FOREWORD

Internationally, 1972 will be remembered as the year when then US President Richard Nixon made his historic trip to China. The same year, he also signed the Anti-Ballistic Missile (ABM) treaty with the Soviet Union to limit their respective numbers of nuclear missiles. These were watershed events that were to have significant repercussions on global geopolitics in later years.

Regionally, the Vietnam War was still raging. Peace talks between the Americans and the North Vietnamese were faltering.

At home, it was the first year when Singapore took full responsibility for its own defence. The British military withdrawal from all its bases "East of Suez", announced in 1968, came into effect in December 1971.

Strategically, the withdrawal created a security vacuum in Singapore, which the fledgling Singapore Armed Forces (SAF) struggled to fill.

Economically, it was a blow as British military expenditure had accounted for some 20 per cent of Singapore's GDP. Intensive efforts were made by the Singapore Government to attract foreign investments and create employment to fill the economic vacuum, and ensure our economic survival.

In the shadow of these strategic shifts in global geopolitics, coupled with the bleak security and economic backdrop at home, laboured Dr Goh Keng Swee, then Minister for Defence and architect of modern Singapore.

It was in 1972 that he spawned yet another of his innovative, nation-building ideas – to establish a local defence science research and development (R&D) capability.

Singapore's small size and limited resources, Dr Goh believed, made her vulnerable. The only viable defence strategy was to leverage on science and technology as a force-multiplier.

Though most of what the SAF needed in its early years were available in the open market, Dr Goh saw that there would be certain sensitive and critical-edge technologies that would never be for sale.

Such were the higher strategic considerations that prompted Dr Goh to establish a local R&D capability; to create indigenous know-how in defence science and technology.

It was a bold move, and given Singapore's practice of importing technologies and systems from abroad then – completely against the grain.

Thus was born what we now call the DSO National Laboratories – or "DSO" in short. Our staff strength of 3 at birth has grown more than 300-fold in 3 decades to 1,000 strong today. It is now Singapore's premier and most established R&D laboratory.

Over the last few months, we have interviewed the pioneers of DSO and sought the perspectives of those in the Ministry of Defence (MINDEF) and the SAF who had influenced DSO's development over the years. Their thoughts and words have been collected and preserved in this book.

> "Warfare is the most unstructured field in human affairs. It is natural and inevitable that it draws on the most advanced technologies available to the protagonists... But, because of higher strategic considerations, states often invest in science and technology for reasons that are not economic or academic, even though, in the long term, there might be economic benefits."
>
> BG (NS) George Yeo,
> Singapore's Minister for Trade and Industry,
> at the 1st German-Asian Young Leaders' Forum Dinner, 11th May 2002

It is the story of how the seeds sown by Dr Goh in 1972 have matured into a national treasure. DSO is a trove of technological knowledge and know-how, dedicated to creating the *technology edge* for Singapore's security.

As someone who has been in DSO for more than twenty years, I have learnt much from the insights and perspectives of our interviewees. We are deeply indebted to them for providing us invaluable information that has filled a vacuum about DSO's early heritage.

In a sense, this book is more than the story of a national institution. It reflects the rich diversity of perspectives on defence science and technology in the Singapore landscape. In each excerpt lie gems of wisdom, management and science, polished by the rich and diverse experiences of our interviewees. They give us a rare, personal view of an entirely home-grown, Singaporean-built organisation.

The raison d'etre of DSO is to create technological surprises to sharpen the cutting edge of our national security. It is thus inevitable that many of our accomplishments and capabilities cannot be spoken out loud. Herein lies the paradox of defence R&D – the more critical our achievements, the more covert they must remain!

Some of the things we did more than twenty years ago still cannot be revealed. Over the years, however, we have begun to adopt a more open profile. In line with this, we take the opportunity to share with you, a selection of our R&D capabilities in this book, to provide you a glimpse of the journey we took to build up each of them over the years. These complement the various interviews which focus more on the genesis and evolution of DSO and our relationship with our stakeholders.

Even then, words can never fully paint the emotional tapestry of each capability journey, such as the disappointment of failure, the anxiety of flight testings, the joy of discovery, the jubilation of success, the power of shared vision, and the teamwork and trust engendered through shared experiences.

In collecting and collating materials for this book, we are constantly inspired by the strength of the DSO spirit and the strong emotional bonds, forged through our three decades of history, which link each and every member of the DSO team, past and present.

Given the constraints of space and security, our main regret is that we are unable to include everything that we have collected in this one book. Despite that, we hope that this collection helps to unravel some of our mystery to give you a sense of DSO's distinctiveness and capabilities. We also hope that it contributes in a modest way to the history of Singapore.

This book is a tribute to our founder Dr Goh Keng Swee and to the many unsung and unassuming DSO heroes. These men and women have created many significant capabilities over the last thirty years of DSO's history. These capabilities have contributed to the professionalism and respect that the SAF enjoys today.

DSO staff and management, past, present and in the future, can take pride in DSO's achievements over the last three decades. We hope that this collection will inspire current and future generations of DSO staff to have even bolder R&D dreams to further sharpen the *technology edge* that our predecessors have created.

We are indebted to Melanie Chew and Bernard Tan for agreeing to be the co-authors of this book. For them to have fathomed the intriguing world of defence science and to have successfully navigated the jungle of technical jargon and MINDEF/SAF acronyms to bring you this book is no mean feat in itself. We are also very grateful to the DSO Book Editorial Committee for the endless hours they have spent in the making of this book. Last but not least, we would also like to thank the many people who have contributed materials to make this book possible.

With this book, we have taken another step to demystify DSO. If what you discover in this book delights you as much as would the discovery of a pearl upon opening up an oyster, it will have served its purpose well. Have an enjoyable read!

Quek Tong Boon
Chief Executive Officer
DSO National Laboratories
August 2002

A TRIBUTE TO DR GOH KENG SWEE

PICTURE BY THE STRAITS TIMES

DSO National Laboratories had its beginnings in the far-reaching and searching mind of a great Singaporean – Dr Goh Keng Swee.

"Dr Goh" – as he is affectionately known – is the architect, engineer and hand-craftsman of modern Singapore.

With an iron hand and stern gaze, an impish humour and a deep concern for his fellow men, he transformed the ageing, abandoned island-fortress which was Singapore of the 1960s, into a gleaming, ultra-modern capital of finance, commerce and communications.

The aching, third-world poverty which was Singapore three decades ago, is now a steel-sheathed, sky-rocketed, technology-driven metropolis.

The schemes and plans which made this transformation possible – the Economic Development Board, Port of Singapore Authority, Jurong Town Corporation, Housing and Development Board, Ministry of Education, and Central Provident Fund – were inventions cast in Dr Goh's extraordinary mind.

If you add more of Dr Goh's tinkering – the Singapore Symphony Orchestra, the Jurong Bird Park, the Zoological Gardens and Sentosa – you can appreciate the diversity of his interests.

For he delved not only in the high world of economics and finance, but in art, culture and the appreciation of nature.

Dr Goh had a deep commitment to improving the welfare and lives of all Singaporeans. Every man and woman, he felt, needed to earn well, be educated, sleep soundly under a solid roof, listen to music and enjoy the greenery of nature.

He took each of these concerns to heart, reading voraciously, pondering over solutions and summoning experts. Solutions would take shape, crafted in the bold, broad strokes of a master.

Satisfied, he would place a phone call.

For he had a special skill; his ability to single out the individual men and women who could translate his vision from his mental workshop bench, into realisation in the Singapore landscape.

Each young officer who received his phone call, was baptised into a unique school for leaders and nation-builders. They emerged inspired, determined and truly touched by his blend of wisdom, commitment and pluck. To this day, they regard him with a mixture of awe and fondness, remembering each encounter with "Dr Goh" in an archive of anecdotes, both playful and profound.

Security and Defence

Dr Goh also felt that human life and well-being, economic confidence and national courage, were built on a nation's ability to provide security and defence for all its people.

Every person needs to feel safe and secure. Having lived through the Second World War, he and his generation knew this from painful, personal experience.

He believed that nations would be unjustly treated if they possessed no military force. In this world, many disputes amongst nations are settled by a call to arms and national interests apportioned by victory in battle.

He predicted that future outcomes would hang on the capability of an armed force – skilfully led, well-armed and equipped with the most advanced technology of the day.

Dr Goh was determined that Singapore would have such an armed force.

Starting from a scratch team of volunteer militia, Dr Goh built an Army, Navy and Air Force, capable of achieving national security and deterring a wide range of threats.

This was the Singapore Armed Forces (SAF).

Science and Technology

Though diminutive in size, the SAF packs a punch.

This is due to Dr Goh's silent, skilful and ceaseless application of defence science and technology.

Dr Goh had, despite his economist credentials, an aptitude for defence science. He had a willingness to tinker with ideas and concepts. He was blessed with a lively, almost child-like curiosity, and romped through reams of scientific journals in the course of his day.

Scientists would be called and quizzed on subjects, some obscure, others at the frontiers of science. They would be given one day to do the research and return a one-page explanation in plain English.

This made Dr Goh an extraordinary initiator of science.

The *Technology Edge*

Dr Goh believed that in the 21st century, warfare would enter the realm of science and technology. Victory in battle would go to those who mastered this brave new frontier of lasers, smart bombs, battlefield sensors, remotely piloted vehicles and electronic wizardry.

To a small country like Singapore, the application of science and technology was even more critical. The country suffered from a small space and tiny population. Only the *technology edge* could overcome these natural constraints.

In a new century, he predicted, victory in war would come not from parade grounds and barracks, but in the laboratories of defence scientists.

Project Magpie

In 1971, he called together a team of newly graduated, fresh-faced engineers, seized upon their return from scholarships and First Class Honours from the world's best universities. Called the Electronic Warfare (EW) Study Group, they were to plot an approach towards secret-edge technology. They were bundled into isolation, working in secrecy.

This was Project Magpie.

Needing a cover story, they called themselves "ETC" – Electronics Test Centre. They brought in a young university lecturer called Dr Tay Eng Soon to lead their research.

It was a small, groping and humble start. But it was to lay the foundations for defence science in Singapore: developing the skills of its engineers, acquiring the tools and setting up laboratories.

PICTURE BY THE STRAITS TIMES

ETC was the vital first step in the creation of a new generation of defence R&D professionals and an ideal environment for R&D.

Three decades later, Project Magpie would be known as DSO National Laboratories.

Electronics Test Centre

It was 1972 that three young men – Dr Tay Eng Soon, Benny Chan and Toh Kim Huat, started work on the second floor of a converted detention centre on Onraet Road. They were joined, in the course of the year, by "returned scholars" – outstanding young graduates such as Su Guaning, Foo Say Wei and Tham Choon Tat, who had returned from scholarships abroad.

Dr Tay immersed his young researchers in laboratory and field work, and trained them to build simple equipment – and then more complex systems.

By 1976, the original group of three had grown to 20, and had moved to larger premises on Marina Hill. In 1977, they were renamed Defence Science Organisation, or DSO. The entry of an elite group of engineers who had built Singapore's first missile gun boat, known as the Systems Integration and Management Team, doubled the overall staff size to 50.

Defence Science Organisation

In 1980, the head of DSO, Dr Tay Eng Soon, went on to a political career.

Philip Yeo, Dr Goh Keng Swee's protégé, technology buff and Permanent Secretary of MINDEF, assumed the helm at DSO as Chairman of the Executive Committee, the EXCO.

Under Philip Yeo's unique brand of "submarine" management, together with Tham Choon Tat, Su Guaning and Ho Ching, DSO became steadily more focused and capable.

In 1983, led by the present Chief Defence Scientist, Professor Lui Pao Chuen, MINDEF embarked on an audacious drive towards technical excellence in the SAF. As the major benefactor of all pro-technology MINDEF schemes, DSO grew rapidly in capability and numbers.

During this period, DSO began to recruit engineering students from the university, shedding some of its iron-clad secrecy to do so. The best and brightest students were identified and signed up, leading to DSO expanding in numbers to 300, then 500 and upwards towards its present 1,000 strength.

The growth in DSO was not solely quantitative. The quality of its recruits, and the slow, steady growth of its know-how and R&D skills, began to show in the mid '80s. By 1985, DSO had led major projects for MINDEF and the SAF, and developed benchmarked credibility and technological capability in each of its chosen fields. The quality of DSO's technology began to appear in the string of Defence Technology Prizes which DSO began to garner in the next decade.

Defence Technology Group

In 1986, MINDEF formed the Defence Technology Group (DTG). This united the technology and logistics groups in MINDEF, and established DSO as the centre of R&D for the SAF.

The scientists and engineers in DSO were recognised and professionalised in a series of restructuring exercises which evolved DSO from a MINDEF agency to a national R&D laboratory. In the later part of the 1980s, DSO outgrew its facilities on Marina Hill, and dispersed its laboratories and staff to several locations around Singapore.

And it was at this time that SAF began to display, in its officer cadre, an awareness and appreciation for technology. SAF officers began to work closely with DTG to bring the SAF into the technology age, harnessing the advances of defence science into the SAF's equipment, weaponry and organisation.

In 1989, DSO moved into a brand-new headquarters in Science Park – a move which required its role and importance to be publicly revealed for the first time.

Gaining More Autonomy

It was the Gulf War in 1991 which was to focus Cabinet attention on DSO and spark its exponential growth. Through the 1990s, as DSO's numbers approached one thousand, DSO expanded to open the re-developed Marina Hill Complex in 1998.

And throughout the 1990s, DSO continued to grow in size and capability, nurtured by technology-driven and enlightened leadership at all levels of MINDEF, the SAF and in the higher reaches of the Cabinet.

The DSO mission was becoming increasingly urgent, and appreciated in the highest levels of national, political and military leadership.

Throughout the 1990s, DSO's facilities, manpower and resources were approaching state-of-the-art.

With these basic issues resolved, DSO turned its attention to another mission: to become, simply stated, "the best environment for applied R&D."

The solution lay in what the then Director, Su Guaning, was to refer to as a "black box" status. Within a strong and secure shell, DSO should be an organisation with operational and financial independence, and freedom – the freedom to recruit the best and brightest researchers, to pursue the best science, and to seek friends and collaborations with other defence scientists around the world.

In 1991, DSO was one of the first MINDEF agencies to be granted "Executive Agency" status, giving it partial financial and operational autonomy – the first move out of MINDEF and the first step into the role of national research laboratory.

DSO National Laboratories

By 1997, DSO received a charter as DSO National Laboratories, a not-for-profit corporation. From this time, and particularly in the year 2000 with the establishment of its own personnel scheme, DSO finally attained the autonomy that it long aspired for.

It was a signal that DSO had finally earned the full respect and confidence of the MINDEF and the SAF, who regarded DSO as a full partner in the creation of the *technology edge*.

DSO 2002 – a Tribute to Dr Goh Keng Swee

It has been 30 years since Dr Goh called the EW Study Group together and ETC was founded. Since then, Dr Goh's far-sighted vision of a defence science laboratory, creating the *technology edge* for the SAF, has been realised.

The Singaporean-grown, thousand-strong DSO National Laboratories has given reality and immortality, to Dr Goh's vision.

It is a one hundred per cent Singaporean success - planned, powered, and implemented by a young generation of engineers who gave their heart, souls and powerful minds to the defence of their nation.

Because of these pioneers, Singapore's defence has the *technology edge*.

This is the story of DSO National Laboratories.

It is also a tribute to Dr Goh Keng Swee.

1972 – 1980

PRESENT AT THE CREATION

CHAPTER 0001

In Dr Goh Keng Swee's vision of the battlefield of the future, electronic warfare (EW) was at its heart. Central to EW is to have mastery of the electromagnetic spectrum and the need to have electromagnetic superiority.

He called on some of his brightest young officers to study this subject, under the codename Project Magpie.

Three young engineers, Er Kwong Wah, Toh Kim Huat and Benny Chan were brought in to create a scientific organisation for defence R&D. Wanting to leave a lasting legacy, they named the organisation, "ETC" after themselves.

Dr Goh believed that for Singapore to gain the *technology edge*, absolute secrecy was essential. Code names, covert practices and leak-proof compartments characterised ETC from its earliest days, well into its metamorphosis in 1977 as DSO — the Defence Science Organisation.

As an additional measure, Dr Goh buried the organisation deep within the Security and Intelligence Division (SID) of MINDEF, under the administrative management of its Director, now the President of Singapore, S R Nathan.

The names and whereabouts of DSO's laboratories, the projects and advances, remained tightly under wraps.

According to the cover, ETC was the "Electronics Test Centre", testing electronic equipment purchased by the SAF.

The first home of ETC was at Onraet Road. There, in an anonymous three-storey building surrounded by a police detention camp, the "secret scientists" could eat, sleep and work.

At first, ETC was only a handful: initially, just Benny Chan and Toh Kim Huat, later joined by Su Guaning, Foo Say Wei, and Tham Choon Tat – all fresh-faced and recently graduated, with a clutch of scholarships and brilliant academic results.

In their tiny digs at Onraet Road, and later on at a converted officers' mess at Marina Hill, these young engineers started Singapore's first defence science laboratory.

At their head was the equally youthful Dr Tay Eng Soon – an engineering lecturer at the University of Singapore, with a quiet, probing and inspiring character.

Dr Tay had a keen sense of duty and understood the need for secrecy. But within this tight outer shell, he ensured a liberal regime, characterised by freedom and innovation. Under his leadership, ETC became a nurturing and supportive environment, nurturing a certain independence amongst the young engineers – and a singular passion for science.

No one knew anything about electronic warfare, which was the primary mission for ETC. Instead, they set about learning new skills, gaining some experience, building and designing simple gadgetry and then more complex systems. It was, at first, "the blind leading the blind". But from this small beginning was born a new generation of Singaporean research scientists and engineers.

Dr Goh and Dr Tay envisioned a team of two hundred secret scientists, working in laboratories, exploring the outer realms of defence science and technology.

But in the 1970s, ETC was to remain just a handful of young engineers, struggling to understand their science, bound by the iron-cast mechanisms of secrecy.

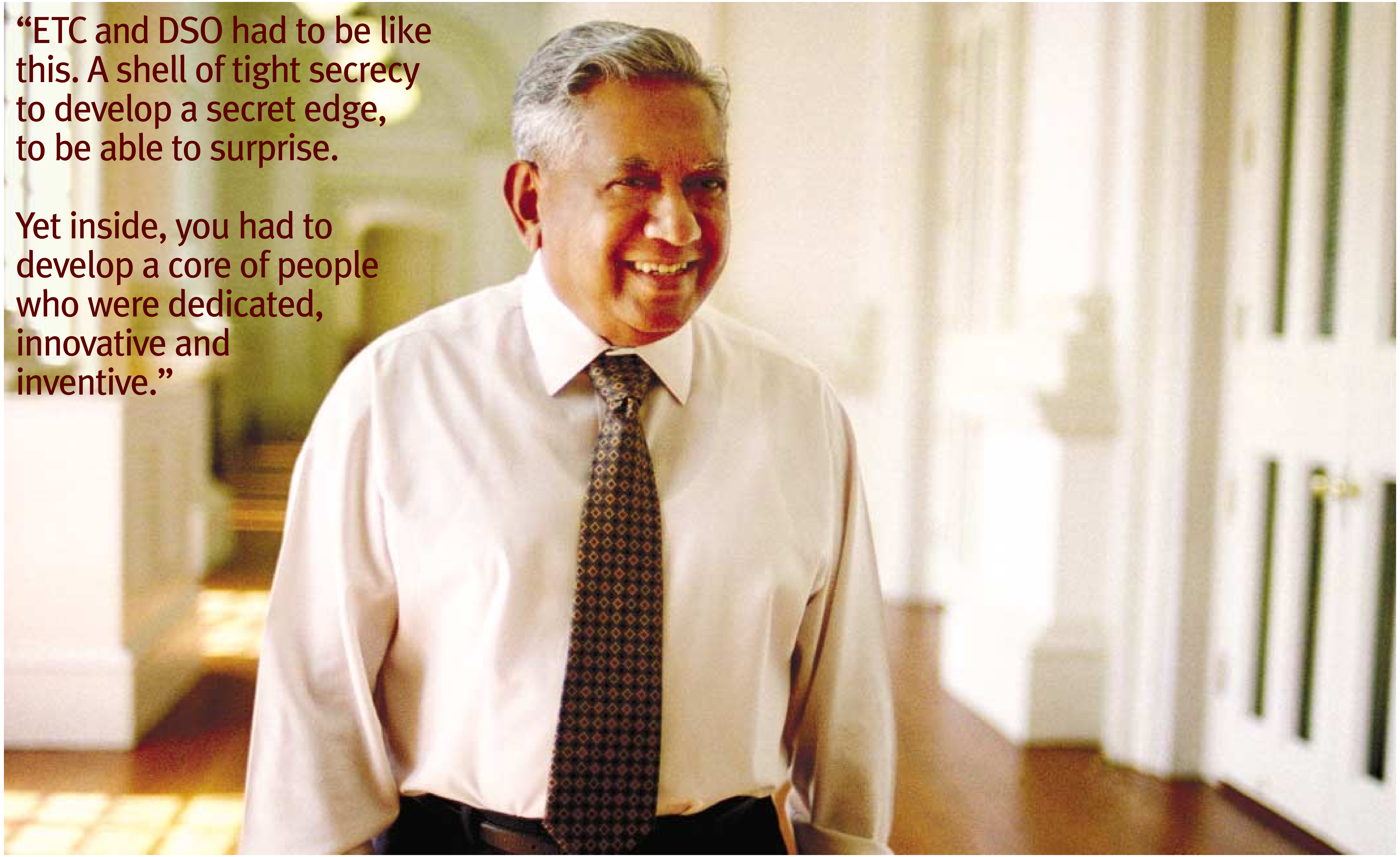
And similarly, in the 1970s, the Singapore Armed Forces (SAF) was getting off to a shaky start. Without the basics of arms and equipment, the SAF was making do with second hand gear, broken-down trucks and leaky tents.

Both organisations were far from the *technology edge* which Dr Goh had envisioned.

But those were the early days...

"ETC and DSO had to be like this. A shell of tight secrecy to develop a secret edge, to be able to surprise.

Yet inside, you had to develop a core of people who were dedicated, innovative and inventive."



HIS EXCELLENCY, THE PRESIDENT OF SINGAPORE MR S R NATHAN

Born in Singapore in 1924, S R Nathan began his career as a medical social worker. He joined the Foreign Ministry in 1966, and was Director, Security and Intelligence Division (SID) in the Ministry of Defence from 1971 to 1979. In 1972, under the Minister for Defence, Dr Goh Keng Swee, he took charge of the fledgling Electronics Test Centre (ETC), which in 1977 became the Defence Science Organisation (DSO). From 1982 to 1988, he was Executive Chairman of Straits Times Press Ltd and later, a Director of Singapore Press Holdings Ltd as well. In 1988, Mr Nathan became Singapore's High Commissioner to Malaysia and in 1990, Ambassador to the United States. He was elected as President of the Republic of Singapore in 1999.

President Nathan, you were Director of SID, which was the Security and Intelligence Division of the Ministry of Defence. And ETC, the predecessor of DSO, was under your command. Can you tell us how that came to be?

Yes, SID was in MINDEF. But SID had a certain independence in that it was not under the control of either of the Permanent Secretaries of Defence. As Director, SID, I had the rank of Permanent Secretary, and reported direct to the Minister, Dr Goh Keng Swee.

I would meet Dr Goh every Saturday, usually from eleven to twelve thirty. And I would brief him on matters that he needed to know pertaining to my division. This included a briefing on political and defence-related questions that had significance for Singapore. If there was a question, I would answer. Generally it turned to a discussion and an exchange of views.

The conversation touched on all kinds of matters, even subjects beyond my area of responsibility. For me it was always an educational session, with directions on what my Division should be focusing on.

How did you first hear about Dr Goh's plans for a Defence Science Organisation (DSO)?

It was one of my Saturday meetings that Dr Goh spoke to me about the need for the SAF to have a *technological edge*. At that time, the Air Force was in its infancy. The Navy had some patrol boats, more for coastal deployment. To build up these two arms of the SAF, Dr Goh said, "We must have something extra, something up our sleeves."

I did not immediately understand what he had in mind.

We had a long chat. He talked about our constraints of manpower, size of our territory and the limited reaction time to face any military threat.

Then he said, "We have to supplement 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*. And this has to be developed secretly – in strict secrecy – so that nobody knows the kinds of defence-related technology and capability that we have developed."

Did he appear to be knowledgeable about this subject?

Yes! He was always well-read in the subjects that he was focused on. In fact he gave me a book about electronic warfare (EW) and electronic counter-measures (ECM).

In the nature of electronic warfare, one must expect adversaries to develop counter-measures. As soon as each EW capability becomes revealed, the search begins almost immediately for counter-measures and counter-counter-measures and so forth.

He reminded me, "Technology gets obsolete very fast and one must keep abreast all the time. One cannot rely on technology permanently. And we must keep strict secrecy about what we are doing..."

And then he told me that he had this study group since 1971 and he wanted to see to its development. I was not sure what he was getting at, in so far as SID was concerned. It seemed more like a technology-related matter, about which I knew nothing.

So the EW Study Group had already formed.

Yes, he had apparently started the group in 1970 or 1971.

Subsequently at one of our weekly meetings, Dr Goh told me, "Things are not moving. We must get this going. You know there is this EW group and there is some work going on at a particular location. Let's go together."

One afternoon, a few days later, I went together with him. I saw lots of gadgets, small gadgets and a few young officers from MINDEF, explaining about what they were experimenting on. The place was a technical workshop of the Ministry of Home Affairs and staff from both ministries were working in the open – with no compartmentalisation.

After we came back to MINDEF, he said, "Give it a thought. We must get things moving. How can we go about it?" I was not clear what he wanted me to

> "And we must develop indigenously that *technological edge*. And this has to be developed secretly – in strict secrecy – so that nobody knows the kinds of defence-related technology and capability that we have developed."

address. With his emphasis on secrecy, I decided to focus on measures to safeguard secrecy of the project.

I gave it a thought and reported back a couple of days later. I told Dr Goh that there were two things that needed addressing.

I remembered saying that we could not work in secret if we were to depend on other departments for technical support and space. If we want to keep it a secret, then it has got to be really secret. The project must move to a new location, entirely within MINDEF.

The second matter I raised was about someone able to lead "full time". I said, "You must get somebody who knows about EW, and who can lead the team, work and develop it." All this transpired without any written communication or notes. It was essentially in conversation.

Perhaps a month or so later, Dr Goh called me to see him. He asked me to meet with the late Dr Tay Eng Soon. "See what you think of him – whether he can fit into our mission."

I did not know Tay Eng Soon then. He came to see me and we had a long chat about the nature of our security and defence concerns. We talked broadly about how the Vietnam War was developing, and how circumstances in the region could change drastically and fast.

I mentioned what Dr Goh had told me about the EW Study Group and how he wanted to develop a technological capability in a variety of defence-related areas to beef up the SAF.

He responded that he was lecturing full-time at the University, and was a representative of the University Staff Union.

He said, "It would be very difficult for me. I'm teaching and also undertaking staff union work, and am in the midst of negotiating with the university's management. I can't possibly come here to work in secret."

I reported my meeting with Dr Tay to Dr Goh. After seeing Dr Tay several times, Dr Goh decided that we should get him out of the university. Dr Goh told me to work it out for Dr Tay to be seconded to the ministry, without any loss of career prospects in the university.

I sorted out the matter with the university and got Dr Tay Eng Soon seconded. With his coming into the picture, the ETC – the Electronics Test Centre – was set up as a branch of SID.

I also looked for someone with a science background from among my SID staff. I was fortunate to have Mr Chou Tai Yun, who had read physics at Oxford University and who by temperament was quiet and most dependable among my staff. He was known for being able to quietly get things done. He was also one who was up-to-date on Singapore's defence and security circumstances and possessed a sharp mind.

Thus, ETC became a project under my administrative management, although operationally it was self-driven by Dr Tay, in consultation with Dr Goh.

Why was it under SID?

This was for several reasons.

Number one, secrecy. I didn't want too many people to get involved. SID was a compartmentalised division and one worked on a "need to know" basis.

We did not seek to satisfy people's curiosity, even fellow civil servants or the military establishment.

Number two – funding. Because you can't have all sorts of people questioning ETC, "Why are you buying this," or "Why are you not buying something else?" There had to be a shorter line of management and a quicker way to get approval and oversee its workings, consistent with the merits of its purpose and SAF's priorities.

So with SID, it was just on my authority, which I exercised with Dr Tay, whose proposals and evaluated plans had Dr Goh's approval.

Important decisions involving expenditure, staff and acquisitions, were processed by my ETC project management team, before being surfaced for ministerial approval.

So that's how it began.

What was Dr Goh's mission for ETC?

He went to the basics. The basics were that we should have a technological ability, beyond the reach of those who were likely to threaten our security. And that we must be able to possess this technological ability at all times.

And Dr Goh kept saying, "Keep working at this *technological edge*." It's not static. You cannot stop and say, "I've arrived." Because technology is changing fast. You have to keep pushing forward.

Could we have bought technology off-the-shelf?

It is a well-known fact that those who want to sell such equipment or know-how to you, are often the worst source of leaks. You can expect them to tell others, "Singapore is buying such and such equipment or focusing on this or that area of technology. You should also focus on them and buy the same stuff from us."

That's why you have to develop in-house capability to build your own technology, once you have gotten over the learning phase.

What were Dr Tay's plans for ETC?

I am unable to say what his development plans for ETC were. This was done in consultation with Dr Goh. His first step was to get people – the right type of people. They had to have appropriate qualifications in subjects relevant to ETC's development needs.

He, together with Chou Tai Yun, were head-hunting, scrounging for PSC scholars who had graduated, or graduates coming back for National Service. They were always trying to interview and speak to those considered worthy of involving in ETC work.

We looked at the returning scholars, and also through the lists of National Servicemen, always looking for engineers with particular areas of specialisation. So this required some intervention by the Manpower Division of MINDEF. Mr Wong Kan Seng was then Director, Manpower. So with him it was easier to get people, so long as we could justify our need.

That was ETC's first task – looking for people for our projects. So we had to head-hunt and bring them in.

I think Su Guaning will tell you how he came to see me. After satisfying myself, straightaway, I asked him, "When can you start?" He was taken aback by the short interview!

> "That was ETC's first task – looking for people for our projects. So we had to head-hunt and bring them in."

But this was because Tay Eng Soon and Chou Tai Yun had interviewed him earlier, and were highly impressed with him. He was quietly confident, soft spoken and one likely to undertake quiet research without seeking the glare of publicity. That was how I saw him.

But the most important message that I gave each of them was this: secrecy of their work was uppermost in our requirements.

How did you explain the need for secrecy?

I told them, "You have to keep this a secret if your work is to be beneficial to the SAF and to Singapore. I know this is a constraint; you can't say anything and share information about your work, even to your wife. For the sake of the nation, you have to accept this constraint. If you can't, then it is best we part company at the outset."

Your recruits were very young – all fresh graduates!

Well, they were young, they had the right educational background. I felt that under Dr Tay's guidance, they could make a contribution. Tay Eng Soon could channel them to particular fields of ETC's endeavour and develop them. We knew that ETC's projects would need long years of painstaking experiment and research. The question was always whether they had the staying power to work in secret, without the glamour of high position in the civil service or the private sector. As bright people, they were impatient to rise to prominence.

And you moved ETC to Marina Hill in 1976...

SID managed to acquire Marina Hill for ETC. A quiet location, away from the eyes of others.

What was your impression of Dr Tay?

Oh, he was a very fine person. An excellent manager. A very good teacher. A man who was hands-on and yet could see the larger purpose very clearly.

He had a quiet passion for his work and for the nation. He perceived our national interest and grasped the larger purpose of ETC and its mission. Above all, he was intellectually honest and would disagree and say what he felt.

He had no ambitions to have a high profile. He was a quiet man, working well with people and self-driven to look at various fields of technology relevant to SAF's needs.

He knew very well what we needed to do. He had a very balanced approach to things. He knew our vulnerabilities. So he was ready to identify projects to make up for these vulnerabilities.

Were there people who didn't support Dr Tay or were impatient with the progress that ETC was making?

Perhaps after Dr Goh had left – I cannot say.

But Dr Goh, never for one moment, wavered in his support for Tay Eng Soon and for ETC. He was happy with what was going on and with the progress, and had absolute confidence in Dr Tay and his mission.

According to Dr Goh, ETC began to move very fast thereafter. Compared to the past, when there was no momentum, ETC was building up very fast. It was building up on its research capabilities and branching out into many areas, and all sorts of developmental activities. Projects were being generated. The benefits were clear.

Also, ETC developed people with the ability to evaluate acquisitions for SAF, in areas of ETC capabilities. So there were cross benefits. By monitoring defence-related journals and getting up-to-date in defence technological advancements, ETC began to focus its attention on areas relevant to SAF's needs, compatible with our physical and climatic conditions.

Did you go to visit ETC in Marina Hill?

Yes, once in a while. But I didn't want to go too often because I was immediately identifiable with SID. Like it or not, the guards were liable to talk and associate ETC and its secret activities with my area of responsibility.

It was like a spy novel...

Yes! All the secrecy of ETC's operations may read like a spy novel!

But it was for real – in real life! And ETC, and later DSO, was really developing various capabilities critical for Singapore's defence and SAF's needs.

Can you tell us about Dr Goh?

He had a brilliant, penetrating and far-ranging mind. Yet he was a very practical man. He disliked jargon and wanted things written in simple English. He, too, wrote in plain language.

He was a great teacher, but also a perfectionist. He would call an officer concerned directly, however high or low. This way, he really spotted talent and trained them.

Also, he was good at spotting talent that could be trained or moulded. You see, one of the unique features in MINDEF during Dr Goh's time was that people like Lim Siong Guan, Philip Yeo, who were very junior officers in the Administrative Service, could take on far higher responsibilities, well before their time.

If they had been in any other ministry, they could never have risen so fast! Their exposure and progress would have gone through many slow stages of plodding.

But because MINDEF was totally managed within MINDEF, it could take liberties to expose officers to new responsibilities and test them ahead of their rank – without constraints of the Admin Service procedures.

In MINDEF, one could try out people – like Philip Yeo in charge of Logistics, or Siong Guan in charge of Finance. By rank, they were not very high. In the Admin Service, there was no way they would have been given such responsibilities, well above their rank.

But by exposure to Dr Goh, with his type of management, they acquired the know-how, the confidence. And he dealt directly with them. So they really learned. He was a great teacher. They came up very fast. He taught them well.

There were many other officers like Philip Yeo and Lim Siong Guan, who were taken under Dr Goh's wing. They had exposure that no books or university courses could have provided them.

Some people were petrified of Dr Goh.

Petrified, yes! When you made mistakes and tried to cover up! Well I learnt one thing – when he drummed his hand on his chair – he is getting agitated! It is time to leave!

It's true – many were petrified. When he was eating at the MINDEF Lunch Club, nobody would venture to sit nearby, in case he called out for them to sit with him. He would surely have raised probing questions, for which they may not have answers!

But he's quite a fair-minded...

Yes! He was very fair-minded, with a strong sense of justice.

You could reason with him. If you disagree with him, put your case on paper, but make a good case. Tell him "Yes, this action you propose – these are the consequences." You give your advice and some options. If you put it down logically and it made good sense, he will be prepared to accept. Or he would come back with improvements and new ideas.

So my experience with Dr Goh was a very rare one. Here was a boss that you could deal with. You could reason with him. There were instances when he knew he was wrong. Then he'd say, "You do it your way."

I don't think people knew the true man. He was intensely curious. He was curious about all sorts of things. With very innovative ideas.

I mean, could you imagine a Scottish Bagpipe Band in Singapore – with all Singapore girls? Your waterfall in Jurong Bird Park? The Zoo? Singapore Symphony Orchestra? Even Sentosa Island. He got many things going in Singapore.

You could never tell what would attract his interest. He had the curiosity of a child!

Yet at the same time, he was intensely practical. Very down-to-earth. In a crisis he was always cool and not easily excited or alarmed.

> "Without secrecy, without SID's involvement, we could not have advanced the way we did in DSO's early years."

You know, Dr Goh was very sharp and always got to the nub of the matter. Pages and pages of paper in a brief did not deter him.

On one occasion, there was this supplier who wanted to sell us a particular type of aircraft.

So at the weekly Monday meeting, the person came to the door, "Oh! Hello Dr Goh, how are you?" And so on. We were all waiting to see what would happen, because this particular person had claimed to be on first-name basis with Dr Goh.

When the meeting began, Dr Goh said, "Sit down, I got a few questions for you. Number One, has this aircraft operated in any terrain other than yours?"

"No," the guy replied.

"Number Two, have you sold this aircraft to any country with a terrain similar to ours?"

"No."

Then a third question, for which the answer was also "No."

Then, Dr Goh said, "When you have affirmative answers to these three questions, come back and see me."

The man's face went white.

Dr Goh was that kind of a man – very incisive in addressing any problem.

In whatever he did, he was meticulous and very thorough. For example, his knowledge of military affairs – he acquired it by himself. Self-taught! Yet he could speak to any military officer or foreign leader, and speak knowledgeably. And he could question them sharply as well! He always was in command of the subject he was dealing with, whether it was foreign affairs, defence, security, sports, whatever ...

Yet he was never in the limelight.

Yes. He was a very private person. He had one white coat, hanging in his closet. It's one of those made of old tropical material. Whenever he had visitors, that white coat would come out.

He was also a very frugal man. And that frugality, he applied to Government expenditure.

No unnecessary expenses! When he travelled, he used to carry soap flakes to wash his underwear in the hotel bathroom!

Why did he work so hard for Singapore's success? Ministers were certainly not remunerated well in those days.

He was obsessed with building Singapore. Not only him. All of that generation of leaders starting with Mr Lee Kuan Yew – Dr Goh, Rajaratnam, Toh Chin Chye, Eddie Barker, Lim Kim San – all of them.

All that group, they were obsessed with Singapore. From morning to night, they thought and talked of nothing but of Singapore. "Can we do this? Can we do that? What can we improve?" It was an obsession!

When they travelled overseas, they saw something that took their fancy, like a fountain. "Oh, that's very nice. Should we have it in Singapore?" At one time, we had fountains everywhere! Remember?

So wherever they were, they were constantly thinking of Singapore, and how they could add value to Singapore. It was an obsession.

Do you remember any difficulties with ETC?

My difficulty was with some of the bright, young people who worked with Eng Soon. Some could not understand why ETC had to be kept secret. I think there was frustration on their part about the secrecy in which DSO, as ETC later became known, was shrouded in.

They wanted a public profile. They wanted to be open, they wanted to be acknowledged for what they were doing. They did not like the compartmentalisation and wanted to be given free rein to satisfy their curiosity about projects that others were engaged in.

But if DSO became public, then the secrecy of DSO's various projects would be blown! And these projects were still in an experimental stage!

And we had great difficulty with a few individuals – we could not get them to appreciate this need for secrecy and compartmentalisation. This caused a lot of frustration for Tay Eng Soon because he was caught between me and them.

My priority was to preserve secrecy, until they could be disclosed without loss of advantage. And there were many quietly ganging up to demand that DSO broke out of SID.

How did you reply to that?

No one confronted me directly. Attempts were made to reach the ears of political leaders other than Dr Goh.

But with hindsight, I can say this: without secrecy, without SID's involvement, we could not have advanced the way we did in DSO's early years.

With SID in charge, no questions were asked. As long as you were on to some good project, worthy of experimentation, that was OK. And if you failed, after an earnest effort, we considered it a part of the process of learning and experimenting.

Dr Goh and SID looked long-term. We knew there would be failures. But we considered this a necessary part of learning, as long as the failures were not through negligence or irresponsibility.

This atmosphere and liberty you will never get anywhere else in the civil service. In the civil service, you are subject to all sorts of procedures. You have to account for this and that, justify, push papers, all kinds of things. Time was not of the essence. And if you fail, you have to explain.

With DSO, we always ran against the clock. DSO had no time to explain, to justify, to push papers. We were racing for the *technology edge*.

It has been 30 years now. But I still remember the frustration of those young DSO officers and can understand their feelings. But we were on a far more vital mission. Of course, those critical of SID didn't understand. They didn't understand that we were working in secrecy, not because we enjoyed being so, but that national interest demanded it of us.

Could there be a happy balance between secrecy and the recognition of DSO's staff?

Secrecy and compartmentalisation are safety mechanisms. Unless there is a need to know, you should not know.

I know it's difficult. But you do it, not for your private pleasure, but to answer the national call.

With maturity, they will understand.

That's why, when I spoke to Eng Soon in 1972, I felt he had a certain quality. He was not interested in publicity. He was not interested in fellows applauding him for what he was doing. He had a real passion for helping improve Singapore's defence capabilities. And he realised the importance of a tight regime – to keep a shell of secrecy around his organisation.

> "With DSO, we always ran against the clock. DSO had no time to explain, to justify, to push papers. We were racing for the *technology edge*."

> "Secrecy and compartmentalisation are safety mechanisms. Unless there is a need to know, you should not know. I know it's difficult. But you do it, not for your private pleasure, but to answer the national call."

And yet, within this shell of secrecy, Tay Eng Soon had to be liberal in his management. He had to give his men the space and leeway to do their work. He had also to recognise there may be success but there will be many failures.

It took a special person to do Tay Eng Soon's job. He had a gift for it.

ETC and DSO had to be like this. A shell of tight secrecy – to develop a secret edge, to be able to surprise. Yet inside, you had to develop a core of people who were dedicated, innovative and inventive. And without the constraints of micro-management – procedures, financial or otherwise.

DSO is now a huge laboratory. It would be hard to hide it in the same way as before.

Now you can't. And, maybe, by the time you made it public, you had a certain edge already.

"Given that Tay Eng Soon was a pure academic, without ever having the benefit of a military background or even a hint of training, he did very well. And he came into MINDEF which was a very closed, secretive environment. And he was supposed to ferret out SAF's needs, and develop advanced technology for us. It was not an easy task."

WINSTON CHOO

Lieutenant General (Retd) Winston Choo was born in 1941 in Singapore and enlisted into the Singapore Military Forces in 1959. He attended the Federation Military College and was commissioned as Second Lieutenant in the Singapore Infantry Regiment in 1961. He attended the Command and General Staff College in Singapore in 1971 and Fort Leavenworth in 1972. It was as Chief of General Staff in 1974 that General Choo was a member of the ETC Steering Committee and DSO Executive Committee (EXCO). General Choo became Chief of Defence Force in 1990.

After retiring from active service in 1992, he went on to serve as Singapore's High Commissioner to Australia, Papua New Guinea and South Africa, and Ambassador to Fiji, as well as Chairman of Chartered Industries of Singapore and Deputy Chairman of the Central Provident Fund Board. General Choo has been Chairman of the Singapore Red Cross since 1996.

From your perspective, what led to the birth of ETC?

In the early days, Dr Goh was the man behind Singapore's defence. He did all the thinking. He was the creator and prime mover of MINDEF, SAF, everything! We were just planners and people who implemented his vision.

Dr Goh was concerned about Singapore's small size and population. We were two million. So when it came to the numbers – how many in the Army, Navy, Air Force – we were never in the running.

So he felt that the only way for Singapore was through science and technology.

The SAF was just beginning, raising units, training, and spending a fair amount of money, at a time when Singapore wasn't that rich, you know. So, Dr Goh felt this was not sufficient.

Dr Goh felt Singapore needed a *technology edge* – something money couldn't buy. We needed a force-multiplier, which could make up for the small size of our SAF.

And this could only come about if you had indigenous, in-country capability in R&D.

The easy way was to go to the university. But Dr Goh did not believe – with due respect – he did not believe that academics would be able to do this.

So he said that this effort had to be within MINDEF. We must build the R&D capability, create the winning technology completely in-house. This was the start of the EW Study Group in 1970.

Now, he also wanted the R&D to be conducted in absolute secrecy. He felt it was vital that this capability be hidden away. It had to be top secret until the edge was so great, the gap was wide enough, and then you could start letting people know what you had.

And so, in 1972, we formed the Electronics Test Centre. It was led by Dr Goh, personally. It was a small start, you know, improving some of the equipment that we had bought, upgrading it and then putting in an extra something, so it was better than the original product. So ETC started that way.

But the SAF was also, just beginning...

Now, if you look at the SAF in those days, the early '70s, it is amazing that Dr Goh should have even thought about technology. For us in the SAF, high technology was the furthest from our minds. Because everything about the SAF in those days was so basic, so crude.

At that time, people like myself were too busy to think technology. We were so busy just trying to raise units, convincing parents that National Service was okay, taking in soldiers who were mostly ill-equipped, ill-motivated and ill-educated, to train them for the SAF.

I mean, the kind of equipment that we had – second-hand, mostly inherited from the British. The Army went out on hand-me-down British trucks. There wasn't any armoured equipment to talk about. Then you look at the Air Force, they also had second-hand Hunters, second-hand Bloodhounds, and the communications equipment were second-hand, inherited from the British.

And we almost bought the tropo-scatter equipment, for communication between Singapore and Western Hill in Penang. The British wanted us to take it over. We had an advisor, who was Commander in Chief of the Far East Air Force. I went against him. I was almost sacked! But I managed to dig up a good electronics journal from the UK, which called it "the two white elephants of Singapore."

The Navy had almost nothing. Right? We had the *Panglima* which was an old riverboat. Then we bought an old oil-field riverboat from the Dutch which was fitted with land communications equipment. That's it!

What did the SAF think about ETC?

You can't ask, "What did the SAF think?" I mean, the SAF was too busy just trying to get off the ground!

When I look at the early days of the SAF, when we just started National Service, it was a struggle. We made do with the most basic, simple tools.

For how long did the SAF remain at this stage?

A very long time! At least ten years. The first "modern" thing the SAF had was the M16 rifle, which was only after Chartered Industries of Singapore (CIS) got the licence from Colt to manufacture.

> "In the early days, Dr Goh was the man behind Singapore's defence. He did all the thinking. He was the creator and prime mover of MINDEF, SAF, everything! We were just planners and people who implemented his vision."

When did the SAF start to appreciate ETC?

I think we first began to appreciate ETC, or DSO as it became after 1977, for the work they did when we wanted to buy equipment. They did a thorough study, every aspect was scrutinised. Effectiveness, performance – everything.

As an end user of DSO's technology, did you have any difficulty dealing with the scientists at DSO?

I spent eighteen years as CDF. And at the beginning, in the early SAF days, we didn't know anything about technology. Nothing! We were combat soldiers. Yet slowly we had to learn what technology is being developed, how it applies to us. And then we had to educate the scientists. Just as we didn't know science, they also didn't know a thing about the military. That was a gap that we had to try to close.

How?

We had to train our SAF users to speak to the scientists. I mean, to use the same language, so that they could understand each other. Otherwise they can't put across what they need, the problems, the difficulties – and the scientists will not understand.

The SAF tried, using hands and fingers, to explain to ETC what we needed. But it didn't convey the message. So we had to train our officers. I mean, you can't make them engineers or scientists but at least they must understand the basics of technology.

Did the scientists feel that the SAF was not communicating its needs well to DSO?

The development of DSO was almost parallel to that of the SAF. As SAF officers improved, become better educated, more aware of technology, then DSO was able to rise up and do its work better.

It depended on the SAF being able to tell DSO what we needed! And if DSO produces something, they have got to depend on SAF to give them good feedback.

If SAF can't speak the right lingo, they cannot tell DSO what the problems are!

In the early years of ETC and DSO, there was such tight secrecy, the SAF did not even know that they existed! How could they talk?

They didn't know about ETC. But by the time DSO was formed – they roughly knew what was going on. They knew that DSO was looking at high-level technology. But the specifics, they did not know. Even at MINDEF HQ, only very broad aspects of DSO's work were discussed.

Was there any resistance to DSO – or a resistance to technology – amongst some in the SAF?

I don't think so. The military realised that anything which allowed them to work better, was going to be to their benefit. It could save their lives! They were just as excited by the potential of technology as the scientists. They didn't shy away from it.

I understand that there was one case where the pilots were not happy with an avionics upgrade. They felt that nobody asked them about it.

It's understandable. I mean, you put a black box into their aircraft. They are not told how it works or what it does. They get upset!

But this is not a case of operators not wanting to embrace new technology. It's the case of operators wanting to be involved. They want to understand what they are doing!

Do you feel that between DSO as defence scientists, and the SAF as end-users, you had found the right balance between buying equipment in the market, and building it in-house?

When we started off, it was all "Buy".

And then, it became "Buy Wisely." Because DSO was able to tell you about the equipment, and what to buy.

Then came a stage, "Buy, Improve."

Then, "Buy Some, Make Some."

It also paralleled the capability level of the SAF.

Because as far as the SAF was concerned, when we first started. I think our needs could be met by buying off-the-shelf. Our requirements were pretty simple, then. And we didn't have the time to wait.

Then, we became more sophisticated. We are now able to define our unique requirements, to an extent that we are not satisfied with off-the-shelf. And we have time to plan, well ahead. That's why we have to build. And we can build.

A lot of what we want now, is so advanced, so sophisticated, that no country will ever sell it to us. They have their *technology edge*, you know. They have their defence secrets to protect.

Was there tension between people who wanted to buy and people who wanted to build in-house?

Yes, there was. There was a tension. Build or buy? Because if you take a look at the users – the Army, the Navy and the Airforce – they each have their own five-year plans, their annual budget and their own projections.

So if you don't buy something off-the-shelf, but ask DSO to develop it, obviously you stretch the timetable. In-house R&D takes a lot of time.

It was something for MINDEF to decide. It was a matter of education, really. But again, in the early stages, to be fair, ETC did not have a strong capability. MINDEF and the SAF were not confident that ETC could deliver.

It was only towards the later '80s, early '90s, when we could look to ETC, by then it was DSO, with any confidence. By then, DSO was able to deliver.

Were there things that the SAF wanted but ETC was not able to deliver?

There are many things that the Armed Forces will want. Just like the boffins like to play with new technologies, the SAF also likes to experiment! So it's a case of trying to match the ends and means together.

But what we arrived at was a very good balance of open-market purchase versus in-house development, you know.



> "When we started off, it was all "Buy". And then, it became "Buy Wisely." Then came a stage, "Buy, Improve." Then, "Buy Some, Make Some.""

Sometimes we are clearly better off buying equipment. But, again, because we have DSO, we don't just go out and buy. Right? We buy and then, after we have bought, we upgrade. In other words, we do the modifications to make an even better platform, or better avionics system or a fire-control system, whatever it may be.

Were you in the steering committee of ETC?

Yes. And sure, we went through the projects. There were two parties in the process. One, the user – which was me who provided input on what the SAF wanted. The other was the boffin – who was Tay Eng Soon – who could develop new projects and show you some new toys.

So I think the committee had to balance this. It was important to apportion the projects correctly. It was not the money. It was more of manpower – the trained engineers and technical people. We did not have enough of these people to go around, or do everything we wanted to do.

So the duty of the committee was to prioritise ETC's projects and narrow down the list.

What did you think of Dr Tay as head of ETC and DSO?

Given that Tay Eng Soon was a pure academic, without ever having the benefit of a military background or even a hint of training, he did very well. And he came into MINDEF which was a very closed, secretive environment. And he was supposed to ferret out SAF's needs, and develop advanced technology for us. It was not an easy task.

But I thought he had the right personality for this work. He could be friendly to people but he didn't need to reveal his work or talk about himself. We were very close. But, he didn't talk. Eng Soon was like that.

And, in terms of his thinking and perception, I think he was able to conceptualise and come up with projects that the SAF needed. Not just going straight for the project, but building up the capability, slowly. Building up the capability for what we eventually wanted to do.

> "In the early SAF days, we didn't know anything about technology. Nothing! We were combat soldiers. Yet slowly, we had to learn what technology was being developed, how it applied to us. And then we had to educate the scientists. Just as we didn't know science, they also didn't know a thing about the military. That was a gap that we had to try to close."

Because in science, you just don't jump straight away to the end product. You got to build up the expertise, step by step. It is a slow process.

Who gave him input from the military side?

He spoke to the General Staff and the Steering Committee, and there was interaction with the Head Plans in each of the Services. We discussed areas where we wanted to build up capability, what were the areas of concern, what could we do, how could we better improve?

"Many people have vision. But he was different. He not only had vision, but he had the iron will and strength to push things through. I mean, he was a man with very strong ideas of how things ought to be. So he will see them through, come what may. That's Dr Goh."

Can you tell us about Dr Goh? How did Dr Goh know so much?

He read. He's a tremendous, voracious reader. And not only did he read, he would flag out a place in the journal and sent it down to me with one line, you know, like, "What do you think of this?" I would spend the next three days catching up with my reading. But I know he's read it, so I had better do it.

And then he would call you up?

Yes! The secretary called, and you know, she didn't say why, what the matter was. She just said, "Minister wants to see you."

It's a good five minutes' walk to go into the MINDEF main building. You know, it was like walking the Stations of the Cross!

Throughout, I was thinking, "What the hell does he want this time? What could have happened? Am I in trouble?"

And finally, I got to his office and he said something like, "Oh Winston, how's your golf swing?" He did things like that to you, you know!

Dealing with Dr Goh, you never know what's going to happen!

But more seriously, as far as the development or build-up of the SAF, the person who provided the thinking was Dr Goh. I'm not ashamed to say that. We came in – as military officers to implement, operationalise his ideas.

Mind you, Dr Goh was very famous for his completely unorthodox approach. But you never said "no" to him. Don't reject things without considering, first. No matter how unorthodox or different. You go and do some work, come back later and say, "There's a problem, this problem and that." He will accept it. So his point is you must go away and think about it. He was an excellent teacher.

You know he was very careful about expenditure. He's an economist by training, and he was very cautious about spending. And especially for himself. He was a very frugal man, that's for sure.

He had vision...

Well, many people have vision. But he was different. He not only had vision, but he had the iron will and strength to push things through. I mean, he was a man with very strong ideas of how things ought to be. So he will see them through, come what may. That's Dr Goh.

Do you know, the whole National Service and SAF was something completely unnatural to Singapore? Without Dr Goh, nobody could have pushed it through. Only he could have done it.

