much lower cost.

Today, the RSAF's heli-lift capability comes from the Super Puma medium-lift and Chinook heavy-lift helicopters. The RSAF also operates the Apache battlefield attack helicopters and the Sea Hawk naval helicopters deployed on board the Navy's frigates.

The engineering behind the design and operation of helicopters is complex. In order to support safe helicopter operations and future helicopter projects, a number of engineers then from ALD and DMO were trained on helicopter engineering in France during the acquisition of the Super Pumas. They were the initial cadre from which helicopter engineering capability was built up in ALD and DMO.

The RSAF's experience in supporting rotary-wing operations was not entirely smooth sailing. Much valuable experience, which could not be taught in the classroom, was learnt the hard way, especially during the initial years of Super Puma operations, which sadly was marred by a number of incidents and accidents. It was the strong engineering competence in ALD that enabled the engineers to investigate what went wrong, draw the right lessons and then resolve the root cause of the problem and move on. The need for strong technical knowledge and safety emphasis has since etched as part of the RSAF's anatomy and permeated throughout the organisation, enabling the RSAF to maintain a good safety track record.

The remainder of this chapter is devoted to reflecting on some of the important experiences in helicopter engineering, both in operations and support, as well as the upgrading of the RSAF's helicopter fleet to meet new operational challenges.

Section 3.4.2
The Super Puma Experience

The Super Puma helicopter was inducted into the RSAF in the late 1980s.The first acquisition was to meet two important mission requirements which have been the traditional domains of the helicopter fleet since the beginning. The first was the search-and-rescue requirement as the RSAF was and still is responsible for Singapore's civil aviation search-and-rescue. The Bell 212 helicopters, which were specially acquired and configured to undertake this role, were limited in range and capacity.

Singapore wanted to step up its capability in this important area in view of the increased intensity of civil aviation flying in its Flight Information Region (FIR). The same consideration led to the introduction of the Chinook helicopter in later years as the commercial aviation flying in its FIR continued to increase over time due to the growing economies in the region. The second was the increase in heli-lift demands and it was evident that more UH-1Hs and UH-1Bs would not be the answer. The Bell fleet was also getting old and supportability was a concern although, as was typical of the RSAF then and now, the readiness of the fleet was maintained at a high level even as the fleet became due for retirement.

The Super Puma, known as "SP" in the RSAF, was a new aircraft then and not an update of the Puma helicopter which had been in service for a many years in different air forces. When it was being evaluated, there were not many options in its category of aircraft and its main disadvantage was that it was newly developed. With the acquisition and, later on, a second buy, the RSAF was operating the largest and leading fleet of SPs in the world for a long while.

The introduction of the Super Puma was marred by two major problems. These were logistics supportability and engineering issues.

Spares unavailability, which resulted in many helicopters being grounded pending delivery of urgently needed parts by the OEM created a very urgent problem as the RSAF's expectations on its fleet's flying operations and availability has always been high. As the RSAF was the lead operator, experience was being gained as problems arose during routine support of its demanding level of operations. Though parts were provisioned as for other aircraft in its inventory, reliability data provided by the OEM on which the provisioning model for spares was based was not proven as there was no field experience on the Super Puma then, and the reliability data then had certainly not yet been corrected for the RSAF's operating conditions.

At that time, the OEM's logistics support system was not ready to support the level of operations that the RSAF needed. Information on the RSAF's outstanding demands resided with the different OEM's manufacturing units supporting each category of items. So, while the orders were on record, the information at the OEM was dispersed at its various centres and the overall ground situation at the user end was not known to the OEM. The problem was finally resolved after intense efforts by all parties, including the lay-in of spares in Singapore which were committed upon by the OEM but had not been laid-in yet when operations began.

The more serious problems were technical in nature as these affected the safety of operations and reliability of the fleet. One of these problems experienced during the operations of the Super Puma was with the main gearbox cowling, a large structural part for a helicopter the size of the SP. The cowling installation was very sensitive to vibration and air-loads, resulting in high defect rates. The problem came to a head on 28th March 1990 when a main gearbox cowling actually came off in flight leading to an accident. In the course of subsequent investigations, amongst the causal problems were the security of the locking mechanisms which secured the cowling, the rigidity of the cowling structure and the allowable tolerances at different critical areas of the cowling in view of the level of vibration, and the air-load during flying operations. Modifications had to be made to improve the security of the cowling, to tighten the tolerances and inspection limits of the structure, and to increase its rigidity. The cowling design for the later helicopters, as noted on the RSAF's second buy SPs, was changed by the OEM to improve its rigidity and to achieve better security of the installation.

In another serious incident during a fight test in January 1991, a tail rotor failed in flight. This led to the rear portion of the tail boom being torn off and resulted in a catastrophe leading to a loss of crew comprising two pilots and two technical staff, and the helicopter. This was at the height of a very difficult period in the early stages of the new helicopter introduction into the RSAF. After a very exhaustive investigation it was concluded that the accident was not related to the technical support of the helicopter. The failure of the tail rotor was also assessed to be not initiated by normal wear-and-tear.

As a result, the OEM recommended a series of precautionary actions and took the necessary actions internally to avoid recurrence of the problem. The fleet resumed operations with no repeat incidents thereafter.

As the Super Puma was procured to meet an operational role, an infra-red suppressor system was included in the purchase to improve the survivability of the helicopter against heat seeking missiles as such weapons were becoming more common. Though the system was supposed to be certified for a certain number of flying hours, premature failure in the form of cracks was experienced at a very early stage in the introduction of the infra-red suppressor. Engineers from the RSAF investigated the problem with the OEM and this led to improvements being made by the OEM in the design of the suppressor and its testing and certification, so that the suppressor could perform to expectation.

The introduction of the Super Puma was marred with many difficulties. Each of the issues was fully resolved by the engineers from the RSAF working together with the OEM. When the RSAF needed more heli-lift capacity at a later point in time, additional SPs were added to the fleet. Subsequently the fleet went through various capability upgrades and “mid-life” and standardisation updates. This is detailed in later parts of this section.

Each aircraft has its unique set of problems because it is a complicated machine built to perform many complex mission requirements in demanding environments, not just to provide a transportation function. A newly developed aircraft has perhaps higher potential for even more surprises as it has not seen service yet and any inherent deficiency in its design and reliability will not have surfaced, much less resolved.

But this is the conscious trade-off between buying a newly-developed aircraft incorporating the latest technologies at the point of its acquisition to meet user’s defined requirements but with the inherent risk of "infant mortality" failures, or a “proven” platform with known inadequacies in technology, reliability and potential obsolescence but with more stable reliability during its "normal life" period!

The lesson learnt should perhaps be the awareness that such unknowns might arise and, for a new platform, more unexpected issues and incidences could surface in the earlier stages of the aircraft induction into service. The A-4 Crisis showed that introducing a very established platform, with many years and thousands of hours flown by various air forces, including the USN, was not a panacea to preventing serious issues from arising. The SP, as a new aircraft, had perhaps more than its fair share of infant mortality problems. It was not, however, the last aircraft which the RSAF would be the lead operator of. Most importantly for any operator, especially a military one (because of the nature of military aircraft operations and the pressure to purchase the latest technologies to give it an operational edge), a strong and competent engineering organisation is necessary to ensure that it has the resilience to recover from problems faced in the course of operations.

Adding Night Capability to the Super Puma

In 1995, a programme was underway to equip the Super Puma with a FLIR system for its search-and-rescue mission. This is an electro-optical (EO) sensor housed in a steerable turret and provides high magnification viewing, via a cockpit-installed display, of imagery of interest in low-light, poor visibility or night environment. This would enable the Super Puma to operate in a day or night environment and in a wider range of weather conditions, enhancing its search-and-rescue capabilities and allow the air crew to see and identify objects that might otherwise be too indistinct.

A project team from DMO and ALD was formed to manage the project. ST Aerospace was to integrate the FLIR turret onto the platform. In evaluating the FLIR system, a number of key considerations emerged which were keenly deliberated by the engineers involved. The assessment included the available technologies then and the types of EO sensors to be employed, the technical maturity of the sensors and associated risks, the performance of the sensors in our operating environment, the experience and track record of the FLIR suppliers, and the risks of integrating the preferred FLIR system to the platform.

The EO sensor is the heart of the FLIR system. The project team evaluated the two prevailing types of EO sensors that were employed in FLIR systems. These were the smaller 8-12 μm (micrometre or micron) scanning detector array (commonly termed as the 8-12 micron EO sensor) that was a mature and widely used sensor at the time, and the new 3-5 μm staring matrix detector array (commonly termed as the 3-5 micron sensor) which was just emerging then. The latter sensor used technology that allowed longer dwell time on the object of interest, hence enabling more infra-red (or IR) energy from the object to be captured, thus providing better discerning of the object. In short, it was a question of selecting a mature, proven and widely used sensor technology versus an emerging technology with the promise of better detection performance but accompanying development risks.

Most of the established and reputable FLIR manufacturers in the western world had at the time invested heavily in the 8-12 μm technology in their FLIR systems and thus the push was strongly for this sensor solution in view of the experience of established users and their reputation as suppliers of similar systems to major air forces in the western world. These manufacturers had good track records as airborne FLIR system manufacturers.

In the evaluation of available systems in the market, the project engineers also considered the new 3-5 µm EO system manufactured by a non-traditional source. This manufacturer had experience in land and naval FLIR systems but not airborne FLIR, systems and was eager to work with a launch customer in order to enter the airborne FLIR market.

The project team carried out studies and conducted demonstrations of the two different types of EO sensors in our local environment and concluded that the 3-5 µm EO sensor gave superior performance. However the development of this sensor was still in its infancy stage then and there were risks in getting the sensor into production and, finally, into a working FLIR system. The choice facing the engineers was thus product maturity and proven track record of the older type of FLIR system versus newer technology, better performance, but higher project risks of the newer type of FLIR system.

In what could be termed as opportune timing, the Super Puma project was a potential launch platform for the 3-5 µm FLIR OEM. The project team was thus able to negotiate favourable but realistic contractual guarantees from the OEM on the installed and integrated FLIR operating performance in our local environment, not performance as tested in the laboratory or test bench in a controlled environment. Ultimately a favourable "launch customer" contract was secured.

The integration effort by ST Aerospace was not insignificant. ST Aerospace had to derive the necessary airframe data, in particular the vibration signature in the installation area, induced mainly by the main rotor blades' low frequency vibration. As the FLIR turret was to be mounted under the nose of the Super Puma airframe, the installation design included structural modifications to the lower nose airframe area to accommodate the turret. The ground clearance between the lower fuselage of the helicopter and the ground was insufficient, so the FLIR turret had to be installed as a retractable turret which could be lowered for use when the helicopter was airborne and retracted before landing. An electrical retracting and lowering mechanism was designed and manufactured. Redundancy had to be considered in the design in case the electrical retracting mechanism failed, as the helicopter could not land with the turret extended. ST Aerospace engineers designed a secondary manual retracting mechanism as a backup.

ST Aerospace also undertook significant work to accommodate the new EO display in the cockpit instrument panel. This involved the re-location of some existing instruments to create room for the display panel and modification of the instrument panel. Engineering effort included temperature survey, cooling analysis, new wiring and routing analysis, night lighting and night vision goggles compatibility, and ease of installation and removal of the system components from the maintenance point of view. Finally a foldable "arm" was installed on the right hand side of the co-pilot's seat to hold the FLIR turret control unit. This arm could be stowed out of the way when the FLIR system was not in use.

The EO manufacturer also faced some unique challenges while developing and packaging the system for the Super Puma. The turret had to be made as light as possible in order to have minimum effect on the forward shift of the CG of the helicopter.

Learning Value from FLIR Project

The SAF has unique terrain, weather and other operational requirements. At that time, the project team had accumulated some experience in studying our operating environment and the performance of various EO devices for land, naval and airborne applications. Operating an EO system in our local environments is quite different from doing the same in Europe, the US or Australia. In this instance, the established EO products in the market were found to be not suitable for the Singapore environment as the OEMs did not have the data or experience on the performance of their systems in Singapore's environment. The Super Puma EO system project strengthened the RSAF's and DMO's experience, knowledge and confidence in making independent decisions based on engineering tests and evaluation, and not just followed what others did as their operating environments might not be the same as ours.

Upgraded Super Puma with FLIR turret deployed

Since this was a developmental system, the project team had the valuable and rare opportunity to participate intimately in every stage of the FLIR system development; from specification definition, to system qualification, and aircraft integration. On turret design, our engineers learnt about the considerations to accommodate the helicopter operating environments and the packaging of the EO sensor and other mechanical and electronic components in the FLIR system. On platform integration, experience was gained about human factors engineering considerations to optimise the FLIR display, rearrange the cockpit instruments and FLIR control panel design, electrical and cooling analysis, structural and vibration analysis, aerodynamic impact of the installation, and weight and balance issues. The success of this project could be attributed to all the stakeholders and engineers who had a "can do" and "dare to do" attitude, and who were willing to take and mitigate the risks.

From Land to Sea

Another milestone for the engineers from DMO, the RSAF and DSO was the indigenous build-up of helicopter-ship qualification and testing capability. In the mid 1990s the SAF began developing its capability to operate helicopters off naval vessels operating in blue waters. There was a need to deploy the Super Puma on board the Navy's Landing Ships Tank (LSTs). This required deploying helicopter aircrew and maintenance crew on board the ship with all the associated aircraft spares, support equipment and other logistics support, and operating at sea for a sustained period.

The helicopter-ship dynamic interface is a difficult and hostile environment that presents many technical challenges before a helicopter type can be certified for take-off and landing on board a specific ship's deck. The landing and take-off of a helicopter over a moving ship's deck create a complex air flow situation due to the air wake from the ship's superstructure and flight deck, varying ambient wind speeds and turbulence levels, and the influence of downwash from the helicopter's main rotor blades. Modelling, prediction and analysis is therefore a complex task.

Laboratory simulations and analysis were conducted to determine the influence of the ship's environment over the helicopter's operational characteristics. This yielded a preliminary launch and recovery envelope. As part of the work, computational analysis was performed by DSO, followed by wind tunnel studies at a European facility.

Flight tests of the Super Puma on-board the Landing Ship Tank (LST) were later conducted to explore and validate the preliminary ship-helicopter operating envelope, with the tests finally leading to a certified helicopter-ship operational envelope for safe launch and recovery operations under defined weather and various sea-state conditions.

Besides "aero-certification", there is also the issue of "electro-magnetic compatibility" between helicopter and ship. A naval ship has many electro-magnetic transmitters and emitters and emissions from these might potentially cause undesirable effects and interference to an approaching helicopter's electronic systems such as its critical avionics and flight controls. The approach required careful and often lengthy analysis of every possible "source and victim" situation. In the worst case, if there is no work-around, the particular emitter may have to be turned off during helicopter landing and take-off.

The pioneer engineers who did this work had to build up the helicopter-ship certification capability largely on their own as this was then a completely new competency domain to the RSAF. Engineers from ALD's Aerodynamics Branch and DSO performed the majority of the certification work, with assistance from an experienced European test facility. In meeting the challenges, the project team was able to develop the safe operating envelope for the Super Pumas to operate from the LSTs, in conditions that are more severe than land operations.

The continued build-up of this competency enabled the RSAF to later certify the Chinooks and Seahawks on board the LSTs and frigates when these helicopters were acquired. This allowed the effective and safe deployment of the RSAF helicopters on board the Navy's ships in far-away places like the Gulf of Aden on anti-piracy operations, and in very intense operations off Meulaboh after the 2004 Indian Ocean Tsunami.

The probe held on by the securing device on the LST

To enable the Super Pumas to land on the deck of the LST, ST Aerospace integrated the Aircraft-Ship Integrated Secure and Traverse (ASIST) system to the underside of the helicopter. The system essentially consisted of a retractable probe that could be held to the deck of the LST when the helicopter touched down. During the helicopter's descent to the deck, a corresponding ASIST system on the LST would continuously track and monitor the exact position of the helicopter relative to the designated landing area and the information displayed to the pilot through visual landing cues. It was an aid to help the pilot in his approach and landing. Simultaneously, a "capture and securing" device on the deck of the LST would be guided automatically to maintain its position directly beneath the probe of the helicopter. Immediately upon touchdown, the device would securely hold the probe. The device and the helicopter would then be ready to be traversed along a track on the ship's deck into the hangar in the LST.

RSAF's A332 Super Puma taking off from the Navy's LST RSS Resolution, with the USS Russell on the horizon

The load on the probe from the heaving and rolling motion of the LST was significant. Without compromising the structural integrity of the helicopter, ST Aerospace's engineers designed a new structure to adequately and appropriately transfer the point loads of the probe, via new structural members, to the primary structures of the helicopter. The design of the probe structure within the constraints of an operational helicopter was not without challenges. A hard decision was made to remove the Number 6 fuel cell in the lower fuselage to create space for the probe load transfer structural members. The resultant penalty was a slight reduction in internal fuel carried. With known internal loads of the major airframe structure, the probe attachment structure was designed using finite element analysis.

To garner a high level of confidence of the probe's structural design, a tedious process of static load tests with an array of strain gauges appropriately mounted on the helicopter and probe structure was carried out to measure the actual strains experienced to thoroughly validate the finite element analysis model. The design team's effort was well rewarded with the successful helicopter-ship certification.

From Steam Cockpit to Glass Cockpit

The RSAF's Super Puma fleet was not homogenous, resulting in operating complexity for the aircrew and support difficulties for the engineers.

The helicopters were a mix of several configurations. They were bought in two batches at different time frames, which meant that there were inherent manufacturing differences. In addition, there was a search-and-rescue version as well as a general heli-lift version. The latter version was also divided into aircraft with and without weather radar and there were also two versions of the turbo-shaft engine. All these resulted in four different cockpit instrument panel layouts and designs. To make matters worse, the local modifications and upgrades added over the years created further cockpit sub-configurations because these upgrades were not required to be implemented fleet-wide. There was thus a strong impetus to re-design and standardise the layout as far as possible as part of the upgrading initiative.

The Super Puma came with an analogue cockpit, meaning that it had analogue instruments and gauges, with each gauge providing one specific reading or measurement. Each system in the aircraft also had its own cockpit control panel. For example, if there were three different radios installed in the helicopter, there would be three separate radio

Super Puma cockpit – before (left) and after

control panels in the cockpit. The cockpit was thus cluttered and space available for additional instruments or control panels was scarce. Military aircraft manufacturers had for a number of years then begun designing “glass” cockpits. These were aircraft cockpits that feature digital electronic displays (usually large LCD or LED displays) which were “multi-functional” and could be configured to separately display flight, navigation and route information, or engine parameters as selected by the pilot.

In addition, the digital display also took the place of physical control panels as the display could be touch sensitive or have “soft” keys around the display with each key programmed to control a desired function. Comparing new and old, the analogue cockpit was usually nicknamed in aviation circles as a “steam cockpit” and the analogue gauges aptly called “steam engine gauges”, a term derived from the old gauges in the driver’s compartment of a steam locomotive!

With experience gained from the F-5 combat avionics suite upgrade, which included designing a new glass cockpit for the fighter, a project team comprising engineers from DMO and the RSAF working with ST Aerospace was given the task to modernise the outdated avionics of the Super Puma.

The project team standardised the new glass cockpit into two configurations; one for search-and-rescue, and the other for the general heli-lift variant of the helicopter. This simplified the pilot workload and increased crew efficiency. A positive outcome of the glass cockpit modernisation was the inherently lighter weight of the displays and electronic boxes compared to the steam cockpit. This weight saving increased the capacity for additional equipment in future. Along with the upgrade came improved reliability of modern-day electronics.

While the DMO/RSAF team defined the technical and integration requirements, ST Aerospace was appointed the prime contractor and systems integrator for the project. This was a totally indigenous undertaking. ST Aerospace was to integrate various sub-systems from the legacy Super Puma cockpit, such as the electronic warfare (EW) display and control, digital moving map, GPS and flight information, and navigation and engine information of the legacy aircraft cockpit. Multi-function digital displays replaced the old steam gauges and control panels in the cockpit.

The project also incorporated an indigenously designed and manufactured mission computer, the heart of the avionics system. ST Aerospace had invested in a development programme of a high-end mission computer to overcome the uncertainties and time-loss issues with each avionics development programme. Details on this computer, derivatives of which are currently used in various RSAF's aircraft, are in Section 4.8.2 of this book.

The intended outcome was to have full control of the aircraft software, both the mission computer operating system and the aircraft avionics software, known in the industry as the OFP. This was important as it enabled the system to be configured in the most efficient and cost-effective manner. For efficacy of the avionics upgrade design, a variant of the ST Aerospace-designed mission computer was developed to serve the requirement.

Mission computer used in SP Avionics upgrade with top cover removed, showing shop replaceable units

The project also provided the opportunity for the ST Aerospace team of avionics hardware and software engineers to test their mettle and validate their experience, competency and overall capability in avionics upgrade of a complex helicopter platform with multiple roles and configurations.

Section 3.4.3
Developing the Light Observation Helicopter and Light Attack Helicopter

The Eurocopter AS 550 Fennec helicopters were acquired by the RSAF in 1991. Besides fulfilling their role as basic helicopter trainers, some of the helicopters were customised to the Light Observation Helicopter (LOH) role to support battlefield scout and reconnaissance missions while the remainder were configured in the Light Attack Helicopter (LAH, a term coined by the RSAF) role, to allow the RSAF to explore, understand and develop operational doctrines in the battlefield attack role. The LOH and LAH represented a further development of the Fennec by the manufacturer. The following discussion highlights some of the value-added work of the engineers from DMO and ALD. The project team worked together with the RSAF pilots and the helicopter manufacturer to define these unique configurations and see through their implementation.

Much more work went into the development of the Fennec helicopter configured for the LAH role. The requirement for arming the helicopter for its intended role was ambitious. The US-made TOW-2 anti-tank wire-guided missile was selected to provide the anti-tank missile capability. As the missile and helicopter manufacturers were from different countries, special effort had to be expended to facilitate the interface data exchange between the OEMs to ensure compatibility and correct functioning between aircraft systems and missile which was crucial to the successful integration. This is another illustration of the approach which Singapore adopts: to select each equipment it deems the best available for its needs and be able to integrate them into one high performing system. Getting the best value from its acquisitions and upgrades has always been an important objective of Singapore's military programmes.

There was also an RSAF requirement for the LAH to be quickly reconfigurable to carry a gun. The initial design proposed by Eurocopter engineers was termed as a “floor-mounted gun”. In this design, the aircraft manufacturer proposed a structural beam to be mounted laterally across the cabin floor, extending out of the starboard side of the fuselage, with the fuselage door removed. A 20mm cannon (from the French manufacturer Giat) was to be mounted at the starboard end of the beam. This design was adopted from a similar design in the French Army’s Gazelle helicopter programme. During a design

Fennec light attack helicopter with gun pod and munitions laid out

review mid-way through the programme, it became apparent to our engineers that there could potentially be a CG limit issue with the helicopter.

The CG of the helicopter could exceed the design and authorised forward limit in the specific configuration when the helicopter was configured for the "gunnery" role, loaded with ammunition, full fuel and with the TOW-2 roof-mounted sighting system (Helitow sight) and missile fire control system installed at the same time. To solve the CG issue, the manufacturer proposed to impose a limitation, to either prohibit the installation of the Helitow sight or to limit the helicopter's fuel load with a corresponding reduction in operating range when the helicopter was configured for the gunnery role.

As the Helitow sight was not used in conjunction with the cannon, the recommendation of the OEM was one possible approach but it would limit the quick role-change capability and constrained flexibility in helicopter employment, an important option in the battlefield. The Helitow sight also doubled up as a very useful general observation sight when the helicopter was configured for the gunnery and rocket roles.

The engineers from the OEM and the Singapore team finally arrived at a solution using a 20mm gun pod mounted to a newly-designed external stub wing on the starboard side of the fuselage. On the port side, a similar stub wing carried a rocket pod, firing CRV-7 rockets. These external stub wings were moved further aft, thus resolving the forward CG limit problem. The new stub wing was also designed to include pilot-trim-adjustable feature for the gun pod, thus allowing the pilot to point the cannon at the target while in hover. However the single 20mm gun pod mounted on one side of the helicopter fuselage and further away from the fuselage centre-line could potentially introduce an undesirable side effect by inducing a yaw (turning motion) to the helicopter during gun firing because of the recoil from the gun. DMO and the RSAF engineers then worked closely with the aircraft manufacturer during the development programme to define a set of ground and flight tests for the installed gun pod. The yaw of the helicopter due to the torque generated from the gun's recoil forces was also investigated to ensure that there was no adverse impact on helicopter yaw control.

Fennec fitted with TOW missile and gun pod

While a TOW-2 equipped variant of the Fennec was introduced earlier to the Danish Defence as a dedicated anti-tank missile helicopter, the RSAF, together with the OEM, further developed the Fennec into its reconfigurable missile, and gun or rocket roles. Through this programme, engineers from the RSAF and DMO worked closely with the helicopter OEM to identify problems while meeting the operational requirements of the RSAF and finding solutions that enabled the requirements to be achieved through good engineering solutions which did not compromise the performance of the helicopter. A good validation of the positive outcome is that the TOW-2 missile and 20mm gun pod is still among the armament options offered by Airbus Helicopters (the new name of Eurocopter) today to worldwide customers of the Fennec helicopter.

Section 3.4.4
Heavy-Lift Helicopter Evaluation – The Russian Experience

Two candidates were evaluated for the RSAF's heavy-lift requirements in 1993. These were the Boeing CH-47D Chinook and the Russian Mil Mi-26T heavy-lift helicopters. The Chinook was eventually selected based on the outcome of a detailed evaluation and assessment of the two helicopters. The following is a reflection of the unique experience during the evaluation of the Russian helicopter.

In 1993, a large team of engineers and pilots from DMO, the RSAF and ST Aerospace spent three weeks in Russia to conduct an in-depth technical and flight evaluation of the Russian designed and built Mi-26T heavy-lift helicopter. The Mi-26T is a huge helicopter, with an empty weight of 28 tonnes and a maximum take-off weight of 56 tonnes. It has a 20-tonne maximum lift capability. One notable feat of this helicopter is that in 2002 it undertook the under-slung lift and recovery of a damaged US Army Special Forces MH-47E Chinook helicopter in Afghanistan. The lift was performed at an altitude of 8,500 feet.

The Singapore evaluation team spent a significant amount of time at the then Mil Design Bureau in Moscow. This was one of the two centres of excellence for helicopter design in Russia, the other being the Kamov Design Bureau. It was obvious that the helicopter was not designed in accordance with western aeronautical standards. Thus a large part of the evaluation was spent understanding the Russian aeronautical design and certification standards, the level of compliance of the Mi-26T to these Russian standards, and the similarities and differences between Russian and Western aeronautical design standards for helicopters.

The RSAF's and DMO's engineers interacted extensively with the Mi-26T design team (including working into weekends) to establish and understand the helicopter's detailed design standards and certification requirements. The assumption of the evaluation team had been that, while the aircraft's design criteria were different, it should not be a basis for rejection of the helicopter as it might not be necessarily inferior to western standards.

Unlike the experience with western aircraft manufacturers, design and engineering data were not readily retrievable or perhaps they might not have been documented with a view for commercial sales. The information was also in Russian. Thus it was a painstaking process of working with Russian designers and engineers through translators, to go through the manuscript design data, and to understand the key design aspects of the helicopter. The Singaporean team was impressed by the calibre of their Russian counterparts and established that their design standards and certification requirements were no less stringent than western ones. Where possible, there was deliberate effort by the designers to ensure that their design met the US Federal Aviation Regulations (FAR-29) for airworthiness standards of rotorcraft (helicopter).

As part of the next phase of the evaluation, the team divided itself into smaller groups to spend time at the various plants that manufactured the major components of this helicopter. These plants were spread out throughout Russia and states of the former Soviet Union, including Rostov-on-Don (where Rosvertol, the airframe manufacturing and final assembly line was located), Zaporozhye, Ukraine (where Motor Sich, the turboshaft engine manufacturer was located}, the industrial town of Perm near the Ural Mountains (where main gear box was manufactured), Omsk (fuel control unit), Saint Petersburg (intermediate and tail gearboxes), Ufa (auxiliary power unit and swashplate), Stupino (main and tail rotor hubs), Saratov (automatic flight control system) and Pavlovo-On-Oka (hydraulics).

The Rosvertol airframe assembly plant was a large facility where other aircraft types were manufactured besides the Mi-26T. The Mi-26T line was a low-rate production one at the time of the visit, presumably because of limited order book. Most notable was the fact that the aircraft was entirely "hand-built". There was the usual use of production jigs and tooling to aid the assembly process, but there was none of the robotic tools used in high-rate production lines of western manufacturers. Each individual rivet hole, for example, was hand-drilled and then hand-riveted.

In terms of structural design, the Singapore evaluation team established that the Mi-26T was optimised to a different standard compared to western helicopters. There was greater latitude in the helicopter's structural safety margins unlike western designs with tighter safety margins.

The concept of on board systems mechanisation in the Mi-26T was also different from western helicopter design, as manifested by the four-crew cockpit of the Mi-26T comprising two pilots, a navigator and a flight engineer, versus a two-crew cockpit that was typical of western designed helicopters.

One key area that the evaluation team established was that the avionics of the Mi-26 was less suitable for the RSAF's operations. The baseline avionics was assessed to be mostly outdated and the feasibility of upgrading the legacy avionics systems to equivalent western avionics was further examined. Except for the power generation system, engine instrumentation sensors and transducers, and automatic flight control system, most of the aircraft's existing avionics systems were assessed to require replacement with western ones if the Mi-26T were to be operated and supported over the long-term.

This would also give some degree of commonality with existing western avionics systems already operated by the RSAF, thus simplifying and easing the logistics and technical support.

Although the evaluation for the heavy-lift requirement ended with the Chinook being selected, the evaluation of the potential "non-traditional" source option had provided an interesting and eye-opening insight for the team.

A chartered civilian MI-26 lifting a damaged MH-47E Chinook at an altitude of 2600m in the mountains near Sirkhankel, Afghanistan

Section 3.5
Commercial Aviation

Section 3.5.1
Endeavours into Commercial Aircraft MRO

Over the years starting with SAI, later renamed ST Aerospace had developed strong capabilities in MRO of military aircraft, engines and components. Its starting focus was to serve the MRO needs of the RSAF which it did. In the mid 1980s it started on its journey into the major military aircraft engineering development and aircraft upgrading business, starting with the A-4SU in addition to its MRO activities. As the RSAF's fleet grew and transitioned to new aircraft types, ST Aerospace, as the RSAF's strategic partner in defence, continued to extend into new capabilities to enable it to support the RSAF effectively. In the early 1980s, it also endeavoured to support the needs of other air forces from within ASEAN, the Middle East and beyond.

In the late 1980s a decision was taken to venture beyond military aviation business as the opportunities in the external military aviation market were not significant. It started with commercial aircraft MRO and modifications, something it had experience on, albeit for military aircraft. Subsequently it extended its reach beyond airframe work into commercial engine and component MRO and modifications. These were ST Aerospace efforts to diversify its portfolio into related commercial aviation businesses. This and the following sections of the book will share on some aspects of ST Aerospace's journey into commercial aviation MRO; aircraft, engines and components. Commercial aviation engineering would be covered in Section 3.6.

Points of Entry into Commercial Aircraft MRO

ST Aerospace is known as the largest commercial aircraft MRO in the world for more than a decade by now. Prior to its entry into the commercial aviation MRO market, the company was largely a military aviation MRO and engineering company. Two significant global events contributed to its decision to go into commercial aircraft MRO.

The first event was the emergence of fatigue cracks on "Section 41" of the B747-200, -300 aircraft up to line number 685. As Boeing's resources were fully committed to the development and production of new airplanes, it did not have the engineering manpower to perform the structure replacement work to "terminate" the Advisory Directive (AD) on the affected aircraft. The projection of the potential market for Section 41 replacement was substantial.

The second event was the impending handover of Hong Kong from Britain to China in 1997. In view of this, there were a number of experienced commercial aviation people looking for opportunities elsewhere because of the uncertainties in Hong Kong then.

As its first undertaking in commercial aviation work, ST Aerospace started with aircraft modification type of work in view of the Section 41 market opportunity which presented itself, and as most of the commercial aviation maintenance companies in the market did not have the engineering modification experience that it had. ST Aerospace's competitive advantage was its aircraft engineering development and modification experience from its military aircraft works. However, it did not have the commercial aircraft types MRO experience of the established MROs in the market which were largely airline-owned and to try to start with pure MRO as its initial focus might be difficult.

The extension from heavy modification work into commercial aircraft MRO work later was fortunately natural, as along with the engineering modification work there was naturally lots of MRO work to be done concurrently.

Besides the experience built up through its work on Section 41 and the MRO work that it won from the market, ST Aerospace's initiation into commercial aircraft MRO also benefitted from the support of its customers, and later the aviation OEMs. Amongst the customers who extended their support were airlines like All Nippon Airlines (ANA) and Japan Airlines (JAL) which took the relationship beyond that of customer and supplier, and were willing to train ST Aerospace so it could do their outsourced work well. So were other customers and even the OEMs who came to recognise the performance of ST Aerospace and saw it as a competitive advantage for their businesses. Today, ST Aerospace is recognised by many passenger and freight airlines as a preferred centre of excellence for both aircraft MRO and modification (including PTF) works. Its achievements were made possible by its strong global customer base who trusted its brand name and proven track record.

Starting with SASCO in Singapore and MAE in the U.S., ST Aerospace continued to extend its reach globally. It set up new MROs, increased the capacity (new hangars and facilities), and extended its aircraft capabilities to include the entire range of McDonnell Douglas DC-8, DC-9, DC-10, MD-10, MD-11, MD-80 and MD-90; Boeing B727, B737, B747, B757, B767, B777 and B787 (developing); and Airbus A300, A310, A320, A-330, A340 and A380 aircraft. Today, ST Aerospace has, over the last two decades, redelivered more than 10,000 commercial aircraft after major maintenance, modification and conversion to freighter work.

Setting Up of First (Wholly) Commercial Aircraft MRO

At the beginning, with no experience in commercial aircraft MRO, ST Aerospace started by exploring various collaboration and joint venture options with potential airlines and engineering and maintenance companies locally and overseas to try to jumpstart its commercial aircraft MRO business.

With the support of the Economic Development Board (EDB) of Singapore, SASCO was set up with SIA and JAL, each taking a strategic stake of 10 percent shareholding. ST Aerospace held the remaining 80 percent. SIA and JAL were invited as partners with the hope of securing their support through initial workload to establish the needed track record and experience for the new company. Both were highly reputable airlines in Asia even then.


SIA and JAL aircraft at SASCO hangar

SASCO's envisaged primary role was to undertake Section 41 replacement on the B747. MRO was deemed necessary but was secondary then, as it was an uphill task securing MRO work from the airlines on an ad hoc basis.

Whilst the senior management of SASCO was largely from SA, most of the professional staff were recruited from the commercial aviation market. Commercial aircraft MRO required managers with understanding of civil aviation requirements and LAEs to undertake the work. They were recruited from Singapore and overseas. Naturally a significant group of its people came from Hong Kong and other Asian countries like Taiwan. As mentioned, in the early 1990s, many Hong Kong residents were looking for opportunities to migrate and settle elsewhere. About 100 commercial aviation specialists who were attracted to the job opportunities in Singapore chose to migrate to Singapore with their families to work in SASCO. Many of these became citizens of Singapore and are still working in SASCO and other parts of ST Aerospace today, some contributing as senior technical specialists while others have risen to senior management appointments.

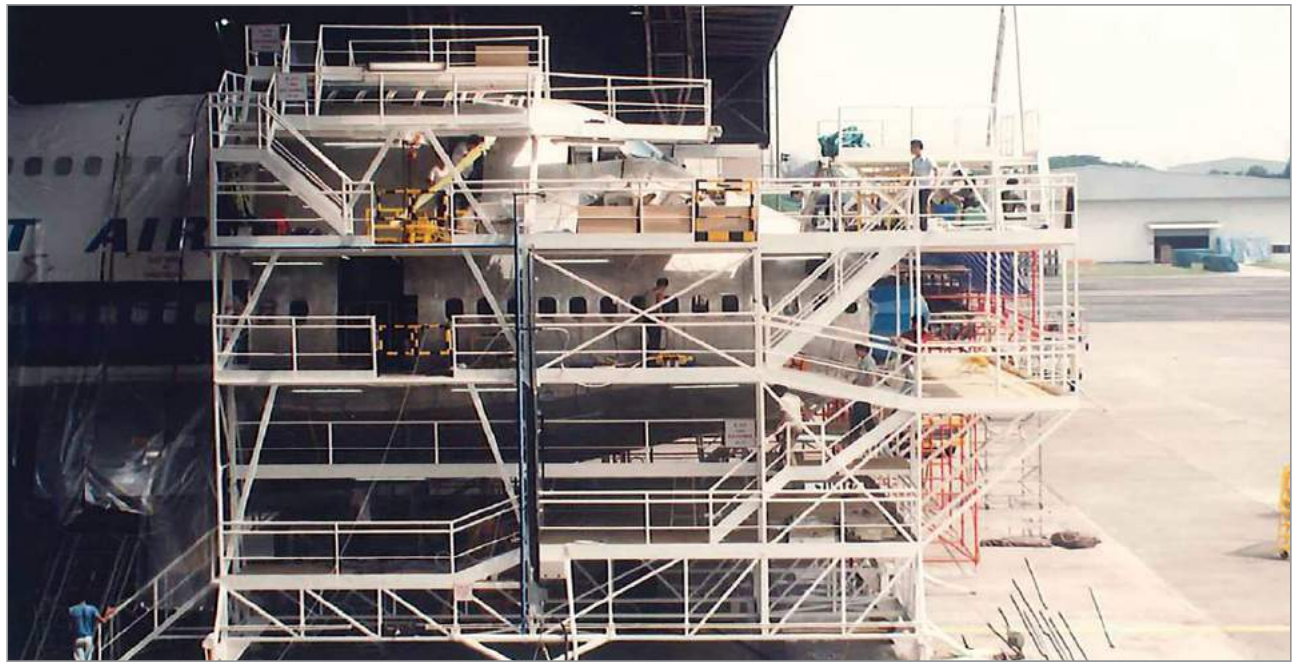
SASCO's initial success would not have been possible without the capabilities of these pioneers and other skilled foreign talents who joined later. It continued to become very successful. One of the reasons was its ability to integrate this initial core group of specialists with its other employees that it subsequently recruited from Singapore and elsewhere.

With its success on Section 41 termination, SASCO became the market leader with 66 aircraft modified, more than any other facilities in the world when the available Section 41 work ended. Section 41 termination work usually came with heavy maintenance and a good mix of other repairs and modification work as the Section 41 work grounded. The aircraft for a long time (in commercial aviation parlance) and thus presented the client with the opportunity to clear MRO work, which might otherwise end up grounding the aircraft later just to do the scheduled MRO work. Section 41 on the Boeing B747 not only launched ST Aerospace into commercial aviation work but helped SASCO to establish a solid reputation for doing it well. "Section 41 in 42 days" was SASCO's advertisement.

Over the years, SASCO also became a leading PTF conversion centre for Boeing, starting with the conversion of two DC-10s followed by the MD-11s. Because of its performance, SASCO became the preferred MD-11 PTF conversion centre globally and did most of the MD-11 PTF conversions. In later years, it was also selected for PTF conversion of the B767-300 for ANA.

HMVs later became another SASCO's forte and it won many long-term contracts for HMVs with leading global airlines. HMV has become one of the pinions of ST Aerospace's core business over the years.

In HMV, the first hurdle was to acquire capabilities for the work, the certifications and, most importantly, the first aircraft. This



B747 Section 41 modification

was SASCO's disadvantage in the early days as it was a third-party start-up MRO. However, as recounted, it had very good customers who were confident that it could be their long-term supplier and partner. Without the help of these customer-partners, it might not have achieved the progress it did.

SASCO has continued to do well in many other areas in HMVs and PTF conversions since.

What is Section 41 Modification?

The Boeing B747 Section 41 Modification was a mandatory structural modification on the earlier models of the B747. Section 41 is the forward section of the fuselage stretching from the aircraft nose section up to the first passenger door, including the flight deck and upper deck areas. In 1986 cracks were found in the fuselage structural frames in this area. In the original design, Boeing had used 7075-T6 aluminium alloy for the structural frames because of its high strength and lower weight for equivalent sections, but the material has poor fatigue-life property. The aircraft underwent constant compression and decompression in service over time, resulting in serious cracking problems. All B747 aircraft built up to line number 685 were affected by AD 86-23-06 (later superseded by AD 86- 03-51) which required regular structural inspections of the area.

Inspections would be required, starting at a total accumulated time of 8,000 flight cycles (FC) and would continue until 19,000 FC. After 19,000 FC, the inspections must be performed more frequently. To be able to operate the aircraft efficiently would require the replacement of the affected structures, to terminate the AD.

Section 41 of a B747 was where all of the controls, navigation and other controlling functions of the aircraft were located. The instrument panels in the cockpit with all the instruments, equipment, wirings and cables would have to be removed for access to perform any structural inspections behind those panels. This made it very time consuming and expensive to perform periodic inspections on these areas. Section 41 was divided into nine zones so that an operator had the option to terminate certain zones and keep on inspecting others.

The extensive downtime involved in performing these inspections, and the cost of man-hours, meant that most operators would seek to terminate the AD and associated inspections by carrying out the necessary structural modifications. Terminating the inspection meant the replacement of the nose section frames and structures with new 2024-T42 frames which had better structural fatigue property. SB 53-2272 covered this termination action. Boeing would provide the kits free-of-charge, but all other costs would have to be borne by the operator. About 32,000 man-hours were required to terminate all nine zones of Section 41. The total cost could easily amount to US$2 million. Because of the extensive work involved in the Section 41 termination, most operators would chose to undertake the modification during the aircraft D-check (heaviest scheduled maintenance check).