I mean ...he provided the inspiration. He provided the vision. But he actually barged it through, overcame the bureaucracy and the obstacles. He made sure it succeeded.

Really – he is the architect of the SAF. And, ETC, DSO and our science capability would not have existed, if not for Dr Goh.

Do you think ETC was a successful organisation?

No, I won't say ETC in itself was a success. I mean, you can't. It was only the start of things to come.

But if you ask me about the whole process, from ETC to DSO, and till today as DSO National Laboratories – I would say, "Yes, it's a success!"

It has been able to achieve what Dr Goh had envisaged. He had hoped for an effective R&D organisation, able to develop a *technology edge* for the SAF – and that has been achieved. Perhaps it has been achieved over and above his dreams.

There are so many things – perhaps we will never be able to speak openly about them – that DSO has done, which has created force multipliers for the SAF. Really. And that makes a difference.

You know, the Singapore Armed Forces of today is recognised as one of the world's best in terms of state-of-the-art technology and ability to use this technology in its operations. More importantly, much of our technology has been developed, or upgraded in-house, indigenously. That means DSO.

This is recognised internationally, not just regionally. And it's not just me who says this. There are many journals, publications, which have written about this.

And I credit ETC – that little seed planted in 1972, and DSO as it became, with a large measure of the SAF's success.

That's the *technology edge*...

Yes.

"The whole idea started with Dr Goh Keng Swee. He was driving it himself, personally. Otherwise this group couldn't have been formed. The word came directly from him. It was top secret. Even within MINDEF – nobody knew..."

PROJECT MAGPIE

"Electronics Test Centre" – that was only the cover. The real meaning of ETC was "Er, Toh & Chan" – Er Kwong Wah, Toh Kim Huat and Benny Chan. The real work of ETC was electronic warfare. In the conversation which follows, Er, Toh and Chan, together with Su Guaning, Foo Say Wei and Tham Choon Tat, give an account of the earliest days of DSO, codenamed "Project Magpie."

ER: Dr Goh was always talking about electronic warfare (EW). He said that our officers were still fighting with swords and spears. "The future warfare is not like that! It's all electronics, and remotely controlled!" And he talked about the Remotely Piloted Vehicles (RPV). "Our kind of terrain, we must have RPV. We must see the enemy without being seen!"

SU: This was 1970, you know. It was in the '60s that technology started to take over in warfare. Vietnam was the first use of smart bombs. From the Middle East, Vietnam – Dr Goh saw the use of lasers, computers and other technology. That was the start of high technology warfare. Dr Goh saw this very clearly.

TOH: The whole idea started with Dr Goh Keng Swee. He was driving it himself, personally. Otherwise this group couldn't have been formed. The word came directly from him. It was top secret. Even within MINDEF – nobody knew...

SU: EW was very much a black art. It's very secret, *hush hush*. It started with the Vietnam War... I didn't even know what EW was. Nobody did.

Did Dr Goh know?

ER: In terms of concepts and ideas – quite good you know! He understood. He also read up on his own. Then, he got people like us – young officers – to run around collecting information. He called us to his office, direct. No hierarchy – go straight to the guy. "You are the engineer in charge of this. Now you tell me how this thing works."

SU: Dr Goh said something and then everybody ran!

ER: A lot of people – running around.

SU: So one of the results of this running was the creation of DSO...

ER: So the whole idea was to get organised, get everything in one place, you see. Dr Goh told Joe Pillay, get people onto EW. The word was "Go and handle this project." So Joe Pillay got three persons: Toh Kim Huat, who was from the Science and Management Group (SMG), Benny Chan from the Systems Integration and Management Team (SIMT), and myself from Comms and Electronics (C&E).

TOH: After I graduated in 1971, I was posted to the Science & Management Group or SMG. Maybe I was the first to be recruited from SMG specifically for this project.

It was not long after I joined, that Henry Cheong, who was head of the Science Branch, told me about this project. It was to start the EW capability, and of course, we had to have radar knowledge. We were to start an R&D group. And it's very secretive, highly secretive. Because by nature, EW has to have an element of surprise. So we had to be very low profile, yet develop a lot of skills, in-country capability in high frequency electronics.

What about you, Mr Chan?

CHAN: Myself, I was with the Litton Scientific Support Team or LSST. Litton was the consultant on the MGB. I was a systems engineer on the project. There was a consultant from the United States. He belonged to Old Crows, the EW association. He studied EW on the MGB project. I was trained by him.

Then, I was called up by the Minister, Dr Goh Keng Swee. That was how it started. Dr Goh called me in. He said he had a concern. And he wanted people to look into EW. So we got Er Kwong Wah who was with C&E, and Toh Kim Huat from the SMG.

That time, there were very few trained scientific people. When we started, there were only six engineers in MINDEF. All were Colombo Plan, returned scholars.

So EW was the main study. Actually Dr Goh was very concerned, you know, I think he read a lot about EW, radar, microwave and fibre optics. And ECM, for instance, our *Gabriel* missile, how vulnerable was it?

I think he was keen to study missiles and ECM. For instance, that time, people were talking about chaff. How vulnerable was the *Gabriel* to chaff? You know, he read a lot. He was not very technical, but he could understand the problems, OK?

"Dr Goh was always talking about Electronic Warfare (EW). He said that our officers were still fighting with swords and spears. "The future warfare is not like that! It's all electronics, and remotely controlled! We must see the enemy without being seen!""

– Er Kwong Wah

How about you, Mr Er?

ER: After Benny Chan and I came back in 1970 from Canada, Benny went to SIMT to work on the MGB, I went to SMG but was attached to C&E. We did research on ECM – very basic things, plumes and chaff. Very old-fashioned EW.

TOH: I heard you threw beer cans out of a plane!

ER: That was EW at the time. There were a lot of experiments but very crude and basic. We even started a research laboratory with fifty thousand dollars, approved by 1PS Pang Tee Pow. Then in 1970, Tee Pow approached me to join the EW Study Group.

So the three of you – Er Kwong Wah, Benny Chan and Toh Kim Huat – all young, newly returned scholars, were brought into the EW Study Group in 1970. What did you understand as your mission? How did you start?

CHAN: It was not very clear. We had to do research. We were looking at surveillance stuff and something with the missiles. The three of us sat down in Pearl's Hill – we had an HDB flat there, top floor. We started to plan, find a place, manpower, budget, get money.

We were very hazy about how to start. But we needed some project. The radar was connected to the missile, *Gabriel*. That was actually the starting point.

This was the work in C&E, and also it was done in SIMT. Why not continue there?

ER: Dr Goh said, "EW has to be under cover." So it had to be alone. Outside of our small circle, nobody knew about us. Then, I also wanted it to be under somebody powerful like Dr Goh or his PS, directly.

OK, tell me how you started.

ER: Our first job was to produce the paper. So we were planning and brainstorming. We had all the proposals – organisation, structure, the terms of reference, what we were supposed to do in different departments... I think there were three departments like radar, communications and so on.

We had no information, so we wrote to our old universities. I wrote to the University of Toronto to ask about Electronic Counter-Measures (ECM). And they sent us catalogues on electronic counters – you know, for counting money. One whole stack of brochures! That was how little people knew in those days.

Then we said that we had to have a name for this thing you see, as a front, call it "Electronics Test Centre" or ETC.

CHAN: We needed a name that had to do with electronics, as a camouflage. We had a hard time finding the name. We thought that "Electronics Test

Centre" would be convincing. Because we had electronic equipment, so it's got to be tested in-house.

ER: Actually I had something else in mind. "Er, Toh & Chan"...

What? ETC is actually "Er, Toh & Chan"?

ER: Yes! "Er, Toh & Chan" is ETC. Well, our thinking was this: we thought that since we were going to start this, might as well give it our own imprint – make it last a while. And our MINDEF bond was another one or two years, and then we might be gone! So, let's leave a legacy behind.

CHAN: You can say ETC was born in Pearl's Hill. That's where we sat down and wrote the papers. Then when MINDEF moved to Tanglin, we all moved along with it and we got Block 42, Harding Road. That's where we did the interviews. And from there, we moved to the first ETC office in Onraet Road. It was late 1972 when we finally moved.

TOH: It was one of the Police detention centres. It was actually very quiet. There were no windows. Everything was closed. We had our own entrance.

Why at a detention centre?

TOH: Dr Goh Keng Swee personally told us, "You have to be prepared to work, eat and sleep in the same place." So we were supposed to look for a place which had an office, also bedrooms and all that.

SU: So you went to a detention centre!

THAM: You can sleep there if you want too!

SU: Yes, under lock and key!

CHAN: Actually, our first task was to look for a boss for our group. We didn't have a Head for ETC. We had to look for one!

How did you look for your own boss?

CHAN: OK – ETC's going to be highly research-orientated. So the first thing which came to mind was the university. So we decided that we wanted some person from the university, someone doing microwave. Initially we had two candidates. The first to be interviewed was in RF, radar and microwave. I think he was quite interested but his first question was, "How much pay do I get?"

I think he actually had experience in the UK in EW. He worked in microwave. Of all the candidates, he was the most qualified. At that time, there were very few such people!

ER: Then we had Dr Bernard Tan. He was an interesting one. He was supposed to be enlisted for full-time NS but he did not qualify. So he was enlisted for part-time NS but in the Army – not in the Police, not in the Vigilante Corp. He was the only part-timer in the Army! Nobody knew what to do with him! He was loitering around, doing eight hours a week. So they asked me, "Do you need this chap?"

So I got his CV. He had PhD, physics from Oxford, not bad, *man!* So I got him in. He served his part-time under me in C&E.

Then I picked Tay Eng Soon up from the newspapers. There was a lot of publicity when he came back to Singapore. Atomic scientist, returning

> "Er, Toh & Chan" is ETC. Well, our thinking was this: we thought that since we were going to start this, might as well give it our own imprint – make it last a while."
>
> – Er Kwong Wah

to Singapore, with his wife, big picture in the Straits Times! So I saw it in the newspaper – *wah*, this one must be very *kuat*. Atomic energy, close enough to EW. Atoms and electrons!

SU: It was a misnomer to call him an atomic scientist. He did plasma. Not atomic energy. He was actually more microwave plasma...

CHAN: Dr Tay was not keen. His first reaction was "No." I mean, he was quite reluctant. He told us that his first love was teaching. Besides his lecture work, he was quite active in politics. He had just joined the university union. Well, Dr Goh convinced him. So he started on a part-time basis. Just to see how it was. I think during that time, he still kept his post at the university.

So now, you had your boss and your new office. Who were the first members of ETC's staff?

TOH: Benny Chan, Toh Kim Huat and Dr Tay.

Just three of you?

TOH: Er Kwong Wah stayed on in C&E because his boss did not want to release him. Then after six months, I left for the US for a one-year attachment on the A4 Skyhawk project. So of the three who started ETC, Benny Chan was the only one left. And Dr Tay was only part-time.

CHAN: And then we started looking at the returning scholars who were bonded to MINDEF. I called Su Guaning who was a fellow Colombo Plan scholar in Canada. I think he's the fourth member of ETC.

SU: I came back from the US in '72 after doing my Masters. Actually, I was getting all set to go for NS because I got called up like everybody else. Then Benny Chan called me up, out of the blue, and said, "Are you interested in doing some technical R&D instead of National Service?" That meant I needn't have to do NS. Quite attractive!

I think they went through all the CVs of people coming back from scholarships, and called up those with engineering degrees. So later on, I talked to Dr Tay. I think the person who really made the decision was SR Nathan. I remember going to see him in his office.

> "I picked Tay Eng Soon up from the newspapers. There was a lot of publicity when he came back to Singapore. Atomic scientist, returning to Singapore, *wah*, this one must be very *kuat*. Atomic energy, close enough to EW. Atoms and electrons!"
>
> –Er Kwong Wah

What did they say about the job?

SU: Actually they were very secretive. They said, basically, research and development. They mentioned radar. Other than that, they said nothing. But I accepted the job. I even started to receive my salary. I was considered to be doing my NS, serving my bond, so the clock was ticking! But I never went to work!

They said, "There is no place for you to go, stay at home, read this book." So that's all I did. I read Skolnik's *Introduction to Radar Systems*. Not bad, staying at home and getting paid.

TOH: I was also given a thick radar book to read...

SU: Oh, Skolnik. OK, same thing.

FOO: After Su Guaning joined, he called me. At that time, I was in Lands and Estate Department. I had an interview with Dr Tay and later 2PS of MINDEF sent me a letter for transfer to 2PS Office. My boss was surprised. He thought something big was going to happen! I joined just a few days before Tham Choon Tat came in.

THAM: That was 1973. I had finished in Adelaide. Whie I was still in Australia, must have been 1972, Su Guaning wrote to me about ETC. And then after I came back, I was contacted by Dr Tay and all those SID people.

What did they tell you about ETC?

THAM: Well, they didn't tell me very much. But they said, "You're in." Then I was sent home to read Skolnik.

Were you all on scholarships?

TOH: Su Guaning and I were classmates in Canada, on Colombo Plan. We were classmates here in RI and we went to the same university in Canada, University of Alberta. We were room-mates! Two years, wasn't it? Actually all three of us in ETC were from the same RI class.

Were you serving bonds for your scholarship?

SU: All of us were! Why do you think we came into MINDEF? In fact, the whole ministry was full of bonded scholars.

ER: Those were the days. When any person comes back, Colombo Plan, First Class Honours, straight away you went to MINDEF!

TOH: Those days, the bond was shorter, five years.

ER: Dr Tay wanted a lot of engineers. His plan was 200.

SU: He had less than ten!

ER: These are the real pioneers, you know.

How did Dr Tay build ETC?

SU: There was no organisation. So he built it up from scratch.

ER: The organisation was just on paper.

TOH: He started to devise projects for us, small projects.

SU: Build up capability, basically. I thought he was being pulled in too many different directions. Sometimes you do this, sometimes you do that.

You see, when they decided to set up ETC to do EW, nobody knew anything about the subject! Where to start or what to do first. The priorities and so on. So they were not able to say what project they wanted! So you have to "self-generate" your projects. And none of us were any wiser in terms of expertise. So you'd end up doing a lot of literature search, just trying to find information.

Now the subject of EW at that time was quite hidden. What is EW? It's quite broad and it was really "black" then. People don't talk about it, don't write about it. You can't find much in the literature.

So I think Dr Tay's initial strategy was to build capability. Not to go straight into project work. So he was getting people to do computer programs, do calculations, study various subjects and technical things. So we did a lot of circuit design, putting circuit boards into boxes. And also to make use of a workshop, eg. machine-lathe, to build things. We had discussions, about how we were going to pull ourselves up. We initiated a lot of projects ourselves to gain experience and to build capabilities.

How often did Dr Tay meet with Dr Goh?

SU: I remember it was quite frequent. Because they had a Steering Committee with Dr Goh, SR Nathan and Winston Choo. And this was how ETC was run for quite a number of years.

Did Dr Tay come back from those meetings with a long list of things to be done?

SU: There were all kinds of evaluations that SAF was doing. We were a group of technical people, so we were roped in to do evaluations – like assessing the missiles, what was the best, what was the most suitable type of equipment. More to do with buys and acquisitions.

Can you remember some of your early projects?

THAM: We did a lot of funny things – nothing really to do with EW. There were many small projects. Once in a while, MINDEF needed some technical expertise. I think all kinds of technical odd jobs got passed to ETC. That's where the problem was. That's why the projects were not very definite.

> "It was the blind leading the blind. But if you look, it was not time wasted. We got experience and learned how to do things ourselves."
>
> – Su Guaning

One of the things I remember was that shortly after I came, we took a trip on the MGB to do something and everyone got seasick.

SU: Only the captain wasn't sick. I think it was measuring radar range. The ship was going out to sea to see how far we could go before we stopped receiving signals. Anyway, it was a bit of a disaster.

We were also in Gombak checking out the air defence radar. We were supposed to check whether it was hazardous. That's very high power transmission in the microwave range. So of course, in the most severe case, you could get cooked. It is the radar that keeps watch on the airspace in Singapore.

After that, we started to have more things. I remember there was something about night vision. Certainly, RPV. We were evaluating something for the Navy, and we were also involved in the acquisition of the EW equipment.

TOH: Looking back at that time, the tools we had were all very crude. We had a system in the back of a Datsun station wagon, 120Y. And we would go around, taking measurements.

SU: We had a wooden platform that we could take out. And then some kind of an antenna that we put on a pole. I remember looking for a sturdy enough tripod to put the thing on. Tham was doing some of those stuff. And then Foo did some of that too. I remember building a falling raster display.

It was the blind leading the blind. But if you look, it was not time wasted. We got experience and learned how to do things ourselves.

Do you think that Dr Tay was frustrated by the lack of progress?

SU: He was a very positive person. Very upright, very dedicated. I mean he was a very principled person. I think he took the approach of, "I make the best use of what I've got." Or "I will do my duty." I don't know whether he was in the position to argue for a lot more people and all that.

What was your first project?

FOO: I think the first big project was when we bought some systems from overseas.

When you buy systems, you take the opportunity to learn about the system, as you have to evaluate, operate and possibly maintain the system. Attachment to a supplier is another means of learning from experienced people. In the end, you learn and you gain confidence in building similar systems yourself. My attachment was not too bad, quite enjoyable.

In DSO, I was developing a number of electronic devices, some of which were integrated into the system.

And because of this big project, Tham Choon Tat successfully developed some similar systems. With that, we developed our capabilities to make electronic devices, carried out system integration and in the process, built up certain expertise.

Did the black nature of ETC make it difficult for you to work?

THAM: It was a big problem. Because due to security, we had to compartmentalise every project. The project was broken up into pieces. You will never get the full picture. You won't know what is actually happening. You're only given half the information to work with.

That was for security. ETC was very compartmentalised. You wouldn't even know what the guy sitting next to you was doing. As a result, some of the work done was not optimal.

But you had such a small workshop. Wouldn't you see everything?

THAM: You see things but you're not told what the next guy is doing. And you don't ask. So you don't know how your fellow engineers relate to you. I mean, you are developing something for some guy. You don't talk to that guy! You talked to Dr Tay.

Sometimes, he didn't pass you all the information you needed. He kept some information back, because he didn't think you needed to know it. Then you worked to finish it and later found that it didn't meet the user's requirement because you did not get the bigger picture. Because the guy there didn't know what you were doing.

You also didn't want to ask. He wouln't tell you also. That was the culture then.

Did you have any foreign consultants to help you get started?

TOH: Definitely not. It was too secretive.

THAM: We built DSO from scratch. We didn't have any expertise and couldn't really consult anyone. So that was very difficult in ETC in the early days and it was really a struggle to make progress.

ETC moved from Onraet Road to a new building on Marina Hill in 1976.

THAM: Marina Hill was a former Officers' Mess. A rather big building. Plenty of rooms and they ended up with two big labs at the bottom. Then the engineers' rooms at the top. About ten, twenty rooms.

Well, it was not very nice at first. You know, at that time, the civil service didn't allocate air-conditioners. So most of us didn't have air-conditioners except Dr Tay and a few others. We were complaining like hell but nothing happened. We asked for air-con and he said, "No." Until one day, Dr Tay's air-con broke down, he couldn't stand the heat! After that he said, "OK, you can all have air-conditioning."

ETC was a black outfit. Did you lose out in any way?

THAM: Recognition is one thing. Then, interaction. Information flow. In terms of what was going on in MINDEF. And our relationship with MINDEF.

TOH: We were quite worried about promotion prospects.

SU: Yes, we were quite worried about that.

ER: How to tell PSC what you have done? I mean, when they ask, "What do you do?" And you say, "Sorry, can't say. It's top secret."

> "When you talk about R&D, you need time. You have to build up the capability. You build up the numbers. It's a very slow process."
>
> – Su Guaning

Was morale affected? Did people leave?

THAM: For the first few years, there was no turnover. We were all under bond and we couldn't go anywhere else.

Looking back, ETC was probably not a very good place for a new engineer to start at that time. Because you didn't get guidance from the top and you didn't know what's happening. Now, engineers coming in, I think, are probably given better opportunities. Because systems are in place and you have equipment, you have experience and you can build up faster.

In 1977, ETC became DSO. What changed?

THAM: Our staff doubled because of SIMT joining us after they finished the MGB project. So we went from about 20 staff to 40 staff, maybe 50. But other than that, there was no change.

We didn't really grow much in the 1970s. Because at that time, DSO was not open, and you had to go to the university to talk secretly to the people whom you wanted to recruit.

I think Dr Tay approached some students, and those students would approach others within their circle. As a result, in 1978, we had a big group of recruits and some returned scholars from MINDEF – more than ten in one big group. It was only in later years that we were allowed to recruit openly.

The main problem with being such a black operation was the recruitment. When we were advertising for people, we put up the advertisement, and they had to contact the advertiser – we just gave the P.O. Box Number.

What was achieved in the '70s when DSO was under Dr Tay Eng Soon?

SU: We used the time to build up some useful experience. But I think we could have done more if we had more resources and a very clear direction.

But in the '70s, we kept developing electronic circuits. I know Tham Choon Tat, Foo Say Wei were fiddling around with electronic circuits.

It was not such a big deal really, as compared to the stuff we really started putting our minds to in the '80s.

I have a feeling that Dr Tay was actually trying hard to establish DSO properly without sufficient resources to do things. And he was having a hard time making headway. Because other people were saying, "Well, you guys, I guess, are doing things that don't result in anything." Whereas the other people like Logistics, DMO or other places are buying guns, buying missiles, ships and all that.

Whereas when you talk about R&D, you need time. You have to build up the capability. You build

> "You see things but you're not told what the next guy is doing. And you don't ask. So you don't know how your fellow engineers relate to you. I mean, you are developing something for some guy. You don't talk to that guy! You talked to Dr Tay. That was the culture then."
>
> – Tham Choon Tat

up the numbers. It's a very slow process.

You can't have the Big Bang approach. That's when you recruit a Director from somewhere and you suddenly dump a whole lot of people together and say, "OK, you do research." A lot of things fall by the wayside, a lot of mistakes are made, that way.

So I think in ETC, or DSO, we took a very gradual approach to R&D. We had very small numbers. We grew slowly. Built leadership. We only started to grow ten years later, in the '80s. It wasn't that bad. I think it turned out OK.

Did you make mistakes?

SU: Definitely. I think we did too much electronic design. We worked without focus.

See, ultimately you want results. You don't mind working hard at something if at the end, you have something. So you need focus and direction. You need to build capability but you also need a clear direction.

Was the setting up of ETC in '72 too early?

SU: I wouldn't quite say that.

I think what we managed to achieve in the '70s was to have a core number of people who became leaders in the '80s. That's probably the way to look at it. This was the most important achievement of ETC.

If we had waited until the '80s, we would not have had much of the leadership in place when the growth occurred.

So, I guess, the most valuable thing we did in ETC was to build leadership for the 1980s.

I'll give you an example. If it wasn't for DSO, I might not be in MINDEF today.

I guess you know the story. I told Philip Yeo I wanted to do PhD and I wanted a university scholarship. So I applied, through him. Then he said, "Don't take that one. That will only send you to Waterloo, something like that. DSO will give you a scholarship, you go to any university you want."

So that was interesting enough for me to sign up with DSO. Because I was already out of the bond by then. If there wasn't a DSO, I would probably not be around today. And this may apply to many of the science and technology leaders of today.

So Dr Goh's project was actually a very far-sighted measure.

SU: Dr Goh was far-sighted in that he wasn't constrained by the immediate need. He didn't look at the whole thing as just short-term. He said, "I am going to need this capability some time or another. I better start it now." But whether he anticipated ETC and DSO growing this way, becoming a brain trust for MINDEF in the long term, I doubt that. This was with the benefit of hindsight.

DSO was able to keep the people, perhaps because DSO was a place that people could grow, and develop capability and leadership. And they did. That's why this generation became the science and technology leaders in the next two decades. They became a very valuable resource for MINDEF.

Were there any other achievements in the 1970s?

SU: Another thing, we did provide some good advice to SAF on acquisitions. I think we were the only group that was able to get down to the real technical data and work out evaluations. That provided a much more unbiased, technical evaluation as opposed to the kind of system where SAF just relied on information from salesmen.

In the '70s, SAF was in its infancy. Did they know what they wanted?

SU: The SAF had to evolve, in parallel to DSO. When the SAF first started, all they knew was how to buy things. Buying things meant they accepted what was available in the market. So the best value that you could add to the process was to decide on which was the best system to buy.

"I think what we managed to achieve in the '70s was to have a core number of people who became leaders in the '80s. That's probably the way to look at it. This was the most important achievement of ETC."

– Su Guaning

It was only in later years, I would say in the early '80s and later on, that the SAF had the capability to define what they wanted. And later on, they had more sophisticated or complex demands, which was not available in the open market.

So the SAF slowly built up their own capability in the '80s, '90s and so on. While ETC and DSO was growing, there was a corresponding development of the SAF capability to specify what they wanted of DSO.

So I would say when DSO was first started, it was constrained not only by the fact that we did not have any R&D experience, but SAF itself also didn't have any experience in specifying what they wanted.

So it was only in the more recent years that the SAF was able to be a better, more demanding partner in R&D. They are now in a better position to say, "This is what I want and this is special about our operational requirements."

That's when DSO was able to get to work, generating solutions for the SAF.

SU: That's correct.

CREATING THE INVISIBLE SHIELD

Guided weapons (GW) technology, together with the other advanced defence technologies – electronic warfare (EW) and stealth technology – which had been steadily developed ever since the days of the Vietnam War, ushered in a new era of modern warfare in which technology could make the crucial difference between defeat and victory. During the 6-day war of 1967, the Israeli destroyer Eilat was sunk by four Soviet-built Styx missiles fired from two Egyptian boats – the first successful use of anti-ship missiles in combat, and a decided turning point in the history of naval warfare.

Towards the end of the Vietnam War in 1972, precision laser-guided bombs were used by the Americans to destroy important supply bridges from North to South Vietnam which thousands of conventional "dumb" bombs had failed to hit in earlier attempts. During the opening hours of the "Yom Kippur" War of 1973, the Israelis lost many tanks to the skilful use of Soviet-built AT-3 Sagger anti-tank missiles by the Egyptians. Almost ten years later, during the Lebanon War in June 1982, the Israelis skillfully combined guided weapons, remotely piloted vehicles and electronic warfare to suppress and destroy Syrian SAM (surface-to-air missile) batteries deployed in the Bekaa Valley. As a result, the Syrians lost at least 87 aircraft while the Israelis lost only a few helicopters.

The Gulf War of 1991 saw the use of a new generation of smart weapons, guided accurately to their targets over hundreds of kilometres by sophisticated guidance and navigation systems, making use of intelligence provided by satellites orbiting hundreds of kilometres above the earth. Many of these missiles were launched by stealth aircraft. Sophisticated EW systems were also used extensively to blind the Iraqi radars and hence suppress the Iraqi air defences.

Dr Goh's Foresight: The Beginnings of EW in DSO

It is therefore a tribute to Dr Goh Keng Swee's foresight that he foresaw the importance of technologies such as EW, sensors and remote control way back in 1972 when DSO was established.

The pioneering DSO engineers faced many difficulties, as these were subjects not normally taught openly. The know-how was very closely guarded and protected (which remains so even today). They had to start from scratch, compensating their lack of experience with commitment, passion, enthusiasm and perseverance!

By the 1980s, the group had learnt enough to proceed with computer modelling and simulation tools. Computer simulation not only allowed them to create the virtual systems and scenarios they needed to aid their understanding and analysis, it also allowed them to play with a multitude of possibilities and 'what-ifs', giving them a virtual test bed to exercise their innovation and creativity and to explore and test their ideas quickly.

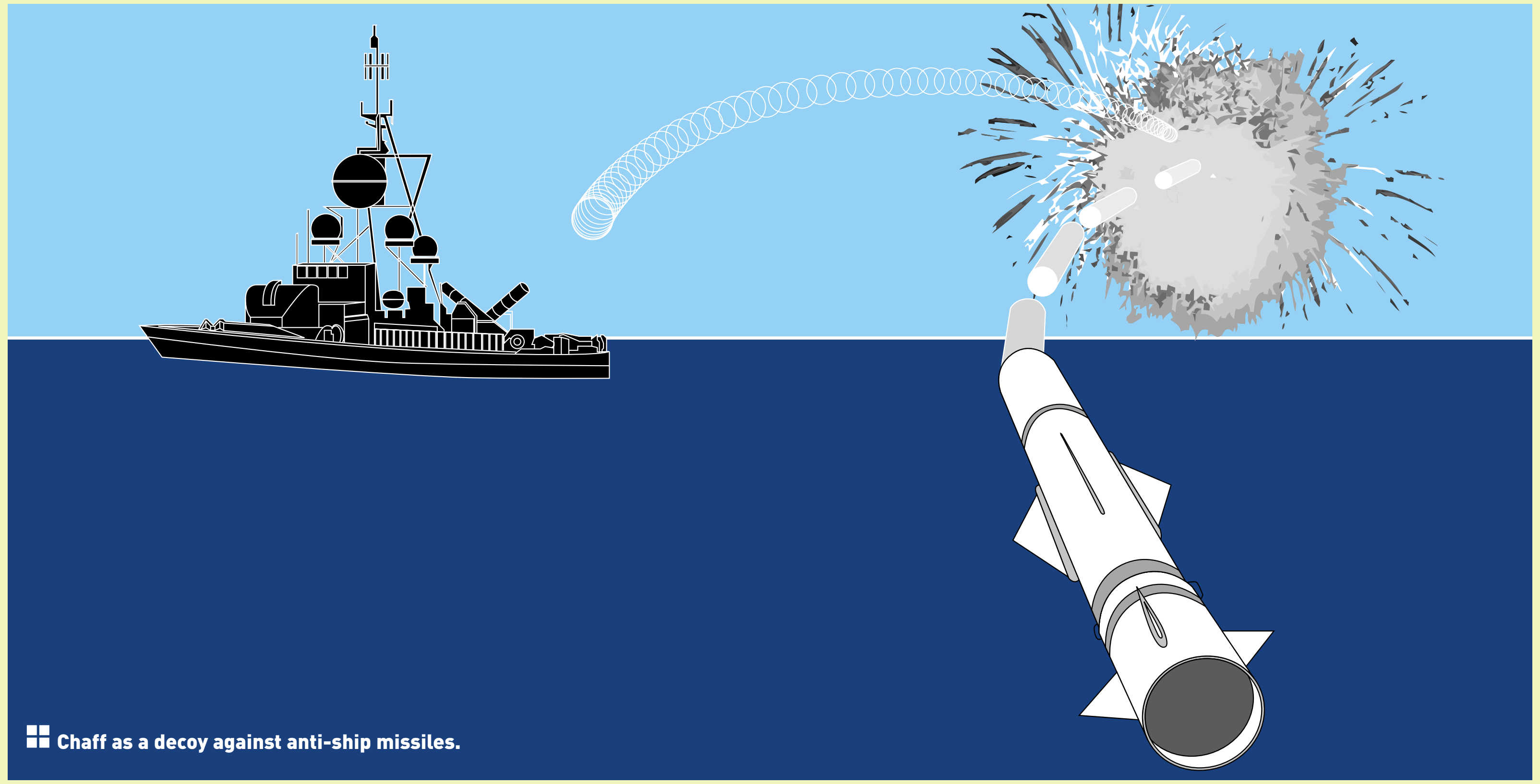
The MGB and MCV Programmes

In the late 1970s, a major learning opportunity came when the Republic of Singapore Navy acquired ESM (electronic support measure) and chaff systems for their new missile gunboats (MGB). The ESM and chaff systems together formed an EW system for the MGB, protecting it against threats such as missiles. The ESM is a radio receiver system which listens for and identifies radio signals emitted by a missile radar seeker during an attack. On confirmation of an attack, it activates the ship's defence by launching chaff, which is basically a physical decoy made of a cloud of metallic strips of various lengths designed to confuse the radar seeker systems of the threat missiles.

A key challenge then was to develop chaff technique against such threats, which involved the analysis and deployment of chaff as an effective target to lure the missile away from its intended target. Modelling and simulation provided important insights into the dynamics and complexity of this multi-faceted problem. The DSO engineers needed to understand chaff in terms of a cloud of dipoles acting as an effective radio wave 'reflector' and how its effectiveness could be complicated by the effects of environment and the behaviour of radar. For example, it was necessary to know how a missile radar seeker views an area of interest and how it selectively accepts only the relevant signals of interest.

The many projects the engineers had to work on often demanded the concurrent study of a range of different topics, yet the collective learning from the various teams involved converged in a common mission to advance DSO's GW and EW capabilities.

For example, at a particular time they might have been involved in studying various aspects of a missile guidance system on board an MGB, such as the signal to noise ratio, match filtering, probability of



Chaff as a decoy against anti-ship missiles.

detection and false alarm, and how these should be applied in a radar seeker for target signal detection. They might also have to understand and model the relationship between the radar seeker's detection of the target of interest and how the threat missile translates this information into flight command and control signals.

At another moment, they might be trying to understand the physical characteristics of radio wave propagation, including the effects of the sea surface, so that they could model the effects of the sea environment on the multipath propagation and reflection of the radar seeker realistically. Textbook learning and computer simulation were supplemented with actual sea trials to study and verify the performance of the systems on board the MGB, so that solutions could be developed to improve the relevant systems' performance. Many of the experiments and trials were conducted on board ship and out in the open sea, often resulting in seasick DSO engineers.

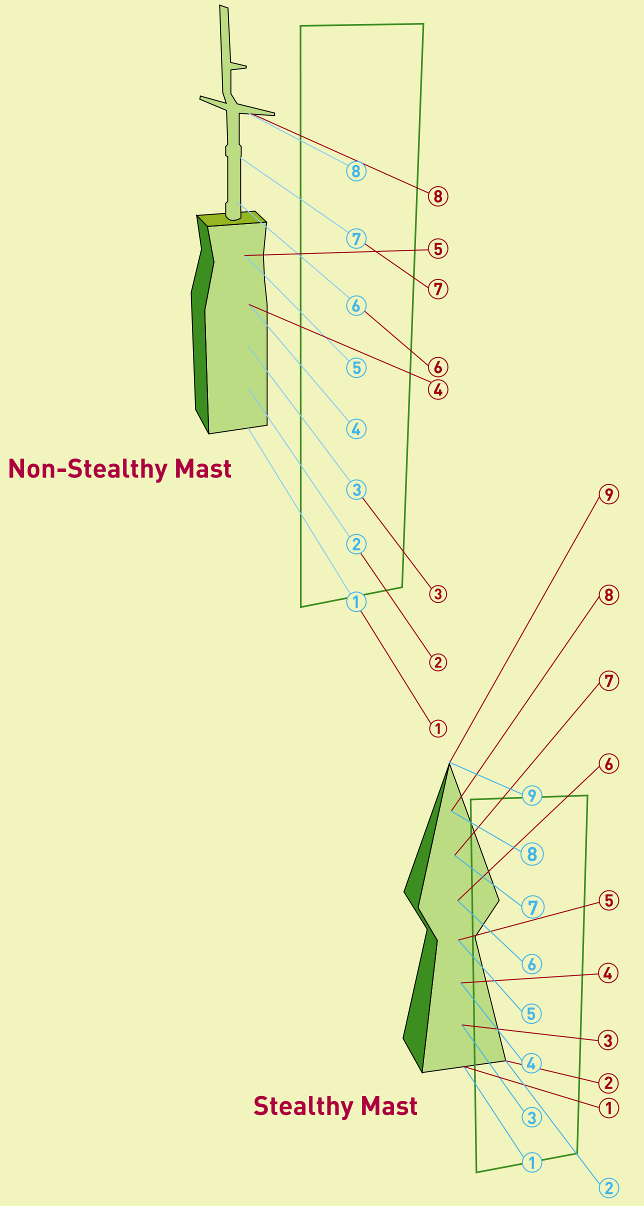
The experience gained with the MGB missile systems in understanding missile dynamics and flight behaviour stood the DSO engineers in good stead, particularly when the Republic of Singapore Air Force acquired the AGM-65A Maverick Missile which presented them with another learning opportunity. They excitedly followed the many live-firing exercises, as these were golden opportunities to witness real missiles in action. They went into pre-flight simulations as well as post-flight assessments to analyse flight behaviours, particularly those that were out of the ordinary. They became increasingly conscious of the necessity for simulation fidelity and accuracy, which led to the acquisition of the Maverick 6 Degree of Freedom (6 DOF) simulation software from the then Hughes Aircraft Company. The 6 DOF simulation tool not only helped them to validate the knowledge they had built up, but also gave them a better understanding of the capabilities of advanced simulation tools. As a result, they gained important insights into the Maverick's strengths and weaknesses and helped the user develop tactics to improve its effectiveness.

The Navy's missile corvette (MCV) programme in the '80s marked another important milestone in their learning and capability development. By then, what they had learned from the MGB project – modelling, simulation, operational trials and system modification and improvement – were applied to the MCV programme. A very close relationship developed between the Navy personnel and the DSO EW engineers. The EW engineers worked very closely with their Navy counterparts, meeting regularly to discuss and brainstorm, and to integrate EW techniques and tactics into the best possible anti-ship missile defence for the MCV.

The knowledge and capabilities built up over the learning years taught the DSO engineers how to verify technical performance and challenge manufacturers' claims when necessary. They became confident enough to recommend and select systems that were in development, and therefore more capable and closer to the state-of-the-art, instead of playing safe by selecting only systems already in production (and therefore more likely to be outdated by the time they were operational). This forward-looking approach greatly facilitated capability development and had full support from the Navy, so that each ship was 'built for its time and not timed at its build'.

The low observable MCV mast project

Besides EW, the MCV program brought about the first low observable (LO) requirement (the need to make a ship difficult for an enemy radar to observe) for the Navy. The main requirement was to lower the MCV signature and therefore reduce detection range within which it could be significantly detected by radar for the purpose of enhancing ship survivability. The ship's mast presented the main challenge as on the one hand, it provided the necessary height for its antennas, but on the other hand, its height rendered it more detectable by an enemy radar. The radar signature (i.e. the characteristic image it presents to a radar system) had to be reduced as much as possible, in spite of



The blue lines are the incident rays while the red lines are the reflected ones. Note that for non-stealthy mast, there are several reflected rays running parallel to incident rays while none for the stealthy mast

the fact that the antennas on the mast needed extra electromagnetic shielding structures which resulted in an increase in the mast signature. Solutions were proposed, but found to have some limitations because radar signature reduction technology at the time was much less advanced than it is today.

The MCV mast challenge triggered and facilitated the acceleration of the building up of DSO's capabilities in RCS (radar cross section, or the visibility of a system to an enemy radar) and EMI/EMC (electromagnetic interference/electromagnetic compatibility). RCS prediction codes and software were subsequently developed or acquired, and measurement and test capabilities were put in place. Consequently, the capabilities needed to optimise combat effectiveness of the MCV radar systems, while maintaining low signature and ensuring EMC, were acquired and strengthened.

The acquisition of the Barak anti-missile missile (AMM) system for the MCV was another golden opportunity to raise DSO's GW capability further. DSO's engineers participated with the manufacturer's experts in working to validate the GW simulation software for the numerous firing tests. This gave DSO the capability to perform pre-flight analysis to determine safety templates and work out the extremes of the missile flight envelope. They also became proficient in conducting post-flight analysis on the missile flight profile and behaviour, in particular to identify and explain deviations in flight behaviour.

At the time of the MCV programme, there were many willing and eager suppliers of EW systems but these were at best basic systems capable only of rudimentary capabilities, akin to ovens sold without timer controls and without recipes. In chess, every player starts with the same sixteen pieces and plays by the same rules. Yet the possible strategies are limitless, a critical factor being the player's skills and ingenuity. In the hands of a grandmaster, strokes of genius often emerge. In EW the strategies are also limitless. Unlike chess, however, the EW technique used has to work the first time, every time, and within split seconds. The challenge is speed and time. Many man-years of effort have to be put in to design, develop, test and retest the solution to ensure that it is timely, precise and effective and will work when it is needed. The MCV project allowed the DSO engineers to master the necessary EW and GW technologies, and to accumulate valuable and relevant hands-on experience. The MCV has been operational for quite some time now. DSO engineers are now applying the experience they have accumulated from the MCV and other previous projects to the even more exciting

Land-based magnetic field measurement facility for measuring ship signatures.

and sophisticated challenges posed by projects such as the new naval frigate programme.

The invisible shield and Singapore's defence

DSO's contribution in creating the invisible shield for Singapore's defence was well-summarised by Deputy Prime Minister and Minister for Defence, Dr Tony Tan when he opened the new DSO Marina Hill Complex in October 1998. He said:

"Electronic warfare protects our aircraft, ships and fighting vehicles from in-coming threats such as missiles by building an electronic shield around them. The shield denies enemy sensors and communications from performing their intended functions by frustrating, deceiving or jamming them. This is known, in electronic warfare jargon, as electronic countermeasures or ECM.

The SAF depends on the ingenuity and innovativeness of DSO engineers in EW because EW is regarded as a secret art that no country wants to share. At best, overseas suppliers are prepared to sell us black boxes. EW is like a game of chess. DSO must always be a few steps ahead in order not to be surprised by ever more sophisticated threats."

Many of the original DSO team members are well into their forties now, having gone through 20 years or so as pioneers to become EW and GW "grandmasters" in their own right. Upon their shoulders also rests the responsibility of grooming and nurturing the next generation of EW and GW engineers to continue this exciting mission.

0010

ENHANCING SITUATION AWARENESS

One of the most potent weapons in the military cannot be seen or held, but can often make the difference between victory and defeat. Information, or intelligence, as it is often called in a military context, can affect the balance of power in a conflict which can often make up for a lack of superiority in weaponry or in numbers. The gathering of intelligence has used methods ranging from the time-honoured one of sending human agents (or what we may, more bluntly, call "spies") into hostile territory, to the most modern advanced electronics and sensors, coupled with the deployment of high-technology spy satellites or unmanned airborne vehicles (UAVs).

Electronic Surveillance

In the days before electronic surveillance was possible, an attacking force could plan their offensive and move towards their objective under cover of darkness and reasonably hope that the element of surprise would give them a significant advantage over their opponents, which might make the difference between success and failure.

Today, however, no advancing force can assume that any move, no matter how stealthy, will remain undetected for long. Electronic surveillance techniques, ranging from the tracking of radio signals to the use of sensing technologies deployed in aircraft and satellites in earth orbit, are capable of tracking their every move and relaying this intelligence to the opposing forces.

In any conflict today, even before a shot is fired, it is imperative that as much detailed information be gathered about the adversary – their strength and deployment, their training and preparations, and their possible strategies and tactics. In the last few decades, the phenomenal advances in electronics and information technology, as well as in sensor and detector technology have made possible hitherto undreamt–of possibilities in surveillance and intelligence gathering. Advances have been made not just in the hardware, but also in the software and mathematical algorithms which have made possible the extraction and enhancement of useful information from signals and images which appear to be so noisy and random as to be unintelligible to the naked eye and ear.

Ensuring that the Singapore Armed Forces (SAF) have the full benefit of the state-of-the-art in electronic surveillance capabilities has been and remains one of the key areas of DSO. Space and security constraints do not permit a complete account of the work which has been done and is being done by DSO's researchers. However, a glimpse, at least, can be provided of DSO's work in some areas related to electronic surveillance, such as in communications and sensing technologies.

Radio Receivers

DSO's work on electronic surveillance had to start virtually from scratch, as research on such techniques is generally not published in the open literature. DSO engineers began by studying the usefulness of radio receivers, whose frequencies could be manually tuned, for monitoring transmissions from radios communicating with their own units. When a radio transmits sounds such as voices, it does so by superimposing the sounds onto a radio wave which vibrates extremely rapidly. The rapidity of this vibration is known as its frequency, and each radio transmission vibrates on a particular frequency. If we know what frequency a radio set was using to transmit its signals, we could tune a receiver to the same frequency to receive that transmission.

In the early days, radio receivers were mainly manually tuned. These receivers were tedious to use, because it was necessary to laboriously tune the receiver's frequency over a wide range of frequencies slowly, so that any transmission would be detected when the receiver's frequency matched that of the transmission of interest. This had to be done slowly, as tuning through a frequency range too quickly might result in a weak enemy transmission being missed.

The advent of receivers with digitally controlled frequencies made it possible for the scanning of a receiver's frequency to be computer controlled. The scanning and searching algorithms needed to be optimised to ensure timely detection. This kind of scanning and searching for a transmission of interest, raising an alert when one is detected, not only makes the process much easier and more controlled, but also frees up valuable manpower for other tasks. The DSO team gained in-depth understanding of these and other aspects of surveillance receiver technology, and was able to identify areas for further R&D.

An equally important objective in searching for radio transmissions is to locate the source of the transmission, and hence its position. Antennas can be designed to be directional (for example, the TV antenna on the roof of a house has to be pointed towards the TV transmitter), and this can be used to determine the direction from which the enemy signal comes. This method, however, can only determine the general direction, and not the actual location of the signal source. With more than one antenna, more accurate direction finding or DF becomes a more realistic proposition, and DSO entered this important area of surveillance by first evaluating and assessing the available techniques, and then becoming proficient in the fundamentals of DF.

Radar

Radio waves, while important in telecommunications, have an equally important application in the remote detection of moving objects, such as enemy aircraft. By sending out a short burst of radio waves towards such an object, and detecting the reflected radio waves from the object, it is possible to gain information about the object's location and speed. This technology, which we know today as radar (which is an acronym for "radio detection and ranging") is widely used in military and civil applications, including the radar speed traps set up by the Traffic Police to detect speeding motorists. Ironically, the inventor of radar, Sir Robert Watson Watt (a direct descendent of James Watt, the inventor of the steam engine), was once caught in a radar speed trap, and thus was hoist by his own petard. He was bemused enough to pen the following poem:

Pity Sir Robert Watson Watt,
Strange target of his radar plot,
And this, with others I could mention,
A victim of his own invention.

A pioneer group of radar engineers launched DSO's thrust into radar systems by providing the evaluation and analysis of radar systems in support of the SAF's ongoing acquisition of radar systems. To make up for their lack of experience, DSO's young radar engineers spent a considerable amount of time in the SAF camps to gain first-hand experience in the operation and maintenance of radar systems. Armed with this experience, the engineers went on to develop specially tailored software packages designed to evaluate the performance of radar systems in our local terrain, and in the presence of the radio noise and signals peculiar to our local environment. Experimentation with the radar hardware, initially by building simple instrumentation to be interfaced to the radar systems for data collection and system characterisation, allowed DSO subsequently to provide solutions that enhanced the performance of radars in the SAF.

DSO's work in radar led naturally to the rapidly advancing field of high resolution imaging radar, more commonly known as Synthetic Aperture Radar or SAR. This technology goes well beyond the capabilities of normal radar systems, enabling the high resolution mapping of terrain, the detection and tracking of surface targets in a cluttered background, and high accuracy target recognition. The advantages and growing importance of high resolution SAR technology led to it becoming the natural next step in building up DSO's radar R&D capability.

In SAR research, the DSO team has had the opportunity to collaborate with Singapore universities and overseas research organisations. They soon learned that engineers had to work alongside mathematicians and physicists to analyse the complex theoretical and mathematical problems often encountered in SAR research. The group had to overcome the challenge of getting people with very different backgrounds to work together: mathematicians think in terms of theorems and lemmas, physicists think in terms of electromagnetic fields and waves, while engineers think in terms of signal-to-noise ratios and time/frequency domains. The deeper understanding of the problems and the much-improved solutions which resulted were well-worth the effort, and opened a new chapter in DSO's radar R&D.

DIRECTION FINDING (DF)

After their initial learning experience with direction finding (DF) technology, DSO engineers and scientists focused on developing its capabilities in array signal processing. DF accuracy is important for locating radio transmissions and is dependent on the environment, among other things.

A single antenna may be able to roughly indicate the direction of an incoming radio signal, as the received signal strength will be at a maximum when pointed towards the source. Two or more antennas pointed towards the source from different locations will be able to indicate not just the direction of the source, but its actual location which is the intersection of the directions measured from different locations. The accuracy of location however depends on the angular resolution of the antenna, or the narrowness of its beamwidth. The higher resolution also enables the differentiation of

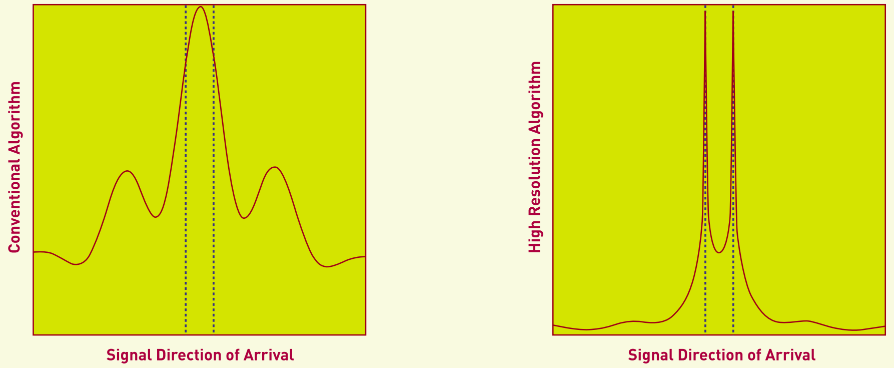
Experimenting with array antennas.

two separate signals from the same general direction. An array of antennas working together at a single location can give much higher resolution than one antenna by itself; this technology is known as array signal processing. DSO proceeded to develop its capabilities in this field by researching into the relevant high-resolution algorithms (for example, Capon beamformer, ESPRIT, and MUSIC) and simulation techniques.

At the same time, a data acquisition system was designed and integrated to collect data for understanding the problem as well as to test the algorithms. The task was more difficult than expected, with challenges such as maintaining the coherency and integrity of the signal even when the characteristics of the electronics hardware change with time. Many experiments and field tests had to be carried out all over Singapore, often in difficult and trying conditions such as unbearable day-time heat and the constant assault of mosquitoes during night-time trials.

The path to success was fraught with obstacles: expertise-building from scratch, compressed schedules, detailed understanding of the propagation environment, major disagreements among key team members, and failure of reputable suppliers to deliver key modules with adequate quality. Undaunted, the team pressed on to successfully demonstrate its high DF accuracy.

Direction Finding Spectrum Plots



SYNTHETIC APERTURE RADAR (SAR)

High resolution imaging radar, commonly known as Synthetic Aperture Radar or SAR, may be considered to be an extension of conventional radar technology designed to achieve results far beyond the reach of conventional radar systems. SAR enables radar to produce high-resolution images and can even outperform normal optical imaging techniques in certain cases.

When images are formed by an optical system, such as a camera or a telescope, a lens or a mirror system is needed to receive the rays of light from the scene or object to be imaged. The lens or mirror then focuses the light rays to an image plane where the image is formed. Both light and radar waves are electromagnetic waves, so that essentially the same techniques applied to radar can in principle form images. The resolution of the images formed, or to put it another way, the smallest objects which can be seen in the image, depends both on the wavelength of the light or radar waves, as well as the size of the lens or mirror used to form the image.

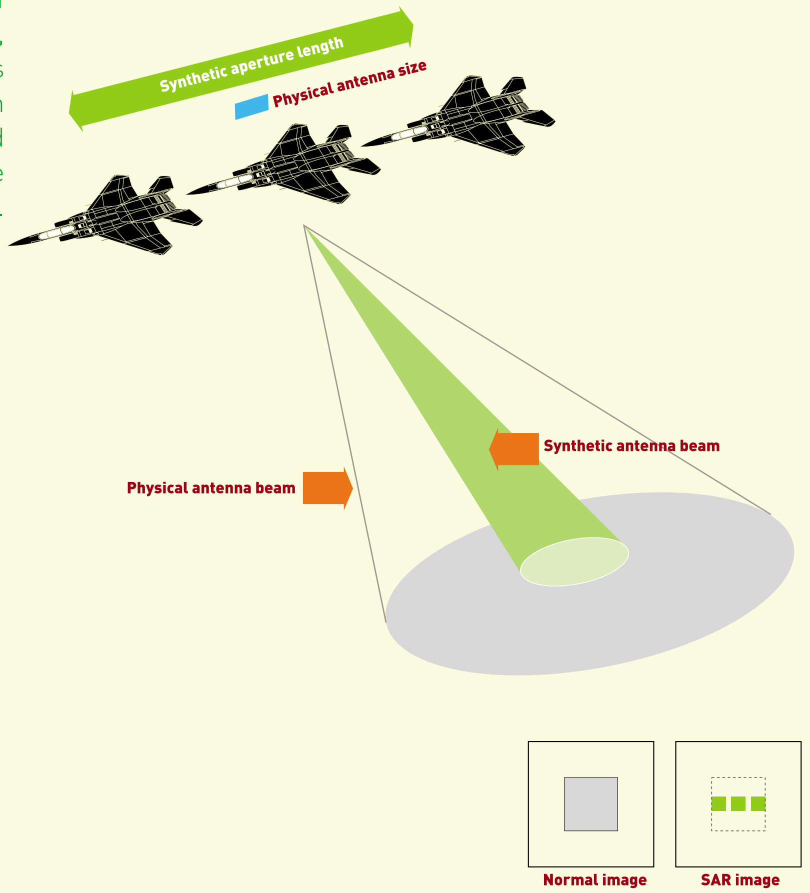
Radar, while in principle similar to optical imaging systems, differs from them in a number of ways. Radar waves are of course invisible to the naked eye and have to be collected by an antenna (analogous to the lens or mirror in an optical system), which results in a visible image on a radar screen. The wavelength of radar waves is much longer than that of light waves, ranging from the millimetre to metre range. Radar systems send out radar waves which are reflected from the scene or object to "light up" the scene, in much the same way that a camera flashgun produces the necessary light to illuminate the subject. While radar waves are invisible to the naked eye, they are able to penetrate objects which block visible light, such as clouds, and hence are able to produce images of cloud-covered scenes not visible to optical systems. Radar can also operate over a wider area and at longer distances than optical systems.