SASCO managed to secure its first contract for 4 B747 Section 41 modifications from Kuwait Airways in 1990. The aircraft were inducted on 15th July 1990. Kuwait was soon invaded by Iraq thereafter during the Iraq-Kuwait War which began on 2nd August 1990. The modifications were successfully completed while Kuwait was still under the occupation of Iraq and the aircraft were operated outside of its home base until the war was over and the aircraft were successfully returned to their owners on 20th September 1990.

Following the success on the Kuwait Airways' aircraft, SASCO continued to secure more Section 41 modifications and other maintenance work from various airlines including JAL, South African Airways, Northwest Airlines, FedEx Express, South Africa Airways, Middle East Airlines, Air Hong Kong, Air China, Alitalia, ANA, Atlas Air, Evergreen International Airlines, KLM, Pakistan International Airlines, Saudi Arabian Airlines, SIA, Tower Air and Virgin Atlantic Airways in its early years.

Kuwait Airways' B747's Section 41 termination

The B747 also had also a design problem with its pylons requiring the mandatory modifications of the pylons. This could be performed concurrently with the Section 41 modifications. Over time, with more experience and continuous improvements, SASCO was able to perform the Section 41 modification with the Pylon Modification and heavy check in 42 days (most other MROs were taking 55-65 days or more). It became the preferred centre to do the modification. SASCO eventually contracted and completed a total of 70 Section 41 modifications, making it one of the highest number of aircraft to be accomplished by a third party MRO.

The recovery-work on the B747 Section 41 and Pylon Modification was very important to SASCO in its initial years. It was meaningful work in terms of the magnitude of the job and it gave SASCO access to many major airlines as the Boeing B747 was the wide-body aircraft of choice for many international airlines. SASCO also built up a good reputation from doing it well.

In the subsequent years, SASCO continued to extend its capabilities beyond the B747 to perform maintenance on other Boeing and Airbus wide-body aircraft types and established itself as a preferred MRO supplier for many of the major legacy airlines and operators like JAL, ANA, FedEx Express, Northwest Airlines, Qantas Airways, KLM, Lufthansa, and others. It also set up capabilities for PTF conversion (see below on how PTF started in ST Aerospace) and became an established centre of excellence for wide-body PTF conversions. Besides FedEx and United Parcel Service (UPS), some of the other freighter conversion customers included Lufthansa Cargo, Aeroflot, China Eastern Airlines (CEA), EVA and Finnair.

Narrow-body Commercial Aircraft MRO Work

ST Aerospace Engineering (formerly SAMCO) was the first company of ST Aerospace. It was the aircraft MRO of the RSAF and was also the focus for smaller commercial aircraft, up to narrow-body aircraft like the A320 and B737, in Singapore. Following the success of SASCO in commercial aircraft MRO and modification work in late 1990, it was decided that ST Aerospace Engineering should take on commercial narrow-body aircraft MRO as part of its portfolio.

SASCO's hangars were sized for wide-body aircraft and to use them for narrow-body aircraft would be sub-optimal. Narrow-body aircraft customers were then also not SASCO's primary customer base and to ensure such customers' needs would be well taken care of, it would be better to have them served by another of ST Aerospace's MRO company.

ST Aerospace Engineering had, on the other hand, hangars to handle aircraft like C-130s and Fokker 50s. In its repertoire of capabilities, it had handled the B727s and customers with B727s could easily migrate to operate B737s and A320s over time as the B727s retired from service. At that period, the airframe workload for military aircraft was also reducing and ST Aerospace Engineering had to have more airframe work to maintain the desired size of its skilled workforce.

ST Aerospace Engineering became the specialist company in Singapore for narrow-body aircraft such as the B737 and A320, initially from regional airlines. The scope was later expanded to cover LCCs as they became the vogue in Asia. In later years, in order to meet the requirement of FedEx to have a faster build-up of its B757 freighter conversions, it started B757 PTF conversion.

This same logic would not hold in the US as the predominant aircraft (in numbers) in its aviation market was the narrow-body aircraft. So, MAE and San Antonio Aerospace (SAA) serve a mix of narrow-body and wide-body aircraft simultaneously. As the US is a country with a number of large airlines operating at different hubs and they require MRO providers for their outsourced work within reasonable proximity, this supported the build-up of maintenance companies in different parts of the country. Transporting aircraft to MRO and back is something which all airlines would like to minimise, as the efficiency of an airline's operations is very important in the very competitive market there.

First Overseas Operations Company

The US was, and still is, the largest commercial aviation market in the world. At about the same time that SASCO was being built up in Singapore, SA incorporated MAE in Mobile, Alabama, US, in April 1989. MAE was a greenfield operation and got its approval in January 1991 when it started with a single-bay hangar to try to access work in the US aviation market. The old hangar facility which it occupied was built in the 1950s as the Mobile Brookley Aeroplex, an ex-USAF base, to house the USAF B-52 strategic bombers. The large hangar facility built for B-52 was renovated and refurbished. MAE started by leasing one wide-body bay of the huge complex. Over time, as MAE grew, it occupied the whole facility and built additional new hangars to meet the US Airline's demand for good MROs within the US.

MAE was started in collaboration with WorldCorp, Inc., a US company that had two subsidiary airlines (World Airways and Key Airlines) providing chartered passenger and cargo air transportation. WorldCorp was looking for a facility to support its fleet of DC-10 and B727 aircraft. As part of the collaboration, WorldCorp seconded a few of its technical management staff to work with the small team of Singapore managers who were sent to set up MAE and its operations. The main production and technical staff were recruited from the US market or trained in the US by MAE under the Alabama State's local airframe and powerplant (A&P) school. The first customer aircraft was a Key Airlines' B727, which was inducted for maintenance when MAE started operations.

Mobile Aerospace Engineering, Inc. is one of the ST Aerospace's airframe maintenance facilities set up in the US in the 1980s

1991 was the start of the first Gulf War. From July 1990 to March 1991 the US economy went into recession and the aviation industry was badly affected. Even with WorldCorp's support, there was insufficient workload to sustain the start-up operations at MAE. MAE struggled during its initial years and it appeared that the new venture might prove to be not viable. A new management team was sent to take over the operations and renew the efforts.

At that time, FedEx was not happy with its conversions being done at its then supplier and tendered out the work for "one firm order and 12 options". As FedEx wanted to ascertain which of the parties contending for its PTF conversion programme could really deliver before it committed on its programme, it signed a contract for one firm aircraft conversion plus 12 aircraft options with several contractors. The contractor which could "deliver" on this commitment would be selected as its supplier.

The first conversion by MAE was successfully completed and redelivered in 75 days, 15 days earlier than the contractual 90 days. FedEx exercised the 12 options and eventually, MAE converted a total of 23 B727 aircraft for FedEx.

First converted B727 freighter carried out by MAE

The success of MAE on the B727 PTF conversion programme affirmed its capability and FedEx began to contract MAE for its maintenance and modification work for its fleet. Initially MAE started with small drop-in, ad hoc and small modification work. Its performance led to it eventually being contracted for multiple lines of nose-to-tail HMV work. This was the beginning of a long and mutually successful relationship between FedEx and ST Aerospace.

In view of the confidence and trust built up between FedEx and ST Aerospace, FedEx sent MRO work to SASCO and other ST Aerospace facilities, including engines and some components. Ever since 1998, SASCO has been performing all the C-checks for the entire FedEx fleet of MD-11 (about 60 aircraft). FedEx became the largest commercial aviation customer for ST Aerospace.

MAE continued to expand its capacity, capabilities and customer base to include many of the major US airlines, and became a major player in the US MRO market. With close to 1,000 employees at its peak, it became one of the biggest employers in Mobile City.

Passenger-to-Freighter Conversions, Part and Parcel of Commercial MRO

The FedEx B727 PTF programme was a key milestone for ST Aerospace as it was its first PTF conversion. Although the programme started with only a contract from FedEx to provide the touch labour to perform the conversion work according to the engineering drawings and instructions as per the STC developed by FedEx, it was the launch pad from which ST Aerospace established itself as a credible PTF conversion company.

From that, ST Aerospace progressed to win more PTF conversion programmes for other wide-body aircraft like the DC-10, MD-10, MD-11 and B767-300 from Boeing.

While the above PTF conversions were about carrying out modifications per FedEx or Boeing's designs, besides the skilled technical workforce and LAEs (in the case of Singapore), the development engineers of ST Aerospace also helped to contribute to the positive outcome. They assisted with the resolution of the engineering problems that arose during the conversion, as well as liaised with the customers' engineering staff back in their home base (or on-site) and the owner of the PTF design. Needless to say, each aircraft for conversion usually had its own history of repairs and users' modifications, some of which would affect the PTF work and work-around had to be developed. Having qualified and competent engineers on the ground was very helpful.

ST Aerospace Spreads its Wings

The initial successes in both Singapore and the US gave ST Aerospace the confidence to expand and grow its operations both locally and globally. In Singapore, it continued to invest in new hangar facilities and capabilities in its Changi, Paya Lebar and Seletar operations. It also expanded its global footprints through acquisitions of various facilities, greenfield start-ups and joint ventures, to gain access to overseas markets to serve its customers better.

Following MAE, ST Aerospace acquired Dalfort in Dallas, Fort Worth but as this was found to be sub-scale and its hangars were also only sized to take in narrow-body aircraft, ST Aerospace finally decided to close the facility. In 2002, ST Aerospace acquired a much larger facility in San Antonio, the "ex-Dee Howard" facility.

San Antonio Aerospace (SAA, later renamed as VT SAA) was a greenfield start-up with its management team and technical specialists seconded from MAE and Singapore. UPS was the first anchor customer and continues to this day to be its largest customer. SAA's primary customers are UPS, Southwest Airlines and Delta Airlines.

In 2004, ST Aerospace formed a joint venture with CEA to start up Shanghai Technologies Aerospace Company (STARCO) in Shanghai, China. The company started with the CEA's hangar facilities at Hong Qiao Airport, the transfer of management and systems from ST Aerospace, and selected technical and maintenance staff from CEA Technic.

A new two-bay wide-body hangar facility was constructed at Shanghai Pudong Airport and completed in 2010. ST Aerospace's main objective besides serving CEA was to provide its services to foreign airlines operating into China. At the same time, it would enable it to support other Chinese airlines requiring aircraft maintenance within China. As its commitment to STARCO, ST Aerospace brought in its global customers like ANA, JAL and Delta Airlines to STARCO.

ST Aerospace's airframe maintenance and modification companies in the world

In 2012, ST Aerospace signed a second joint venture in China, this time with the Guangdong Airport Management Corp to start ST Aerospace (Guangzhou) Aviation Services Company Ltd (STAG) to provide aircraft MRO services through a greenfield start-up. The first phase hangar complex was completed in early 2014.

STAG commenced operations in mid-2014 with work secured from a Chinese airline and Delta Airlines. STAG is located next to FedEx Express Hub in Guangzhou, Baiyun International Airport and hopes to support the FedEx fleet operating in and out of Guangzhou. Planning and construction of the second-phase hangars will commence in 2015/16.

In 2010, ST Aerospace was identified by Elbe Flugzeugwerke GmbH (EFW), the freighter conversion subsidiary of EADS (later renamed the Airbus Group) based in Dresden, Germany as a potential developer of its A330 P2F programme. Airbus' engineering resources were unavailable due to the introduction issues with the new A380 and the development of the new A350 programme. As part of the collaboration, ST Aerospace took a minority share in EFW, and EFW became part of ST Aerospace's global MRO network covering the European region. EFW is responsible for the A330 P2F prototype aircraft conversion and the programme industrialisation, and is the centre of excellence for Airbus aircraft PTF conversions.

People behind ST Aerospace's Growth

One of the key reasons behind ST Aerospace's ability to grow globally is its people. It has more than 8,000 employees of different origins around the world. ST Aerospace started with its local pool of technical and experienced personnel from its military aviation business and integrated them with a good mix of skilled and experienced aircraft specialists and MRO management, initially from Hong Kong and other parts of Asia. As it extended its business to different parts of the world, it continued to successfully induct and integrate new employees from wherever it operated.

In the US, MAE was able to bring in and retain experienced A&P mechanics and management from the open market, airlines and other MROs. In China, it started with specially selected experienced Chinese aircraft engineers and technicians from its joint venture partner, CEA. For all its overseas facilities, only a small team of Singapore managers were seconded to each new facility to facilitate the start-up and integrate it with the rest of the Group. They integrated well with the local managers and over time the new team proved its mettles in its work for ST Aerospace's global customer base.

To ensure a sustainable supply of skilled and quality workforce, ST Aerospace invested heavily in training for its freshly recruited staff and in developing its people, both locally and across the group. For example, about 150 Chinese engineers and technicians were recruited from China for STAG and placed in ST Aerospace’s facilities in Singapore for about two years' of training, including on-the-job training before they were transferred back to Guangzhou when STAG started operations. As part of staff development, selected management staff were rotated amongst its global facilities to work and to gain experience working in different cultural settings.

Aircraft apprentices working on
an aircraft as part of the training

Emphasis on Quality

The emphasis on quality, quality systems and work, which started in the early days of the company as the military's MRO provider continued to be behind the quality systems that evolved with cross-learning between military and commercial aviation's best practices.

ST Aerospace developed from all its best practices and continuous improvement initiatives, robust operating procedures/processes and quality management system that comply with CAAs’ and customers’ requirements. These were implemented across all its subsidiary facilities so that the customers were able to experience similar practices and processes, and a consistently high level of service across its network. For new start-ups, the transfer of these procedures, processes and quality systems from the parent company allowed them to start up quickly and also obtain their MRO Repair Station Approval from the necessary aviation authorities in a shorter time.

And, Most Importantly, Customers

Commercial MRO customers are always on the constant search for reliable MRO providers with good quality work and services, short and reliable turnaround time (TAT) and competitive pricing. As a third-party independent MRO, ST Aerospace worked hard on establishing a growing global customer base ranging from major legacy international and domestic passenger and freight airlines, LCCs, leasing companies and OEMs.

Its strong customer focus initiatives and responsive services had created strong interdependence between ST Aerospace and its customers, and this resulted in good retention of customers. As a result, most of its original customers have remained as customers today even as new ones are added.

Many customers, especially those who have global operations, have their aircraft maintenance outsourced to more than one of ST Aerospace's global facilities.

World map of ST Aerospace’s commercial aviation customer base

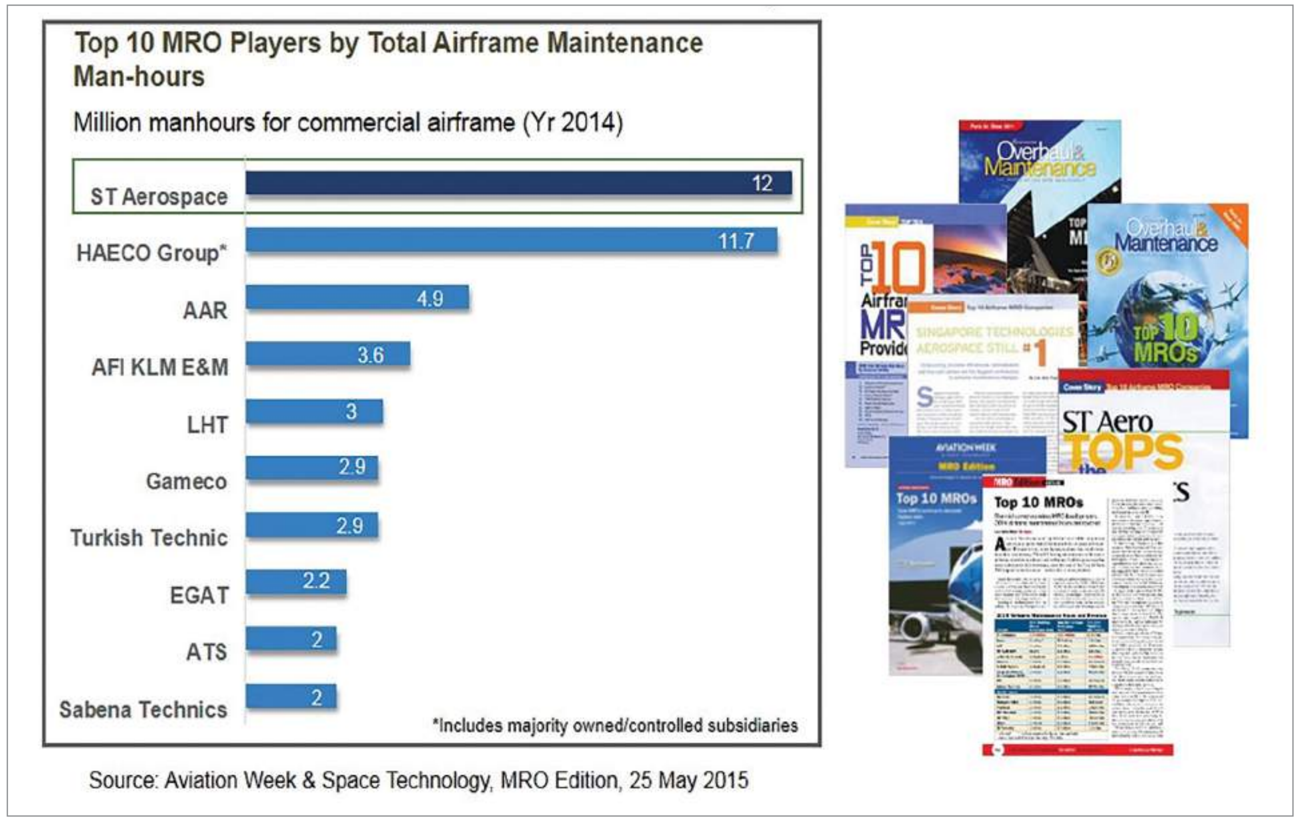
The venture and journey into commercial aviation MRO had not been easy for ST Aerospace. Over the years, the aviation industry had gone through many critical events like the aftermath of September 11 attacks, the Iraq War, SARS outbreak, airlines Chapter 11s and bankruptcies, and financial crises. Each of these had caused significant dips in demand that negatively impacted many aviation companies, airlines and MROs alike.

Bolstered by strong fundamentals and agility, ST Aerospace had managed to maintain a steady course of growth over the long term despite the downturns in the industry. A major factor why it had managed to do so was the strength of its customer base.

World’s Largest Independent Third-Party Airframe MRO

Within a span of just over 12 years, ST Aerospace had established itself as a major global player in commercial aviation engineering development, MRO and PTF conversions. It distinguished itself in the highly competitive aviation industry with its strong customer service, a growing network of facilities globally, and technological and operational excellence. High quality, fast turnaround and value-added services have become the trademarks that its customers, large and small, have come to expect over the years. Many of its customers with global operations would look upon ST Aerospace’s global network for support across the Asia Pacific, the US and Europe. The ability to serve customers in multiple locations is a significant benefit as the customers receive a consistent and familiar level of service wherever they fly and operate around the world.

In 2002, ST Aerospace’s industry leadership was recognised by Aviation Week Group’s Overhaul & Maintenance magazine as the world’s largest third-party airframe maintenance company. This has been repeated over the following 12 years in the six biennial surveys that have been conducted



World ranking chart for third-party airframe maintenance companies by Aviation Week Group's Overhaul & Maintenance Magazine

since then. In 2014, ST Aerospace had an annual (sold) capacity in excess of 12 million airframe man-hours.

Becoming the biggest commercial aviation MRO in the world is an achievement in itself. Even more so considering that ST Aerospace had no prior capability in this field of work, and the short period it took to attain this position. As an independent third-party MRO which could not count on assured work coming from a parent airline, this has been possible only because of its ability to attract and retain a very credible customer base, one which had include all the major freight airlines and many of the world's largest passenger airlines.

But equally important is that amongst its customer base were many smaller airlines and commercial aircraft operators, some with only a handful of aircraft. This is a very important aspect of the company which might go unnoticed amidst the many major aviation players in its customer base. Many companies would find it natural to serve its major customers well. But to be able to look after the interests of both its small and bigger customers well at the same time reflects well on ST Aerospace's ability to align its interests with that of all its customers, an important quality for any service provider.

Engineering and modification work has continued to be important businesses for ST Aerospace. These activities continue to be an important make-up of its commercial aircraft work today although its MRO work has grown even faster and contribute more to the commercial aircraft work than modification type work.

Section 3.5.2 Endeavours into Commercial MRO – Engines

Commercial Engine MRO in STA Engines

ST Aerospace added ST Aerospace Engines Pte Ltd (STA Engines) to its stable in 1985. Today's STA Engines is a significant aftermarket service provider in the narrow-body aircraft engine MRO market. Its global customer base consists of more than 80 airlines operating out of 28 countries. And beyond just engine MRO services, its bundled offerings including technical and asset management are an integral part of the ST Aerospace's suite of Total Aviation Support (TAS) capabilities that provides nose-to-tail services on Airbus 320 and Boeing B737 families worldwide.

STA Engines' journey from its birth as a military engine maintenance depot for the RSAF to its current market standing as a key commercial engine MRO service provider bears testament to the ingenuity and industriousness of its leaders and people. They leveraged what little they then had in terms of commercial engine MRO, and grew the scale and depth of capabilities through engineering applications and business acumen to become the significant market player it is now.

The Beginning

STA Engines came into being when ST Aerospace acquired SAEOL from SIA in 1985. The strategic consideration at that time was to leverage the acquired infrastructure to support the RSAF's growing engine depot maintenance requirements.

MRO capabilities for the JT8D Standard Engine series that powered narrow-body aircraft such as Boeing B727, early 737 and Douglas DC-9 was inherited by STA Engines as a result of its acquisition. SIA's engine MRO strategy then was to focus on the considerable fleet of wide-body aircraft it was inducting to fuel its growth internationally.

In 1990, ST Aerospace embarked on its commercial aviation MRO strategy to complement its established military aircraft maintenance and modification business. This was in support of its strategy to enter into the commercial aviation market and to enhance the robustness of its engine business. STA Engines had to take the only commercial engine MRO capability it had then to ramp up operations in an attempt to grow in the JT8D market. During those early days this was a tough proposition to sell, as STA Engines did not have any meaningful track record on the JT8D engine.

Internally, STA Engines drew on the considerable engineering know-how, technical capabilities and processes that were built up supporting military engines, and applied these to ensure that both technical abilities and cost efficiencies of its JT8D operations would be benchmarked favourably with its competitors. With the confidence afforded by a competitive operating structure, STA Engines worked ceaselessly with existing and potential customers to fulfil performance commitments that began to draw in business volume. These hallmarks of efficiency in engineering and operations, and partnership with the customer continues to be the cornerstone anchoring STA Engines' business approach today.

Over a decade, STA Engines leveraged its strong capabilities and ST Aerospace's network to establish itself as a major JT8D MRO service provider in its first decade, achieving a track record of serving JT8D customers from every continent of the world. Going into the new millennium, STA Engines expanded its JT8D MRO capabilities to the JT8D-200 model that powered the MD-80 aircraft.

Starting with this new JT8D-200 engine variant, STA Engines made its first foray into the PBH business. Once again, its approach to customer partnership allowed STA Engines to launch this new engine variant and PBH business model with an existing customer as the launch customer. By the time JT8D MRO operations was phased out, STA Engines had redelivered more than 3,000 JT-8D engines to satisfied customers globally.

New Chapter

Building on its growing reputation for JT8D MRO services, STA Engines successfully launched MRO capability for the CFM International's (CFMI) CFM56-3 engine model in early 2000. This was a natural progression as many of its JT8D engine customers were rolling over their fleet to B737-300/400/500 aircraft.

The manner of launch for the CFM56-3 engine model was again true to STA Engines' core values. From the technical perspective the CFM56-3 engine, being a high by-pass turbofan, represented a new challenge since the JT8D engine had a different design architecture. STA Engines' engineering and operations teams had to overcome a steep learning curve to attain the specific overhaul know-how to redeliver engines with the highest performance standards. Faced with limited support from the engine OEM then, STA Engines had to scout for external talent to infuse the existing engineering and operations core with the necessary knowledge. Through a structured process, full technical capabilities were attained and certified by key airworthiness authorities and customers within a year from the decision on product launch.

On the customer side, STA Engines once again partnered with the same airline that launched its JT8D-200 capabilities, to co-invest in two CFM56-3 spare engines, in addition to the provision of MRO services. This was the start of a one-stop aftermarket service by STA Engines, where provision of spare engine, whilst to keep the affected aircraft flying while the customer's engine was undergoing shop visit was offered as a bundled service.

This was an important development, as the airline industry was changing with the rise of LCCs that outsourced significant portions of their engineering and maintenance functions in contrast with legacy airlines. Bundling of engine aftermarket services, and in alignment with ST Aerospace's increased service scope under its TAS enabled STA Engines to reach out to this fast growing segment of the airline industry.

STA Engines further expanded its CFM56 engine portfolio by launching MRO services for the CFM56-7B in 2005 and CFM56-5B in 2008. The CFM56-7B is a sole-source engine for the B737-600/700/800/900 aircraft family, whereas the CFM56-5B engine is one of two engine types that power the A320 family of aircraft.

A New Footprint

ST Aerospace embarked on its China MRO strategy in 2005, starting with the Airframe Maintenance joint venture formed with CEA. At that time, STA Engines had more than 25 percent share of the Chinese CFM56 MRO market. On the back of this success, and in support of the group's strategy, STA Engines establish its second engine MRO facility in Xiamen, ST Aerospace Technologies (Xiamen) Pte Ltd, through a joint venture with Xiamen Aviation Investment Company in 2008 to be closer to its customers in China.

This facility had an initial start-up capacity for 150 engines per year, doubling STA Engines' then capacity in Singapore, greatly facilitating STA Engines growth strategy for the future.

Another important milestone was reached in 2008, when CFMI and GE entered into a series of long-term strategic partnership agreements with STA Engines, in recognition of the latter's growing customer network and ability to bring value to its customers. For CFM56 engines, the OEM technical and material support enhanced STA Engines' value-add to customers. As a testimony to its technical capabilities and world-class MRO processes, STA Engines was appointed the first non-OEM engine shop where every engine redelivered would be certified to meet CFMI's TRUEngine standards without further in-process qualification by CFMI. At the same time, this also marked STA Engines' ascension as the only independent member of the CFM56 Engine MRO network. A high note for the end of this decade was the signing of a long-term CFM56-7B contract with Jet Airways valued at more than US$750 million.

In 2011, STA Engines became the first independent GEnx On-Wing Support Centre in the world, attaining certified operational capabilities at the same time as GE, the OEM of the engine. This marked STA Engines' first foray into MRO support for wide-body aircraft engine type. STA Engines operated as an integral part of GE's network to support the entry into service for both B787 and B747-8 aircraft, and gaining valuable insights into the engine's technical performance and enhanced customer engagements that would not have been possible if it had remained just as an off-wing engine overhaul provider. Today, STA Engines' on-wing support teams are regularly deployed globally to ensure that technical dispatch reliability of these engines meet Boeing's and GE's commitments to their customers.

With more than 10,000 narrow-body aircraft delivered and a backlog exceeding 2,000 aircraft to be delivered by Airbus and Boeing, the CFM56 engine family has a long future ahead, and STA Engines remains poised to grow as an integral aftermarket provider for these engines for the next decade. Just as the Boeing B787 was pioneering a new chapter for composite use in commercial aircraft, it was hoped that with the GEnx engine, new chapters would be written for the next evolution of commercial engine aftermarket solutions from STA Engines and Singapore.

Section 3.5.3
Endeavours into Commercial MRO – Components

Component MRO Capabilities

The component MRO business in ST Aerospace started in 1969 as an avionics workshop in SAB, part of SEEL (Singapore Electronic and Engineering Pte Ltd) and then known as SEEL Aviation. Back then, SEEL's (now known as ST Electronics) main competency was in its maintenance activities for ships, but the management felt it had to diversify into areas with potential for higher growth, thus the foray into the aerospace arena. In 1982, the component MRO business was officially established as a registered company under the name Singapore Aero Components Overhaul through the amalgamation of the Avionics Aviation division of SEEL and the Mechanical (Components) Division of SAMCO under the Singapore Aerospace Industries group.

It has since grown in capability from supporting old analogue and electromechanical components on early general aviation aircraft to advanced analogue/digital avionics and mechanical components on modern commercial aircraft like B737NG, B787 and A320, and military fighter aircraft like F-16 and F-15. The company had progressively expanded its components repair and overhaul capability in response to market demand and had also re-aligned its name as part of ST Aerospace's corporate identity to ST Aerospace Systems (STA Systems) today. In terms of physical size, it had expanded from a 70,000-square foot facility to an over 150,000-square foot facility by 2008 with modern test facility and capability to support more than 25,000 part numbers. Its maintenance capability covers both avionics and mechanical components. In avionics it has capabilities from simpler aircraft electrical and electronic panels to sophisticated modern-day components like digital displays, and flight and mission computers. In aero-mechanical components, it carries mechanical and hydraulic/pneumatic components ranging from smaller parts like hydraulic pumps and engine starters, to large components like landing gears, transmissions and propellers.

Aviation Approvals and Certifications

STA Systems first got its FAA approval in 1973, one of the first for component MRO in Asia and it is now approved by 15 airworthiness authorities including FAA, EASA, CAAC, JCAB and CAAS. In addition, in view of its good quality standards and capability to bring value to OEMs through good support of its customers globally, STA Systems is the approved service centre for some 30 OEMs from around the world. The need to meet the different certification requirements of the various OEMs and aviation authorities, as well as of its diverse customer base has resulted in STA Systems evolving an internal quality system that is of a very high level to meet the various requirements of its customer base. STA Systems' quality management system is certified to international standards ISO9001:2008 and AS9100B.

Capabilities and Customers

Components maintenance needs good throughput to be efficient. To date, the STA Systems' components maintenance shop has serviced more than 1.5 million components from a broad customer base. It is the largest independent component MRO shop in the Asia Pacific.

In 2015, ST Aerospace component MRO business won the "Best Component MRO in the World" award through the voting of aviation authorities, air forces, commercial airline operators and a panel of distinguished judges from the aviation industry and consultants. This award was accorded by Aircraft Technology Engineering & Maintenance magazine, leading international magazine for commercial aviation engineering and maintenance.

STA Systems has been a strategic partner of the RSAF in supporting the component MRO work for its fleet of aircraft, and STA System's capability has grown in tandem with the types of aircraft operated by the RSAF. Capabilities are developed to ensure in-country support for the RSAF to maintain its operational readiness requirement, and to provide engineering support for aircraft and aircraft components upgrade and modification. With this charter, the capabilities developed are broad enough to support most of its critical systems on the aircraft operated by the RSAF and the depth of repair is sufficient to ensure good engineering understanding of the components. This allowed STA Systems to not only provide efficient, cost-effective and timely repairs, but to undertake obsolescence management and upgrading of the components throughout the life of the aircraft as well.

In the early days, when the main fighter fleet was the A-4 and F-5, the components repair capability of STA Systems was built up to over 80 percent of the installed components. Today, the capability on the more established current generation aircraft like the Super Puma, C-130 and F-16 has reached similar levels. It covers critical systems such as transmissions, propellers, hydraulics, pneumatics, avionics and electrical power generation and distribution. STA Systems has also developed a centre of excellence on helicopters transmission maintenance for the Puma, Super Puma, Chinook, Bell and Agusta helicopters.

Such a strong components capability on all these aircraft types has also enabled the company to support many other military operators around the world like the USN, USAF, US Coast Guards, US Army and the other air forces in Asia. This has benefited these air forces through reliable and high quality services with good turnaround time and responsiveness to meet their operations needs. For air forces that are further away from Singapore, they could also depend on STA Systems for their deployment in Asia. One such example is the US Military Services which engaged STA Systems for components maintenance for both their fleet in Asia Pacific and those back in the US. As an example, in 1984, a contract was signed with the USN to provide components support for its fleet in the Asia Pacific and in 1987, STA Systems was awarded the USN ARC182 UHF/VHF radio maintenance contract for its fleet worldwide under international competition. Today, STA Systems continues to support the same contract which is competitively tendered every few years. Another long term contract awarded is for the maintenance of the US Coast Guards C-130 propeller which was first won in 1989 under international competition. The contract had since undergone another 3 rounds of competitive tendering and STA Systems had successfully competed for the work each time.

Long-term customers are important and a priority to the whole ST Aerospace group of companies and maintaining the support of all its customers, small and large, military and commercial, is a significant measure of its success over time.

Extension to Commercial Component MRO

While STA Systems continued to excel in military aircraft components maintenance, the experience, skill and know-how acquired had also enabled them to extend the capability to support commercial aircraft components. Besides military mission-specific components, there are a lot of common technologies between military and commercial aircraft components. The know-how and skill of the maintenance personnel and many of the maintenance and test facilities can be adapted for dual-use except for situations like in hydraulic components where commercial aviation hydraulics use Skydrol while the military aviation use a MIL-SPEC hydraulic fluid commonly called "red oil".

The two MRO activities, on military and commercial components, are complementary. Whilst the military work resulted in STA Systems developing a very wide range of capabilities and some of the latest technologies, the commercial capabilities benefited from the broad access to a wide range of customers internationally and also supports ST Aerospace components Maintenance-by-the-Hour (MBH™) business. With its extensive components repair and overhaul capability for both military and commercial aircraft, and an international clientele of more than 150 commercial and military customers globally, STA Systems has helped in its small way to enable Singapore to realise its vision of its being a leading aviation hub in Asia.

Complementing ST Aerospace Total Aviation Support Concept

Components repair and overhaul capabilities also played an important role in complementing ST Aerospace's airframe and engine maintenance business by providing customers with a one-stop shop services or what it termed as Total Aviation Support. This is a differentiating factor for airlines which are looking to improve the efficiency of their maintenance outsourcing process to support their operations. For some customers who have aircraft on MRO in ST Aerospace as well, components are turned around and returned to the same aircraft as well after servicing. This component service for aircraft on checks is called ST Aerospace's “return to aircraft” programme and it had been recognised as an advantage by customers like FedEx, UPS, Delta Airlines, LHT Cargo, Lynden Air Cargo and Air Canada. The ability to implement last minute compulsory Airworthiness Directive to modify components due to flight safety reasons is also an advantage to ST Aerospace's customers. An example of this was when, just before one of the customer's aircraft was to complete its upgrade and servicing check in

ST Aerospace, the customer received an AD to modify all the 17 fuel transfer pumps in the aircraft. There were no modified pumps worldwide since this was an Airworthiness Directive that had just been issued. With its full infrastructure and skills set in fuel pumps, STA Systems set up the capability to work on the pump within a day. All the pumps in the aircraft were modified within two days, over the weekend and the aircraft took off on the fourth day without any delay to the original planned departure schedule.

As for aircraft, STA Systems works closely with STA Engines and other engine shops in Singapore and Asia to provide servicing of engine components removed from engines which came in to these engines workshops. Components are returned and re-installed on the engine from which it was removed. Beyond cost and convenience, this keeps the serial number integrity of the engines from what it was when the engine was on-wings.

As will be explained in a separate section (Section 4.6), ST Aerospace's Components Total Support group offer components MBH™ services in response to customers' need. These MBH™ programmes are supported by STA Supplies and Airline Rotables in the UK for the asset management aspect, and STA Systems which does the technical repair work. The programme currently supports more than 600 aircraft from 18 customers worldwide.

Although the concept of MBH™ started with commercial aircraft, the RSAF also adopted it for its Super Puma fleet of helicopters and other aircraft. This is a good attestation of the spin-off in dual-use technologies, not only technically but from a business angle as well.

Section 3.5.4
Components Manufacturing Capability

While ST Aerospace's core capabilities are in aircraft components repair and overhaul for both military and commercial aircraft, the engineering capabilities honed in developing repairs has enabled it to, on a selective basis, undertake manufacturing activities in support of its business in aircraft engineering development.

One aspect is in manufacturing of aircraft wire harnesses in support of the company's aircraft upgrading business. In an aircraft upgrade programme, especially the major upgrades, complete systems are developed and installed onto the upgraded aircraft. Large portions of the wire harness are replaced.

For the A-4 and F-5 upgrades, the complete wire harnesses on the aircraft were replaced. The new wire harnesses were manufactured in-house by STA Systems.

In addition, the company needed a capability to manufacture interface boxes and other peripherals components to meet the needs of its aircraft upgrading programmes. From this, the capability was extended to manufacture aircraft control panels and radios for OEMs under licence, smart weapons-control and interface boxes. Over the last decade, this translated into manufacturing of sophisticated flight mission computers, yaw damper computers and other aircraft components.

Such manufacturing techniques involved the handling of multilayer printed circuit boards with soldering standard meeting IPC J-STD-001 standard, conventional plated through-hole soldering and surface-mount soldering for ball grid arrays, electrostatic sensitive devices handling and control, and environmental stress screening of the computers and avionics boxes manufactured.

Section 3.6
Engineering Development for Commercial Aviation

ST Aerospace's CG for engineering development began 35 years ago at its Engineering and Development Centre" and bracket (EDC). The creation of EDC was to support the RSAF's desire to be self-sufficient in the upgrading of its aircraft. While the support of the RSAF remains EDC's focus and much have been achieved to date, EDC has also extended its engineering capabilities into commercial aviation engineering over the last two decades.

Today, EDC remains at the forefront of ST Aerospace engineering development capability, with over 400 engineers. It develops and integrates sophisticated avionics and systems upgrades for its defence customers, and provides turn-key solutions for major aircraft modifications required by both its military and commercial customers.

The initial step into commercial aviation engineering was modest and was primarily in support of its commercial aviation MRO business. However, over the last 15 years, ST Aerospace took on the challenge in PTF conversion engineering development and established itself as a proficient vertically-integrated freighter aircraft conversion house. The PTF engineering activities are covered in Chapter 4. This section explains the build-up of commercial aviation engineering support of its MRO business.

Section 3.6.1
Supporting Commercial Aviation MRO

When ST Aerospace ventured into commercial airframe MRO in 1990, the main focus was to quickly put in place a management team and production departments competent in performing maintenance and modification of commercial aviation aircraft.

From its initial success on the Boeing B747 Section 41 modifications at SASCO, ST Aerospace expanded into airframe MRO operations in Singapore and then set up airframe MRO operations in the US, China and in Europe through the acquisition of a majority share in EFW.

The primary focus at each of ST Aerospace's airframe MRO facility was its maintenance operations and engineering modification work. However, the MRO and PTF conversion work would not have been possible, or as successful, without the contribution of the technical support departments, including Planning and Production Control, Supplies and Engineering Services (ES). And it was through ES that ST Aerospace started to delve into commercial aircraft engineering.

ES' main role in airframe MRO was to assist Production Department in the resolution of defects or discrepancies that could not be resolved by referring to published maintenance manuals and technical documents such as the aircraft Troubleshooting Manual, Fault Isolation Manual, Aircraft Maintenance Manual, Structural Repair Manual and Engineering Orders.

ES engineers would document the defect or discrepancy in detail and where possible, develop a repair, rectification or engineering workaround, often based on the principles already established in the maintenance manuals, and consult the appropriate engineering authorities (typically the OEMs and/or the airline's engineering department) for their approval prior to releasing the engineering disposition to production. This consultative process led to this engineering support activity being known as "liaison engineering". It was especially important in those cases where the airline customer or OEM did not have engineering representatives on site to work with the MRO company.

Expanding Commercial Engineering Services

In early 2000s commercial aviation engineering was expanded to include a host of engineering and planning services related to Continuing Airworthiness Management. More commonly known as Fleet Technical Management (FTM), Continuing Airworthiness Management enables an airline to fulfil its regulatory obligation as an Air Operator Certificate (AOC) holder to ensure that its fleet of aircraft and installed components and engines are airworthy. FTM became an important component of the ST Aerospace's business as it expanded its activities to support LCCs.

Although the responsibility cannot be delegated by the airlines, some airlines (like the LCCs) have chosen to outsource the performance of FTM functions to companies like ST Aerospace as they do not want to be burdened with the cost of sustaining a full complement of engineering and planning personnel. Besides liaison engineering, FTM includes maintenance programme management, maintenance planning, reliability engineering, configuration control and technical directives (Airworthiness Directive and SB) evaluation.

FTM capability was developed by ST Aerospace as an important component of its TAS programme which was developed for LCCs and start-up airlines which did not want to or did not have the ability to build up and sustain their own maintenance and engineering resources, processes and systems to support their fleets' technical operations.

Even though liaison engineering might not be as deep in engineering content as design and development engineering, it is demanding as a function because of the time criticality of its decisions. For example, inappropriate handling of defects or discrepancies could result in an "aircraft-on-ground" event. This would disrupt the airline's flight operations. Fortunately, the timeliness requirement was not something new to ST Aerospace as an independent third-party MRO and especially one with good understanding of military aviation expectations.

Moving Up the Value Chain

Taking advantage of the engineering capabilities that it had developed through targeted acquisition of commercial aviation engineering and manufacturing companies in the US, ST Aerospace next moved up the value chain into design and development work in PTF conversions and "cabin solutions" where it undertook product development activities in compliant with the requirements of civil aviation regulatory authorities, like FAA, EASA and CAAS. The below will only cover "cabin solutions" as PTF work is covered under Chapter 4.

Section 3.6.2
Cabin Interiors Engineering

In 2008, ST Aerospace ventured into cabin interiors modification as another area where it could add value to both its customers and aircraft OEMs. Leveraging its commercial aircraft engineering support experience, ST Aerospace set up dedicated aircraft interiors engineering and programme management groups to handle such activities. It also secured EASA certification in Europe and FAA certification in the US for this new business. To complement its value proposition, ST Aerospace acquired a company manufacturing and refurbishing interiors monument in the US. A breakthrough was achieved when it secured a complete turnkey cabin interior refurbishment project from JAL to upgrade its fleet of Boeing B767s. Thereafter, more cabin interiors projects from various airlines including Air Canada, ANA, Air Asia X and Jet Airways were secured. Concurrently, in the US, it has set up a luxury aircraft interiors division, Aeria, to tap into the VIP market. It has since successfully delivered a fully furnished green Boeing business jet to a private owner in February 2016.