The name Synthetic Aperture Radar provides a clue to the advantages of SAR over conventional radar. The resolution which a radar image can provide is determined by the size of the radar antenna. The antenna shoots out a narrow beam of radio waves which is reflected from its target; the larger the antenna, the narrower the beam and hence the smaller the objects which it can distinguish. In a conventional airborne radar system, the maximum diameter of the antenna which an aircraft can carry is at most a few metres, providing a beamwidth of not less than a few degrees in angular width. At the distances typical of the targets of interest to an airborne radar, this would translate to a beamwidth resolution at the target of several kilometres, which is too gross to detect individual vehicles, aircraft or buildings.

To produce very narrow radar beams and high resolution images, a very large antenna several kilometres in diameter is needed. It is of course totally impractical for a real antenna of such a size to be carried by an aircraft. However, by flying an aircraft carrying a much smaller antenna over a certain distance, the radar beams which it emits as it covers this distance can be processed in such a manner that they combine to give the effect of having been emitted by a single antenna.

This single "synthetic" antenna is as large as the distance over which the aircraft has been flying while emitting the radar beam. If this is a distance of say, a kilometre, the effect is of the beams being emitted by a kilometre-diameter antenna, with the resultant dramatic narrowing of the beamwidth. This technique is known as Synthetic Aperture Radar because an antenna of large diameter or aperture has been synthesized by special processing of the emitted radar beams. The accompanying diagram is an illustration of the SAR technique.

Principles of Synthetic Aperture Radar



The Future

In electronic surveillance, a growing trend is the use of multiple sensors integrated to complement each other in the surveillance, providing a significant improvement in responsiveness and accuracy in detection. There is certainly much potential for further development to significantly enhance the effectiveness of future military surveillance.

Newer radar concepts such as ultra-wide band radar, and advanced communications techniques such as spread spectrum and digital communications, are now proliferating and leading also to the overlapping of the frequency bands as well as the technology of both communications and radar (for example, waveform coding). In both the communications and radar areas, the increasingly demanding requirements have also motivated the development of areas such as compact, high performance and high bandwidth receivers, the analysis and design of antennas, electromagnetic compatibility, and mechanical and thermal engineering, all of which require a truly multi-disciplinary approach.

The phenomenal advances in electronics, computers, processing algorithms, and information management have continued unabated. DSO is determined to leverage on these technological advances and to continue enhancing its capabilities to enable it to give its users a decisive edge. The DSO team has benefited greatly from its close rapport with and the strong support of MINDEF/SAF, and will continue to nurture this synergistic relationship. The ultimate objective will remain constant: to enable the SAF to ensure that any adversary in the battlefield has "no where to hide, no time to hide, no way to hide".

Array of antennas for a ground-based air surveillance radar.

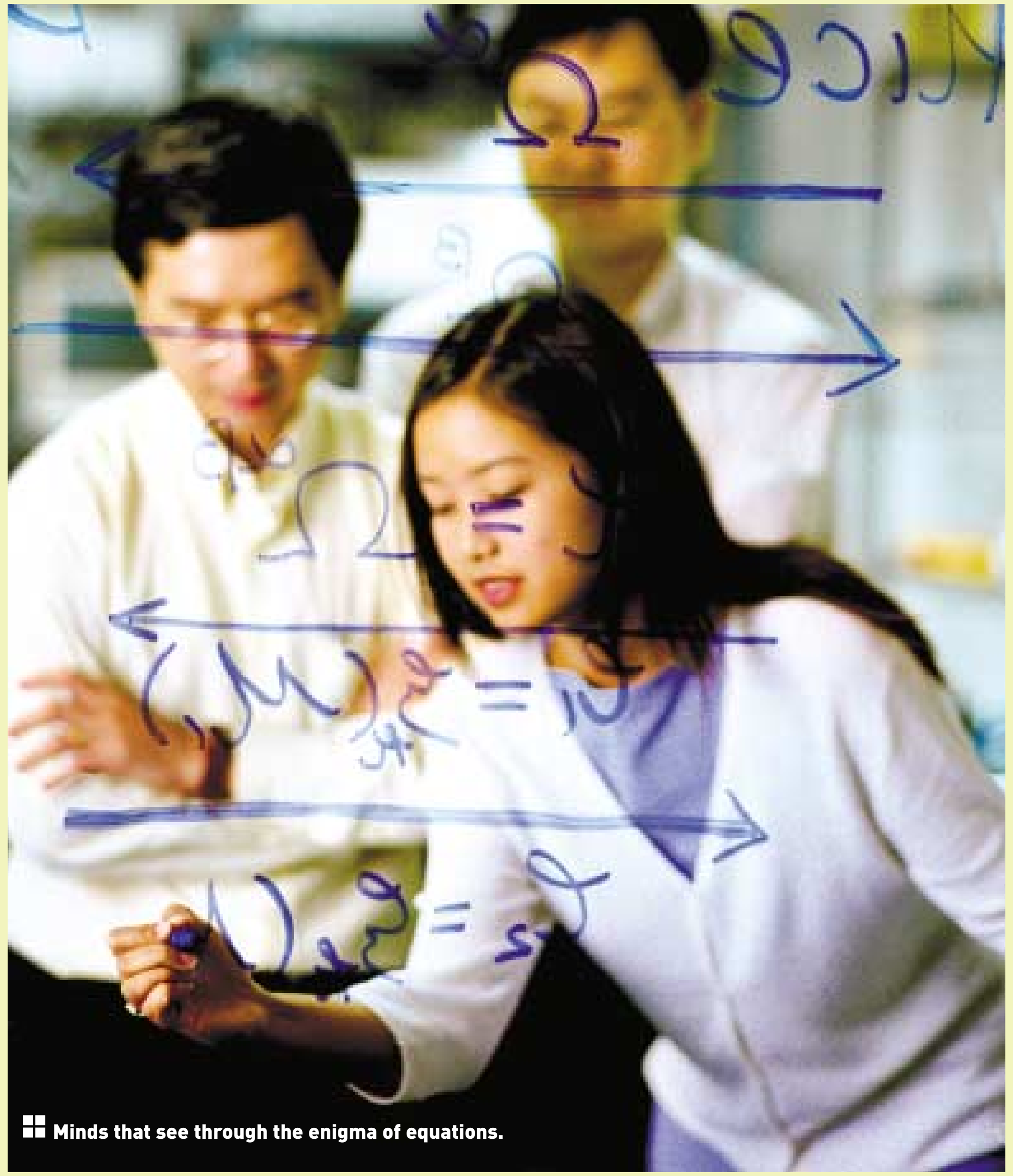
0011

SECURING OUR COMMUNICATIONS

The need to conceal or withhold the meaning of a message from unwelcome eyes came about almost as soon as a method of writing had been devised by a civilisation. The Roman alphabet which is used today in the English language, as well as in many other modern languages, had its origins in the early writing systems of the Phoenicians and other ancient peoples of the Middle East. Such an alphabet can easily be manipulated, by means of procedures known as codes and ciphers, to make the message which it carries unintelligible to a casual viewer. Indeed, one of the oldest means of concealing a message carried by the Roman alphabet is known as a Caesar cipher, after the famous Roman general (and emperor later), Julius Caesar.

Messages can be concealed using two broadly different techniques, known as cryptography and steganography. Steganography attempts to hide the message altogether; one common method has been to shrink the message and put it under something small and unobtrusive, like a period (or full stop) in a printed text. Cryptography does not attempt to hide the existence of the message, but conceals by disguising it in such a way (using codes and ciphers) that it cannot be read without knowledge of the method of disguise. Historically, cryptography (whose name and that of its associated science, cryptology, come from the Greek word "kryptos", meaning "hidden") has been developed over the centuries into a highly sophisticated technology, and has played a major role in the political and military affairs of most of the world's nations.

A message which is to be disguised is known as the plaintext or cleartext; after it has been disguised or encoded into a seemingly unintelligible text by a cipher, the disguised text is known as the ciphertext. The intended recipient will be able to decode the ciphertext to retrieve the plaintext only with knowledge of the ciphering method, as well as a secret password known as the cipherkey. An enemy will have to deduce the method of ciphering and guess the key, to retrieve the message. This process of breaking down a cipher is known as cryptanalysis, and is, as one might expect, a highly mathematical process which is very suitable for attack by computers.



Minds that see through the enigma of equations.

For example, one of the earliest working electronic digital computers – the legendary World War II machine called "Colossus" at the secret British intelligence establishment Bletchley Park – was built in 1943 with 1,500 vacuum tubes, solely for the purpose of breaking a German cipher even more difficult than that generated by the Enigma ciphering machine. Colossus (which legendary computing pioneer Alan Turing had a hand in designing) and similar machines worked on ciphers which operated at the level of the individual alphabetic character. However, as messages came to be stored and processed by computers as binary numbers (which have only "1"s and "0"s as digits), cryptography moved into encoding methods which operated by manipulating the binary digits, or bits, of the message.

Whether at the alphabetic or binary level, most cryptographic algorithms use a secret code known as the key which is needed to encode (or encrypt) and decode (or decrypt) the ciphertext. Symmetric key systems use the same key to encrypt the plaintext into the ciphertext and decrypt it back into the plaintext. Symmetric key systems come in two forms: stream ciphers in which the messages are encrypted character by character (in a continuous stream), and block ciphers, in which the messages are encrypted in blocks of several characters at a time. Examples of stream ciphers are RC4, A5 and PKZIP (well known to PC users) and examples of block ciphers are Lucifer, Data Encryption Standard (DES) and Advanced Encryption Standard (AES).

Symmetric key systems have the advantage of being simple and fast, but their disadvantage is that both the sender and receiver use the same key, which implies that both can decrypt messages encrypted with the same key. If a receiver needs to receive messages from several senders, all of them need to have the key, which implies that the receiver must transmit the key to all the senders. This is a possible weakness in the system, as during the transmission of the key, it might be stolen by an unauthorised person, who would then be able to read all the encrypted messages using the key. Furthermore, the existence of so many senders holding the same key is itself a security problem.

One solution to this problem of multiple copies of the key being held by many senders, is an asymmetric key system, in which the encrypting key is different from the decrypting key. Public key cryptography is an asymmetric key system in which the encrypting key is freely made public to anyone wanting to send secret messages to the receiver, who has a different decrypting key (known only to the receiver) to decode the ciphertexts received. Provided the receiver keeps the decrypting key securely, the public knowledge of the encrypting key will not allow the ciphertexts to be decrypted by anyone other than the receiver. Some examples of public key systems are the Knapsack system, RSA and ECC.

The key is the ultimate potential weakness in a cryptographic system, as even assuming that it has not been stolen, it has to be long and complex enough so it cannot be guessed at. A key which is used only once and then discarded (the so-called "one-time tape") is invulnerable, and if long and complex enough, cannot be guessed at. However, the intended recipient of the message must still receive the one-time key from the sender which lays it open to being stolen by the enemy.

Capability Build Up

During the 1970s, information security was still very much in its infancy and there was little which had been published, if any, in the open literature from which one could gather much. It was a subject developed mainly for military use, unlike today when cryptography is widely used in civilian applications and crypto algorithms and cryptanalytic techniques are freely published in the open literature and available on the Internet. Staff development was thus mainly done through on-the-job training, and the study of what basic literature was available.

Initially, DSO engineers had to start from scratch, teaching themselves about ciphers and their mathematical fundamentals. Efforts were made to keep abreast of leading edge technology by interacting with other crypto experts and users. This gave DSO a head start in mastering the fundamentals of modern cryptology theory. After the block cipher DES and public key systems were made public, a number of conferences on the subject of cryptography were held, which were important means of enabling DSO to keep up with these technologies.

DSO's initial efforts were focused on stream ciphers, which was partly due to the fact that the mathematics behind stream ciphers was more well-established, and that most of the cipher machines in use then employed stream ciphers. DSO also embarked on the study of block ciphers, focusing, like most other groups, on the analysis of the DES system.

Besides MINDEF, other organisations also approached DSO for support in algorithm evaluation and certification, and for advice on security and operational issues. Over the years, DSO's cryptographic capability expanded to the evaluation of a wide range of communications security (COMSEC) algorithms.

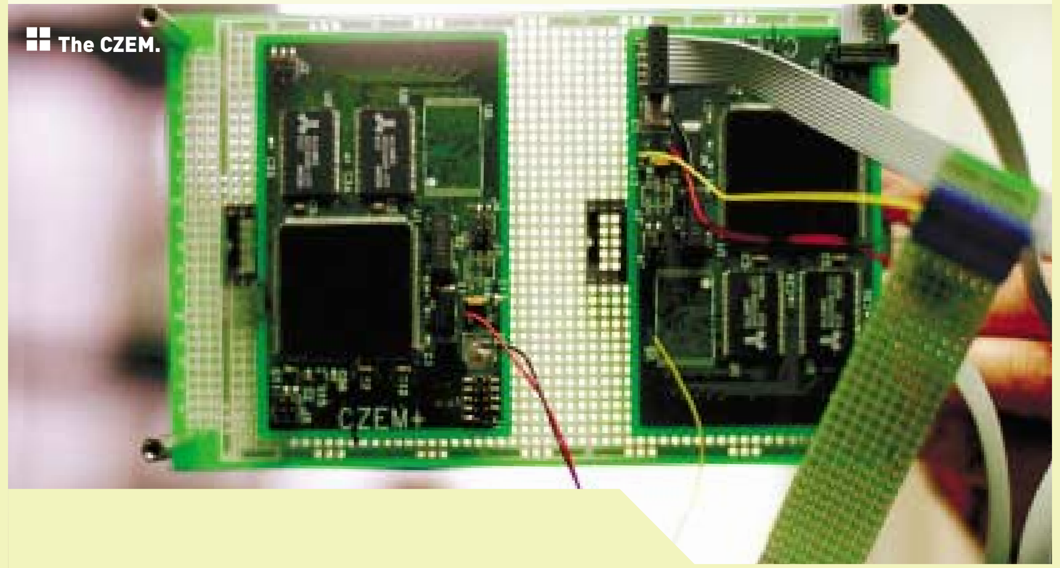
In the 1990s, the experience gained in previous years permitted the further building up of DSO's capability in the design, analysis and implementation of crypto algorithms and systems to a higher level, including the capability to design and implement algorithms for high speed applications, evaluating high-end computing resources and developing more testing tools. Prototypes were also built for the demonstration of special applications, such as a high performance encryption module and a card-sized encryption module.

DSO also embarked in research into advanced areas such as hash function study, elliptic curve cryptography study and its development, secure protocol study, secure token study and random number generation. DSO researchers also benefited from continuing collaboration with the National University of Singapore on selected research topics and courses and seminars by eminent invited cryptologists.

DSO has also been involved in several user projects, both within and outside MINDEF, which have varied from the very small modules to large and complex systems. Some examples are cash cards, hardware encryptors, and Electronic Road Pricing.

PORTABLE ENCRYPTION ENGINES

In June 1998, a research project was initiated to develop a credit card-sized software-configurable cryptographic engine. The card-size encryption module (CZEM) was designed and developed to house DSO's proprietary cipher algorithm and authentication protocol. This development enabled DSO to further explore a customisable CZEM which offered a flexible and reliable security solution for different applications. The prototype was demonstrated at the DSO Technology Showcase in November 1998 and attracted much interest amongst DSO's users, as it had the potential of shrinking shoebox-sized encryptors.



The CZEM.

The Future

There is a growing need in using the Internet and portable communicators such as cellular phones to store data and exchange messages in a secure environment. To meet this need, many security products are now emerging and are widely used in protecting data and messages. At the same time, many cipher algorithms and secure protocols are freely available in the open literature and on the Internet. With the advent of AES, stronger algorithms can easily be obtained from the public domain and the Internet, as a search using a search engine such as Google will reveal quickly.

However, it does not necessarily mean that a really secure system can be easily built and it is generally difficult to find a product that is completely free of security bugs and design flaws. In most commercial products, security is not a high priority during the design phase but is an "add-on". Furthermore, there may not be adequate quality control and security evaluation. Therefore, even if the basic algorithm is strong, it may have been implemented improperly, or manipulated in such a way as to compromise the system.

It has been said that quantum computing, currently the subject of intense research, will herald the ultimate in cryptography. Quantum computing uses the physical laws of quantum mechanics, a branch of physics which deals with the behaviour of particles at the atomic level where the everyday physical laws of our human-sized world do not hold. A quantum computer will be able to work phenomenally faster than the most powerful supercomputers of today, and hence be able to break unknown ciphers by brute computing force much more easily. Perhaps a more important application of quantum computing for cryptography is to transmit a one-time tape from sender to receiver. If done correctly and carefully, quantum methods can enable a key to be delivered such that an attempt to steal the tape can always be detected, and hence thwarted.

These advances and glimpses into the future will spur the cryptographers in DSO to continually enhance and develop its cryptographic capability so as to provide better methods and technologies for even more secure communication.

1980 –

1986

BUILDING CONFIDENCE

CHAPTER 0010

"The first time we had a consultant in," related Ho Ching of her DSO years, "he told us everything, and we dutifully copied it down, like students.

Then, the next time he came, our people started arguing with him. OK, we're making progress.

And the third time he came, our guys began to tell him that he was wrong! And I thought: Good! We made it!"

During Ho Ching's DSO years, DSO was transformed from the uncertainty of a student to the confidence of someone who has "learned by doing."

The uncertainty began in 1980, when the Head of DSO, Dr Tay Eng Soon, left DSO to enter politics.

His sudden departure left a vacuum at DSO. Many of the pioneers and senior staff members were away. Tham Choon Tat became the Assistant Director in 1980 and rose to become Director in 1981. Only in 1983, did Ho Ching and Su Guaning return, to join Choon Tat as Deputy Directors of DSO.

In their absence, Philip Yeo, the then-Permanent Secretary of MINDEF and Chairman of DSO's Executive Committee, and one of Dr Goh's most trusted and capable discoveries, assumed personal charge of the organisation.

Philip Yeo has a special gift for creating and managing technology organisations. He saw DSO as doing too much with too little resources. Under his watch, DSO refocused on a few core areas.

For, in accordance with his unique philosophy – *Management by Submarine* – any successful organisation has a single concentration and forsakes all others.

Having decided upon the target, the energetic leader brought new resources to DSO. One thousand engineers were recruited for MINDEF, out of which DSO netted the most, the best and the brightest. No justifiable request for funds or facilities was refused. DSO enjoyed his powerful financial backing for its projects. Even some controversial requests, such as a new HQ building at Science Park, and Ho Ching's million-dollar computer, were approved.

In 1983, DSO adopted a higher profile to recruit engineers and scientists from the universities. Its numbers doubled, giving DSO adequate manpower to staff its projects and begin new project teams.

Although DSO was growing, there was little co-ordination between the SAF's technology needs and DSO's R&D output. DSO remained a mystery to the SAF. This remained the case through to the end of 1986, when the Defence Technology Group was formed.

In this period, 1980 to 1986, DSO underwent a major transformation. With each successive year, DSO steadied in leadership, crystallised in focus, and received steady infusions of funds and manpower.

And through the painful, slow process of "learning by doing", DSO acquired skills, capability and confidence.

And at the end of the era, it became more closely integrated with the SAF.

HO CHING

A President's Scholar, Ho Ching joined MINDEF after graduating from the University of Singapore with First Class Honours in Electrical Engineering. Her first posting was at the Systems Integration and Management Team (SIMT), which was merged with ETC in 1977 to form the Defence Science Organisation (DSO). She went to Stanford University for her Masters of Science degree in 1980, returning in 1983 to assume the post of Deputy Director of DSO and Director of Defence Materiel Organisation (DMO) in 1986. From 1987, she joined Singapore Technologies (ST) as Deputy Director of Engineering, and held the post of President and CEO of ST before leaving in 2001. She is currently Executive Director of Temasek Holdings Pte Ltd.

Did you know Dr Tay Eng Soon before you joined DSO?

Yes, he was my University lecturer. He was famous for being very generous with grades, so everybody liked his course.

As a boss, what was his style?

He was like a friend – a friend and a mentor. It was a very easy relationship. It wasn't a hierarchical relationship. He's not an administrative sort of boss.

He enjoyed the technology, enjoyed talking about technology, so you could always engage him in discussion.

I remember you had to keep away from his office because he was smoking pipes – and the guys who were in the office around him had to suffer the smoke!

I think he was trying to break his smoking habit, by smoking pipes.

Do you remember any stories about Dr Tay?

I remember that in those days, in SIMT and then in DSO, we were very poor, very frugal.

When we travelled to London, we went to a hotel. Dr Tay looked at the price and said, "Too expensive". So we took our luggage and we walked out into the street, looking for a cheaper place!

Budgets were tight....

Oh yes, especially in those early days! I remember sleeping in a place where you could smell the gas at night, because they had got the heaters on. I cannot remember where the hotel was. All I remember was us trundling our suitcases in the cold, you know, how you pull a suitcase along? And looking around for a place close to the Tube station.

What projects did you do?

At SIMT, we were having fun, playing with things. Some chaps were running around, doing the MGBs (Missile Gun Boats). I was trying to digitise some artillery training radar, replacing all those valves with some microprocessors and digital systems.

We were trying to understand how that radar worked, which were the parts we could cut out and replace with a little box, which was like a computer, a digital system for display.

We could then also use that to inject artificial signals for training, so that we didn't need actual artillery firing to train soldiers to use the radar system. That was my first project.

There were several such projects – all very fun for engineers.

What was DSO like in the early days, before you left for Stanford in 1980? Was it lacking in directions?

I remember it as a place where there were a lot of discussions and exchanges on many subjects. It was a lot of fun! I don't remember DSO as lacking direction.

But DSO had a lot of sensitive projects, so there was a sense of compartmentalisation then. That was part and parcel of work. That can happen anywhere.

Did Dr Tay face any criticism for not putting the resources DSO had to good use?

Clearly, there were pockets of people who did not know what we were doing and thought it was a waste, that sort of thing. And they could do better elsewhere, and all that.

But this was quite normal, given that DSO was not to publicise its work. We were all not supposed to be talking about our work to anyone.

But I remember when I was in DSO, we were very conscious about having to add value. At least I was very conscious of having to make sure that whatever we did, added value.

Because you do a quick calculation. There are only so many engineers graduating from the university. If you take "x" number of engineers, it's like, "Hey, you're taking ten percent of the graduating cohort!"

And that to me is a huge cost to the country. You have to make use of these engineers in a very productive and a value-added way.

> "We had a consultant. The first time, the consultant told us everything, we dutifully copied it down, like students. The next time he came, our people started arguing with him. By the third time, our guys began to tell him that he was wrong. That they had another solution. And I thought: Good, we made it!"

So we were very conscious of putting our efforts to where it would count, where it would provide a force multiplier effect.

This was something which we debated among ourselves as colleagues.

But that is very much part and parcel of looking at the world, and saying, "You know, I ought to be doing something useful."

Because if you are not doing something useful, you might as well go and do something else more useful somewhere else.

Some people contrast Dr Tay's and Philip Yeo's styles of management. Dr Tay is very hands-on. But Philip, by contrast, leaves them alone.

Maybe that's Philip learning from Dr Goh. That's Dr Goh's style. He found capable people and left them alone.

The major thing I remember about Philip – I was trying to persuade him that we needed a major computer system that would allow us to do simulation of complex systems. This was a hybrid computer.

You see, I was very passionate about a particular large-scale DSO project. We needed this computer system for part of the development.

I remember I was trying to get this hybrid computer system, because it was relatively cheap compared to other systems.

But even "relatively cheap" was like one million dollars. And for this amount of money, you had to write papers, up and down, up and down, ... and we were getting very frustrated.

Then Philip called me up, and asked, "Do you really need this system?" I said, "Yes, otherwise, you can't do this or that, blah, blah, blah, ..."

Then he said something like, "OK. But my head is on the chopping block."

And at that time, even for MINDEF to consider buying a computer system, we had got to go all the way to the Ministry of Finance. Buying a computer system was such a big decision!

So the way MINDEF got around this was to call it, not a computer, but a calculating machine!

And that's probably how we got the system. That was part of the early history behind some of the capabilities you see today in DSO's development.

So I remember Philip more in that light. If there was a problem, it's less of papers going up and down. He'd call you up and talk to you. Then, I guess he would make his decision, based on what you told him, and his assessment of you – whether you could deliver or not.

And the other thing which I remember of those days, which I was very happy with, was this system we were trying to develop, but new to all of us. And so we got this textbook that we all hung on to, for dear life! Dr Tay was reading the same textbook as us.

We also had a consultant – an experienced man, and later a very good friend. The first time, the consultant told us everything, we dutifully copied it down, like students.

Then, the next time he came, our people started arguing with him, "No, no, this way, that way." OK, we were making progress.

By the third time, our guys began to tell him that he was wrong. That they had another solution.

And I thought, "Good, we made it!" I remember that very distinctly. That was an enormous pleasure.

It meant that the guys had learnt, had internalised and had begun to make their own independent judgement to think and to create solutions. I remember this feeling, even up till today.

You know, there's this feeling in Singapore that we don't have the technology, nor the capability. We can only import from overseas.

One of the very strong beliefs I have is that we have the people, we have the capability or at least, we have the potential for that capability.

I've seen what our people have done in DSO, MINDEF and the SAF, and it's like, hey, if you ask me today, "Can we build an aeroplane?" I'd say, "Sure! Not a problem!"

I mean, if we decide to build, or not to build an aeroplane – it is an economic, market demand decision. Do we need 500 aeroplanes? No? Then OK, let's not build aeroplanes. This is the market test.

But you know, it is not technology or a technical impediment per se. Because I am confident that we have the people and the capability, if the demand is there.

And this confidence comes from having people who have actually gone through the technology development cycle, who actually developed working systems, putting together complex working parts.

They have gone through all the pain, gone through ups and downs, and delivered systems that work. And they work pretty well, you know!

And DSO is one place where you had the opportunity to develop things yourself......

Yes, DSO was a place where we had the confidence in ourselves to try, to dare and to do new things ourselves.

Yes, we brought in people as consultants and we learned from them. But it's always a growing, learning relationship.

You are a pupil, but after a while, if you have capability, you're an equal. Or you could even be the master of your trade, your speciality.

And it is this learning which, I think, is important. "Learning by doing". It's a big plus for us.

I would get very frustrated when people started thinking that we couldn't do it, and we have to call in a consultant." I'd say, "We can do it! You want us to build technology, to build aeroplanes, or whatever? OK! We can do it! That is the challenge, and that is the fun."

Do you think that Singapore has gained in capability from having a place like DSO? Because DSO is a "learning by doing" organisation. And once you go through the experience of doing things, you gain confidence...

Yes, yes. Why is it that you can argue with the consultant? Because you are not reading from the textbook. You have actually done it, you have gone through the scenarios, the processes, you've made mistakes, you have finally succeeded.

And from there, you say, "Ah, I can do it."

You get this confidence, and this is the most important thing.

Now, if you have not done it yourself, you will never have that kind of confidence.

In Singapore, we tend to lack confidence. If things are invented by a foreigner, that means they're good. If they are invented here, in Singapore, they can't be good.

The assumption is that we don't have the law of large numbers with us – we only have a small population, so how can we have a Bill Gates?

But Bill Gates was one guy from a small town, so how much law of large numbers has that little town? Ideas do not depend on the law of large numbers – the betting average may be the same in percentage terms.

Anyone from Singapore could just as well be one out of the 6 billion on this planet – the law of large numbers in that sense, no?

Sometimes, we can see issues and say it ourselves, but others who have not the knowledge or experience to judge, won't believe you. If you get a consultant, a foreigner, to come in and say exactly the same thing, everybody thinks, "What a great idea!"

But that is a mental crutch.

So there's a frustration that Singaporeans can actually do things, but are not taken seriously because they are local... rather than foreign?

It's not so much a local versus foreign issue. It is a question of whether we have the confidence to judge, and that comes from knowledge, experience and courage.

DSO as an organisation must have the confidence to say, "We can do it." DSO has spent 30 years, "learning by doing."

And when we interacted with other ministries, even in the early days, we had this sense, "Hey, we've done these things before, you know. And it's very simple."

You don't have to go and spend a lot of money for consultants from abroad. Go and see what DSO has done, what the Navy, the Airforce and the Army have. See what MINDEF has achieved. Then you'll have confidence that our people can do it.

Otherwise, you go to the vendors, you will be listening to their big and sweet stories – and you are impressed. But you don't know that, actually, in your own backyard, you've got something as complex and sophisticated as DSO. And it's live, it's working.

So DSO has been "learning by doing", and our people now have the confidence that they can do it. But partly because of secrecy or compartmentalisation, or maybe ignorance, our other agencies just don't know. They don't know that right here in Singapore, you've got people who can develop much more complex systems.

And DSO has built systems up from scratch, "learning by doing". That makes a difference in outlook.

How do you manage people and nurture an organisation like DSO so that they will have this confidence?

You've got no choice. Just let them do it. Give them the opportunity to "learn by doing". There's no other way.

You know, you can read all the books, but if you don't do it, you won't have the confidence.

And you won't understand that there are little tweaks that are slightly different from what the textbook says. You won't feel where the trade-offs are.

So you've got to do it.

Will they make mistakes?

If there is an overall goal or mission, you trust that your people will do their best. Then, you let them go.

Not just scientists! I think it's the same with anyone.

With your cleaners, with your office attendants, with your *amahs* in hospitals.

You've got to trust them that they can do it.

"DSO was a place where we had the confidence in ourselves to try, to dare and to do new things ourselves. "Learning by doing". It's a big plus for us."

They can add value. You've got to just respect each individual for who they are, what they can do. And let them do it.

Yes, they'll make mistakes. But that is part of learning.

You check and you stand back, and sometimes you have to hold yourself back from interfering, so that the chaps can gain the experience of doing it themselves.

You just make sure that the mistakes won't sink the ship, and you take out those who cannot learn from their mistakes.

And you stand ready to fish them out before the mistakes get too big. Check them out, patch them up and set them off running whole again.

There's no unique way of managing a scientific institute like DSO, as opposed to a company or industry?

I think DSO is an "applied science" institute, rather than a pure basic research institute.

We're very focused in trying to solve a problem, or deliver a solution, or get to a specific end-point. You get your money with the specific objective in mind, or a specific capability in mind.

If you're in a basic research institute, then there's what we call "blue-sky" science. It's blue sky – you can do anything you want, within certain bounds. It is a journey of discovery and you don't know what you will discover. You check this out, OK, this one doesn't work, you check out another line of thought. So the target is far more amorphous.

In a construction company or a factory, it's very, very clear. It's like – "I want this factory up in 14 months, and first wafer out 3 months later." Everybody just works towards that. It's very, very targeted.

But that's only the first step. Because if you want to do business, construction, science, or whatever, you must at some point begin to add value in terms of knowledge.

Whether it's materials, whether it's shorter processes, stronger concrete – you must add value, deliver a better product, or lower the costs. You do this by using your brains, by using science or engineering or some knowledge you have.

If you don't, then you're just a mere coolie. And you reach a point where you need to go to the next stage – and you cannot. Because you are like the slaves being driven by the Pharoah.

The next stage has to be when these guys, these builders, begin to understand, "I'm building this, this is my project, maybe I can find a better way." And they begin to figure things out – and that is when they use their brains, science and knowledge. And they add value, they take ownership.

And you know, this is the stage where they become enthusiastic! Getting people to be enthusiastic, whether it is a scientist or a cleaning lady, is critical. Then they will have trust, respect and confidence in themselves.

So how to manage? You give respect, confidence and support. "Can do, no?" you say. Sort of challenge them to try. But when there's trouble, you've got to support.

Sometimes, you grit your teeth, but you give support to get through the bad patch.

When you feel like "Arrrrgghhh" and you are about to say, "Stop!", sit back and wait. You must be capable of that! You must wait for them to make that mistake, to incur that cost, to swing across the chasm themselves.

Just take a general manager. He wants to invest in a project. You think it's wrong, you don't agree with that judgement. But you could be wrong.

So if you let him go, if he's right, fine. He has gained the confidence of success, and you've just been proven wrong. No problem there, you learned something new yourself!

But if he's wrong, and you're right – by him making that mistake, he will remember that mistake more than any amount of lecturing!

And he will have the lesson in mind when he goes to the next investment. This is experience and

"You can read all the books, but if you don't do it, you won't have the confidence."

confidence, that comes from "learning by doing" and "learning from failures."

Like learning to ride a bicycle by falling down – you get the sense of balance quickly.

Then you don't need to have a system to micro-control, to supervise this guy. Because he has become a self-motivating, self-driven and self-learning engine.

Leadership, whether managing scientists or individuals, is how we create an environment where everybody becomes a self-driven engine.

All you need to let them know is their mission and their focus. They know there is a goal-post there. They can run this way, or that way, but everybody knows where to score.

And you sit back and let them play. You have to be careful about when you should step in. Sometimes, you just have to hold it, keep your mouth shut and let them play on.

People won't go far wrong....

Not if you have an overall mission.

You must have an overall mission. Then, the only things you need from the guy – he must be capable, he must have the confidence and the competence, and he must have integrity and the commitment.

I mean, without integrity, he'll skive all the way, and you get nothing! Right?

Without the commitment and competence, every project, whether it's a business, research or building, is bound to run into trouble.

These are values, right? Integrity and commitment are values. The determination to get over problems, find a better solution – that's important.

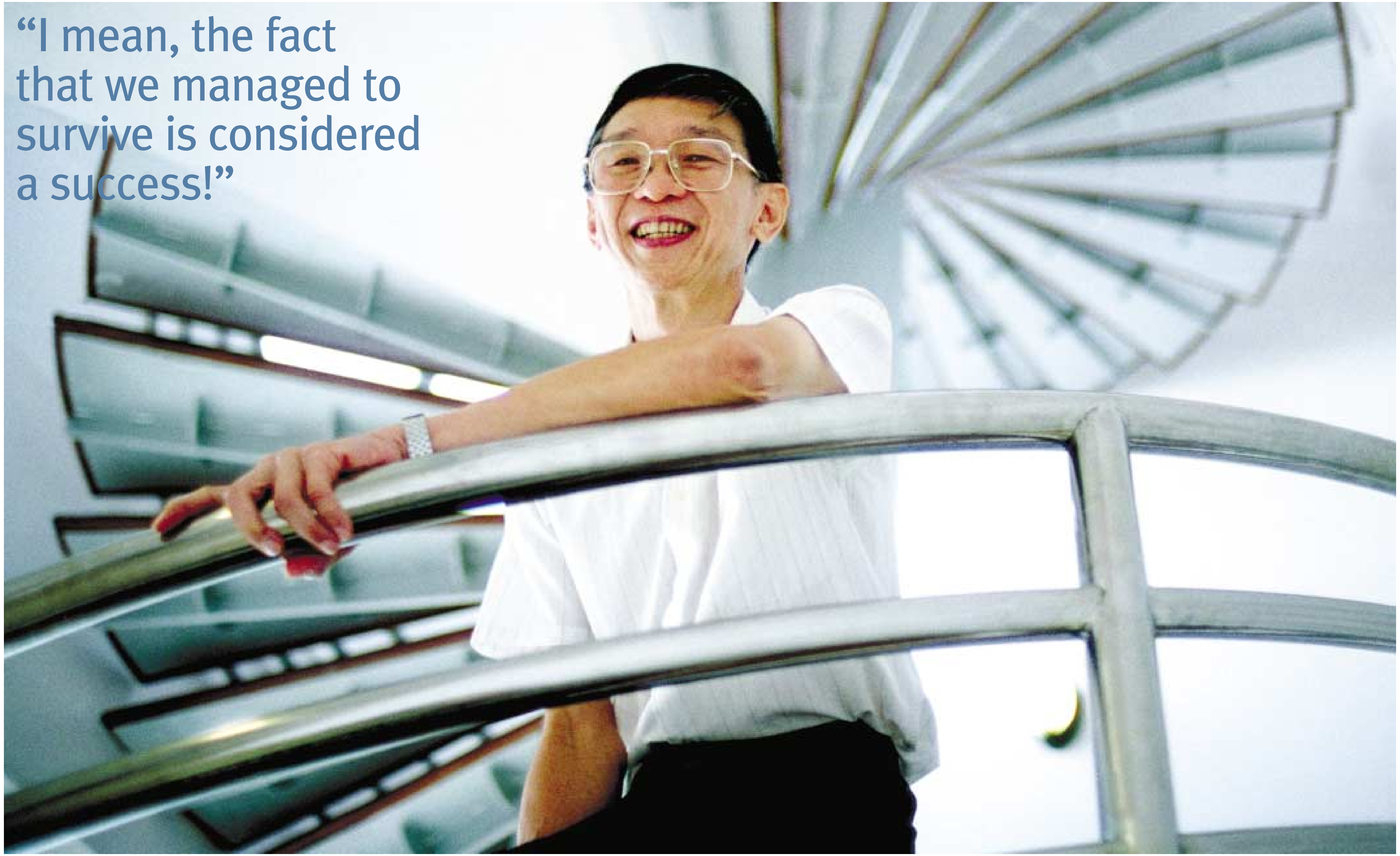
These things, you cannot dictate. It has to be there, in the person's make-up.

Was there something you learned from your days in DSO that you cherish?

I suppose many, many things. You made mistakes, you had friendships, you had troubles, you had successes, many things.

I think the biggest value from DSO was the confidence we gained – the confidence that "we can do it". The confidence we built up, "learning by doing."

“I mean, the fact that we managed to survive is considered a success!”



THAM CHOON TAT

Tham Choon Tat joined the fledgling group of young engineers in ETC in 1973. He had just completed his studies in engineering at the University of Adelaide, on Colombo Plan scholarship. He was the sixth member of staff of ETC, and began his career at Onraet Road. In 1980, he became Assistant Director of DSO and rose to become the Director in 1981. He left DSO in 1986 to join Chartered Industries of Singapore.

In 1980, Dr Tay Eng Soon left DSO to become a politician. You were left to run the show. Was it a surprise to you that Dr Tay left?

Quite a surprise. We didn't hear anything about it outside. One day, he just told us he was going.

After Dr Tay left, Philip Yeo took over the organisation. He was Chairman, EXCO. Did he give you any brief about your role as Director?

What do you mean brief? Philip Yeo was not one to give you a brief! He just said, "Go and look after these things!"

So he just told you "Look after DSO." How many people did you have in DSO at that time, in 1980?

Only about one hundred or so, including people from Systems Integration and Management Team (SIMT). Not all were engineers – this included a lot of support people. There were three labs.

Many people were away!

Yes, Su Guaning was away. Ho Ching left later, I think.

Under Philip Yeo, we had a big push to give scholarships and that's why so many people left around that time.

If the organisation was so compartmentalised during Dr Tay's time, then if you removed Dr Tay, how did you co-ordinate everyone's projects?

By that time, each of the groups could run their own projects. Also projects did not cross inter-departmental boundaries.

Were there many projects in 1980?

In 1980, there were already major projects for the Army, Navy and Air Force.

The atmosphere in DSO, in Marina Hill seems very informal...

Yes...it's quite informal and less bureaucratic than other government organisations. There was more freedom for people to get on with their work.

Some of the projects that we did involved a large number of people in a wide range of technologies. It was not possible for a single person to cover everything and most projects required expertise in specialised areas. Since even the project leaders were relatively new, they needed to trust people in their work.

What was the EXCO's role?

Most of the time, EXCO was very supportive. They set out general directions and provided funds from MINDEF for our projects. Senior members of the Armed Forces were in the EXCO and this facilitated co-ordination between DSO and the SAF.

When Dr Tay left, we did not realise that DSO's work covered such a lot of areas. It was only after that, under Philip Yeo, that we had a better understanding of the work involved. We knew then that we couldn't do everything, so we started to focus on the more important areas.

Was it good that you focused?

Yes. Otherwise, we would be going around, trying to do everything and in the end, achieving nothing.

Under Philip Yeo, did the EXCO change in its management style?

Oh it changed! I mean, before, they had a Steering Committee, chaired by the Defence Minister who was Dr Goh. Then when Dr Goh left MINDEF in 1979, the next Defence Minister who was Howe Yoon Chong – he was less involved. After a while, the Steering Committee disappeared.

So then we had EXCO and Philip Yeo was the Chairman.

Philip Yeo was the Permanent Secretary by then?

I think he was already PS. The Deputy Secretary, I think, was Lim Ming Seong. Then, in EXCO, there were some Services reps, like DS (Airforce), DS (Navy) and DS (Army).

Was Philip Yeo the same type of manager as Dr Tay?

No! He was different! Completely different. I mean, Dr Tay ran things in detail. He practically did the project for you. Philip Yeo – he was more open. He'd let you decide on things and you would just report to him every now and then, to tell him what's happening.

> "When you're small, you tend to group all the specialists together because they can learn from each other. When you get to a certain size, even if you split them, they can still learn within their own smaller group."

How often did he check on you?

We supplied monthly reports of DSO activities and projects to him but we did not have regular meetings. He would call up whenever he had a query, and I contacted him when there were issues to be sorted out. His office was very open.

EXCO meetings were also not regular. It was convened whenever the Services or DSO put up project or financial papers to EXCO for decision or approval.

Initially, there were few procedures for project approvals but as we went on, the procedures became more structured and formal.

You were alone!

Most of the top level guys were away, and then, there were people who went and never came back.

It was about 1983 before they all came back. Then I went for about eight, nine months in 1983. Ho Ching covered as Deputy Director. Then Su Guaning came back and there were two Deputy Directors.

When Ho Ching and Su Guaning were Deputy Directors, and concurrently in DMO, did that create any confusion or conflict of opinions?

DSO and the Defence Materiel Organisation (DMO) were building up at that time, and there were areas which were beginning to overlap. There were questions as to whether DSO should be doing acquisition work or whether DMO should develop some R&D capability. There was a need to define more clearly, the boundaries, the work and expertise to be developed in both organisations. Also DMO had mainly been involved in mechanical type projects but electronics was playing an important role in defence systems.

Their presence in DMO and DSO helped in clarifying the roles of both organisations. Conflicts and confusion arose when engineers in DSO were at times asked to help out in DMO projects.

These problems arose not only between DSO and DMO. DSO and the Systems and Computer Organisation (SCO) also had an overlap in some software areas.

Within DSO, we faced the same problems that occurred at the organisational level.

When you're small, you tend to group all the specialists together because they can learn from each other. When you get to a certain size, even if you split them, they can still learn within their own smaller group. But by splitting them, they are nearer to the end-product. So we had to decide between working on a matrix organisation or to let the expertise develop organically within each division.

Did your numbers go up quite a lot around 1983, '84?

Yes. Our numbers went up quite a bit. We were quite actively involved in recruitment exercises with the other MINDEF organisations.

Was this particular recruitment more successful?

Oh, yes, it was. Because it was more open. We went directly to the universities. And we targeted at the students before they graduated. We made them offers. And then found ways to keep them, to recruit them in – before the other parties made them other offers!

Did DSO have difficulty digesting the rapid growth in numbers in 1983 and the years after that?

No, I don't think we had any problem.

Did the senior officers spend a lot of time training?

I mean not directly training, but getting the new engineers to work in projects and trying to make use of them. I suppose it was also tough for those senior engineers, because you got raw engineers in your projects, which was not so productive.

But by the '80s, we had our in-house projects and acquisition projects. So when the new people came in, there were a few project leaders to guide them.

Like, if he was doing circuit design, you've got to give him the time to learn, before he can come up with the circuit you want. With acquisition projects, it was not so much of a problem, because the technical content is not so great. We could also send engineers to the vendor's place for training.

Did the EXCO feel that in-house projects were not as valuable to MINDEF and SAF, than acquisition and maintenance projects?

Not as a whole, though individual EXCO members might prioritise projects differently. Since EXCO approved the work for major projects, they would have considered them to be useful to MINDEF or that it would lead to capabilities that would in future, be useful.

We had to develop capability in anticipation of future needs. During the years, we changed our emphasis. Earlier on, we concentrated on building and developing entire systems. Later on, we decided that it was more important to learn how to use the systems intelligently and to improve them.

In 1986, when the Defence Technology Group (DTG) was formed, did DSO undergo much change as the result?

Yes, Teo Ming Kian was probably the first one, at least formally, to become responsible for technology in the whole of MINDEF, including SAF and industries. That's when DTG was formed. So all the technological arms came under one head, I mean structurally. Previously, they didn't have a single person.

Why was there a need to form DTG? Was it that there was insufficient interaction between DSO and the SAF?

DTG helped to define the position and role of DSO within MINDEF. With DTG, the SAF had a one-stop organisation that provided it with technical support. The SAF did not have to deal separately with each of the DTG entities.

Prior to the formation of DTG, few people in the SAF knew about DSO. In the EW area, secrecy wasn't only in DSO but also in the SAF too.

The people operating and maintaining these equipment were kept separate from the rest of the SAF. The guys in the Navy didn't know what was onboard the ships except for a selected few.

> "Earlier on, we concentrated on building and developing entire systems. Later on, we decided that it was more important to learn how to use the systems intelligently and to improve them."

When we put EW into the aircraft, the pilots were not told of their functions. This created many operational problems.

When EW in MINDEF and DSO became more open, the SAF would interact with DSO from the very beginning of each project. There was more synergy and co-ordination. I think that was important.

I mean, by then, SAF had people who could talk and put forward their requirements to DSO and discuss with DSO, from the very start.

What was the role of the Chief Defence Scientist, Professor Lui Pao Chuen? Did this new post in MINDEF further integrate technology into the Armed Forces?

Professor Lui was involved quite early in DSO, when he was Director of Special Projects Organisation (SPO). He was an EXCO member, so he was part of DSO.

But you know, between us, we were working together, but we were also fighting. Because when SPO was building up, they were also looking for engineers and they tried to poach from DSO! And we were competing during the recruitment exercises. All the organisations were looking for engineers. Everybody, not just us.

During the '80s, everyone was growing and there was shortage, especially of technical people. And actually DSO had the largest number of technical people. I mean, DSO had engineers who knew hardware and had hands-on engineering experience. And when SPO was building up, they really needed that kind of people.

Do you think that the secrecy, the compartmentalisation, in DSO had stopped or slowed down the progress of the organisation?

In the initial years, in the '70s – not very much. Because we hardly really knew what we were doing, or where we were going. There was even less knowledge in the rest of MINDEF, so it didn't make much difference to us.

During your time, was there any move to open up, to be not so secretive?

Well, we opened up with our first open recruitment effort, around 1983, when we recruited a lot of engineers. We also started working with the industry. There were a couple of facilities that we built up with local industry, like environmental test and electromagnetic interference (EMI) measurement facilities. We used Singapore Technologies in some of our projects and we helped them develop some capability, like the shelter integration. We also went out and talked with other organisations overseas.

At some point, DSO became too big for Marina Hill. And then in 1989, DSO moved into Science Park.

I was involved with starting the Science Park building. We were looking for a place for a purpose-built building to suit DSO. Marina Hill ran out of capacity years ago and we had offices in Ayer Rajah Crescent. We were looking at various places. Somebody suggested Gombak but we didn't really want to go to Gombak because it was too near MINDEF HQ! So we did some EMI measurement and said, "No way, it's going to affect our systems, so we can't go there."

And then this land in Science Park wasn't selling so well, so they offered it to us. We took it. And then we started the building. Actually at that time, we had a hard time justifying it!

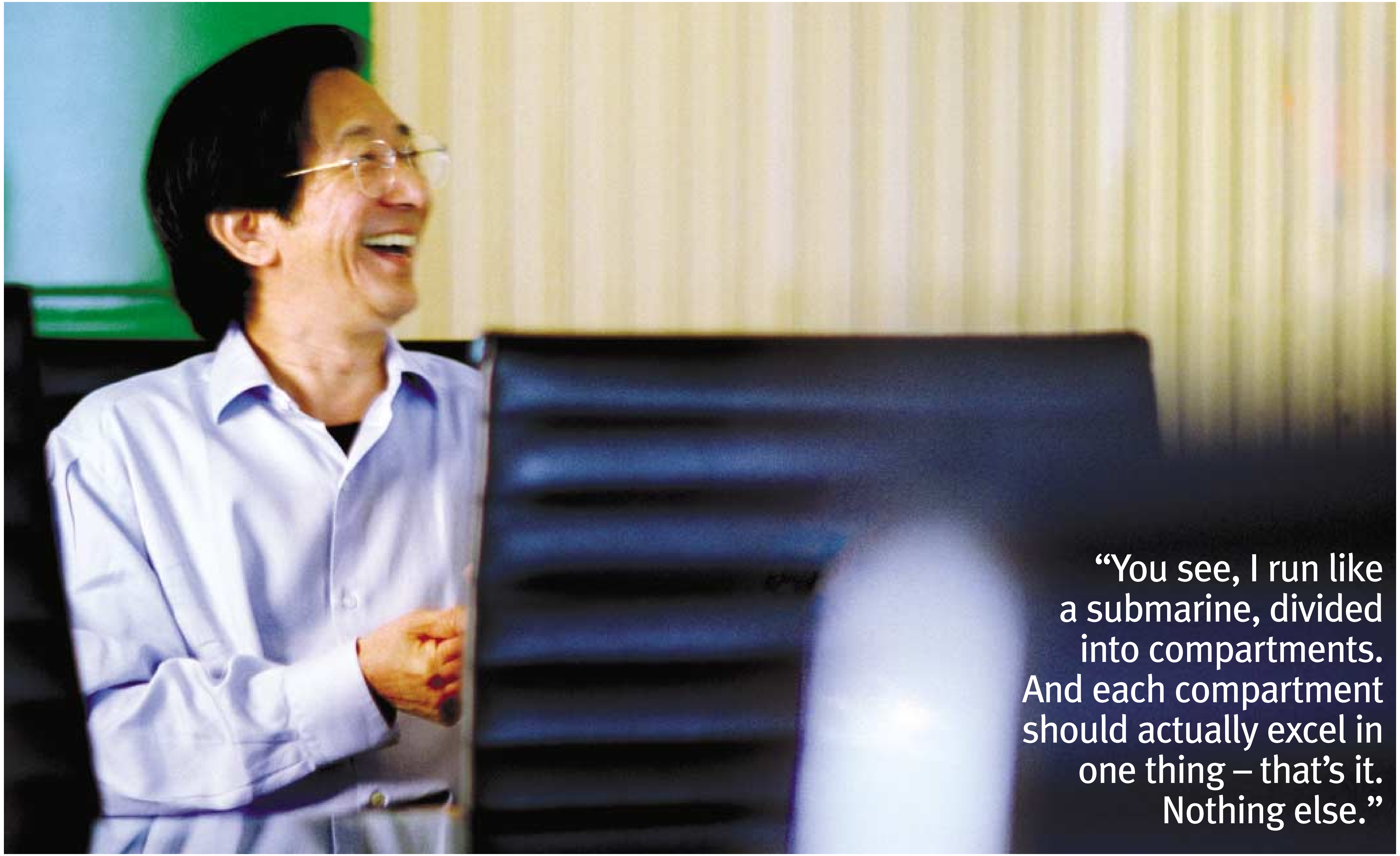
We initiated the project under Philip Yeo. And when we wanted to build it, it was under Lim Siong Guan. Chan Kwong Lok was the guy who actually had to put up the papers, and he had to find ways to justify building this complex!

So you were in ETC and DSO from 1973 to '86, thirteen years, out of which, for six years you were Director of DSO. Do you feel the organisation was a success?

I mean, the fact that we managed to survive, is considered a success!

I think what you can also consider successful, is that we managed to work and co-ordinate better with other parts of MINDEF, and get a better idea of what and where we were heading, and to define DSO's role at that time.

And we managed to get some involvement in the defence industry and build up some capabilities which are still useful now.



PHILIP YEO

Born in Singapore in 1946, Philip Yeo went to the University of Toronto on Colombo Plan Scholarship and Harvard University on a Fulbright Scholarship. He joined the Administrative Service in 1970 and became Permanent Secretary, MINDEF in 1979, and Chairman of the DSO Executive Committee (EXCO) that same year. Amongst his many posts in the course of a brilliant public service career, he served as Chairman of many companies, including Chartered Industries Singapore (CIS), Singapore Shipbuilding and Engineering (SSE), Singapore Technologies Industrial Corporation (STIC), and Pidemco Land, and Executive Chairman of SembCorp Industries Ltd and also as first Chairman of the National Computer Board. He is now the Chairman of Agency for Science, Technology and Research (A*Star), and Co-Chairman of the Economic Development Board (EDB).

How did you get involved?

When I came back from Harvard in 1976, I remember ETC was becoming DSO. That time, I was Director of Logistics, then I was Deputy Secretary in 1978 and Permanent Secretary the following year in September.

Because Dr Goh called me in to supervise DSO. Tay Eng Soon always had a direct link to Dr Goh. Direct, straight to the Minister. So there was nobody supervising Eng Soon. He was on his own, all this while.

I supervised DSO as Chairman of the EXCO until I left MINDEF in 1985. Long time! One of the longest I spent anywhere, you know!

What did you do?

You see, I run like a submarine, divided into compartments. And each compartment should actually excel in one thing – that's it. Nothing else. So I think of everything in compartments. And for each compartment, I have a good manager. That's how I run things.

See, if you want to build an organisation, you must be very clear about what you want to do.

If you are not clear, you'll never get anywhere!

In fact, in the original paper by Eng Soon, still in my file, he wanted to do everything! Like EW, armament, tanks, everything!

So I said, "No, no, no. You better concentrate. Focus. Electronic warfare (EW), you have a big bunch already built up, OK? So that's one. And one or two areas. OK! Enough!"

The rest, I am not interested, don't get involved. Not your compartment!

Like a submarine, you see?

Is this "Management by Submarine"?

My thinking is simple. I don't want Tay Eng Soon to end up doing exotic science that is of no relevance to the SAF. Let's say if you want to do astronomy – no, I'm not interested in that. Underwater diving, I'm not interested!

And I said, "Eng Soon, please don't get distracted. You want to do this, do this. The rest, you don't do. That's it."

Also, no production. DSO is R&D, not production. I did not want DSO to go into production. So anything developed by DSO – *whoosh* – get it out. For example, Eng Soon wanted to make radio sets. I said, "You are crazy, huh?"

See, I have industrial background. So I can see, "Look, this can be done, that cannot be done." For example, this guy wanted to make an artillery computer. Silly idea. I said, "Forget it."

There is a difference between the guy who develops and the guy who produces. And so I said, "DSO should never go into production." Never, never. The day you go into production, you will have a different orientation.

You cannot be a thinker and tinkerer. Very different. The guy who thinks and the guy who produces things are very different in mentality.

So DSO was concentrating on research and development. All production, I said,"sub-contract out." That's it.

Don't duplicate the defence industry. Because in Chartered Industries (CIS), they are making a lot of guns and bullets. For electronics, I created Chartered Electronics (CEI).

How did you put these rules on Eng Soon without killing his enthusiasm?

Easy! I just said, "This one, forget. That one, forget." That's it, very easy!

Focus. I always believe in focus. I want to do certain things, I do certain things. The rest I'm not interested. Meanwhile, you don't distract me.

That's your management theory?

Yes. I believe, once I focus, I'll make it.

Give me three, four years, I'll be there. By hook or by crook.

But first, I need focus. That's the key. Once I decide on my focus, I put in all my energy and I get it done. I need not be an expert but I'll accumulate enough knowledge, find enough people, and get the job done.

So once I did this, DSO was on track.

Then I sat back and said, "OK, all these compartments work well, the whole machinery runs!"

> "Focus is the key. Every time there is a new focus, I create a new company! Because I don't want this present bunch to be distracted. So it is like yeast, budding."

Did it work?

After that, it was easy for Eng Soon. After I took over, Eng Soon and I, we moved very fast.

And what Eng Soon wanted, he got, right? He wanted supercomputing, he wanted this or that, everything he got. The only thing I never agreed to was the wind tunnel. Because I have seen how wind tunnels are always under-used. You spend a lot of money, what do you do with it? That's the only thing I stopped DSO from buying.

Because my job was to support Eng Soon, get him to focus and guide him along. Not to kill him, right?

So you see, it was better for him. Focus on key areas, forget the rest! We moved ahead.

Do you apply your submarine theory everywhere you go?

Yes. I like to see things in clear groups. That way, you build up speed. You build up expertise.

I mean, I took over CIS in 1979. It was a disaster, you know! When I left in 1982, it was already revamped, focused only on production. And CEI was focused, doing hybrid chips for electronic fuzes, right? That's electronics, so I don't want DSO to do it, right? Right? Understand? So I started CEI.

You see, I started CEI for fuzes because the fuzes we had were all mechanical. So, when the bomb hits the ground, when it detonates, the killing area is very small. So, especially in our terrain, you go through the trees, you've had it! Whereas if you have an electronic fuze, radar echo, it detonates 12 metres above ground. Then the killing area is big. So DSO did R&D, but who is going to manufacture? This is production, so DSO can't do it. It is electronics, so CIS shouldn't be doing it. So I started CEI.

So, CIS focused on production. Then CEI did electronics, made fuzes, things like that.

Focus is the key.

That's why when you look at the Singapore Technologies (ST) group, every time there is a new focus, I create a new company! Because I don't want this present bunch to be distracted. Something new and really different, comes up, I form a new company. So it is like yeast, budding.

In 1979, I took over ST group. By 1987, I had 88 companies. Then I realised, "OK, that's enough, let's have a look, pull it together." So the idea is string it out and then, at one time, gather the good ones back.

Then you know which ones to dump, right? So you have to do this.

Now the key in any organisation, if you want to do anything, do it quick. Don't dilly-dally.

If I want to kill you, I've got two choices. Either I bleed you to death or I chop your head off. If you have a choice, chop your head off, please. Because most times, in organisations, they slowly bleed the guys to death. That is *bad.*

See, if you don't do the job quickly, you do it slowly, and what you see is slow bleeding. Perpetual reorganisation, restructuring, changing – never finishing. Just bleeding and bleeding. Bad for morale.

Was Tay Eng Soon typical of an R&D scientist? Is there a way to manage scientists?

Well basically, Eng Soon was a keen scientist, a good scientist. He really believed in science. He was one of those people who had a lot of passion, you see.

But Dr Goh, on the other hand, was a very practical man. There isn't a more practical man here. In my life, I have never met a more down-to-earth man.

So Dr Goh was a very practical person and he wanted to make sure that DSO was productive. That's all!

At the same time, Dr Goh had great faith in technology and weapons. Like Churchill. Churchill liked to tinker around, learning about science and all that. So Dr Goh was very much in that mould. He liked to experiment, try things, learn how to do things.

So Dr Goh was very interested in defence science – that's why he started DSO! But on the other hand, he was a practical man. So he needed practical science.

Like me, I am also very interested in science, but I want my science to produce something which the SAF can use. So Dr Goh, Eng Soon and myself, we are all quite similar in mind – but we have different time horizons.

After Dr Goh left the Defence Ministry in 1979, were the other Ministers as supportive of ETC or DSO as Dr Goh?

Well, next was Howe Yoon Chong. He was not an easy person to get along with. But I protected Eng Soon. I mean, Howe Yoon Chong didn't *kachow* him.

You see, I always protect my people. So when I took over DSO, Dr Goh and Howe Yoon Chong never gave DSO trouble. When I supervised the Air Force, I brought in George Yeo, Lim Hng Kiang, all these people. The Navy – Teo Chee Hean.

Because I believe that the key in all these organisations is the people. And everywhere I see very good people, I grab them! Get them in, give them scholarships, build up their know-how. Then, let them run!

Dr Tay left in 1980...

He went into politics and I had to recall Ho Ching. Because I had sent Ho Ching to do a Masters and was thinking of letting her do a PhD. Then I called her, "You better come back!"

Because Su Guaning was away. Vijay Mehta was in Stanford. So one shot when Eng Soon went into politics, *wah* shaky! I went in, acting director, unpaid, so I got Tham to act as Director, called back Ho Ching.

That time, the whole technology push, DSO – very shaky. So I had to be involved, to take charge. If I did not do it, there would be no such DSO now!

There was a period when you appointed Tham Choon Tat as Director, and two Deputy Directors – Su Guaning and Ho Ching. Then they all went their own ways.

They all had different backgrounds, running different divisions. All three were different.

So it didn't bother you.....

The *worst* is an outfit where everybody listens to me! What I really like is diversity. There must be differences, there must be a natural tension. Because then, you have ideas! If everybody listens to me, it's a *shitty* outfit, you know?

Why do you think I go around giving out scholarships? Bringing up scholars? Because I want to make sure, when I chair a meeting, they are not all from NUS! Or NTU! There has to be diversity! When I chair a meeting, I have got talent in front of me, that's the best, *man*. They will all have different views, there will always be tension.



"Dr Goh used to call me an octopus. He says, " An octopus functions by having a simple brain but many tentacles.""

Your job as director was to manage the tension.

That's it! If there is no tension, then the outfit is dead. When you are dead, your whole body will have no tension, right? It'll be terrible to have everybody love each other!

You see – there were lots of R&D crazy guys like Eng Soon, Guaning, Tham and Ho Ching.

Fortunately they all reported to me and I would moderate them.

After you left, there was a lot of restructuring. There was the Defence Technology Group (DTG) formed in 1986, which combined all the technology groups under one roof.

Before I left in 1985, I already created the DTG. It was during my time. Then I passed it to Ming Seong and Teo Ming Kian.

See, what I did was to divide all our people into three groups. One was research, the other was all engineering and logistics, and the third group was industries.

When I was there, all the assets were more or less shared. But after I left, there was a lot more tension.

How did you persuade the three groups to share?

Because I always supervise, check and balance. So the users, developers and producers share. I never support one or the other! The moment I left, there was nobody doing this balancing act. They all started doing guerrilla warfare. So that's the background. Hopefully there is less now.

Some people complained that DSO was not connected, wasn't supporting the SAF closely enough.

A lot of the complaints were because people just didn't know. I mean, DSO was a classified outfit. So not many in the SAF even knew what it did, OK? So they complained.

"The worst is an outfit where everybody listens to me! What I really like is diversity. There must be differences, there must be a natural tension. Because then, you have ideas! If everybody listens to me, it's a *shitty* outfit, you know?"

What about the decisions of what should be developed in-house, and what should be bought off the shelf? Was it that SAF would rather buy something off the shelf than wait for DSO to build it?

There is a simple, but fundamental difference between Singapore and many other countries. It is how we make acquisitions or buy weapons. In Singapore, we separate the user – the SAF – from the guy who develops, which is DSO and the manufacturers, CIS or whatever. Right? Check and balance.

Dr Goh was the only Minister for Defence who saw that. So he said to me, "Look, never allow the users to buy." Dr Goh believed in check and balance. He never gave the SAF any authority to buy things.

Now, the civilians who are developing things, doing R&D like DSO – they will always be criticised because you know, "These guys never fought a war." *Bullshit*! I didn't fight a war. But I can build weapon systems, guns and artillery. The guys who built the V2 rocket also never fought a war. They are pure technical people. Correct?

In fact I believe the user should never be allowed to become a developer! We developed a vehicle in three years because we had very clear focus. The US Army took 15 years to develop a *Minimi*. We took three years to build the *Ultimax*.

Why?

Because technical people do not get distracted.

So there's always a natural tension between MINDEF and SAF when it comes to acquisition. And between the SAF and DSO about development. Check and balance is important. Separate the users, the developers and buyers. That's important.

Ideally, it's the Minister who decides or arbitrates. You must have a strong Minister who is impartial and neutral.

Were there times when the SAF doubted DSO's ability to produce the goods?

When I came back from Harvard, on my table was the contract to buy two thousand General Purpose Machine Guns (GPMGs). The contract licence? More than ten million dollars! I looked at it – threw it away. Winston Choo hit the roof! I said, "Very simple, I can build them for you. Why would you want to buy?"

Actually at that time, I really couldn't do it. Our industries at that time, they couldn't do it! How to start? But I went around, learning everything, figuring out a way. OK, it took a while, but we did it! See, you focus and you can do it.

You know, if you have focus, willpower, you can go out and get knowledge, resources, whatever you need. I have been to all these countries, I only go to the factories to get what I want, then out. Don't get distracted. I went to China forty times, I've never seen the Great Wall. Don't know what it looks like. But which factory in China, which semiconductor line, which foundry – I know everything!

So in the same way, I go around, I can learn how to build a GPMG. We have it now!

Of course, the SAF prefers to go out and buy.

My argument to them is that ,"You want to buy, they want to sell. That's too simple. How are you going to build up? So even if you buy, you should carry on developing."

Even if they buy, it's OK. So we develop, we buy, we know everything about what we buy. We can improve on it. We can take it apart.

So even if you buy, you should still make it yourself.

To sit down and tinker, that is not easy. But when you tinker, develop yourself and you know more, your capability grows.

So to me, the tension between DSO and SAF... that's just natural. If the Air Force loves DSO like crazy, then something is wrong. There must be tension. It's how to ensure that the tension is constructive. And on the way, we build up capability in the SAF and DSO.

It's a decision, a policy. My preference is: we make, we buy, but at the end of the day, we build our capability.

During your time at DSO, how was the staff turnover and the morale? Was recruitment a problem?

When I took over DSO in 1976, I realised we had all bonded scholars. So there was no turnover until everyone finished their bond. Then for sure, they would leave.

So there was no turnover. But the morale wasn't great.

So we needed to get people to see that DSO is a place where they can develop themselves.

My belief is in scholarships. I want to send everyone for training. Develop them.

In DSO, Su Guaning, Ho Ching, the whole lot went, you see. They were all on scholarships.

So that is my policy. You develop your people through scholarships.

You know, if I have a choice, I will send everybody off for training. We are not only keeping them in the organisation, we are developing our population, building our national capability. Even if

> "My purpose of monitoring is not just to know what they are doing, but really – it is to know when they fall into the *longkang*. Then I intervene – I help them."

they don't stay in DSO, we are building up the asset in the country. That is my belief.

When you came to DSO in 1976, there was no scholarship scheme?

We wanted to give, but we were not allowed. That time, only PSC could give scholarships. Nobody else could. Just like the whole of Singapore, only the Ministry of Finance could have computers, the rest couldn't. So we were not allowed to. So I had to find a way out. When I came to EDB, they also refused to give me scholarships, so I went to get donations from our industries. Fifty million dollars from Glaxo, twenty million dollars from Mobil. The terms and conditions, I decided.

Everywhere I go, I give scholarships. The ST Group, Sembawang, EDB. I mean there are 287 scholars in EDB today, and it's because I started this scholarship. In Sembawang, I was Chairman from 1994 to '99, I have 75 scholars. MINDEF, I don't know how many scholarships I gave. Singapore Technologies, NCB, I had 120 scholars. EDB, I have 30 scholars going every year.

If DSO is the first of its type, a Singaporean R&D institution, can you tell us what lessons you have learned managing R&D institutes?

When I supervised DSO, I developed key competence areas. When I supervised the defence industries, I still focused on competence areas. So wherever I go, I want people to focus.

No focus, you achieve nothing.

I mean, it's very hard to motivate people when you don't know where the *hell* they are going. When they are all wandering around in deserts for 40 years, it's terrible.

So it's not possible to provide good leadership unless you tell people, "Gentlemen, we are out there to take that."

Beyond that, I left them alone. But I don't constrain them to narrow paths. Because at the end of the day, I don't care how they got there. I mean, who am I to tell them, every day, "Do this, do that."

But I get their directions right, keep them focused. That's all.

What about structures? You know, cost control, management, the bureaucracy, ...

What I think is this, "Easy to be a father, hard to be a mother."

You know, I created so many of these institutes, IME, ISS, NSTB. All these R&D type institutions, they have a lot of freedom. So I said, easy to be a father, hard to be a mother.

The key is to monitor. See, people say I'm very liberal. But I'm not liberal in the sense that I monitor people very closely. When I run DSO, I know what's going on. I run 80 companies, all their reports are on my table. I don't interfere. I don't call every day, but I know exactly what is going on.

You can't start and leave it to them, you know? You know there is no outfit in EDB that runs without my knowing. Dr Goh used to call me an octopus. He says, "An octopus functions by having a simple brain but many tentacles."

So you give freedom but you monitor.

You must monitor.

When do you intervene?

You must give people freedom. But my purpose of monitoring is not just to know what they are doing, but really – it is to know when they fall into the *longkang*.

Then I intervene – I help them. If I do not know they are in the *longkang*, how do I help them?

And you know, most CEOs – they do not know they are in the *longkang* until it's too late. And if they know, they don't tell you.

So I monitor every company.

But everyone's fear is that the scientists will run wild. You give freedom, how do you ensure the scientist doesn't run wild?

Money.

Money?

Yes...I mean you got a project, you got no money, how far can you go? How wild? I cut off the money and you're gone already.

You've got to monitor. You've got to manage. The key is how much you can allocate. At the end of the day, money is a scarce resource. You can only allocate so much.

I mean, you've got to tell the guy – very simple, "Hey which project ...which one do you want to prioritise? Which do you want to cut?" There is no such thing as no priority. If money is free, then there is no priority. But money is finite, then you better prioritise.

Now, you say to the guy, "You've got ten toys to play around. OK, you choose. Which one do you want to allocate your money to?"

So the key is to get the scientist to discipline himself. But you control the money.

Again, it's focus. The discipline will come if there is focus. And if there is scarce money and there's focus, then the scientist will know what to do. You don't have to do anything.

You don't intervene except to help your people. And you don't discipline except to set the parameters – within the parameters your people will know how to self-discipline. Which priorities to set. That's management.

OK, we agree on your focus. You define the scope, you tell me your plans. We agree in principle, then, you carry on. Meanwhile I'll watch you like crazy. All the reports will be on my table. None of the companies can get away without my knowing. But I don't interfere.

OK, I'm not breathing down your neck, right? But, I know what the *hell* is going on. When you are in trouble, I already know what the problem is. Maybe earlier than you do. So I'm ready, remote control. I'm prepared.

Remember this, it's very different to be a father and mother, you know? Father is easy. Mother is hard.

How do you keep everyone happy?

We kept the engineers happy because there was a lot of work...if you give the guy a lot of work to do – good work, fun – he'll be so busy with work, he won't ask for the pay! That's the joke we have.

You know, some young officers ask me, "What is my career path?" I say, "Don't tell me about career path. There is no such thing as career path."

What is a career path? You just do the *damn* job, whatever is fun. If it's not fun, quit!

This is what I think – if the work is challenging, fun, that is your career path. It's the work that defines the career path! Not your promotion! I mean, what the hell. You spend all the years in DSO, is it a career? I don't think I offered a job saying, "This is your career." No, man, you've got work to do!

This is your work, if you think it's fun, carry on. If not, quit! I mean, switch to work that you like. Your career path is defined by your work you enjoy doing. That's what I believe.

"This is DSO's success – You developed your people. You developed the nation's human capital. People worship the structure, the building. No, it's meaningless. The most important assets are the two-legged ones."

Do you think that DSO is the first of the R&D institutes in Singapore – the first of its breed?

I guess you can say that. DSO is the first. Of course, no one knows this. The work was all classified and nobody else knew what the hell we were all doing.

Dr Goh's belief was that "never tell people what you have." Because then, you lose your strategic advantage of secrecy. That was Dr Goh's view. So no one knew.

Do you think DSO has been a success?

DSO is really home-grown. Sure, it started small. And then it was under cover, right? So as a result, we have in DSO, all Singaporeans, right?

Then I came on to the scene, I gave scholarships. As many as I could give. OK, they go overseas to study. Come back, Masters or PhD. So they come back with ability. They organise, they work, and they are locals – right?

What has happened – the country is richer! These are real assets, two-legged assets. Home-grown assets. This is capital – human capital.

This is DSO's success – you developed your people.

You developed the nation's human capital.

You know, your people are the most important thing in DSO.

Tomorrow, you burn down the building, tear down the labs, the people come out, we can form a new DSO, right?

People worship the structure, the building. No, it's meaningless. The most important assets are the two-legged ones.

DSO is not a lab. It is people like you, *man*. With you, I can form another DSO tomorrow morning. It's very simple.

So DSO must concentrate on developing its people.

And for the future?

It's simple. You focus on a few core areas. Don't get distracted. You develop your own people, promote from within. Give plenty of scholarships. Don't build fancy labs. No big facilities. Instead, you grow your people. That's the way.

"OK, I'm not breathing down your neck, right? But, I know what the *hell* is going on. When you are in trouble, I already know what the problem is. Maybe earlier than you do. Remember this, it's very different to be a father and mother... Father is easy. Mother is hard."

0100

MODELLING THE PARTS AND SEEING THE WHOLE

In a general sense, armed forces have throughout history employed simulation and modelling in planning their campaign strategies and tactics. War-gaming, using physical models of terrain and toy armies, has long served both to assist generals in planning possible scenarios in an actual campaign, while also providing entertainment for war-gaming enthusiasts who want to relive historical battles.

Operations research or OR, which is a primary mathematical tool for the optimisation (i.e. finding the best and most efficient solutions) of complex operations, is now commonly used in nearly all aspects of daily life. It has in fact been utilised from the days of the Second World War. During that conflict, the British used OR techniques to study the optimal deployment of their radar systems, as well as in the management of convoy, bombing, anti-submarine and mining operations. The now well-known OR technique PERT (Program Evaluation and Review Technique) was actually first used successfully in the 1950s to manage the development of the Polaris submarine launched missile, which became a key factor in the strategic nuclear balance of power during the Cold War.

OR, together with modelling and simulation, have become, with the aid of the digital computer, powerful tools not just in battlefield and war-gaming applications, but also in almost every aspect of military and defence science and technology in which they can be applied. Indeed, ENIAC, one of the first electronic digital computers to go into operation, was expressly designed for the computation of missile trajectories, and may have been used for other military applications. The digital computer brought new life to war-gaming and other gaming genres, such as Dungeons and Dragons. Complex environments and scenarios could be modelled in the computer with ever-increasing realism, as computers became more and more powerful. The widespread popularity of arcade and LAN games, enabling players to experience an almost real-world simulation of combat conditions, has not gone unnoticed by the war-gaming community, which has also used computers in the modelling and simulation of a wide variety of battlefield situations.

Since then, the use of computers in modelling and simulation and the application of OR has become an essential tool in the design and testing of both offensive and defensive military weaponry, battlefield simulation, as well as in the optimisation of military and defence operations in general. In the military context, operations analysis (OA) is synonymous with operations research.

Capability Buildup

In 1984, then COL Lui Pao Chuen (now Chief Defence Scientist) established the Operational Analysis Department (OAD) within the Singapore Armed Forces (SAF), after pioneering initial operational analysis work for the SAF. OAD conducted operational analysis for the evaluation of weapons systems and force mix; development of tactics; and the design and analysis of military exercises and war-gaming. An Operations Analysis Branch (OAB) was also set up in DSO to specialise in modelling and simulation of weapon systems in an operational environment.

At that time, military OA modelling and simulation was not a widely applied field in Singapore and operations analysts were sent for formal training in military OA theory and applications, for example, at the Royal Military College of Science (RMCS), UK. Military OA specialists from overseas were also enlisted to build up the expertise of the analysts rapidly.

One of the first projects of OAB was the development of a simulation model to compare the performance of different weapon systems under a variety of scenarios to support the RSN's missile corvette (MCV) acquisition programme. The knowledge base on warheads and analysis of warhead effectiveness and target vulnerability was also built up, and one of the first warhead trials by DSO exploding two old 1,000 pound British-made General Purpose Mk 11 bombs was conducted at Pulau Senang to determine their blast parameters. The two big bangs that shook Pulau Senang thus marked the beginning of warhead analysis expertise in DSO.

Painstaking efforts were made to search for and acquire the resources for the analysts to draw on, and to conduct OA, including analytical and simulation models, OA software, and data on weapon systems performance which served as inputs for the OA models.

With this buildup, DSO kept pace with the weapon system engagement modelling and simulation needed to support weapons evaluation for MINDEF's acquisition projects.

The demand for OA studies grew, and in order to achieve better results, OA modelling and simulation took on increasing sophistication with higher resolution and speed. The models of weapons systems and combat platforms increased their depth of performance details, requiring more detailed engineering studies of the relevant weapons and combat platforms. One example is the study of anti-armour weapons equipped with shaped charge warheads, deployed against armoured vehicles.

The simulation of the combat interplay between weapons and targets became more complex with the incorporation of tactics and counter-actions undertaken by each side. As a result, the more sophisticated modelling and simulation started to converge with other simulation applications. The simulated combat interaction among forces at different levels also took on increased breadth. For example, for campaign level scenarios, different land, naval and air units under various force structures were made to undertake different missions, employing different weaponry and platforms. Operations analysts use such simulation techniques to analyse the results of various combat strategies and tactics.

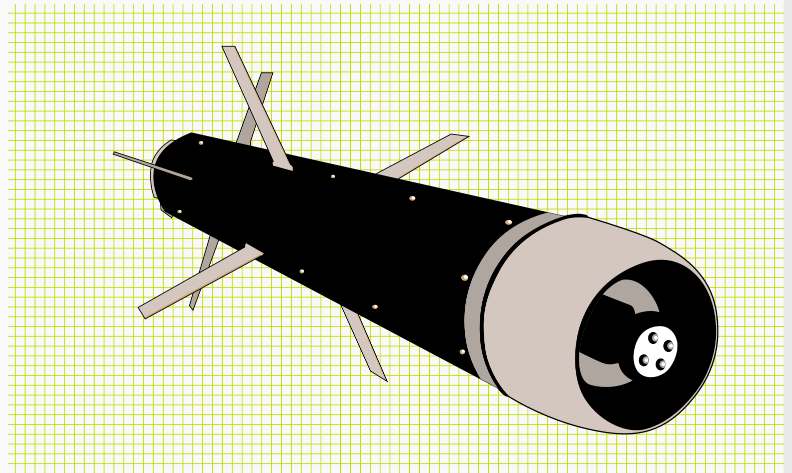
SHAPED CHARGE AND ARMOUR DESIGN

Warfare is very much the history of the evolution of offensive weapons and the corresponding response of defensive and protective measures. From primitive times, the threat of simple but lethal weapons such as swords and spears have been met by protective armour. As such armour was utilised, new offensive weapons were devised to overcome the protection afforded. The development of the crossbow enabled the bowmen to launch arrows of high velocity which could pierce body armour easily. Nevertheless the English longbows used at the Battle of Crecy showed that accuracy was as important as velocity, where arrows were concerned. These high-speed projectiles in turn led to the design of more effective types of armour to counter them.

One of the earliest offensive weapons devised by man is the spear. To survive eagle-eyed spear throwers, soldiers protected themselves by wearing chain mail (a flexible form of armour) and iron breast plates. This protective clothing was in turn countered by the invention of the bow, which was able to propel arrows at high enough speeds to penetrate an opponent's iron breast plates.

The modern day equivalent of the breast plate is armour, which is mounted on main battle tanks, armoured personnel carriers and even helicopters. The challenge of weapons designers is to design a "spear" that can pierce through thick armour plates, and the corresponding defensive challenge is to design an armour that can protect against such offensive weapons.

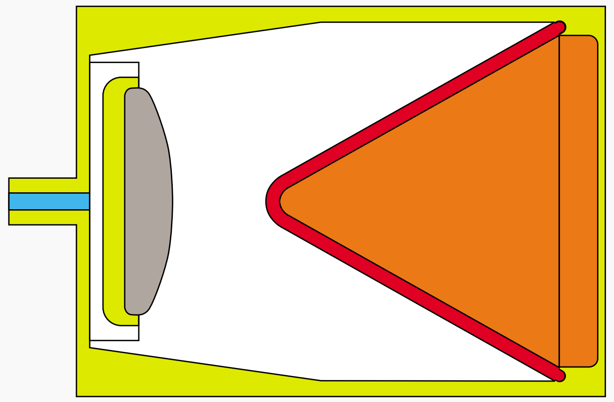
One such modern "spear" is SPIKE, a 3rd generation man-portable anti-armour weapon, able to operate in day or night under fair or adverse weather to engage stationary and moving armoured vehicles, using a precision infra-red cum TV guidance target seeking system.



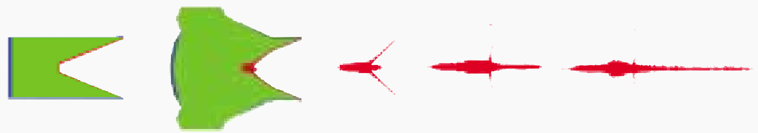
SPIKE, an anti-armour weapon.

A key feature of the SPIKE missile is its warhead design. This comprises a shaped charge warhead that can penetrate advanced armour designs. A shaped charge warhead is basically a cylinder of high explosive with a conical metal cover (or liner) at its leading end. This conical liner, usually made of copper or aluminium, collapses upon detonation of the explosive to form a potent and effective spear-like penetrator (called the shaped charge jet) that travels at high speeds of up to 10 km/s, equivalent to 36,000 km/h!

Shaped charge warhead



Modelling and simulation can be used to analyse the formation of the shaped charge jet and its interaction with the armour target. The sequence of pictures shows how the shaped charge works graphically. The explosive is shown in green, and the conical liner is in red. The detonation of the explosive creates a detonation wave that hits the metal liner with very high pressure. This causes the liner to collapse towards the axis of the warhead, forming a spear-like projectile. The "spear" that is explosively formed has an extremely high speed of up to 10 km/s which enables it to pierce through armour plate.



Shaped charge formation process.

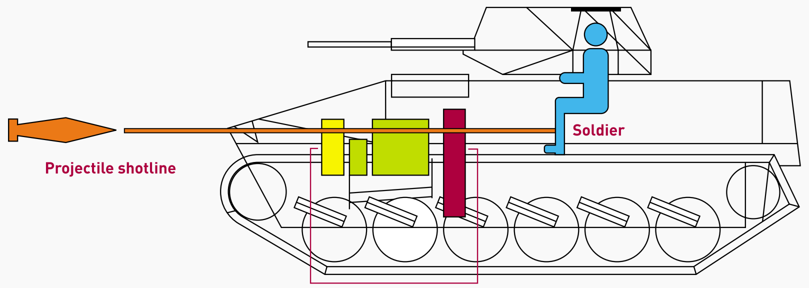
One of the most challenging tasks of armoured vehicle designers is to study how to protect the vehicle from attacks by such lethal shaped charge warheads.

ARMOURED VEHICLE VULNERABILITY MODELLING

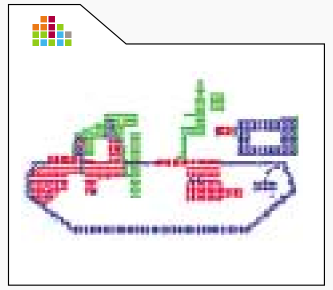
With vehicles of modern warfare such as tanks,armoured cars and personnel carriers, the design of protective armour for such vehicles has become a highly sophisticated technology, involving much research and development effort.

DSO was tasked to study the vulnerability and survivability of different possible designs of the vehicle against different threats to the vehicle. Different designs involve different arrangements and placements of the different components of the armoured vehicle, as well as different types, levels and placements of armour material on the skin of the vehicle. The threats to the vehicle may be conventional artillery shells, anti-tank armour-piercing shells, and special shells which are shaped to maximise the penetration through armour (the shaped charge warheads described earlier).

DSO's approach was to create a detailed three-dimensional computer model of the armoured vehicle design with its various compartments and components accurately placed with respect to one another. Shot-lines representing the path of the incoming weapon were then projected into the vehicle model and the vehicle components that were in this path were thus identified.



Schematic of an armoured vehicle under attack.



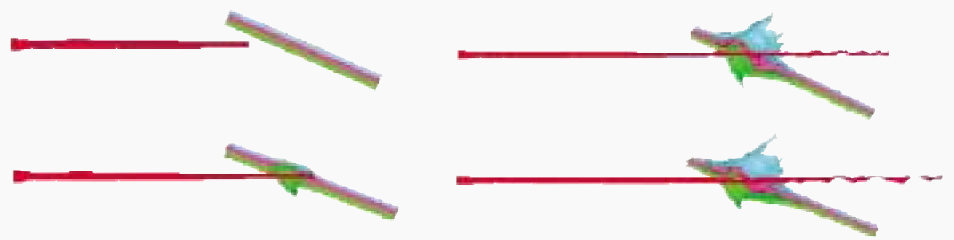
Hypothetical simulation results with colours showing areas of different vulnerabilities.

Whether a particular component is hit or penetrated depends on the penetration performance of the incoming weapon. The performance characteristics of the weapon can be obtained in various ways – the weapon manufacturer's specifications, formulae based on the physics and engineering of the weapon, computer simulations or actual test results using real weapons. It also depends on the placement of other components and armour protection in the path of the weapon.

Whether a vehicle component hit by the weapon is "killed" i.e. destroyed or disabled depends on the vulnerability of that component to the impacting weapon. In most cases, a component would be "killed" if it is hit. Whether the entire vehicle is "killed" (i.e. destroyed, disabled, or whether its occupants survive or not) will depend on which components or combination of components are "killed".

In this way, the functional survivability of different vehicle configurations and the effectiveness of the armour protection from attacks in any direction by various types of weapons can be studied. Recommendations can then be made on changes to the vehicle design e.g. in the addition of armour material, or changes in the positioning of critical components to enhance the vehicle's survivability.

After identification of critical surfaces to protect the vehicle using a computer-aided-design (CAD) model, new armour designs for protection against shaped charge warheads and armour-piercing rounds were investigated. Various armour designs were investigated by simulating the penetration performance of the attacking weapon, including parameters such as armour materials, armour plate thickness, angle of inclination, and spaced plates. Actual firing trials were conducted in 1999 to validate the results from the simulations.



This sequence of pictures from the simulation shows the effectiveness of a lightweight armour designed to protect against shaped charge warheads. As it penetrates the armour, the shaped charge jet is "disturbed" and broken up by the armour, hence becoming ineffective in penetrating the vehicle.

AIR-TO-AIR COMBAT SIMULATION

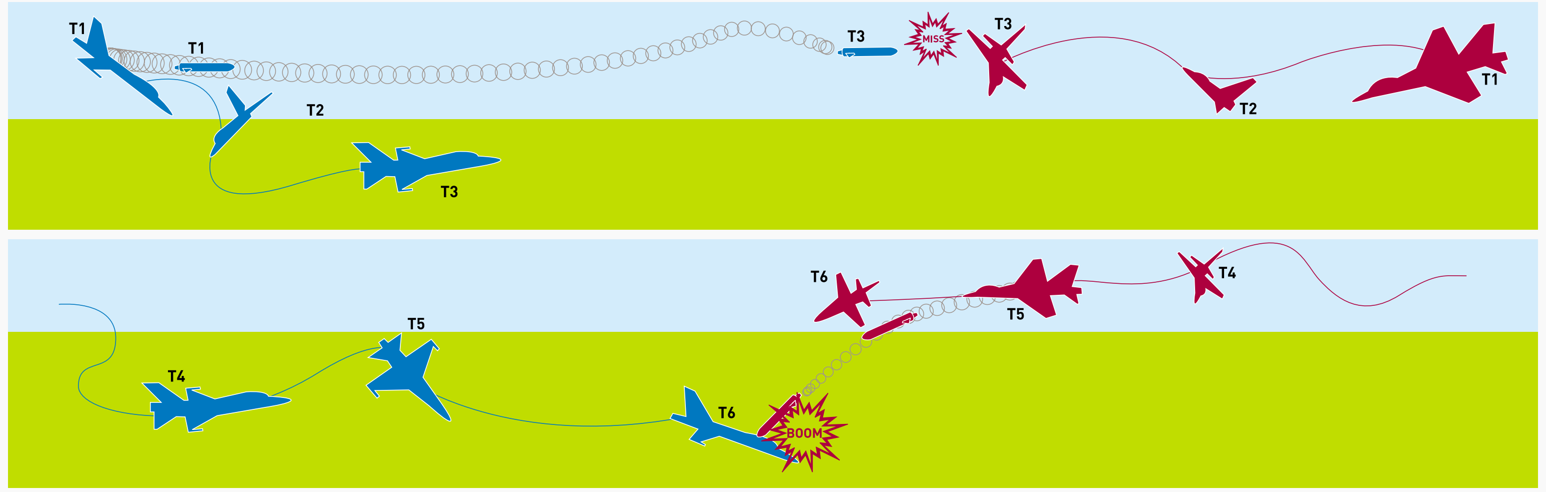
One of the simulations developed by DSO is the Air-to-Air Combat Model (AACM) which simulates engagements between opposing fighter aircraft in 3-D space deploying air-to-air missiles (AAM). The aircraft and missiles are modelled in medium-high resolution performance simulations based on the detailed flight performance behaviour of specific fighter aircraft and missiles. The simulation also models the performance of the radar systems on board the aircraft and the missiles. This not only takes into account the technical specifications of the radar systems simulated, but each of the target aircraft or missiles is also modelled to present an accurate radar image using radar equations which take into account how each of the target aircraft reflects incoming radar signals.

The simulations are realistic and detailed in that the actions and reactions of the pilots in the aircraft are modelled and incorporated into the simulation software. This determines how each aircraft will act and react to different operational situations in the engagement, such as being tracked by an opposing aircraft's radar, or being fired upon by a missile. These events will cause the aircraft manoeuvres to change dynamically in order to avoid being hit by a missile or to score a hit on an opposing aircraft. The uniqueness of this software is that it can be modified easily, to take into account different pilot behaviour and aircraft characteristics, without having to recompile the entire programme, unlike other similar simulations in which the decision rules determining pilot and aircraft behaviour are embedded deeply in the main simulation programme. In this way, the model can be used to study the effectiveness of different pilot responses, tactics and flight manoeuvres on the outcome of varying air-to-air engagement scenarios involving small numbers of aircraft.

The sequences of pictures below illustrate the application of the AACM to study the effect of missile range in air-to-air combat between two opposing aircraft, with one aircraft firing the missile at the other aircraft.

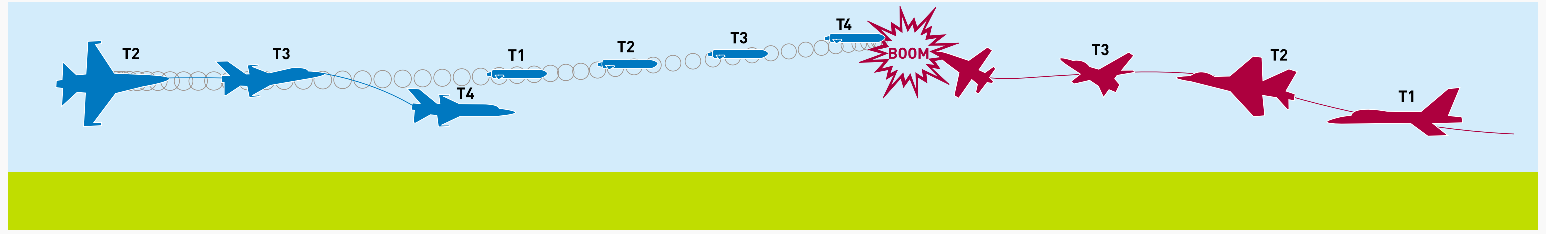
SEQUENCE 1 : SHORT RANGE MISSILE

In the 1st sequence, the BLUE aircraft fires a shorter range missile at a RED aircraft at near to its maximum kinematic range. When the RED aircraft detects the incoming missile, it is able to turn sharply and evade the missile successfully, as the missile when near its maximum range has not enough speed to follow the violently manoeuvring aircraft. The RED aircraft then fires back a missile at his opponent and is able to hit the BLUE aircraft.



SEQUENCE 2: LONGER RANGE MISSILE

In the 2nd sequence, the starting engagement range is the same, but the BLUE aircraft is now launching an AAM with a longer range. In this case, when the missile reaches the RED aircraft, it still has enough speed and manoeuvrability to catch up with the evading aircraft.



DSO has started development work on a simulation tool to support the decision-making process in the planning of military campaigns involving land, naval and air forces. The objective was to develop a realistic simulation which will allow force commanders to assess various combinations of military forces drawn from these three Services in a given theatre of operations. This autonomous campaign level simulation model uses 2 opposing sides, labelled RED and BLUE, to assess the results of interactions of their opposing air, land and naval forces in a given area of operations (AO).

In this simulation model, the land forces are aggregated at the brigade and battalion level, while air units are modelled as single fighter aircraft or pairs of such aircraft. Naval units are modelled as individual ships and task force groups. The simulation also included other elements such as sensors including Airborne Early Warning (AEW) aircraft, ground-based surveillance radars, and land-based, shipboard and fighter aircraft weapons. The simulation of the AO for the land forces represents key geographical locations, waypoints and targets as nodes, while possible routes of advancement and speeds of movement over these routes (which are based on analysis of the actual geographical terrain) are represented as arcs. The AO simulation model is thus a network of nodes and arcs over which the land forces can move.

The battle plans, campaign rules of engagement, mission objectives and starting force structure, for each of the two opposing sides are set up and defined at the start of the simulation. Typical mission objectives might be to capture and hold certain key geographical areas for the land forces, to conduct air missions for the air force, or to conduct an escort of merchant ships to ensure safe passage through a specified sea lane for the naval forces. The simulation includes algorithms which automatically compute the optimum routes to be taken by the forces to reach their objectives, on the assumption of certain known threats as well as given survivability considerations.

When the conditions for an engagement between the two opposing forces are met, for example if they come within the range of each others' weapons, the engagement between the two forces is automatically initiated and proceeds as determined by the initial conditions and the simulation algorithms. The eventual outcome of each battle is determined on a probabilistic basis, influenced by the relative combat power of the engaging forces. The simulation run continues according to the battle plans until the end-time for the simulation run is reached. The entire simulation run is repeated many times and detailed information is collated for each run. Hence, the final analysis provides detailed information on the progress of the war such as the attrition rates over a defined time interval, the probability of mission objectives being achieved, and the final disposition of the combat forces.

This campaign simulation tool can be used to aid in the design of tri-service force structures, to study the effects on the outcome of a campaign of introducing a new weapons system or capability, to analyse and compare the effectiveness of different military strategies, and to support high-level war-gaming exercises.

At the start of this fictitious operational scenario, the BLUE forces comprising infantry and armoured units, aircraft and naval task force were clustered near Clearwater Bay, while the RED forces also comprising infantry, armoured units, and aircraft were deployed along the Mitcham River, with a RED naval force deployed both in the Mitcham River and in Clearwater Bay. RED armoured units were also deployed at strategic points along the Yardick Highway, and on the Nigel Highway in defence of the key city of Roseville in the south to which the two Highways lead. The objective of the BLUE force was to capture Roseville by opening either or both of the two Highways for a major thrust towards the city. The battle at one point of the simulation is depicted in FIG 1.

The simulation ends with BLUE forces occupying Roseville, and the Yardick axis completely cleared of RED forces.

FIG 1

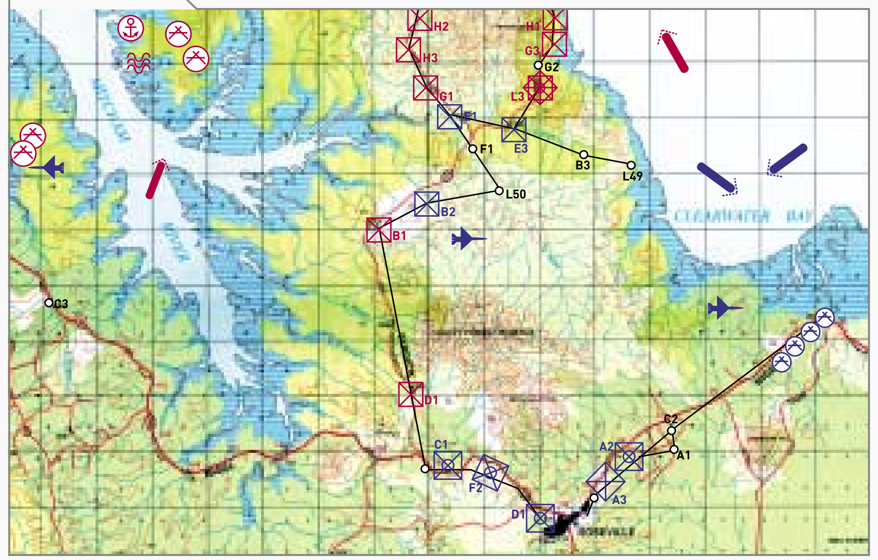
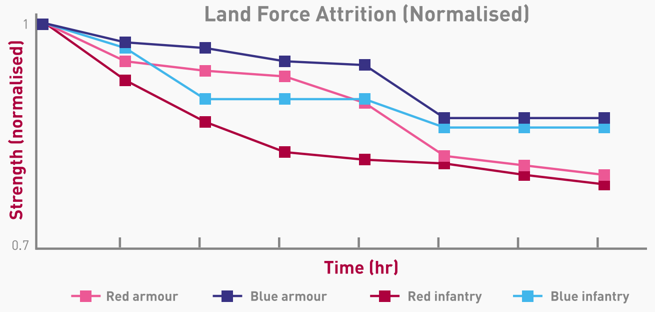
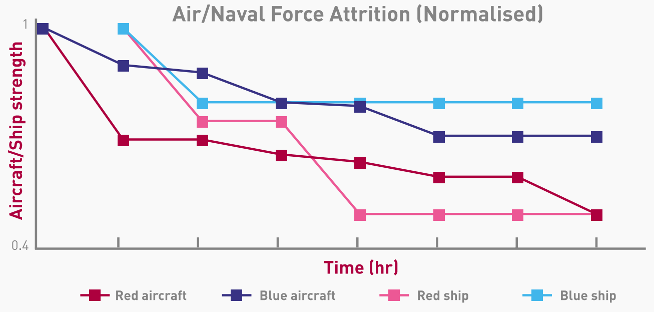


Fig 1 shows that Roseville has been captured by the BLUE armoured and infantry units which advanced along the Nigel Highway and defeated the defending RED forces on that Highway. After taking Roseville, these BLUE units are now continuing their advance beyond Roseville along the Yardick Highway to join up with the BLUE airborne units which are blocking RED reinforcements attempting to move south along the Yardick Highway. The BLUE airforce has successfully attacked the RED airbases along the Mitcham River. The RED naval task force in Clearwater Bay is in retreat from the BLUE naval task force.

The results of the battle can be summarised by the software in the form of graphs. For example, the plots below show the attrition of the RED and BLUE units as the battle progresses.





Conclusion

As weapons systems become more complex, it will become more difficult to evaluate and test them, particularly for two or more inter-operating systems. Computer modelling and simulation will therefore offer the best practical means of evaluating such systems. Battlefield scenarios will also increase in complexity and become more difficult to evaluate and compare, requiring modelling, simulation and OA capabilities for the analysis of strategies and tactics. DSO intends to remain at the cutting edge of these techniques and technologies to ensure that the SAF is able to obtain the most cost-effective weapons systems for its missions.

ENGINEERING FOR QUALITY

Background and History
In a world where we continually put our lives in the hands of others whom we trust to design and manufacture products safely and reliably, the question of quality assurance and management in engineering and technology is no longer just a peripheral topic to be added as an after thought to the product development process. Every time we fly in an airplane, or take a journey (no matter how short) in a car, we are putting our lives in the hands of all those who have been involved in the design and manufacture of that vehicle. Indeed, even the smallest part in an airplane, if not properly designed, manufactured or installed, may cause lives to be lost.

Aerospace applications and missions are among the most complex organised by governments and large corporations, and one would expect great attention to be paid to the quality aspects of such missions. It is therefore all the more dramatic, and sometimes tragic, when a mishap occurs in a complex project such as a Space Shuttle mission.

Indeed, such a disaster did occur on January 28, 1986, when the Challenger Space Shuttle exploded 1 minute and 38 seconds after launch, resulting in the tragic deaths of its seven crew members and the destruction of the vehicle. The consensus of the independent commission appointed by NASA and chaired by Nobel prize winning physicist Richard Feynman, was that the disaster was caused by the failure of just a rubber ring, commonly called an O-ring on account of its shape, which was supposed to serve as a seal between two segments of the rocket propelling Challenger. The manufacturer, Thiokol, and NASA had both failed to take into account the fact that at the low temperatures at which the Challenger launch took place, the rubber O-ring would not be as flexible as it should have been and thus would not have made as good a seal as was designed. This was a failure of the overall quality management system which led to the resultant catastrophe and the tragic loss of the seven astronauts.

The NASA Challenger disaster is not only a dramatic illustration of the need for


Environmental stress testing of system components in a climatic chamber.

quality assurance at the component level, but also underscores the importance of a robust quality management system in any complex engineering project. Defence systems and projects can be among the most complex undertaken and hence the issue of quality must be a prime concern of those in charge of major defence projects. Quality assurance and management has therefore been one of DSO's key areas of attention since the early '80s, when a critical decision was made in mid 1980 by MINDEF to produce, in large quantities, a key item of equipment which led to DSO's investment in its first environmental test capability: a vibration test machine and a humidity chamber.

The Quality Assurance Division (QAD) in DSO was formed in September 1982 and it progressively developed its capabilities to cover reliability engineering as well. In January 1987, the QAD was renamed the Reliability Technology Division (RTD) to better reflect its focus and became part of the newly formed Defence Materiel Organisation (DMO), while still providing specialist support to DSO. In March 1993, the Product Assurance Department (PAD) was formed to fully serve the interests of DSO in quality assurance, reliability engineering, component engineering, test engineering and integrated logistics support in R&D projects, while RTD focused totally on DMO.

Quality Management System

In line with MINDEF requiring its suppliers to have a certified Quality Management System (QMS), DSO undertook to set up its own QMS even though it was then still an internal MINDEF organisation rather than a supplier. A QMS for software development was certified to ISO9001 standard by the Productivity and Standards Board (PSB) in May 1994. This was extended into an integrated Quality Management System, certified in October 1996, incorporating defence systems development, and a Failure Reporting and Corrective Action System (FRACAS) and Failure Trend Analysis (FTA) which would prevent the occurrence of the Challenger O-ring type of failure. The scope of the QMS was subsequently expanded to include all development work including non- defence systems development, exploratory development and technology development work.

A further key development was the institutionalisation as part of the QMS, in July 1997, of an Integrated Logistics Support (ILS) methodology for full-scale design and development of logistics packages to maintain defence systems in continuous operation. Such an ILS methodology, which can account for 10% to 35% of the development cost, develops and optimises the whole series of facilities, documentation, maintenance skill training, spares, etc. needed to maintain a defence system.

In 1998, a key decision was made by DSO to use the Singapore Quality Award (SQA) framework as the benchmark in its quest to become an organisation of excellence. The persistent efforts to improve when DSO was admitted to the prestigious Singapore Quality Class (SQC) in January 2001.

Product Assurance

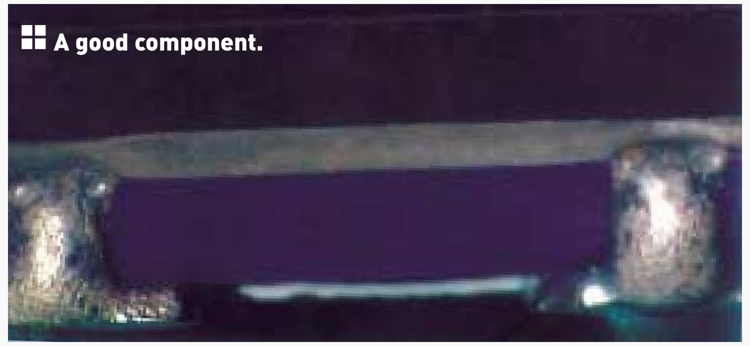
Defence systems very often have to operate in very harsh environments with a high level of reliability and maintainability. When the PAD was formed in 1993 to focus on reliability engineering in DSO, reliability programme requirements were established and a suite of software tools for reliability analysis was acquired. Automatic test equipment and an environmental stress screening methodology were established for the testing and inspection of prototypes and incoming components, including concurrent testing. Failure analysis capabilities were developed in-house, including capabilities in the reliability analysis of networked systems, shelf life testing, Bayesian reliability demonstration, smart built-in test and reliability prediction for mechanical systems, and the failure analysis of integrated circuits.

The frequent unavailability of military components strongly motivated DSO's efforts in component engineering in order to increase the use of commercial-off-the-shelf (COTS) parts and modules in DSO projects. Non-military components were evaluated for their reliability under harsh environmental stress in order to make the COTS policy a practical and useful reality. A series of guides on failure modes, qualification tests and reliability prediction models were also developed for a whole range of component types including microwave components, integrated circuits, semiconductor devices and inductors, surface mount technology chips, multi-chip modules, plastic electronic modules, etc. This allowed the reliability of each system developed to be systematically assessed.

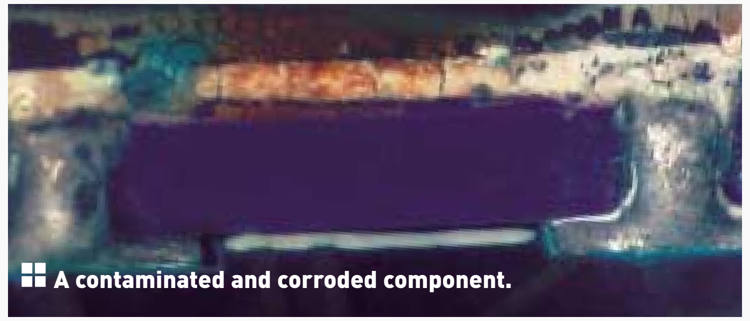
FAILURE OF A RUGGEDISED COMPUTER

As an example of the painstaking investigation which has to be conducted to trace the source of system failures, we highlight an investigation that was conducted on a system which had been developed and deployed, but whose reliability was far from the desired target. It was found that a large proportion of the failures were due to the fact that two of the system's key components were not performing as intended.

One of these components was a personal computer supposedly ruggedised to meet the demanding conditions of industrial use, but which was failing intermittently i.e. only at odd times which could not be predicted. Such an industrial-grade personal computer should be designed to function well under conditions of physical shock and vibration which may cause a consumer-grade personal computer to fail. The industrial computer had indeed been ruggedised against shock and vibration. However, after investigation, the cause of the intermittent failure was traced to additional printed circuit boards being incorporated into the computer with inadequate ruggedisation. The team solved this problem by incorporating a clamp to provide adequate support for the additional printed circuit boards, thus preventing the intermittent failure.



A good component.



A contaminated and corroded component.

The other problem component was an electronic compass which was giving an abnormal failure rate. The investigation found clear evidence of contamination and corrosion on the faulty compass, which was the source of the abnormal failure rate. This was remedied by the additional application of conformal coating to provide additional protection against the highly humid operating environment, hence preventing the corrosion and contamination.

SOFTWARE ENGINEERING

Over the years, software has become integral to many systems. The effect of software unreliability hence can have a drastically negative effect on a system. Unlike for hardware, the reliability engineering methodology for software is relatively new and much less well developed. It is not clear whether the use of hardware reliability principles on software development is appropriate. However, it is clear that the implementation of well-defined software engineering practices is a positive way to improve the reliability of the software being written. Hence, the approach has been taken to build reliability into the software as it is being developed, rather than to use reliability accounting principles on completed software packages. DSO's software developers were trained and equipped with the essential software engineering practices, as well as an automatic software test environment to support them in their reliability engineering tasks. In parallel with this, new technologies, such as network programming and Java programming, were continuously studied and adopted as appropriate, and test guidelines were developed to facilitate their usage.

In one particular project where DSO was consulted on software reliability, DSO's in-house software engineering expertise discovered that the software specifications, interface requirement specifications and software test descriptions for the software package in question were out-dated as the contractor had adopted an earlier version without revisions. Some revisions lacked sufficient detail to qualify the software properly. It was also found that many design changes that were proposed had not been incorporated into the finished software package. These investigations created concern that the software was not ready for use despite the contractor's assertions that the software had been tested thoroughly. However the contractor did not take the investigations seriously nor followed-up adequately, resulting in major system crashes.

One example relates to the need for error correcting codes and protection bytes. These are methods by which errors which occur in the course of transmitting and receiving data (which may occur due to external factors such as electrical noise or other physical disturbances) can be corrected and made good. Unfortunately, while the software package did incorporate such codes and bytes, some modules within the software package which were alerted by these error-correction codes and protection bytes of the possible presence of errors in the data, failed to respond to these alert signals by validating the correctness of the data. To make matters worse, when a reset operation took place (an operation which usually restores the system to some preset state), a message that was supposed to maintain the existing state was misinterpreted as a command to change the system's state and hence its identity. This unintended identity change resulted in the system believing that it had lost control of the running of the software, and led to an inevitable system crash. This crash could have been avoided had the specified and defined software engineering procedures been rigorously adhered to when the software was being developed.