To enhance its aspiration to be a one-stop cabin interiors provider, ST Aerospace expanded its development into cabin products, including galleys, lavatories and commercial aircraft passenger seats. It successfully designed, developed and delivered its first galleys and lavatories to private and corporate jets in 2015. Its latest endeavour is a range of class-leading, lightweight passenger seats, the first of which was displayed at the 2016 Singapore Airshow.

Through these developments, ST Aerospace has been positioning itself to grow new businesses where it owns the intellectual property (IP) rights to enable it to configure new products to meet the needs of its customers. The hope is to create a new eco-system whereby an end-to-end supply chain for integrated cabin solutions is developed in alignment with Singapore's aspiration to be an aerospace hub.

Making a Difference

If it was not for its strong engineering development capabilities, built up through the support of the RSAF upgrade programmes and enhanced through working on various commercial aircraft programmes like the PTF conversions, ST Aerospace would not have been able to venture into or expand its commercial aviation engineering development capabilities to what it is today.

The capabilities of its engineering organisation and engineers, and their initiative to continue extending beyond the boundaries of their engineering work, have enabled ST Aerospace to venture into commercial aviation engineering. Through their efforts they have thus far established the company as a leading global PTF conversion provider and into aircraft interiors, including being an equipment provider.

From being initially a third-party MRO, ST Aerospace has built up a comprehensive technical services arm that enables it to partner airlines seeking to outsource its engineering activities. ST Aerospace's engineering capabilities have also enabled it to compete successfully to serve airlines, especially in the LCC sector which was the primary source of growth of commercial aviation over the last decade.

What started as an effort to tap on its in-house engineering competencies to help it undertake commercial aviation MRO and hands-on engineering modification work resulted in the capability becoming an important competitive advantage in serving its commercial aviation customers better. In addition, the same engineering competencies has enabled ST Aerospace to evolve beyond MRO and helped it access new business opportunities in support of LCCs, in PTF development, in aircraft interiors furnishing, and hopefully other aviation business areas in the future.

Section 3.7
Unmanned Aircraft Development

The SAF began exploring the potential of UAVs, also known as remotely piloted vehicles (RPVs), for surveillance missions in the late 1970s. UAVs for missions were however not common then and there were not many options in the market. The first system the SAF started experimenting with was the Mastiff system. This was a very basic system capable of providing airborne real-time video coverage of the target area during its flight. With the experiences gained from the Mastiff system, the SAF continued on to acquire more sophisticated UAV systems such as the Scout in the 1980s, the Searcher in the 1990s and 2000s, and later, the Hermes 450 and Heron 1.

In the 1990s, ST Aerospace was contracted to provide maintenance and logistics support for the Searcher UAV under the RSAF's

Searcher UAV system

commercialised programme concept. Similar to the practice for manned aircraft, ST Aerospace stationed a team of engineers and technicians in the airbase where the Searcher UAV system was based.

ST Aerospace's team worked with the RSAF team to conduct daily operations. This was followed by ST Aerospace's involvement in the upgrade of the Searcher. More details are described in Chapter 4, under "Delving into New Products Development.

Early Endeavour in Developing UAVs

ST Aerospace started to experiment with UAVs in 1989 through the building of "SARA" (Singapore Aerospace Research Aircraft). The aircraft, made mainly from balsa wood, was controlled by an in-house modified radio-control unit purchased from the hobbyist market. SARA was first launched from an open field near Lorong Ah Soo, one of the few places in Singapore where radio-controlled aircraft modelling enthusiasts took their aircraft into the sky. A hand-held VHS recorder was subsequently installed to record video from the aircraft frontal view. To avoid losing visual contact of the aircraft, engineers installed an electronic module on SARA that produced a bright flashing light in flight. Adopting simple but effective solution was the design philosophy. This effort, done outside its engineers' regular work, was to generate interests in unmanned aircraft and marked the first attempt by ST Aerospace to build an unmanned aircraft.

SARA research RPV with video payload (Held by the engineer on the extreme right) and the development team after a flight, at Tuas

In anticipation of the possible future requirement for extensive usage of UAVs by the SAF, ST Aerospace embarked on a series of UAV developments to get its engineers to understand unmanned aircraft concepts. In 2002, a stealthy looking platform with a unique name called ALOFT, was conceived. The prototype was designed quickly and the entire build-up process inclusive of fabrication, assembly and rigorous testing took just 12 months.

Due to limited airspace in Singapore, the ground tests, low- and high-speed taxiing and flight trials were conducted over several weekends in Pulau Sudong, an island south of mainland Singapore. Despite the difficulty of securing flying slots, the team was fully committed to the effort and was overjoyed when the aircraft flew up to a height of about 30m and landed safely during its first "hop and pop" run, as part of its high speed taxiing test.

ST Aerospace's ALOFT prototype

Despite the progress made, the project was discontinued due to more pressing requirements. Nevertheless, the experience gained from the project provided valuable lessons to the team involved in the subsequent UAV developments.

ALOFT being prepared for launch at Pulau Sudong

Seizing the Opportunity to Develop Mini-UAV Systems

The opportunity to develop a UAV system for operational use arose in the mid 2000s, when the Army identified a requirement for a man-portable system that would allow small units of troops to perform their own reconnaissance missions independently using their organic resources. This need gave rise to the search for a mini-class UAV and the Army started small scale trials to evaluate mini-UAVs available in the market. With the objective of offering an in-country developed option, DSO and ST Aerospace jointly developed prototypes designated as Skyblade I and II systems from 2002 to 2005, as part of the capability development to build unmanned aircraft. The use of portable UAVs in its operation was quite new to the Army. Hence, a spiral development process was adopted to explore new operational concepts using commercial technologies and unique in-house developed algorithms. With their early experience from Skyblade I and II, DSO and ST Aerospace were awarded a contract to develop the Skyblade III mini-UAV in 2007. The contract was for a light-weight rugged system that would be man-packable by a two-man team and designed primarily for short-range surveillance operations by average-build Singaporean soldiers.

Through the Skyblade III programme, the local industry developed engineering capabilities in the areas of mini-UAV design, development, integration, certification, production and training. In March 2009, after two years of development, including trials, production go ahead (PGA) was approved and the first production Skyblade III system was delivered to the Army in October 2010. This was the first indigenously developed UAV to go into service for the SAF. Due to its contribution to the SAF's operational capability, the Skyblade III programme was awarded the Defence Technology Prize for engineering in 2009. The successful development and production of the Skyblade III system represents a significant step forward in the build-up of UAV system development capability in Singapore.

Importance of having Control of Key Components

Besides the aero-mechanical aspect of the development, a key to the success of the programme was the development of the in-house flight control computer (FCC) for Skyblade III. This enabled the programme to be carried out successfully as it was difficult to find a capable and reliable supplier able and willing to provide an affordable product of the high standard needed.

The original intent was to use an off-the-shelf FCC but the programming instruction set for these FCCs were generally limited and not sufficient for the close control of the manoeuvring and navigation of the UAV. In addition, because of the frequent changes in requirements due to the nature of spiral development of the Skyblade III programme, it was difficult to commit on bigger production run of any configuration of the FCC. The cost for a supplier to respond quickly to small production runs would be high. Strategically it was also not desirable to be dependent on third parties for critical parts of the system which could not be clearly defined yet.

To overcome these issues it was decided to develop an in-house FCC. This was assessed as feasible leveraging the knowledge and experience of ST Aerospace's engineers who had developed the in-house mission computer for the RSAF's manned aircraft upgrade programmes.

Without this capability, the programme might not be realised as smoothly, and certainly not within budget. This event is another validation of the importance of having a competent and flexible engineering capability to realise outcomes which might otherwise be infeasible.


Skyblade III aircraft is ready for bungee launched

The Skyblade III was designed for rapid mission deployment. It could be bungee or hand launched, with autonomous recovery via deep stall fully managed by its on-board FCC. It was designed to support conventional and urban warfare operations and had a communication and video link with an 8 km range and a flight endurance of 1 hour.

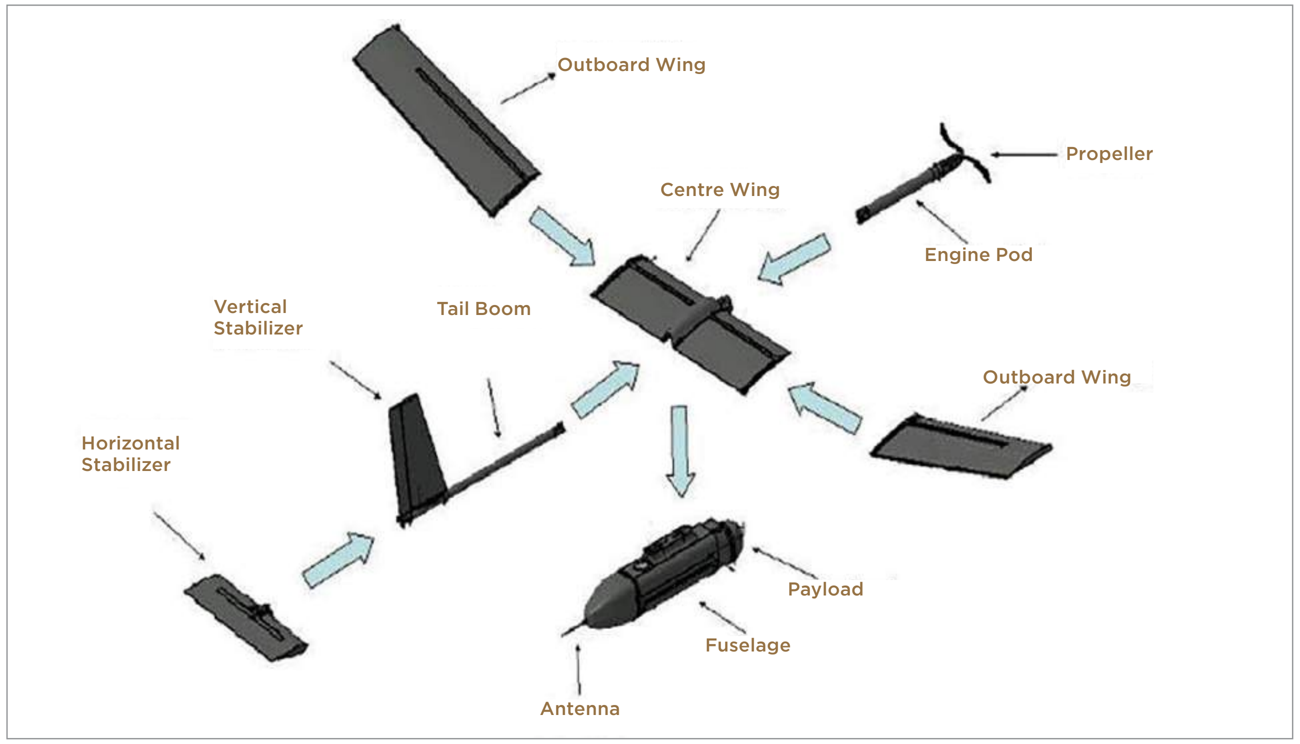

Skyblade III is a hand-launched UAV

The modular lightweight carbon composite airframe and minimal logistics footprint enables the deployment of the Skyblade III by a two-man team in less than half an hour. The ruggedised ground control station (GCS) is based on a game console, hence learning to use would be easy. The operator can upload pre-planned routes with the flexibility of altering routes on the fly if necessary.


A SKYBLADE III system ready for launch


Ergonomic ground control station


Modular payload on Skyblade III



Skyblade 360, modular design similar to Skyblade III

Skyblade III carries an Agyro stabilised 2-axis payload camera capable of both day and night operations to provide real-time video. The entire system consisting of one GCS and up to three aircraft can be packed in one or two man-packs of up to 20kg each. The rugged packing design ensures maximum portability during missions, where the manoeuvrability of the users is important.

Following Skyblade III, the next requirement for its slightly larger sibling with longer endurance and range, was again jointly developed by the Skyblade III team. Retaining most of the design features and concept of Skyblade III, the larger UAV was designated the Skyblade 360. For easy transition, it shares the same GCS including the graphic user interface (GUI).

The longer endurance required was achieved by integrating a “plug-and-play” swappable hybrid fuel-cell/batteries as energy source with a special power management algorithm. The larger aircraft could also carry a wider range of payloads to meet specific user requirements.

Attempting a Bigger Close-Range UAV System

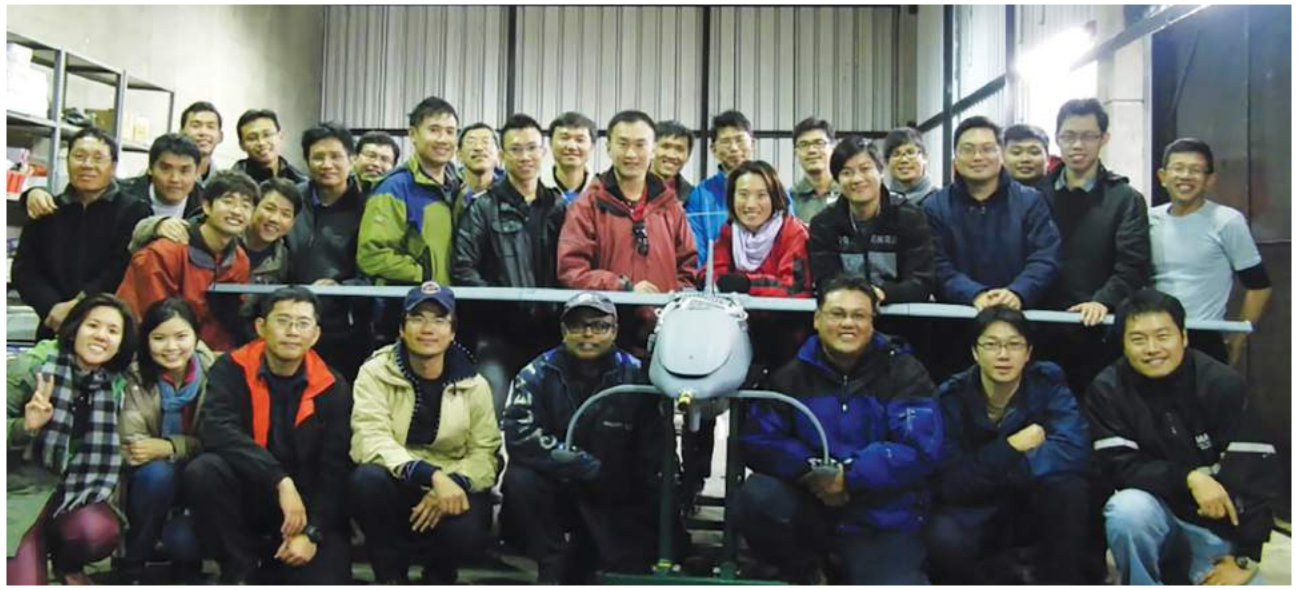
At about the same time when the Skyblade III was launched, ST Aerospace and DSO also jointly embarked on the development of a Skyblade IV system. Skyblade IV would be a close-range UAV weighing around 70kg. Due to the more capable payload which was called for by its mission and a longer-range communication link, Skyblade IV would operate autonomously from launch to recovery without the need of a runway, and could perform a wide variety of missions ranging from reconnaissance and battle damage assessment, to maritime security operations.

As this UAV would be bigger, fly higher and further, the design considerations were approaching that of a manned aircraft. A team of DSO engineers was seconded to ST Aerospace to form an integrated product team to develop Skyblade IV as a joint development programme.

Part by part, components purchased from commercial vendors were progressively

Skyblade IV's first launch in Australia

Skyblade IV mounted on top of a vehicle in ground test



Completion of Skyblade IV full system demonstration in June 2013

integrated with the in-country developed FCC. This approach ensured that they could be customised subsequently for various other SAF's applications as the operation concept evolved. The undertaking to develop the computer hardware and flight control software was not an easy task, but perhaps the other equally important challenge was the limited airspace to test Skyblade IV. The team had to search all the available sites as far as Finland and the US, before it eventually selected Australia for the first test flight.

On 28th August 2008, after a year of hard work, Skyblade IV made its first flight. An unmanned airplane designed by Singaporean engineers flew in Australia - an important milestone for the team. However, it was only the beginning as there were many challenges ahead to make the system robust, fully autonomous and to ensure ease of use in a rugged environment.

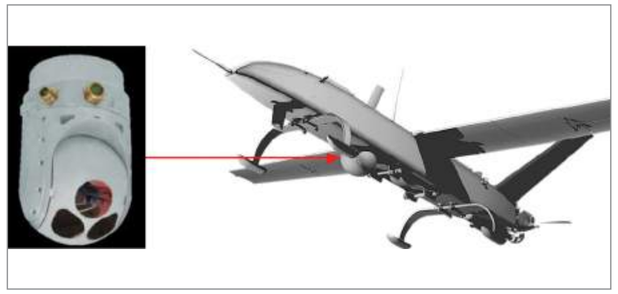
In view of the limitation of airspace for flight testing, it became important to be able to validate any changes and improvements made through innovative tools and methods before conduct of flight tests. Developing a suite of ground simulation tools linking up all the hardware into a laboratory to allow the software to be rigorously tested was part of this effort. Similarly, various methods to do ground verification tests on the parachute recovery system, ranging from running parachute deployment tests in the night to doing drop tests in the sandy areas in Tuas, Singapore, were conducted.

In the final phase of the development, another journey was embarked upon – this time to South Africa for the final flight trials. Issues that had never been seen on the ground were slowly popping up. Changes had to be made quickly and solutions implemented thoroughly. Even though extensive time was spent away from their family, way beyond the planned duration, the team persevered and solved all the problems faced. The Skyblade IV capabilities were finally demonstrated in June 2013 to the satisfaction of all.

The Skyblade IV System

The Skyblade IV is a fully autonomous tactical UAV designed to provide real-time battlefield intelligence. It is designed for maximum operational versatility and mobility, and integrates easily with a forward observer or intelligence analyst. All flight operations including mission time are fully autonomous at ranges up to 100km, with endurance of up to six hours. The system could be flexibly used to support conventional and urban warfare operations, and paramilitary and civilian applications such as general surveillance, early warning, monitoring, inspection, battle damage assessment and patrols.

The modular airframe is fully made of composite materials. The baseline payload is a dual-axis gyro-stabilised surveillance and observation system, providing high-resolution



Skyblade IV tactical UAV

Parachute recovery for Skyblade IV

video with continuous optical zoom and automatic video tracker.

No runway is required for take-off or landing. The aircraft is launched from an automatic catapult-assisted launcher and recovers using an automatic parachute recovery.

Proving of Capability

The UAV development has enabled engineers in MINDEF, DSTA, DSO and ST Aerospace to undertake the full development of unmanned aircraft systems from concept stage to fully operational fielding of a system. The effort was not only on the air vehicle although the earlier UAV programmes were more focused on the development of the aircraft. The full effort covers, besides the air vehicle, the development of the various sub-systems like the launch and recovery system, flight computers, mission payloads and datalink system, and their integration into a complete system to meet specified operational requirements. This will give the SAF the option of buying off the open market those systems that better meet its requirements or embarking on the tailoring of a system to meet its special operational requirements, cost effectively.

USTAR-Y VTOL UAV

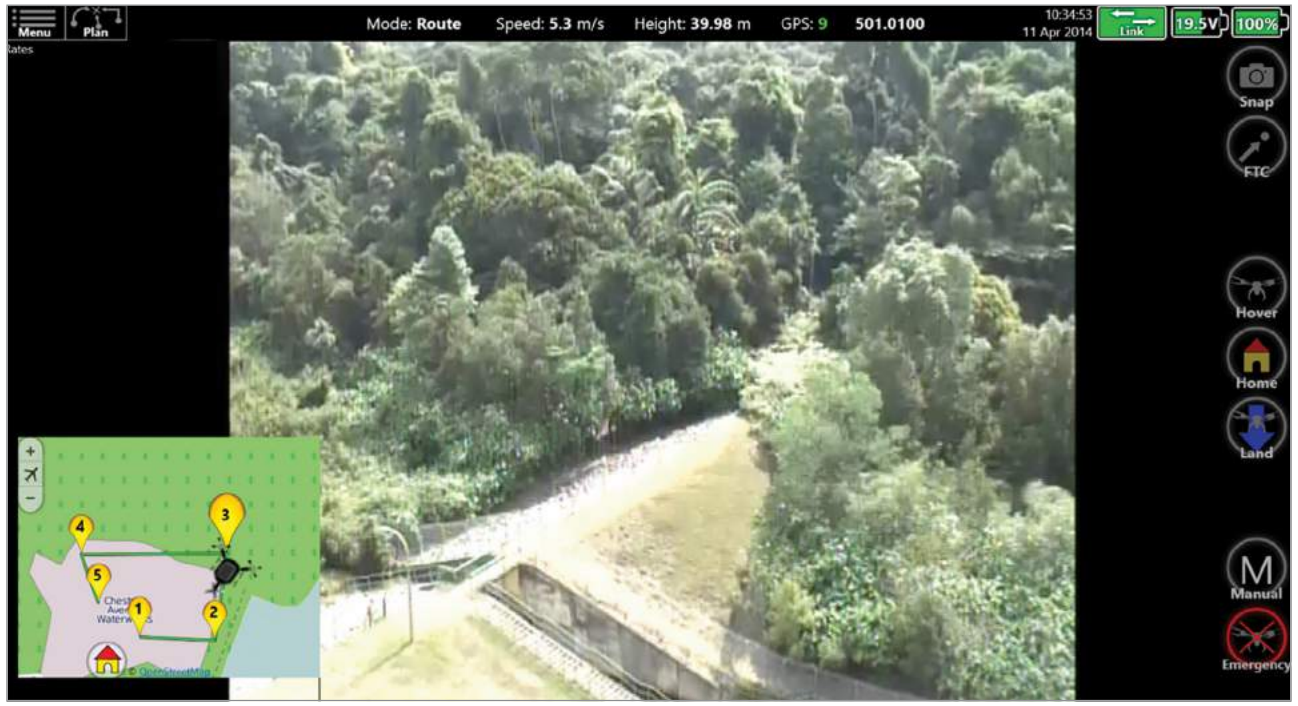
The capabilities acquired have also enabled ST Aerospace to develop non-military UAV products for the commercial market as unmanned systems are not unique to military use. The ability to cross deploy engineering competencies across commercial and military domains would also benefit both ST Aerospace and MINDEF, and Singapore as a whole.

An example was in the development of the USTAR VTOL family of products by ST Aerospace, which consists of the USTAR-Y and USTAR-X UAV. USTAR stands for "Universal Surveillance and Tracking Autonomous Rotorcraft". In early 2013, in an effort to explore the opportunities in the commercial UAV market, a decision was made to develop the USTAR-Y multi-rotor VTOL UAV.

A target was set to be ready to demonstrate the possibilities of these systems by the 2014 Singapore Airshow. An important aspect of the challenge was to ensure the system could fly reliably, safely and repeatedly in demonstration anytime, anywhere during the Airshow.

USTAR-X in flight

The USTAR-Y was to be significantly different from earlier R&D USTAR-X Quad-rotor (one propeller on each of the 4 arms) VTOL UAV prototype. It has an unconventional rotor layout with contra rotating pair in a "Y" configuration in order to reduce the footprint size and also ensure rotor redundancy. It used ST Aerospace's latest in-house developed micro FCC (mFCC) for maximum flight performance and was equipped with the newest in payload technology which carried a two-in-one day-and night gimbal-stabilised camera. The GCS introduces a refreshing experience with the new touch interface and updated GUI. The twin-rotor, with one stacked above the other, reduces the overall footprint but also affected the propeller efficiency when they are rotating in opposite directions. The form and shape of the aircraft was evolved via computer-aided design and the actual fabricated airframe was a masterful combination of modular functionality and aesthetic. The very first flight of USTAR-Y took place in August 2013. Although it was in manual control mode, it took only six months to develop. Eventually, the USTAR-Y system performed several successful demonstrations to local and overseas parties during and after Singapore Airshow 2014. After two years of continuous improvements, the USTAR-X and USTAR-Y VTOL UAVs were ready for trials by military, para-military and civilian end-users.



Video image and map overlay from USTAR-Y's payload

There is good potential for UAV in both military and commercial applications. Future products can include the use of artificial Intelligence to address specific user requirements. It is expected that the use of UAV in commercial, as well as military applications can only increase over time. New challenges will arise out of operating in commercial environment such as intermittent GPS coverage due to non-line-of-sight environment, processing data from large numbers of sensors planted to monitor the environment, or reducing dependence on manpower through use of multiple UAVs operating in the same arena, just to name a few.

Chapter Four

AVIATION ENGINEERING CAPABILITIES - PROCESSES AND PRODUCTS

Section 4.1
Life Cycle Management

In defence systems, we often talk about a system from its concept phase, through evaluation, design and production, introduction into service and sustenance of operations, and finally to retirement and disposal. We measure the success of a defence system by its operational availability, capability and supportability over its life span, and not just the ability to meet the contracted cost, schedule and performance specifications. LCM is a MINDEF process of acquiring defence systems and inducting new capabilities into the SAF, maintaining the system in optimal operational readiness, keeping them operationally viable through system upgrades as necessary, and finally retiring the system at the end of their useful life. A “system life cycle” approach is thus used for the planning, acquisition, operations and support, and retirement of all major weapon systems. The MINDEF LCM framework puts together the wealth of knowledge, experience and lessons learnt by our engineers over many years of defence systems acquisition and support.

In the early years of the RSAF (SADC), most of the systems (aircraft, air defence and weapons systems) inducted were pre-owned systems as it was the most cost-effective solution then. In any case, the RSAF's focus then was on building a capability to train pilots and technical manpower needed for the build-up of an operational air force. For these systems, the support infrastructure, including spares, and maintenance and operations manuals had come along with the systems inherited or acquired.

Even when it bought new systems, such as the F-5s and the earlier Super Pumas, the RSAF had relied on the recommendations of the system OEMs for maintenance and servicing. As the OEMs were not necessarily the support specialists because they did not field their systems operationally themselves, their recommendations were based on their designs to meet broad-base requirements spelt out for a wide array of potential users. Over time, with its field experience in the environments it operated in and the system defects and failures that it had encountered that were not anticipated by the OEMs, the RSAF began to factor these as considerations in its logistics support model for the systems concerned.

In 1983, the RSAF engineers were exposed to the USN's comprehensive logistics planning process when the E-2C Hawkeye airborne early warning aircraft were acquired. The USN had a structured way of working out the logistics support requirements for aircraft acquisition programme. As part of the process, all spare parts for the aircraft and systems were defined, the level of repair for each component was determined and the necessary support equipment, tooling, building infrastructure, data and training were provisioned for. It was a good approach for a well-planned integrated logistics support (ILS) programme for a complex weapon system. From the E-2C experience, the ALD engineers moved on to manage a similarly comprehensive ILS effort when the F-16A/B fighters were acquired in 1985.

With experience in comprehensive logistics support planning gained from these major aircraft programmes, ALD in 1987 developed an internal working control document known as the Logistics Support Management Plan (LSMP) for its future acquisition programmes.

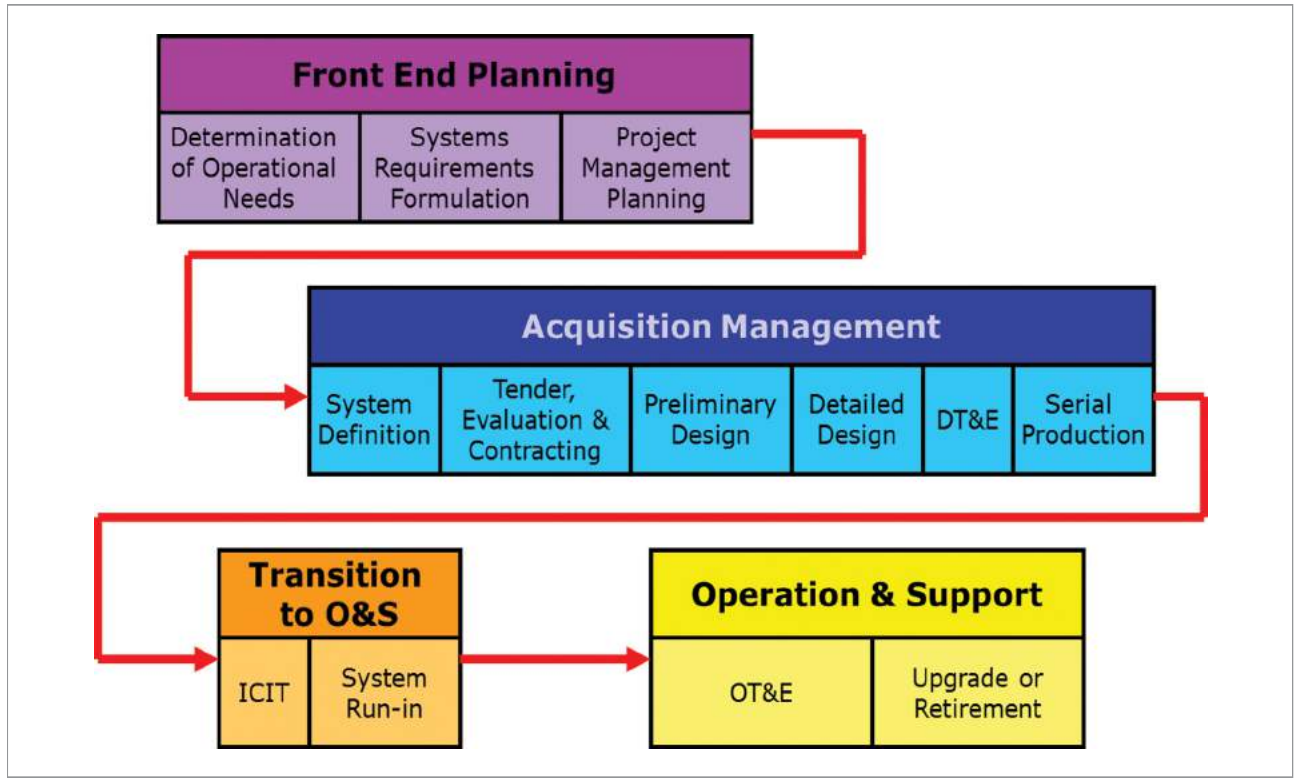
The LSMP document is a management tool to document and communicate the ILS definitisation process, major decisions made, ILS deliverables, “level of repair” analysis and support posture to be adopted, establishment of in-country capability including facilities build-up and technical manpower required, training, time frame for implementation, and responsibilities of various stakeholders in assuring a successful introduction of the new system. It ensures that a consistent rigour is given to the logistics support elements of an acquisition programme. The LSMP is still in use today for major programmes, as one of the requirements of the LCM process.

Development of the LCM methodology began formally in 1987 when MINDEF decided to develop and formalise a robust acquisition management process across the SAF. The LCM was institutionalised as a structured and coordinated management process to plan, acquire, deploy and operate, and retire an asset or capability. A senior level LCM Working Committee was then formed and included members from MINDEF, DMO and the SAF.

Supporting the committee in developing the methodology and writing the LCM manual was a team of systems engineers from DMO and specialist engineers from the logistics departments of the three SAF Services. During the early part of its effort, the LCM team was assisted by Professor Melvin Kline, a specialist practitioner in LCM systems from the US Naval Postgraduate School in Monterey, California. Other logistics advisors, experienced in large-scale programmes, also contributed to the development and enhancement of the methodology over time, especially on ILS requirements.

The impetus for an LCM methodology stemmed from a few key considerations, an outcome of managing large acquisition programmes. The first requirement was that the prime equipment, associated equipment such as simulators and trainers, in-country capability and necessary spares and support equipment must be defined and tendered in one stage. These ensured decisions would be made based on a more complete understanding of the various cost elements over the life cycle of the system being acquired. The aim was to ensure visibility and transparency on the full cost of an acquisition. Secondly, system performance and reliability requirements must be addressed during the tendering and project management phases and not left to chance after the system was fielded. This would ensure a more robust and comprehensive equipment planning and procurement process as well as commit the OEM to the cost of supporting its system. Thirdly, engineering support from the OEM for, say the RSAF and ST Aerospace in the case of air systems acquisition, must be defined and provisioned for in the contract, especially for sophisticated systems. This would include negotiating for software and engineering data releases, and engineers’ training on the design consideration of the system. The objective was to ensure that MINDEF and the RSAF could be a "smart user", able to undertake in-service modifications throughout the life of the system.

The LCM process would begin with the formulation of projected operational needs from MINDEF’s long-term plan and the SAF’s capability build-up plan. These top-level needs would be transformed into specific and realisable operational capability requirements. In the acquisition phase, the solution that would be able to meet the required operational capability and has the best operational benefit for the dollar spent ("value for money") would be selected from a range of alternatives. Clear roles and responsibilities for all stakeholders would be defined at every stage, from acquisition to project implementation, system delivery, operations and support and finally retirement of the system. The life cycle would end with the physical disposal of the weapon system at the end of its useful life. During the operations and support (O&S) phase, the operational service life of the system might be extended to meet changing operational scenarios by mid-life upgrades and technology



Phases of life cycle management

insertions. Thus, the LCM phases could be summarised in a simplified form as: front-end planning, acquisition management, transition to O&S, O&S, and system retirement.

Key to the LCM methodology was the use of a systems approach and systems life-cycle cost. In planning and acquiring a defence system such as a new fighter aircraft, the project team would consider not only the operational performance of the new prime equipment or fighter, but also how the system would be utilised and supported in peace and wartime throughout its entire operational life. Considerations here would include an evaluation of the growth potential of the system during its operational life, and capability of in-country defence industry to support future development and sustainability of the weapon system. Unlike the initial acquisition cost of the system, life-cycle cost would include the initial acquisition cost plus spares and support equipment cost, and the cost of operations and maintenance support throughout the system's life cycle which could be 30 years or longer. This would be estimated based on projected operational usage, reliability data obtained from the original OEMs' and field data from other major users. Finally acquisition of a weapon system might require specific obligations from the buyer country to the government of the seller country with regard to the future disposal, transfer or resale of the system upon retirement. These obligations would have to be made clear from the onset.

The O&S phase for an aircraft would include MRO, and modifications and upgrades to meet changing requirements. It would also include engineering support from the OEM, spare parts management and consumption, obsolescence management, reliability engineering to improve availability, and training. The O&S cost during the entire system life cycle of an aircraft could amount to around 60% of the system total life-cycle cost. It would thus a major part of the life-cycle cost and an important consideration for the project team when evaluating competing solutions.

MINDEF adopted the full LCM methodology

it developed since 1990 till 2012. The LCM process made MINDEF, the SAF and DSTA a smarter buyer, user, systems designer and integrator. The payback was in better overall cost-effectiveness of defence systems inducted into the SAF's inventory.

Since 1993, the AHPa sophisticated decision-making tool, has been in use for the evaluation and selection of all major systems. Modelling and simulation tools for tactical and campaign analysis was subsequently incorporated as an enhancement to the AHP.

The LCM methodology was constantly evolving. Over the years, as solutions to the SAF's war fighting requirements moved from off-the-shelf weapon system purchase to one of heavy customisation and programmes that were highly developmental in nature, new tools such as risk management methodology were added. Contractual requirements were also been modified to cover the differences in systems which were developmental in nature. This was to manage risks, and allow for some degree of flexibility in delivery schedules and performance of the final product. Critical milestones were provided for the SAF and DSTA to review the programme and to exit if it was clear that the desired system performance and operational capability would not be met.

The SAF has always placed safety as one of its core values. The first formal WESSAB was set up in MINDEF in 1991. The origin of this was in the late 1980s when a formalised review was initiated to make an independent assessment of the A-4SU before it was committed to production. WESSAB's role was to provide impartial and independent advice to MINDEF and the SAF on the safety of the SAF's weapon systems. This approach has since been adopted for subsequent major projects undertaken.

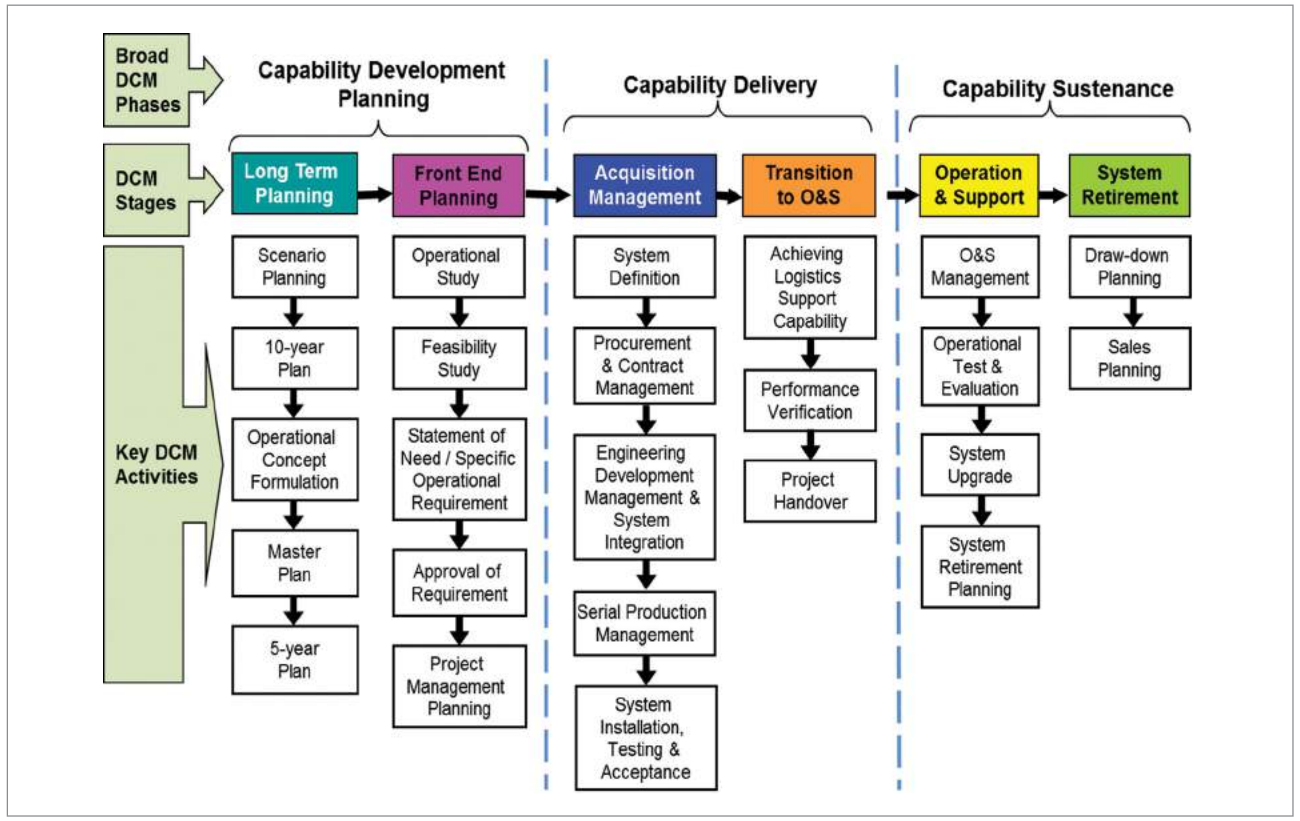
In the late 1990s, the SAF, together with DMO, embarked on a journey to introduce the concept of system safety to further enhance its safety framework and this was formalised in 2005. With the experience gained from the implementation of the system safety process for the safety assessment of ordnance, munitions and explosives, MINDEF, the SAF and DSTA expanded the system safety concept to the safety assessment of weapon systems such as aircraft, ships and land fighting vehicles in 2006.

A Residual Mishap Risk Management Framework, as applied to the MINDEF, the SAF and DSTA, was formalised in 2010. Since then, all weapon systems and ordnance, munitions and explosives have been subjected to a rigorous process of system safety assessment, hazards mitigation and residual risk quantified and accepted prior to the systems being operationalised. System safety assessments are also reviewed when there are major upgrades or changes to the operational profile of any weapon system.

Defence Capability Management

In 2010, an organisation-wide, strategic review of the LCM was initiated to position MINDEF to meet the future challenges of managing increasingly complex and networked weapon systems in the 3rd Generation SAF, maximising coherency across defence ecosystem and enhance our ability to push the boundaries of technology. New processes were needed to enable MINDEF to view the acquisition from a "capability life cycle" point of view. The LCM framework was thus further evolved into a broader Defence Capability Management (DCM) framework to provide a more holistic basis for capability development planning, delivery and sustenance. The DCM manual, which codifies the DCM Framework, officially replaced the LCM manual in 2012.

Key changes incorporated under DCM include technology transition process that had been tested during the trial implementation; the need to consider sustenance requirements in upstream planning for major capabilities to



Flowchart on defence capability management

ensure comprehensive system supportability downstream; greater operations-technology (ops-tech) integration to engender more ideas and generate innovative solutions to enhance the robustness of system architecture; strengthening linkages between capability planning, operations and sustenance; strengthening the oversight of outsourcing to create capacity for higher value of work and to operate and manage more sophisticated systems.

A Walk-Through the DCM Processes

The following uses the replacement of the aging A-4 Skyhawks as an example. During the Long-Term Planning Phase, the operational concept would be developed. Various operational studies would be conducted to distil the operational needs and subsequently the operational requirements for the new aircraft. The operational requirements would then be approved and funding allocated.

A project team would be formed to prepare the acquisition. A market survey of available aircraft would be made and an acquisition approach would be developed. Tender would be issued and the response to the tender would be evaluated using AHP. For comparison of complex capabilities like air power where they could be dynamic scenarios and many interdependencies, operations analysis as well as modelling and simulation might be used to aid the evaluation.

Based on an objective cost-benefit comparison, the most cost-effective solution would be selected. The contract would be signed and the project team would proceed with engineering development through design reviews and verification of the product through acceptance tests. Rigorous reviews of safety would be undertaken to ensure that all the necessary safety measures were put in place to minimise hazards to a manageable level.

After the system was accepted, it would be inducted into service. Operations and support would begin. The ILS acquired during acquisition would sustain the initial years of operation, allowing the RSAF to build up field data on failure rates and consumption patterns to undertake re-provisioning of spares and consumables. Evergreen blanket ordering agreements would be put in place with OEMs to ensure that pricing and availability of spares were secured along with engineering services if required. However, from time to time, obsolescence might creep in and replacements would need to be introduced.

Each weapon system would be led by a systems manager who would have a team of engineers and material specialists to ensure sustenance of the system. The systems manager would double up as the contract manager for outsourced services required from the industry. Continuous airworthiness assessment would be made to ensure the aircraft continued to be safe as modifications were added to enhance the aircraft's performance and capability. This would tap on the engineering and logistics know-how that would have been built up over the years. This would continue till mid-life where an upgrade might be initiated to introduce technology refresh, capability enhancements and major improvements to extend the capabilities of the aircraft till the end of its life.

Section 4.2
Engineering Software capabilities

The Beginning of Airborne Software Development

The involvement of Singaporean engineers in airborne software development started in the mid 1980s with the RSAF's A-4 Skyhawk avionics upgrade programme. The new avionics suite incorporated, under one of the two major upgrades to the aircraft at that time (the other being the engine upgrade), not only replaced all the obsolete controls and avionics, but also incorporated a set of automated weapons delivery and navigation functions. The automation was important as it helped the pilot to integrate the various information he received from on board sensors and also to manage the potential new threat environment that the aircraft had to operate in. Although the state-of-the-art laser INS, together with the HUD and other new equipment and sensors were important parts of the modern day hardware of the avionics suite, it was the new software which integrated the suite of advanced equipment to display all related information in a timely manner to enable the pilot to manage the aircraft as an integrated weapon system.

Airborne software is not like the software used in most industrial systems. For a fighter aircraft operating at high speed, timing is critical and accuracy is paramount. Large amount of information is constantly gathered through the aircraft sensors and the software has to interpret and manage these data into real-time information to be presented to the pilot at the right time – not earlier, nor later. This software is hence called "real-time" software. As software takes time to execute, it had to be carefully optimised to compensate for the computing time. In the early days, the computers were at least a hundred times slower than today's hand phone processors, and the efforts to compensate for the lag was even more important then.

Most of the airborne software suites are "predictive" in nature. For example, in order to land a bomb on the visually acquired or pre-planned target, the software algorithms have to use information of the immediate past to predict the flight of the bomb through the time-of-flight until it reaches the target. The computation has to include the time to release the bomb, the separation of the bomb from the aircraft pylon, as well as the delay in the response of the pilot in activating the pickle button in response to the symbols on the HUD. This is just a small illustration of the differences between real-time software and conventional logic-based software.

Engineers from ST Aerospace and MINDEF first tasted the complexity of the real-time software, the huge size of the software packages, and the rigour of airborne testing during the A-4 avionics upgrade. The 12 engineers (six from ST Aerospace and six from DSO) dedicated to software, and a half dozen more each in systems engineering and hardware development, were important investments made. These engineers, after learning from the experts and specialists at the OEM's facilities overseas, formed the backbone of the software development team which, supplemented with new engineers over the years, handled the maintenance and upgrades of all the subsequent aircraft upgrade programmes of the RSAF.

In the following paragraphs, some of the characteristics of real-time software will be explained so that the complexity of airborne software and the importance of honing this capability over the years to keep the RSAF's operational requirements well supported is appreciated.

Real-Time Software – What is it Really?

Unlike conventional software that emphasise mainly on logic correctness, real-time software is more stringent in requirement and complicated in nature. It needs to meet strict timing constraints and data must be processed efficiently within defined timelines. In short, real-time software behaviour must be highly efficient and deterministic. This makes it more difficult to develop, especially in a modification programme where it has to be integrated with a large number of legacy systems originally developed by the OEM of the aircraft.

Development of real-time software requires specific skill set, many of which can only be acquired through experience and training. As an illustration, a normal software engineer might code a simple mathematical equation as:

Y = X / 2.0;

But an experienced real-time software engineer would code it as:

Y = X * 0.5;

Both equations would yield the same result mathematically. The subtle difference is that the latter would be more efficient in terms of execution time as the number of executions required by the computer would be smaller compared with the former. A 10 microsecond saving per instruction can amount to 1 millisecond saving for 100 instructions. In real-time software, the machine cycle works in 20 millisecond cycle, thus milliseconds count.

As avionics software engineering work was non-existence in the early 1980s in Singapore, it was not possible to recruit such software engineers then. All software engineers with real-time software experience had to be trained in-house. Tasked with the responsibility to build up the software development capability from ground level, the pioneer group of software engineers rose to the challenge. They came from various engineering disciplines; some with systems engineering background while many were electrical and electronic engineers by training. Very few had knowledge of real-time software.

The recruitment and training of software engineers to form the ESW in ST Aerospace was an important milestone in its engineering history. The setup of software engineering and development capability has enabled ST Aerospace to undertake the many systems upgrading programmes of the RSAF over the years. Without the software capability, the RSAF would have to depend on support from various components and sub-systems OEMs. Besides the significantly increased cost of developing new capabilities, the work processes would be less efficient. It would also certainly compromise the RSAF's ability to responsively address its requirements as and when they arose. Besides increasing cost and time to implement any requirements, the outcome would be less effective as the engineering responsibilities would be split amongst various parties.

Developing and Maintaining Real-Time Software

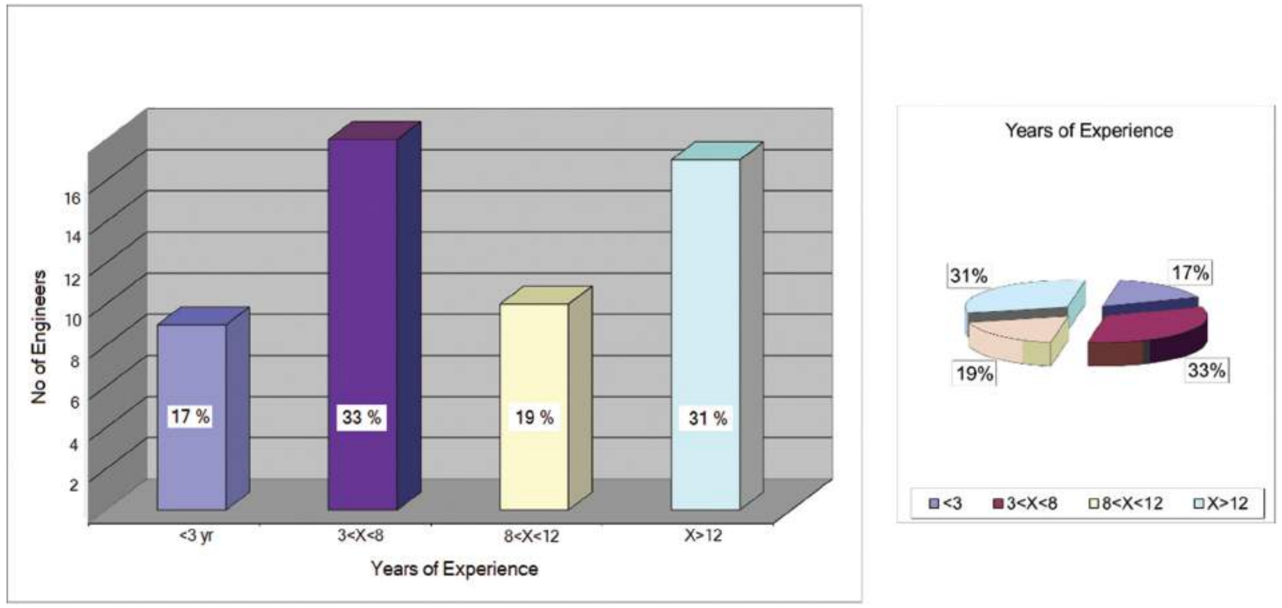
After completing the various testing in laboratory setting, usually in client PC and server environment, the newly developed software will be compiled to the CPU of the airborne mission computer which would host the software, using a real-time operating system. The purpose of the OS is to provide a platform and the basic software libraries to facilitate the execution of the real-time software. During the A-4 upgrade in the 1980s, reliable real-time OS to host the software was seriously lacking.

Most of the operating systems, like UNIX OS and TeleGen Ada real-time OS which were available in the market then were only in their infancy state of development. These OS' were equipped with very limited support software libraries and other software tools. This made the software development work labour intensive and time consuming. The absence of user-friendly debugging tools made spotting defects by eyeballing of the tens of thousands of lines of source codes daunting, and the lack of customised software support tools made the entire software development engineering process even more complex.

Faced with this challenge, the pioneer engineers made good use of their knowledge and resources to develop customised tools to facilitate software design, coding and testing. Although the customised tools and software skill set developed internally were inefficient by today's standard, these engineers who had gone through the early years had their skills sharpened in overcoming the difficulties through the development of in-house tools and processes.

They also had to train subsequent batches of real-time software designers and developers, and despite the demanding efforts, managed to build up a very competent and experienced group in ESW over time.

Today, ESW has expanded to a sizeable pool of engineers covering multiple software disciplines and aircraft platforms, with each platform type supported by a mixed group of veterans and novices. The veterans



Experience chart of engineers in ST Aerospace's engineering software department, as in 2015 provide stability and quality assurance of the software produced while the young engineers bring with them new ideas and different perspectives. The experience profile of ESW represents a healthy distribution of engineers at various levels of experience. As part of their career growth, some of the more senior software engineers would move to quality assurance, product development, systems engineering and programme management. The sustenance of a strong software group is a key responsibility of ST Aerospace, MINDEF and the RSAF, to meet the strategic need of the SAF.

Many of the early software engineers were trained overseas, working alongside OEMs' engineers to co-develop new features for the systems acquired by the RSAF. This not only improved the engineers' knowledge of the systems concerned but also prepared them to support the systems upon their induction into the RSAF. Despite being relatively inexperienced then, the software engineers never failed to impress the OEMs on their ability to adapt to the new engineering requirements.

One of the pioneer batches of software engineers working in an overseas OEM premises

In an upgrade programme, the best-in-class and value products and sub-systems might be integrated to form the best system that money could buy. However, software from these different OEMs might be written in different languages and developed using different tools. In recognition of this, and in order not to allow these to impose any limitations on the RSAF, ESW has evolved to become very flexible and adept at managing multiple software languages under this unique circumstance.

The software codes inherited from the various OEMs from the 1980s include Coral, Jovial, Ada, C and assembly languages. Software integration required software language interoperability and software engineers had to write codes to 'gel' data representation and calling mechanisms between different languages. This made software integration a laborious task and, very often, a perfectly seamless integration might still not be achieved. Code reusability and sharing of common resources like software libraries would also be hampered.

In addition, as there was no standardised software process to govern the entire software development work, the quality of the software developed could not be assured. Most importantly, software safety requirements might not have been fully addressed. As an illustration, a typical software failure that would adversely affect safety in software would be the "division by zero" defects. When a division is been performed, the denominator represented by a variable might drop off to zero unexpectedly. When this happens, the software usually terminates abruptly. Imagine the impact, should the pilot be performing some critical mission and suddenly he/she loses all the information that determines the success of the mission!

This situation can be prevented if good software safety practice has been observed to ensure that the envisaged situation will never happen. The onus is on the developer of the software to ensure the integrated package has addressed such potential situations that might compromise the outcome of the mission.

Software Safety

Software safety has always been an important aspect of software engineering practice. What is software safety? In essence, the basic idea behind software safety is to ensure that the source codes are tested to validate its execution correctness and performance. All abnormal observations have to be identified, diagnosed and fixed before any software release can be released to the users.

In the mid 1980s, the software engineers relied mainly on "brute force" or intensive testing of the system and eyeball scrutiny of the many lines of source codes in the then standalone systems to detect software defects. There were then very few certified tools to automate testing and detection of software defects. Trying to detect software defects by brute force is laborious and unreliable. Elusive software defects also tend to evade detection by eyeballing. Nonetheless, when the software packages were mostly standalone and simple, reliance on brute force methods to detect and resolve software defects was still possible. This would, however, not be practical for the more complex and integrated systems in today's scenario.

As part of the development process, a software hazard severity and risk assessment has to be incorporated into the standard process. A Software Risk Index Matrix is established to determine the degree of criticality of the safety critical software. For illustration, an example of Software Risk Index Matrix is shown below.

For software modules that are identified with Software Risk Index 1 and 2, additional tasks and tests (code coverage) must be conducted to attain "100% decision coverage" (very thorough testing) before the software is released.

An example of software module that is likely to be identified with Risk Index 1 is the software that manages critical events like weapon release. In the event that the software for this module fails to operate as intended, one possible outcome is that a weapon might be released erroneously resulting in extensive damage.

By identifying this module as having Risk Index 1, engineers have to focus their efforts to perform the required tasks to ensure 100% safety of this module.

Hazard Severity Category		F*	P	O	R
Catastrophic – Could result in death, permanent total disability, loss exceeding $A	**I**			**3**	**5**
Critical – Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, loss exceeding $B but less than $A	**II**			**4**	**5**
Marginal – Could result in injury or occupational illness resulting in one or more lost work day(s), loss exceeding $C but less than $B	**III**	**3**	**4**	**4**	**5**
Negligible – Could result in injury or illness not resulting in a lost work day, loss exceeding $D but less than $C	**IV**	**4**	**4**	**4**	**5**

*F – Frequent P – Probable O – Occasional R - Remote

The interpretation of the Software Risk Index is as follow:
1 – High risk 2 – Serious risk 3 – Medium risk 4 – Low risk 5 – Negligible risk

Example of Software Risk Index Matrix

Software Development Model

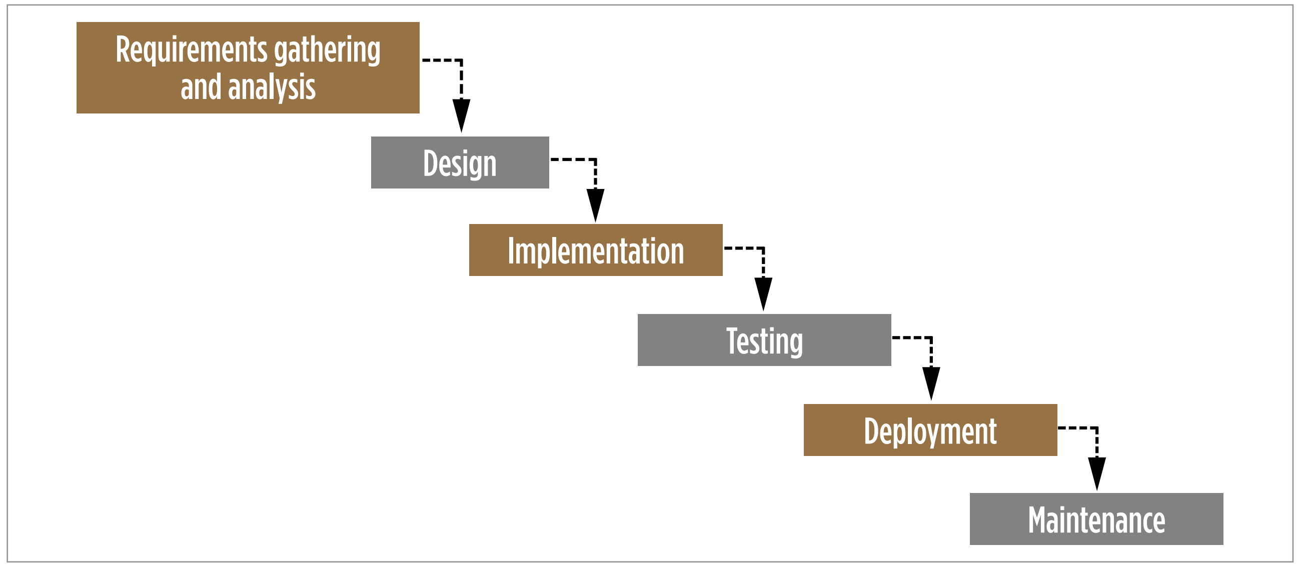
As the software package becomes larger and more complex, the number of embedded software defects is expected to increase. Holistically, a good software development model is required for the entire software development process. It is also necessary for the development of real-time software to comply with certain standards in order to reduce and, if possible, prevent software defects.

There are many software development models available to achieve the desired objectives. The Waterfall Model, also called the linear-sequential life cycle model, is one of the oldest models used. It is simple to understand and use for projects which are relatively small and requirements are defined. At the end of each phase, a review would be done to determine if the development needs to be redesigned or reworked. In this model the testing starts only after the development has been completed. Due to the complexity of the software ST Aerospace was developing, the Waterfall Model was deemed not suitable. Instead a newer software model called the Incremental Model was adopted.

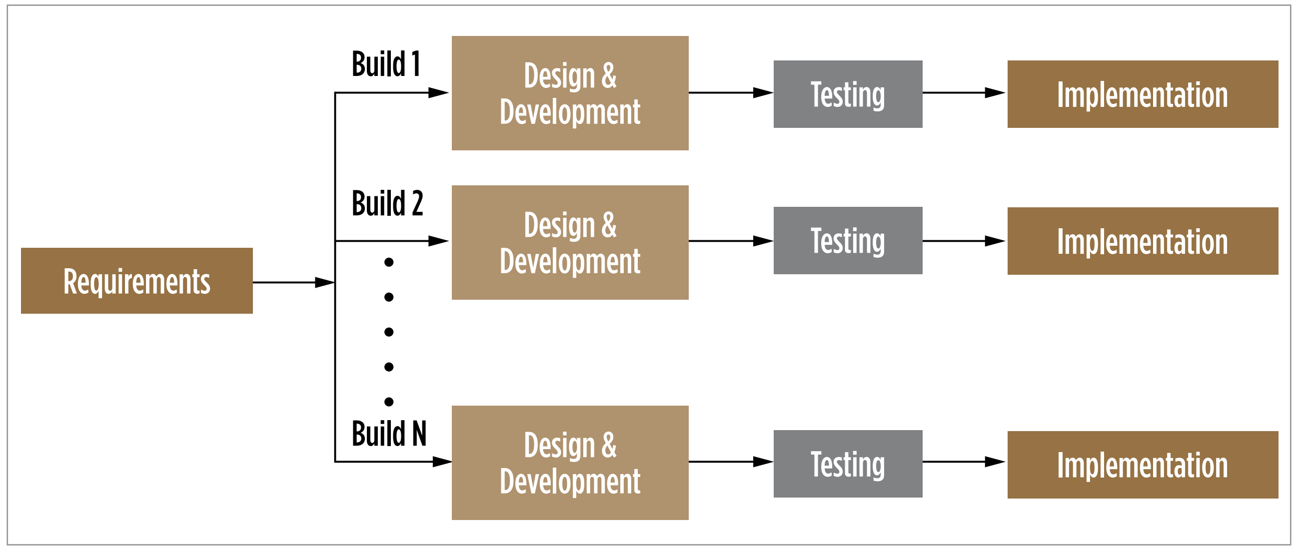
The Incremental Model requires the user to be familiar with the systematic approach methodology encompassing good planning and the ability to have a clear definition of the whole system designed. To illustrate, the entire software requirement could be divided into various builds so that multiple developments could take place concurrently, creating a "multi-waterfall" model. Cycles are divided up into smaller and easily managed blocks. Each block passes through the requirements, design, implementation and testing phases. A working version of software is produced during the first block, so a working software is available early in the software development cycle. Each subsequent release of the block adds new function(s) to the previous release. The process continues until the complete system is achieved.

The Challenges Faced in Software Integration

Software integration is a process used to link different software applications together to function as a coordinated whole. During this process many software "bugs" may be discovered, and the common causation may be due to misinterpretation of the operational requirement, or the operational requirement is not definitive enough. As a simple illustration, a designer may state in the requirement document that the display symbol shall "breathe", intending for the symbols to change in size every second. If the programmer who translates this requirement into software codes choose not to clarify the exact requirement with the designer before software coding, incorrect interpretation may result.



The Waterfall Model



The Incremental Model

Another challenge faced during software integration is the absence of actual equipment or subsystems that the software has to communicate with. It is normal to use emulators to represent the equipment which cannot be physically available during software integration testing. An issue may be that the emulators delivered by the equipment or subsystem suppliers may not have a sufficiently high fidelity to the equipment it emulates. This results in a requirement to conduct multiple iterations during testing. As an incentive to the party responsible for supplying the emulators to supply emulators of high fidelity, and to minimise exposure to self, the supplier will be made accountable for any unnecessary iterations due to the emulators' non-performance.

The challenges mentioned above are some of the pitfalls that have to be overcome, and as they are being overcome, new ones may surface when dealing with the development of highly complex real-time software with stringent testing acceptance criteria. To minimise the impact and risk to the development programme, ST Aerospace put in place a process to ensure consistency in the software it developed.

Software Process Certification

In the early 2000s, a decision was made in ST Aerospace to benchmark its software development process through a globally recognised model – CMM. CMM is a process improvement training and certification programme developed by Carnegie Mellon University. It is a requirement for US Government contracts involving software development.

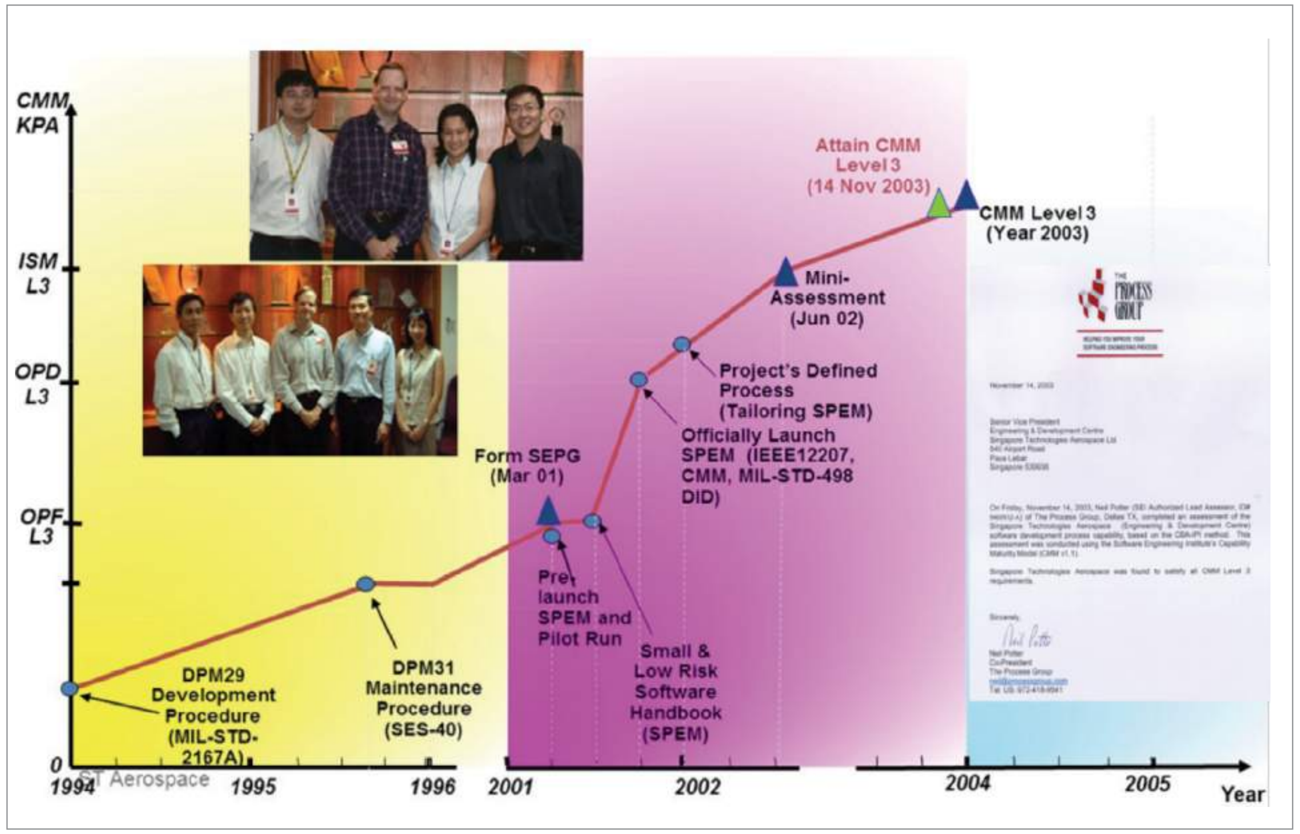
The motivation for going through the benchmarking process was to build up a robust internal system that would be internationally recognised. Equally important, compliance with the standard meant the system in place has the capability to share data and lessons learned across all projects handled by the company, hence ensuring continuous enhancement of the experience level within the organisation. This was particularly important especially after the dot.com bubble imploded in the late 1990s and early 2000s, as high mobility of experienced software engineers was common. Although the company had been fortunate to retain most of its engineers over the years, the ability to assure the sharing of information and lessons learnt would nevertheless be beneficial.

ST Aerospace's software development process was accorded CMM level 3 recognition in November 2003 by a six-member team led by Mr Neil Potter, SEI authorised lead assessor of The Process Group. CMM level 3 provided a set of guidelines for ST Aerospace to develop and refine its processes during software planning, management, development and integration to deliver better software products. Attaining CMM level 3 assured ST Aerospace's customers that its processes were operating at an international standard and the required infrastructure was in place for continuous improvements. CMM level 3 is today specified as entry criteria for most government programmes.

To ensure the software development process continued to comply with the best code of practice, ST Aerospace established a set of process engineering manuals which would ensure the system in place would continue to improve over time. With this rigorous process the company would be able to manage the software requirements and configuration better. Schedules and resource estimates would also be more accurate.

Potential

With the software competencies that ST Aerospace has acquired over the past 25 years and a good spread of experience levels amongst a sizeable pool of software engineers, ST Aerospace is well equipped to support MINDEF's and the RSAF's future development requirements. A key factor to ST Aerospace's ability to build up new software knowledge over the years has been the availability of challenging development work and the self-renewal of its software manpower resource pool. Young engineers with fresh minds are continually inducted and trained. They are deployed on actual project works under the guidance of their more experienced colleagues using well-established software development process. The good retention of capable software engineers over the years led to the build-up of experience in ST Aerospace which is essential to meet the exacting needs of the RSAF.



ST Aerospace journey to CMM level 3 certification

The most important factor making this possible has been the existence of interesting and demanding work. Where possible, more senior software engineers are also deployed in affiliated engineering roles like systems engineering and programme management so they get personal enrichment in scope of experience, as well as to contribute to overall system development capability of ST Aerospace.

The build-up of a strong software development capability is essential to the system development capability of ST Aerospace. Together with the other engineering disciplines, this provides a complete repertoire of skill set to develop and sustain the important requirements of MINDEF and the RSAF. The software capability, like most other engineering capabilities, is not domain dependent although there is domain knowledge relevant to certain applications.

In the aero-mechanical and electrical engineering world, ST Aerospace has leveraged its military engineering capabilities to undertake major commercial aviation engineering work like PTF conversions. The software capability completes the ability of ST Aerospace to undertake avionics systems upgrading work on commercial aircraft.

Section 4.3

Electromagnetic Compatibility Capability

In a winter night on 22nd December 1920, the radio station of KönigWusterhausen southeast of Berlin broadcasted the Christmas concert of the German mail officials. It was a live event near the famous castle of KönigWusterhausen and the audience included the German Chancellor Hermann Müller. The Chancellor was not very amused by the electrical noise interference generated by vehicles passing by and he gave orders to immediately prevent such disturbances. The hour of "radiated emission" had come and was then later on called EMC[1].

EMC means nothing more than "an electronic or electrical product shall work as intended in its environment. The said product shall not generate electromagnetic disturbances, which may influence other products in its vicinity". In other words, EMC deals with problems of electromagnetic noise emission as well as electromagnetic immunity of electronic and electrical products and systems.

During the Second World War, the use of electronics devices such as primary radios, navigation devices and radars accelerated. Instances of interference between radios and navigational devices on aircraft began to increase. Since then, agencies around the world started to control and regulate the allowable electromagnetic emissions from products and systems.

In the early days when the RSAF's aircraft modification and system development projects were first carried out, the impact of EMC was new and not much was known about the subject. There were no experts around to learn from in the aviation community. EMC could appear as something mysterious or daunting and had earned the nickname "black magic" as it was not easy to understand what caused EMI. After all, the problem was different from classic electrical/electronic circuit theory and so could not be dealt with using conventional method. Despite this,

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[1] Sources from Diethard E.C. Möhr, Secretary of IEC TC77 EMC

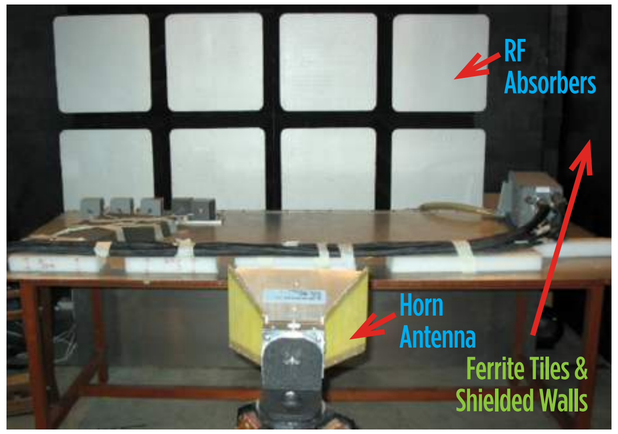
EMC test on F-5 aircraft

the various engineering groups in the RSAF and the defence industries like ST Aerospace had to quickly establish EMC expertise in parallel with the major military aircraft modification and upgrading programmes. Test and measurement equipment for EMC testing and troubleshooting, like a basic spectrum analyser which was the tool of the trade, cost almost as much as a private car then.

MINDEF was very supportive of developing local capabilities in aviation EMC. Opportunities were created for engineers to be attached overseas to learn this skill. With this strong support, engineers in MINDEF and the defence industries had, over the years, accumulated invaluable experiences from numerous local and overseas projects. Engineers undertaking major projects recognised the importance of considering EMC at the beginning of a project or product development life cycle. The engineers quickly learnt from their experience that if EMC had not been taken into consideration from the onset, the outcome would likely be a costly rework later.

This is especially so for product development of airborne equipment, where specifying and planning for the product EMC qualification and certification is an essential phase of the job. Examples of these included the development of in-country aircraft mission computers by ST Aerospace for various military platforms such as the Super Puma helicopter, and the F-5 and F-16 fighters. In these projects, EMC considerations were incorporated in the design right down to the printed circuit boards by applying important design rules to high speed digital designs. In today's technology where computer processor speed can more than double every period and data are sent at ever increasing speed, there is a need to constantly keep abreast of the latest development on EMC matters and work closely with the designers to maintain electromagnetic compatibility.

It has taken years to establish a good EMC working culture among the local defence engineers but it is not always easy to implement EMC considerations into products during initial design. Airborne equipment not only demand robustness in EMC but also in other variables like thermal performance and mechanical structure strength, as well as resistance against many other environmental elements, all within weight and size constraints. Despite these seemingly contradicting requirements, the culture of compliance with established processes has become ingrained in the EMC engineers.



Product EMC testing in a semi-anechoic chamber

Every variant of locally developed mission computers by ST Aerospace and special mission equipment by DSO, for example, was put through an extensive series of EMC qualification tests, as required by military standards on EMC. These products, designed and built to meet stringent EMC conditions, would then be able to work reliably in their intended operating environment.

EMC compliance does not stop at the product (equipment) level. It is carried on to integration on the aircraft, followed by EMC ground and flight tests. EMC tests at aircraft level focus on the compatibility and interoperability between the new and existing aircraft systems. Since the 1990s, ST Aerospace had carried out numerous EMC tests on aircraft, to ensure there were no EMI concerns, particularly with communication and navigation systems, by performing on-board receivers and transmitters measurements.

From the early days, when very basic analogue test equipment was used for EMC tests, test capabilities had been enhanced through the continuous introduction of state-of-the-art test equipment and by developing in-house test software to improve EMC measurement accuracy and increase test efficiency through equipment connectivity and automation.

Electromagnetic-field measurements of an EC-120 trainer helicopter

Since the beginning, aircraft EMC tests were conducted in enclosed space like a hangar and had to contend with aircraft transmission

Inflatable EMC shielded shelter

reflection and receiver interference. Very often, the A-4 and F-5 fighter aircraft under test had to be towed to an open field for EMC tests but this exposed both the aircraft and test equipment to the elements. An anechoic chamber would be the answer but that would be costly. There was a need to find a way to house the aircraft cost-effectively and yet minimise unwanted electromagnetic signals and noise from its surrounding environment. One of the pioneer engineers in the EMC group thought of an innovative solution, borrowing the idea from portable tents in children playground to provide an environment for conducting aircraft-level EMC tests without investing in multi-million dollar shielded chamber.


Mini inflatable EMC shielded shelter

The concept was to build an “inflatable EMC shielded shelter” big enough to house a typical fighter jet. This was possibly a world-first EMC shelter of such concept. The idea was validated with some time and effort from a handful of engineers. The shielded shelter was completed successfully and put into use.

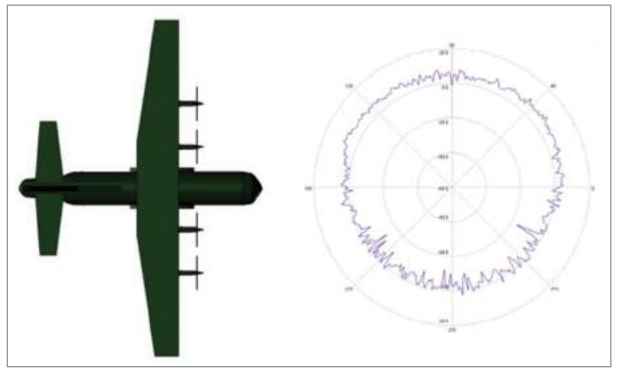
There were other applications that spun off from this idea, like mini makeshift shielded chamber for use at remote test site. This proved to be very useful for testing of small components and products, providing a quick means to perform measurement in an electromagnetically quiet environment. This concept changed the approach from bringing the equipment to the test chamber, to bringing the chamber to the equipment, wherever it may be. It was especially useful where the equipment was too big or difficult to move. The chamber could also be custom-built to the size needed for the equipment being tested.

Another important area is EMC safety for ordnance, fuel and personnel. EMC is a critical aspect of aviation safety as it involves human and aircraft safety.

An illustration on the importance of EMC to ordnance safety came from an incident that happened on 29th July 1967, when the US aircraft carrier USS Forrestal was deployed off the coast of the then North Vietnam.


Fires on board USS forrestal following a catastrophic EMI incident (Source: The United States Navy, Photo #USN 1124794, PD-USNavy)

In another example, during the prototype test phase of the F-5 upgrade programme, it was found that a particular aircraft radio communication transmission caused some of the aircraft flight control surfaces to jitter slightly. It was established to have been caused by shield leakage. The electromagnetic radiations emitted from the radio transmission managed to penetrate the aircraft metallic skin and was coupled to the flight control wirings. This could have been catastrophic if it had not been discovered earlier, as it could lead to the aircraft going out of control in flight. This was avoided as the cause for the electromagnetic interference was quickly traced and corrected through proper shielding.


EMC modelling and simulation

New ways of ensuring EMC in aircraft were always being explored. One such development involved EMC analysis. In past projects and even in today’s small-scale projects, EMC predictions would usually require physically bringing in the aircraft concerned to perform measurements to collect data for further analysis work. These could result in reduced aircraft availability for the customer. Such inconvenience could be overcome by using software simulations in place of a physical measurement for large-scale projects, and the reduction in cost and effort involved would be worthwhile. Working closely with the Institute of High Performance Computing (IHPC) of A*STAR, Singapore, software simulations applications were developed to identify preferred locations for new aircraft sensors installations. For example, on one of the aircraft upgrade project, both aircraft radio frequency measurements and EMC software modelling and simulation were employed for EMI/EMC analysis and prediction of incompatibility between multiple transmitters and receivers. In this case the research capability of A*STAR was gainfully employed to develop new modelling tools to improve EM prediction.

On the commercial aviation front, extensive EMC experience was gained over the years from working on Boeing and Airbus aircraft, and ST Aerospace had applied its EMC knowledge and skills in various development work like PTF conversion, and aircraft interior modification and upgrade. In these projects, EMC testing was part of the critical requirements for CAAs’ certification.

The trend in commercial aviation has been moving towards wireless in-flight entertainment and in-flight Wi-Fi data access, both utilising dual-band links. The aviation industry will be gearing up to meet this demand of customers for electronic accessibility during flight and that would require better knowledge and application of EMC techniques to achieve the desired outcome.

In the years ahead, aerospace technologies will advance rapidly towards technologies enabling better connectivity with smart devices, advanced aircraft systems and even between different aircraft, utilising high speed transmission to transmit huge amount of information. These would contribute to more EMI in the already heavily congested frequency spectrum, putting even more emphasis on EMC control and thus making it an indispensable part of future development working skills. Although the EMC capacity has matured over the years, the capability will continue to evolve to support the requirements of aviation companies' efforts to meet aircraft EMC standards and regulations for aircraft safety.

Section 4.4
Establishing a Global MRO Footprint

ST Aerospace’s core commercial aviation business is as an aviation MRO and engineering service provider. It operates on a global basis supporting the requirements of passenger and freight airlines. The scope of its MRO capabilities covers aircraft, engines and components. In terms of its aircraft MRO operations, it has facilities in two locations in Singapore, two in the US and two in China. The capacity of its aircraft MRO operations was reported to be the largest in the world since 2012, according to surveys by Aviation Weeks to date. Its aircraft MRO undertakes maintenance and engineering modification work including PTF conversions.

Beyond aircraft MRO ST Aerospace also undertakes engine and component MRO. Its engine MRO is in Singapore and China, while its component MRO is in Singapore and Europe (where it provides PBH support). These activities were not included in the Aviation Weeks survey as it covered only airframe MRO.

While ST Aerospace is a global MRO from a physical presence perspective, what is perhaps more important is its global customer base which is what makes its global MRO network feasible. The customer base includes a wide array of commercial aviation operators large and small. Amongst its global customer base are all the major freight airlines and many of the world's largest airlines. It includes many significant LCCs and many smaller commercial aircraft operators. ST Aerospace also works closely with the major aircraft, engines and components OEMs to support their requirements and that of their customers.

Global MRO Network

To be able to deliver its services to its customers, ST Aerospace established its global MRO network over the years, starting from early 1990s. Broadly, its US aircraft MRO operations supports its customers in the US while its China MROs support its Chinese airlines customers as well as its international customers flying into China. Its Singapore MROs support its global customer base operating in Asia, as well as in other parts of the world. It has also a good spread of military customers from many countries around the world.

ST Aerospace's global facilities

Its American aircraft MROs in Mobile, Alabama and San Antonio, Texas serve the largest commercial aviation market in the world where some 50% of the world's commercial airlines flying hours are flown. Its China operations in Shanghai and Guangzhou are in one of the fastest growing commercial aviation market in the world. Its operations in Singapore serves many global and regional airlines because of Singapore's central location and position as a major aviation hub to which a large number of international and regional airlines operating in Asia fly to.

Many of its larger customers operate on a global basis and are supported by ST Aerospace from more than one of its global operations. As an illustration, FedEx is supported for airframe MRO and PTF conversions by Mobile Aerospace in the US, and SASCO and ST Aerospace Engineering in Singapore. When UPS wanted to convert MD-11s to freighters, it had the work done by SASCO, the centre of excellence for MD-11 PTF conversion, while its MRO is undertaken by SAA. Delta Airlines is supported by Mobile Aerospace and SAA in the US, SASCO in Singapore and STARCO in China. Both JAL and ANA have their work done by SASCO and STARCO.

On Competition and Competitiveness

Competition in the commercial aviation MRO market is very high. Of the different commercial aviation MRO activities, the one with the lowest barrier to entry is commercial aircraft MRO. Engine and component MROs have different competitive considerations which raise the barriers to entry somewhat.

The bulk of the outsourced aircraft MRO work is in HMVs and major modifications, works which may require both MRO and engineering capabilities of the service providers concerned. Most airlines, and even many of the LCCs, do their own line maintenance as it is nearer to their operations. However, they usually do not have the scale and cannot utilise the large number of highly skilled manpower needed to do their own HMVs and major modifications efficiently.

There are many types of service providers offering heavy maintenance capabilities ranging from airline owned MROs leveraging capabilities they have built up to support their own fleets, major independent third-party service providers like ST Aerospace, and a number of smaller MRO companies leveraging whatever form of accessible financing and other advantages to try to secure a foothold in the market.

In HMV and major modification, where more in-depth engineering capabilities and experience might be needed to resolve technical problems experienced during such work, ST Aerospace has internal capabilities in engineering that it can draw upon to support its commitments to its customers. This is by virtue of it being one of the very few MROs with significant engineering design capability. This is recognised by its major customers as an important consideration whenever problems surfaces which are not in the realms of normal maintenance or repair requirements.

Also, on freight aircraft, especially those that are developed by ST Aerospace, it has significant advantages because of its intellectual property, engineering know-how and experience.

Competitive Advantage

In the early 1990s, ST Aerospace entered the commercial aviation MRO space leveraging its military aircraft MRO experience. Over the last 25 years, it developed its commercial aircraft MRO and engineering capabilities. These have given it a strong competitive advantage through the scope of its offerings, the ability to bring capabilities and resources to bear, and its service standards.

Fortunately, aviation is an area where price is not the only consideration of most customers. Quality of work performed on their aircraft and safety of their fleets are equally, if not more, important to most customers. However, in the highly competitive environment that airlines operate in today, cost and hence "value for money" is always important.

The competitive advantages that ST Aerospace depends on in its commercial aviation business as a MRO are the quality of its service, responsiveness to customers' requirements, and its ability to perform.

Drivers Affecting Outsourcing and Being Cost Competitive

Many of the larger airlines, especially those in the US and those in high cost locations, have taken a firm policy to do less in-house MRO over time because of exceedingly high internal cost and recognition that they would not have the cost structure nor scale of operations to undertake their own heavy maintenance in-house. Some also consider MRO as distraction to their managements' primary responsibility of running airlines.