Looking Forward

As the playing field becomes more and more competitive, and defence systems become more and more complex, the need to be abreast of the latest developments in quality management becomes paramount. DSO will endeavour to keep up with state-of-the-art practices and ensure that no Challenger-type disaster will ever take place for systems designed and developed by DSO. The ISO9000 QMS standard, the Singapore Quality Award framework and other domain specific quality models will be the foundations of DSO's never ending quest for excellence in quality assurance and management.

1986 – 1996

BRIDGING THE GAP

CHAPTER 0011

When DSO became part of the Defence Technology Group (DTG) in 1986, it seemed that the party for the "secret scientists" was over.

DTG was the amalgamation of the technology and logistics groups within MINDEF. It seemed to some that MINDEF's formal procedures would take its hold over the liberal environment of DSO.

Was the party over?

"No," exclaimed the creator of DTG, then – MINDEF Permanent Secretary, Teo Ming Kian.

The aim of DTG was not to cramp DSO's style. It was to bring a new synergy and integration among DSO, MINDEF and the SAF.

For by 1986, DSO had grown tremendously in size and capability. But it was still isolated and insulated from the SAF. There was a yawning gulf between the two, created by secrecy, and exacerbated by a lack of co-ordination among the MINDEF technology organisations.

DTG was meant to bridge that gulf.

There was always an agreement that the freedom of DSO had to be preserved.

For as its then – Director Su Guaning emphasised, DSO had to be a genuine and credible R&D organisation. And this innovation, creativity and passion for science required freedom.

DSO had to become something of a "black box." Outside of the box, there was a wall of control and secrecy. Within the box, people had to be free to pursue their work and their dreams.

Teo Ming Kian agreed. DSO had to have certain autonomy in managing itself. But at the same time, the link between DSO and the SAF had to be strengthened.

RAdm (NS) Teo Chee Hean, the Minister for Education and Second Minister for Defence, agreed. The aim was not to stifle DSO. It was more that the SAF was improving and becoming more technology-capable and knowledgeable, and wanted a closer and more productive partnership with DSO and the other technology units within MINDEF.

By 1986, the SAF had matured to the stage where it took a great interest in science and technology. The SAF began asking itself the very questions that Dr Goh asked 15 years before – "How do we multiply the effectiveness of a very small SAF by using technology? How can the SAF exploit science and technology to the full, adding customised, value-added features to off-the-shelf technology? Can Singapore develop a surprise, secret-edge advantage through defence R&D?"

Perhaps one of the major factors in this new relationship between the SAF and DSO was the change of R&D fund allocation within MINDEF. Previously, DSO received all its funds directly from MINDEF as a funding grant. But under the new scheme, the Army, Air Force and Navy, were allocated monies which they could assign to R&D projects of their selection.

Suddenly, DSO became a service provider. The SAF was the customer – or "client."

This turned the spotlight on DSO.

Was the party over? Not so, said Teo Ming Kian. Quite the reverse. The party was just beginning...

TEO CHEE HEAN

Teo Chee Hean was born in Singapore in 1954. He was awarded the President's Scholarship and the SAF Scholarship in 1973 and graduated with First Class Honours in Electrical Engineering in 1976, Master of Science in Computing Science in 1977, and a Master of Public Administration degree in 1986. He held command and staff appointments in the Republic of Singapore Navy and the Joint Staff before assuming the post as Chief of Navy in 1991. In 1992, he left the Navy for political life, serving as Minister of State for the Finance, Communications and Defence Ministries, and as Minister for the Environment. Currently, RAdm (NS) Teo is Minister for Education and Second Minister for Defence.

Tell us about your first contact with DSO.

My first meeting with DSO was when I had just come back from overseas. This was in the 1970s.

I was asked to work on secure communications, which was a new field for me. I went up to Marina Hill and met a few people. At that time I was spending a lot of time at sea. So I read up on the subject, and spent some days and weekends with Chan Kwong Lok and others at DSO.

My second encounter with DSO was when I was serving as the Executive Officer of the missile gunboat, *RSS Sea Scorpion*, and DSO people came and did some modifications to my ship. Then, they locked up the compartment, and wouldn't let me go in! This made me very upset.

I said, "Look, I'm the Executive Officer of this ship, responsible for safety and security. It's not possible that you create a compartment in my ship and don't allow me to go in." They eventually did.

My subsequent experiences with DSO were when I was Head Naval Plans in the early '80s.

The Navy was looking to redefine ourselves, to redefine our mission.

We were operating missile boats, which we knew were not adequate for the mission, tactically as well as strategically.

When we looked at the fleet, we knew we needed additional systems.

I drew up the list of things which the Navy should work on, and sent it to Tham Choon Tat who was Director of DSO. It was about two to three pages long, describing the various areas which we could work on. I think if you look at the letter today, it would show a sort of naivete. Operators like us, in those days, were quite naive.

What do you mean?

I don't think we had a complete understanding of what the technology could provide for the operator. I was a relatively well-informed operator in those days, but still did not have a full appreciation of what technology could offer to the Navy.

There was a gap in understanding between the operators and the technology people.

The operators in the Services did not understand what technology could offer. And similarly, the engineers and scientists at DSO could not explain what technology could offer or understand what the Services wanted or needed.

That would have been the situation in the 1970s and up to the mid '80s.

Can you give an example of the mismatch or gap in understanding?

Well, I don't think Tham Choon Tat ever took the note I wrote very seriously! Perhaps he thought I didn't understand the technology – which was probably true. And maybe he didn't understand what I needed.

What happened to the letter?

Later, Choon Tat told me, "Oh, I thought you were joking!", which reflected, I think, the gulf between the technology people and operational people.

The real achievement that we have made in MINDEF since the 1980s is to bridge that gulf.

How did you do this?

To be successful, relationships have to have the correct organisational structure, the right approach, and right attitude of mind.

The relationship between the Navy and DSO was very successful. This was partly because the Navy was prepared to let DSO try things. And in part, the Navy had no choice.

No choice?

The Navy never had big budgets, especially in comparison to the Army and Air Force.

So we really had to take our time to think about projects. And we worked very closely with DSO, in communications, and in electronic warfare particularly. From these projects, both the Navy and DSO learned. We developed a lot of mutual confidence. Both the Navy and DSO worked together with a lot of unity of purpose.

"It has been very satisfying to see both the services and the DSO grow steadily in capability and mutual confidence."

Was the Navy leading the other Services?

I'm not sure that we were leading the other Services. But as Head Naval Plans I was quite happy with our working relationship with DSO. We had quite a number of programmes and projects during that time.

For instance, I had the pleasure of working with one of your engineers, Ng Sin Yong, on a communications project. It was a very good programme and the system that resulted still forms the bedrock of the communications system in the Navy.

These may not have been the largest things that DSO was doing at that point of time.

But it was an important phase in the development of DSO, because the Navy projects were good platforms for DSO to develop capabilities.

It brought a lot of integration between the operators, engineers and scientists. So I would like to think that the Navy projects were particularly important in bridging the gap between DSO and the SAF.

Why was the Navy taking the lead?

There are a number of reasons for the good working relationship between DSO and the Navy. In the Navy, many of the operators, the sea-going officers, are engineers by training. So they have a greater understanding of things technical. I think that's one of the reasons.

And on-board a ship, there is much more integration between the operational and engineering sides.

What about the other Services?

The relationship between the DSO and the Services changed in the second half of the 1980s, when I was in the Joint Staff. I strongly advocated a change in the way that DSO was supported and funded.

Previously, DSO was given R&D funds directly by MINDEF. The Services then had to ask DSO to carry out projects for them.

But from the mid '80s, when I was in Joint Staff, the R&D budget was divided into two portions. One portion was for long-term R&D, which was directly controlled and funded by MINDEF HQ. The other larger portion was given to the Services to control, from which they could fund R&D by DSO. So overnight, the Services became important as a partner – you could call them a customer – of DSO.

I think that had a major impact on DSO and the whole defence R&D equation.

Because the Services became responsible for proposing and fighting for R&D dollars. Only then, would they have money to fund DSO to provide the services and capabilities they most needed.

That changed – overnight – the relationship between the Services and DSO.

I think this is quite critical.

So the Services became the clients and customers of DSO, rather than everything flowing through MINDEF.

Yes.

And perhaps the third reason why DSO and the Services became much closer in the late '80s was the Defence Technology Group (DTG). DSO became more closely integrated with MINDEF and the SAF when DTG was formed.

In 1986, DTG combined DSO with Defence Materiel Organisation (DMO) and the other organisations such as Land and Estates Organisation (LEO) and Systems and Computer Organisation (SCO). Did you think that DTG was actually the best structure?

Before the formation of DTG, there were tensions between these organisations. And the technology organisations lacked coherence, especially from the user's point of view.

I remember that the Navy was developing a C3 system for ships. The command and control end was being handled by Special Projects Organisation (SPO) and DSO was handling the communications. So two parts of the C3 were being done by SPO, the third part by DSO, and they all had to be combined together to form the C3 of the same ship! The two organisations had completely different ethos and ways of working. It was quite frustrating!

Did the new DTG eliminate the incoherence amongst the various technology organisations?

No. DTG did not completely deal with incoherence because within DTG, there still continued to be compartmentalisation.

We were doing C3 in three different organisations – in SCO, in DSO, and in DMO! It didn't make sense.

For example, SCO was doing systems for operational manpower and logistics. Some simulators were being done in SCO, and others by DMO. The technology for simulators and many of the command and control systems were converging very quickly.

If C3 was a critical area, and we really believed that C3 was going to be a force multiplier for us, it was better to put those things together!

It was better to have problems on the boundaries of C3, rather than to have boundary problems within subsets of C3.

So we eventually formed C3 Systems Organisation (CSO) in the mid '90s. C3 is a key force multiplier for the SAF.

Was there an improvement?

Yes. Very much so.

So during the 1980s, the gulf, or the gap between DSO and the Services, was somehow bridged.

The key was to get the resource allocation issue properly sorted out. We had to structure the relationship so that it worked properly – and each party was motivated to work together.

And another factor that you must appreciate was that in the 1980s, the SAF became a lot smarter vis-à-vis technology. You need a smart user in order to be able to make use of technology. If you have a 'dumb' user, the engineers will be pulling their hair out. So you need a smart user. And during the 1980s, the SAF was becoming very technology savvy.

At the same time, you need an operationally savvy DSO. And DSO too was making progress in their understanding of the SAF.

The engineers at DSO and the operators in the Services have to respect each other. In the early years, there was no respect between engineers and operators. Each did not think that the other was capable of understanding. I'm putting it very bluntly. This was a human problem that has bedeviled us for many years.

That is behind us. Now, the engineers, the scientists and the operational people have improved in their capabilities, they have worked together and they understand each other. There is a mutual confidence which has grown over the years. That's very important.



> "All the Services need systems with a *technology edge*. This is an edge they could not otherwise have, if they were just to buy equipment. And this is what DSO can offer."

A lot of it comes from working together over many years, on many projects between the DTG as a whole, and DSO in particular, and the Services. They have overcome many difficulties together. Projects never follow a straight line. There are always delays, there are always problems, there are always changes in requirements of the users as the users became smarter... requirements change, and technology is also changing and offering new possibilities. Or sometimes the technology is not as promising as we hoped. So we had to make a change.

As the DSO, DTG and Services worked through these problems together, trust and confidence have grown over the years.

From my experience in the Navy, both sides have derived a lot of satisfaction from seeing things work.

So today, when the ship goes to sea, the men and women know that the systems have been worked through with the engineers in DSO and the rest of the DTG. And they know that these systems are going to work. And that makes a lot of difference!

And the engineers in DSO and DTG know that the lives of those people onboard depend on what they do. And that's true also for the Air Force and for the Army.

This trust and confidence have been built up very slowly over the years. It has been very satisfying to see both the Services and the DSO grow steadily in capability and mutual confidence.

When you were in Joint Operations and Planning Directorate (JOPD) you would have looked at the other Services. Were the other Services as ready as the Navy to use DSO – rather than buy foreign technology off-the-shelf?

There are differences between the Services in their ability to utilise DSO.

All the Services need systems with a *technology edge*. This is an edge they could not otherwise have, if they were just to buy equipment. And this is what DSO can offer.

In the Navy, you have to invest in engineering anyway to build a ship to your specifications, even though you are not building very many ships. So, you want to get the highest value for that, and you are prepared to invest in R&D.

> "In MINDEF, we are very tight with manpower and allocation of money. So the fact that we've been allocating quite a lot of manpower to DSO must be an indication that it is doing something very useful."

In the Army, each platform is relatively not so expensive, and needs to be so because we need many of them. So in the past, they were kept relatively simple and did not require high R&D content. But this is changing because the Army now is more prepared to invest in higher value force multipliers, and also understands the advantage of designing equipment that is best adapted to our environment. And if we require them in numbers, then there is an opportunity to manufacture them locally – the volume is such that our industry will be interested. The investment can be amortised over the larger numbers being produced.

The Air Force has generally bought aeroplanes off-the-shelf because they are very expensive to develop. We also do not require so many of them. The equipment too, tends to come with the platform because the non-recurrent engineering that we have to invest would be very difficult to amortise. So the systems the Air Force needs, we have tended in the past to buy rather than to build ourselves.

But there has been a change in the Air Force because as you move towards more smart weapons, unmanned warfare and expendable systems, then the economics will change. The volumes will go up, and it would make sense to build such platforms yourself, in-country.

In the thirty years since DSO started, has MINDEF or SAF gotten good value out of it? Or are you looking forward to getting good value?

I think we get good value out of DSO. You know that in MINDEF, we are very tight with manpower and allocation of money. So the fact that we've been allocating quite a lot of manpower to DSO must be an indication that it is doing something very useful. Otherwise we would have cut its manpower a long time ago.

But, it may be just a black hole. I mean, the nature of the R&D work is that you have to pour money in, not knowing what you'll get in return.

Yes, there is always a risk in R&D and you can never run away from that. But I think the engineering organisations, DSO particularly, and the Services, today recognise and understand those risks, know how to manage them and get value out of them. That's very important. But you can never be sure, and that's the nature of R&D.

Actually, this story is more the maturing of the client.

Both of DSO and the SAF. It's the co-evolution of both sides which has made for a successful relationship.

Were there any landmarks to this evolution?

I would say that the mid '80s till the late '80s were the critical years. From the user's point of view, those were the years of very rapid growth for interaction with DSO. During those years, if I can put it this way, DSO *professionalised* the way it dealt with SAF.

In the 1970s, early 80's, it used to be very frustrating working with DSO. In my earlier years, I could see a clear difference between the way that DSO was operating with the clients and the way that SPO, for example, was operating with the same clients.

What was the difference?

DSO was very much an R&D office. It had an R&D orientation. Very academic in approach. How should I say this – DSO took a more generous view of schedule and budget.

They had less sense of urgency?

You could put it that way. Whereas SPO was very focused on programme, budget, time, installation, setting to work, these sort of things.

SPO was very driven by their critical path charts. DSO, on the other hand, was very interested in the technology. The approach was really different.

But in the mid to late '80s, the way they restructured, got working together in DTG, bringing DSO into the Long Term Planning Group, the different mode of funding – these factors made a great difference to the working relationship between DSO and the Services.

When the Services started submitting proposals for the AOR, I think that made a very big difference. There was no change in the amount of funds. And the actual monies still flowed through MINDEF. But there was a psychological change in the way DSO began to look at the Services, and what the Services began to demand from DSO. The money comes from the Services' budgets.

That's the key!

Do you approve of DSO becoming quite independent? In 1991, the Executive Agency scheme, and in 1997, a corporate scheme?

I approved it. It was the correct thing to do.

DSO needs a lot more independence in order to operate an R&D set-up.

There are different cultures at work in each organisation. DSO needs to be able to develop its own culture. It needs a certain flexibility to develop its people, its capability. So I think it is important for DSO to be quite different, separate from other parts of MINDEF.

Do you worry that the gulf between SAF and DSO – that you work so hard to bridge – will be opened once again?

Yes, I do. But you see, you go through different phases of evolution in every organisation. Sometimes you come back to the same point again. There is nothing wrong with that provided that is the best given the existing circumstances.

> "Like buying a CD player you have to know what's going on inside the player – how it works... I think in our case, as long as we don't know what is happening inside the player, we always feel uncomfortable. So that is where DSO comes in."

Do you see that DSO may move into wider areas – supporting for instance homeland and national security functions?

I certainly see that. One example is the way the Navy has worked with the Police to build up the Police Coastguard.

So now, some of the equipment that in this example, CSO has produced is in the Police Coastguard, in particular the command and control systems.

We have a happy situation where the Navy and the Police Coastguard are well integrated in terms of command and control. And the CSO technology is being used in a wider sense – not just in the SAF.

There are many other examples where defence technology can be applied – sensors, pattern recognition, facial recognition, recognising motor vehicles – these technologies have applications in other sectors.

That's great. Now Singapore is having so many more of these R&D institutes, do you think that DSO is a successful model that the other R&D institutes will follow?

The R&D institutes function in different levels and ways. DSO is very closely linked with its clients. And the balance between basic and applied research is different from other research institutes and the universities in Singapore.

Their orientation would be much more towards basic research. In fact, MINDEF, through DSO, is working with a number of research institutes and universities to develop synergies with their research.

This helps build capability in DSO and makes for a wider pool that DSO can draw on.

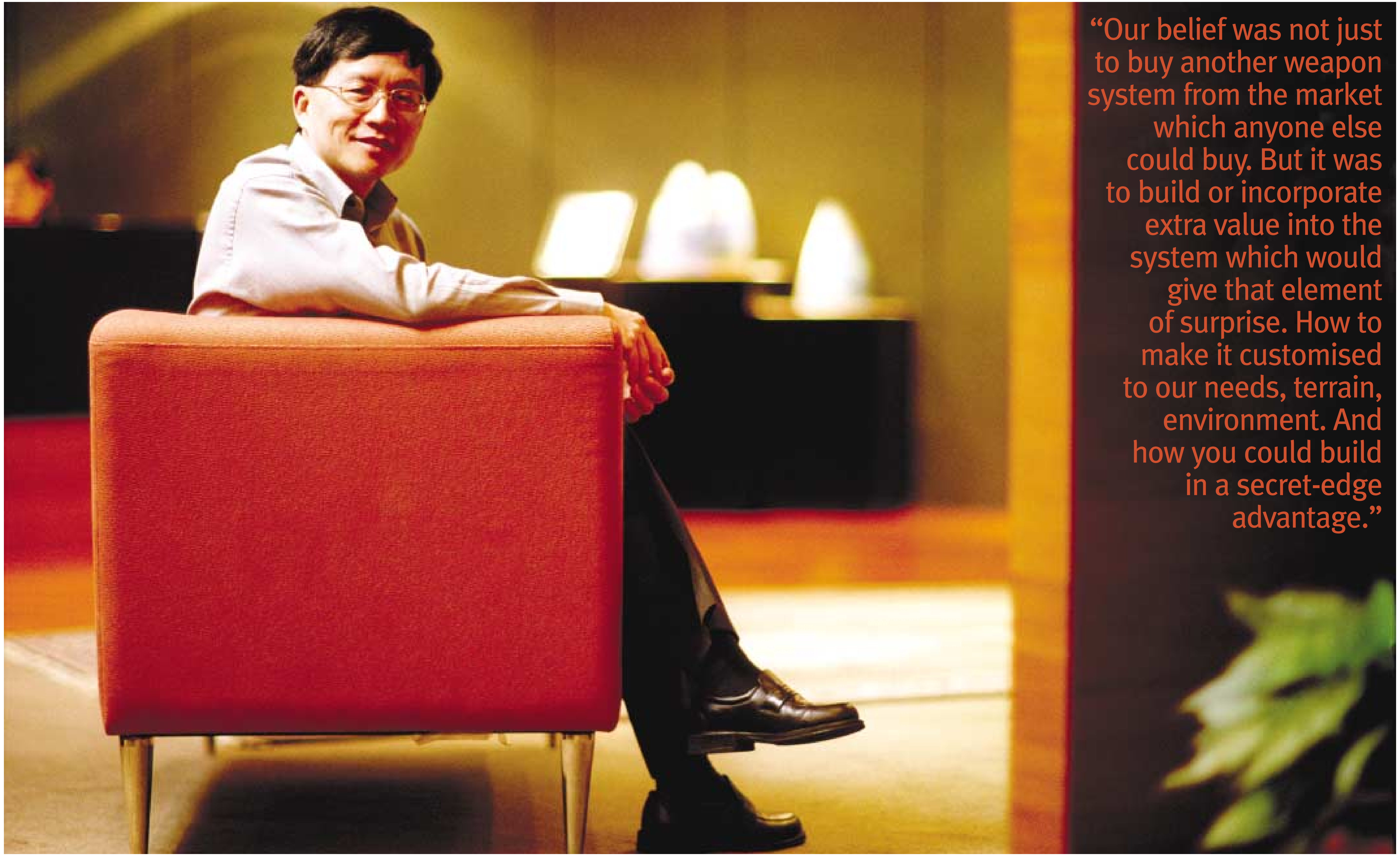
Do you have any last thoughts on DSO, over the three decades?

For a long time, we could not talk about what DSO is or has. It's involved in things that are critical...

If we did not have the capability in DSO, then it would be like buying a CD player where the supplier tells you, "You can only play this one piece of music, if you want to change the music you must come back to me." But you don't only want to play this piece of music. So either you take the player, and figure out how to make it play your own music, or you develop your own player. Either way, you have to know what's going on inside the player – how it works.

I think in our case, as long as we don't know what is happening inside the player, we always feel uncomfortable. So that is where DSO comes in.

And then you can show your soldiers, "See, when you need to play this piece of music, it will play and this will happen." That will convince your soldiers that they have that something extra at the critical moment that can turn the tide of battle.



> "Our belief was not just to buy another weapon system from the market which anyone else could buy. But it was to build or incorporate extra value into the system which would give that element of surprise. How to make it customised to our needs, terrain, environment. And how you could build in a secret-edge advantage."

TEO MING KIAN

Born in Singapore in 1952, Teo Ming Kian was educated at Raffles Institution. Under the Colombo Plan Scholarship, he went to Monash University, graduating with First Class Honours in Mechanical Engineering before entering MINDEF in 1975. Since then, he has taken his Master of Science from MIT, graduating in 1986. It was as MINDEF Deputy Secretary (Technology) that Teo formed the Defence Technology Group (DTG), which coordinated all the logistics, technology and industrial arms of MINDEF. In 1992, he was Permanent Secretary (Defence Development), and in 1995, he became Permanent Secretary (Ministry of Communications). He was Executive Chairman of the then National Science and Technology Board (NSTB), and now serves as Executive Chairman of the Economic Development Board (EDB).

What was your perception of DSO before you became involved with it?

My personal involvement with DSO was greater around '83, '84, when I was appointed the Deputy Secretary of the Ministry of Defence. Before that, I was Director of Logistics which was subsequently re-designated Director, Material Management Organisation or MMO. MMO eventually became DMO, or Defence Materiel Organisation.

So, in these appointments, I had worked with the late Dr Tay Eng Soon when he was Director of DSO. But that was also a period when DSO was quite a mystery to me! At that time, not many people knew about DSO, even within MINDEF.

DSO was seen to be the organisation doing its own things. That was a common perception. Very few, even within MINDEF or SAF knew about DSO.

Well, you can take this perception in two ways. One, that they were doing a lot of secret and confidential things. The other was that very few people, particularly those users on the ground, knew what DSO was doing, or saw them as direct contributors to the overall defence effort! So you can take it as positive or negative, but I think that was the perception.

Even when I was later involved as a Deputy Secretary, Resource Management, I was not quite sure about DSO! Of course, DSO had not come directly under me yet. And we were trying to build up the overall defence engineering capability – not only technical, but in terms of manpower. We had considered DSO as part of the build-up but not directly. It was not very integrated, let's put it that way.

When did DSO come under your supervision?

I was appointed DS (Technology), that was when DSO came directly under my supervision.

And you formed the Defence Technology Group, (DTG).

DTG was formed in '86 when I was appointed DS (Technology) to integrate the various defence technology capabilities in MINDEF.

Can you give us the philosophy behind DTG?

All along, even when I was Director (Logistics), and subsequently Director, DMO, one of the main concerns that I had was, "How do we multiply the effectiveness of a small SAF?"

And a few of us believed very strongly that technology can be a great force multiplier.

Because if we looked at our own SAF, numerically we are not so big, we are in a way, a citizens' army, a national service force. So how do you build up that capability, how do you multiply that capability?

We felt strongly that technology was an area that we needed to enhance. And that was the reason why we needed to build up a strong engineering workforce.

We felt that these engineers could develop the technology which were force multipliers. Then we can really build a "smart" military force.

I think we were beginning to talk about being not only a smart buyer but a smart user as well. And it's not just simply buying equipment, capital equipment and weapons. But how are you able to use these weapons effectively? How are you able to adapt and customise them? Not just to our local conditions but to customise them for maximum effectiveness.

And how are we able to, from there, build a life cycle system for the weapons such that we could have many more sorties, so that we could really maximise and exploit the usefulness of those weapon systems?

And how are we able to develop these things in-house, which could provide the element of surprise?

So that was the consistent thinking and philosophy. We tried to build technological capability and entrench this capability into our SAF.

So it is not just technology?

The principle of technology is not just to buy new weapons like a fighter plane, an intelligent weapon system, or other things, off-the-shelf.

Our principle of using technological capability as a force multiplier involved quite a different thinking altogether.

It was not just in doing R&D for that equipment, but the added value that we could incorporate into it

"I remember I looked at DSO, I was very impressed and thinking how I could exploit DSO's capability to the full. Certainly what was in my mind was that, we can do a lot more with that capability."

to give your weapon system an unexpected or surprise element. And the whole life cycle management of equipment, weapon systems, things like that.

Our belief was not just to buy another weapon system from the market which anyone else could buy. But it was to build or incorporate extra value into the system which would give that element of surprise. How to make it customised to our needs, terrain, environment. And how you could build in a secret-edge advantage.

And then, you took over DSO, in 1986. What did you see? What were your first impressions of DSO?

When I went around DSO, I found tremendous capability in the people. The people in DSO were very impressive.

But one thing I realised was that DSO was probably not well exploited.

This was because, for 15 years, it had been isolated and kept under wraps. Not many knew it even existed.

So because of it being hidden, its capability and its effectiveness were not well exploited.

The Defence Technology Group, with DSO as one of its members, but incorporating DMO, Land and Estates Organisation (LEO) and Systems & Computer Organisation (SCO), was to bring DSO out of the woods and into the mainstream of MINDEF and the SAF.

With DTG, DSO could work directly with DMO, LEO, SCO, CIS and the defence industries, as well as with one SAF to deliver even more.

I felt that there were certain threads that we could use to link right across these organisations and to create synergy.

That was the time when I implemented various co-ordinating meetings, DS meetings and all that. And that's when we began to have much better sharing.

The DTG was to promote synergy throughout MINDEF, SAF and industries.

Right.

There's another thing I want to point out: I felt what was particularly lacking in DSO was the recognition of the things that they do and the capabilities that they have.

We decided to implement the Defence Technology Prize.

I think several DSO officers won the prizes, although very often, we found it tremendously difficult to provide public citations of what they did. But still I think it was very good public recognition for DSO.

These prizes were to show to the users, many of whom were still not well acquainted with DSO, what DSO was doing. So the SAF, MINDEF and industries would be aware of the capabilities that we have in DSO. In that way, greater capabilities could be developed and better exploited.

There were other things besides the prize. We implemented the Defence Technology Seminar, for instance. And the Technology Management Scheme.

DTG enabled us to provide that synergy amongst the many technology groups working in MINDEF, and for their capabilities to be recognised and exploited.

Also, within SAF, we formed committees which linked DSO directly to the SAF – the General Staff and the Joint Staff. The LTPG – Long Term Planning Group – was a key element for this.

DSO did not have a good relationship with the Ministry and SAF before 1986...

I think it was quite "stand alone," quite insulated. Certainly, before 1986, I didn't know very much about DSO. And I was at quite a high appointment as Director (Logistics) then!

When I was in MINDEF HQ, I didn't think any of the issues of DSO was raised at all, even at that level. It was known to a very small circle, perhaps the Permanent Secretary, Minister, service chiefs and Head Plans. That's it.

So it was very insulated and hidden. And divorced, I would say, from mainstream MINDEF.

I am not suggesting that they were not doing good work. They probably were. But if people were not aware of what DSO is, or what DSO knows or what DSO is capable of, then the problem would be that DSO is not fully exploited. The potential is not utilised.

And that was how I was thinking at that time. I remember I looked at DSO, I was very impressed and thinking how I could exploit DSO's capability to the full.

Certainly what was in my mind was that, "We can do a lot more with that capability."

Did any particular project in DSO draw your interest?

One of the application areas that I found most interesting was electronic warfare. But underlining these areas, I found that DSO had a very good foundation technology and capability, which I felt could be employed to many other things.

Did you suggest further projects for DSO at that time?

There was huge potential-enhancing electronic warfare, underwater warfare, things like that. Each would really be a critical field for the SAF.

Was there any resistance within DSO to being brought into DTG? Perhaps DSO treasured their isolation!

I remember it was Tham Choon Tat who was Director of DSO. There were certainly some concerns. If I remember, the concern was a loss of independence and autonomy.

When DSO were on their own, they could do a lot of things themselves. But once DSO got much more involved, and integrated with other parts of DTG or with a larger technological group, and more importantly with the SAF, I think there were some concerns that this independence might be lost.

With a loss of independence, I think they were concerned that DSO would not be able to start projects on their own, or do things in their own way.

How did you convince them?

One major feedback that I got from the SAF was that, the SAF didn't know what DSO was doing. "We do not know what sort of payoff they are giving us." And rightly or wrongly, real or perceived, I didn't think that it was healthy.

> "One major feedback that I got from the SAF was that, the SAF didn't know what DSO was doing. "We do not know what sort of payoff they are giving us." And rightly or wrongly, real or perceived, I didn't think that it was healthy."

This was one major reason that I gave DSO at that time.

I remember telling Choon Tat that if we wanted to see DSO making greater and greater contribution, we must bring up this awareness of DSO amongst the SAF. We must correct any misperception if they exist. No point allowing these things to fester.

I don't think there was very serious resistance. The concern from DSO was more that it involved change. And change is always very uncertain. So I would not put it as resistance to greater integration to the mainstream of the SAF or to the MINDEF.

As part of the reorganisation, we renamed the DSO departments as "laboratories." This was to better align with what they do, experimenting and creating new capabilities, to give them the recognition that they are doing R&D, scientific and leading-edge work.

So we thought that the word "laboratories" would be more accurate, to describe their work.

Then instead of "project engineer", I think we were looking for another work title. Earlier, we called them DESO, or "Defence Engineer and Scientific Officer" thus recognising them as engineers and scientists.

These titles were important for our recruitment as we were aggressively building up DTG.

I remember one recruitment session at the NUS in 1983. When it was question time, one of them asked, "Why do you need engineers to run up and down hills carrying rifles?" I mean that's the sort of perception of what defence engineers were doing.

Over time, I think DTG had come to be accepted as a premier organisation for engineers and scientists. DSO was a key contributor to this. People is key. Good people beget good good people. They have to be managed well.

You know, when we first started, there were very few engineers in MINDEF. So in earlier days, I probably knew every single engineer.

I strongly believed in our people in the whole DTG. I'd been very involved with them, went out with them on trials, even out to the sea. And I saw how they worked, how they thought, the sort of solutions and systems that they had come up with.

But, researchers, scientists – I'm not sure whether you can say that they are unique. But they have their own idiosyncrasies. Some of them would work best on their own. If you were to put some of these people as managers, I think, not only will you destroy a researcher, you would destroy a manager as well. So, it's a double loss.

There are of course researchers who could be good research managers, programme managers as well.

So, I think you need to clearly understand their needs and their idiosyncrasies.

I was very actively involved in the promotion of these researchers and scientists with the Public Service Commission (PSC). In the early days, there weren't very much that we could do. But subsequently we gained more autonomy over promotion. I must give due credit to the Chairman of PSC and some of its members. They became more aware of our needs, and how we had to recognise and promote our R&D people, to develop and build them up.

DSO was really the only place you could do science R&D.

It was then. So the technical challenge was there.

NSTB was set up only in 1991. There were not many research entities in Singapore. Before '91, if you were interested in doing R&D, if you were thinking of pushing the boundaries of technology and science, really I don't think you could find it anywhere outside DSO.

But more than that, I think we were also selling the idea that coming to DSO was more than one's personal aspirations, or one's interest in R&D. They are the people who would really make a tremendous difference to our nation, because they are contributing tremendously to our force multiplier in defence. That they are enhancing our defence capability. So this is a much larger purpose.

I think we had tried to summarise that into a tagline – "Engineering our nation's defence."

We tried to capture, encapsulate this higher, national purpose.

Many of our engineers and scientists felt that what they did really had a tremendous contribution to the nation.

A final thing I want to mention. I didn't think that people at the Government level, Cabinet level, were aware that we had the technological capability in DSO. And that DSO could be exploited to enhance the force multiplier for SAF.

So I recommended that we should really raise the awareness of DSO to as high a level as possible. We began to get the Cabinet and the Prime Minister to visit DSO. There were several briefings. When I became Permanent Secretary in 1991, I was able to push things a little higher.

As a result, I think the Cabinet became a lot more aware of DSO, and of Singapore's need to build up science and technology as a force multiplier.

And when the Gulf War in 1991 demonstrated how technology can be so effective in winning battles, many people in the Government became very interested.

I think that provided a tremendous thrust and impetus to the development of DSO and DTG. Before that, while DSO had great capability, it was seen almost like a garage, you know!

Dr Yeo Ning Hong was the Minister. I think he referred to DTG as the "Fourth Service." So in addition to the Army, Navy and Air Force, you have the science and technology arm. He was very supportive, I must say. In fact, I would say all the Ministers that I had served at MINDEF were very supportive.

And MINDEF had the confidence to leave DTG quite autonomous, to help build the defence capability. MINDEF was operating at block vote budget. So we were able to do things a little more independently than other Ministries where they have to have individual line items budgeted for. We had far more autonomy, flexibility to change things and to initiate new things.

But it posed tremendous discipline and responsibilities on ourselves, conscious that we were responsible for the entire block vote. We had to be even more rigorous, and put systems in place, to make sure that the budget was well utilised.

By the 1990s, a lot of sophisticated defence systems became freely available on the world market. Did you have pressure to buy off-the-shelf technology? rather than invest time and resources into developing your own?

Oh, all the time, constantly. The whole issue was always, "Build or buy?"

In almost every major weapon system, we have been subjected to that sort of argument. Some more strongly, some less.

So certainly, when we started having more contact, discussion, between SAF and DSO, and got DSO much more involved with the SAF, we had far fewer problems. The SAF was very, very supportive of many of these new weapon systems that we developed.

In certain equipment, we need to ensure that our own system, our own thinking, our own secret edge needs are preserved. These are a little easier to say, "Build", for example for electronic warfare system.

Having achieved the integration of DSO into DTG, why did you let DSO go in 1991 as an autonomous, Executive Agency?

Well, we didn't really let DSO go in that sense.

We wanted an integration and synergistic arrangement of the technological entities, so that we could achieve the maximum effect. That was the purpose of the Defence Technology Group.

But we also understood that each of these organisations and entities had to have certain autonomy in managing themselves.

What do you mean by "autonomy"? Is it financial, or manpower?

Well, it's more than that.

You don't want to confine and restrict people's innovative capability.

You want to encourage people at all levels to be able to come out with ideas and suggestions. If they are too much restricted and circumscribed, I think, very good people will be undermined.

And yet you cannot allow everyone to run totally on their own, in chaos and disorder in all directions.

> "Managing R&D is quite different from managing businesses. I learned quite a bit from DSO that I implemented in NSTB when I was appointed as its Chairman in 1993."

So, you want to have a certain direction, synergy, integration. And yet you want to allow a certain chaos, independence, for innovations to come about.

Well, I'd say that it's not just for DSO but DMO and other DTG organisations.

And it's not so much whether they have enough freedom or not. But you do not want an organisation which is centrally planned – that every decision has to be taken right up the very top, made by a small group of people.

If you do that, you cannot fully exploit the capabilities, the intelligence and the innovativeness of the people.

You were not involved in the corporatisation in 1997.

No I had left already. Although I would say that the idea of corporatisation was discussed at all times. It was a question of whether we should form a separate statutory board, as DTG, or whether each of the elements of DTG, like DMO, DSO and SCO should form their own separate statutory boards. Or whether we should corporatise some of the elements. These were all being considered. In the end we went for a mix of solutions.

But the thinking was that, in recent years, since 1991 when NSTB started, there is increasing R&D activity in Singapore. So I was concerned – I talked to Su Guaning about this – that DSO would start to lose people. So some of the ideas I thought of was letting DSO people do start-ups. And yet link back to DSO.

These are ideas which DSO can do now, as a company. It would not have been possible to do it before DSO became autonomous.

Was DSO a trailblazer?

I think that DSO has led the way in Singapore's R&D environment. It was the first, the oldest of the research institutes.

Managing R&D is quite different from managing businesses. I learned quite a bit from DSO that I implemented in NSTB when I was appointed as its Chairman in 1993.

How to recognise and value researchers and scientists, for one. How to organise projects and facilities. Create the right environment for innovation.

And also, recognising that payoff does not come immediately. Really, R&D is an investment, rather than an expense. There are companies that would cut their R&D budget the moment they hit trouble. These companies would not survive long.

R&D is an investment for a longer horizon. The strategy is long term. The process is the development of people – training, developing people who are innovative and can think up solutions.

In DSO, we began to have much closer links with the universities and research institutes to leverage and collaborate with them. We also had quite a bit of joint R&D with the universities. And some research centres in the two universities were started by funding from DSO or MINDEF.

So certainly I would say that DSO has contributed much to Singapore's overall R&D environment and the entrepreneurial environment.

You left MINDEF in 1995...

Yes. Peter Ho succeeded me. You should talk to him.

"Accountability is fine but it has to be "after the fact". The only way for DSO to operate in that environment is to create a shell that defends the activities so that the research is not too visible. Let people work! When it's the right time, you have something to show, only then you bring it out. I think that's the only way."

SU GUANING

A President's Scholar, Professor Su Guaning is a true pioneer of DSO, having joined in 1972 as the fourth member of staff. He holds a Bachelor's, Master's, and PhD in Electrical Engineering from the University of Alberta, California Institute of Technology and Stanford University respectively. In 1983, on his return from Stanford, he became Deputy Director of DSO. In 1986, he assumed full Directorship and led the organisation into a new, research-oriented phase. He then went on to MINDEF as Deputy Secretary (Technology) before assuming his current position of Chief Executive of the Defence Science & Technology Agency (DSTA) in 1998. Professor Su is Adjunct Professor in the Department of Electrical and Computer Engineering, NUS, where he teaches radar systems and signal processing.

Professor Su, you were amongst the DSO pioneers. Then, you left on a post-graduate scholarship in 1980. Can you pick up the story from there? Perhaps you can start from 1980, when Dr Tay left DSO to become a politician and Minister of State.

In actual fact, that was a very bad moment for DSO. In 1978, there was tremendous agitation from some DSO people for post-graduate scholarships. The first one who got it was Lim Kok Huang. She went to MIT in '78. Then in '79, Foo Say Wei went. I went in 1980. Ho Ching also went. Several of us were out of the country when Dr Tay was called into politics. So his departure left a significant vacuum.

Tham Choon Tat was made Assistant Director. Philip Yeo was the Permanent Secretary at that time, and he was Chairman of the EXCO. So he ran the place. We used to see him quite often. Sometimes he would just come into the lab, tap you on your shoulder and say, "Hey, what are you doing?" That's his hands-on style!

Philip Yeo took the organisation into a new phase. I think he gave the organisation a fair bit more power.

Philip Yeo was a very different PS from Joe Pillay, or Pang Tee Pow...they didn't seem to be very much involved.

In the early years, the Defence Minister was Dr Goh Keng Swee, and he used to personally chair the Steering Committee. Mr SR Nathan had a Director SID position, so his officers helped DSO from the admin and finance side. Dr Tay Eng Soon reported to Dr Goh, directly. So no Perm Sec's were involved.

It was only later, the Minister – Howe Yoon Chong, gave up the role of Chairman to Philip Yeo who was then Perm Sec and chairing the EXCO.

Why was Philip Yeo so involved?

He was personally very interested because he's very much a science and technology man. He saw that we could do a lot with the set up. So I think it was very good for DSO.

When did you return from your studies?

I came back in 1983. There were three of us – Tham Choon Tat as Director while Ho Ching and I held Deputy Director positions. After a while, Tham left for ST and Ho Ching left for DMO, so I was made Director, in 1986.

When you took over as the Director in 1986, it was the time when the Defence Technology Group (DTG) was formed. DTG was to unite and integrate the technology organisations in MINDEF. How did that impact on the organisation?

A lot of processes became a lot more complicated! Actually this started in 1985 when Philip Yeo left, before DTG formation. Spending money, how to buy things, procurement, paperwork... suddenly the whole MINDEF bureaucracy descended on DSO and I think it got a lot of people quite unhappy, actually.

It was because MINDEF decided to put us back into the system. It was different approach. You see, Philip Yeo was quite happy for us to be out of the system. He had the other organisations in the system, fair enough. But he had DSO out of the system. He didn't mind. In fact, he was quite happy to do that. Because then he could do things that he wanted through DSO. He's an anti-bureaucrat.

I was reading some of your circulars from 1986, and it sounded like you wanted to wipe the slate clean, start all over again. And you wanted to change DSO in a radical way.

Well, there were different cultures in the different parts of the organisation. I think there was a lot of uncertainty about the future of DSO.

DSO had become quite big, very fast. There was a big recruitment of engineers in 1983.

And DSO was continuously under question, under fire, from others.

Somehow there was a feeling in MINDEF that DSO was just playing around. Other organisations, departments, other people were doing things but DSO was just playing around.

I mean, the rationale for the existence of DSO had always been an unresolved question. I think we didn't establish, even by 1985, the case for having DSO.

Whereas, now, DSO is quite well established.

> "Developing products is not what R&D hangs its hat on. DSO will not be able to survive on that. So we had to switch to a higher plane... to research."

Now, no questions are asked. But in 1985 or 1986, when I took over, there were still plenty of questions.

What happened, what changed, between 1986 and now?

Well, I think that, to be recognised, to be relevant, you have to be doing something that nobody else is capable of doing. And some of the things we were doing in 1985, before I came in as Director, were a little too close to things that others can do.

So, I mean, you got to have some breakthrough stuff!

You have to be able to say, "I can do this" and then show it to SAF. Not a "me too" kind of approach. You just can't survive.

But even when I came back from my post-graduate studies in 1983, I felt that DSO had to change, shift to doing research. So this was what I announced in 1986.

Now in 1986, research was a dirty word!

So this focus on R&D was quite new. That took a while to build up.

You know, there's a difference between a bunch of people who are used to just designing things, to a bunch who can do breakthrough stuff. Stuff that nobody else has done before.

That's why I started, in 1987, sending people on scholarships for their PhD. If you want to get your PhD, you have to do breakthrough work! You can't get a PhD by just designing or developing products.

Developing products is not what R&D hangs its hat on. DSO will not be able to survive on that. So we had to switch to a higher plane.

You switched DSO's mission to breakthrough R&D.

Trying to make a case... but it took a while to build up. There were good people in DSO. The major change was to shift DSO people to research.

Were there obstacles?

I think the obstacle was that, people were not used to doing research. You know Singapore has a very pragmatic culture. Unless you can see the end point, a time frame, they would say, "Why do I want to go down this road?"

But if you're going to do research, all you can say is, "This is the general direction. I can't tell what will come out of it at the end."

So you need to have autonomy. So that you can do certain things, you can allocate resources there, yourself. Then you have some time and space to do something, provided nobody discovers it early enough!

Then after a while, you have some results, you show them. Then they'll tell you, "OK, very good. Carry on."

That's why we needed autonomy from MINDEF. In the Government, everything must be accountable. Every dollar spent must be accounted for, where you spend your money, who gets what, results and so on.

But in research, no such thing! Accountability is fine, but it has to be "after the fact."

In research, how do you predict what is going to happen? How are you going to predict breakthroughs? You don't do that! How are you going to predict something that you don't expect? It's impossible.

So, the civil service environment was quite hostile to research.

So the only way for DSO to operate in that environment is to create a shell that defends the activities. So the research is not too visible. Let people work! When it's the right time, you have something to show, only then you bring it out. I think that's the only way.

Is that how you ran DSO as a Director?

Yes, in a way. Because you have a lot of external dealings, contact, with the rest of MINDEF. So you have to hold that line...like a shell...and protect your people inside. Inside, you have to be relatively flexible. You have to give people the space, the leeway, to do things.

Can you give an example of how you could protect people in DSO, at the same time, giving them space?

In the late '80s, I put up this paper. It was when Teo Ming Kian was Perm Sec. Essentially, we were trying to crystal-ball gaze to say what size, how many people, we needed for DSO.

Because MINDEF was getting more and more uncomfortable with the growth of DSO as it got bigger and bigger. Because they didn't know what came out of DSO! They couldn't pin a value on the thing!

So I did that with Teo Ming Kian. Basically, we went through a number of areas. So there was a paper I put up that said, "So many for this area, so many for that area." *Yah!* We actually went through quite a high-level process, but we got that paper accepted.

Well, if you put it like this, looking at each individual area, nobody will argue. And then the number of people – this is a judgement call. So in some sense, they trusted my judgement and also, it's not really that high.

That, in a way, is an example of a shell. That means you've protected a certain number of people. Then within this number, you don't have to stick to this. I mean, if you find something that is developing better, then you put more people on that thing. If some thing is not going forward, then you may not want to invest your people, your resources. So within this shell, you can let things grow.

So in that way, we moved towards the Executive Agency (EA) framework in 1991.

The EA helped. Because then, MINDEF looked at the overall resource. It's accountable – the EA had an account. But it also gave a certain autonomy inside the organisation, to do certain things. So that also allowed DSO to work.

The EA scheme created a shell, within which you enjoyed autonomy.

The concept of Executive Agency really means having a more complete set of accounts, and basically you have a bottomline. Although it's a "pretend" bottomline – it's not a profit or money paid out. But it is real in that it appears in the books of the Finance Division.

So as an EA, we were accountable for the funds, and we could show the numbers at the end of the year. You have a Supervisory Board that you deal with, answer to. You don't have to go through the MINDEF bureaucrats, the policy committee, whose standard answer was always, "No."

So there were limits and accountability. But within these areas, we could do what we wanted.

Can you give me an example of something you were able to develop because of the "shell"?

OK, I'll talk about two areas.



"You have to be a guerrilla fighter! That's the only way to do technology. Look, I can't write out a plan and announce to you, "I'm going to be here!" No way!"

I think we first went into computer security in 1994. At that time, nobody asked us, nobody talked about it, but we started doing something. I asked William Lau to do something and he got a few people involved. As an EA, we didn't have to ask anybody. We just went and did it.

So a few years later, when computer security became hot, we already had people working on it! So we were able to say, "Hey we can do this." Now it's quite a major area in DSO!

If you talk about synthetic aperture radar, that's another field. This was a subject we had been talking with other countries for some time. So we had been looking at some of their equipment. I think, in a sense, we were trying to go according to our old ETC strategy – trying to work with other people, boot-strap ourselves. But we didn't get very far.

So it came to a point, "I think we have to do something ourselves." And we went ahead and did it.

So right now, we have our own capability in computer security and radar, these are significant areas in DSO! Now, MINDEF is very happy that DSO has these capabilities!

You can plant seeds. But it's only when they start to grow big, you've got the rationale for their existence, you are able to justify them. Because these seeds, they become noticeable only when they are big. But in the first phase, when you are just getting the seeds started, planting them – no one will support you!

But you have to be like a guerrilla fighter!

That's R&D, you know? You have to be a guerrilla fighter!

That's the only way to do technology. Look, I can't write out a plan and announce to you, "I'm going to be here!" No way!

Look at Chemical Defence. We set it up when there was no firm operational demand for such an area of R&D.

But since we were an EA, we were able to put some resources in to Chemical Defence. We recruited a number of people

"MINDEF was getting more and more uncomfortable with the growth of DSO as it got bigger and bigger. Because they didn't know what came out of DSO! They couldn't pin a value on the thing!"

without having to worry too much. So we put in some resources.

Then, when we had developed some experience and expertise, we could go to MINDEF and SAF and say, "We have chemical defence."

We had put in the resources for some time already, DSO people knew about the area and what needed to be done. That is one example where DSO has moved ahead of demand.

But that is because we had the freedom to move ahead.

Who put forward the idea for an EA, the Executive Agency? Was it DSO?

Remember the time we got pulled back into the MINDEF system? In 1985 or '86?

We were trying to get out! Because it was a real dampener on people who wanted to do R&D.

Because everything you wanted to do, not only do you put up endless papers, you've got to go to somebody and justify. And everything you asked for, they'll say, "Why? Why you do this?"

It was very frustrating because you feel there was a lot you can do, but you can't do it.

That's why we pushed for the EA scheme. We thought we would have a lot more independence that way, to decide on our projects, to direct our resources, that sort of stuff.

Did anyone oppose the EA scheme?

Actually no. Because at that time, there was a coincidence of interests. Because MINDEF also wanted to know how much resource was going into DSO. So they could control their resource allocation.

So from DSO's point of view, we were able to say, "Give me the resource, what you're already giving to me and I'll manage it myself." For DSO, we wanted a lump sum, which internally we were free to allocate and manage. DSO was better off that way.

And from MINDEF's view, they were happy because they knew exactly what funds were going into DSO.They have control over the total. They can limit, cap the amount. So it's also good for them. So nobody really opposed it.

In a way, it was a victory for DSO. Because you want to have an organisation that runs like a black box. They just give you the money, lump sum, an overall budget.

The EA wasn't completely that way, but we had more autonomy than before.

Was the EA scheme successful?

I guess so, because it went a further step, leading to the corporatisation of DSO in 1997. Because without the EA as an intermediate step, it would have been very hard to proceed to the next step which was corporatisation.

Can you explain the 1997 corporatisation, which established DSO National Laboratories. The format was that DSO became a company limited by guarantee.

The whole purpose of corporatisation was to get DSO its own manpower scheme. This was so that DSO could run itself and its own people.

DSO wants innovative people. And innovative people need to have space. And you've got to give them other resources including people and financial resources.

And this is much easier to do if you are independent.

This is the reason why we pushed for autonomy.

Now, EA didn't actually get us the autonomy we wanted. That's why we pushed for corporatisation, which followed in 1997.

Although I must say, the 1997 corporatisation didn't actually achieve the intended effect because MINDEF still didn't let us operate a flexible manpower scheme.

So even though corporatisation was granted in 1997, you did not achieve your purpose?

No, because MINDEF didn't let us free on the manpower. The key was manpower.

And it remained an issue, outstanding, until the rest of the DTG formed DSTA in 2000.

For us, I think that a flexible, autonomous manpower policy was the biggest prize in terms of going corporatised. And we didn't get that initially. We were able to hire the kind of people we wanted in DSO, but it wasn't quite as independent as we hoped.

What were the other implications of corporatisation in 1997?

In fact, some effects were negative. I mean now there was real money being paid to DSO, just like a commercial company. Not just "pretend" bottomline like before in the EA.

So in 1997, when DSO was a company, it had more pressure, financially. And yet, at the same time, they were not quite free on manpower, hiring and promotion. So I think corporatisation was actually quite a negative thing. An anti-climax.

I think one of the drawbacks of the corporatisation was that you had to look quite closely at the finances and how you were funded. Somehow that tightened things, and reduced your space.

Previously, with the EA mechanism, I think it was a little more flexible because we were still in the Ministry. So you could tap various resources within the Ministry.

> "In a way, it was a victory for DSO. Because you want to have an organisation that runs like a black box. They just give you the money, lump sum, an overall budget. The EA wasn't completely that way, but we had more autonomy than before."

Once you were outside, everything was out in the bright sunlight, everything was funded on a project basis, actually you had very little room!

You didn't get any more money unless you got a project – but to get a project you had to prove, justify to somebody. Sometimes it's very hard to be flexible and innovative if you have to justify each project and get the money every time.

So perhaps DSO has become too commercial?

I don't think DSO is too commercial. But I think DSO needs a bit more leeway and flexibility. I think some things have been done along the way, in the last few years. And this has loosened things up.

Well, when you are first set free, you want to do more of the things you couldn't do before.

One, is that you want to be contributing in different ways, not just defence. And the other thing is that your performance is a little bit more tangible, in terms of recognition, in terms of what can be published, and how you set up the charging and financial returns.

But you have to balance this whole thing, otherwise you jeopardise the fundamental existence of DSO.

You know, if something can be done in the university or institutes, get them to do it! If something can be done by the industry, get them to do it. DSO must focus on its unique strengths, and do things which cannot be done elsewhere.

I don't think we should expect DSO National Laboratories to become like a commercial company. It won't survive.

Why not?

Well, I can see only two paths. One, is you concentrate on defence and you try to squeeze as much out of the contracts as possible. But that can easily become a downward spiral. Because there is an issue of trust – are you doing this because it's good for SAF, or are you doing this just to make money?

And the stuff DSO is doing, for most of it, SAF doesn't have a choice. So if DSO charges what the market can bear, after a while, SAF will say "I don't like doing work with them because they are always trying to make money." Then they start building another group, in-house, to do their work. Another ETC or DSO. The whole thing starts again!

The other path is, you start to look at all the excellent manpower resource in DSO and you start looking to make better money in the commercial sector and then you start shifting your resources there, then you may lose the MINDEF business!

And I am not certain that we are going to be successful in the commercial side. I know that scientific and technical-wise, DSO will be successful. But success in the commercial side is a lot more. There are a lot of business issues, the market, and meanwhile, you end up being neither here nor there.