In addition, while it might have been necessary in the old days for major airlines to do their own HMVs to ensure their aircraft were well taken care of, this is no longer a persuasive argument as there are today significant and competent MROs to outsource such work to.

Third-party service providers have to keep their cost structure low to be competitive, lower than the cost of their customers' internal cost and more competitive than their competitors. Besides discipline and efforts to improve efficiency, an advantage for major MRO service providers is the scale of their operations as a result of their ability to aggregate work from different customers. The ability to offer affordable prices, however, depends on an MRO's cost. MROs have to cover their cost and be able to make a reasonable return. This is important if they are to continue to serve their customers on a long-term basis.

Over the years ST Aerospace has undertaken many initiatives and invested in programmes, including lean initiatives like "Kaizan", to improve on its efficiency and to achieve a better cost structure. Each aircraft MRO must also be capable of attaining a certain critical scale to be cost effective. While driving cost down, ST Engineering is aware that it has to be done without compromise to quality and performance. Evolving a company culture to recognise and deliver high quality and performance is important and can only be achieved through consistent efforts.

One Key Resource

Equipment can be bought, hangars can be built, and spare parts can be stocked. All are important to an MRO and can be done at a cost and some lead time. But the most important resource of any commercial aircraft (and other types of) MRO is perhaps its trained and experienced human resource. For an aircraft MRO, its pool of LAEs, as known in most of the world and as A&P mechanics (designated as "A&P") in the US, is one of its most important human resource and is in fact one of its strongest competitive advantage for delivering safe aircraft on time and making a profit! It is a requirement to have well-qualified and competent LAEs (or A&Ps) to do a job well.

Experienced and skilled personnel of all categories are always hard to come by in any organisation, and in commercial aviation this is something that has to be managed well to be able to deliver quality work consistently. In the case of LAEs where training, qualification and experience take many years, it is important to be able to retain such experience and skills. In addition, company culture is important in maintenance and this could only be ingrained over time.

Having enough LAEs (or A&Ps) is necessary but skilled personnel are costly. It is not only costly to train staff but there is a recurrent cost to maintain their capabilities. The resource is also perishable and, if not used, is lost on a day-to-day basis. In most MROs, having sufficient LAEs (or A&Ps) is not a given.

To maintain its critical manpower resource, all ST Aerospace MROs have a structured in-house training programme to produce LAEs especially and other essential staff, in sufficient numbers for its needs. In the US, A&Ps are trained under the company's sponsorship. Depending on the opportunistic availability of LAEs (or A&Ps) from the open market is not a viable proposition.

Good LAEs or A&P Mechanics may be available from the market at times and some have contributed much to the company over the years, but this cannot be the primary approach for any serious company to depend on this critical resource being available in the right numbers and at the right time.

It was in recognition of this that ST Aerospace started its own LAE training programme in Singapore in 2000. Previously, when its requirement was small, it depended on training courses from airlines as some airlines who organised such courses for their own LAE trainees did accept other airlines and MROs' trainees for a fee. In view of its decision to expand its commercial aircraft MRO in a serious way in early 2002, it could not depend on opportunistic availability of such training courses. To be a leading global MRO, it must have assurance about its own supply of this critical resource. Otherwise, it would be facing a perennial problem which could not be fixed quickly.

Besides training LAEs A&Ps on technical skills, an in-house training programme also enabled the company to inculcate a strong sense of quality and commitment of its employees to its values and its customers' needs. In addition, there were also other important aspects like culture and soft skills of its employees. Consistency in performance and predictability are something that customers justifiably expect. To commercial customers, for example, consistency in turnaround time is more important than just speed.

As a reflection of its commitment to training and education to continually upgrade the capability of its workforce, ST Aerospace also seized upon an opportunity in 2006 to induct graduate engineers into its LAE training programme.

Graduate Engineers as LAEs?

In the 2006 CAMP 6 batch of its in-house LAE training programme, ST Aerospace noted that a number of graduate engineers had applied for the LAE trainee positions advertised. Sensing that while the adverse economic environment then might have been a contributing factor, there might also be an opportunity to interest engineering graduates to take up career as LAEs due to the attractive job prospect. The company went ahead to enlist these graduate engineers who passed its selection process as it was of the opinion that an engineering education would be useful. In subsequent years, advertisement for LAE trainees would include graduate engineers as one of the qualification criteria and graduates continued to enlisted as LAEs since.

So a graduate engineer could join ST Aerospace as a design engineer, maintenance engineer or as a LAE depending on his inclinations. Each job has its attractions, and LAEs had made it all the way to the company General Manager's appointment, and done well!

From the company's stand-point, having graduates as LAEs would enhance its ability to serve its customers even better. Although there is a starting pay market adjustment for graduate LAE with an engineering degree, there are no other special advantages accorded to LAEs with a degree as performance was, and should be, the primary differentiator.

When ST Aerospace formed a joint venture company with CEA in 2004 to launch STARCO, and LAE trainees were being recruited from China to be trained for STARCO, it also recruited fresh degree and diploma graduates from institutions of higher learning in China to be trained as LAEs under the CAAC system. So it is at least in Singapore and China that LAEs might have a degree in engineering.

Meeting Certification Requirements of Multiple Aviation Authorities

Certification by CAAs is very important to ST Aerospace. As a global third-party MRO, certification by the relevant CAAs of its board customer base is important to enable its MROs to service their aircraft.

It has to be able to serve a broad customer base registered under different CAAs. Except for those of its MROs which operate within markets where there are sufficient in-country workload, like in the US, having more certifications is an important pre-condition to being able to serve more potential customers.

This is true even for the Singapore market, where the main airline SIA has its own MRO; work for ST Aerospace has to come from foreign-based airlines so having foreign certifications is an imperative to the company!

Even ST Aerospace's MROs in China have to have the ability to undertake work from airlines from outside of China. Although China has many large airlines, the main Chinese airlines have their own MROs as well, and the opportunity to secure work from them is somewhat limited. Hence support of foreign aircraft operating into China is important to ST Aerospace joint venture MRO in China.

The same considerations which apply to qualification of engineers working on aircraft also apply to engine and component MROs.

Business Risk of Aircraft MRO

The most critical business risk for an MRO is during its build-up phase. Whenever a decision is made to invest in a new MRO or in a new country, the biggest issue is not if ST Aerospace has the knowledge to do the work and operate the MRO well. It is about where the work would come from.

The main cost items of an aircraft MRO are essentially the cost of hangars, equipment and at least 300 to 500 employees for a start. The cost of setting up an MRO varies from country to country depending on the unit cost of land, facilities and human resources. These are deterministic. There is also a residual value recoverable from disposal of assets should things not turn out as intended. The cost of ramping up operations is not insignificant and cash outflow to sustain a planned extended period when revenue is uncertain is important. However these are either known or can be planned for. The uncertainty is when would the work materialise?

The ability to secure work was always the unknown. Besides the fixed and overhead cost, the staff cost would continue to be incurred and the risk of incurring operating losses with no idea when it would end was a serious business risk. Although having a global network of MROs and a strong customer base was a competitive advantage, each growth of the network was not without uncertainty. Existing customers would not be able to give the company work which did not exist or which is already committed as well. This, however, did not deter ST Aerospace from its expansion since its inception.

Options for the Starting a New Company

Over the years, as ST Aerospace set up its MRO network of companies, first in the US in parallel with its setting up in Singapore and later in China, the options could be through acquiring an existing on-going operations or setting up a greenfield operations.

Each approach had its pros and cons, and the objective here is not to prescribe which is better but to comment on an important consideration from the customer's point of view.

The systems, processes and management of an MRO were easier to standardise. Skills could be trained. The biggest problem of acquiring an on-going operation was the assimilation of a large number of employees which had been accustomed to certain norms such as in work practices and in expectations. Managing the difference was made more difficult because of the sheer number of people in an aircraft MRO. Existing customers would naturally expect the same touch and feel and would be the first to notice if there were differences in the service they had received. Customers might be persuaded to accept some differences because of people and cultural background but other aspects had to be reasonably similar. As a result, the expectation of ST Aerospace's existing customers towards each new MRO was high.

From an aircraft MRO's perspective, a greenfield set-up might appear less complicated. Its biggest challenge is to build up fast enough to reach the scale needed to be profitable. However, recruiting manpower is never easy and the location of an aircraft MRO is one of the key considerations. Skilled manpower work where it is attractive to work and even different locations within a large market like the US have significant differences from this perspective. The same applies to other large markets like China or Europe. As the risk in a greenfield set-up is the ability to ramp up fast enough to avoid being sub-scale for too long, ready availability of qualified manpower is one of the very important considerations.

Market Access

Proximity to where the work arises is also an important consideration for the siting of aircraft MROs. Pre-positioning cost is an important factor to customers, especially for aircraft MRO work where the downtime might not be very long.

When ST Aerospace ventured into the US market in the early 1990s, it had just started doing commercial aviation MRO work in Singapore. It had not yet established itself as a credible service provider and was not known to airline customers in the US then. SASCO, in Singapore was on similar uncertain grounds. Singapore seemed to be an unlikely place to undertake commercial aircraft MRO work as its cost of labour was higher than most of Asia. In addition, many Asian airlines had their own MROs.

However, some 50 percent of commercial aviation flying was flown within the US, and while many of the US major airlines did their MRO in-house in the early days, there was still the potential. This potential was realised in later years when many major US airlines became leaders in outsourcing of their heavy MRO work. Other major US airlines subsequently decided to shed their MROs as well, as part of their restructuring due to airline level losses as a result of intense competition and high fuel price. The higher cost for HMVs if done in-house and the globalisation of their operations had made centralisation of MRO within their respective home bases impractical.

So, MAE was in the right market and that certainly helped in its ability to gain access to work from the airlines and freight operators. But, as explained, it was its performance on work for FedEx, to deliver the first FedEx B727 PTF conversion, that gave MAE its first major customer from which it managed to grow its customer base.

Against tremendous odds, ST Aerospace's SASCO in Singapore overcame its disadvantages and became highly successful, again largely through its performance. It understood well the importance of quality of service and being responsive to customers, and performance. Although there was no in-country airline work, it managed to secure work from many airlines around the world, from as far as North Asia, the US and Europe. The central location of Singapore and it being an important aviation hub helped but those major customers could have gone anywhere else to get their work done. Fortunately, they decided on SASCO because of their favourable experience. ST Aerospace's presence in the US also helped draw many major US passenger and freight airlines who operated in Asia to consider SASCO favourably. But it was ultimately SASCO's performance as an MRO that made it a preferred centre for many global airlines.

The move to China was not for work from the fast growing Chinese airlines. Those MRO activities from China's main airlines were mostly done by the airlines themselves. The objective for going to China was to provide an option to foreign airlines operating into China. A large number of these airlines were already customers of ST Aerospace or were aware of the ST Aerospace brand name.

Importance of Customers

For an Independent third-party service provider like ST Aerospace, its customer base is most important. Every customer is important and, having internalised that it is easier to retain a customer than secure new ones, there is no difficulty in reconciling the company's interests with the customers' interests. Operationally, repeat-customer's workload is also important as improvements in efficiency will not be possible if each job is new.

Some examples might best illustrate the positive outcomes that had helped to build up ST Aerospace's customer base over the years.

The most important first success for MAE was gaining FedEx as a customer through its performance. From then on, it continued to support FedEx well as it extended its support to Boeing, North West Airlines, UAL, Continental Airlines (now merged with United Airlines) and others.

When SAA was acquired, UPS became one of its early customers as it was looking for a reliable service provider. Up to then, UPS was not a customer of ST Aerospace. UPS continues to be with SAA today and had since inducted work on PTF conversions and HMVs to ST Aerospace's companies in Singapore.

JAL was a shareholder of SASCO and helped to build it up. It became an important customer for SASCO and continues to be so to this day. Subsequently, ANA, the other major Japanese airlines also became a customer and the relationship grew with many different outsourced work from ANA, including HMVs, cabin modifications and B767 PTF conversions. SASCO served both JAL and ANA well and has a very strong customer relationship with both.

North West Airlines was a long-time customer but unfortunately it went into Chapter 11 in 2005. Throughout the period when it was under Chapter 11, ST Aerospace continued to support its MRO requirements, including its short-term checks. This enabled the airline to continue flying throughout this period and after it emerged from Chapter 11, the relationship continued. Subsequently North West Airlines was acquired by Delta Airlines which also became a major customer for ST Aerospace on a global basis.

Recognition, creditability and track record are important competitive advantages in aviation but they are not enough to sustain any relationship. Performance and trust between customer and the service provider are perhaps even more important.

Over the years, the company has built up a very credible customer base, one that even its competitors acknowledge. What is perhaps also significant and interesting is that amongst its customers are many natural competitors in their business operations - large airlines, leading freight operators, legacy airlines and LCCs, and many smaller customers. To illustrate, JAL and ANA are natural competitors in their airline business, but they are both very important customers of ST Aerospace. So are FedEx and UPS.

Leveraging all these considerations, ST Aerospace established a competitive and global MRO. As a business entity, ST Aerospace joined the ranks of Singapore companies that have managed to grow beyond the shores of Singapore to serve its growing international customer base. Notwithstanding this, it has remained firmly established and committed to its role to support Singapore's defence needs.

Section 4.5
Passenger to Freighter (PTF) Conversions

Beyond B727 PTF Conversions

Following the conversion work for FedEx B727 in the early 1990s, SASCO in Singapore and MAE in the US continued to perform third-party aircraft modification work on commercial aircraft which changed the configuration of aircraft according to designs approved by the different CAAs. Such modifications were engineered by the OEMs and released in the form of SB, or by after-market non-OEM specialist design houses which possessed the necessary engineering design and substantiation processes, as well as modification kit manufacturing capabilities and conversion of the aircraft. The latter modification work would typically be certified by the CAAs as airworthy by way of an STC.

Sasco scores regional first

ST AVIATION Services Company (Sasco), a unit of Singapore Technologies Aerospace (ST Aero), has scored a first in South-east Asia by converting a DC-10 passenger aircraft into a freighter.

ST Aero said that the technically complex conversion was completed yesterday, 20 days ahead of the contract's schedule.

The aircraft will be delivered to the Boeing group later this month.

The Boeing Capital Corporation, a worldwide provider of lease and loan financing for commercial aircraft, will then place the aircraft with an operator, ST Aero said in a statement yesterday.

Sasco is a leading third-party repair station, specialising in heavy maintenance of airframes and modifications of commercial aircraft.

ST Aero is a member of Boeing Airplane Services' international network of modification and engineering facilities.

ST Aero president Wee Siew Kim said that this was one of a number of conversion projects the company had lined up with the Boeing group.

"We will strive towards achieving greater mutual benefits on our many collaborations with Boeing, here and in the United States, where we are working on the Boeing 757 conversion," he said in the statement.

Passenger-to-freighter conversions have been rated the most technically complex of aircraft modifications, entailing the reconfiguration of all the features of a passenger aircraft.

Achievement announced on the Straits Times on 7th November 2000

(Source: The Straits Times © Singapore Press Holdings Limited. Permission required for reproduction)

Following the B727 PTF conversions, ST Aerospace undertook conversions for wide-body aircraft like the DC-10, MD-10, MD-11 and B-767-300 for Boeing. Beyond Section 41 termination work, it did other major modification work like the B-747 pylon modifications.

Anticipating strong demands for DC-10 and MD-10 PTF conversions (the MD-10 PTF included the conversion of the three-man cockpit on a DC-10 into a two-man MD-11 cockpit configuration for FedEx), Boeing set up a number of sites to undertake the conversions. Amongst them were well-established conversion houses like Aeronavali in Naples and Venice, Italy, and IAI-Bedek in Israel. MAE was awarded the DC-10/MD-10 conversion programme, mainly for FedEx, in 1997 because of its good performance and its positive relationship with FedEx. SASCO was later selected in 1999 as the second site in ST Aerospace for this work.

The first DC-10 PTF conversion by SASCO was in year 2000. SASCO had the advantage to learn from MAE's experience on the DC-10 PTF conversion. The conversion was completed ahead of schedule and Boeing's Programme Director, Mr Jack Jewell in his speech during the re-delivery ceremony, commended that of all the conversion sites that Boeing had set up, SASCO was the only site that was able to re-deliver its first DC-10 ahead of schedule. However, SASCO only managed to convert one more DC-10 as the DC-10 PTF conversion demand anticipated by Boeing, did not materialise. However, this led to a demand for MD-11 PTF conversions instead as the MD-11 aircraft was a newer aircraft and was being replaced as a passenger aircraft by new Boeing and Airbus deliveries.


UPS MD-11 freighter converted by SASCO

Then, UPS contracted Boeing to convert 38 MD-11 to introduce the MD-11 freighter into its fleet. SASCO competed against well-established PTF conversion houses for this programme. It managed to convince UPS and Boeing to win the MD-11 conversions award based on its good performance track record and experience on the FedEx MD-11 MRO inspection checks which it had been doing since 1998. The UPS prototype aircraft conversion was completed and re-delivered on time for UPS to launch the MD-11 as part of its fleet expansion. Following this, SASCO successfully completed the other 37 MD-11 conversions for UPS.

Initially, the converted UPS MD-11 fleet was maintained by SASCO. Subsequently the maintenance of the entire UPS fleet was transferred to SAA because of UPS's operational requirements. SASCO continued to do well and secured more MD-11 PTF conversions from FedEx, Lufthansa Cargo and other operators and became the centre of excellence and preferred facility for MD-11 PTF conversions and MRO globally. SASCO converted a total of 68 MD-11 over a short span of seven years. In 2004, SASCO was selected for the Boeing Supplier of the Year Award for its performance on the MD-11 PTF programme.


First ANA B767 PTF conversion by SASCO

SASCO's good performance was well recognised and acknowledged by Boeing. So in 2008, when Boeing decided to move its B767-300BCF conversion programme from one of its European conversion facility, it decided on SASCO. Boeing was contracted by ANA to convert seven B767-300s. As the programme was behind schedule, Boeing decided to move the programme to SASCO. ANA was pleased with Boeing's decision because it was familiar with SASCO's performance. SASCO lived up to its commitment and together with Boeing was able to complete and re-deliver the first B767-300BCF prototype, including certification, on time to ANA. Each of the remaining six aircraft was also completed and re-delivered either early or on schedule. ANA subsequently contracted another 5 B767 conversions to SASCO.

Undertaking PTF Engineering Design and Development

Engineering Capabilities and Considerations behind the Build-Up of PTF capabilities

The engineering capabilities of ST Aerospace, built up through major upgrading and conversion programmes for the RSAF since the early 1980s, were extensive and included both aero-mechanical and electronics (avionics and software) design and development capabilities. However, as the RSAF moved on to its new aircraft fleets, although it continued to make enhancements to them to meet new operational requirements or enable technology insertions, most of such system-level enhancements would not require the same degree of structural modifications as in the A-4 and F-5. However, in order to meet its responsibility to carry out military aircraft upgrades, ST Aerospace had to maintain a full spectrum of engineering capabilities. Where there were excess resources because of changing requirements, they had to be re-deployed or gainful alternative employment had to be found. This was the situation in the later part of the 1990s.

Some opportunities were found through work on foreign military programmes such as the Turkish Air Force and Brazilian Air Force upgrade programmes but more substantial and sustainable engineering work needed to be found further afield. This led to the endeavours into commercial aircraft modification work.

Besides the differences in end application, the engineering knowledge and processes for design and development work between commercial and military aircraft are not fundamentally different, especially with regards to aircraft structural design and development. In addition, the focus on safety and other considerations are also similar. However, the approval criteria, processes and responsible authorities' considerations were areas which ST Aerospace had to understand better when it first started engineering work for civil aviation aircraft. The work that it did had to be fully compliant with the expectations of the applicable CAAs, something it was not familiar with then. This, fortunately, proved to be an advantage for ST Aerospace as its engineers were brought up to be strictly compliant with proper engineering processes and the requirements of the customers, through their work on military aircraft for the RSAF and others.

Amongst the many kinds of aircraft modifications performed by SASCO and MAE, passenger aircraft-to-freighter (PTF, also known as P2F) conversion design and development was identified as an area where ST Aerospace might find opportunities for its engineering capabilities to be deployed to undertake design and development work in the commercial aviation arena.

PTF development and conversions represent the extreme of commercial aviation modification from the aircraft structures point of view. Such design and development activities would not only be challenging but meaningful to its engineers. ST Aerospace might, through PTF development, find a new business opportunity which would also beneficially employ its large group of structural engineers which became available in the late 1990s.

The magnitude and complexity of PTF engineering was as significant as those done by the company previously on military aircraft. In addition, although the general perception might be that PTF engineering development would involve largely structural engineering work, the reality was it required many other engineering competencies like electrical, hydraulics controls and environmental engineering. As ST Aerospace had a rather complete range of aviation-related engineering skills, this facilitated its undertaking of PTF development, reduced the risks undertaken and was a strong competitive advantage.

From an organisational perspective, PTF engineering was also value adding to ST Aerospace in that following the design work, there would be significant conversion work potential for its MRO companies. Concurrent with PTF conversions was the MRO/restoration work that most customers would want done while the aircraft were undergoing freighter conversion.

Beyond relevant engineering development work, PTF conversion and MRO work, the PTF development work also enabled ST Aerospace to support customers from one of its important customer base better. Amongst its major customers for freighter work were companies like FedEx, UPS and DHL, the world's leading freight airlines. While most of its PTF work were for these large freight companies, there were many smaller freight operators who had special requirements necessitating specialised designs, including some on pallets to enable quick change like the RNZAF. Because of their smaller requirements, their work would be rather disruptive to the OEMs of the aircraft they wanted to have converted. Besides the interesting variations in work from these operators because of their unique requirements, it also enabled ST Aerospace to work with new customers which might be important for its MRO business in the longer term.

PTF Conversion Design and Implementation

Typically, a freighter differs from a passenger aircraft by having a large cargo door on the left side of the aircraft which, when opened, will provide a clear opening to enable cargo to be loaded or unloaded. The same main (or upper) deck space that is used to accommodate passengers in an airliner is used to accommodate cargo in a freighter. To strengthen the structure that provides the opening to the cargo compartment, reinforcements are installed along the four edges of the rectangular opening.

A barrier is required to separate the crew members in the flight compartment (also known as cockpit or flight deck) from the contents of the cargo compartment. This barrier not only establishes the boundary of the cargo compartment, it also stops loose cargo from lurching forward and harming the crew members in the event of a sudden forward deceleration.

Fire on board a flight is one of the most fearsome conditions an aircraft can encounter. To detect the presence of fire at its earliest possible stage, a smoke detection system is a must for the cargo compartment, as fire is almost always manifested by smoke. To further protect the fuselage structure from accidental damage, flame-resistant sheet and board materials are made into barrier liners and attached to the boundary of the cargo compartment, forming the side wall and, if necessary, the ceiling of the cargo compartment.

A freighter is converted from a passenger aircraft by emptying all its passenger-carrying facilities, and by properly incorporating the aforementioned freighter features. That would have essentially got all the key elements in place to satisfy the major requirements of airworthiness certification. However, to make the resulting aircraft operations- and maintenance-friendly, many other details will be necessary to enable the end product to become attractive to potential customers.

The need to guard against fire and smoke propagating in the aircraft has been explained. However, the need to get rid of excess pooling of water (due to, for example, loading of cargo in adverse weather) within the cargo compartment effectively and efficiently might not be obvious. Water and waste management is equally important to a freighter as it is to a passenger aircraft, as corrosion is one of the key enemies of airframe structures as long as metallic materials are used in aircraft in any significant quantity.

One desirable feature that is not covered by any current airworthiness design codes or requirements is the ability for a freighter to carry more occupants in a flight than the bare-minimum team of flight crew members. A typical flight compartment of an airliner would accommodate a pilot (captain), a co-pilot (first officer) and two observers, who could be training or airworthiness certification personnel travelling on board to observe how the flight crew members conduct the actual flying.

Usually, the requirements in a PTF conversion do call for accommodating some additional passengers. Most operators like to have a means to support the carriage of extra "non-revenue" occupants, known as "supernumeraries", such as cargo handling personnel, mechanics or other company officials who need to accompany the cargo to outstation destinations.

Providing accommodation for supernumeraries requires a careful trade-off study of space utilisation between the cargo and intended occupants, as well as the layout and availability of associated amenities and emergency support equipment. The designs for such amenities might generate additional certification requirements to satisfy the airworthiness authorities (sometimes of different jurisdictions) that the fire/smoke and cabin safety aspects of the converted aircraft are fully evaluated to meet the regulatory requirements vis-à-vis those for passenger aircraft.

It is noteworthy that in designing and certifying a so-called "factory-produced' freighter, an OEM will have the same set of design considerations as an after-market PTF conversion specialist. The key difference lies in the fact that the unique characteristics and features of a factory-produced freighter are incorporated at the original production line ("line-fit"), resulting in a "clean-sheet" product that could be efficiently produced by the OEM's production system even if the order quantity is small when compared with that for passenger aircraft.

For an after-market conversion specialist, in addition to having the same engineering design and substantiation know-how that the OEM has, it must also take into account the uncertainties of working on decades-old aircraft, and the fact that customers who procured used aircraft for conversion might not necessarily be able to acquire a fleet of the same configuration due to availability, cost and other considerations. Therefore, there is much tailoring of the work to the particular entry condition of each build number and the PTF developer has to be responsive and efficient in making necessary adjustments during the conversion. This is something that ST Aerospace is well versed in because of its extensive experience as a modification house for both military and commercial aircraft, but which might not be efficient for the aircraft OEMs to undertake.

Airworthiness Certification and Collaboration with OEM

The ideal outcome in the PTF conversion, whether by an OEM or a third-party after-market specialist, is for the conversion product to mimic the factory-produced freighter that has already obtained airworthiness certification. The availability of a "go-to" configuration that is already certified provides a basis or benchmark for the customer, the OEM/after-market conversion specialist and the airworthiness authority. This allows them to jointly determine the configuration and the capability of the conversion product that can be most reasonably produced with some degree of balance between meeting the operational requirements of the customer and the safety requirements of the airworthiness authority.

Since freighter conversion is usually done on aircraft some 15 years after factory delivery as a passenger aircraft, generally no ground-breaking technologies should be introduced into the conversion in order not to complicate the certification process. Moreover, the market would reasonably expect the development cycle of a conversion to be typically a fraction of that of a new type design.

Indeed, the same desire to reduce development cycle, cost and risks has recently also driven the OEMs to adopt derivative model evolution as the means to introduce improved designs, resulting in the development of the Airbus A320NEO and Boeing B737MAX family of airliners.

The availability of good engineering data is an important starting point for the development of the PTF solution. Having the original design package of data is preferred and more optimal than to try generating equivalent data. ST Aerospace has good relations with the OEMs of the various aircraft that it developed PTF solutions for, and is therefore able to adhere to its preference of working with the OEMs to deliver PTF solutions that are based on original design data. Besides achieving a more optimal solution in the design, it also has the important advantage of ease of ensuring good support for the converted freighter through its service life.

From the airworthiness authority's point of view, having OEM's data and involvement in the PTF conversion STC application process is an advantage and assurance, instead of having to go through the path of trying to assess the adequacy of engineering data that were generated independently.

ST Aerospace preference for working with the OEM to provide an "OEM Solution" is seen in not only aircraft modifications and conversions but in its work on engines and components as well.

Design Organisation Approvals

For a solution, PTF or whatever, to be authorised, approval of the responsible CAA is needed. Given the global nature of aviation, it is important to be able to have the cross-approval of the relevant authorities which in the case of PTFs is principally the FAA and EASA. Fortunately, the airworthiness certification processes established by these authorities are largely similar in terms of technological requirements, although there are differences in exact implementation and documentation details. The bilateral agreements between the two authorities helped in streamlining the validation process, and a design approved by the FAA and validated by EASA, or vice versa, would almost be universally acceptable to the rest of the world, save for country-specific details.

Under many CAA rules there is the concept of the Design Organisation Approval (DOA). Organisations which applied and have been assessed by the applicable CAA to be suitable may be granted DOA status with responsibility to perform certain certification work on behalf of the CAA concerned. A rigorous initial and recurring audit process by the CAA is instituted to ensure that the holders of DOA privileges would stay within the approved boundaries.

In December 2005, ST Aerospace successfully obtained DOA status from CAAS, followed by similar approval from EASA in June 2007. In addition, to meet the special EASA requirements on fabrication of aeronautical parts and components, ST Aerospace applied for and obtained EASA Production Organisation Approval (POA) in December 2015.

In the US, ST Aerospace owns DRB Consultants, a specialist design house which has FAA Organisational Designation Approval (ODA) privileges, which is similar in scope to the EASA DOA.

Although such authorisation does not cover major works like a PTF package, it is very useful to enable ST Aerospace to better support its customers in commercial aircraft engineering work. These are parts of the "processes" it has built to undertake commercial aviation engineering work more efficiently and is only possible because of its assessed capabilities by the CAAs.

The PTF Journey

Large-scale PTF conversion activities took off in the US in the 1980s when both OEMs, Boeing and McDonnell Douglas, and third-party after-market conversion specialists undertook design and physical modification work to give older airframes, typically about 15-20 years of age, a new lease of life. This activity was supported by the FAA who saw it as a healthy progression to encourage airlines to be more active in fleet renewal, since newer aircraft would tend to raise safety records of air travel, and greater demand for newer aircraft would in turn spur the OEMs to develop and produce better and safer designs. The cycles of renewal and progress in production and conversion of airliners also coincided with the birth and development of the express delivery industry in the US.

Boeing B757 PTF: First Opportunity for ST Aerospace in Freighter Design and Development

In the late 1990s, DHL was looking to acquire and convert a fleet of B757-200 to freighters. In 1999 Boeing was contracted by DHL to design and engineer the conversion package to produce the B757-200SF (Special Freighter). At that time, Boeing named all post-delivery conversions of its airliner aircraft that became freighters as "Special Freighters"; today it would be known as Boeing-Converted Freighter (BCF) models.

Converted freighter cargo hold

Typical of any PTF conversion, the airframe that would become a B757-200SF would be stripped off of all the passenger-related systems and installations, so that the main deck cabin (where the passengers used to be seated) could be converted into a so-called Class E cargo compartment, equipped with the aforementioned main deck side cargo door.

The Class E cargo compartment is one where in-flight cargo fire and smoke events would be dealt with by a so-called "FL200" procedure – descending and depressurising the cabin at 20,000ft altitude so that the sources of fire could be brought under control if it could not be extinguished through air (oxygen) starvation. In the case of the B757-200SF, the environmental control (air conditioning) system had to be modified to be similar to that of the production B757-200PF (PF stands for Package or Production Freighter), in addition to the introduction of a cabin smoke detection system capable of detecting smoke within five minutes of the onset of an on-board fire.

The cargo could be carried either on pallets or igloo-shaped containers, both collectively known in the airfreight industry as Unit Load Devices (ULDs). The handling and security of the ULDs for air transportation would be facilitated by a cargo handling system, and a cargo net would be installed at the forward end of the Class E cargo compartment, to restrain possible forward movement of on-board cargo in the event of emergency landing. Without any requirement for supernumerary accommodation, the Special Freighter design as proposed for DHL would enable the converted aircraft to carry 14 standard narrow body freighter ULDs (of 88 inches by 125 inches foot print) and a smaller foot print unit load device (ULD) to maximise available main deck volume. This capacity is known in the industry as 14-1/2 ULD position, or simply "14.5P". The PTF conversion design as outlined would modify the Boeing B757-200 passenger aircraft, originally certificated by the FAA, with a type design certificate ("Type Certificate"), through a supplemental type design certification process, leading to an FAA STC.

In consideration of MAE's significant experience in PTF conversions, Boeing invited MAE to co-produce a significant portion of the B757-200SF conversion engineering design, in an IPT pioneered by the development of the Boeing B777 family of airliners.

Besides the opportunity to partner Boeing, this was the opportunity ST Aerospace was looking for to further leverage its engineering expertise. ST Aerospace decided to move up the value chain to undertake the co-development of the engineering design, prototyping, testing and certifications of the B757-200PTF programme for DHL as a risk-sharing partner in a tripartite arrangement with Boeing and IAI in 1999. The DHL programme was for a total of 34 aircraft of which ST Aerospace was responsible for converting 17 aircraft with all the work to be performed at MAE.

The successful completion of the DHL programme reinforced ST Aerospace management's belief that PTF conversions had the right kind of engineering and production business mix that would be meaningful to the company's search for how it could play a role in commercial aviation engineering. Following the DHL programme, ST Aerospace assessed that there could be other possibilities for the B757 freighter, but that the market interests might not be for the same configuration as that delivered to DHL. As Boeing's engineers were committed on their new aircraft developments (B777 and B787) ST Aerospace took up the challenge to underwrite the full engineering responsibility to develop its own B757-200 PTF STC with data licensed from Boeing.

The FAA regulation on some aspects of any new freighter had also changed. An example was the more stringent smoke protection system and variants beyond the 14.5P cargo that DHL needed. The market was likely to require FAA certification as EASA was barely formed as a new airworthiness entity, succeeding the former Joint Aviation Authorities then.

The engineering development was decided to be in the US and MAE became the natural choice as the STC applicant. The US marketplace was also more suited for ST Aerospace to extend its engineering capabilities in view of the market potential for development work and the ready availability of engineering manpower needed to expand ST Aerospace's engineering resources.

To complement the initiative, a Fabrication Inspection System (FIS), required by the FAA to control the manufacturing of modification kits, was also established in MAE to bridge the important gap between engineering design and production/operations in the STC development process chain. The FIS provides a firm foundation for ST Aerospace to grow its supply-chain (out-sourcing) business to support all its commercial aviation activities.

In order to solicit inputs from the industry, a design review was held in late 2005 with participation from Boeing, the FAA, major equipment suppliers, and leading cargo airlines and operators. The event was a success. All participants agreed that the design presented was on the right path to FAA certification and becoming a successful product, and the business approach of partnering with the OEM to deliver "OEM quality at third-party price" was affirmed. Drawing release began in early 2006.

At about that time, the RNZAF had two used Boeing B757-200 passenger aircraft for transportation of its military personnel and state officials, and was keen to expand the versatility of the aircraft to meet its operational needs for which there was no ready product in the market. Its requirement called for a multi-role, passenger-cargo combination configuration with quick-role change capability that will enable the aircraft to be outfitted as a Very Important Person (VIP) transport, a "standard" two-class passenger cabin, a full freighter, or a few configurations in-between. The requirements involved integrating additional features such as palletised seating, powered air stairs and alternate entry path into the aircraft cabin through the electronic equipment bay. It was a rather complicated requirement with many different requirements through a "quick-change" method, which ST Aerospace had some previous experience on.

Equally interesting was the fact that the work would not be released through an FAA certification as the FAA does not take on certification work on foreign military-owned aircraft. However, while the RNZAF was experienced on being the military aviation authority for major conversions of their military aircraft, for the B757 it wanted the engineering and development work to be done as for a full FAA certification but without going through the FAA application. So it wanted a supplier which was conversant with PTF and STC processes.

Boeing was approached but it would not be cost effective for a major OEM to undertake the work, especially in view that it was only for two aircraft. Knowing that ST Aerospace had an interest in the B757 freighter and had proven its capabilities on the DHL programme, Boeing approached ST Aerospace to consider the job. To ST Aerospace, it was a complicated but interesting programme. The concern was that there was no possibility of recovering any losses made on the conversion work on the initial aircraft through going down the learning curve with successive aircraft. In this case, there would be only two aircraft.

However, in view that it was a New Zealand programme, ST Aerospace decided to undertake the job. New Zealand and Singapore has a good and long-standing

The FedEx B757 freighter taking off

relationship. The RNZAF had maintained a military presence in Singapore from before Singapore's independence and it had helped the RSAF on its A-4 experience through exchange officers. A separate project team was set up to manage the RNZAF's requirement. Through the mutual cooperation between the RNZAF and ST Aerospace, the design and conversions were done well and the RNZAF recognised ST Aerospace for this special effort.

At about the same time, FedEx, one of the participants of the 15P freighter conversion design review in 2005, requested MAE to tweak its proposed conversion to suit its special needs. The 2005 B757 Freighter review had opened a potential interest to their fleet planners who were looking to replace their ageing B727 freighter fleet. After its evaluation, FedEx decided on the larger-capacity B757-200 in lieu of the smaller Boeing B737-300 it was considering previously.

In 2007, after a very intense competition with several other providers, FedEx awarded the B757 PTF contract to ST Aerospace, for 87 aircraft conversions with 34 aircraft in the first of three tranches. This was the single largest conversion contract ever awarded to any conversion house. The prototyping and industrialisation was done in MAE under compressed time frame. Three continuous conversion lines were set up in MAE.

In any major development programme of this type, the initial conversions would include much efforts ironing out details that were not adequately covered in the engineering design. There would also be a learning phase when the crew, no matter the experience, improve productivity. Hence the prototyping aircraft involved a lot of additional engineering and conversion man-hours. Typically, there is a learning curve that the conversion house has to traverse before the conversions could become profitable. This will take at least several conversions. If the work is done at multiple sites, the learning phase is repeated and this incurs extra cost at each of the sites.

In the case of the B757 PTF, FedEx decided that it needed its aircraft faster than originally planned whilst the initial conversions were being done at MAE. In response to FedEx's increased requirement, two conversion lines were set up in STA Engineering in Singapore, in addition to the three lines in MAE. This is a classic illustration of one of the advantages of ST Aerospace, being able to leverage its global capacity when needed. The two sites were supported by the same engineering management and continuous improvement initiatives were shared between the two sites to improve on the conversion efficiency. The five lines achieve a typical annual throughput of 18 conversions per year. As of September 2015, 104 aircraft had been completed and re-delivered.

B757 conversions undertaken
at STA Engineering, Singapore

ST Aerospace now had two quite different B757 conversions running in parallel, both for customers which were important to the company. In view of the heavy development workload, the engineering teams at MAE had to be supported by additional design engineers based in Singapore. Coupled with a network of parts and equipment suppliers worldwide, these programmes reached a scale that was not envisaged earlier. Fortunately, because of the spread and depth of its resources, ST Aerospace was able to meet both programmes' commitments.

FedEx's requirements included the reduction of the main deck cabin smoke detection time from five minutes to within one minute to meet the new regulatory requirement of the FAA. This was a challenging requirement as smoke propagation behaviour was difficult to predict, and actual ground and flight test had to be designed and validated to prove the system and components were airworthy. Furthermore, FedEx had a requirement to accommodate up to three supernumeraries, in a separate "courier compartment" between the flight and the main deck Class E cargo compartment. This meant that the original B757-200SF's cargo net design could no longer be used, as a distended cargo net in an emergency landing event could pose an unacceptable safety hazard to the occupants located forward of the net. A rigid cargo barrier installation was designed, built, installed, tested and certified to replace the original cargo net design.

In view of ST Aerospace's engineering capabilities and experience, the various ground and flight tests were well executed, and demonstrated that the converted aircraft met every regulatory requirement. The FAA issued the STC to MAE in April 2008. Eventually, FedEx committed to converting a total of 119 B-757-200 aircraft into freighters, making their B-757-200 freighter fleet one of the

FedEx 100th Aircraft
Re-delivery Ceremony in MAE

FedEx 100th Aircraft Re-delivery Ceremony
in STA Engineering

largest commercial freighter fleets conversion programme in history by a single supplier.

Meanwhile, the more complicated RNZAF combi conversion programme, from the systems integration perspective, was successfully completed in 2009 with the two converted aircraft re-delivered approximately six months apart. In consideration of the achievement, the New Zealand Minister of Defence Category A Award of Excellence to Industry 2009 was bestowed on ST Aerospace, with the following citation:

> *“Nominated by the Ministry of Defence, Mobile Aerospace Engineering (MAE) and Engineering & Development Centre (EDC) Divisions undertook the design to modify two New Zealand Defence Force B757-2K2 passenger aircraft to a multi-mission, combination configuration. EDC took the lead in the design, integration and certification. MAE's engineering department managed the overall programme. ST Aerospace stood out with its innovative and adaptive engineering design for the first-of-its-kind Boeing B757-200 combi aircraft, and is one of the few MRO providers in the world with an in-house aircraft design engineering capability. Their products broadened the RNZAF's strategic airlift capabilities and have been proven effective and functional. This award is a testimony of their expertise, experience and engineering finesse.”*

CERTIFICATE OF REDELIVERY

This is to certify that ST Mobile Aerospace Engineering, Inc has successfully Redelivered NZ 7571 in accordance with the provisions of Contract No.: AD 218-01 dated Oct 7, 2005, Contract Variation No.1, dated May 15, 2006, Contract Variation No. 2, dated Sep 22, 2006, and Contract Variation No.3, dated Sep 10, 2007.

Tay Kok Khiang
President
4 Aug 08

Kevin McMahon
Project Director
4 Aug 08

AIRCDRE Richard Newlands
NZDF Representative
4 Aug 08

Chairman ST Aerospace receiving the RNZAF defence award in New Zealand

The successful execution of the RNZAF programme was also important to ST Aerospace in that it affirmed ST Aerospace flexibility to support the interests of its customers, regardless of their programme size.

Within a short span, ST Aerospace had become a major after-market commercial aircraft conversion specialist. Furthermore, the RNZAF combi conversion programme demonstrated the company’s ability and willingness to undertake unique product developments. In 2010, ST Aerospace was approached by TNT Airways, the airline affiliate of the European-based logistics service provider TNT, to provide a specialised B757 combi aircraft design that would form a logistic transportation system solution to meet a North Atlantic Treaty Organisation (NATO) requirement. The required aircraft, which would be used to transport a pre-determined mix of passengers and cargo on the main deck, could be met with the FedEx converted freighter configuration with the aft portion of the original passenger cabin retained intact.

B757 combi freighter

However, the means of managing cargo fire suppression could no longer be through air (oxygen) starvation. A more complex “Class C” cargo compartment with a Halon-based active fire suppression system had to be incorporated. In addition, the supernumerary compartment had to be upgraded in terms of comfort as a flight crew rest quarter, primarily through the installation of two business class seats (in lieu of the original triple supernumerary seats) and a galley.

TNT Airways accepted the proposed configuration which was based on the FedEx 14P converted freighter STC. A contract was sealed albeit with only one aircraft, and work began in earnest in December 2010. Final flight testing was satisfactorily completed within approximately a year, proving that 85 passengers and crew members could safely travel around a large compartment of released Halon gas for 222 minutes with not a trace of the gas at harmful levels in the occupied areas, much to the relief of the design team. The converted aircraft received FAA STC certification and validation from EASA, and was re-delivered to TNT to support NATO’s worldwide operation in May 2012. A most significant aspect of the project was that although the end product received US and European certifications, it was planned and executed by ST Aerospace using an optimum combination of its resources deployed in different parts of the world. Beyond engineering work done in the US and Singapore, materials and parts were sourced internationally from as far as China and South Korea.

Broadening the Scope to Airbus PTF

Following the TNT B757-200 combi conversion programme, ST Aerospace was approached by EFW on the possibility of collaborating to develop a conversion of the A330-200 and A330-300 wide-body passenger aircraft into freighters.

A large Airbus and EFW joint evaluation team came to ST Aerospace to evaluate its STC design, development and certification processes, as well as the supply chain system, over a period of six weeks. Airbus was convinced that ST Aerospace possessed the engineers and processes, as well as the capability to undertake this new A330 P2F initiative. This agreement launched ST Aerospace into wide-body aircraft conversions with, this time, Airbus. This was followed by the agreement on the A321. Further details on the A330 and A321 P2F are covered in Section 4.8.4.

The A330 and A320/321 P2F products add to the line of PTF products that ST Aerospace has designed. Both the B757 and the A330, A302/321 freighters would provide options for use of those aircraft which are no longer required for passenger airliners role or whose market price makes them attractive for conversion to a freighter role. They would serve the needs of the major freight forwarding companies and airline owned subsidiaries as a viable cost-effective alternative to new-build freighters.

Whilst the Boeing B757 PTF was developed as an FAA STC, the Airbus PTF would be developed under EASA-approved STC. The structural modification and parts manufacturing scope for the PTF kit are similar to that for B757 PTF programme and although the jurisdiction are different, there are many similarities between the two sets of requirements.

Section 4.6
Power-by-the-Hour

The concept of PBH began in the early 1990s. In a PBH programme, the airline will pay a service provider a fixed fee per flight hour. The concept was simple and created a business potential through transferring the risk for investments from airlines to PBH service providers. Although it was initially to support small operators that did not have the financial resources to own costly inventories which PBH service providers could, through consolidating the support needs of multiple small airlines, it became an increasingly accepted practice in commercial aviation.

The PBH business model is particularly attractive to an airline shedding off its heavy burden of overhead and manpower cost which would remain regardless of the level of its operations. It is almost the standard model adopted by LCC start-ups because these airlines do not have a legacy of overhead and manpower, and do not want to have to incur a heavy up-front investment in capability setup and in inventory stock as such do not generate cash flow. The PBH service provider will make the investment instead. This frees up cash-flow for LCCs to make other necessary investments for the start-up of their operations. PBH also provides a more predictable cost per flying hour in terms of component maintenance costs. If anyone wonders why an LCC could sell tickets at such attractive prices, it is, amongst other things, because it manages its cost structure very well, which invariably means that it is very good in negotiating competitively priced contracts from their suppliers and service providers.

This service model is common for aircraft components and engines. However, the concept can and has been extended to aircraft HMV, and even technical and engineering services although the predominant use is for components and engines.

Component Power-by-the-Hour

For component PBH, the fee is dependent on the range of components being covered, as well as the different services required. This includes the provision of an inventory of components for the airline's exclusive use (consignment stock), access to the service provider's inventory pool (pool access) and repair management of unserviceable components. Whenever a component becomes unserviceable, the airline is provided with a replacement serviceable unit by the service provider within a contracted service period. The unserviceable component is repaired and goes back into the pool or consignment stock as serviceable component.

ST Aerospace was one of the very first companies in the world to offer component PBH when it launched a subsidiary, Airlines Rotable Limited (ARL) in the UK in May 1990 to specialise in this business. This was to fill a business potential then, more than a decade before LCCs became prevalent. In order to offer a competitive PBH programme, there are essential engineering functions that need to be developed to interface with the airline. One of these is an inventory provisioning analysis to support an airline for its timely despatch of flights. This is an important skill set to master as it determines the adequate level of component stock to be maintained for the timely exchange of the unserviceable component removed by the airline with serviceable component.

Another factor is the component stock level at the geographical locations of designation network the airline operates. The component stock level maintained impacts on the PBH service provider's investment and its financial performance. When the component stock level is inadequate, the investment by the service provider is lower but the airline serviced may not have timely despatch of flights. This will lead to the inability to meet the contractual airline service level, as well as result in the potential of incurring penalty payment to the airline. On the one hand, too much investment may either lead to a contract loss or low profit returns, and low return on investment to the service provider. The skill set is to balance the stock level to meet airline's service level and achieve a reasonable return on investment on the stock.

ST Aerospace was able to tap into the growing pool of engineers produced by Singapore universities and polytechnics to develop the necessary component provisioning tools and processes, to optimise the level of inventory investment required to support multiple airline customers in the region. Statistical analyses and the computation of mean-time-between-failure (MTBF) of components are applied to predict the amount of inventory required. The actual MTBF data belonging to the fleet being supported would be compiled to fine-tune the analysis. Logistics consideration (how long it takes to bring a component from one country to another) is one of the parameters involved in the decision of inventory level, leading to the pre-positioning of components in different parts of the region. Engineers working on this task have been known to be "artists" at times. The balancing of different customers' requirements at multiple locations, the anticipation of component failure and corresponding inventory provisioning can indeed be likened to an artist at work as it requires a feel of the potential outcome, creativity and a great deal of spontaneity.

In the business of PBH, opportunities are aplenty for aspiring engineers to undertake the challenges and harness their engineering know-how in programme management and reliability engineering which are essential engineering functions.

Reliability engineering involves the study of failure rates, causes of failure, analyses repair work scope and maintenance practices in order to improve reliability. The more reliable a component is, the longer it will remain on the aircraft with lower repair expenses being incurred, thus leading to cost savings. To the airline, this reduces aircraft down-time and minimises the amount of inventory required to support flight operations and hence a satisfied airline customer.

As part of its responsibility as a PBH service provider, ST Aerospace engineers work closely with OEMs and airlines to perform field investigations on component reliability issues, to implement improvement programmes and to conduct regular review sessions with the airlines' engineering teams. Analysis of the previous repair work performed on a particular component down to the level of checking if a sub-assembly had been replaced due to cycle life, the seals and type of filters which had been installed, are examples of details that would be analysed to drive improvements in reliability. No detail is too small to be missed. Being able to identify the cause and correct the faults brings about a sense of gratification for the team and the efforts invested are greatly appreciated by the airlines. Both benefits from the outcome. Increased on-time flight departures means better economics and profits for the airlines supported. It is a field that merges analytical know-how, technical skills and use of advanced technologies to bring an improvement in component reliability.

Engineers working in the management of PBH programme are constantly faced with decisions to meet the airline service requirements, resolving technical issues and balancing it with cost effectiveness resolutions. It is a fast paced environment and the requirement from the airline is dynamic. It is important to make swift decisions to ensure airlines have the components timely. Components may not be available to the airline, they might be undergoing repairs or the components might be in different locations not designated by the airlines. The programme manager has to decide the most cost-effective solutions and to co-ordinate the logistic process to despatch the component to the airline on time. In PBH programme, the company has to also manage the component configurations. The aircraft fleet of the airline has various configurations and the engineers have to develop tools to track the component configurations and institute processes to incorporate improvements from airworthiness authorities or OEM to the components to update the configurations. At all times, engineers need to think "out-of-the-box" to meet the customers' requirements.

Today, ST Aerospace is amongst the leading PBH service providers in the world, with some of the largest LCCs in the Asia Pacific region as customers. ST Aerospace's home grown engineers have the opportunities to work with airlines in Australia, China, Denmark, Japan, South Korea, Malaysia, Taiwan and the UK. The diversity in cultures and professional demands from the different customers means that our young team of engineers has to continuously improve and challenge themselves in order to meet customers' expectations. Understanding each customer's culture and expectations is an important dimension of the ability to work with different customers and building up mutual trusts. This eclectic mix bodes well for interaction with customers and boosts the comfort and confidence level amongst customers especially.

Each service provider leverages its competitive advantage to provide solutions to customers. For example, Singapore is an ideal place to support PBH contracts because there are many OEMs who have in-country repair facilities in Singapore. This is an important advantage as it greatly improves turnaround time in terms of component repair, as well as on-site communication needed to resolve issues with the vendors. The connectivity of Changi Airport in terms of flight routes and frequency also contributes positively to Singapore as a hub for PBH business.

Engine Power-by-the-Hour

In addition to component PBH, ST Aerospace also undertakes engine PBH programmes. To be competitive, especially in engine PBH, it has to invest in the development of in-house engine repair processes to control and reduce repair costs besides the normal PBH function. A key aspect of engine PBH is the minimisation of engine removals through improvements in engine reliability and on-wing repairs.

The overhaul of aircraft engine provides a very interesting multi-disciplinary focus for our engineers. It also translates into diverse possibilities for our engineers from various different disciplines such as materials, mechanical and aerospace engineering. A modern jet engine is an extremely complex machine. The jet engines are packed with technological advancements in order to achieve fuel efficiency. Exotic materials and coatings are also employed. Component designs such as the turbine airfoil progresses from 2D to 3D shape. Hollow sections for cooling efficiency in order to maximise exhaust gas temperature margins are also an important parameter in fuel-burn efficiency.

As the manufacturing processes of a modern jet engines increase in complexity, so do the repair processes involved. This provides a challenging environment for engineers to transform the theories they have learnt into practical solutions. The principles are similar to component PBH but an engine is a more complex and larger component, and the cost involved in an engine PBH programme is naturally much higher and the ensuing business risks are higher. So, whilst statistical capabilities remain a baseline approach, the understanding of the history of the engine, its usage and maintenance and operations practices of the airline come into play more significantly.

STA Engines' engineers working on the programme have to try to understand the usage and history of the fleet they are making a proposal for and understand or try to forecast the future technology trends and their impact on the reliability of the engine and cost of supporting it. In the final analysis it relates to ensuring the airline is well supported, at the lowest cost, and leveraging the MRO's repertoire of competencies to solve the customer's problems on support. The cost of not being knowledgeable and rigorous can result in the loss of a bid, and more importantly, losses in executing the programme after winning the competition for the contract.

We shall see in the following section that the proliferation of LCC in the Asia Pacific region in the early 2000s brought new growth opportunities to the local aerospace MRO industry. LCC support, in particular, go beyond the traditional airframe, engine and component repair services that MRO companies provide to airlines. In the logical extension of the rationale, MROs have progressed today to become part of the airline's engineering department.

Section 4.7
Low Cost Airlines

Emergence of Low Cost Carriers in Asia

The emergence of LCCs as an alternative means of air travel compared to full-service airlines provided a significant boost to the regional and international tourism industry. Air travel has since become more affordable to a larger segment of the world's population.

The concept of LCC air travel started in 1967 and adopted its current name in 1971. Southwest Airlines made air travel in the US not only inexpensive but fun, thanks to the presence of spontaneous cabin crew who livened up the atmosphere with wit and humour. In Europe, easyJet and Ryanair have been dominating the LCC market since the mid 1980s, offering super-low-cost fares. In Southeast Asia, the story of how the founder of AirAsia bought over an ailing government-owned airline with two Boeing B737s for just one Malaysian Ringgit, thereafter transforming it into currently the largest LCC in Asia made the headlines. AirAsia began operations in 1996.

In Singapore, the first LCC, Valuair, started operations in 2004 with two Airbus A320 aircraft. Valuair tried to differentiate itself from other LCCs by offering in-flight meals, more leg-room and checked-in baggage. But it did not manage to grow, and a two-aircraft fleet was very sub-scale. Valuair was acquired by Jetstar Asia a year later. And there are many more LCCs, some also of very significant size.

The shift in travel patterns, whereby passengers are prepared to compromise comfort level for affordable ticket prices particularly in the short-haul regional sectors, led to a phenomenal growth in the LCC market. As a result, MRO support for LCCs became a significant growth market, and a global one, in the US, Europe, Asia and the Middle East. Equally important, over the last decade and more, LCCs was the primary growth sector of the civil aviation market compared to legacy airlines.

LCC Impact on Aviation Maintenance and Engineering

As with everything they do, LCCs' approach to maintenance and engineering is driven by keeping costs low while not compromising their operational efficiency. They maintain this philosophy from the selection of aircraft to the selection of aircraft installations, aircraft fleet and system standardisation, as well as their maintenance programmes.

Amongst the considerations, LCCs need to build up fast to achieve the scale of operations to reduce their unit cost structure to compete with legacy airlines and other established LCCs. They will avoid tying up their capital in assets and physical infrastructure that do not contribute to the generation of cash-flow.

On maintenance and engineering, their approach is to outsource so that they do not have to expend precious resources on these activities. They are thus the main proponent of PBH arrangements with asset management (leased and not owned) thrown in so that they do not have to tie up their money on spare parts and incur overhead staff costs to manage their MRO and logistics support activities. In addition, most LCCs do not have the baggage of existing in-house MRO capabilities, especially manpower deployed in these support activities, to contend with when they decide to outsource their MRO.

The different maintenance philosophy of LCCs presents opportunities for an MRO company with the right spectrum of capabilities to step up to their requirements. ST Aerospace's value proposition is its position as an independent MRO, with no affiliation to a parent airline and hence potential for conflict of interests between the LCC customers and the parent airline of the MRO.

LCCs and ST Aerospace

As a third-party service provider, ST Aerospace's business model is to provide its customers with cost-effective and high-quality maintenance, something they might not be able to achieve internally because they usually do not have the economic scale. This is why heavy airframe maintenance activities, engine overhauls and component repairs are often outsourced by many airlines, as these are labour-intensive and costly in terms of facilities, equipment and manpower. The options for the airlines are to outsource to the OEM, an airline shop, or a third-party MRO. Each has its advantages and disadvantages, and it is not the purpose of this section to engage into a discourse on the merits of each.

While most airlines today are open minded about outsourcing their MRO, line maintenance and fleet technical management (including production planning and control) are typically kept under their direct control as they are considered business critical with direct impact on continued flight operations.

Depending on the dispositions of the different start-up carriers and LCCs, some might even prefer to outsource the complete spectrum of aircraft engineering and maintenance functions to capable MRO providers. Whilst the outsourcing of heavy maintenance is driven by economic necessity, as it takes time and heavy investment in terms of resources to build up good capabilities, the outsourcing of line maintenance and engineering may be due to expediency or strict adherence to the belief that an LCC should not undertake non-core activities that are not revenue generating.

However, regardless of the extent of outsourcing, CAAs require that airlines be ultimately responsible for the continued airworthiness of the aircraft they are operating and be able to demonstrate that they are in control. While maintaining adequate oversight is being maintained by the airline, it is paramount that they outsource to capable and reliable suppliers. With its broad spectrum of MRO and engineering capabilities, including offerings for airframe expertise, and engine and component MRO and PBH, ST Aerospace has a strong competitive advantage to compete for the LCC market. Its marketing concept is akin to a supermarket, with a comprehensive range of products and capabilities from which its customers could pick and choose from, including traditional MRO like heavy maintenance on aircraft and repair and overhaul of engines and components, line maintenance, maintenance planning and engineering and fleet technical management. ST Aerospace had to build up those capabilities which it did not normally undertake as a commercial aviation MRO for legacy airlines and freight operators.

These additional capabilities were, however, not really new to ST Aerospace. Since the early 1990s, ST Aerospace had provided full-fleet maintenance support for the RSAF’s Commercialisation Programmes covering many of aircraft types. Leveraging the experiences and understanding built up from these programmes, and combined with its experience and technical knowledge on commercial aircraft, ST Aerospace embarked in 2000 on the development of a full spectrum of commercial airline engineering and maintenance services. This was the backdrop of ST Aerospace TAS model from which it could tailor various service packages depending on customer needs. TAS is a concept, but the underlying must be the capabilities ST Aerospace has in-place to undertake successfully any of the MRO activities that an airline might like to outsource.

As a leading independent MRO with a large global customer base, ST Aerospace had an added advantage of being able to learn from its airline customers what they value and expect in the support of their operations. This willingness to learn was well illustrated in how it built up military aircraft MRO, engineering capabilities, commercial aircraft MRO and PTF conversion. All these were not lost on ST Aerospace's customers. In fact, some of its customers took advantage of this and "taught" ST Aerospace what they wanted to outsource instead of sending their work to service providers who were already undertaking similar work for others.

As a perspective, ST Aerospace started to delve into component PBH and asset leasing business since 1990 when it set up ARL in the UK in 1990. Component PBH was in its nascent stage globally then. In 1998, STA Engines started to work on its first engine PBH programme with SAFAIR on the JT8D engine. On line maintenance, SASCO was already doing this at its Changi Airport location where it supported customers who also wanted line support. And, from the RSAF's Commercialised Programmes, besides flying the aircraft, it handled everything else needed to run the squadron's technical operations including line operations, maintenance planning and fleet engineering. So, ST Aerospace had most of the knowledge mix needed to undertake the support of LCCs even before such integrated support became a vogue for LCCs.

Besides the smaller air operators that ARL supported in Europe, the first LCC that ST Aerospace supported in Asia was AirAsia, then a two-aircraft start-up. The first full aircraft line and technical services for commercial airline was first undertaken in 2004 when ST Aerospace undertook the support of Valuair in Singapore. This was followed by Jetstar Asia and later, Biman Bangladesh Airlines (Biman). Besides line and technical services, the support for LCCs like Valuair and Jetstar Asia included component PBH. Significant LCCs like AirAsia, Lionair, Spring Airlines (in China) as well as legacy airlines like Xiamen Airlines and Jet Airways who adhered to some of the relevant LCC practices, also used various aspects of ST Aerospace compendium of capabilities according to their needs.

Beyond Total Aviation Support

Beyond TAS, in 2004 ST Aerospace provided Biman with an Aircraft, Crew, Maintenance and Insurance agreement in 2004 for two Boeing B737 aircraft. Under the agreement, ST Aerospace was wholly responsible for providing the airline with full support, allowing it to focus solely on flight operations. This programme included the provision of aircraft, flight and aircrew, insurance policies, as well as a full suite of maintenance and engineering support for airframe, engines and components.

Whilst the engineering and maintenance tasks were familiar work, the selection of pilots and cabin crew posed a whole new and interesting set of challenges. The Aircraft, Crew, Maintenance and Insurance programme for Biman was the first of its kind for ST Aerospace. Providing aircrew and insurance were not core business for ST Aerospace but to meet a customer's request, it undertook the challenge and successfully demonstrated its responsiveness, flexibility, initiative and its ability to step up to the requirements of its customers. The programme was highly successful and demonstrated to Biman what could be achieved. However this would not be the new normal but it did prove what could be done successfully, very successfully. It was a "proof-of-concept" demonstration with real aircraft, crew, passengers and operations.

Helping to Launch an Airline

Beyond being a maintenance provider, ST Aerospace played a pivotal role in getting Valuair, Singapore’s first LCC, off the ground.

Valuair selected ST Aerospace as its TAS partner after intense competition with other more established service providers. Besides MRO services, Valuair's senior executives looked towards ST Aerospace's support in helping the airline to secure an AOC from CAAS, which would allow it to operate scheduled revenue flight services out of Singapore. Staying true to the LCC mantra, Valuair's engineering and maintenance management team was extremely lean, staffed with the minimum number of persons required by CAAS. ST Aerospace was requested to and helped in developing the policies, procedures and associated manuals that would govern the airline's technical operations in compliance with AOC Requirements and relevant Singapore Airworthiness Requirements. Another significant development that contributed to Valuair achieving its AOC was the implementation of a best-in-class software application that was used to manage the multi-faceted and highly interdependent functions and database associated with the airline's engineering and maintenance programmes.

Many firsts were achieved in the partnership with Valuair, from the beginning right up to the time that Valuair merged with Jetstar Asia, another Singapore-based LCC that had also engaged ST Aerospace to help setup and run its technical operations. Later on, several other airlines in the Asia Pacific region followed in Valuair's footsteps in engaging ST Aerospace's services.

Beyond Asia, ST Aerospace extended its TAS services to LCCs in Europe and the US.

Providing TAS to LCC overseas

Operating Airbus A319s out of Columbus, Ohio, Skybus began flight operations as an ultra-low-cost carrier in 2007. Airbus, acting as the prime contractor, issued a Request for Proposal for support of all of Skybus' MRO except engines which was already outsourced to GE, the engine OEM. The contract included helping Skybus launch its start-up operations. The contract award to ST Aerospace was significant as it was the largest TAS programme that ST Aerospace had secured globally to-date and the competitive tendering by Airbus saw ST Aerospace compete with established airline MROs of large airlines which had significant advantages over ST Aerospace.

ST Aerospace was awarded a 12-year engineering and maintenance services contract to support a planned fleet of 65 A319s. The scope of services provided by ST Aerospace included line and base maintenance, and fleet technical management, as well as component and material services. During the initial setup and deployment of Skybus, as was the case for Valuair and Jetstar Asia, ST Aerospace had to immerse itself in the airline's certification process to obtain Part 121 approval from the FAA. This included the joint development of engineering and maintenance procedures that went into the General Maintenance Manual. ST Aerospace thus had to participate in various table-top exercises with the FAA and supported certification flights. Even at that stage, the Skybus, Airbus and ST Aerospace collaboration readily gained acceptance from the FAA as being well-integrated, capable and compliant. As such, the airline was successfully issued with its operator's certificate without a hitch.


Skybus' A319 aircraft

ST Aerospace developed the structure of the airline's engineering and maintenance operations from scratch over a relatively short period. It drew on the technical manpower resources from its airframe MRO company based in Mobile, Alabama and a small team of TAS specialists sent from Singapore. The processes, procedures and systems used to manage the operations were largely from ST Aerospace, with adaptations to meet the requirements from the FAA and the airline.

The ST Aerospace team on-site in Columbus, Ohio was supplemented by local hires, eventually grew to the size needed to effectively manage day-to-day tasks that were time-critical to the airline. This team also drew on the expertise of ST Aerospace in Singapore in providing TAS.

In-spite of the many challenges associated with working in an unfamiliar environment, Skybus's first commercial flight was launched without a hitch. The maintenance programmes designed by ST Aerospace, with the on-site team's diligent efforts in executing operations, resulted in the airline being recognised as the industry leader for achieving a record-high equivalence of an average of 4,000 flight hours per aircraft per year as assessed by the customer. Unfortunately, Skybus went into insolvency owing to cash-flow problems. The programme, however, proved ST Aerospace's capability to extend itself to assist its customer and the viability of its TAS programme from a competitiveness and performance standpoint.


Symbolic blessing on first flight

Today, ST Aerospace has established itself firmly in the LCC support space. It has a broad range of capabilities to deliver its TAS model for LCCs. Although the focus is on aircraft most favoured by LCCs, the A320 and B737 families of aircraft, it can step up to the same for other models of aircraft so long as it is economically viable. The technical and business processes are established and proven.

Section 4.8
Delving into New Product Development

Besides MRO and engineering development work, ST Aerospace had ventured into new product developments when necessary. Some aspects of these are cited in Chapter 2 in relation to the background on why these capabilities were developed whilst this section describes the specific products.

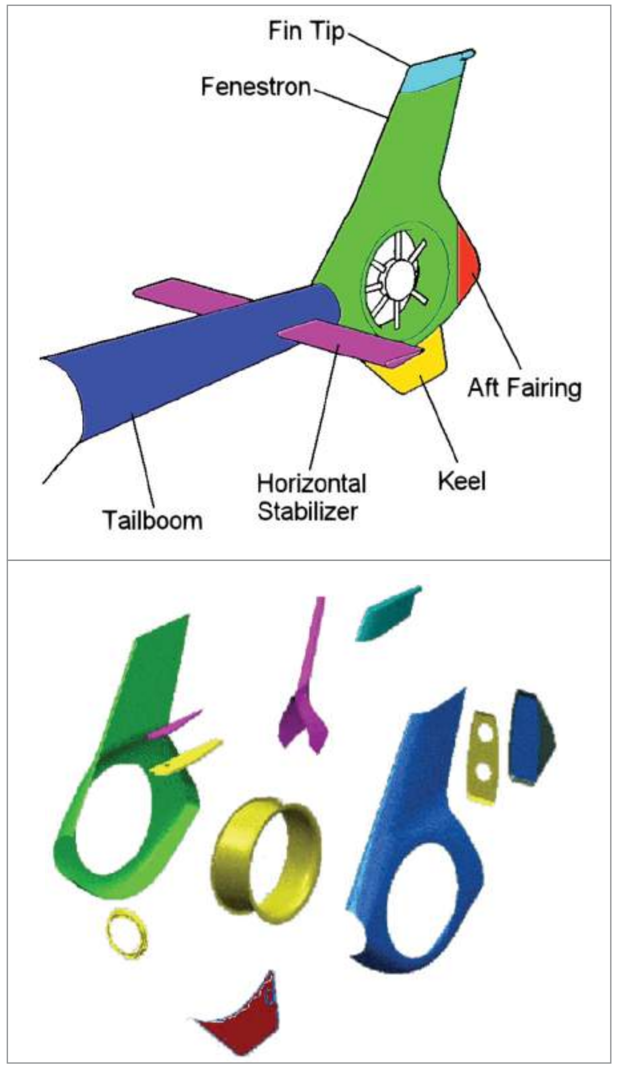
New product development is not a core focus of ST Aerospace but the company has the ability to step up to the challenge when needed. The diversity and complexity of the products that it has developed so far illustrate the breadth of its capabilities. ST Aerospace would only invest in a business because it believes there is a strategic consideration or that it could be commercially viable. Occasionally, it might undertake an activity because it is necessary to support other areas of its businesses which are important. This section on product development should therefore be read with this perspective.

Four examples would be used to illustrate some of the new product developments that ST Aerospace has gone into, namely composite design and development for EC-120, mission computer for aircraft upgrade, structural parts for PTF programmes and UAVs.

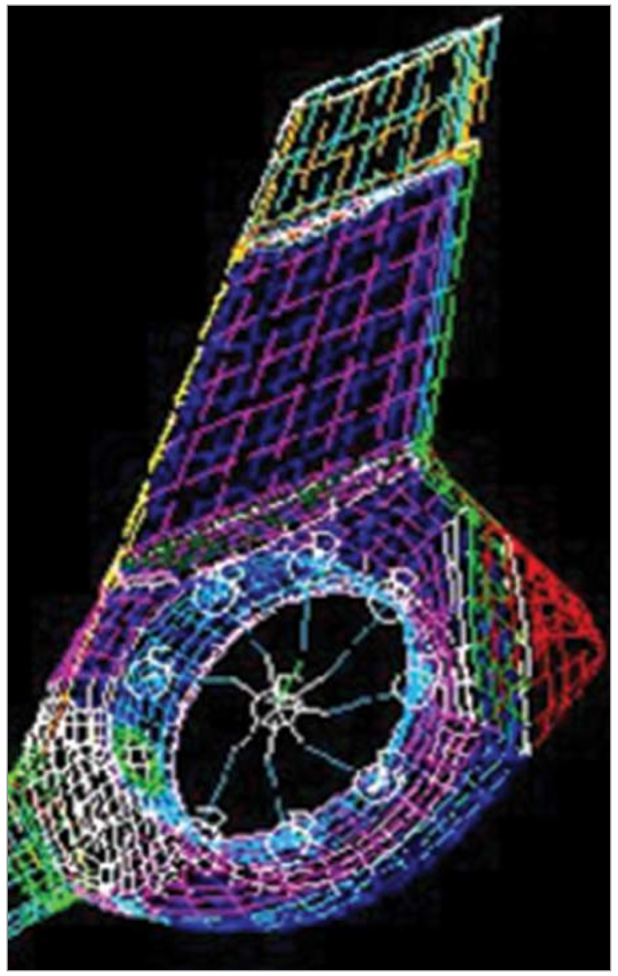
Section 4.8.1
EC-120 Helicopter

EC-120 was the first significant programme which ST Aerospace undertook to develop new products. This was also ST Aerospace's first international collaboration programme. The motivation was not for profit but to develop international collaboration and build-up capabilities deemed critical to its future as an aviation company. ST Aerospace was approached to participate in this programme together with other partners.

ST Aerospace was responsible for the design, development, certification and manufacturing of the whole rear structure as its work-share in the new EC-120 helicopter development programme. This included the tailboom, Fenestron and horizontal stabiliser, cabin and cargo doors, communication panels, as well as "transparencies". The design and development activities included design (using CATIA), analysis (using I-DEAS & MSC Nastran) and structural full-scale static and fatigue testing of the rear structure in a new facility set up in ST Aerospace.



EC-120 rear structure



Finite element modelling
for composite structure

It was challenging as this was the first project that involved design and manufacturing of major composite aircraft structures. One of the challenges was the preparation of engineering drawings for the composite structural parts and assemblies. Unlike parts made from metal, engineers had to learn and be familiar with the way composite design and manufacturing information was transmitted through drawing and specification documents. The stress analysis engineers had to learn how to do Finite Element Modelling on composite structures using I-DEAS & MSC Nastran software as this was in the early days of ST Aeospace's build-up.

Completed composite prototype
Fenestron subassembly

Composite material properties and behaviour were also areas the engineers had to learn and master. The mechanical properties of pre-impregnated carbon and glass fabric, and the combined strength after bonding vary much depending on the manufacturing process. Many tests had to be done using specimens to verify actual versus theoretical properties.

However, the biggest challenges were the design and manufacturing of the composite cabin door frame. Due to allowable weight limitations, the entire door frame had to be hollow, and manufactured as one continuous piece without joints. Before achieving the desired product outcome, it took the team numerous attempts to eradicate all the problems encountered, including voids between the composite layers at sharp corners and concavities. Various methods were deployed to increase the localised pressure applied to eradicate the formation of voids. All these were valuable experiences on composite manufacturing. Besides getting the composite design right, mastering manufacturing engineering was equally important. The team learnt quickly that the manufacturing and test facilities, at least for the prototypes pieces, should best be co-located with the design team.

Ultrasonic scanning to check for defects

Completed tail structure
and testing being done

The EC-120 programme had many complications, amongst which was the coordination of the efforts and interests of the three partners from China, France and Singapore. Nevertheless, this first endeavour into product development was a success and, to-date, more than 700 helicopters have been sold internationally.

More importantly, the engineering knowledge and experience gained by the engineers was useful to staff who nowadays have to deal with the proliferation of composites in current generation aircraft. The manufacturing and certification experience that were the implicit responsibilities of the team on the programme was also beneficial.

Besides the engineering knowledge which remained relevant, this was a useful programme in that the engineers had to understand fully the business considerations and financial implications behind the programme. This experience was very useful when ST Aerospace had to evaluate other collaboration programmes in later years.

Section 4.8.2
Mission Computer

The mission computer is a core component in an avionics upgrade programme. Traditionally, all components for an upgrade programme would be "bought-in" items from equipment OEMs. In the 1990s, ST Aerospace decided to design and develop its own mission computer for two primary reasons:

- To provide a more optimal technical solution for its aircraft upgrade programmes for the RSAF. With both the software and hardware (the mission computer) under its charge, it could better optimise the design of the overall system by allocating functions according to whether the function could be more efficiently achieved through a software or hardware solution.
- To better control the development and manufacturing schedule of the aircraft upgrade programmes in order to reduce the overall time to complete each upgrade programme. This would result in significant benefits in time, as the same savings in the development cycle time would be realised for each subsequent upgrade programme.

Every new aircraft ages and would need at least one upgrading of its systems over its life cycle. Hence there would be much benefit from shortening the time to undertake an upgrade programme. Owning the product design would also reduce the life-cycle support costs of the computer and the system linked to it, and it would also avoid over-dependence on third parties for a very important component of the upgrade.

When the idea of developing its own mission computer was initiated, there was much concern if ST Aerospace should undertake such an endeavour. While ST Aerospace had developed simpler components in the past to support its upgrade programmes when such parts were not available in the market, in-house development of a top end mission computer was a different ball game. The investments, in terms of development costs and engineering efforts, would be much higher and so were the technical risks.

Nevertheless, ST Aerospace decided to press ahead with the development and put its confidence in its fledgling group of engineers.

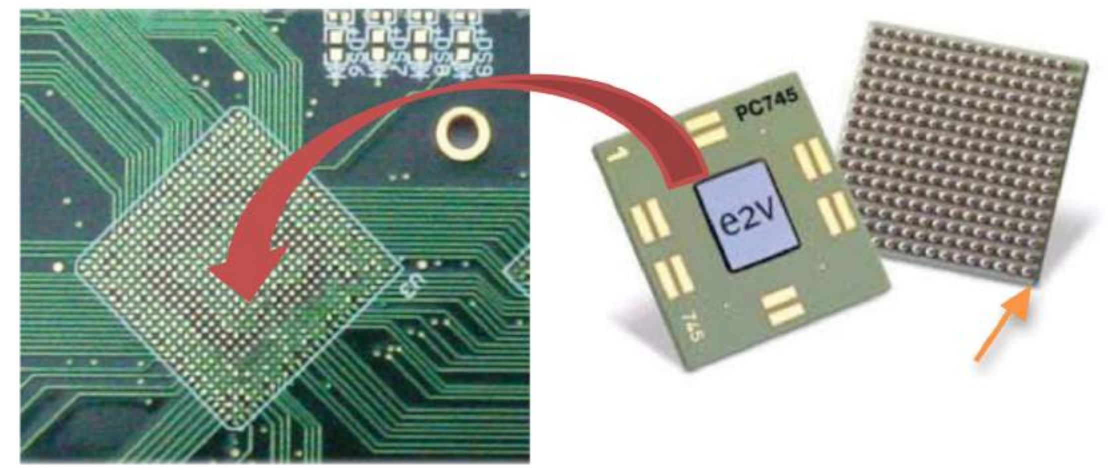
Since a significant sum of money would be spent to develop a mission computer, the technical specifications were benchmarked against leading products in the market then. The new mission computer must be superior to what could be obtained commercially. Otherwise, there was no reason to invest in the efforts and costs in developing it. Mission computers in the market then used the 486 Chip. A Pentium Chip was assessed but rejected due to the heat that it would generate. Instead, a Power PC Chip was selected, though it had never been used on mission computers then. The mission computer was successfully developed and had superior performance, partly due to the performance of the Power PC Chip. Incidentally, today many of the mission computers manufactured by the leading avionics OEMs use the Power PC Chip. A number of additional capabilities were also incorporated into the ST Aerospace mission computer to improve its functions. Several variants of the mission computer have since been developed, incorporating capabilities required to meet mission requirements of the different upgrade programmes.

Manufacturing the new mission computer posed a challenge. It was difficult to find a competent and experienced manufacturer who could produce it at a reasonable price, due to the small number of units required. Hence, ST Aerospace decided to undertake the manufacturing of the mission computer internally. Fortunately one of ST Aerospace's subsidiaries STA Systems, the component MRO company had the capabilities to undertake the manufacturing work. The manufacturing of the printed circuit boards was outsourced as it was more economical than doing so in-house in STA Systems. Such work would be typically done by Electronics Manufacturing Suppliers in the consumer/industrial market. Such a qualified supplier who met the quality requirement and was able to do the job was found within Singapore's small and medium size companies.

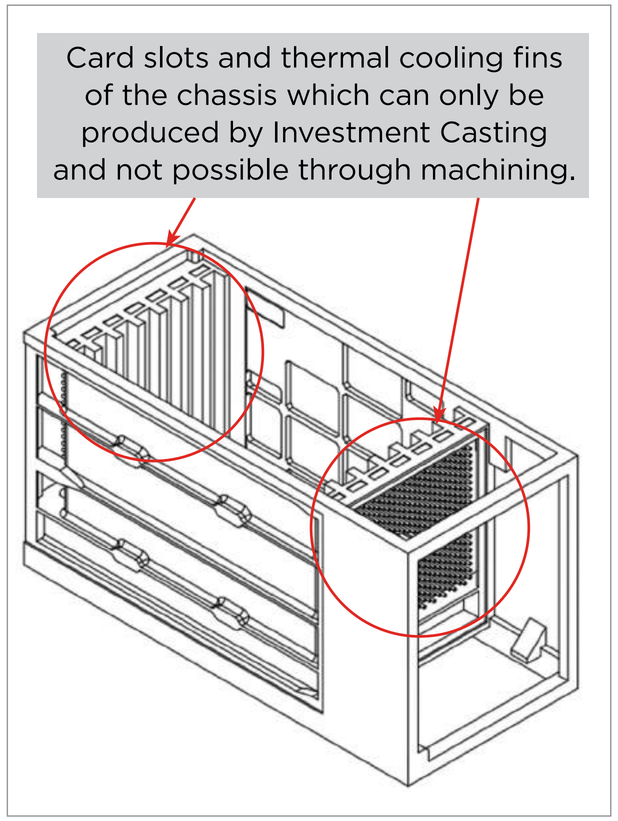
The manufacture of an airborne mil-spec mission computer required stringent control on quality during manufacture to produce a highly reliable product. However, the early prototype mission computers failed their qualification tests. The problem was finally traced to the soldering at one of the corner "balls" of the Ball Grid Array assembly, a problem that is common with such manufacturing.

Another lesson learnt from the manufacture of the mission computer was its mechanical enclosure. The conventional way of producing the mechanical parts like the chassis would be by machining. To overcome problems with producing certain parts that could not be machined, as well as to improve on the efficiency of manufacturing, the use of Investment Casting (or Lost Wax Casting) was adopted to produce the more complex parts of the mission computer. Multiple parts could be manufactured as a single component instead of as individual parts and assembled.

The first mission computer developed was a success and performed well in an actual



Board with ball grid array footprint (left) and arrow pointing at one of the corner balls on ball grid array package IC (right)



Finalised design of the chassis for investment casting

aircraft upgrade programme. Today ST Aerospace has produced at least four versions of mission computers for different aircraft upgrades. Derivatives were developed for each new requirement for the respective upgrade programmes. The capability and experience gained also enabled ST Aerospace to develop flight computers for its UAV initiatives. The ability to design a sophisticated hardware like a mission computer, undertake the certification to aviation standards, see it through manufacture and successful introduction into service is both an end unto itself and a step forward in the building up of a product development capability in ST Aerospace. This time for electronics components.

The key difference is the competitiveness of the solution. The time to deliver a typical avionics upgrade programme is reduced, the system developed is more efficient and effective in that trade-offs could be made between a hardware or software solution, life-cycle support is more cost-effective and upgrades could be undertaken without being limited by conflicting OEM interests. And engineers' time is also not wasted in having to learn programming languages from different equipment OEMs with each upgrade programme.

Section 4.8.3
Boeing B757 Passenger-to-Freighter Conversions

The Beginnings

ST Aerospace's introduction to PTF conversion work was on the Boeing B727 PTF conversion for FedEx in 1991. The work involved implementing a FedEx-owned conversion design approved under its own STC. Following that, more PTF conversions were undertaken for Boeing on various Boeing aircraft.

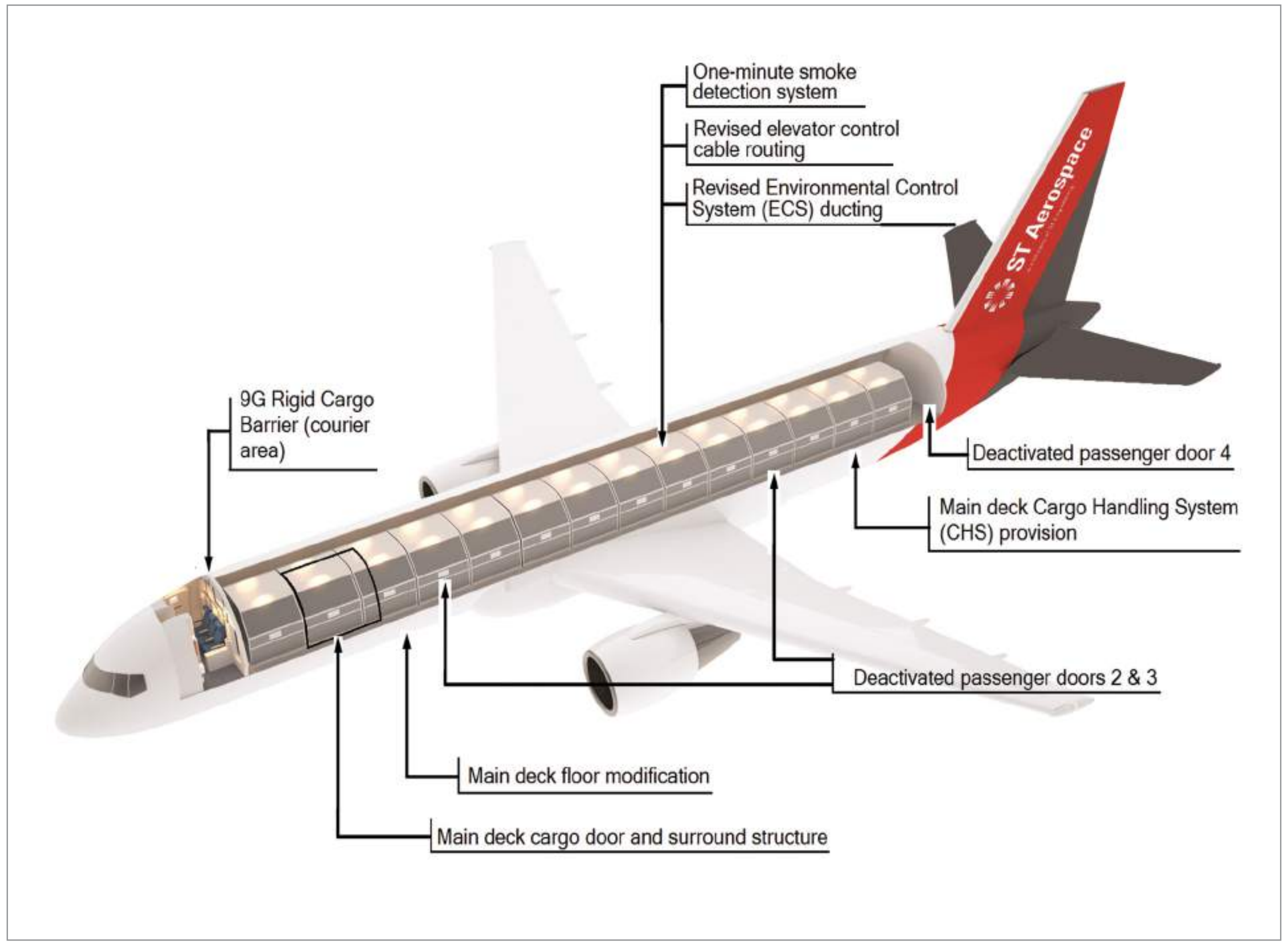
Boeing's B757-200SF Passenger-to-Freighter Conversions

With the related experience gained from working with FedEx and Boeing STCs, and the engineering capabilities that it had built up undertaking design and development for military conversions, ST Aerospace decided to undertake its own in-house PTF design and development.