But it was the year 2000 before DSO finally succeeded in becoming fully independent.

Yah! DSO finally got our own Employment Scheme in 2000.

Because DSTA was formed. And all the technical people in MINDEF moved to DSTA. With that, there was no reason why DSO couldn't have total manpower freedom.

Also by now – by the 1990s, DSO had to compete for manpower. Many other R&D institutes have come up, and researchers are at a premium. For DSO to compete in the open market for its people, it must have freedom to hire, fire, and promote according to market rules, not according to PSC or MINDEF rules.

Wesley D'Aranjo was Deputy Secretary (Technology) when you were still Director of DSO. Can you describe his contributions to the evolution of DSO?

Wesley was very supportive of DSO as DS(T). He was very interested in the technology we worked on, and often told people – tongue in cheek – that he would rather trade places with me! In his dealings with acquisition projects, he was very conscious of the potential of enhancing DSO's capabilities.

I would say his biggest contribution to DSO in the years before the formation of CSO (C3 Systems Organisation) was his support of the new projects replacing proprietary systems with systems using commercial, off-the-shelf computers.

It was daring at the time. It took a leap of faith to believe that an untried group of software engineers in DSO, used to working on proprietary systems, could actually replace the foreign contractors in much of the work. This support was vital in building up the command and control capability that ultimately became the core of CSO and the IT group in DSTA today.

It's the 30th Anniversary. Can you describe the 30 years of DSO's history in terms of years and themes?

I would characterise it this way. For the first ten years, the seed was planted. We were sort of going in this direction, trying this, trying that, a little bit of a "Brownian motion." I think the whole of the '70s was that way.

Then Dr Tay left in 1980. The next period, Philip Yeo was more or less the guy in charge, 1980 to 1985.

This phase, early '80s, had a clear sense of direction. I think Philip Yeo tidied things up. Whereas Tay Eng Soon was more academic. Philip Yeo believed in setting clear directions, go! We were all clear what to do. In case of doubts, you could always go to him. You knew who was in charge.

And 1986?

I think in the second half of the '80s, we were growing fast, and we finally had enough resources. So we were building real capabilities which started to be evident in the next decade, in the '90s. But we were constrained by the bureaucracy. That's why we pushed for autonomy, which we got in 1991 under the EA scheme.

And so the third decade, 1991 to the present?

In the third decade, we had real R&D capabilities. We were clearly able to deliver things.

> "DSO has reached a level where suddenly the whole scene opens up! And you start to feel, "Actually there are many things I can do!""

> "I would characterise it this way. For the first ten years, the seed was planted. I think in the second half of the '80s, we were growing fast, and we finally had enough resources. In the third decade, we had real R&D capabilities. We were clearly able to deliver things."

And we have started to benchmark, internationally. We are able to sit at the same table with the R&D establishments of all these advanced countries, and have a real exchange. In the 1970s and '80s, we could not have done that. We had nothing to exchange.

And that happened when Peter Ho came in as Perm Sec. He broadened our international collaborations a lot, setting up the international panel of advisors which gave us a lot of exposure.

And now, we are able to collaborate with others because DSO can come to the table and say, "We've got this interesting research." You bring people to visit and they will be impressed in a few of our areas.

When Peter Ho came back in 1995, I remember him saying that he saw a drastic difference from the time he left MINDEF in 1989, to when he returned. The difference was clear.

And what's next?

Ask Tong Boon! It's not my call. You know, it's hard to say what's next unless you are running the place and you have a real appreciation of the issues.

I am in the Board, still. I think one of the key challenges facing DSO today is how to divest things that industry ought to do, so that we can concentrate our resources on the real breakthrough stuff.

DSO has reached a level where suddenly the whole scene opens up! And you start to feel, "Actually there are many things I can do!"

Then the challenge is to choose your core areas so that you have maximum impact.

You have to choose, you have to focus. If you have a clear focus, a clear direction, people will say, "*Wah*, great place! You produce a lot of wonderful stuff!" As opposed to people saying, "*Aiyah*, it's such a big place and you waste a lot of resources! "

I guess those are today's challenges.

BUILDING UP CHEMICAL AND BIOLOGICAL DEFENCES

The sarin attack in the Tokyo subway in March 1995 focused world-wide attention on the frightening possibility of chemical weapons being used by terrorists in an attack on civilian populations, as a means of furthering their causes. The attacks on the Pentagon and the New York World Trade Centre on 11 September 2001, and the subsequent spate of anthrax attacks through the mail, heightened worldwide anxiety about chemical and biological weapons being used as weapons of mass destruction by terrorist groups. The chemical and biological defence research and development capabilities in DSO serve as a vital means for Singapore to build up its defences against such threats.

The Infancy Stage

While chemical defence research actually commenced as early as the mid '80s in DSO, recruitment for professionals in this area really started in earnest in the late '80s, when a small group of NUS postgraduate students chose to begin their post-PhD careers in pioneering this area of research for Singapore in DSO. This led to the setting up of a small laboratory which was equipped only with the basic analytical chemistry facilities to undertake testing and evaluation, and technical services for the SAF.

The initial work managed to spark off some interest in this field, and more funding was subsequently made available for long term projects. This allowed the fledgling group to build up some capabilities in the niche areas of research, including tropical protective materials, non-aggressive decontaminants, water purification technology and the rapid analysis of chemical agents.

The Applied Chemistry Laboratory

The 1995 Tokyo sarin attack triggered the requirement for the rapid identification of agents used in terrorist incidents to facilitate medical treatment and site decontamination. It was also the year when the group, known then as the Applied Chemistry Lab (ACL), had a breakthrough in developing new technology for the rapid sampling and analysis of chemical agents. The participation of the laboratory was sought in several exercises to provide much needed support in site assessment, undertaking sampling and analysis of the chemical contaminants, and advising on site decontamination for contingencies involving the use of chemical contaminants.

This involvement paved the way for ACL to be the de facto national agency for chemical defence research, and for ACL to be engaged as the technical consultant in the handling of incidents requiring its expertise.

At around the same time, ACL's chemical defence research was extended to cover skin decontamination and studies on nerve agent inhibitors and reactivators. The latter study led to the current work on pharmacology and toxicology, which has provided much insight into the effects of various nerve agents in the body and the possible optimisation of antidotes for treatment of nerve agent intoxication. The building up of scientific capabilities

DSO scientists undertaking the Static Drop Test for evaluating performance of protective garments.

in chemical defence was subsequently also extended to cover a number of biological defence areas.

Learning from Collaboration

The group's collaboration with similar chemical defence groups in Sweden and France has led to the building up of several significant capabilities in ACL. One good example is the verification capability, which was developed quickly through the attachment of some of our staff to Sweden's national defence R & D establishment to work with analytical scientists there. This attachment programme allowed our researchers to shorten the lead-time in building up a world class analytical capability. From a modest laboratory equipped with a basic gas chromatograph-mass spectrometer, DSO is now equipped with sophisticated instruments for analysis by gas chromatography, liquid chromatography, tandem mass spectrometry and nuclear magnetic resonance spectroscopy. Coupled with the analytical expertise, the group is now able to rapidly and unambiguously identify traces of chemical agents and related compounds, including the precursors and degradation products in complex environmental and biological matrices.

The solid phase micro-extraction (SPME) technology which was investigated jointly with Sweden also helped position the DSO chemical defence group as a leading laboratory in the verification of chemical agents.

The capability build-up has allowed DSO to participate in the international inter-laboratory proficiency test organised by the Organisation for the Prohibition of Chemical Weapons, an exercise with the objective of designating competent laboratories world-wide to undertake verification tasks in the event of a possible attack. DSO's Centre for Chemical Defence was amongst the 20 laboratories world-wide selected for participation.

The collaboration with France also contributed significantly to our capability in physical protection, particularly in the studies of materials for protective garments. The knowledge gained from studies in formulation and evaluation of decontaminants also led to the development of DSO's capability in non-aggressive decontamination emulsions today.

Expansion and Undertaking New Roles

By the mid '90s, it was clear that the laboratory space could no longer handle the volume of research work in DSO's chemical defence research programme.

Two new buildings were completed in October 1998 in Marina Hill to house the facilities for the detection, verification, physical protection, decontamination, biomedical and microbiology programmes.

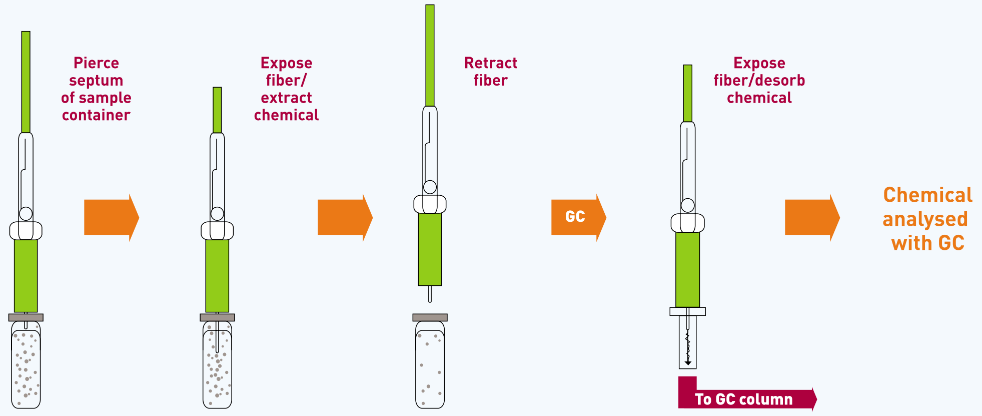
Since June 1999, the group has been formally known as the Centre for Chemical Defence as part of DSO's restructuring. It is now geared to respond quickly to the needs of its customers. DSO's knowledge in global chemical disarmament issues was acknowledged nationally when the group was tasked by the Ministry of Trade and Industry in 1997 to provide the manpower expertise for the National Authority in implementing the Chemical Weapons Convention in Singapore. The work of the National Authority includes integrating the convention's requirements with trade and industrial regulations, advising relevant governmental and industrial bodies on the requirements of the convention and co-ordinating with the Organisation for the Prohibition of Chemical Weapons on the implementation of the convention in Singapore.

DSO is therefore in an excellent position to serve the nation in strengthening its defence against chemical and biological weapons. Its research and development staff have now developed expertise in many specialised areas spanning the fields of chemistry, chemical engineering, molecular genetics, microbiology, biomedicine and materials science.

SOLID PHASE MICRO EXTRACTION (SPME)

The retrieval of minute traces of toxic chemicals from a given environment or location and their expeditious analysis and identification became, after the sarin attack in Tokyo in March 1995, a critically important area of research in chemical defence technology. Until then, the sampling and identification of toxic chemicals from environments such as soil, water and building materials required tedious and time consuming procedures which could take up to several hours. The sarin attack drew attention to the fact that these methods were far too slow, as the results of analysis are needed quickly in responding to such incidents. Knowledge of the type of toxic chemicals involved in such incidents is of the utmost importance, as it can make a vital difference to the medical treatment of casualties.

Solid Phase Microextraction: A simple sample extraction process



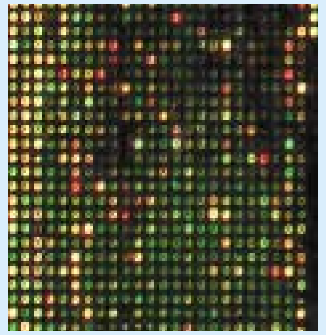
Two years of intensive research on the use of solid phase micro-extraction (SPME) at DSO provided a possible means for the rapid sampling and extraction of unknown toxic chemicals. DSO scientists adapted this novel technology, which was originally invented for the analysis of traces of impurities in petroleum, for the rapid sampling of minute traces of toxic chemicals used in chemical warfare and their degradation products from a particular environment, in just 15 to 20 minutes.

The new technology utilises a one-centimetre long piece of fibre which is about a millimetre thick, to pick up these chemicals from the contaminated materials. The fibre can be analysed by gas chromatography (GC) or high performance liquid chromatorapgy (HPLC), as well as by mass spectrometry. Because the toxic chemicals can be sampled so easily and quickly, the identification and verification process is consequently shortened to about an hour as compared to the previous conventional process taking several hours. This method is a significant breakthrough for the rapid identification of contaminants in the event of a chemical attack or accident.

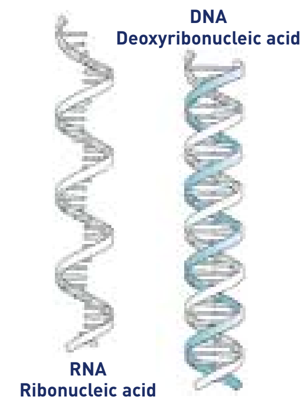
This rapid verification capability based on SPME, which DSO initially pioneered for chemical agent extraction and analysis, is now capable of being used for fungal and marine toxins. DSO's scientists are now working to further adapt the SPME concept to monitor the pollution of the environment by chemical contaminants and toxins. DSO is confident that it will be able to leverage on its achievements in SPME to remain at the forefront of advances in this area of research and development.

MICROARRAY FACILITY (HOST RESPONSE STUDIES)

The Microarray facility at DSO.



High density microarray of 6000 spots/cm^2



Macrophages, which are a type of white blood cells, play a central role in defending humans from infection. Apart from helping to kill invading micro-organisms, they also play a major role in initiating, maintaining, and resolving host inflammatory responses by releasing chemicals known as cytokines and chemokines. They are also a habitat for a group of pathogens which utilises them as a refuge from extracellular defence mechanisms. To turn the hostile environment of an activated white blood cell into a sanctuary, the pathogens which invade macrophages have developed a multitude of survival strategies. This puts considerable stress on the infected cells, which respond by activating an array of defence mechanisms aimed at eradicating the invaders.

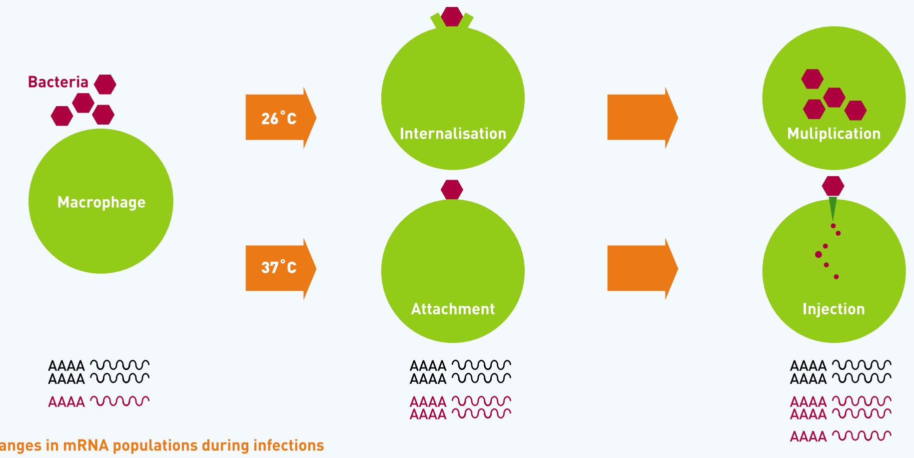
During the battle between the macrophages and the invaders, changes in the amount and types of proteins produced by the macrophages occur. All the proteins that a cell can possibly produce are encoded by long molecules called DNA. Each protein corresponds to only a short segment of the entire DNA molecule. The DNAs of all the cells of an organism are identical. Differences between cells exist because each cell type makes a different subset of all the proteins coded for by the DNA. In order to make a particular protein, the cell generates a copy of the segment of the DNA that codes for that protein. This copy is called mRNA. Although this copy is slightly different chemically from its corresponding DNA segment, it is identical in terms of information about the protein that is to be made. Since each of the different proteins has its own mRNA precursor, instead of tracking directly which proteins are present in a cell, one can track the mRNAs instead.

Until fairly recently, it was only possible to determine the expression level of each gene at a time. However, with the development of gene microarrays or "gene chips", the amounts of each one of thousands of different mRNA species can be determined simultaneously. Microarrays thus provide a more complete picture of the state of the cells in question than ever before.

DSO's microbiology group is one of the first in Singapore to make use of gene microarrays. Using microarrays, the microbiology group aims to elucidate and characterise the events and changes that occur inside macrophages infected with the micro-organism *Yersinia pestis*, the bacteria which causes the dreaded disease known as the black death. The infection of the macrophages may take place by internalisation and multiplication of the bacteria, or by their attachment and subsequent injection. These infections may be tracked by identifying the changes in the associated mRNA in the macrophages. The knowledge gained will not only lead to the understanding of the events which take place in the macrophages as they attempt to defend the body against attack, but will also aid in the design of novel strategies to diagnose and combat the infections.

Thus far, the microbiology group has identified tens of genes that are affected by *Yersinia pestis* infection. They include the cytokines mentioned earlier, as well as factors which regulate the production of mRNA, molecules which receive messages from other cells and molecules involved in cell replication. Work to investigate all these changes is underway, which will help the group not only to better understand the action of the *Yersinia pestis* bacteria, but also to devise strategies for dealing with other virulent micro-organisms.

Infection model of *Yersinia pestis*



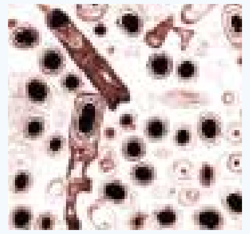
Changes in mRNA populations during infections

ANTHRAX VERIFICATION FACILITY

At the end of 2000, DSO decided to set up a small Biosafety Level 3 (BSL3) facility, mainly to support research on highly infectious biological agents. The BSL3 hood keeps disease-causing bacteria contained within its confines and allows R&D samples to be prepared and rendered safe before they are taken out for other R&D work. The DSO facility, which includes both HEPA and carbon filters, is able to handle both biological and chemical agents. Within the hood, the samples required for chemical analysis can be biologically inactivated so that they can be safely taken out of the hood for chemical analysis. Those samples intended for biological analysis can be kept within the hood.


Screening for anthrax in the BSL3 hood.

This new facility became operational after the 11 September attacks, when letters suspected to be contaminated with anthrax spores began to pop up in the US and many other countries, including Singapore. Though it was initially meant only for research, the BSL3 facility was quickly identified as the only operating facility in Singapore that could handle the suspicious letters and powders.


Microscopic view of anthrax spores.

Anthrax is a notorious micro-organism which causes a high fatality rate if it is breathed in, and if the sufferer does not seek prompt treatment. In Singapore many letters were sent in for testing which appeared to contain a white powder, resembling the dry anthrax spores in which form the micro-organism can be disseminated to cause widespread harm. A procedure for collecting, receiving and processing the suspected anthrax samples was worked out to handle the suspected samples. Sampling kits consisting of agar plates and swabs were prepared for use at the sites of suspected anthrax contamination.

The process of verifying whether the samples contained the anthrax bacillus (i.e. the anthrax germs) includes microscopy, polymerase chain reaction (PCR) and culturing. In microscopy, the anthrax spores are examined directly under strong magnification. PCR is a technique which enables genetic material in the suspect powder present in microscopic quantities to be multiplied many-fold, so that the genetic characteristics of the material can be more easily analysed for positive (or negative) identification. The suspect samples can also be sent for culturing, which allows any microscopic organisms present in minute quantities to multiply by natural growth and form colonies of cells which are more visible.

The samples sent in for analysis and verification included letters with white powder, and powder collected from indoor environment, mailboxes and a variety of other places. Close collaboration was maintained with the Criminal Investigation Department (CID) in collecting evidence to trace the culprits responsible for the perpetration of anthrax scares or hoaxes.


The BSL3 facility in DSO.

The Future

The world since 11 September 2001 has changed irrevocably, and it is now necessary for those responsible for the nation's security to be as well-prepared as possible for all possible threats, conventional or unconventional. The possibility of chemical and biological weapons being used should not and must not be ignored. On hindsight, the setting up of the chem-bio defence R&D capability in DSO has provided a valuable head-start in preparing for any emergencies or eventualities of this nature.

PUSHING THE FRONTIER IN LASER RESEARCH

One of the most important technological inventions of the twentieth century, the laser, is today to be found in many common applications. The word "laser" itself is an acronym coming from the first letters of the phrase, "Light Amplification by Stimulated Emission of Radiation", which more or less describes how it works, but in language intelligible only to physicists.

Most people would know that the laser is a very special kind of light source, which can do things ordinary light sources cannot do. Science fiction movies and TV shows have accustomed us to the potential of a high-powered laser beam to deliver immediate and highly focused destructive power. Invented by Thomas Maiman in 1960, the laser produces coherent light, which is another way of saying that laser light is uniquely pure and intense.

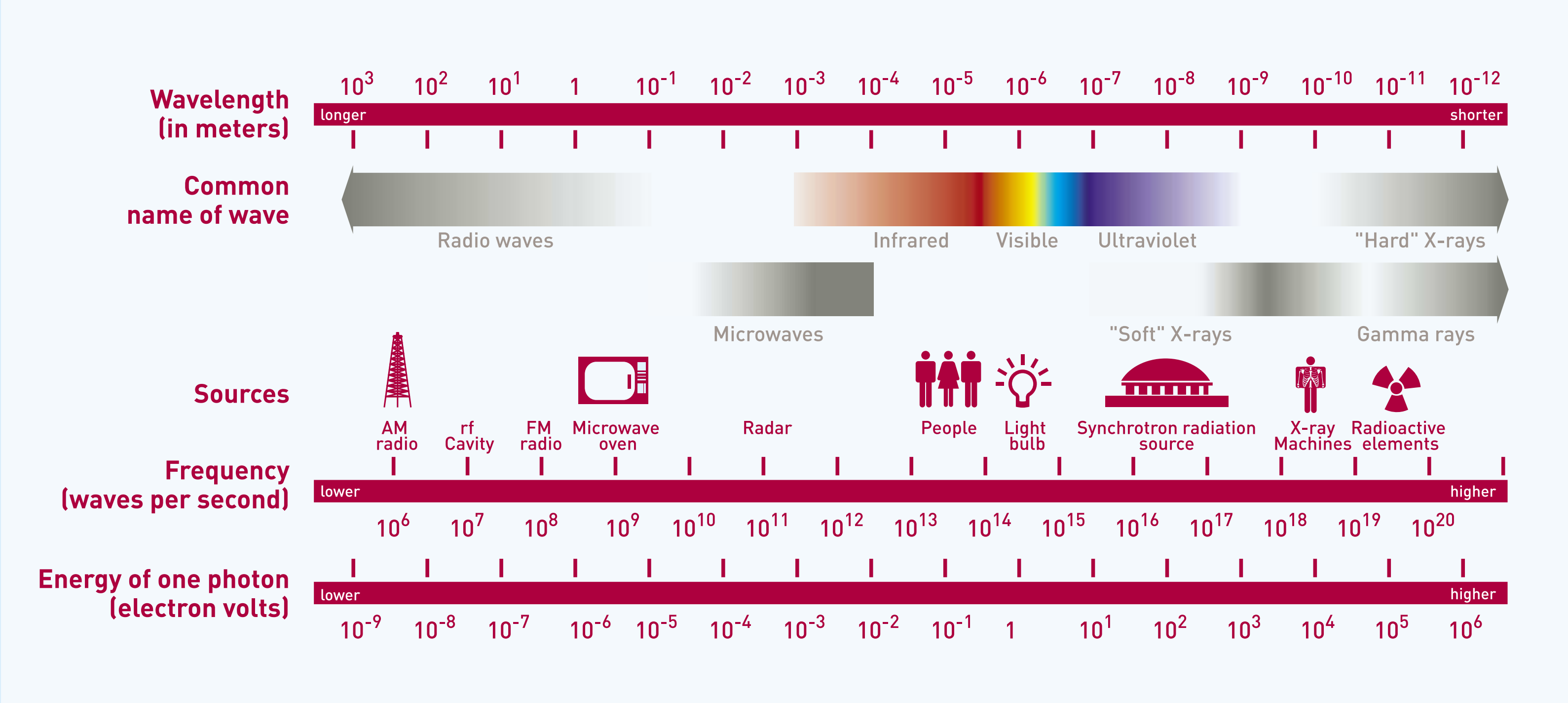
Today, however, lasers can be found in many everyday applications. The ubiquitous laser pointer, used in talks and lectures to point at slides and diagrams on a screen, with its ability to beam a tiny spot of light a great distance away, illustrates one of the laser's virtues, as compared to an ordinary battery powered flashlight. Compact disc (CD) players all use lasers to read the information written in microscopic tracks on the discs. The laser is no longer a solution looking for a problem, as it was dubbed when it was invented.

Ubiquitous as it is in everyday life, the laser has powerful and unique capabilities which make it enormously useful in defence applications. The DSO Laser Group is a relatively young part of DSO, but they have already chalked up an impressive number of technical achievements, including a number of world records in laser power output.

Early years of the Laser group

DSO's laser research began in 1996 with a joint collaboration with the Optical Crystal Group in NUS which lasted for one and a half years. This first collaborative project was focused on the development of a device known as an optical parametric oscillator, or OPO for short (see the story on tunable OPO sources for an explanation of OPO).

THE ELECTROMAGNETIC SPECTRUM



After working for one and a half years in this area of non-linear optics, the group became more ambitious. Their next step was another joint project with NUS to build a laser itself. The type of laser they chose to build was a diode-pumped solid-state laser or DPSSL. In a solid-state laser, the active part which produces the laser beam is a solid such as a particular kind of crystal. In order for such a crystal to produce laser light, the atoms in the crystal need to have energy supplied to them i.e. they have to be excited or pumped. Flashlamps similar to those used in flash photography are conventionally used to pump solid-state lasers; however this is not an efficient method of pumping as much of the flashlamp energy is lost as heat.

The DPSSL uses diode lasers instead of flashlamps to pump a solid-state laser. The diode laser itself is a semiconductor laser (like the ones we use in our CD player or laser pointers) and because its light is purer than a flashlamp source, its power is more efficiently absorbed by the solid-state laser medium. DPSSLs are ten times more efficient than conventional flashlamp pumped lasers. The other key advantages of such DPSSLs are their compactness, robustness, low maintenance and long lifetime.

In-house Projects: Mid-infrared Lasers

The group's first totally in-house project was an ambitious one to develop a high power mid-infrared (mid-IR) solid-state laser i.e. a laser near the 3-5 micron wavelength range. The highest power mid-IR solid-state laser ever demonstrated was 20 watts, by the renowned US laser research establishment, TRW, in 1999 and currently still holds the world record. To the layman, 20 watts may sound very lame. After all, a typical light bulb already produces 60 watts of power. However, as it produces only 0.00001 watt in the mid-IR band, 20 watts of mid-IR laser radiation is certainly non-trivial.

A high power laser head for pumping OPO for wavelength conversion

Two approaches to building such a laser are possible: The first approach is to start with a mature 1-micron laser (such as the Nd:YAG laser) and to use this to pump two OPOs in series. The first OPO changes the wavelength of the laser from 1 to 2-micron and the second OPO subsequently converts this 2-micron wavelength to the mid-IR region. The advantage of this tandem OPO approach is that we start with a mature 1-micron laser which is relatively easy to design and build (or even commercially available), but the disadvantage is the low efficiency from cascading two OPOs in series, which is only a few percent.

The second approach is to build a laser which produces laser light directly in the 2-micron wavelength. However, such 2-micron lasers are not technologically very mature yet. They are being studied and developed in many research labs currently, because this 2-micron wavelength has several potential commercial applications such as in medical surgery.

Some of the achievements of DSO in recent years in pursuit of the goal of building a high power mid-infrared laser are as follows:

- The coupled tandem OPO: An OPO within an OPO
- A novel Tm:YAG laser pumped within a 1-micron Nd:YAG laser
- A 150 watts Tm:YAG Laser: a record power for a 2-micron solid-state laser
- Intracavity pumped diffusion-bonded walk-off compensated KTP OPO: a record power intracavity OPO

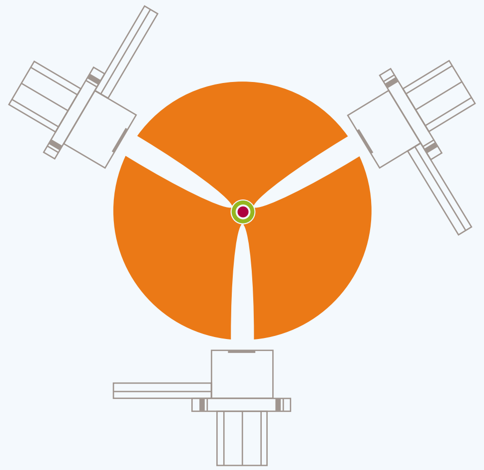
We will describe in more detail two of the significant achievements in building mid-infrared range lasers: a record power 2 micron laser, and a record power intracavity OPO laser.

A WORLD RECORD POWER 2-MICRON SOLID-STATE LASER

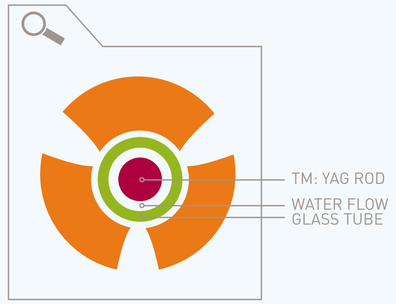
Light waves, like sound and water waves, have a wavelength which determines the colour of the light; visible light has a wavelength between 0.4 and 0.7 microns, where a micron is one millionth of a metre. Light with a wavelength of 2 microns is in the infrared range and invisible to the naked eye, but has several important applications in medicine and remote sensing.

2-micron lasers are particularly difficult to construct, and the highest power 2-micron laser has a power of only 115 watts, built at the Lawrence Livermore Laboratories in the US. The Laser Group embarked on an ambitious project to build such a high power laser, and to match or better the 115 watt record set by Lawrence Livermore. The solid material which actually produces the laser light is a crystal known as Thulium Yttrium Aluminium Garnet, or Tm:YAG for short. In order for this material to produce laser light, its atoms have to be excited by having energy pumped into them. The Tm:YAG crystal is pumped by shining intense light on it, and the more the intense and brighter this light, the more the crystal will be excited and consequently the laser light produced will be more powerful. The core of the laser is the Tm^{3+} (Thulium) ion embedded in the crystalline Yttrium Aluminium Garnet (YAG) host, and the physics and dynamics of laser action involves solving complex differential equations governing the rate of excitation and de-excitation of these Thulium ions by the pumping light – which involves equations derived way back by Albert Einstein himself.

CPC diode-side-pumped Tm: YAG laser



The 3mm ϕ X 105mm long CPC side pumping scheme. The Tm:YAG rod is pumped on its side by 3 high power diode laser arrays through compound parabolic concentrators (CPC).



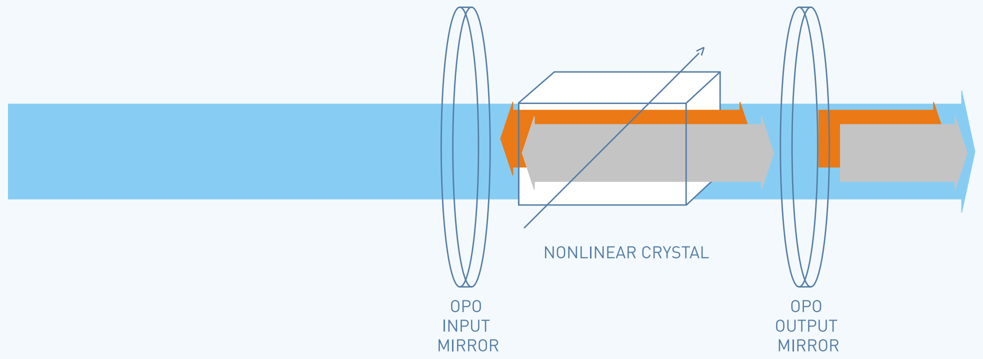
The Tm:YAG crystal is in the form of a long thin rod. In the Lawrence Livermore laser, the crystal is pumped by shining light on its two ends. The DSO Laser group used a better way of pumping the crystal, by having light shone on it from the sides, and hence getting more light energy pumped into the crystal. In order to maximise the amount of light on the crystal, the DSO team designed a laser cavity for the crystal which concentrated the light on the sides of the crystal. The key to their success in increasing the laser power was the cavity design. The diagram shows the crystal (the red circle) sitting in the middle of a solid block of metal called a Compound Parabolic Concentrator or CPC.

The light which pumps the crystal comes from three diode laser arrays (each consisting of several diode lasers) and is concentrated on the crystal rod by the specially shaped channels whose sides are parabolic curves (hence the name CPC) and which thus direct the diode laser light onto the crystal. With this ingenious design, the DSO team achieved an output power for their 2-micron infrared laser of more than 120 watts in April 2000, which they reported at the renowned laser conference, CLEO 2000 (Conference on Lasers and Electro-Optics) in Nice (France) later that year. In the following year, the team broke their own record and achieved 150watt output from the Tm:YAG laser.

COMPACT AND TUNABLE OPO LASER SOURCES: ANOTHER WORLD RECORD

Another approach used by the DSO team to produce a high power 2-micron laser was by using a technology known as Optical Parametric Oscillator or OPO in short. The starting point was a commercially available high power 1-micron laser, and OPO technology was used to convert the 1 micron laser light to 2-micron laser light. The 1-micron laser used was a Nd:YALO (Neodymium Yttrium Aluminium Oxide) laser, which is not used as widely as other more popular 1-micron sources (such as the Nd:YAG laser). The advantage of Nd:YALO over other more common 1-micron sources is that it produces polarised light (light which vibrates in one direction only) which is more suitable for the OPO process.

The heart of an OPO device is a special crystal (technically known as a non-linear crystal) which changes the colour of the laser beam when it passes through the crystal. However, the crystal, which in this case was Potassium Titanyl Phosphate (or KTP for short), can perform this colour change only when the laser beam reaches a certain power level. Unfortunately, if the laser power is too high, the crystal can be damaged. Hence the laser power has to be



OPO scheme where lights of 2 wavelengths (orange and grey colour) is generated in the nonlinear crystal by the pumping light (blue colour).

within a certain narrow range, and the DSO Laser team had to learn by themselves how to design an OPO which was efficient at the conversion without damaging the OPO crystal.

The 1-micron laser light (like all light beams) consists of particles called photons. Each photon has an energy which depends on the wavelength of the light; the shorter the wavelength, the greater the energy of each photon. A 1-micron photon, for example, has double the energy of a 2-micron photon. The OPO basically consists of a special crystal, KTP, which is able to split each 1-micron photon into two 2-micron photons, thus converting the 1-micron laser light into 2-micron laser light.

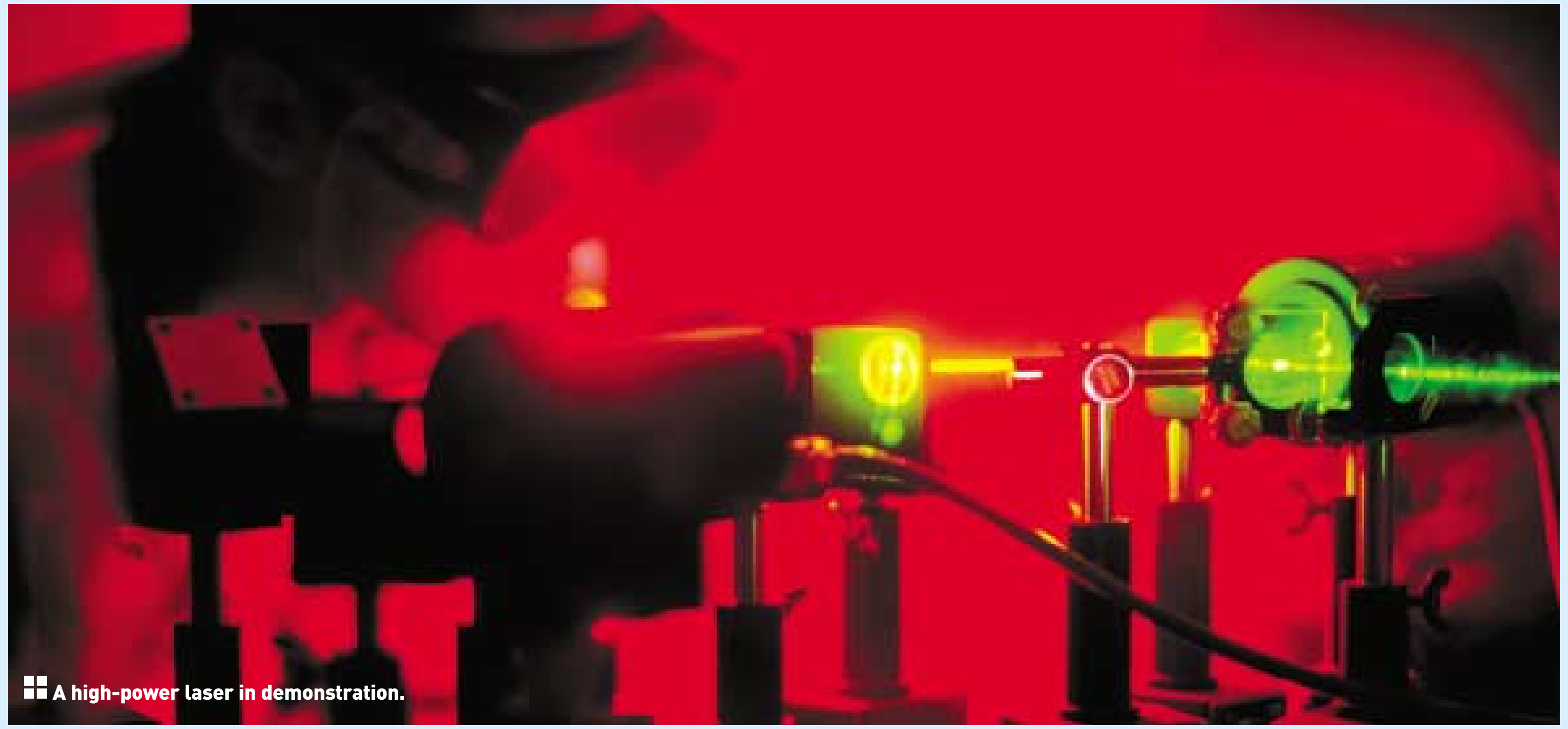
The DSO team has used two methods to make their OPO more efficient. One is to put the OPO crystal actually inside the high power Nd:YALO laser in what is called an intracavity configuration. Another innovation is a technique called diffusion bonding to bond two KTP crystals together in what is known as a walk-off-compensated configuration. Basically, by bonding these two crystals together in such a configuration, the OPO process is given more chances to work, allowing the 1-micron photons to be converted to 2-micron photons more efficiently.

Using these and other ideas put together, the DSO team was able to obtain the highest reported intracavity OPO output power of 24 watt from their system. Typical intracavity OPO outputs obtained from other labs in the world had been in the region of only a few watts. A bonus was being able to obtain such a high power output in a compact, easy-to-align, and portable configuration, which in fact is ready to be brought out to the field for testing and hence is not just a laboratory prototype. This achievement was reported in Optics and Photonics News Journal of Optical Society of America (November 2000 issue) and was also reported in the CLEO Europe 2000 conference in Nice (France).

Further results of OPO conversion to obtain 2.5 watt in the mid-IR were reported in the Advanced Solid-State Lasers 2002 Conference in Quebec (Canada), and a novel compact Laser Integrated Coupled Tandem OPO (LICTOPO) configuration producing 2.5 watt in the mid-IR was also presented in the CLEO USA 2002 conference in Long Beach (USA).

The future

The infrared lasers produced by DSO have many interesting and important applications in remote sensing. For example, they can be used to detect the presence of chemical warfare agents from distances of up to several kilometres with pin-point accuracy. Basically, the precise laser wavelength can be used to identify the unique energy levels (like the fingerprints) of a particular chemical agent. This technique can also be used to detect explosives or mines which give off certain distinct chemicals. It can also be used as a laser radar (LIDAR) to map the pollutants in the air around a city, or the wind field in front of a jet plane to monitor areas of turbulence. The DSO team will continue to be at the cutting edge of infrared laser development and will strive for more achievements to add to their world record-beating efforts.



A high-power laser in demonstration.

1997 – 2002

TAKING FLIGHT

CHAPTER 0100

RAdm (NS) Teo Chee Hean and Peter Ho were senior naval officers before assuming positions in MINDEF. Both agreed that the partnership between the Navy and DSO was of great mutual benefit. DSO benefited by developing capabilities through Navy projects. And the Navy benefited by having, in DSO, a dedicated, in-house R&D laboratory.

The role of the Navy in boosting DSO's growth was due to several factors.

Firstly, there was a natural affinity of Naval officers with technology and engineering. The Navy has very customised and specialised requirements. The technology they required was not for sale, and required in-house development.

By the late 1990s, it was clear to Peter Ho that DSO had been transformed into a credible and internationally benchmarked defence science R&D organisation.

In 1998, with the opening of the redeveloped Marina Hill complex, came a landmark announcement which opened a public window on DSO, revealing a first glimpse of its capabilities.

And this new public profile paralleled the development, in the 1990s, of a large scientific R&D community in Singapore. It became important for DSO to adopt a higher profile in order to attract the best and brightest researchers.

In 1991, DSO took the first step towards autonomy, adopting the status of an Executive Agency. This gave it some autonomy, although the freedom to operate independently came only in 1997, when DSO was corporatised as DSO National Laboratories. Not until 2000, did DSO finally adopt an independent personnel scheme.

In 2002, DSO National Laboratories is celebrating three decades of R&D for defence science and technology.

It has been the pioneer of R&D in Singapore, as the largest and earliest R&D institute.

It has a track record of successful research and development, and has built a base of capabilities and facilities over 30 years.

Over the many years, DSO has "learnt by doing." Through a hands-on approach to science, and the amalgamation of many fields of science, it has generated innovative solutions to many defence and security problems.

It stands now on a new horizon, with its 1,000 strong community of scientists, researchers, engineers and support personnel, experienced, capable and moving ahead.

This history of DSO, according to the current Chairman of DSO and Chief Defence Scientist, Professor Lui Pao Chuen, is due to the early vision of Dr Goh Keng Swee.

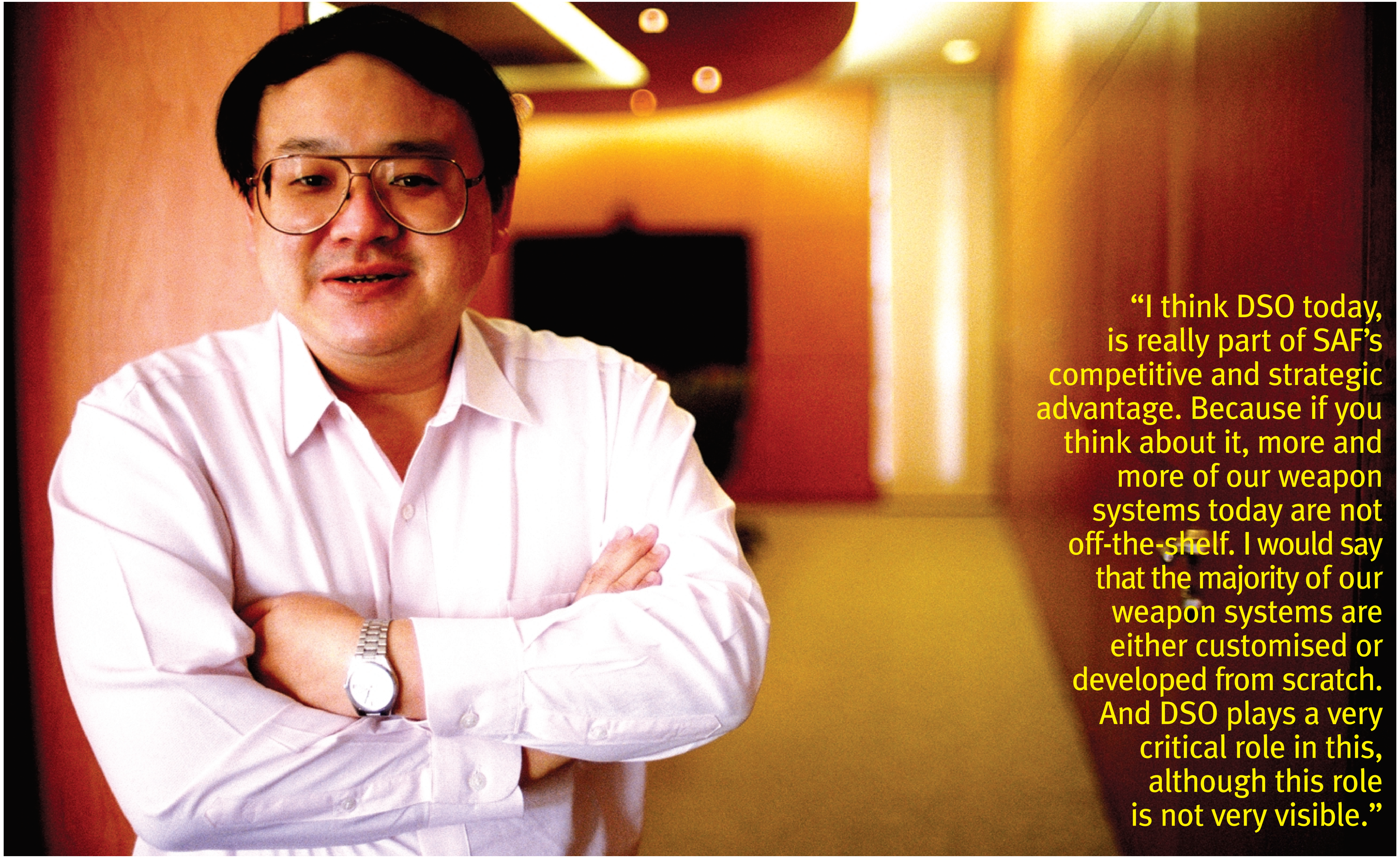
Its first Director, the late Dr Tay Eng Soon, established an ethos and atmosphere conducive to science, which is still a hallmark and signature of the organisation.

Philip Yeo lent DSO his unique management style, funding and manpower resources, and sense of freedom.

These three pioneers, and many others, have made DSO National Laboratories a truly great place for science.

In the three decades, DSO has developed unique capabilities in defence science – capabilities that will allow DSO to create the *technology edge* in the 21st century.

It may be said that Dr Goh's vision has been fulfilled.



PETER HO

Peter Ho was born in Singapore in 1954, and obtained his Honours in Engineering from the University of Cambridge as an SAF Overseas Scholar. He returned to Singapore and held command and staff appointments in the Republic of Singapore Navy, the Joint Operations and Planning Directorate, and in MINDEF.

In 1989, he transferred to the Administrative Service and was Deputy Secretary (Policy) in MINDEF. After serving in the Ministry of Foreign Affairs as Deputy Secretary, he returned to MINDEF in 1995 as Permanent Secretary (Defence Development) and Permanent Secretary (Defence) in 2000. Peter Ho served as the first Chairman of DSO National Laboratories after its corporatisation in 1997.

Tell us about your first encounter with DSO.

It was when I was Head of Naval Plans. We were planning for a new ship for the Navy. It was a project, famously called *Springboard*, because it was supposed to be the "springboard" to transform the Navy from a demoralised, down-and-out outfit into a modern and capable Navy.

Springboard was a watershed for the Navy in two ways. It was a watershed in terms of the way we planned for the project. And also, *Springboard* ushered in a whole new strategy for the Navy. And a lot of the things you see in the Navy today were derived from those days in *Springboard*.

This must be around the mid '80s?

Yes, around there. Now, this was the first time the Navy had really assessed what it needed for a fighting ship. Before that, we just bought whatever people told us to buy. Essentially, we bought off-the-shelf.

And this was the first time we really looked at the environment. We looked at our operational requirements. And we determined what performance and weapon systems the ship should have.

There are two important things about the ship which are germane to DSO.

One, was the conclusion that this ship should be equipped with electronic warfare (EW) systems. Because the conclusion was that, if you didn't put on these systems, the ship would not have the capability to fight a modern naval battle.

The second very critical decision was that this new class of ships should have an underwater warfare capability. This was the first time we went into underwater warfare systems. We had absolutely no experience in this field. This is the anti-submarine kind of thing.

I think it was almost an act of faith that DSO was able to deliver the goods! Because DSO did not have much experience in EW. And whatever work they were doing in EW, was highly classified.

In fact, DSO had installed one system on our Missile Gun Boats (MGBs) but we were not informed what it was! In fact we were not allowed to enter the little room where this system was located!

What? You were not told what it was?

Yes! It was on the ship but nobody was allowed in. Now, it's much better. But at that time, DSO and what it did were hidden away from us.

But now we know that the real start of EW in DSO was in the Navy. Because this was the first time they were getting real resources and real facilities to support the R&D into EW. And I guess, this was where the Navy gave DSO a modest boost.

It had a lot to do with a few people who were struggling at that time to shape the future of the Navy.

The Navy thought very hard and deeply about where it was going. And essentially, the Navy developed very strong skills in terms of determining its requirements and making very good long-term plans.

Adversity is the mother...

Adversity is the mother of invention! And so, when you look at the Navy plans in those days, you didn't just see plans to acquire these things for so many hundred million dollars, but you also saw parallel supporting plans for manpower, training, doctrine development and R&D.

So we allocated resources, meaning, funds and people, to support the R&D effort as well.

So, I would say that was something good for DSO. Because certain areas like underwater warfare and electronic warfare – were to prove very critical. There was a sure base load for DSO, some years down the line.

Did they deliver? Was your faith redeemed?

My own view is that EW is the kind of area where you cannot buy the capability. It's a black art, very black. And just because companies sell you the system, doesn't mean that they sell you the whole system, or that you'll be able to use it effectively. So you really have to develop your own indigenous capability in EW.

I would say DSO is doing quite alright in EW today. Not only EW for the Navy, but EW for all the Services.

> "When I returned, in 1995, what was most striking to me was how much progress DSO had made in six years. It seemed that in the six years that I was away, DSO had taken off like a rocket!"

Was DSO at that time appreciated – or even known to the SAF?

It was not. I would say that one of the biggest problems with DSO in those days, was that it was essentially a close sensitive unit. It was referred to with bated breath. If you had to deal with DSO, you were like an intruder!

They were an ivory tower..

Something like that. And it was very difficult to deal with them. Because of DSO's culture of secrecy, you only met certain people, and you couldn't meet anybody else.

And the question was, how did you know what DSO was doing? Who to meet? That was the problem.

The Defence Technology Group (DTG) was formed in 1986. Did that change things?

The formation of DTG shouldn't be seen in isolation.

What happened was in those days, a decision was taken to rationalise the various technology and logistics groups in MINDEF. So they created DTG, which reported to the Deputy Secretary (Technology).

So it was already a clustering of the technology departments into one group, and a re-ordering of the administration and policy departments under another.

It was just a bit of housekeeping. I wouldn't say that it was a huge and strategic organisational change. All it did was to formalise something that already existed.

But perhaps, psychologically...

Yes, it gave an identity to the engineers.

But I don't think it made a great deal of difference to DSO. Although DSO was now part of DTG, it was still separate because of the veil of secrecy that surrounded DSO.

When did you lift this veil of secrecy?

By the late 1980s, we felt that DSO had matured to the point where we could discuss some of its activities. So in 1989, when we opened up the first DSO building at Science Park, I remember that Lee Hsien Loong, then Second Minister for Defence, made some broad references to the capabilities of DSO.

This was followed by the opening of a second building at Marina Hill, I think it was 1998.

There was already very clear evidence, by 1995, that DSO was a credible R&D organisation. So this bit of publicity was not without basis.

And there was also another reason. Because we were at that point, in the mid '90s, in steep competition for good quality R&D manpower. The other research organisations were growing, and scientists and researchers were at a premium.

I was very concerned that, if DSO was so secret, so "black", you were not going to get people joining DSO, at least not in the numbers and quality needed.

Unless people are aware of DSO and know what it does, and feel that it is a premier organisation for R&D, why should they apply to DSO for a job?

And how can they have the confidence to forge their careers with DSO?

Why did you think of corporatisation?

I was away from MINDEF for six years.

When I returned, in 1995, what was most striking to me was how much progress DSO had made in six years. It seemed that in the six years when I was away, DSO had taken off like a rocket!

Not just in EW, but in many areas, and as an organisation. It now had a whole range of areas. I was very encouraged to see that.

And one of my conclusions was this: DSO was really a major component of SAF's strategic advantage.

That DSO was supplying SAF with a *technology edge.*

Now, if you share my conclusion, then you have to decide how you are going to sustain that advantage and how you are going to *grow* that advantage.

We concluded that the competition for such manpower was getting more severe and it would do us no good if we continued to have DSO operating as part of the Ministry of Defence, as a department of the Ministry.

I came to the conclusion that the critical thing was people. DSO used a completely different type of talent from MINDEF and the SAF, and so was competing for a completely different pool of manpower.

It was restrictive to have R&D people within the same organisation and under the same managerial regime as MINDEF and the SAF which are essentially devoted to operations. So, the only way is to cut the Gordian knot.

Basically we wanted to give DSO autonomy in its manpower policies so that it could recruit the people it needed.

I had concluded that we would have to separate both DSO and DTG from MINDEF. But I didn't want to take it in one big step. So, I decided to split it into phases. The first phase was DSO, a smaller, in fact less controversial part, moving out in 1997. DTG was to move out later, as DSTA. But that was not until 2000.

So DSO was corporatised in April '97.

In the end, DTG went a different route. It became a Statutory Board on 15 March 2000.

Thus, we were not thinking about the corporatisation of DSO in isolation. There was a plan to do it in two steps. That is, DSO first, then the rest of DTG afterwards.

Do you have any advice for DSO for the future?

There's one more thing I should say about DSO. This relates to how you sustain and build up your capability.

One, you must invest in people. That's why in one of my remarks, I said the key to DSO is people, people, people.

But the other thing that I thought was very important and critical, was to get DSO to do more work with reputable R&D institutions overseas. Because that is the only way you will know how good you are.

I think in the last five years, in DTG as well as DSO, we have been able to give an enormous push towards world benchmarking.

And there was a seminal speech, given by DPM Tony Tan at the opening of Temasek Laboratories in NUS. Because that really spelt out how we see the basic, underlying approach to defence technology.