DHL's B757 converted freighter, ST Aerospace first engineering development programme in collaboration with Boeing

ST Aerospace jumped at the opportunity when Boeing invited it to participate in a collaboration to develop the B757-200SF STC. The arrangement included follow-on conversions of 17 B757 aircraft as part of ST Aerospace's work share under the collaboration for the DHL programme. The last aircraft was re-delivered to DHL in 2003. The programme was successfully completed but at a great cost because of complications arising from the execution of the works. Interestingly, the engineering design and development aspect proceeded without any serious problems despite this being ST Aerospace's first foray in such significant engineering design for commercial aircraft. Instead, problems were faced with the conversion activities. As ST Aerospace had many positive experiences on converting passenger aircraft to freighters, this was surprising. The experience on this programme demonstrated the importance of having good alignment of interests between the partners in a collaborative programme.

As ST Aerospace assessed that the B757 freighter could have a future market, it was willing to build on the experience gained from the DHL programme. However, Boeing's engineering resources were stretched at that time because of its new aircraft development initiatives and ST Aerospace signed a data licensing programme with Boeing for B757-200SF data to develop other B757-200 freighter variants on its own. ST Aerospace hence held the responsibility for developing the STC for the new variants and fronted the design, certification and manufacturing activities with the FAA. ST Aerospace developed various variants for the B757 over time. While the B757 production freighter which Boeing started with could load up to 15 ULDs in its main deck cargo compartment, the DHL B757-200SF which had a cargo net separating the flight deck and main deck could load up to 14.5 ULDs.



B757 14P configuration with courier area

For some customers which required supernumeraries to be carried in the cabin, the cargo net which would distend should the cargo moves forward in an emergency condition had to be replaced by a rigid barrier similar to that in the production freighter. This was one of the different configurations developed and there were many other variations as each customer had its own peculiar needs.

14P B757-200SF – A New Design by ST Aerospace

The design team was given a new challenge when FedEx approached ST Aerospace in 2006 with a requirement to separate the flight crew from the supernumeraries. To provide space for the separate compartments, the new configuration had 14 ULDs. This also meant a new design for the courier compartment and requirement for a rigid cargo barrier to protect the supernumeries.

The 14P B757-200SF programme for FedEx is covered in Section 4.5. The initial contract award was for 87 aircraft and this was increased to 119 aircraft since. The number of aircraft involved is the largest from a single customer in the history of PTF conversions.

Designing a Multi-Role B757 for the Royal New Zealand Air Force

In parallel, whilst one design team was working on the FedEx B757 PTF programme, another team was formed to convert two B757-200s for the RNZAF. The RNZAF needed a multi-role quick-change capability to support its multiple passenger/VIP-and-cargo-transportation configurations depending on operational requirements. To meet the quick role change objective, all the seats and necessary interior monuments were mounted on pallets which were rolled in and out to make up the required configuration for each mission. This was then another variant of the B757 freighter. Although the design was certified under an STC issued by the RNZAF, and not the FAA, all the design and documentation were generated following the FAA STC application process.

A Unique B757 Combi for TNT Airways/ Guggenheim Aviation Partners

Guggenheim Aviation Partners, acting on behalf of TNT Airways, wanted to produce a combi B757 freighter aircraft capable of carrying cargo and passengers simultaneously. Since TNT is a European operator, it was necessary to obtain both an FAA STC and certification approval from EASA. To meet the re-delivery schedule, concurrent certification by both the FAA and EASA was initiated. Although the design was largely similar to the FedEx configuration up to the eighth ULD position, the presence of passengers meant that the fire-fighting method had to be different from that of a dedicated freighter aircraft. In a dedicated freighter aircraft, the fire would be “starved” by allowing the air to be sucked out from the aircraft. In the case of the combi aircraft, the design had to be modified and fire suppression was through the discharge of Halon gas to extinguish any fire. As Halon is hazardous if inhaled, good sealing and maintenance of a sufficient positive pressure differential between the cargo and passenger compartments was a safety critical necessity. Halon is also an Ozone-depleting substance and its usage is tightly controlled under the Montreal Protocol. All the testing involving the release of Halon into the environment were tightly controlled and carefully planned to avoid repetitive testing.

B757 combi freighter configuration

With all these developments, ST Aerospace can claim the B757 freighter as one of its products, or rather a family of its products. To meet the requirements of its various customers for the B757 freighter, ST Aerospace demonstrated its flexibility and willingness to adapt its product to whatever the customer needs. This nimbleness is important as customers have their own important considerations and it would not be well received to be unreceptive of customers' needs.

Section 4.8.4
Airbus Aircraft Passenger-to-Freighter Conversion

A330 "P2F" (terminology for Airbus) Passenger-to-Freighter Conversion

First Attempt on Wide-Body Aircraft Passenger-to-Freighter Conversion

In 2012, ST Aerospace was approached by EFW, a PTF specialist subsidiary of the Airbus Group, to undertake the conversion design of the A330 P2F configuration. Under the agreement, Airbus would provide the aircraft data for the A330 P2F programme and ST Aerospace would lead the engineering and certification activities. EFW took responsibility for marketing and sales activities, as well as to perform the aircraft conversions in Germany post-STC issuance. The specifications of the A330-300PTF converted aircraft call for 26 main-deck ULD (88” X 125” X 96”) positions, while the A330-200 P2F converted aircraft would have 22 main deck ULD positions. EgyptAir Cargo became the launch customer for the A330-200 P2F conversion, with a firm order for two and an option for another two. At the time of writing, EFW was actively pursuing operators to launch the A330-300 P2F conversion programme. Current plan is to obtain the STC award and re-deliver the first converted aircraft in the 2017 timeframe.

A330-300 configuration freighter

A320/A321 Passenger-to-Freighter Conversion

While the A330 P2F conversion collaboration agreement was in the final stages of discussion, another part of Airbus was re-evaluating the joint development programme that EFW and its Russian partners had been working on – namely, the A320/A321 P2F conversions. That evaluation eventually led to a decision in 2011, based on economic considerations, to dissolve the partnership, and terminate all work on the A320/A321 P2F conversion STC development then. The market hardly felt the impact at that point in time, as the conversion initiative was generally deemed to be ill-timed and too expensive for the average operator, in part due to the high residual values of the A320/A321 aircraft feedstock.

However, conditions could change and the

A321 configuration freighter

A320/A321's secondary market value would also decline over time. ST Aerospace was accorded the “last right” to the A320/A321 P2F programme in the event that Airbus should decide to re-activate the programme.

Since the launch of A330 P2F conversion programme in 2012, a dedicated engineering design facility in Paya Lebar, Singapore, was established to support all the detail and installation designs, as well as engineering analysis tasks related to the programme. In view of the smooth progress of the engineering development work, successful design reviews and on-time release of drawings for manufacturing and installation, EFW and Airbus have been encouraged by ST Aerospace to look beyond the A330 P2F.

The market condition for high-capacity narrow body aircraft had also changed since 2011. In 2015, both EFW and ST Aerospace felt that the right time had come to re-launch the A320/A321 P2F programme. This culminated in the signing of another collaboration agreement at the Paris Airshow that year.

For this second attempt to bring the freighter versions of the popular A320/A321 aircraft to the market, ST Aerospace will bring along her experience in conversions, to focus on the critical aspects of programme performance, and leverage lessons learnt by EFW from the previous attempt, to deliver end products at affordable and competitive fly-away prices.

The A320 P2F conversion specifications call for 11 main-deck ULD positions while the A321 P2F will have 14 main-deck ULD positions. Both STC award and first re-delivery have been planned for 2018.

Passenger-to-Freighter Conversion in Perspective

ST Aerospace had achieved much over a relatively short period to prove its engineering competencies in the commercial aviation market through its engineering development work, especially for PTF conversions. Through this activity, it had been fortunate to be able to work with both Boeing and Airbus, the leading providers of commercial narrow- and wide-body aircraft in the world. This had also reinforced its partnership with some of its major, as well as a number of new, customers.

Although business opportunities might present themselves at opportune time, the relentless efforts of its engineering and production teams over the years had helped it to transform itself from being a dedicated defence MRO contractor to a highly capable military aviation engineering development company, and from there to commercial aviation MRO and a leading provider of PTF/P2F aircraft design development and conversion house.

Section 4.8.5
Parts Manufactured under FAA Requirements

As part of the STC approval, parts for the PTF conversion had to be produced to FAA Parts Manufacturer Approval requirements. ST Aerospace, working with the FAA Aircraft Certification Office, ensured that all the PTF parts and assemblies produced would meet the airworthiness standards applicable to the type-certified PTF aircraft. Under this arrangement, the FAA Manufacturing Inspection District Office would audit the manufacturing facilities of ST Aerospace and its suppliers to ensure that the production and quality systems were adequately established to produce reliable parts and assemblies according to the design approved.

Computer-aided design image of main deck cargo smoke control panel for the A330 freighter

Being the owner of the STC, ST Aerospace had full authority to control the design, manufacturing and sourcing of components for the STC. In discharging this responsibility and as part of its continuous improvement initiatives, ST Aerospace continually explored and deployed new technologies to achieve a better and more cost-effective product. An example is in the use of 3D printing or "additive manufacturing". 3D printed parts would help reduce weight, time and cost. 3D printing could also be used to manufacture non-structural parts like aircraft interiors monuments, galleys, lavatories and passenger seat upholstery. Structural parts made by 3D printing are surfacing slowly but increasingly in the market today.

Under its A330 P2F effort ST Aerospace took another step forward in the design and development of its first commercial avionics product, the Main Deck Compartment Smoke Control Panel (MDC-SCP), this time under EASA certification.

As a sub-system to process and provide warning signals for the “1-minute” smoke detection system, the MDC-SCP was required to be certified according to DO-254 standards under the Compliance for the Design of Complex Electronic Hardware in Airborne Systems requirements.

From the design perspective, the MDC-SCP was to have a dual-redundant system architecture, a rugged chassis and hardened internal electronic components to protect against radiation from high energy neutrons or alpha particles entering into the cockpit while operating at high altitude.

From a manufacturing perspective, the MDC-SCP must meet the EASA POA requirement. ST Aerospace qualified as a POA organisation by demonstrating parts manufacturing quality consistency through proper control of special manufacturing processes with systematic parts tracking and purchasing processes. Essentially, ST Aerospace had to actively source for manufacturers with qualified National Aerospace and Defence Contractors Accreditation Programme certificate and who had experienced in Airbus manufacturing processes.

All the detailed parts manufacturing processes were imposed and monitored based on POA requirements. Parts purchase and manufacturing status were tracked by a customised supply chain software which was coupled with the necessary modules of SAP software for effective supply chain management.

Throughout the various phases of this project including engineering development, manufacturing and industrialisation, ST Aerospace demonstrated its resolve in complying with OEMs' certified processes and regulatory standards, while exploring new technologies to help optimise its entire design-to-realisation cycle. Through the PTF programmes, manufacturing of parts to the FAA and EASA requirements had been developed as an in-house capability which could be applied to any other aviation product development programme in the future.

Section 4.8.6
Unmanned Aerial Vehicles

ST Aerospace ventured into the development of UAV in 1989. From an engineering perspective, there are special features associated with UAVs designed by ST Aerospace that are important to highlight.

Firstly, an important overarching principle: ST Aerospace treats unmanned aircraft design as it would treat manned aircraft. There are limitations to what can be done on an unmanned aircraft, but where possible, the design and manufacturing capabilities that support these activities are largely based on manned aircraft design principles and practices, where predictability and safety are paramount.

ST Aerospace's UAV development in the early 2000s was to build mini to close-range tactical class UAV indigenously for the Army's operations. These classes of UAV would usually operate in hash and hostile environment (sometimes subjected to small arms fire), and launch and recover without runways.

The potential for damage due to the way it would be operated, like landing with parachute or airbag, and the need to turnaround the UAV quickly for the next flight, drove the concept of modular replacements in the field to the limit. New materials and manufacturing techniques became important to meet a different set of requirements unique for this class of UAV applications. With no human on board, considerations such as lightweight, low-cost, and even "use and throw" became key drivers for design and manufacturing. Materials such as carbon, fibre glass and Kevlar came into use as composite structures for wings and fuselages. Various types of foams such as polyurethane foam and polypropylene oxide foam were also used to provide skin rigidity to maintain wing profile shapes rather than conventional metallic plates and ribs.

The 5kg Skyblade III uses a combination of Kevlar and fibre glass for the wing structures to provide maximum toughness and flexure during airbag landing impact, as well as carbon fibre materials for the fuselage to provide maximum rigidity. The 70kg Skyblade IV is made of all carbon composite and honeycomb structures to achieve minimum weight, while hardened aluminium is used for high stress and compact structures. The two VTOL mini-UAVs, weighing 2.5kg and 5kg respectively, use mainly aluminium materials for the central structure which are then enclosed with ABS plastics to form the shape of the platform.

In contrast to the traditional approach of strengthening structures, certain parts of the Skyblade III UAV were designed to be frangible so that impact energy during heavy landing would be absorbed, or dissipated, through the collapse of these sacrificial parts in order to protect other parts of the UAV. The broken parts could be easily replaced with spares in the field. This approach would also reduce materials used and hence weight.

To further reduce weight, the aircraft structure was put to dual-use by using it to protect the electronic components like flight computer and voltage regulator. Likewise, the aircraft skin would act as heat dissipation surfaces, and compartments between structural frames used to store engine fuel. In parallel, design reviews for manufacturability and maintainability were assessed.

ST Aerospace also tried to shorten the development cycle. This is crucial as commercial UAV now moves at a pace akin to mobile phone replacements. News of new UAV with "cool" looking features appears ever so often. To maintain competitiveness, parts which were produced by conventional manufacturing approaches of composite molding and machining, were progressively replaced with 3D printed parts. 3D printing also enabled quick fabrication of parts to assess their feasibility before being committed to using composite molding, plastic injection molding and thermoforming as permanent solutions. Other than plastic 3D printing, ST Aerospace also worked with partners to explore metallic 3D printing.

While ST Aerospace had adopted the good and tested design practices from its manned aircraft activities onto its UAV development, it has since developed new capabilities in materials and manufacturing engineering unique to UAV applications.

Chapter Five

INTERTWINED AND SEPARATE NEEDS

Section 5.1
How Each Evolved

Section 5.1.1
1st Gen RSAF to 3rd Gen RSAF

The British's decision to accelerate the withdrawal of their forces from Singapore by 1971 resulted in the earlier formation of the Singapore Air Defence Command (SADC) on 1st September 1968, to undertake responsibility for defending the nation's skies. A succession of aircraft and weapon systems were acquired to establish an initial air defence capability. Training institutes were set up to train our airmen and technicians to support flying operations.

September 1971 saw the formal handover from the RAF and the SADC taking over full operational control of the three airbases, the air defence radar at Bukit Gombak and the Bloodhound Mk II surface-to-air missile system.

In 1972 the Air Engineering Department (AED) was formed to oversee the maintenance requirements of the SADC. This was followed by the integration of the department with the then ALD, the organisation responsible for materials support in the SADC. The combined department was designated Air Logistics Department and emphasised the interdependence of the maintenance and materials support for the SADC's flying operations.

A key early milestone in the SADC's development was the purchase and refurbishment of the A-4 Skyhawks to expand the fleet of fighter aircraft. A follow-on buy of a larger number of Skyhawks was refurbished by SAMCO, the SADC's aircraft depot and Singapore's fledgling aerospace industry.

In 1975, the RSAF was officially formed as an independent service to accelerate and focus the developments of the air capability in the SAF. This was followed by the introduction of more capabilities to meet the broader operational needs of the SAF. These included the AN/TPS-43 air defence radar which gave the RSAF its first modern 3-D radar surveillance coverage, the F-5 fighters which brought the RSAF into the supersonic era, and the C-130s which provided troop-lift and disaster relief support.


The RSAF's formation emblem

In 1985, the RSAF restructured itself into a highly centralised command and control C2 structure to facilitate timely information flow and decision-making.

The build-up of flying training ran into the A-4 Crisis in 1985. Despite the severity of the problems, the RSAF recovered from this on its own and continued operation of the A-4 fleet until the aircraft were seamlessly inducted for the upgrade to the A-4SU.

The A-4 Crisis was a watershed event for the RSAF. The aircraft accidents that happened seriously affected the RSAF and could have set it back by many years. It was a defining moment for the RSAF. It demonstrated what it could achieve through the joint resolve of its people and organisation, both operations and the engineering and logistics groups. Under different circumstances and personalities, the outcome might have been different. The A-4 Crisis also led to a clear understanding of its future needs which had to be addressed quickly. That was the need for stronger engineering capabilities to be able to overcome similar or more severe challenges in the future, and to be able to manage the new technologies coming into the RSAF.

2nd Generation: Spreading Wings and Forging Ahead


F-16C/D during Exercise Pitch Black 2010

Following the A-4 Crisis, the RSAF went through a major transformation from a "training air force" to an operational air force. This affected the way it operated and saw the build-up of operational capabilities. In addition to the build-up of capabilities on aircraft and weapon systems, the RSAF also indigenously built-up its "damage recovery" capability under its Airbase Maintenance Squadrons to support sustainability of its operations. The emphasis for the Air Force also shifted from growth to quality. The aim was to build a quality and highly operational RSAF through the tighter integration of air operations and air logistics so as to provide a strong foundation for the RSAF to raise its operational readiness.

The RSAF continued to enhance its capabilities through the acquisition of new and advanced platforms and systems. This included the acquisition of the first F-16, the F-16A/B initially, equipped with digital MFDs and fly-by-wire flight control system. Another major acquisition was the introduction of the E-2C, providing the RSAF with an airborne early warning capability to extend and improve the Air Force's ability to respond to air threats. The RSAF also acquired the Super Puma helicopter to enhance its search-and-rescue capability and its airlift support capability for the Army's operations.


E-2C taking off

This period also saw many major capability upgrades to the RSAF's aircraft. These upgrades were driven by the RSAF's need to enhance its operational capabilities and sharpen its qualitative edge.

In the mid-1980s simulation technologies were maturing rapidly and realistic training was possible through the use of high end simulators. The RSAF proactively and extensively adopted simulation systems for training and operational development, to enhance its capabilities cost-effectively.

In view of the more complex systems to come with the A-4SU, E-2C and F-16, the RSAF also introduced specialisation of its technical workforce to provide in-depth, dedicated and professional competencies on focused tasks. This was to ensure that its technicians would be equipped with the necessary depth of knowledge and skills to handle the increasing sophistication and complexity of the newer systems.

In addition, strict qualification and continual re-certification of technicians through continuous trade training and professional knowledge examinations helped to strengthen and maintain the high standards in technical and operational competencies.

This specialisation concept was brought one more step forward with the integrated "O/I" (Organisational/Intermediate) level reorganisation in 1990. O/I integration required mind-set change and it was after much discussion that the concept was embraced. This was an important outcome with the objective of enhancing the knowledge and capabilities of the technical workforce that would be brought to bear on aircraft maintenance.

In view of Singapore's geographical constraints, the RSAF started to venture overseas for flying and operational training. The first detachment was made in September 1977 to the RAAF base in Williamtown, Australia with eight Skyhawks for five weeks. In July 1978, a detachment to Thailand to Don Muang Airport was launched with Skyhawks. A year later, in August 1979, the first operational basing was made by the Hunters at Clarke Air Base in the Philippines.

With the rapid expansion of the RSAF due to the induction of various aircraft platforms, overseas training became a norm and the concept was honed through multiple overseas detachments of a significant part of its aircraft fleet simultaneously. This included long-term overseas detachment programmes such as the F-16 CONUS detachment. The seamless support of a significant part of its fleet "globally" on top of its demanding operations in Singapore, illustrated its operational capability.

The RSAF also started to participate in bilateral training exercises overseas with its foreign military partners as it provided the SAF with realistic training opportunities. These efforts also allowed the RSAF to develop new techniques and tactics while training in different environments. In addition, it gave the RSAF the opportunity to understand and learn from other air forces while deepening defence relationships with its partners.

The logistics and engineering support of its global operations was seamlessly carried out by ALD and ST Aerospace. Whether for flying training or conduct of operations, the technical staff that supported the overseas deployment was the same one that supported it back home. The Commercialised Programmes of the RSAF which saw both training and operational squadrons of the RSAF supported wholly by ST Aerospace on a contract basis operated in the same way. Such was the integration achieved.

3rd Generation: Towards a Full Spectrum, Integrated and Ready Air Force

In early 2000s, the RSAF progressed even further in the Internet age of advancing technology and improved information sharing. With the onset of asymmetric threats and low-intensity conflicts, innovation was recognised as one of the keys for the organisation to grow and evolve, to keep pace with the evolving security threats. Only then could the RSAF continue to be effective.

Boxing Day tsunami 2004

Detachment to aid in reconstruction of Iraq

The RSAF's operations has gone beyond the conventional "bombs and bullets" thinking of the 1980s. Beyond operational training and conduct of operations, the RSAF has engaged in humanitarian assistance and disaster relief operations such as the Boxing Day tsunami relief operations in 2004 in Indonesia. It also assisted in the search-and-locate operations for the Malaysian Airlines' MH370 aircraft and AirAsia's QZ8501 aircraft in 2014.

The RSAF also responded to peace support operations through the deployment of its KC-135s to the Persian Gulf to support the multinational effort for the reconstruction of Iraq and Afghanistan. The performance of its operations and logistics organisations in such missions reaffirmed its capability as an operational air force.

Advances in network technology and the advent of social media applications such as Facebook, Twitter and other messaging services enable and enhance interconnectivity in the world today. The RSAF uses a common network to update its systems in real-time with information. Exercises, such as the bi-yearly Forging Sabre live-firing exercise held in the US, provide the RSAF and the Army training on network-centric synchronisation across the full spectrum of command, control and execution.

To enable more effective execution of its air war operations, as well as to be fully integrated with the Army and Navy operations, the RSAF underwent a major restructuring to achieve better command and control, and execution This approach formed the basis for the new organisation structure comprising six operational commands to enhance its capability to operate as an integrated air force and be more integrated with the mission of the SAF. In conjunction with this, the RSAF also initiated development of its professionals with the right competencies and core values, as well as to recognise their achievements.

Over a short time span, the RSAF has transformed from a fledgling air force focused on training of its people, to a fully operational and integrated air force. With an impressive array of modern aircraft and weapon systems such as the F-15SG, F-16C/D, G550 and SPYDER, the RSAF stands ready 24/7 to safeguard the nation's skies. This is a testimony to the airmen and RSAF's defence partners, who have shaped and continued to hone Singapore's 3rd generation Air Force today.

STRIKE AS ONE

The Singapore Armed Forces defends against hostile air and land threats through counter-air and integrated strike operations in Exercise Forging Sabre 2015.

1 DETECT AND RESPOND

Sensors detect incoming aerial threats and ground forces. The Command Post (CP) assesses the situation and activates the F-15SG and F-16C/D fighter aircraft. After intercepting and eliminating the enemy fighters, the multi-role fighters are then tasked to destroy the enemy headquarters and air defence systems.

2 DISCOVER AND TRACK

Concurrently, the Heron-1 Unmanned Aerial Vehicles (UAVs) and Commandos discover enemy armour column and rocket launchers, and update the CP. Using their advanced sensor capability, the Heron-1 UAVs send back timely and accurate intelligence on the movement of the enemy platforms.

3 SEEK AND DESTROY

The CP orchestrates a response and activates the F-15SGs, F-16C/Ds and AH-64Ds to eliminate the ground threats using advanced munitions such as Laser Joint Direct Attack Munitions and Hellfire missiles. Through the cooperative lasing employed by the Heron-1 UAVs, fighters, attack helicopters and Commandos, the multiple enemy mobile targets were destroyed in a single pass.

Integrated Strike in Ex Forging Sabre 2015

Section 5.1.2
How Each Evolved: From Military Depot to Commercial Aviation Engineering and Services Company

ST Aerospace, Support for the RSAF and Build-Up of Commercial Aviation Capabilities

Performing its Strategic Mission

ST Aerospace has evolved on two fronts since its inception in 1975 as SAMCO.

From 1975, ST Aerospace developed military MRO and engineering capabilities in support of the RSAF. As the RSAF transformed from a 1st to a 3rd Generation air force, ST Aerospace remained fully committed to its strategic mission to support the industrial needs of the RSAF, building up MRO and engineering capabilities to support the various aircraft types that the RSAF operated.

As the RSAF's aviation depot, ST Aerospace initially supported the depot-level maintenance of the Hunter aircraft. This was followed by the refurbishment and minor upgrade work of the A-4C Skyhawks. Over the years, on the MRO front, ST Aerospace capabilities tracked the build-up of the RSAF's aircraft fleet – helicopters, trainers, fighters, transport and special mission aircraft such as the E-2C, UAV and MPA.

ST Aerospace also developed its engine depot and component MRO with the concurrent build-up of a materials function in support of its aircraft, engine and component MRO operations. During the A-4 Crisis, it played a supporting but important role in the investigations and recovery work, for both the Skyhawk aircraft and the J-65 engine.

When the RSAF decided to upgrade of its A-4 Skyhawk fleet in 1985, ST Aerospace undertook the upgrade programme, and was responsible for both the engineering development and the conversion of aircraft fleet. As the A-4 upgrade was an extensive and complicated programme and the first major aviation engineering development programme for Singapore, it was a significant undertaking for all parties involved, namely the RSAF, DSTA, and ST Aerospace.

Minister for Defence Dr Ng Eng Hen, accompanied by then Chief of Air Force MG Ng Chee Meng, alighting from a G550-AEW aircraft

During this period ST Aerospace rapidly built up its engineering capabilities to support the RSAF which was transitioning from a 1st Generation fleet to a 2nd Generation fleet. The build-up was accentuated by the fact that both the industrial and engineering capabilities and experience of the company were then at a low level.

As each new requirement was pressing, the build-up of both engineering and operating capabilities were undertaken concurrently. ST Aerospace was contracted not for capability build-ups but for actual deliverables on projects, usually on tight timelines with stiff penalties for non-performance. This continued through the transition of the RSAF to a 3rd Generation air force. Nonetheless, each capability was delivered as committed. It was this attitude and performance over the years from 1985 that resulted in the quantum jump in the modernisation and capabilities of the RSAF. In parallel to the build-up of the RSAF, ST Aerospace also evolved from a fledgling engineering organisation to what it is today.

In addition to the partnership between the RSAF and ST Aerospace on MRO support and engineering development, a third dimension was the development of the "commercialised programmes". Under these programmes, all technical operations of the squadron were outsourced to ST Aerospace and staff from the company were fully integrated with the RSAF squadron as one. In the late 1980s, when the RSAF decided to implement the outsourcing arrangement as part of its first commercialised programme, the RSAF and ST Aerospace worked collaboratively to build a viable and mutually beneficial arrangement that ensured flying operations would not be compromised. The first programme went smoothly, giving both the RSAF and ST Aerospace the confidence to undertake similar programmes in later years, even for RSAF's operational squadrons.

When a squadron operating under the commercialised programme was deployed overseas for training or operations, the modus operandi continued. ST Aerospace personnel would continue to support the RSAF's operations on detachment and in theatres of conflict, as they do so in Singapore. This approach to outsourcing by the RSAF was unique compared to outsourcing initiatives adopted by other armed forces worldwide. It was possibly the only example of an extensive and pervasive approach to outsourcing by an air force. The RSAF used outsourcing not for one or two squadrons but to support an important segment of its flying in Singapore and overseas.

Build-Up of Commercial Aviation Business

The "second front" undertaken by ST Aerospace was in commercial aviation, as an MRO and engineering services company. The set-up of the local military aviation industry to support the RSAF was an integral part of the plan to ensure that the RSAF would be well supported, not only through its organic logistics and engineering capabilities, but also by a complementary defence industry operating on strictly commercial business lines.

This strategic intent could not be met if ST Aerospace were to only serve the RSAF. Indeed, in order to discharge its commitments on defence, and yet not be overly dependent or be a liability to MINDEF, ST Aerospace must venture into complementary fields it could excel in, while remaining committed on its responsibility for the defence needs of Singapore and the SAF. In doing so, the company has to be commercially viable.

So, in 1990, ST Aerospace ventured into commercial aviation engineering, starting with engineering modification of commercial aircraft. By 2002 it became the world's largest commercial aircraft MRO. Leveraging on its engineering competencies, ST Aerospace also entered into engineering development for commercial aircraft. It is today a leading third-party PTF design and development provider.

Foray into Commercial Aviation Business

Following its first listing in the Stock Exchange of Singapore in 1990, SA ventured into commercial aviation MRO leveraging its experience in military MRO and engineering.

- In 1990, SA incorporated ST Aviation Services Company Private Limited (SASCO) a joint venture company with JAL and SIA to undertake commercial aircraft maintenance. Prior to this, the other companies of ST Aerospace had undertaken both military and commercial businesses to leverage the synergies in capabilities and to reduce risks.
- At about the same time, ST Aerospace also ventured overseas to reach out to foreign commercial aviation markets with the incorporation of Mobile Aerospace Engineering (MAE) in the US in April 1989 and Airline Rotables Limited (ARL) in the UK in May 1990.

The early years of its endeavour into commercial aviation MRO were very challenging. It had little relevant experience, capabilities, resources and access to customers. These needed to be quickly acquired and developed.

It was only after the year 2000 that most of its overseas growth and expansion into commercial aviation took place on a broad front, in the US, China and Europe. This growth backed by its market recognition beyond the comfort of home in Singapore, made ST Aerospace a truly "global" commercial aviation services company.

Maintenance, Repair and Overhaul

ST Aerospace's foray into commercial aircraft MRO was highly successful and by 2002, 12 years later, it was recognised as the largest commercial aircraft MRO in the world. It was able to achieve its market position because of several strategic decisions it took to overcome its structural problems on many fronts. The expansion of its MRO network globally from 2000, and its ability to acquire customers, support them well and retain the relationship on a long term basis were some of the reasons that enabled ST Aerospace to thrive in the commercial aircraft MRO business.

ST Aerospace also built up its engine and component MRO capabilities extensively, by expanding its range of capabilities and developing new business models to address the support requirements of LCCs, the primary growth area in aviation in the last decade.

Engineering

Engineering capability had differentiated ST Aerospace from other commercial aviation MRO service providers. ST Aerospace acquired a strong design engineering capability and aircraft modification experience by virtue of its engineering work on military programmes over the years. This enabled it to do well on work like the B747 Section 41 modifications and B727 PTF conversions. Today, it is the leading third-party service provider for PTF conversion development.

Commercial Aircraft Design Engineering

Although ST Aerospace has a strong reputation for PTF conversions having performed well on many PTF conversion programmes, it is its ability to undertake engineering design and development work that really differentiated it from most other commercial aviation MRO companies. Starting with a collaboration programme for the B757, it moved on to develop its own STCs tailored to each customer's requirement.

Following the success of the B757 PTF programme, ST Aerospace was awarded a contract by EFW/Airbus to undertake the A330 P2F development which is still in progress.

Engines: Starting with a legacy JT8D-15 engine capability, ST Aerospace managed to extend its JT8D-15 capability to the -200D series and later to the CFM56-3 engine in 1999. This led to the commissioning of the CFM56-7B engine (used on B737 NG) in 2005 and the CFM56-5B engine (used on the A320 series) in 2008. The build-up of CFM engines capability, which is amongst the leading two engines types powering narrow-body aircraft like the B737 and A320, has enabled ST Aerospace to serve the LCC market globally.

Components: ST Aerospace extended its commercial aircraft components MRO capabilities and grew into Power-by-the-Hour (PBH) support for LCCs. LCCs proliferated into Asia, including China, Japan and South Korea, in the last decade with the two largest fleets being AirAsia of Malaysia and Lionair of Indonesia. Beyond Asia, ST Aerospace supports many airlines in Europe and even took its LCC support to the US where it provided Total Aviation Support (TAS) for SkyBus.

Accessing the Largest Asian Aviation Market: China is a large aviation market, both in terms of its own airlines and foreign airlines flying into China. ST Aerospace entered the China market through a joint venture with China Eastern Airlines in 2004. Since then it has set up two other maintenance companies, in Guangzhou in July 2007 for aircraft MRO and in Xiamen in January 2008 for engine MRO.

Besides engineering and MRO it has also recently entered into training of pilots for commercial aviation and aircraft interior design.

In 1982, when it was listed, the revenue of the company was reported to be S$ 70 million. In 2015, its revenue was in excess of S$ 2 billion. With the exception of one year in 1996, the company has been profitable.

Section 5.2
Common Strategic Interests

The most important common strategic interest between the RSAF and ST Aerospace is the mission success of the RSAF in the defence of Singapore.

This interdependence has been built up over the years and is way beyond ST Aerospace's responsibility as the RSAF's MRO depot maintenance service provider when their relationship first began.

Through the commercialised programmes for whole squadron's technical operations, started since the early 1980s, ST Aerospace has become an even closer and integral part of the RSAF's operations over the years. Under this, ST Aerospace personnel run the technical operations of the squadron in Singapore and deploys with it on detachments overseas, both for training and operations.

ST Aerospace's engineers working on the RSAF's engineering development projects have delivered many systems that have significantly enhanced the operational capabilities of the RSAF. The combined engineering capabilities of engineers from MINDEF, DSTA, the RSAF and ST Aerospace has seen through the development of many major upgrading programmes to introduce the latest technologies to extend the life and capabilities of existing aircraft.

ST Aerospace also contributes to the RSAF's new aircraft acquisition programmes to ensure the support needs of the new aircraft are planned for, and engineering data and capabilities are there for future development.

The recognition by all parties of the importance of their common strategic interests has been equally important in enabling the achievements made to date. As will be evident from many of the sections in Chapter 3, the recognition of these common interests is important to ensuring that plans are well implemented in support of strategic policies.

Section 5.3
Sustainability and Growth

As MINDEF and the RSAF engineers progressed on to senior engineering and management appointments in MINDEF, ST Aerospace engineers also progressed on to senior positions in ST Aerospace and ST Engineering. Depending on their personal inclinations, some ST Aerospace engineers may transition from their military work to commercial aviation development programmes like PTF conversion works and continue to apply their engineering skills quite seamlessly.

The complementary roles played by ST Aerospace's management, engineers and technical specialists deployed on RSAF's military work have enabled the RSAF to focus its critical manpower resources on growing, developing and supporting its operations.

As the RSAF grows and continues to evolve in the years to come, ST Aerospace will have to similarly evolve to remain relevant and be able to discharge its responsibilities to Singapore as it has done so over the last 40 years. The partnership has been sustained over time because of the joint commitment to Singapore.

Commitment and trust are most important for a long-term relationship. However, it should be based on a viable model or the relationship would be tenuous at best. As evident from the various parts of this book, both the RSAF and ST Aerospace have recognised this in the building of a lasting relationship.

So, while ensuring it is fully committed to support the RSAF, ST Aerospace has been able to chart a parallel path in commercial aviation, leveraging capabilities it has, but at the same time benefitting the RSAF where possible.

ST Aerospace has managed to build a parallel commercial aviation engineering and MRO business which is competitive in the commercial aviation market and with a very strong global customer base. Whilst this is in commercial aviation, the basic engineering skill sets are not different between military and commercial aviation – in expectations on compliance, quality, performance, culture and even engineering practices, capabilities and technologies.

There are three major touch points in the collaboration which are important and support the interdependent relationship:

- MRO is a core business of ST Aerospace in commercial aviation, and it is an important requirement for the RSAF. Military and commercial MRO practices in aviation are similar in principles. Even in relation to regulatory authorities, the expectations on quality and safety, are similar and in fact will increasingly merge on quality standards and practices under ISO.
- In engineering development, the fundamentals are engineers and engineering work. While the applied aspects might be different, the basic engineering practices are not different. The experience over the years in transitioning engineers between military and commercial works within ST Aerospace also affirms that engineering resources can be flexibly deployed. Many leading commercial OEMs have also reviewed and accepted ST Aerospace engineering capabilities, built over the years through military engineering work, for commercial aviation work. There is no better accreditation.
- The third touch point is in the RSAF's commercialised programmes which most visibly illustrate the close relationship between the RSAF and ST Aerospace. The experience over many years, on many different aircraft types, both locally in Singapore and overseas, in training or in conduct of operations, have demonstrated beyond any doubt that the mutual trust is well placed and on firm grounds.

While it is most important that the common strategic interest of the RSAF and ST Aerospace is underpinned by the core business interests of each party, it is also important that there is no over dependence of ST Aerospace on the RSAF created as a result. In this regard, ST Aerospace's ability to carve its niche in commercial aviation engineering and MRO while fully discharging its responsibilities to the RSAF is important and necessary as it is a requirement under its founding charter to be "commercially viable".

Chapter Six

ENDEAVOURS TO BE EXCELLENT

Section 6.1
The RSAF as a Leading Air Force

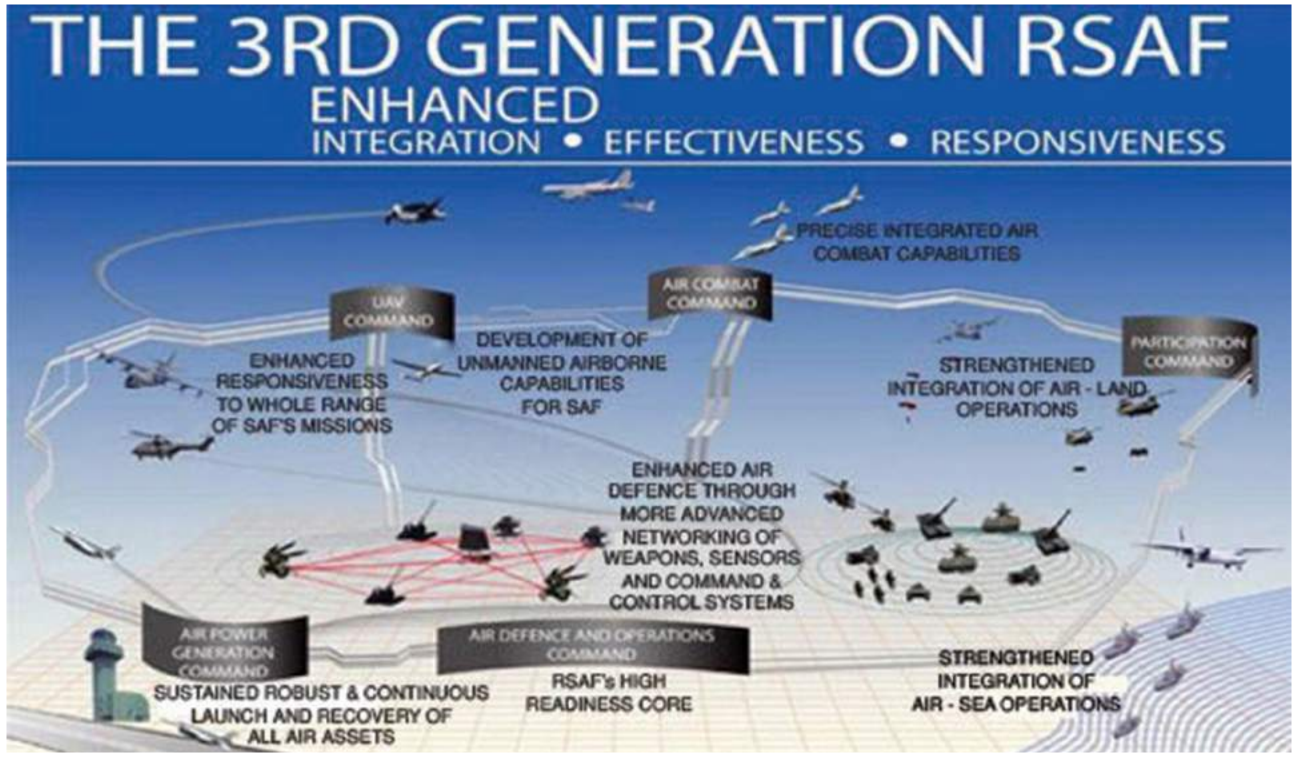
The Need to be at the Cutting Edge

Since its independence 50 years ago, Singapore has grappled with the challenges faced by small city-states – a unique vulnerability in the lack of strategic depth. On top of East Asia's dynamic and increasingly complex security environment, the role of defending Singapore has only become more challenging with time.

In this context, the criticality and potency of an effective air power in safeguarding national security cannot be underestimated. Modern aerial warfare allows for greater precision in strike capabilities, bringing down key targets such as command and control centres, communications facilities and supply depots. The speed and deadly potency with which air power can be brought to bear on adversaries is devastatingly evident in the many conflicts over the last half century in the world's hot spots. A strong air force is a powerful deterrent with immense capability for defence and offence. Likewise, the lack of a credible air power can be the very Achilles heel of even the largest armed forces.

The 3rd Generation RSAF is an integrated, effective and responsive full-spectrum force, able to defend the nation's skies, influence land and sea battles, and is ready to defend Singapore.

Having understood the importance of a credible air force in ensuring peace and security, the RSAF has evolved over the years to be operationally ready, equipped with various platforms and systems to safeguard Singapore's airspace 24/7. The multi-layered air defence shield that comprises fighters, ground-based air defence systems and surveillance radars offer a full spectrum of capabilities, highly integrated, and ever-ready to respond to threats. The RSAF continues to validate its readiness, operations and doctrines through joint military exercises, overseas detachments and humanitarian aid and disaster relief missions. Over the years since the very early days, the RSAF has always been ready to execute missions in support of Singapore's assistance to other nations in need.



The RSAF, The 3rd Generation Air Force

C-130 being loaded for humanitarian mission

How does the RSAF stay at the Cutting Edge?

The potential of an air force to achieve air superiority depends on its ability to generate air power in a robust and timely manner. However, air power is not limited to weapon systems capability alone. While the newest aircraft or latest weapon system may give an advantage to those who possess the skill to harness it, other "soft" factors such as short turnaround time, network integration, knowledge, and importantly competent people all play a part in the generation of effective air power.

System Management and Capabilities Development

Since its inception in 1969, the RSAF has grown by leaps and bounds. It has inducted and integrated many different types of aircraft, weapon and sensor systems in its inventory to become a highly sophisticated and operational Air Force and would continue to do so. This has been necessary to meet the demands of the challenging and constantly changing external security environment, and to develop capabilities across a full spectrum of operations.

Over the years, the RSAF's Air Engineering and Logistics Organisation (AELO) has accumulated a wealth of expertise and experience in system management through the induction, through-life support, mid-life upgrades, all the way through to the eventual retirement of its aircraft, weapon and sensor systems. Each of these systems poses unique engineering challenges depending on the operational context, state of technology during induction, and life cycle logistical support. The expectations from each weapon system and

F-15SG undergoing air-to-air refuelling by KC-135

how these could be attained are encapsulated in its LCM (now known as DCM) doctrine that guides the entire planning, acquisition and support processes so that the capability is maximised to serve the RSAF to the fullest.

All aircraft and equipment in the RSAF are procured only after extensive and detailed studies of their capabilities, as well as ability to integrate with the rest of the RSAF's assets to deliver the required operational capabilities. For example, with air-to-air refuelling by the RSAF's KC-135R, the latest F-15SG is able to extend its range to deliver precise and deadly airpower when called upon to protect Singapore's sovereignty.

To leverage Singapore's defence ecosystem, the RSAF (AELO) works closely with its strategic partners in DSO , DSTA and industry partners to acquire and develop new capabilities that are unique to the RSAF, giving it an edge over potential adversaries. Using the fighter aircraft fleet as an example, the A-4SU Super Skyhawk was one such success story of daring and innovative conceptualisation and effective execution. This was followed soon after by others such as the upgraded F-5 Tiger. With the arrival of the F-16D Block 52+ in 2004, the RSAF's capability was enhanced with one of the then most advanced F-16 variants globally. The RSAF team worked with partners to configure it with the APG 68(V)9 radar, improved computing power, better detection ranges, enhanced tracking capabilities and the unmistakable Conformal Fuel Tanks (CFTs) attached to the upper fuselage which extended its range by up to 30%. This was made possible via the close partnership and cooperation between the different agencies involved in the system management and capability development process of the platform. Since then the RSAF has acquired and inducted the F-15SG as its latest fighter under its Next Fighter Replacement Programme. It will continue to update and upgrade its capabilities to maintain the edge for the RSAF, not only in hardware but in the people and systems who support and operate it as an integrated air power.

Knowledge and Processes

To be able to fully exploit the potential of a highly integrated 3rd generation RSAF equipped with state-of-the-art systems, it is imperative that the Air Force builds up a wealth of technical know-how and deep expertise in the engineering and maintenance of each system that it inducts into its operations.

With this capability, the RSAF is able to maximise the defence dollar through capability development, reliability improvement and life extension of its aircraft, weapon and sensor systems. These objectives are realised through modifications, system upgrades and introduction of new technologies to enhance its capability.

Over the years, knowledge management has been key in driving the growth of the entire organisation. Since the early days as a fledgling air force, management at different levels have recognised the need to clearly document lessons learnt and the rationale behind various decisions. This has served the RSAF well as it underwent the transformation from a 1st Generation RSAF to a 3rd Generation RSAF, allowing the Air Force to take stock and consolidate its achievements at critical junctures.

Never resting on its laurels, the RSAF continues to seek improvements in its readiness preparations. This constant refining of its work processes allows the RSAF to remain robust and resilient, as well as confident of its capability to meet future challenges.

Culture and Ethos

"Team Excellence" is a core value that has been imbued into the RSAF's operational capabilities and the psyche of all airmen. Air Force engineers recover, refuel and re-launch the aircraft to sustain operations. The RSAF's umbrella of sensor suites and ground-based air defence protect Singapore's airspace. Command, Control and Communications (C3) officers orchestrate the air campaign. In order for the team to be successful, each individual must excel in his/her role, and also possess teamwork to work effectively as a cohesive unit.

Together with its operational capability build-up, the RSAF had also developed a very strong *"Safety Culture"* within its organisation which is expressed through the professionalism of its airmen. Ensuring safe day-to-day operations and maintaining a high level of confidence in Singapore's defence capability will deter potential adversaries from aggression. Strong engineering and maintenance competencies underpin this pervasive safety culture, which has allowed our operators to push the boundaries of the envelope and develop more advanced war-fighting capabilities.

The RSAF Engineering – At the Heart of the Action

The RSAF is a fast-paced and dynamic organisation, always evolving to do better and demanding utmost excellence from all its members. In the RSAF, engineers and engineering are dynamic, driven and constantly at the forefront of the latest military aviation technology, and right at the heart of the action.

The symbol of the air force engineer

Akin to other servicemen, air force engineers are first and foremost called to serve the SAF in its mission of enhancing peace and security. This engineering core is responsible for ensuring that our aircraft are in optimal state, our surveillance radars scan quietly but surely, our missiles primed, our cyberspace and networks robust, and our whole array of systems working 24/7 to protect Singapore's sovereignty.

A passion for engineering is required to get all these systems to operate like clockwork. Our engineers are invigorated by the fierce roar of the propulsion plants that scramble the jets to Mach 2, the silky rhythmic twirl of the radars, the explosive separation of an air-to-ground missile, the shrills when testing electronic warfare gear, and the hum of the biggest UAV. They love the sculptured silhouette of the jets as they take off into the blue skies, the imposing dark-pointed missiles pointing skywards, and the bloom of a successfully launched guided missile. They study closely blueprints, schematics, statistical plots, digital readouts and excel in relating to each and every component in the weapon platform to gauge its state of health. They find excitement in taking on a multitude of roles as designers, developers, system integrators, programme managers, evaluators, technical examiners, system analysts and expert advisors to our men and women who operate these systems.

Young aspiring engineers are presented with scholarships and training opportunities in some of the best universities in the world, both locally and abroad. They are educated in various engineering disciplines, including aerodynamics, mechanics, structures, propulsion, electronics, software, and communications system, among others. Throughout their career in the RSAF, they will be continually trained through weapon system upgrading courses, post-graduate studies, as well as military training to further their effectiveness in their work place. They work with the best in the field, training and operating with the world's most advanced air forces, sharpening doctrines and training regimes, and pre-empting the next leap in the evolution of capability. The same emphasis for training of the engineer corps applies to the technical workforce to maintain the RSAF's aircraft at their optimal level.

The RSAF and the Future of Singapore's Security

The RSAF, with its strong and multi-layered defence capabilities always at a high state of operational readiness, is recognised as a leading air force in the region. This accolade is attributed to far-sighted policies, prudent use of the defence budget to acquire new technologies, and working closely with the defence ecosystem that includes DSTA, DSO, academic institutions, defence industry partners and military allies.

"The most dependable guarantee of our independence is a strong SAF. A strong SAF, in turn, depends on the political will to make the effort and pay the price."

Dr Goh Keng Swee

As part of the SAF, the RSAF has provided Singapore with an enviable degree of external security that has, in turn, reassured local and foreign business investors, and contributed in no small way to Singapore's economic success over the last 50 years. It has also been an emblem of Singapore's constant drive for excellence and innovation, solidifying our nation's standing on the international arena.

The capability of the RSAF in the future would be even more geared to the development and support of state-of-the-art technologies to sustain a credible defence edge. Certainly, the RSAF's interest in attracting the best engineers and scientists will remain key to sustain the breadth and depth of expertise required to expand the nation's home-grown capabilities.

For the aspiring technical-minded individual, an aerospace or engineering career holds an abundance of exciting opportunities that value a multitude of engineering disciplines, with rewarding overseas stints to open up the horizon. Ultimately what matters most is that the RSAF's people are skilled and dedicated to the SAF mission. With vision, future generations of the RSAF's men and women will continue to keep the RSAF at the leading edge, upon which a brighter future for Singapore can be secured and built upon for many generations to come.

Singapore's prosperity and success today is built on a solid foundation of stability and security. A ready and capable air force, along with the other services in the SAF, provides the bedrock on which this foundation is built.

Section 6.2

ST Aerospace, the RSAF's partner in the Defence of Singapore, a Competitive Global Aviation Services company, Singapore's Own

Supporting Singapore's Defence Needs but Being Commercially Viable

Committed to its mission to provide industry support for the RSAF, ST Aerospace grew alongside the RSAF since its beginning. As the RSAF evolved from a 1st Generation Air Force to a 3rd Generation Air Force, ST Aerospace has continued to upgrade its capabilities and update its processes to keep them relevant amidst the changes. The interests of the RSAF are the interests of ST Aerospace in the realms of military aviation MRO and engineering.

Over the last 40 years, ST Aerospace has extended its military aviation capabilities beyond being an aviation MRO depot. It built a full aviation engineering capability to support the 3rd Generation Air Force and the upgrade of the RSAF's fleet over the years.

This has enabled the RSAF to do what it needs to update and upgrade its aircraft cost-effectively, to support the weapon systems it upgraded and to induct new acquisitions. The seamless transition from system upgrades and product developments to operations support is especially important in the context of the SAF, in view of its high expectations on operational effectiveness in its fielded systems.

The undertaking of the work and the build-up of capabilities are part and parcel of what most countries do. But what is different, in the case of Singapore, is the expectation for ST Aerospace to be commercially viable so as to be sustainable.

As the engineering requirements of the RSAF can only increase over time as its systems become more sophisticated and the operational demands placed on them increase, it is imperative that ST Aerospace's engineering capabilities match the expectations as driven by the changing needs of the RSAF over time.

Capable engineers, experience from doing the relevant engineering work and engineering leadership are all important ingredients to achieving excellence. And while the responsibility for these is with ST Aerospace, it is recognised and well supported by MINDEF, the RSAF and DSTA.

It is this integrated approach to defence development that has enabled Singapore to achieve what it has over such a short time, as 40 years is a short time considering that the starting level was at ground level in 1972 for the RSAF and 1975 for ST Aerospace.

Building up Commercial Aviation MRO and Engineering

MINDEF's requirement calls for the SAF to be supported by the local defence industry operating on a commercially viable basis. This requirement drives the endeavour for the defence industry to be commercially viable on its own and not be dependent on the SAF only. The journey to be commercially viable started as early as the early 1980s but it was not until the year 2000 when the requirement started to be realised.

Entry into Commercial Aviation MRO

Though the commercial aviation market is a large market, the journey into commercial aviation MRO was not easy. In the beginning, the company had no competitive advantage and had never done commercial MRO work, let alone commercial engineering work. It did not even have assured work upon which to build up its experience.

As it entered into commercial aviation support in airframe MRO, supposedly the work with the lowest barrier to entry, it was severely disadvantaged, with only a strong military MRO and engineering foundation and without the support from any parent airline. Airframe MRO is also a scale business, and it is costly and risky to build scale without some assurance of work.

Based on the experience gained since 1990, ST Aerospace decided, in around 2000, on a series of initiatives to build its commercial aviation capabilities and capacity. It also pushed ahead with the globalisation of its commercial aviation aspirations, first with further investments in Singapore and the US, then into China for commercial airframe work.

Recognising the growing importance of the LCC market, it built up its commercial engine and component Maintenance-by-the-Hour (MBH) programmes, line maintenance and fleet technical management capabilities. Although ST Aerospace was one of the early practitioners of component MBH model from as early as 1990, its growth in this business was constrained in the early years by the valid concern of potential exposure to losses.

Being More Competitive

Competitiveness is key to ST Aerospace. As a third-party service provider, every successful job, big or small, was the result of a more competitive proposal.

And, competitiveness is not just about price though price is always a consideration. The company recognises that competing on price alone is not a viable proposition. Aviation services is certainly not a commodity in the eyes of the airlines, LCCs included. So ST Aerospace decided to differentiate its services through quality, safety and reliability as these are very important to serious operators. Quality and safety go hand-in-hand and are absolutely important to aviation, both military and commercial.

Performance reliability is equally important to commercial operators. It is something that many might not pay much attention to until faced with a problem but the reality is that while many companies might vie for jobs that are being outsourced, their ability to deliver is not a given. There could be a myriad of reasons for failure to deliver and some might be unavoidable occasionally but an illustration of how important delivery is to serious customers is the experience of ST Aerospace from its first job for FedEx B727 Passenger to Freighter (PTF) conversion as recounted in Section 3.5.1. That performance gave ST Aerospace the chance to become a viable alternative to existing service providers in the market, and gained the confidence and support of FedEx which to this day has remained as one of ST Aerospace's most important customers.

Passenger-To-Freighter

PTF work is important to ST Aerospace and a core business. Although it started doing PTF conversion as an area of work where it could have a competitive advantage, its success in undertaking PTF work and the demands from the market demonstrated its potential. From the first conversion that it did for FedEx, ST Aerospace has successfully undertaken many other conversions for various airlines through Boeing's STCs. From there it went into its own PTF design development of the B757 PTF (see Section 4.8.3) and established itself as one of a very few non-aircraft OEM organisation which has been accepted by even the aircraft OEMs as a capable provider and partner.

Heavy Maintenance Visit

HMV might seem a natural for ST Aerospace's foray into commercial aviation MRO but it was not the original intent. This was because it had no advantage as explained in Chapter 4. However, it has developed this business to become the largest aircraft MRO in the world.

Because of its performance on HMV, ST Aerospace became the preferred outsource MRO for both Japan Airlines and All Nippon Airways. Delta Airlines and many other major US and international airlines are also amongst ST Aerospace's aircraft MROs' major customers. As an illustration, Delta Airlines is supported by Mobile Aerospace, and San Antonio Aerospace in the US, SASCO in Singapore and STARCO in Shanghai, China, all at the same time!

Its performances on MRO and PTF conversions have enabled it to become a preferred service provider of large airfreight customers like FedEx and UPS.

So, from having no parent airline advantage it has managed to overcome that by being a capable and reliable supplier.

Engines and Components

Engines and components have quite different business considerations, as compared to aircraft MRO and engineering, and their own competitive landscapes. ST Aerospace has both aviation engine and component MRO capabilities amongst its repertoire of MRO capabilities to support the RSAF. Extending these technical competencies to commercial aviation engines and components might sound logical. However, besides having the basic technical know-how, it did not have the type knowledge and experience.

ST Aerospace overcame these disadvantages and built up its engine and component MRO capabilities to support many commercial customers, including many LCCs on a global basis (see Chapter 3). This was achieved through the company's engineering competencies and ability to leverage its group level capabilities and close working relationship with its customers.

Competition and Competitiveness

The above is a snap-shot of the considerations that helped to leverage each of the points in support of ST Aerospace's efforts to become commercially viable. Regardless of whether it is in the commercial airframe MRO and engineering development programmes, engine and component MRO, or operations support through PBH, and TAS, there are many competitors in the business.

In those areas where the barriers to entry are higher, there would naturally be fewer competitors. For customers needing global-level support, PTF conversions (especially with engineering development) and TAS, competition might be lower as not many service providers have the capabilities. But, generally, there would be no lack of competitors where there is potential of any sizeable contract, commercial or military.

The good thing is that customers are knowledgeable and have experienced people assessing the potential suppliers. So while pricing is important, the concept of best value does prevail in most cases.

What Constitutes Best Value?

Most customers have their own criteria on which they make their evaluation. Although the approaches might differ from customer to customer, in the final analysis the decision outcome might not be very different.

The aviation market is also a small market and professionals in the field usually have good market information on the capabilities of the MROs vying for their work, be they third party, airline owned, or OEM owned.

ST Aerospace differentiates itself through its quality of work, responsiveness to customers' needs, and reliable and predictable in performances. These are key to customers as explained earlier.

From a business consideration the company seeks to develop a sustainable and lasting relationship with all customers, large and small.

Implications of Being Global

Being a global MRO is a competitive advantage as shared under Section 3.5.1. But it also means that much effort has to be expended to maintain those advantages.

Customers would expect similar performances and even "touch and feel" from the company. This is not unreasonable and there are many things such as quality systems, standards of performances and training that can be institutionalised and it is especially important to do so for an aviation company.

However, as a global company with operations in different parts of the world, and especially for an aircraft MRO where many people are employed, the most complicated aspect is how to maintain the consistency of services across the operations because of the different cultural backgrounds of the staff? Some degree of this can be achieved but it is never easy.

A key culture that ST Aerospace has emphasised and which is well ingrained into the people in the company is that the company is an independent third-party service provider and the customer is most important!

Endeavour to be Excellent

Over the years, ST Aerospace has continued to work on building new capabilities, to differentiate itself from its competition and to build up its customer base. This effort cannot ease. ST Aerospace is today recognised as a leading global aviation service provider. That recognition is not measured by the company's spatial dispersion of its operations, the broadness of its range of capabilities or its customer base although each is important.

It has to endeavour to be excellent. Being excellent may mean many things to different customers and understanding that is important.

As a leading aviation service provider, the best recognition is the one accorded by its customers. It is the customers that decide if the performance of the company meets its expectations and therefore is its preferred service provider.

The company has been fortunate to have served and earned the trust of a strong and sizeable customer base over time, a customer base that is distinctive and significant both in terms of numbers and in terms of their market position in their field of operations. Many are the world's leading passenger airlines, leading freight airlines, significant LCCs and some are small individual operators.

This customer base is built through the constant addition of new customers from the market that ST Aerospace competes in, but most importantly, through the ability to retain its customers. ST Aerospace's various businesses have been fortunate to have its customers remain with the company over the years. Many of these customers have been supported by ST Aerospace since the early 1990s when ST Aerospace first entered the commercial aviation MRO market.

While it is very important to ST Aerospace to be able to secure the confidence and support of the big customers, being able to maintain the clientele of the smaller customers is as important. Some of the smaller customers operate a small fleet of aircraft, some operate a few aircraft. Being able to support the smaller customers well is perhaps even more telling of the company's commitment to customers.

Lynden Air Cargo, a specialty service operator headquartered in Canada, is one such customer whose aircraft operate in different parts of the world but are supported in Singapore over the years. Moreover, some smaller customers might become major airlines in time. This is especially true of LCCs and AirAsia is such a customer which ST Aerospace secured when it then operated only two aircraft. Today it is the largest LCC in Asia. And there are many other similar examples.

Singapore celebrated its 50th Anniversary in 2015. It is a short history compared to that of many other countries whose history spans over much longer periods. Despite this relatively short history, Singapore has made its mark in many fields and it is recognised globally for its achievements on many things, too many to try to list them here.

In relation to aviation engineering, ST Aerospace has achieved a recognised position as a leading and competitive global aviation services company in the very competitive environment of commercial aviation. Starting as a military aircraft depot in 1975, it not only supports the RSAF well but has over the last 25 years established itself as a competitive and credible commercial aviation MRO and engineering company on a global basis.

By operating companies in many of the major civil aviation markets, ST Aerospace has a global work force and a more significant customer base than most other commercial aviation engineering and MRO service providers.

ST Aerospace became the world's largest commercial aircraft MRO and has held on to that accolade for the last 12 years. It also became a major service provider for LCCs and airlines, providing components and engines through discrete MRO contracts or PBH Agreements as required by the customer. And it can do so as far as the US. It is also the leading third-party PTF engineering and conversion company globally.

At the same time ST Aerospace continues to build on its many capabilities and competencies to support the needs of the RSAF – leading capabilities that are essential to support and enable the RSAF to be a leading air force.

In both dimensions, ST Aerospace has achieved some successes in its endeavour to be excellent and the outcome to date is the best attestation of its progress on this journey, which has no ending.

Singapore's Own

Singapore does not have a long history of building its own companies or organisations which are recognised beyond its shores, and even less on a global basis. The examples of the RSAF and ST Aerospace, working with their DTC partners, present two illustrations of what have been achieved in one segment of Singapore that has both national and global significance.

Today, the RSAF is a leading air force, comparable with the best in the world, and its partner, ST Aerospace a leading global aviation service provider.

The endeavour to be excellent is critical to the achievements of each and the journey continues.

Chapter Seven

WHAT THE FUTURE HOLDS

The last 50 years saw the transformation of Singapore from an emerging country to a modern city state which is well recognised for its achievements in many dimensions. Despite its lack of resources, it has built itself up as a globally competitive economy with many competitive advantages developed through the efforts of its people.

This has been possible because of Singapore's stability as a nation. Security to Singapore is essential for not only its physical well-being but also for its economic viability. The RSAF, as part of the SAF, is an important component of Singapore's national defence that delivers this assurance on security. This book shares on the build-up of the RSAF and its journey to the present where it is recognised as a leading air force amongst much larger air forces in the world with longer histories.

Engineers and Engineering

This book on Aviation Engineering shares the engineering perspective of the journey. The contributions of engineers and engineering are immensely important in bringing the RSAF to where it is today. They have gone through many trials and tribulations, and have come out on top of the problems that stood in their path over the years.

Of these, a most crucial event, a watershed event for the RSAF and military aviation engineering, was the A-4 Crisis. The A-4 Crisis could have seriously derailed the build-up of the RSAF and adversely impacted Singapore's defence capability. Fortunately, it was also a huge success story for the RSAF as it recovered from the crisis on its own, demonstrating its resilience and competency. The recovery was a result of trust; trust of the engineers in their own professional competency, trust between the operations and logistics (then encompassing both engineering and logistics) communities of the RSAF, and the trust of MINDEF in the RSAF. The crisis demonstrated the cohesion of the RSAF as an organisation and as a command.

Over the first 50 years, much has been done to build up the capabilities of the RSAF. And more will be done in the next 50 years. An inappropriate decision in the acquisition process, or in the conclusion on the optimal solution to the operational requirement, could lead to unnecessary expenses and adversely affect the best use of national resources but, more importantly, could compromise the nation's defence. Even if the most capable systems were acquired, their ability to contribute to the intended end objective would depend on how they were maintained and kept in optimum conditions, and how they were used. Each of the cited examples depends on people, people within the RSAF and in MINDEF, DSTA, DSO and ST Aerospace.

The important difference will always be good engineers and engineering capabilities; in maintenance, in development, in acquisitions and in research. While the outcome on each activity could be measured by the success of an individual endeavour, the combined outcome is measured in terms of its contribution to the overall mission of the RSAF. While the same can be said of most things like running an airline or running a company, the price of failure is much more for a nation's defence.

As systems get more complex and technologies change the traditional ways of doing things, engineers (including maintenance engineers, development engineers and acquisition engineers) and engineering would be key to the RSAF.

The engineering responsibility would require the best from engineers, and maintenance and logistics professionals of the RSAF, MINDEF and ST Aerospace. It was important in the build-up years and it would only become more important into the future. Whilst the conditions are different, the basics are not; basics in capabilities, commitment, innovativeness, ability to adapt to changing conditions, and so on.

Convergence of Interests

From the RSAF's, MINDEF's and ST Aerospace's perspective, an important achievement to recognise would be the synergies that had been achieved from integrating the interests and needs of MINDEF, the RSAF and industry. This unison of interests and integration of resources and efforts is a unique achievement which is recognised by most other countries and should be built on.

Singapore tries to maintain a reasonable balance between what is important as a strategic capability and what is best left to economic considerations. The interests of the SAF come before commercial interests of the defence industry but MINDEF and the SAF respect the right of the company to meet its commercial responsibility.

This approach has enabled the RSAF to meet its operational needs cost-effectively over the years. It has enabled it to decide freely between finding a solution to its requirements through acquisition of new systems and aircraft, or through upgrading of existing systems and aircraft. To ensure it has made as good a decision as possible, it has developed a strong Life Cycle Management methodology (see LCM in Chapter 4) to guide its acquisitions and management philosophy. It has, in the process, also built up, together with ST Aerospace, a competent military aircraft support and upgrading capability to ensure there is a real alternative. An industry capability which can undertake even product development if necessary.

Being Commercially Viable

In the 30 years since it started major engineering development work on the A-4SU and 25 years since it started into commercial aviation MRO and engineering, ST Aerospace has managed to achieve some successes in commercial aviation engineering and MRO on a global basis. In a very competitive environment in the case of commercial aviation MRO, ST Aerospace has managed to establish itself as a leading global aviation services company with a very credible global customer base and a solid reputation. In commercial aviation engineering development, it has managed to achieve a good position as a leading PTF development and conversion house over a relatively short time.

As the environment for commercial aviation evolves, as aircraft needs change, and as new concepts to business and competition models develop, ST Aerospace must continue to evolve. The advantages which it has, which not many others in the industry have, is the spread of its capabilities; ability to access and work in different markets, range of competencies relevant to services needed and engineering know-how.

But equally, if not more important is perhaps its customer base which is ST Aerospace's biggest competitive advantage. It has today a customer base that is its strongest differentiating factor and which the company has to continue to build on.

ST Aerospace has managed to make the transition from being a purely military aviation company to a company with both military and commercial aviation MRO and engineering (design and development) capabilities. This is not as normal as it might seem because not many companies in the history of aviation have managed to do so.

Many reasons have been cited, including the different practices, different cultures and customer expectations. But ST Aerospace has leveraged the benefits and achieved good results.

In addition, beyond establishing itself as a competitive commercial aviation MRO and engineering company, ST Aerospace also found benefits from doing commercial work which has helped sustain its military capabilities because many of the engineering skills are complementary.

People made it Possible

In all aspects of the two dimensions, military and commercial aviation engineering, it is the people who are the essential "glue" that holds the capabilities together. Engineers played an important role in the build-up of both military and commercial aviation in the RSAF, MINDEF, DSTA, DSO and ST Aerospace over the years and they will continue to play equally important roles in the future.

What have been recounted in this book demonstrates the contributions of engineers over the years to both the RSAF's and ST Aerospace's development. As both organisations grow, as equipment and operating systems become more complicated, the need for engineers with the right capabilities and experience increases many folds.

The interdependence between the RSAF and ST Aerospace has been tested through many situations, demonstrating the mutual convergence of interests of both organisations. Increasingly, many technologies, processes, practices of both military aviation and commercial aviation are moving in the same direction; in some cases they even merge. This augurs well for both the RSAF and ST Aerospace to be able to leverage the knowledge from both the military and commercial aspects of aviation engineering. The type of hardware and end applications may be different but the engineering knowledge is generally no different in principles and even in practices.

A common resource which will continue to be important to both the organisations is engineering and MRO professionals. Each organisation has found many ways to interest, induct and deploy its engineering human resources in competition with the draw of other industries. The ability to get a fair share of these resources is important to the future of not only the RSAF and ST Aerospace but, from a broader perspective, to the future of Singapore as well.

Over the last 20 years, Singapore's aerospace industry sector has grown at a compounded rate of about 8.6%, better than many other segments of industry. While the market is increasingly complex and competitive, the aspiration and hope is for this growth to be sustained and even improved.

Looking Ahead

There are good reasons for hope and expectations. With the expected growth and modernisation of Asia in the coming years, the demand for air travel will only increase and the rate of increase would be faster than in the more developed aviation markets of the world. Singapore's more established aviation industry and strong cluster of related industries should benefit from the projected growth and if managed well, could sustain its competitiveness.

The Industry is helmed by many factors. There is a strong cross-section of globally leading OEMs and their capabilities are present in Singapore and this may be expected to grow with transformation of Singapore's aviation interests from a largely MRO capability to one with a more balanced mix of MRO and product development. Singaporean companies, amongst them ST Aerospace, will have to continue to build on its strength as an engineering and development company in addition to its MRO capabilities.

Aviation research would continue to grow through the build-up of capabilities and undertaking of research in support of the major players in aviation. Research in aviation is supported in Singapore through A*STAR, the universities and other institutes of higher learning and research centres of many OEMs and other independent organisations in Singapore. The A*STAR Aerospace Programme is one significant Singapore achievement in undertaking pre-competitive research requirements of many of the world's leading aviation OEMs through a collaborative consortium. Small and medium enterprises in Singapore which is an important part of Singapore's industry eco-system also need to be nurtured through a combination of specialised investment in aviation related capabilities and through partnership in support of the needs of the larger players in the industry, including the leading global aviation OEMs.

As Asia becomes more prosperous in the years ahead, the airlines and aviation industry should benefit from the increased demands. Having a "bigger pie" increases the opportunities for all. Engineers should be able to play an important part in Singapore's effort to secure its interest in this important segment of industry. Increasingly over the last decade, as the possibilities in aviation unfolded, many of Singapore's institutions of higher learning have introduced options in aviation engineering. The take-up has been encouraging and interests in aviation studies have been affirmative. With improved awareness and increasing opportunities, there is a need for more engineers to enter the industry. Besides enabling the aviation sector of Singapore to be even more successful, could this also enable it to grow beyond what it does today?

While the RSAF and ST Aerospace have achieved much from their inceptions, other dimensions of the aviation industry in Singapore have also been growing very positively. The common thread through all these – military or commercial, third party or airline or OEM, public or private enterprises – are the people within the aviation industry. Engineers play an important role in aviation. As the industry grows further in the years to come, engineers in the RSAF and the Singapore aviation industry play an important part to contribute to the furtherance of Singapore's aviation interests and the Singapore economy.

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Authors

Goh Yong Kiat graduated from NUS in 1984 with a degree in Mechanical Engineering. He had earlier enlisted as an Aircraft Technician with the RSAF in 1979 and upon obtaining his degree, he was appointed Air Engineering Officer and served in various appointments in Weapons Branch in HQ RSAF and proceeded to command the Air Logistics Squadrons of Paya Lebar Air Base and Tengah Air Base in 1995 and 1998, respectively. During the course of his RSAF career, he attended and was conferred MSc in Explosives Ordnance Engineering by Cranfield University. Yong Kiat left the RSAF in 2002 and joined ST Aerospace where he held management appointments in ST Aerospace Engines and ST Aerospace Engineering. He is currently the Executive Vice President for Aviation and Training Services.

Hor Gar Yin graduated with a BEng Honours degree in Electrical Engineering in 1984 from NUS. Upon graduation, he worked as a member of the A-4 Avionics upgrade team. He later led a team of engineers in upgrading the avionics and integrating a multimode radar on the F-5 aircraft. Both projects won the Defence Technology Prize (Team) in 1991 and 1999, respectively. From 1996 to 2003, Gar Yin was the Divisional Manager of Aeronautical Systems where he was responsible for all aircraft acquisition and upgrade programmes for the RSAF. Gar Yin is currently Deputy Chief Executive (Operations) of DSTA.

Lim Serh Ghee began his career with ST Aerospace as a mechanical engineer in 1984, and was a member of the team that successfully upgraded the A-4 Skyhawk with the GE F-404 engine. By July 1991, he headed the Aeroscience and Mechanical Systems Department, and oversaw the joint development of the EC120 helicopter as the Programme Manager. Mr Lim rose to become Vice President of the group's in-house Engineering and Development Centre in 1996. During his tenure, he spearheaded the Turkish F-5 Tiger upgrade and the Boeing 757-200 passenger-to-freighter conversion programmes. Mr Lim graduated with a Second Class Upper Honours degree in Mechanical Engineering from NUS in 1984. He is currently the President of ST Aerospace Ltd.

Lim Tau Fuie was amongst the pioneer batch of local graduates from NUS who joined ST Aerospace in 1983 for the A-4SU upgrade programme. He started work as an avionics system engineer and build up a career in engineering. He was the programme manager for the RSAF F-5 avionics upgrade programme in 1991 and was personally involved in many of the engineering development for the RSAF and foreign military aircraft upgrades. When he was the Vice President, Avionics in 1998 and subsequently as Senior Vice President of Engineering Development Centre in 2002, he led the build-up of several capabilities including airborne computer and UAV development. He is currently the Chief Technology Officer of ST Aerospace, an appointment he holds since July 2010.

Tay Kok Khiang joined the RSAF as an Air Engineering Officer in 1972 upon graduating from NUS. He joined the RSAF as a military engineer and held various appointments in MRO operations, as Head Quality Assurance and Assistant Director Special Projects in MINDEF. He became Head Air Logistics in 1985 and retired in 1993. He then joined ST Aerospace, as Vice President and General Manager of ST Aerospace Engineering. From then he worked in various capacities as Executive Vice President Military Engineering, Deputy President and Chief Operating Officer, and President ST Aerospace from 2001. He saw the build-up of ST Aerospace as a partner of the RSAF and as a leading commercial aviation MRO and engineering development company until 2010. He is currently Chairman, A*STAR Aerospace Programme.

Tay Kok Phuan has extensive experience in aircraft maintenance and engineering, systems integration and acquisition management of air platforms. He began his career with the RSAF as an engineering officer in 1976 and took on various appointments in Air Logistics Department, including Head of Engineering Branch. He then moved to Defence Materiel Organisation which later became part of DSTA. He held various leadership positions in DSTA, including Director Air Systems and Director DSTA College. He retired from DSTA in 2010 and is currently engaged in consultancy work. Kok Phuan has a BEng (Mechanical) degree from Monash University, Australia and a MSc (Industrial & Systems Engineering) degree from NUS.

Lim Yeow Beng graduated from NUS in 1983 with a degree in Mechanical Engineering (Hons) and MSc in Industrial Engineering in 1987. Prior to joining the private sector, Yeow Beng's last military appointment was the Head of Air Logistics responsible for the total integrated logistics and engineering operations for the RSAF. Yeow Beng joined SembCorp Logistics Group in July 2003 to plan and execute strategic projects in Asia Pacific, and was appointed President and CEO of ST Logistics in April 2007. He retired from ST Logistics in June 2014 and currently serves as advisor to private companies.

From left to right: Mr Lim Yeow Beng, Mr Goh Yong Kiat, Mr Lim Serh Ghee,
Mr Tay Kok Khiang, Mr Hor Gar Yin, Mr Tay Kok Phuan, Mr Lim Tau Fuie

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GLOSSARY

Acronym	Description
A*STAR	Agency for Science, Technology and Research
A&P	Airframe and powerplant mechanic
ACMI	Air combat manoeuvring and instrumentation
AD	Advisory Directive
ADRU	Air Defence Radar Unit
AED	Air Engineering Department
AELO	Air Engineering and Logistics Organisation
AEO	Air Engineering Officer
AEW&C	Airborne early warning and control
AIS	Avionics Intermediate Shop
AJT	Advanced Jet Trainer
AHP	Analytical Hierarchy Process
ALD	Air Logistics Department
ALO	Air Logistics Organisation
AMAG	Airframe mounted accessory gearbox
ANA	All Nippon Airlines
AOC	Air Operator Certificate
APU	Auxiliary power units
ARL	Airlines Rotable Limited
ASF	Aircraft Servicing Flight
ASIP	Aircraft Structural Integrity Programmes
ASIST	Aircraft-Ship Integrated Secure and Traverse
ATM	Air turbine motors
BAF	Brazilian Air Force
BCF	Boeing-Converted Freighter
BDI	Bristow Defence Industries
C2	Command and control
C3	Command, control and communications
CAA	Civil aviation authority
CAAC	Civil Aviation Administration of China
CAAS	Civil Aviation Authority of Singapore
CAGR	Compounded annual growth rate
CAMP 6	Certificate in Aircraft Maintenance Programme
CATIC	China National Aero-Technology Import & Export Corporation
CEA	China Eastern Airlines
CEP	Circular error probable
CDU	Cockpit display unit
CFD	Computational fluid dynamic
CG	Centre of gravity
CMM	Capability Maturity Model
CNS	Communications, navigation and surveillance
COTS	Commercial-off–the-shelf
CSCI	Computer software configuration Item
CVM	Comparative vacuum monitoring
DESO	Defence Engineering and Scientific Officer
DCM	Defence Capability Management
DMO	Defence Materials Organisation (1986 to 1996), Defence Materiel Organisation (1996 to 2000)
DOA	Design Organisation Approval
DSO	Defence Science Organisation (pre 1997, now known as DSO National Laboratories)
DSTA	Defence Science and Technology Agency
DTC	Defence Technology Community
DTG	Defence Technology Group
DTP	Defence Technology Prize
EASA	European Aviation Safety Agency
ECS	Environmental control system
EDB	Economic Development Board
EDC	Engineering and Development Centre
EFW	Elbe Flugzeugwerke GmbH
EIDS	Engine Instrument Display System
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
ENSICA	Ecole Nationale Superieure d'Ingenieurs des Constructions Aeronautiques
EO	Electro-optics
ES	Engineering Services
ESW	Engineering Software Department
EW	Electronic warfare
FAA	Federal Aviation Administration
FC	Flight cycles
FCC	Flight control computer
FIR	Flight Information Region
FIS	Fabrication Inspection System
FLAT	Flight acceptance test
FLIR	Forward-looking infra-red
FTM	Fleet Technical Management
FTS	Flying Training School
FOD	Foreign Object Damage
GAT	Ground acceptance test
GCS	Ground control station
GE	General Electric
GPS	Global Positioning System
GTC	Gas turbine compressors
GUI	Graphic user interface
HFE	Human factors engineering
HMD	Helmet-mounted display
HMF	Hunter Maintenance Flight
HMV	Heavy Maintenance Visit
HUD	Head-up display
IHPC	Institute of High Performance Computing
ILS	Integrated logistics support
IMP	Improved Maintenance Programme
INS	Inertial navigation system

IP	Intellectual property
IPT	Integrated product team
IRDS	Infra-red detection system
iSET	Integrated System Engineering Team
JAL	Japan Airlines
JCAB	Japan Civil Aviation Bureau
JEIM	Jet Engine Intermediate Maintenance
JV	Joint venture
LAE	Licensed Aircraft Engineer
LAH	Light Attack Helicopter
LASS	Lockheed Aircraft Services Singapore
LCC	Low cost carrier
LCM	Life Cycle Management
LOH	Light Observation Helicopter
LSMP	Logistics Support Management Plan
LST	Landing Ship Tank
MAE	Mobile Aerospace Engineering
MBH	Maintenance-by-the-Hour
MDC-SCP	Main Deck Compartment Smoke Control Panel
MFD	Multi-function display
MFCD	Multi-function colour display
MINDEF	Singapore Ministry of Defence
MoA	Memorandum of agreement
MPA	Maritime Patrol Aircraft
MRO	Maintenance, repair and overhaul
MSG-3	Maintenance Steering Group-3
MTBF	Mean-time-between-failure
MTOW	Maximum-take-off weight
NAA	National aviation authorities
NATO	North Atlantic Treaty Organisation
NFRP	Next Fighter Replacement Programme
NS	National Service
NSF	Full-time National Serviceman
ODA	Organisational Designation Approval
OEM	Original equipment manufacturer
OFP	Operational Flight Programme
OT&E	Operational test and evaluation
OTC	Oakey Traning Centre
PBH	Power-by-the-Hour
PBL	Performance-Based Logistics
PGA	Production go ahead
POA	Production Organisation Approval
PSC	Public Service Commission
PTF	Passenger-to-Freighter
PTO	Power take-off
PZT	Piezoelectric
QA	Quality Assurance
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RAFO	Royal Air Force of Oman (RAFO)
RCM	Reliability Centered Maintenance
RLG	Ring laser gyroscope
RNZAF	Royal New Zealand Air Force
ROCAF	Republic of China Air Force
RPO	Resident Project Office
RPV	Remotely piloted vehicle
RSAF	Republic of Singapore Air Force
SAA	San Antonio Aerospace, now known as VT SAA
SAB	Seletar Air Base
SACO	Singapore Aero Component Overhaul
SADC	Singapore Air Defence Command
SAEOL	Singapore Aero Engines Overhaul Limited
SAF	Singapore Armed Forces
SAI	Singapore Aircraft Industry
SAM	Singapore Aerospace Manufacturing
SAMCO	Singapore Aircraft Maintenance Company
SARA	Singapore Aerospace Research Aircraft
SASCO	Singapore Aviation Services Company
SB	Service Bulletin
SBA	Strategic Business Area
SEEL	Singapore Electronics and Engineering Limited
SEI	Software Engineering Institute, Carnegie Mellon
SIA	Singapore Airlines
SIL	System Integration Laboratory
SLEP	Service Life Extension Programme
SNCO	Senior non-commissioned officer
SHMS	Structural Health Monitoring Systems
SI	Servicing Instruction
ST	Singapore Technologies
STA Engines	ST Aerospace Engines Pte Ltd
STA Systems	ST Aerospace Systems
STAG	ST Aerospace (Guangzhou) Aviation Services Company Ltd
STARCO	Shanghai Technologies Aerospace Company
STC	Supplementary Type Certificate
STI	Special Technical Instruction
SWMF	F-16 Software Maintenance Facility
TAT	Turnaround time
TAS	Total Aviation Support
TM	Technical Manual
TO	Technical Order
TRM	Transmit/receive module
UAV	Unmanned aerial vehicle
UFCP	Up-front control panel
ULD	Unit Load Device
UPS	United Parcel Service
USAF	US Air Force

USN	US Navy
V&V	Verification and validation
VAF	Venezuelan Air Force
VIP	Very Important Person
WESSAB	Weapon Systems Safety Advisory Board
WDNS	Weapon Delivery and Navigation System

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