> "And one of my conclusions was this: DSO was really a major component of SAF's strategic advantage. That DSO was really supplying SAF with a *technology edge*."

And one of the keys is this: we are too small to try to do everything ourselves.

So we try to do defence technology with partners, both locally and overseas. And in fact, a lot of the effort I personally put in, has been to develop these overseas links.

Of course, I'm only the door opener. But some of our key partners are really at the top of their fields. Once we create a critical mass, establish a reputation, it becomes relatively easy to go to others. So we spent a lot of time with the United States and with France, trying to push this relationship.

One of the important things I suggested to DSO, and I remember this was very soon after DSO National Laboratories was set up in 1997, was that they should establish a DSO Advisory Panel. An international one.

So we had this DSO International Advisory Panel for two years and they were quite an interesting lot.

There was Peter Levene who was once Director of Defence Procurement in the UK. He is now Lord Peter Levene, Lord Mayor of the City of London from 1998-99.

And we had Roger Hagengruber from Sandia, and Bo Rybeck who used to be with the Swedish R&D establishment. We had Henry D'Assumpcao, who was Chief Defence Scientist of Australia. We had Moti Heiblum from the Weizmann Institute in Israel.

These are all top names.

So we had them for two years. First, I wanted to get with the start of a new DSO National Laboratories, a group from outside to look at DSO. And to do a critique of DSO. I think they were quite brutal in their assessments.

And secondly, I wanted to get DSO used to dealing with people at this level, psychologically. This is very important.

So, you must get used to the idea that networking is a worthwhile activity. Collaborations don't fall into your lap, you can't sit and wait, hoping that these collaborations will come. You must actively go out and create the network!

Of course, it doesn't mean that you cannot keep certain things secret. But, I think that the shift had taken place. Maybe part of it was deliberate, part of it just happened. But today, DSO is very open, you know, remarkably open.

> "DSO today has reached the point in which they can deliver what they promised."

I would say without a doubt, that today, DSO is world class in certain niche areas.

We saw it pick up in the early '90s. I think corporatisation has helped it a lot. So we really saw a pickup in the last few years.

Can you tell us what you hope for the future?

Well, I think the future direction is more in terms of moving DSO onwards, and building up capabilities in new areas. Because there are always new areas which DSO can build capabilities in.

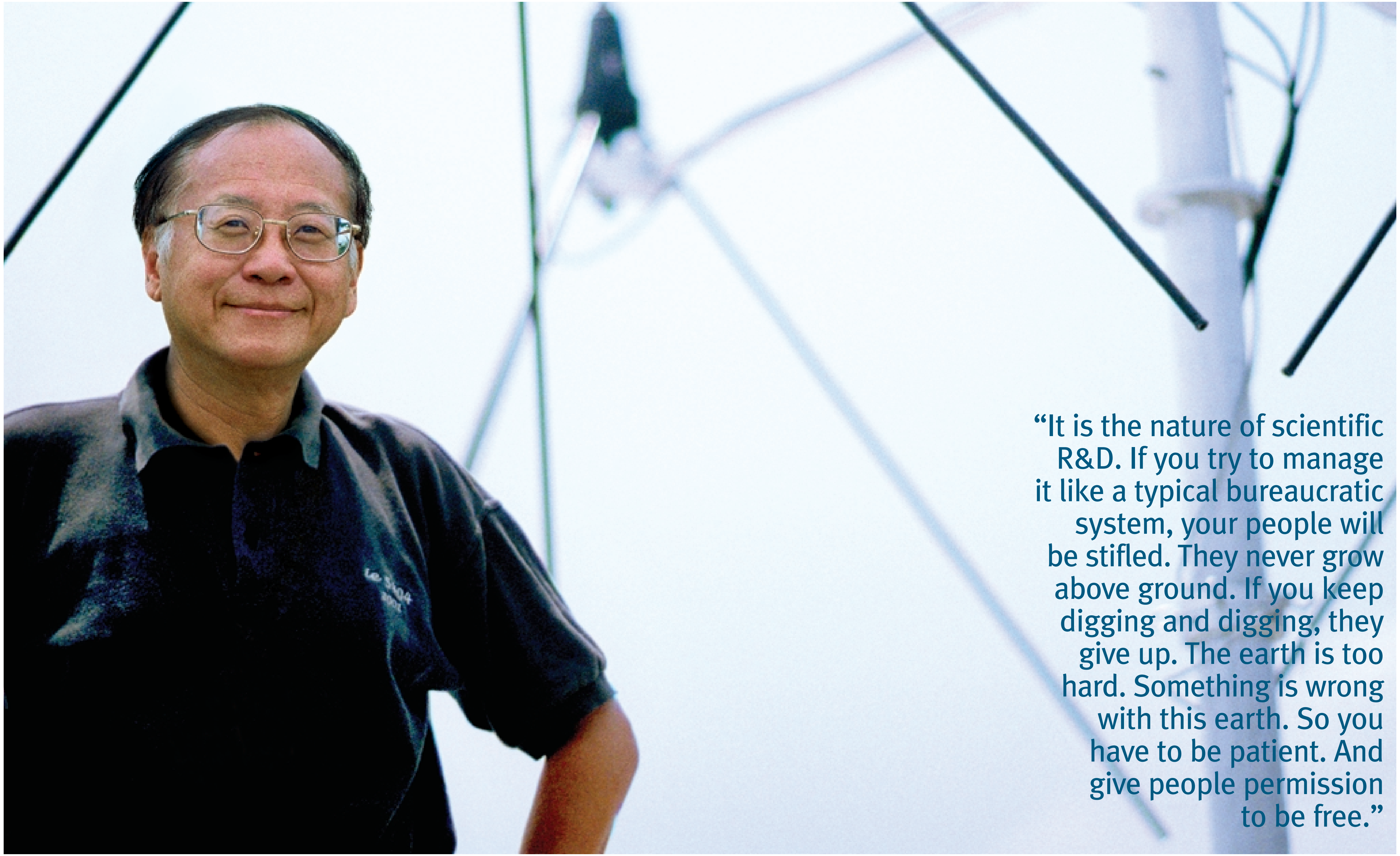
Today, DSO has reached the point in which they can deliver what they promised, and I think the SAF knows it! The trouble is, this is not the kind of thing that you can publicise too much.

But I think DSO today, is really part of SAF's competitive and strategic advantage.

Because if you think about it, more and more of our weapon systems today are not off-the-shelf.

I would say that the majority of our weapon systems are either customised or developed from scratch.

And DSO plays a very critical role in this, although this role is not very visible. A lot of the enabling technologies and initial feasibility studies are done by DSO. Some of the things we do will be a revelation even to the more sophisticated countries!



"It is the nature of scientific R&D. If you try to manage it like a typical bureaucratic system, your people will be stifled. They never grow above ground. If you keep digging and digging, they give up. The earth is too hard. Something is wrong with this earth. So you have to be patient. And give people permission to be free."

LUI PAO CHUEN

Professor Lui Pao Chuen was appointed Chief Defence Scientist, Ministry of Defence in 1986. He graduated from the University of Singapore with a degree in Physics, and began his career as a Scientific Officer in the Radio & Space Research Station. In 1966, he joined MINDEF as a Logistics officer, and in 1970, established the Science & Management Group. After a Master's Degree in Operations Research from the United States Naval Postgraduate School, he was appointed Special Projects Director, Director JOPD and Senior Director of the Defence Materiel Organisation (DMO). He holds an Adjunct Professorship in Industrial and Systems Engineering in the National University of Singapore, and has been Chairman of DSO National Laboratories since 1998.

You have referred to DSO as, "The silversmith, making silver bullets"?

This term, "silver bullet" is perhaps too common. Because it doesn't convey the importance of DSO's work. I prefer, "black diamonds." Because what DSO produces is very rare, very precious.

Black diamonds?

Yes. They create black diamonds of priceless value. Priceless, because you can't buy them. No amount of money can buy them.

See, that's why we invest the top scientific brains in Singapore in DSO. Because these black diamonds are things you can't buy.

Now, there are a number of reasons why money cannot buy them.

One reason is they are not in existence yet. These are concepts, they are just ideas and formulae. You have to create them and make them real.

Another reason is that, it's there – but the country that developed this capability is not going to release it to any others. These black diamonds give it a *technology edge*, a secret advantage, a gap. And it is not about to let anybody else close the gap. So it's a very closely guarded secret.

Because it's a winner. It's the Ace.

Yes! These are the biggest challenges for a scientist. Like the black diamond that has not been invented yet. It's just a concept. You have to invent it. Can you develop it? If you can, you are way ahead of the others.

It means we can use technology instead of soldiers' lives to win our battles...

It will save lives. It will also make a difference to the outcome.

This was why we started DSO. We were looking at the technology areas that would make a major difference in the way we fight. So we brainstormed this question. Dr Goh was closely involved.

You know, our numbers will never be large. The SAF will always be a very small force. So we need to use technology to overcome our lack of human numbers. And Singapore is a small area, physically. So again, we need to use technology to overcome our lack of land mass.

So, we saw that technology would make a great difference. It would be a force multiplier, it can create a *technology edge*.

How long did it take you, Dr Goh, and the others to reach these conclusions?

From day one.

Day one?

Because it was so obvious! These imperatives were very clear.

How did you get your information? Your concepts? Dr Goh was no expert!

Dr Goh was an avid reader, a historian.... He observed the Vietnam War and the wars in the Middle East.

The Vietnam War showed the potential of guided systems. With Precision Guided Munitions (PGM) for instance, instead of dropping thousands of bombs to hit a bridge, the Americans found that two PGMs could do the job. So it was very clear that this was the way to increase efficiency by a big order of magnitude.

And the need for electronic warfare (EW) became clear during the 1967 war, when the Israeli destroyer, *Eilat*, was hit by the Soviet missile, the *Styx*. And after the war, the Israelis realised that they would lose more ships to these PGMs – and their conclusion was they must provide an electronic shield around their ships. Because their missile, *Gabriel,* had a much shorter range than the *Styx*.

So in order to approach the enemy close enough, they needed electronic counter-measures (ECM). And they spent the time – after the 1967 war to the early '70s to develop the first ECMs. And the next time they fought in 1973, they could deflect the *Styx* missiles through the use of ECM.

Dr Goh was very clear. Number one, he knew history. Number two, he was watching what

> "Our numbers will never be large, so we need to use technology to overcome our lack of human numbers. We need to use technology to overcome our lack of land mass. So, we saw that technology would make a great difference. It would be a force multiplier, it can create a *technology edge*."

was going on in recent battles. The conclusion was very clear: in future wars, you don't have to see your enemy. It is a new type of battlefield, in electromagnetic space.

In 1971, he explained this to me. I think it was very profound. He could see well into the future. That's actually what we are trying to do, to this day.

It shows the genius of the man!

Can you tell me how you first heard about DSO, or ETC?

When ETC was formed, I was still here. Dr Goh told me about it. So I knew. That time, we were still in Pearl's Hill, Upper Barracks. You know the two barracks where we started MID?

Ministry of Interior and Defence?

Yes. Ministry of Interior and Defence (MID). Now it is split into two – Home Affairs and Defence. But at that time, it was one Ministry.

In 1965, Dr Goh was Minister for two years, then he went to the Finance Ministry, and I think it was in 1969 that he came back to MID.

I still remember his office at one corner of Pearl's Hill, Upper Barracks. He had some problems with his eyes, so his room was dimly lit. So when I went to see him, it was so dark, I was already shivering like, "I'm going to see God."

It was 1970 or 1971 that he decided, "Look, we must send guys abroad on scholarships." Then he sent me to Monterey in California, to the Naval Postgraduate School. There were two scholarships; one was the SAF scholarship and the other was the SAF Fellowship which is now called the Postgraduate Award. I was the first to go. I went in 1971.

Before I left, he called me in to tell me about his vision for science and technology – what became DSO National Laboratories.

That's amazing – and in 1971, the SAF was just beginning.

That's why I said, "the genius of the man." So I was there, in his office, for one hour, just listening. It got me all fired up. *Wow!* – I was going to Monterey, I was going to learn and come back to do all these things. I got really inspired. I was probably launched that day!

So ETC was formed, 1972. It was a small, "black" group sitting in SID. But it never grew. Then in 1977, Goh Keng Swee gave me a task, "Do a study on how we can leverage on defence science." So I studied what was happening in UK, Australia, India and other countries and wrote a paper.

This paper was the birth certificate of DSO!

What did you propose?

We needed to get the number of people up, recruit more people straight away. Then we needed to leverage on the staff who were already developed in MINDEF, on the project side. Systems Integration and Management Team (SIMT) was an obvious group. So ETC combined with SIMT, and became Defence Science Organisation.

This was in 1977. So that was the start.

What was the problem – did you feel ETC was not big enough?

Very honestly, there was great envy of DSO then.

Why?

Well, you have these DSO guys at the top of Marina Hill, thinking profound thoughts, while we were in MINDEF, on the ground, slogging, chasing after contractors. We didn't even know what they were doing! It was still very black!

If DSO did not have a godfather in Dr Goh Keng Swee, they would have been eaten up. They would have been today's meal! Today's hunger is more important than worrying about tomorrow.

But Dr Goh nurtured and protected them.

So we learned an important lesson there. For this sort of long-term organisation, we need strong leadership on top to nurture them, to protect them from being attacked from outside.

For R&D, you need someone with a long-term view, a godfather.

Because in MINDEF, at Science and Management Group (SMG) and at Special Projects Office (SPO), I was looking for engineers. We were all doing major projects! Massive projects. And the consequences of bad decisions were very obvious. You could see the mistakes, you know. So we really needed engineers and specialists.

Whereas on the DSO side, I mean – R&D, what are you doing?

So there was actually competition between DSO and the other organisations for top brains. And all the top brains wanted to go to DSO! I mean, engineers preferred to do R&D rather than project management.

So you lost out to DSO in the competition for engineers.

Project management is more mundane. You are handling contractors, dealing with black boxes, system integration, system design, that sort of thing.

And DSO got the top brains?

Yes! The top brains.

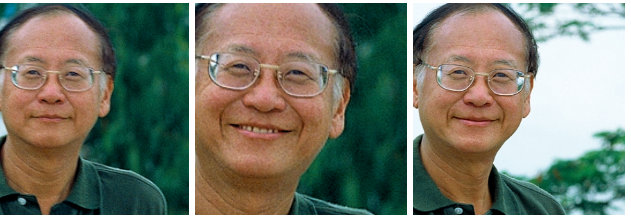
Is it R&D that attracts the top brains?

For people who are academically good, yes!

Doing research is a natural progression, after their studies. R&D appears more challenging, more exciting to them. I mean, you are on the leading edge. So for the bright guys, they want to be there! So it's a challenge.

What did you think about DSO's management?

Dr Tay had a very strong academic reputation in the university. He had a great leadership style. He led by example. He was daring. He came up with new ideas and he was very open.



> "In 1977, Goh Keng Swee gave me a task, "Do a study on how can we leverage on defence science." So I studied what was happening in UK, Australia, India and other countries and wrote a paper. This paper was the birth certificate of DSO!"

He wasn't a hierarchical type of person. Those days, we had bosses whom you had to bow to.

Not Tay Eng Soon. He was one of the guys who said, "Call me Bob." So he had more of the American style, as opposed to the more traditional, hierarchical type of structure.

So actually, Dr Tay was the spark that got all the young guys going and excited about DSO.

He encouraged them. "Hey, got any new ideas?"

And he was very supportive. He was open to new ideas. He didn't say, "You do it my way, you chase my idea."

So that was his great ability. It was a loss to DSO when he went into politics. But it was the gain of the nation. When was that? 1980?

Yes, in 1980. Then after that, there was a time when it was Philip Yeo. Can you tell me about Philip Yeo? He seems to be quite hands-on.

Philip Yeo is a *doer*. I asked him, "Do you do planning?" He replied, "I plan with my guts."

So he saw DSO, he could see its mission and he said "Do!"

Was this a successful management style?

Philip Yeo was a great supporter of DSO. I suppose I would say, number one, he gave DSO the freedom to do what they wanted.

Number two, he created opportunities for them. Because he could see that, by working with other parties and other countries, DSO could move faster. So he opened doors.

And he provided resources. There was no question of money! If you needed a budget, you asked him! He would ask you, "Why do you need this?" You gave a good answer, you got it. He never counted pennies. You need men, you go to see him. He'd get them for you. So he provided resources.

And he protected DSO from being attacked. Otherwise, the other branches or departments would say, "DSO has got the men, let's try and grab them." So there was this constant struggle for resources.

> "This term, "silver bullet" is perhaps too common. Because it doesn't convey the importance of DSO's work. I prefer, "black diamonds." Because what DSO produces is very rare, very precious. Yes. They create black diamonds of priceless value. Priceless, because you can't buy them."

You know, the tightest and scarcest resource was bright people.

So he created an environment in which these bright people could flourish. He provided DSO with the environment, which allowed them to create science...

With his backing, DSO was the right environment for science....

Yes. He created in DSO, the correct environment for science.

If I look back and ask, "Who were the greatest contributors to DSO?" They would be Dr Goh Keng Swee for being able to identify the vision. Then Dr Tay Eng Soon for establishing the correct ethos, in daring to think and to do. And Philip Yeo for building a nurturing environment.

> "If I look back and ask, "Who were the greatest contributors to DSO?" They would be Dr Goh Keng Swee for being able to identify the vision. Then Dr Tay Eng Soon for establishing the correct ethos, in daring to think and to do. And Philip Yeo for building a nurturing environment. These are the three men whom I would say really built the organisation."

These are the three men whom I would say really built the organisation.

Will DSO grow more?

The numbers we have now in DSO is about the maximum that our country can support.

Because we need the balance between economic growth and military capability development.

We could hire more engineers and scientists by paying more salary. But it will be at the expense of our country's economic development. And therefore, the growth must henceforth be through leveraging of the brains in the universities and through overseas collaboration.

Why did DSO become an Executive Agency (EA) and why was it corporatised later on?

The idea is very clear. That DSO, when it was part of MINDEF, and part of the Government, was encumbered by many rules and regulations. This slowed them down.

So they needed to have flexibility. And in the main, flexibility is two things. One is manpower – how to recruit manpower according to your needs. And you must be able to fire them if they don't do a good job. So you must be able to manage and control your major resource which is your people.

The other thing is money. DSO must be able to move very quickly. To buy the technology that they need. And not be constrained by normal government procedures which take time, paperwork and so on.

So the EA was an organisational structure for DSO to operate in the most efficient and effective manner, with flexibility of manpower and funds.

But it seemed that EA was still not giving DSO the flexibility it required. So after careful study, in 1997, we decided that DSO should be corporatised.

So we are evolving, because the whole time we are learning. If things don't work, we change.

What are your thoughts about the management of R&D?

If you look at everything that is neat and tidy, it's not science. If you look at boxes, as soon as you start drawing boxes, you have hierarchy, you are "fossilising" the organisation!

You have to "Let one thousand flowers bloom!"

At a certain stage you are still planting, you are ploughing, you are putting seeds in, and seeing nothing!

You pour water, put more seeds in, add fertiliser, and still – nothing. Then suddenly, "Boom!" Flowers! Harvest! Plant more!

So at a particular stage, you look at it, it's nothing. You see a lot of labour, but no result. Finally you see some little things growing up, you add in more resources. Then harvest. After the first harvest, plant more!

Is this unique to managing science? You have to be like this?

It is the nature of scientific R&D.

If you try to manage it like a typical bureaucratic system, your people will be stifled.

They never grow above ground. If you keep digging and digging, they give up. The earth is too hard. Something is wrong with this earth.

So you have to be patient. And give people permission to be free.

SECURING OUR CYBERSPACE

Origins and History

From its origins in the Second World War when it was invented to help in calculating missile trajectories and to decipher enemy codes and ciphers, the electronic digital computer has become an indispensable and ubiquitous adjunct to modern life, entering into almost every aspect of our daily routines. From email to telephone bills to income tax returns, information and data touching every detail of our private and public lives are processed, stored and transmitted by computers and the networks which connect them.

The importance and ubiquity of computer data has also increased our concerns over the security and privacy of this data. The general public is increasingly worried about what happens to their personal details in computers, especially when unscrupulous website operators may not hesitate to sell such personal data. Worse still, there may be hackers lurking everywhere, waiting to enter our own personal computers or the institutional computers which hold our data legitimately, in order to capture this data or to alter it to their advantage. We have seen that some qualifications have been offered for sale, not just with fake certificates, but with the subsequent alteration of the database of the organisation offering the qualifications, which could have meant that their sites had been broken into.

In addition, the increasing prevalence of financial crimes involving the illegal altering of computer records has made computer security an over-riding issue in every system in which the integrity of the system and its data is of paramount importance. The advent of the Internet and cyberspace, within which hackers can launch attacks against any computer connected to the Internet, has further heightened world-wide fears about computer vulnerability and security. The fact that the best computer hackers are at the leading edge of computer security technology, makes the task of defending systems against attacks by such hackers a very difficult one, demanding that those responsible for computer security (or cyber-security) must be able not just to match, but to defeat the efforts of the most sophisticated hackers.

Long before it became fashionable, DSO started its foray into cyberspace security in 1994 with just 2 engineers. These pioneering engineers studied the security of Unix systems and the susceptibility of computers to computer viruses which were then beginning to pose a serious problem to all computer users. The importance of cybersecurity was soon recognised and the fledgling group expanded gradually. The group expanded its expertise into many different operating systems, hardware platforms, applications, and network protocols, and gained in-depth understanding of how networked and mission-critical systems can fail.

Broadening Perspectives

When DSO was corporatised as DSO National Laboratories in 1997, the Computer Security Laboratory (CSL), as it is now known, started to take on additional assignments outside MINDEF/SAF. The move exposed them to many other kinds of requirements in government systems and commercial systems, significantly broadening their perspectives and their understanding of cybersecurity. In addition to various ministries and statutory boards with regulatory interests in cybersecurity, a number of large corporate clients, some of whom were from the banking sector, requested assistance in assessing the security of their critical systems and networks.

DSO's widening exposure to different user needs and systems over the years has helped build up extensive and in-depth knowledge and understanding in a wide range of systems and user needs. Combined with its significant hands-on experience with actual mission-critical systems, and well-endowed internal resources in terms of people, systems, and equipment, DSO is well-placed and hence frequently called upon to tackle interesting and challenging jobs from diverse users.

In 1997, DSO's cyberspace security team won a Defence Technology Prize (Team), a national level award and numerous DSO Excellence Awards. DSO's staff members serve on national IT security fora to provide technical inputs for policy formulation and have presented their research results in overseas workshops. There are also several research collaborations with foreign R&D organisations on information assurance.

Test Bed for Cybersecurity Studies

Over the years, DSO has built up a substantial test bed for studying cyberspace security. Like most test beds, DSO's test bed consists of PCs and server-class machines running diverse operating systems

Cybersecurity test bed.

and applications. However, unlike most test beds, this one includes a mini-Internet to mimic the actual network interaction between home users and the Internet, and between ISPs (Internet Service Providers). These facilities include high-end routers and switches, a cable modem head end, an ADSL (Asymmetric Digital Subscriber Line) head end, as well as wired and wireless LAN environments. This enables DSO to examine not just the local security issues in LAN environment, but also the global security issues such as routing protocols and the security impact of broadband technology that can go all the way to the end user at home.

Besides the more heavy-duty equipment not found in a typical office, DSO has an increasingly large collection of technological "toys" for evaluation: personal digital assistants (PDA) such as iPAQs and Palms (running Palm OS, Embedded Linux, Windows CE), interesting hand phones (WAP, GPRS, Bluetooth), Bluetooth development kits, 802.11 wireless LAN cards and access points, and tiny Apache/ Linux servers the size of a Rubik's cube.

Penetration Testing and Intrusion Detection

Many of DSO's clients are concerned with the vulnerability of their computer systems to penetration and intrusion by hackers and other unwelcome visitors. One of the most interesting and exciting services offered by DSO to key users is penetration testing of their computer systems. By demonstrating in a hands-on fashion how security weaknesses can lead to loss of revenue/reputation or mission failure, the client can be shown the possible impact which such weaknesses can have on his business.

The key steps in penetration testing are information gathering on the client's system and the planning of the penetration test itself. After the planning, a hands-on demonstration is conducted on the client's system. If this is successful, the next step is the validation of the results and the final recommendations to be presented to the client, which give details of the measures the client should take to strengthen his system.

Penetration testing is one of the tasks which DSO staff enjoy a great deal, as every task is new and challenging in its own way, and gives them an opportunity to apply their experience and knowledge in cyberspace security R&D, often in surprising and fun ways.

DSO has also developed an experimental cyberspace intrusion detection system for its users, the development of which helped DSO to appreciate the users' environment and to understand the relative importance of diverse user requirements. The project was very challenging and strengthened the capability of DSO staff, making them a more matured and focused group. Much inspiration and many insights for DSO's current and future work also came from their exposure to users' systems.

Forensic Analysis of Cyber-attacks

The technical knowledge gained by DSO in cybersecurity has turned out to be useful on many fronts. With the increasing frequency of intrusions into computer systems by hackers, DSO's cyberspace security team began to wonder if they could re-construct the actions of a cyber attacker in an intrusion incident. It turns out that most such incidents do leave trails which provide clues to what was done. To extract such evidence from the hard disks of compromised computer systems efficiently requires in-depth knowledge of the systems, up-to-date technical knowledge, a fertile (and patient) investigative mindset and the relevant cyber tools.

In the recent past, DSO has assisted various parties with forensic analysis and investigations of cyber intrusions. In some cases evidence was initially overlooked but was uncovered by DSO staff when they took a second look at the data. With skill and patience, they were able to reconstruct the trails of some attacks even when the perpetrator had made attempts to cover his tracks by deleting the trails and other incriminating data left behind by the intrusion.

In the process, DSO learned more about how to configure and design computer systems and architectures which will make the forensic investigation of a cyberspace attack more effective and efficient. This might help to discourage hackers from selecting such systems for an attack.

The Future

DSO's focus for the next few years is on the protection of critical infrastructure. This work addresses the security issues which will affect the day-to-day life of every Singaporean. The 11 September incidents in the US, and the high profile cyberspace hacker attacks, show that things cannot be taken for granted. DSO expects its future work to take it to new and exciting domains, in addition to its traditional focus on defence, as almost every sector of our social and commercial life, including the financial, health and utility sectors, depends on the security of its computer systems which ensures their continued viability. We must do all we can to ensure that Singapore can survive should her critical infrastructures ever come under cyber-attack.

A DAY IN THE LIFE OF A CYBER WARRIOR

DSO's Cyber Lifestyle

CSL enjoys and thrives in the diverse views and strengths of its members who are drawn from different disciplines such as computer science, computer engineering, electronics engineering, mechanical engineering, among others. A good number of its members are trained in leading foreign universities. The script on the back of the CSL T-shirt sums up their work attitude informally: **"I don't work here. I am just doing my hobby."** The accompanying sequence of pictures gives some flavour of the life-style of CSL staff as they sweat through a challenging project, and the joy and camaraderie among them as they overcome these challenges successfully.

A day of a cyber warrior in CSL always begins and ends in front of a monitor. Armed with a passion for computer security, the warrior never works according to the hours of the day. Very often, work carries on late into the night and even into the wee hours of the morning. As long as a problem exists, they rack their brains to understand, examine, verify and eventually, overcome it.

However, success does not come easily most of the time. In fact, to study a single vulnerability, rounds of testing have to be conducted, topped off with whiteboard analyses, discussions, exchanges of ideas, in-depth research and most importantly, teamwork.

Once a full understanding of a subject is obtained or a rare discovery is made, this knowledge will be transferred to their security assessment tool bag, which becomes the "secret edge" that distinguishes them from the rest of the market.

With the completion of each assignment, the discovery of a cutting-edge solution, or the achievement of understanding a particular problem, celebration often follows by means of a feast with the team. True team spirit indeed.

ENABLING DECISION SUPERIORITY

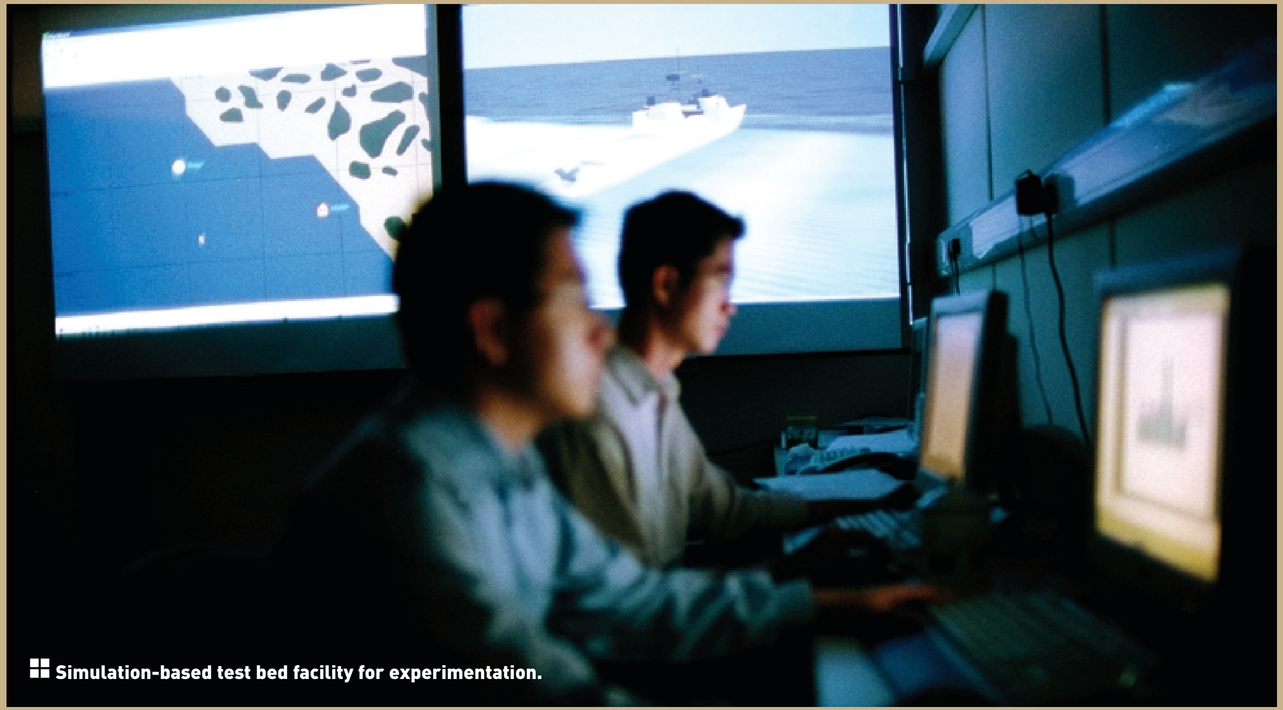
The Role of C3I Systems

The history of warfare can be seen as a history of increasing complexity, from the relatively simple situation of cavemen engaging in battle with sticks and stones, to today's advanced battlefields with their computerised and networked command and control systems. History has clearly shown that the ability of an army's commanders to keep track of what is happening on the battlefield, and to transmit their commands to their forces quickly and accurately, is often more important than superiority in numbers or firepower.

In the days when battlefield information had to be transmitted without the aid of radio waves or electronics, commanders had to rely on their own eyes and ears, calling on the aid of messengers relying on their own feet or on horses, and signallers using flags and flares to send a message to their forces who were beyond earshot. Eventually, flags became too dangerous and exposed for signallers to use them for communications. In World War I, commanders would use their signallers as "runners" to bring messages to their troops in the front lines, often two at a time so that if one was killed the other would get through (perhaps an early form of redundancy in communications!).

The telephone, with its ability to pass messages through wires, was quickly adopted for battlefield communications, and World War I signallers would have to lay telephone cables right up to the trenches in the front line, and re-lay them when they were cut by shell fire. Radio further transformed the command and control situation in the battlefield dramatically, giving commanders the ability to instantly gather information and intelligence, and to transmit instructions to their forces at a distance instantly.

The use of aircraft not only for combat but also for intelligence gathering presented commanders with opportunities to gather information about enemy strength, disposition, and movements which would have been almost impossible to obtain by other means. Spy planes, both manned and unmanned, have made significant contributions to intelligence gathering,



Simulation-based test bed facility for experimentation.

and continue to do so, most recently in US operations in Afghanistan.

Artificial satellites in earth orbit have vastly expanded the scope of such operations, with observational satellites such as SPOT 5 and IKONOS now able to offer images of any part of the earth's surface to an astonishing resolution of 1 metre.

The march of technology has certainly played a key role in the escalation of the pace and complexity of warfare, to the point when the winning of a war is now critically dependent on the ability to gather tactical and strategic information accurately and quickly. Throughout the history of warfare, as we have seen, commanders have had to increasingly rely on technology in order to formulate sound decisions based on such information, as well as to transmit their commands and instructions efficiently to their forces. The ability to collect, collate, process and disseminate information efficiently and accurately in a military situation is now generally referred to as C3I (Command, Control, Communications and Intelligence). C3I brings together real-time and non real-time capabilities in the convergent technologies of computers, networking, multi-media and telecommunications, in order to achieve decision superiority for the side that can exploit these technologies more effectively.

The difference such a capability can make to modern warfare is vividly illustrated by an incident which took place during the US counter-terrorism war in Afghanistan recently. An US Marine spotter on horseback on top of a ridge was being hotly pursued by Taliban forces. He estimated that it would take his pursuers ten minutes to reach his position. He therefore called for an air strike on his position before he rode away. Ten minutes later, the strike arrived and swiftly took out the enemy pursuing him. Such precise engagement was possible only because of enhanced battlefield awareness and decision making brought about by superior C3I.

The fundamental C3I functions are:

- The collection, collation, processing and display of information on the status of the theatre of operations and of the friendly and hostile forces.
- The support of operational planning and decision-making.
- The communication of information between commanders and their forces.

C3I systems may include sensors, computers and networks, graphical displays and data communications links. They are in effect specialised defence software systems.

As the trend towards technologically-based warfare dependent on information and communications systems becomes increasingly evident, the need to further develop our C3I capabilities becomes more and more critical.

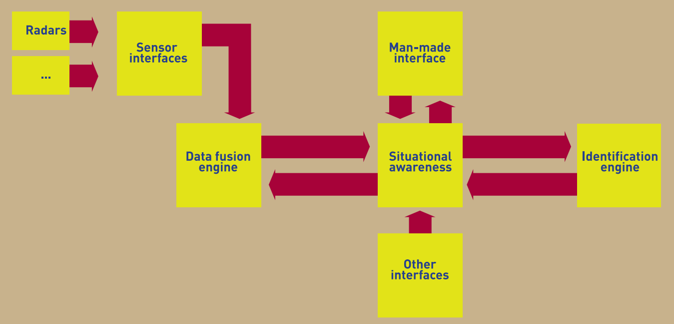
Building up of C3I Systems Capability

The building up of a C3I capability in DSO may be traced back to the setting up of the Defence Software Department (DSD) in DSO in 1984, which was a MINDEF effort to centralise all software expertise in DSO. DSD was able to capitalise on the accumulated experience of previous software systems acquired by MINDEF. They were generally hard to maintain and poorly documented. To build up a pool of young software engineers, DSD used the numerous software acquisition projects to create software engineering On-the-Job-Training (OJT) opportunities with MINDEF's C3I contractors.

This enabled DSO to build up domain knowledge in command and control (C2) systems and to learn best practice skills in software engineering from the contractors. DSO engineers learnt that software engineering is not just programming but should also cover systems analysis, design, coding and testing. These pioneering software engineers played an important role in supporting subsequent software engineering efforts in DSO, and in establishing various important standards for software acquisition, development and support.

Capabilities in platform based C2 systems development were built up, starting with interfaces among C2 systems, leading eventually to the development of a complete platform-based C2 system. A generic illustration is provided in the accompanying diagram. The C2 system takes in onboard sensor data such as platform position and speed, and information through other interfaces. Through the man-machine interface, the commander can select different modes and priorities as the battle develops, to perform data fusion, identification, and tracking of various platforms involved in the battle. The system also presents the commander with the overall battlefield situation through the man-machine interface.

Platform Based C2 System Architecture



Platform Based C2 System Architecture

The successful completion of these earlier projects encouraged DSO to take on the more complex and challenging development of a Command Post C2 system. This system extracts essential information from other platform-based C2 systems, providing a more complete picture of the larger battlefield under the command of higher level force commanders. DSO also started using ruggedised commercial off-the-shelf (COTS) items and has retained this approach as far as is practicable. The adoption of open architecture, Ethernet protocol and object-oriented methodology greatly facilitated integration with COTS.

Over the years, DSO has scored several successes in building up its capability in the fusion of data and information from different sources, with potentially important applications for a new generation of C3I systems.

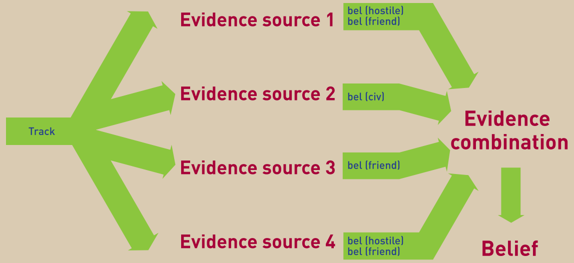
TARGET IDENTIFICATION SYSTEM

During a military operation, information and data may be coming in from a wide variety of sources. If all this information and data are input into a C3I system, there is the problem of combining and fusing the data together so that all the different information sources can be made to reinforce each other meaningfully in order to build up a picture which is useful. Data fusion is the technology of combining such disparate data into a coherent and meaningful whole.

Data fusion as a technology area covers many different levels. At the lowest level, it encompasses the synchronisation in time and space of the incoming data and the extraction of structured information from unstructured data like text and imagery. Other levels of data fusion deal with issues like tracking, classification and identification of data from multiple sensors. The highest level deals with intent assessment from data processed and analysed at the lower levels. Data fusion thus helps the commander to deal with the vast amount of data flowing into a C3I system and to make sense of this information.

One application of data fusion technology was in target identification, as illustrated in the accompanying diagram. This involves the collection and processing of the information from several different sources. The key idea was to have a number of software modules (evidence sources 1, 2, 3 and 4 in the diagram), each acting as an "identification expert" such that each module provides an independent assessment of (or belief in) the possible identity (hostile, friend or civilian) of the detected target. These independent assessments (which are the outputs labelled "bel" for "belief") are then combined through a "belief combination module" (the module labelled "evidence combination"). This combination module incorporates algorithms first developed for MYCIN, the first Medical Expert System, which made medical decisions based on various data inputs. The application of various artificial intelligence (AI) algorithms into a fusion engine for object identification has been a very good learning experience for the AI engineers involved.

Fusion Approach to Identification



NATURAL LANGUAGE PROCESSING

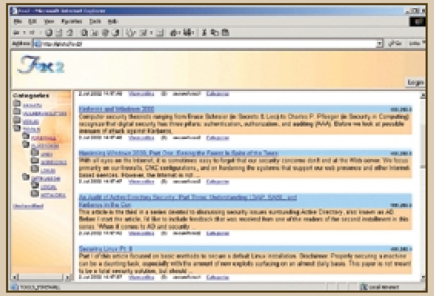
Another capability that has been built up is Natural Language Processing (NLP). NLP is an important branch of artificial intelligence (AI) which seeks to build software systems capable of understanding natural human language. This may appear to be a trivial task, as it seems that humans do not have much difficulty understanding the speech or text of other humans expressed in a language which they know, such as English or Chinese. In actual fact, the task of making a computer understand text as naturally expressed in a human language is extremely difficult, as natural human languages are full of logical inconsistencies which we as humans are able to decipher because we have had years of experience in dealing with these inconsistencies and other subtleties of natural speech and text.

If NLP can be made to function as intended, many advantages would accrue, such as our being able to communicate with computers using natural human language and not some strictly structured computer language difficult for the layman to master. In reviewing the various existing approaches to NLP, it was determined that the so-called corpus-based approach to NLP has the most potential to scale up to handle real-world human text, even though such an approach is still relatively new. Traditional NLP techniques involving the manual crafting of rules and knowledge bases designed to understand simple text, are difficult to scale up to handle real-world human text and speech.

Using the corpus-based approach, the NLP tasks of parsing and word sense disambiguation were tackled. In parsing, the objective is to break up or classify the words of a sentence into its constituent parts like noun phrase and verb phrase. Word sense disambiguation, on the other hand, deals with identifying the "meaning" of a word in a given sentence, especially when that word may have two or more completely different meanings. For instance, the word "interest" in "The bank pays a high interest for your savings." has a different meaning from the word "interest" in "John has an interest in many subjects".

In parsing, we utilise a statistical method known as the Hidden Markov Method (HMM) to learn the "rules" of grammatical structure, given a corpus or body of existing real-world texts. The words in the real-world texts are tagged to reflect their grammatical function. The HMM method is then used to learn the "grammatical rules" from the statistics of the tagged words in the real-world corpus. For example, from the corpus, the learning method can gather the statistics of how articles such as "a", "an", "the" precede nouns like "cat" and "dog", and hence better understand the function of these articles. This method is also language independent and has been successfully tested on English and another language. A US Patent for the HMM approach to Parsing has been granted.

Word sense disambiguation (WSD) is a difficult problem given the many words with multiple meanings or senses and the vast corpus of real-world text from which



An integrated suite of NLP software developed by DSO.

these senses may need to be drawn. The first step was to learn from a sense-tagged corpus of sufficient but manageable size. Such a sense-tagged corpus is not easily available, but one was built up using NUS student manpower. With this sense-tagged corpus, the approach to WSD was formulated as a classification problem, i.e. given a particular word ,the possible senses that word could take were retrieved from the corpus. The results achieved by this approach were impressive compared to other non-corpus based approaches and resulted in a DSO staff member being invited as a keynote speaker in a prestigious international workshop: SIGLEX 97 (Special Interest Group under the Association of Computational Linguistics). A key paper on the corpus-based approach to semantic interpretation published in the Artificial Intelligence Magazine was also co-authored. Given the many requests for access to DSO's sense-tagged corpus from other researchers, it has decided to contribute the corpus to the US-based Linguistic Data Consortium.

This successful research result was used in other applications, such as an application to automatically categorise an incoming document based on its content in which the corpus-based approach was utilised, to learn the rules for categorising incoming documents. This categorisation engine is called "CLASSI" and a paper describing it received a prize for the "best non-student paper" in the SIGIR (Special Interest Group on Information Retrieval) 97 Conference. CLASSI was also benchmarked on the Information Routing Sub-task at TREC-8 in 1999 sponsored partly by DARPA, obtaining the top two scores in this sub-task. The CLASSI engine was also licensed to a local company for commercial exploitation.

Another interesting application was the use of NLP for question answering (QA). In a traditional search engine (similar to engines such as Google on the Internet), the user types in a keyword and the engine retrieves a set of documents which contains the keyword. For QA, NLP techniques were employed to handle questions like "Who is the President of Singapore?". The NLP module analyses the words in the question to provide another level of information besides these words. For example, DSO's QA module would know that the question, "Who is the President of Singapore", is asking for a person (from the word "who"), and would also know that "President" is a title and "Singapore" is a country. The QA engine will attempt to return the sentence within the target document that contains the answer to the question. This is more precise than what current search engines provide i.e. just the document itself.

Future C3I Applications

It is virtually certain that warfare in the future will be information-centric and networked-based. One key enabler which can bring this about is autonomous co-operative system technology. An autonomous co-operative system utilises advanced algorithms to coordinate the problem-solving behaviour of many different software agents representing various entities connected to the network.

For example, in a search and rescue operation, the utilisation and coordination of multiple robots through a communications network will result in searches which are shorter yet more extensive. In another scenario, a number of autonomous sensors with different capabilities, which are coordinated by being networked together, will be able to perform better and more efficiently.

The key technology components for the realisation of such an autonomous co-operative system include decentralised data fusion across a network of sensors, agent negotiation, and co-operative autonomous robots for mobile platforms. These concepts will be validated utilising modelling and simulation technology. A major simulation test bed will be set up in 2002, based on high level architecture (HLA), a high level protocol for linking different simulators.

The coming decades of this new century will definitely bring many more new challenges for DSO. Overcoming these challenges and creating the C3I systems of the next generation, such as the network-enabled knowledge-based infrastructure, will be an exciting and daunting task which will demand all of DSO's creativity, innovation and daring.

Experimenting with autonomous co-operative robots.

1010

ENABLING INTEGRATED WARFARE

The modern electronic digital computer, so much a part of contemporary life, was born in the midst of the greatest armed conflict mankind has ever seen (and hopefully will never see).

While the exact origins of the electronic digital computer are unclear, it is clear that the first such machines or their inventors were very closely associated with military applications. This is perhaps inevitable as all these machines were born just before or during the Second World War.

Konrad Zuse's Z3 was funded by the Third Reich and was used for airframe stress analysis. John Atanasoff and his graduate student Clive Berry had barely completed the ABC (the Atanasoff–Berry Computer) when Atanasoff abandoned his machine to work on physics research for the US Navy. John Mauchly and Presper Eckert built their legendary ENIAC to calculate ballistic missile trajectories, while Alan Turing designed Colossus to crack a German cipher tougher than the famous Enigma code.

However, computers working in splendid isolation from each other, no matter how powerful they may be, cannot derive the kind of synergistic capabilities they gain when they can communicate with each other, or as we prefer to say nowadays, when they are networked.

The mother of all computer networks today, the ubiquitous Internet, was born in the late 1960s as a result of collaboration between civilian computer scientists and the then ARPA or Advanced Research Projects Agency, formed by the US Department of Defense (DOD) in response to the then USSR's launching of its Sputnik earth satellite. This fledging network, or ARPANET, which was originally intended to link up scientists working in academia and research institutes with DOD researchers, has now vastly expanded into today's Internet with its millions of websites.

Networking and the Internet in particular, have made connectivity an integral and essential part of computing, and influenced our lives in countless ways. Universal computer connectivity and widespread Internet access have indeed made the network central to computing, such that it may be said that the network (not the computer), is the system itself.

With wireless devices adding mobility to connectivity, we are now an integral part of the network at all times, and "network centric computing" has now irrevocably replaced the "platform-centric computing" of an earlier age.

This networking revolution is also causing a paradigm shift in the way military planners think about the conduct of future operations. The essence of this on-going Revolution in Military Affairs (RMA) is about the intelligent exploitation of the relevant technologies towards, not just making weapon systems smarter, smaller and faster, but leveraging on the power of networking to multiply their effectiveness many-fold.

The Internet derives its power from being a "network of networks"; likewise, a "system of systems" based on a hierarchy of networks could enable a military force to achieve dominance in "battlespace awareness", giving it supremacy in the control of the theatre of operations.

"The Network is the Computer", so runs the slogan of Sun Microsystems. The Internet appears to reinforce this concept.

Bob Metcalfe, the inventor of the Ethernet, one of the key enabling technologies of local area networking, has pointed out that the usefulness of a network is proportional to the square of the number of nodes in the network, which also explains why the Internet's power has increased so dramatically as the number of nodes world-wide escalated.

By allowing military information systems and their combat unit counterparts to link up with each other and share data to form an intelligent network, with operational and logistic data being exchanged in real time, it is entirely possible that a similar network multiplier effect can be effectively unleashed and harnessed.

The implementation of a network centric architecture will enable integrated warfare by incorporating three essential and critical elements of war fighting:

- An Information Grid or network providing a command, control, communication and decision support backbone.
- Sensor Grids which interconnect far-flung sensors designed to pin-point the enemy.
- Engagement Grids which direct a variety of weapons systems or shooters towards their targets.

A networked force will thus have

the capability to dynamically interconnect sensors, shooters and decision-makers and enable them to collaborate and share information, knowledge and resources. A conventional force which becomes networked-enabled and knowledge-based can greatly increase its combat power through increased system awareness, interoperability and synchronisation among its elements, giving improved lethality and survivability as well as increased operational speed.

DSO has been working on the enabling technologies which are critical to integrated warfare since its early days. Various system concepts are also being actively studied in the areas of distributed sensors, automation of information processing, correlation and fusion with distributed signal sources and dynamic management and dissemination of information. The next step is to combine and integrate all of these technologies – sensors, shooters and computer systems – to enable the SAF to work in an integrated knowledge-based command and control (IKC2) framework.

Sensors

DSO has also been working on advanced sensors which are sensitive to light in the visible as well as infrared and ultraviolet regions, radio waves, microwaves, sound waves both in the audible and inaudible regions, magnetic fields, and chemical and biological agents.

By networking many sensors together, the following advantages can be gained:

- The real time combination of exchange data from different sensors which can improve the overall reliability and accuracy of the signals.
- The ability to activate and control remote sensors.
- Enhancing the resistance of the sensors to interference from deliberately transmitted signals (i.e. jamming).
- Decreasing the probability of interception of sensor information by an enemy.

Communications Networks

A common network architecture which meshes dispersed sensors, decision support nodes and weapons systems, is the key to achieving an effective IKC2 framework. DSO has the vision of developing a secure, highly reliable and tightly integrated common data communications system with the capability to seamlessly combine voice, data and video information. This connectivity should be able to link various communications systems operating at different frequencies and across different transmission media in heterogeneous physical networks.

DSO has been conducting research into wireless communications systems for the battlefield environment since the early 1990s.

Starting at the physical layer, work has been progressing on wireless network system architecture, communications protocols, and waveform and algorithm designs which can provide:

- High data throughput rates with good spectral and power efficiency.
- Efficient multiple-access schemes which can support a multi-user and multi-data-rate environment.
- Robust protection against the degradation of signal channels for highly dynamic platforms like aircraft.
- Good electronic-counter-counter-measure (ECCM) performance which includes a robust defence against intentional and unintentional interference (anti-jamming) and low probability of signal intercept (LPI).

DSO's hardware research effort has been focused on the design of technological building blocks which can be used in a variety of applications and communications systems. Towards this end, DSO has been working on programmable modems (MOdulator-DEModulator) and radios whose characteristics can be altered by their software, which leverage on recent advances in field programmable electronics and digital signal processors.

This ability to change function through software or programmability, will facilitate faster and lower cost adaptations of programmable communications systems. This will enable them to serve the wide variety of system platforms one can expect to be utilised in an IKC2 infrastructure.

DSO has also configured and tested datalink systems (systems which transmit data to and fro) in field experiments. More advanced versions of these systems with higher processing power and the flexibility to enable higher data rates, as well as superior performance against channel degradation due to interference, are being developed.

DSO is also working on the challenging area of ad hoc networks. Such networks have self-organising architectures (i.e. systems which can evolve their configurations by themselves as and when necessary) which are rapidly deployable and adaptable to the traffic and mobility patterns encountered by the network nodes.

Ad hoc networks do not need a fixed infrastructure or centralised control. Nodes in ad-hoc networks are highly mobile and the topology (i.e. the way the nodes interconnect with each other) changes rapidly. Other important characteristics of such networks include peer to peer mode of operation (each node communicating with the other nodes on an equal basis, without any node dominating), multi-hop routing, and adapting to changes in the propagation environment.

DSO has performed many studies including the modelling and simulation of suitable communications protocols (the manner in which communications systems acknowledge each other) which can be readily configured for different operational scenarios.

Through various field experiments and close partnership with their users, DSO has gained a great deal of experience in designing wireless ad hoc networks which can achieve high efficiency in channel utilisation, adaptability to fast changing conditions, reliability and timeliness in data delivery, and high survivability.

Such a capability in the design of communications networks is vital to providing support to DSO's users as they undergo the transition to a network-enabled infrastructure.

DYNAMIC RESOURCE MANAGEMENT

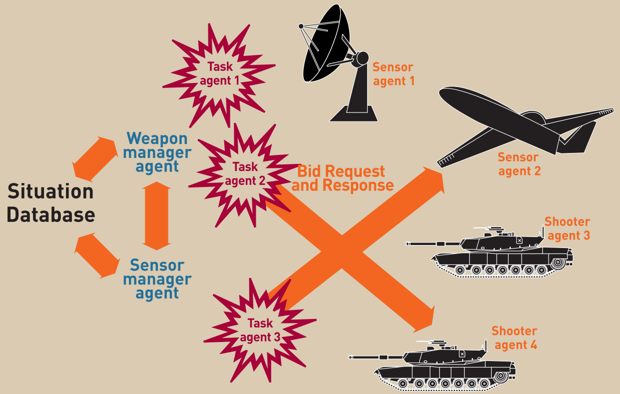
In a battlefield situation, we may have many resources, including sensors and weapons, providing real-time services to the commanders. Sensors provide real-time services to sense and detect the environment, while weapons provide real-time services to engage incoming targets. The concept of dynamic resource management is the provision of a means of mediating between all these resources so as to match them more efficiently to one another.

Borrowing an idea from the Internet dot.com boom era, some dot.com companies were set up to provide a kind of "matchmaking" service among service providers and service demanders. Typically, the model used was a kind of bidding concept, with the service providers bidding to provide a service to the service demanders in the most cost-effective manner.

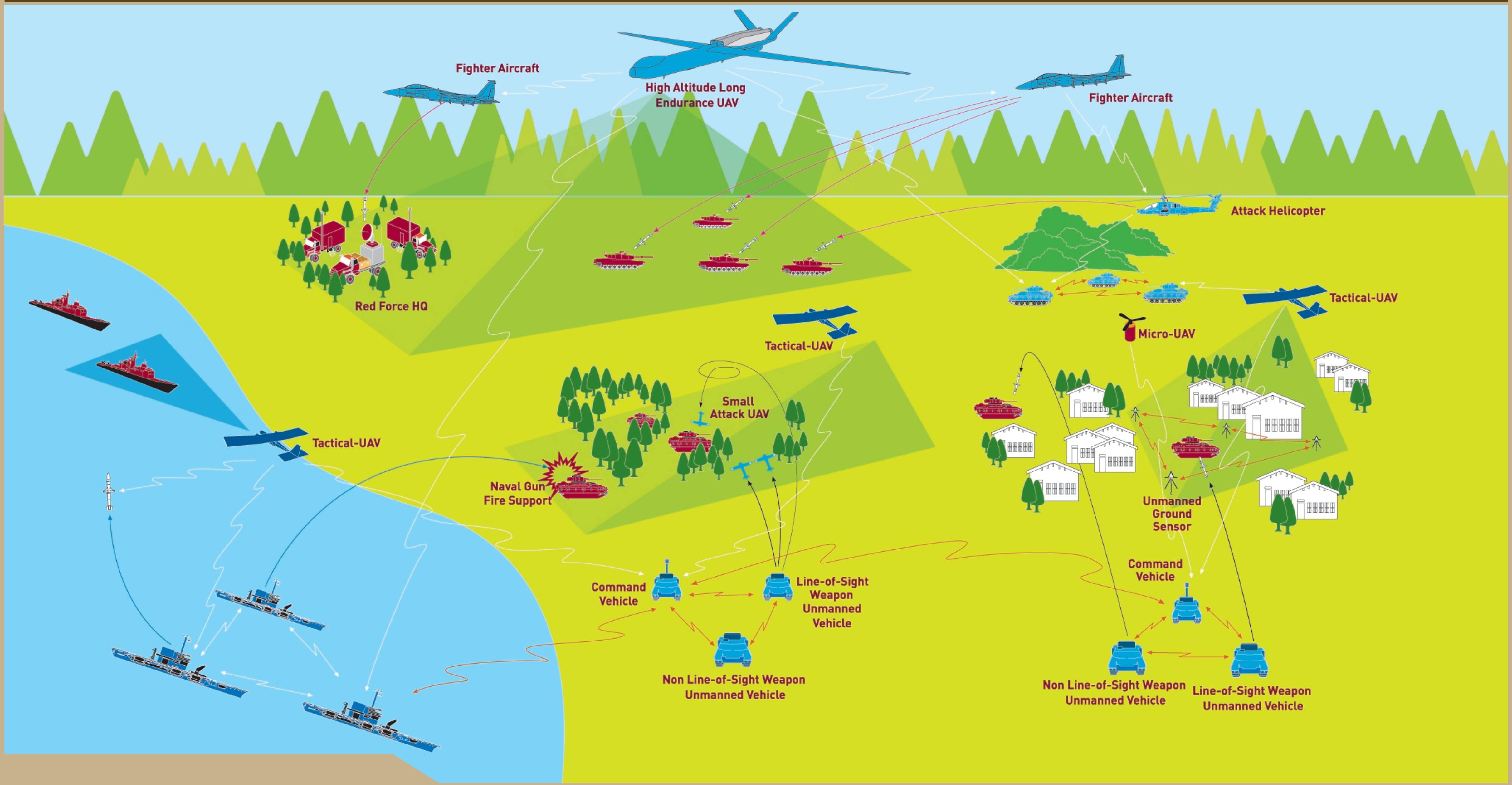
Using the dynamic resource management concept, the targets detected by sensors and confirmed by data fusion methods may be seen as service demanders, while the resources such as the weapons are service providers. The targets and the resources are modelled in the system as software agents, i.e. as entities which can act independently. The software agent for a target monitors its own need to use the resources and submits a "request for bid" for a resource if it decides that it needs to do so. The software agent for a resource, such as a weapon, contains knowledge of its capabilities and is able to assess bids based on these capabilities, for example on the basis of target position relative to weapon, target range etc.

The optimisation and allocation of the resources to the targets are determined in accordance with an algorithm which will search among all the possible combinations of resource to target allocations, for the optimum allocation in accordance with the given conditions. In a real situation, this should result in each weapon being allocated to the target which is most suited to its range and firepower.

Multi-Agent approach to Dynamic Resource Management



INTEGRATED WARFARE CONCEPT



The future

Integrated warfare derives its power from the networking of dispersed forces through an enabling information backbone which gives full access to smart sensors, and enhances the precision and speed of response of shooters. DSO is continuing its drive towards the mastery of the critical enabling technologies necessary for the realisation of a nimble, knowledge-based, network-enabled and integrated fighting force operating in air, land and sea, which is capable of dynamic engagement in all directions and at all times.

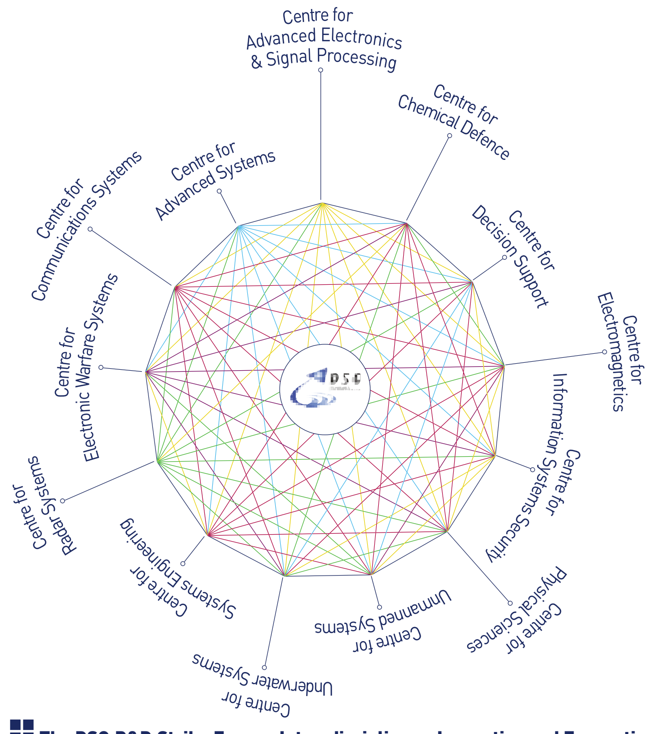
BACK TO THE FUTURE

QUEK TONG BOON, CEO, DSO

It has indeed been an exciting 30-year journey for DSO. Our cloistered beginnings and MINDEF's unwavering support, provided shelter and nurture for Dr Goh Keng Swee's visionary seedlings to take root.

The secrecy and seclusion that characterised DSO in its early years came with some cost. Advancement in scientific research thrives when there is sharing of knowledge. The strict codes of compartmentalisation in DSO at that time inhibited this process. Recruitment was problematic, as few even knew of the existence of DSO. Lack of interaction between DSO and the SAF created a gap between the technology developers and end-users; this was the *gulf* that RAdm (NS) Teo Chee Hean referred to.

Over the years, certain fundamentals in DSO have remained unchanged. We continue to focus on core capabilities such as electronic warfare and sensors as we did in the '70s and early '80s. In these areas, we can do today what we could only dream of, even as recently as ten years ago. Where possible, our users



The DSO R&D Strike Force – Inter-disciplinary, Innovative and Energetic.

have pitted our proposals against global benchmarks and "best of breed" market options, to ensure that DSO is offering the best and most appropriate solution to the SAF.

Our capabilities have since expanded in breadth, depth and bandwidth. In breadth and depth, our R&D capabilities have expanded to include areas such as cyberspace security, C3 (command, control and communications), underwater technologies and chemical-biological defence. In bandwidth, projects that we undertake are increasingly more complex and multi-disciplinary.

Today, our expertise resides in 13 centres of excellence, working collaboratively with each other. They constitute our R&D strike force. What makes DSO unique in the Singapore research community today is our ability to deliver integrated and inter-disciplinary solutions.

However the reader would have noticed that since day one, our key asset is people. When we talk about capabilities, we are really talking about our *people*. Therefore, the story of DSO is really about how we have built up our people and how we have co-evolved with MINDEF and the SAF as part of the defence ecosystem in Singapore.

Over the years, what has changed is the way we manage our people, our process, our customer relationship and our organisational culture. We are now a more open, mature and confident organisation.

Our corporatisation in April 1997 has prompted us to be even more customer-focused. We have in fact, incorporated it as one of our core values and spun a web of linkages at various levels with key users of our expertise in the SAF, MINDEF, DSTA and other national security agencies. Applied R&D is about working with our users to understand their problems, and create knowledge or solutions where none exist before. For our outputs to be operationally useful, thinkers, tinkerers and end-users must connect, communicate and collaborate.

In reality therefore, our users are our partners rather than our customers. Our researchers are now operationally more aware and our partners technologically more savvy. The *gulf* that existed between DSO and the SAF has not only been bridged but has evolved into a symbiotic relationship.

> "With greater capabilities, your contributions went beyond being a mere provider of technological solutions. DSO has directly influenced SAF tactics and doctrines... Unfortunately, many of DSO's contributions cannot be discussed openly... The few stories that I have just mentioned only give a glimpse of the substantial operational payoffs provided by DSO to the SAF over the years. Let me therefore take this opportunity to acknowledge your consistent and invaluable support to the SAF and for all the secret edge capabilities that ironically, we all hope the SAF don't have to use."
>
> LG Lim Chuan Poh, Chief of Defence Force
> Keynote Address delivered at DSO Workplan Seminar
> 9th May 2002

Over the last few years, we have also strengthened our collaborative linkages with various R&D establishments – both locally and internationally – to enable us to benchmark our research efforts and conduct complementary research. Our researchers take pride in being able to spar intellectually with world-class R&D partners and researchers.

The spectrum of our activities today spans from providing impartial technical advice to creating technological wonders that Tom Clancy would be proud to use in his novels. As advisors, we help our partners to differentiate reality from fiction. As creators, we strive to transform fiction into reality. We have shown that once we set our mind on something and focus our attention on it, no endeavour is too complex or high-tech, transcending Singapore's resource limitations. This is the tremendous confidence that comes from learning by doing. Through our *can do* and *gung ho* spirit, we have shown that Singapore can excel in knowledge creation.

One has to see to believe how passionate and committed our people can be. In one of our laboratories, researchers sport T-shirts with the slogan "I don't work here. I am just doing my hobby." Another of our top researcher was asked if he would leave DSO for another company. He replied, "No, not even if I am offered three times my salary because I can never get the same type of challenges elsewhere."

Therein lies our key challenges – people, environment and work challenges. DSO aims to be the magnet for quality people who are passionate about working at the frontiers of science and technology. Like our founding father, Dr Goh Keng Swee, we want our engineers and scientists to have the curiosity of a child, always asking "why?", "why not?" and "what if?" They must be fired up and the adrenaline must rush when they encounter challenging real-life problems. Such challenges provide them the opportunities to grow and glow.

The mission of DSO is a serious one. It is a mission for Singapore by Singaporeans. But that does not mean that we should be staffed with boffins in white laboratory coats or nerds at ease only with computers. We believe in making DSO a place where staff can have fun doing serious work.

The tragic events of 11 September 2001 and the subsequent shocking discovery of the Jemaah Islamiah group in Singapore, have brought home the gravity and reality of the threats of global terrorism. The events have brought fundamental changes in perception about local and global security. It has brought greater urgency to efforts DSO initiated a few years ago to explore how expertise we have built up for defence, can also be applied to other facets of our national security to counter asymmetric threats.

1972–2002

GALLERY

30 years on, we in DSO have many stories to tell.
In the pages that follow, we share some of these stories through a series of pictures, grouped into the themes of Now & Then, Happenings, Bonding, Having Fun, Spirit, Partners and Technology Edge.

This is DSO at a glance.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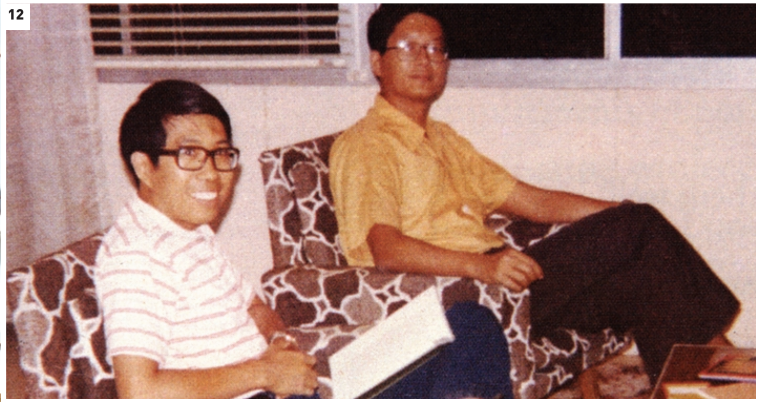
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01 Launch of a cross-Centre, multidisciplinary initiative – Explorer – for idea generation.
02 Pioneers and governors of DSO attending a project briefing.
03 CEO, Quek Tong Boon, at a senior management retreat, aimed at developing the DSO Strategy Map.
04 DSO's very own sweets and chocolates.
05 Editorial Committee working on this book.
06 The late Vijay Mehta, officiating at the Walk-A-Jog in 1990.
07 Dr Goh Keng Swee at the opening of Science Park building in 1989.
08 DPM, Dr Tony Tan at the opening of the re-developed Marina Hill complex in 1998.
09 Our class-100 clean room facility.
10 From collegues to husband and wife, Tan Kia Liang and Chow Yoke Ling.
11 DSO Science Park building.
12 Prof Su Guaning with the late Dr Tay Eng Soon.
13 SAF partners with DSO engineers in the acoustic chamber.

NOW AND THEN

From Mount Ophir to Mount Everest

In the mid '80s, Quek Tong Boon, then a project engineer in DSO, led a team of his fellow colleagues to climb up Mount Ophir in Malaysia. Some 15 years later, Dr Robert Goh, one of our senior aeronautical engineers triumphed over our CEO with his climb up Mount Everest in 1998. In 2000, one of our young aeronautical engineers, Matthew Lim led some DSO staff to climb Mount Kinabaru in Sabah to raise funds for charity. In 2002, Robert outdid himself when he and his fellow mountaineers subsequently conquered Mount Xixabangma, another of the Everest peaks, Alpine style (that is, without oxygen tanks). It's rather obvious from these climbs that our staff love adventures and being on top for certain! May our passion to strive for peaks be everlasting!

As DSO used to be a highly classified entity in its earlier days, staff were told not to speak of their work to third parties, unless instructed to. As such, most were used to speaking only when necessary. New staff were often left alone while their colleagues worked away, silently. In fact, they were not even allowed to go to Marina Hill when they first started work. Instead, they were told to report to work at "Block 42, Harding Road" – off Napier Road, close to where the US Embassy is located today – while their security clearance was in progress. As the clearance could take as long as a month, some staff would be assigned jobs totally unrelated to what they would be doing in their eventual work in DSO.

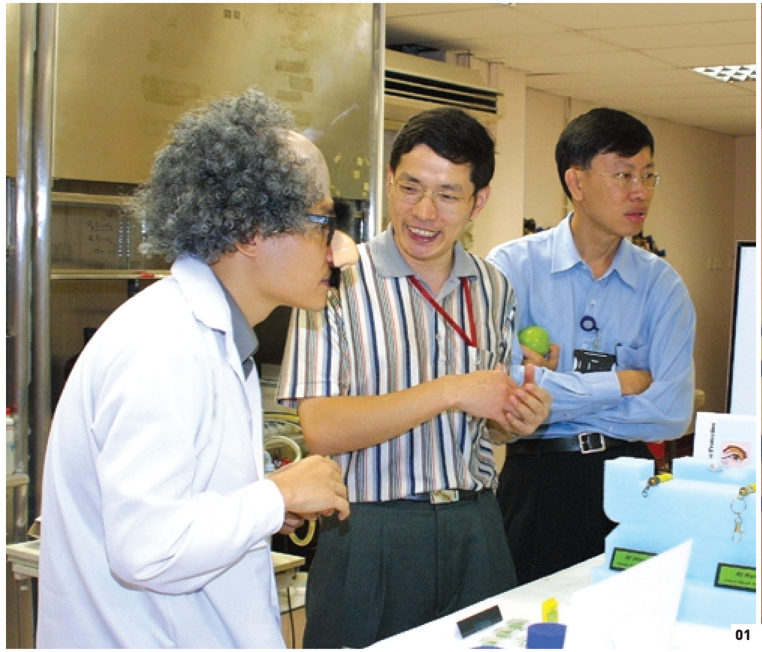
To preserve such secrecy, all outgoing letters in the '70s had to be signed under one name, that is, "G. Su". At one point in time, people were commenting that "G. Su" must have been the most productive person in MINDEF! Imagine, he signed tonnes of letters everyday! Mails to the organisation were all sent to a P.O. Box at the Ghim Moh Estate Post Office. CEO, Quek Tong Boon recalled that in the mid '80s, he received a telex addressed to "Mr Ghim, Moh Estate, Singapore"! To this day, he still wonders how it got to him.

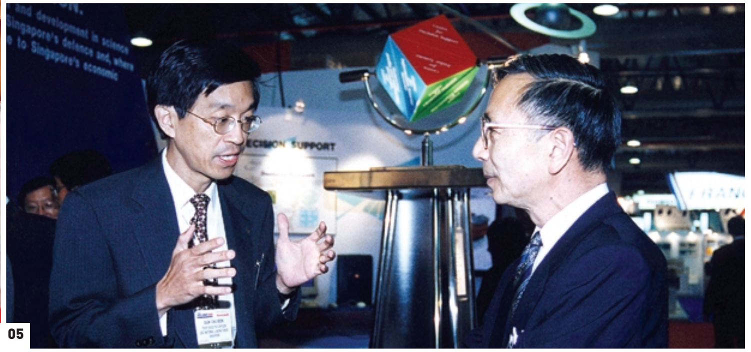
While some of the things we worked on in the early years remain secretive, much of what we would have stamped "SECRET" without second thoughts then are now shared openly. To attract more talents to the organisation as well as to instil a sense of pride among our people, DSO has stepped out of its shadow to face the public, to tell of its work, and to demonstrate the challenges aplenty in the organisation. We are now able to tell people of our existence as well as to discuss with interviewees the excitement that awaits them when they join us.

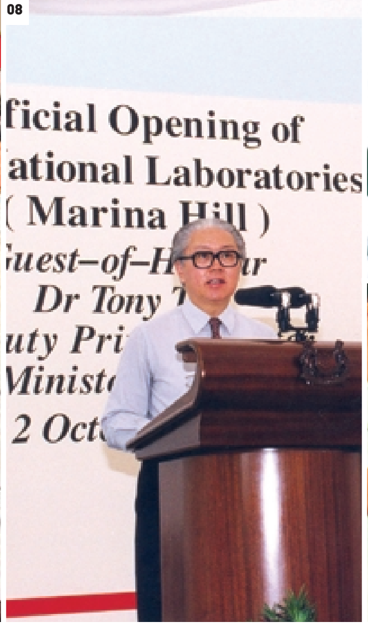
Today, staff are no longer left to ponder in uncertainty. To ensure that every one of us knows the organisation well, each new staff has to undergo a two-day induction programme to orientate himself with both the workplace and his fellow colleagues. Silence is no longer a golden rule. Staff are instead encouraged to share. During the May 2002 Staff Conference, Quek Tong Boon even said, "We share, therefore we are".

01 Joy Mah (left) in 1980 at her then–cubicle at Marina Hill.
02 Joy Mah, 22 years later, at her present work station in DSO.
03 Old Marina Hill building in the early days.
04 DSO's first home at the second storey of the Onraet Road building.
05 DSO engineer, Dr Robert Goh, triumphing over his climb up Mount Everest (top) in 1998 and then the Xixabangma expedition (bottom) in 2002.
06 Quek Tong Boon and colleagues celebrating their conquer of Mount Ophir in the 1980s.
07 What the old Harding Road building used to look like.
08 The re-developed Marina Hill complex standing tall today.
09 The present day DSO Science Park building.
10 The evolution of our newsletter, from LINK to KINETIC.
11 A working desk at Marina Hill in the earlier years.
12 DSO staff swaying to the music at the 1997 Dinner & Dance, celebrating our 25th anniversary.
13 Director (Advanced Development), Yeo Kee Kong (middle) and Assistant Director (SPPO), Ng Sin Yong (left), in 1985.
14 Yeo Kee Kong and Ng Sin Yong, 17 years later in 2002.
15 A typical DSO cubicle today.
16 Female staff in DSO fashionwear, dancing at our 5th anniversary Dinner & Dance.

HAPPENINGS



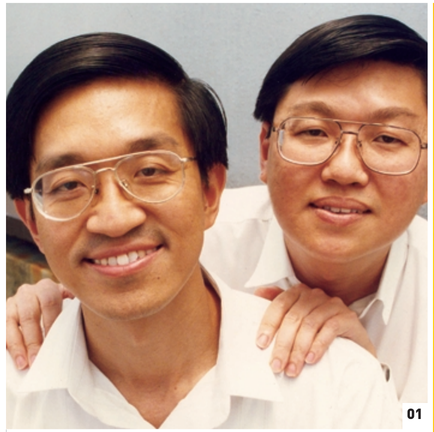




In 1977, we celebrated our 5th anniversary. In 1987, we celebrated our 15th year and then in 1997, we had our 25th birthday. This year, we are commemorating our 30th year in operation! So what has been happening within the organisation in between these milestones? Plenty! Buildings at Science Park and Marina Hill were built to accommodate the growing workforce; a new logo for the organisation was launched; showcases were put up to tell others of our work and achievements; visits were hosted to share information with our strategic partners and key people in the field; innovations sprouted from within the company and many more happenings! It is important to note that in the midst of these going on, DSO holds one strong belief, that without its people, all these would not have been possible.

01 Dr Inno at DSO InnoFair 2001.
02 Dinner & Dance 1997, commemorating DSO's 25th anniversary.
03 Celebrating our 15th anniversary.
04 2nd Singapore International Symposium on Protection Against Toxic Substances in 2000.
05 DSO at Asian Aerospace 2000.
06 New DSO challenges conveyed through a skit by our three Directors during DSO Workplan Seminar 2001.
07 DSO Technology Showcase 2000.
08 DPM, Dr Tony Tan at the opening of Marina Hill complex in 1998.
09 SM Lee Kuan Yew attending a briefing at DSO in June 1991.
10 Launch of our new logo in December 1999.
11 Official opening of Science Park building on 27 October 1989.

BONDING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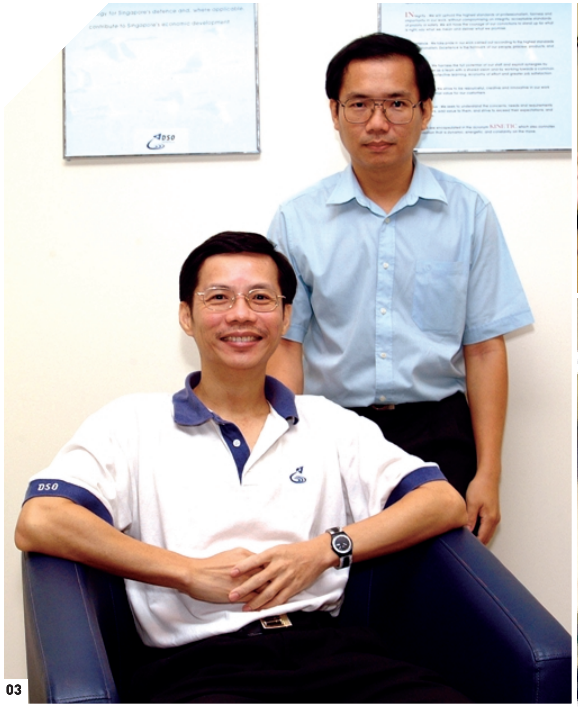
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When DSO was much smaller and younger in the early years, almost everybody knew everybody else by name. The occasional games of bridge, "PACMAN" and "Black Widow" during lunch hours, the car-washing Saturdays, as well as the fun-filled weekends spent together fishing, diving or simply playing sports, were all little activities that helped to build the bond among them. People were closely knitted and the atmosphere was cosy.

Although the growth in our population from tens to over a thousand today did make it more difficult for us to remember each and everyone's names, we still maintain that bond. Organisation-wide family days, celebrations of important occasions such as National Day, annual dinner and dance, staff conferences, technical seminars, retreats, workshops and weekly sports hour, have helped to pull one another closer together. Whether it's an adventurous excursion, a knowledge-sharing session, or a simple fair, we just want to maintain the bond that binds the people for a greater mission. In fact, the bond is getting stronger by the day, now that we have siblings and even married couples working under one roof in DSO.

01 Brothers, Quek Tong Boon (left) and Quek Tong Soon (right).
02 Husband and wife, Bern Yeo and Angela Tan.
03 Brothers, Lee Hian Kiat (seated) and Lee Hian Beng (standing).
04 Department bonding at a retreat.
05 Sisters, Ho Poey Ee (left) and Ho Sok Ee (right).
06 Lee Hsien Loong and wife, Ho Ching looking at a photo. album presented to them by their DSO colleagues.
07 Husband and wife, Yeo Boon Pin and Sim Kwee Choon.
08 Team bonding spirit demonstrated in the first DSO Management Course.
09 Staff bonding at work.
10 The late Dr Tay Eng Soon building rapport with staff at a social gathering in the 1970s.
11 Siblings, Quek Yee Kian (left) and Quek Yee Kai (right).
12 Husband and wife, Khoo Sing Soong and Lim Yee Li.

HAVING FUN

Squash was a big thing in the '80s. DSO took over the Singapore Command and Staff College (SCSC) premises on Marina Hill and to the good fortune of its staff, inherited two squash courts. Among the happy DSO staff who embraced the sport, Teng Ngai Huat, now Assistant Director (Technical Co-operation), was the happiest of them all! Why? Because the court effectively became his property over time, since he was given the keys to it and anyone who wanted to use the courts would have to seek his "permission". Well, the courts quickly became the focal point for the young and macho DSO sportsmen. There was no discrimination against ladies using the courts but they had to bear with the ghost stories and "commando" mosquitoes, which were not intimidated by mosquito coils. However, squash soon faded in popularity in Singapore and knee injuries took its toll on the "no-longer-young" staff. By the time the court was to be demolished for the current Marina Hill complex, all that was left was a derelict building.

Of course, squash was not the only thing DSO played with. In the yesteryears, we jogged, we fished, we sang and we basically had a crazy time! Today, we continue to do all these, while adding to the list with night cycling, soccer, team-building games and many more! In short, DSO never stops having fun! And yes, even while we are doing serious work.

01 Table soccer at the Melting Pot at Marina Hill.
02 Let's learn the hoola-hoop.
03 Night cycling for the younger DSO generations.
04 Staff displaying unity in tug-of-war.
05 DSO Management celebrating Chinese New Year with a feast of *yu sheng*.
06 Christmas celebration with Dr and Mrs Tay Eng Soon in the 1970s.
07 Early fishing days.
08 Barbecue at the old Marina Hill Complex.
09 DSO boys playing street soccer during Friday sports hour.
10 Theme dressing at the 1993 Dinner & Dance.
11 Staff participating in games during a National Day celebration in the 1980s.

SPIRIT

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The DSO spirit is driven very strongly by our core values, KINETIC – Knowledge seeking, creation and sharing; Integrity; Excellence; Teamwork; Innovativeness; and Customer Focus. Bearing these values in mind, we always strive to give our best in our projects and our day-to-day work. From knowledge-sharing platforms such as workshops, seminars and talks, to creative breakthroughs in R&D technology, to customer-focused services, we make continual efforts to live and breathe the DSO spirit.

However, excellence may not come easy when recognition is not readily available. Doing work of a classified nature means that you are not able to breathe a word of your job to any unauthorised third party. Even if you were a great inventor of a cutting-edge technology, only a handful would come to know of your talent. To provide recognition for some of the most outstanding work and individuals so as to encourage remarkable achievements, MINDEF introduced the Defence Technology Prize (DTP) in 1989. It is with great pride to note that since the inception of the Prize, DSO has been a consistent winner of DTP, right up till the present day.

The DSO spirit is also demonstrated through our commitment to our work, even if it means spending days on a "cruise to nowhere", sleeping out in the open, and conducting endless trials with a nauseous feel in the guts! In the 1980s, a typical trial could begin at the unearthly hour of 2.30 am in the morning, followed by hours of hauling heavy equipment onboard a ship, rocking senselessly on a wavy sea, and more hours of going through rounds and rounds of tests without a single break! And all these are topped off with accommodation by means of safari beds in the open, sheltered by nothing but the boundless sky. This was what the senior staff went through in those days. But they didn't mind because all they cared about was overcoming the problem at hand and achieving quality results. We call this the DSO spirit.

01 Quek Tong Boon, Winston Choo and others displaying the hands-on spirit.
02 Project discussion for customer-focused solutions.
03 Real concentration of a DSO engineer at work.
04 DSO as a proud DTP winner (Team) in 2000.
05 The laser group demonstrating how teamwork helped to achieve world record-breaking innovation.
06 First DTP award (Individual) went to a DSO woman engineer, Mrs Chen-Lim Kok Huang.
07 DSO receiving the ISO 9001 certification in 1996.
08 DSO doing our bit for blood donation drive.
09 Knowledge-sharing and problem-solving as a team.
10 A display of support for one another through the fun way.
11 DSO admitted to the Singapore Quality Class in 2001.
12 CEO developing close ties with staff during the Corporate Staff Conference in 2000.

PARTNERS

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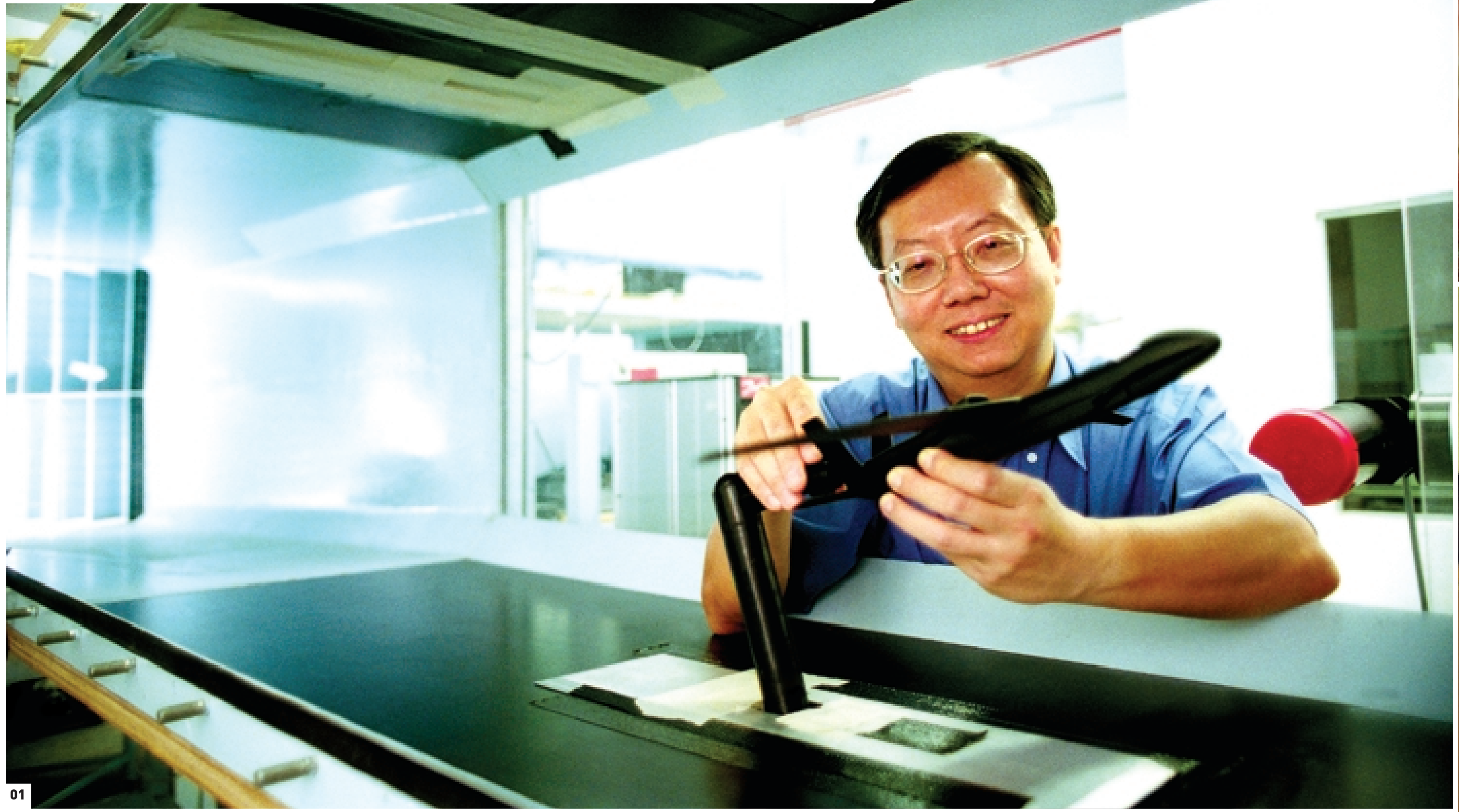
Our ties with the SAF were forged from the very beginning. From the time when we were ETC to the present DSO National Laboratories, whatever role we take on, the SAF has always been a critical element in our operations. In the early days, we had Lee Hsien Loong and Teo Chee Hean (both young officers holding the rank of Captains then) – who were attached part-time to DSO – involved with some of our projects! Today, we have regular interaction forums with the Services, for mutual understanding between the users and the technology-providers in the development of effective defence solutions.

Since our corporatisation in 1997, we have also established ties with other government ministries and statutory boards to provide R&D services to meet their unique requirements.

With a constant belief in partnering for greater achievements, DSO has also been proactive in seeking collaborations with renowned R&D partners to explore opportunities for complementary research. Today, we have research collaborations with distinguished research laboratories both locally and overseas.

01 Partnering with ST Electronics.
02 DSO engineers demonstrating research discoveries to an RSAF delegation.
03 Chief of Navy, RAdm Lui Tuck Yew with Dr Koh Wee Jin, Centre Head for Electromagnetics.
04 A workshop with Joint Staff and DSTA in 2001.
05 Discussion with collaborators from Sandia National Laboratories.
06 Launching the joint Centre for Research in Satellite Technology (CREST) with NTU.
07 Signing of Guidance Memorandum with NUS Temasek Laboratories.
08 An Army delegation visiting DSO.
09 Collaboration with PSA and CET to jointly develop the navigation system for an automated guided vehicle for PSA.
10 Chief of Defence Force, LG Lim Chuan Poh, visiting DSO.
11 Signing agreement with one of our overseas collaborators.
12 Visit by COMR James Tan, Commissioner, SCDF.
13 Partnering with the SAF in the mid '80s.
14 Agreement signing with SMRT and LTA in 2001 for surety assessment of the SMRT infrastructure.

TECHNOLOGY EDGE



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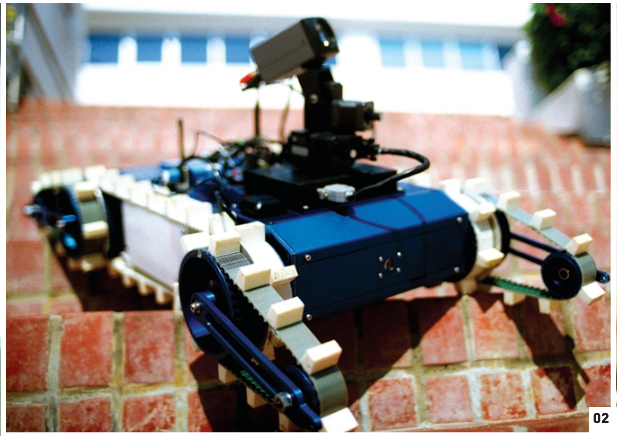

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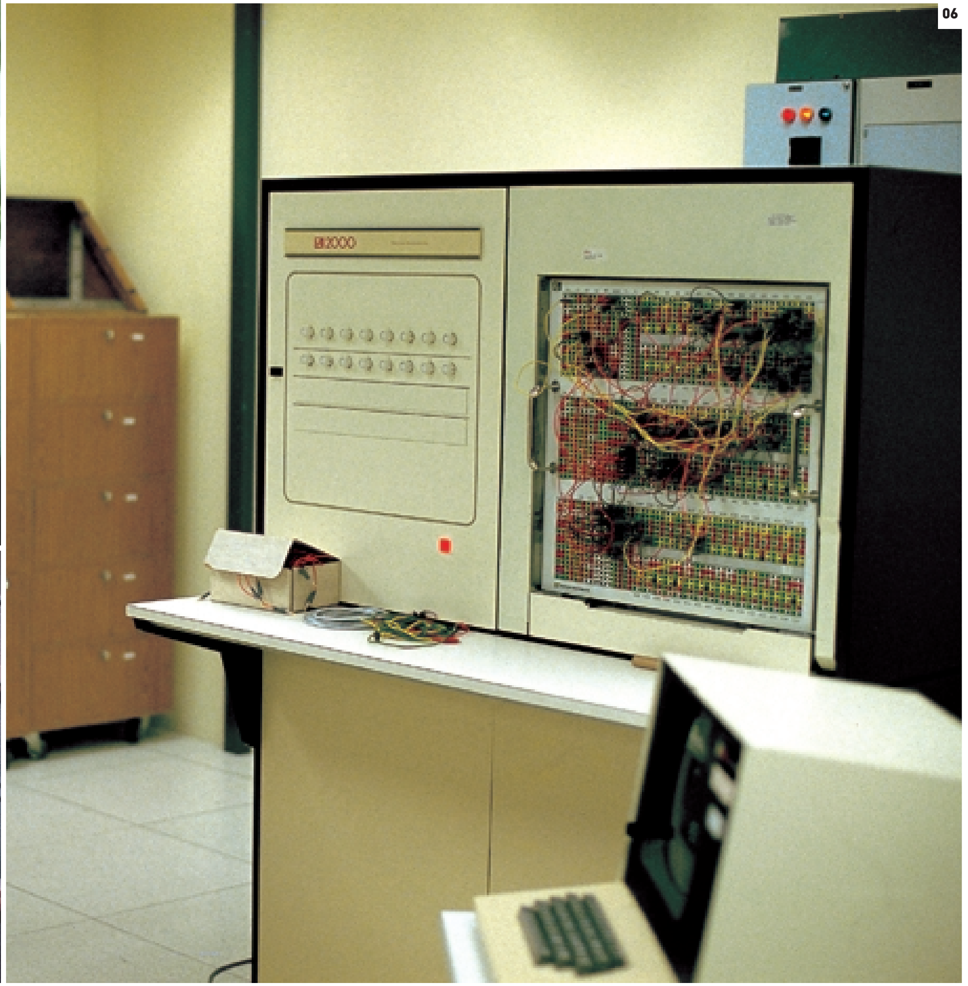

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DSO was established to create the *technology edge* for national defence. This mission lies deep in the heart of our operations right from our inception to the present day. Whatever task that is undertaken, that *technology edge* is always the focus of all involved. To sharpen this edge, DSO has grown from a small team of enthusiasts to a big group of technology fanatics, who strive relentlessly to be at the leading front.

However, the *technology edge* would not have been possible without the advances taking place in the facilities that are used to produce cutting-edge results. Take the field of information technology for instance. In the early years, DSO pioneers had to work with huge cumbersome machines much less powerful than today's notebooks. The first generation of computers brought into DSO included Eclipse, HP3000, Hybrid (consisting of EAI 2000 Analog Computer and SEL 3200 Digital Computer), VAX and Elxsi. DSO bought the HP3000 around the year 1977. The VAX 11/750 cost about half a million dollars and came with one half MB of memory. It was the most advanced machine then and the one of the four available in Singapore at that time. In early '80s, the hybrid computer arrived. Then, 8-inch floppy disks were used while Internet and e-mail were purely text-based. DSO staff were certainly among the first in Singapore to use them.

In drastic comparison today, we enjoy the luxury of powerful light-weight travel notebooks – 1 GHz Pentium 4 (III) processor, 256 MB SDRAM, DVD/CD-RW combo and weighing only 1.6kg – sitting on our laps. Broadband and multimedia technologies have made the exchange of information on the information superhighway such a breeze.

While we celebrate our good fortune, one might ask where are all the old computers today? Well, Eclipse is now at the museum of Nanyang Technological University, HP was given to SCO in the early '80s. The hybrid computer had been written off; while VAX 11/750 and Elxsi 6400 computers were retired and sold to *karung guni* men for a mere $50. Yes, $50 only!

01 Scale model of a HALE (High Altitude Long Endurance) UAV in a wind tunnel.
02 The FIBUA robot climbing a staircase at Marina Hill.
03 An engineer working with the co-ordinate measuring machine, one of the facilities to ensure quality in our products.
04 Outdoor measurement with the mobile electromagnetic (EM) measurement lab.
05 Analysis inside the EM mobile lab.
06 Our old hybrid computer used for simulation work.

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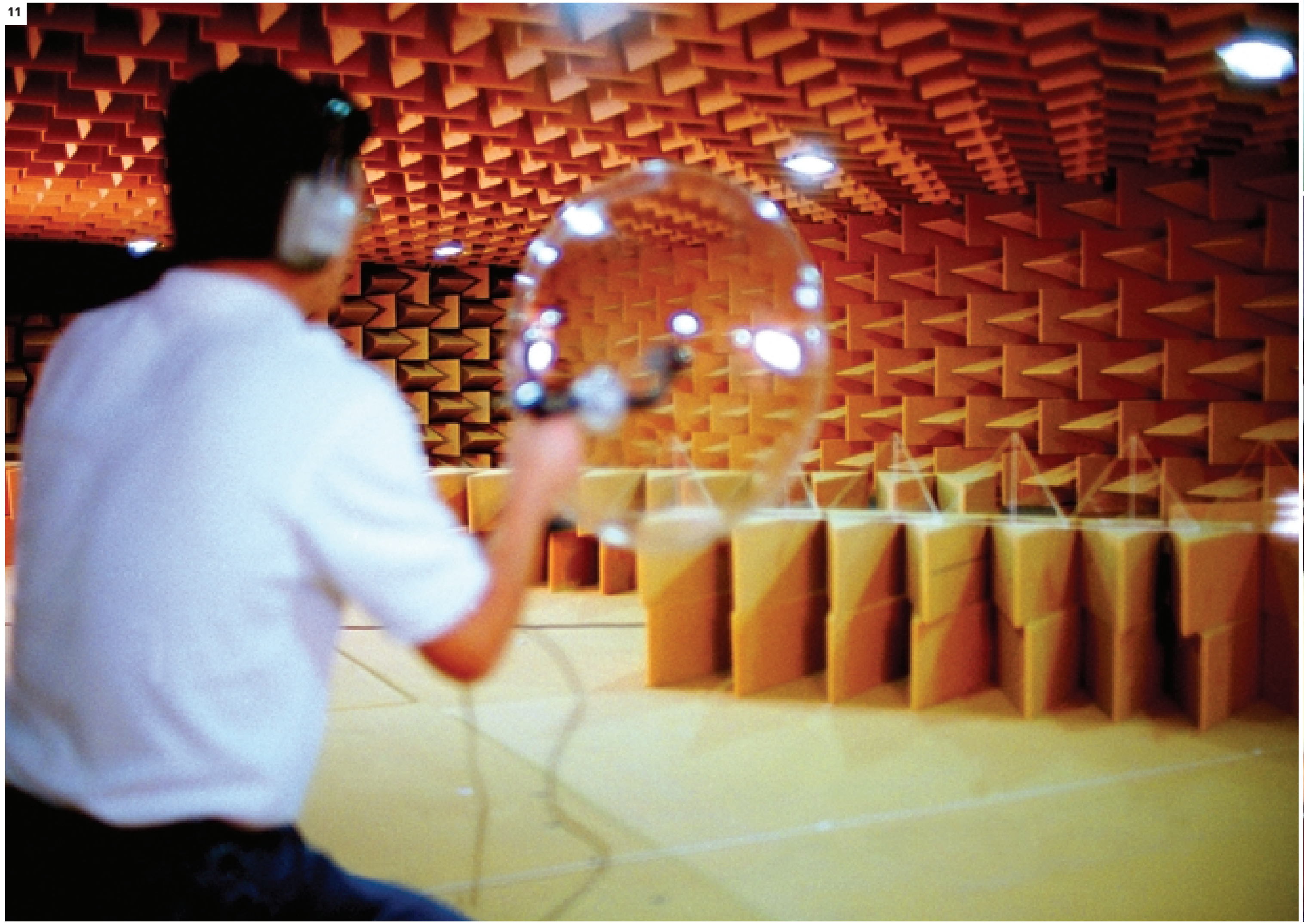

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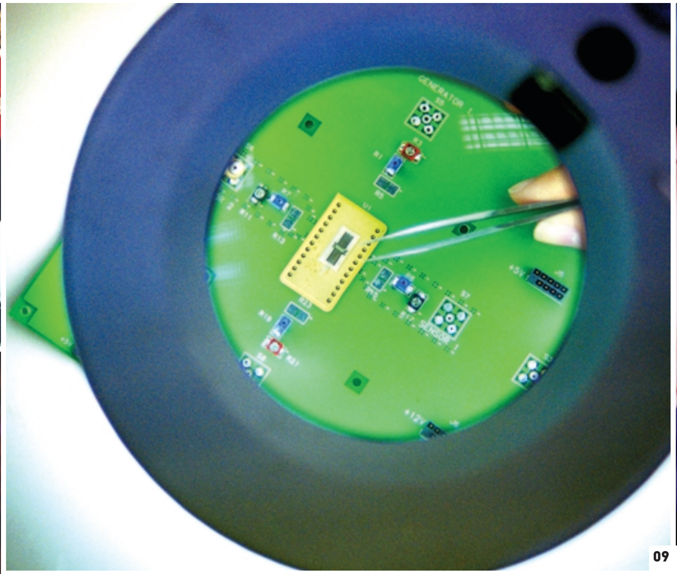

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07 Engineers at work in the old radar lab.

08 Delivery of an integrated EW technique for the RSN's MCV.

09 A MEMS device under the magnifying glass.

10 Chairman, Prof Lui Pao Chuen participating in an advanced system trial.

11 Experimentation in the acoustic chamber.

12 First generation of DSO mini-UAV (Unmanned Aerial Vehicle).

13 Fabrication facility for passive circuit boards.


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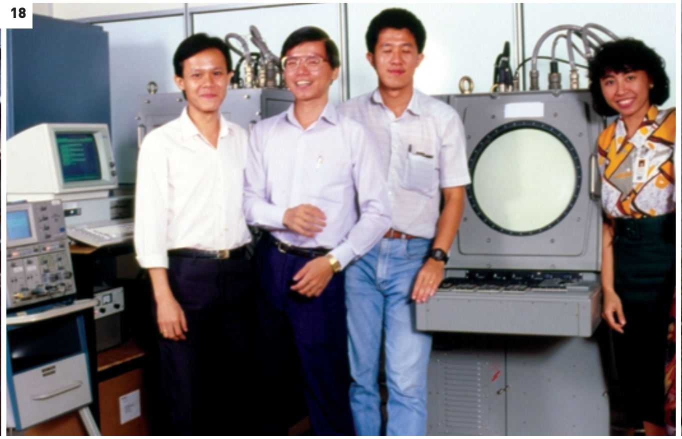
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14 An automatic test equipment for EW experiments.
15 The EO (Electro-optics) mobile lab.
16 The measurement arch facility for testing radar absorbing materials.
17 Ground vibration testing of an air frame.
18 An Electronic Support Measure (ESM) system developed in 1990.

AUTHORS

Dr Melanie Chew

Singapore-born Melanie Chew graduated from St Catherine's College, University of Oxford in 1987 with a Doctorate in Philosophy. After twelve years at the Singapore Command and Staff College teaching Military History, she entered the National University of Singapore as Lecturer in the Department of Political Science, teaching Strategic Studies and International Relations.

Her publications include the history of the Singapore Air Force, *The Sky, Our Country* (1994), a biographical history of Singapore, *Leaders of Singapore* (1996), the history of the Singapore Naval Base, *Hearts and Minds: The Story of Sembawang Shipyard* (1998), and the first national biography of Yusof bin Ishak, the first President of Singapore, *Presidential Notes: The Biography of President Yusof bin Ishak* (1999).

Dr Chew has also written on Singapore's historical landmark, the Fullerton Building, *Memories of the Fullerton* (2001). The history of DSO National Laboratories, *Creating the Technology Edge* (2002), is her sixth historical publication.

Professor Bernard Tan Tiong Gie

Born in Singapore in 1943, Bernard Tan was educated at the Anglo-Chinese School, Singapore, the University of Singapore (Bachelor of Science with Honours in Physics, 1965) and Oxford University (Doctor of Philosophy in Engineering Science, 1968). He is a Chartered Engineer and Member of the Institution of Electrical Engineers (UK), Fellow of the Institute of Physics (UK), Fellow of the Institute of Physics, Singapore, and Fellow of Trinity College of Music, London.

He joined the then University of Singapore (now NUS, the National University of Singapore) in 1968 as a Lecturer in Physics and served as Dean of Science at NUS from 1985 to 1997. He is currently a Professor of Physics and Dean of Students at NUS, where he is also Chairman of the Centre for Remote Imaging, Sensing and Processing (CRISP) and the Singapore Synchrotron Light Source (SSLS).

Prof Tan sits on the boards of Keppel Corporation, the Singapore Symphonia Company and CSA Holdings. He is also Chairman of the National Internet Advisory Committee and the Singapore Arts Festival Steering Committee, and President of the Institute of Physics, Singapore.

His current research interests are in microwave solid-state properties and devices, digital musical analysis and synthesis, and directional perception of multiple sound sources. He has published over 85 papers in international peer-reviewed journals.

He has had a long association with DSO from its earliest days and is very pleased that he is able to be a part of the making of this book.

ACKNOWLEDGEMENTS

The journey, whose story you have read in this book, would not have been embarked upon, nor continued without the many great individuals who together make DSO what it is today. As such, we wanted to put in writing, the spirit of these unsung heroes, their passion and their remarkable achievements.

Given the lack of history about DSO's early years on record, it was indeed a painstaking effort to uncover those earlier years spent in secrecy. It has been a challenging and rewarding 18 months since we started work on this book – months of research poring over dusty documents, countless meetings held late into the night, many hours spent editing the drafts and immense effort taken in finalising the design of the book. But it has been a very rewarding experience.

It is our good fortune to have two distinguished authors, Dr Melanie Chew and Professor Bernard Tan, take on this mission of penning the DSO Story. And we are pleased that they did so with such fervour and vividness.

We are even more delighted when what was initially feared might be a dull history lesson, turned out to be a colourful journey of exploration. Through our conversations with many of our pioneers and those entrusted with the governance of DSO at various points in time, we have uncovered valuable information and insights. For that, we would like to express our grateful thanks to the following:

President S R Nathan
Mr Er Kwong Wah
Mr Toh Kim Huat
Mr Benny Chan
Dr Foo Say Wei
LG (RETD) Winston Choo
Mdm Ho Ching
Mr Tham Choon Tat
Mr Philip Yeo
RAdm (NS) Teo Chee Hean
Mr Teo Ming Kian
Professor Su Guaning

Mr Peter Ho
Professor Lui Pao Chuen
Mr Henry Cheong
Mr Cheong Quee Wah
Mr Quek Pin Hou
Mr Chan Kwong Lok
Mrs Chen-Lim Kok Huang
Ms Tang Kwai Leng
Mr Teai Yam Koon
Mr Tey Wei Ming

Of course, the struggle of our first director, the late Dr Tay Eng Soon, who took on the challenge of realising Dr Goh Keng Swee's vision from scratch, cannot be forgotten. We are grateful to Mrs Rosalyn Tay for sharing with us her fond memories of the late Dr Tay, which have enabled us to feel his dedication to DSO and his strong belief in defence science and technology.

Our heartfelt appreciation also goes to the following, who worked tirelessly beyond their call of duty to provide us with the contents for the technical stories:

Mr Bay Hee Siah
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Dr Chia Tse Tong
Mr Chow Kay Cheong
Ms Foo Meng Fang
Mr Han Yeow Kwang
Dr How Khee Yin
Dr Koh Wee Jin
Dr Lai Kin Seng
Mr Lam Teck Khiong
Dr Lee Fook Kay

Mr Lim Boon Chin
Mr Loh Quek Seng
Ms Ngo Yuen Choo
Mr Ong Kien Soo
Mr Ong Tiang Hwee
Mr Tan Chee Seng
Dr Tan Yang Meng
Mr Frank Teo
Mr Wee Kok Ling
Mr Wong Yue Kah
Mr Yeo Siok Khoon

Last but not least, we would like to express our appreciation to Ms Cheryl Goh and Ms Surine Ng, for their assistance with the interview transcripts; and many others – too numerous to name – who have assisted us in one way or another, in the production of this book.

This DSO Story is a story of our people, for our people. We dedicate this to our founder, Dr Goh Keng Swee and to all DSO staff – past, present and future.

Editorial Committee:

Mr Quek Tong Boon
Mr Ho Jin Yong
Mr Yeo Kee Kong
Mr Joseph Ting
Mr William Lau
Mr Ng Sin Yong
Dr Koh Cheng Heng
Ms Wee Wai Ming
Ms Jessey Beh

GLOSSARY/ ACRONYMS

A4
A4 Skyhawk jet fighter aircraft.

AOR
Approval of Requirement. This is a document that defines the project or system requirements of the Ministry of Defence or the Singapore Armed Forces (SAF). Before MINDEF/SAF contracts DSO for a project, the AOR for the project needs to be approved before funds can be made available.

A*STAR
Agency for Science, Technology and Research. This is the former National Science and Technology Board.

Bond
This refers to the commitment by the recipient of a scholarship to serve the sponsoring organisation.

Brownian movement
First discovered by Robert Brown in 1827, it refers originally to the random motion of pollen immersed in fluid, observed under a microscope. Albert Einstein pointed out in 1905 that this motion is caused by the random bombardment of fluid molecules on the pollen. Modern theory calls this a stochastic process.

C&E
Headquarters (HQ), Communications and Electronics. This is the predecessor of HQ, Signals Formation, in the Singapore Armed Forces today.

CDS
Chief Defence Scientist. He is the Ministry of Defence's most senior scientific advisor to its senior management as well as to the Singapore Armed Forces on matters pertaining to defence science and technology in R&D, acquisition, military tactics/doctrines, personnel, and the defence industries.

CEI
Chartered Electronics Industries. This company is a member of Singapore Technologies.

Chaff
This refers to a dense cloud of radar-reflecting filaments dispensed by a platform such as a ship or an aircraft, to confuse an adversary's radar sensors or seekers about the platform's true position.

CIS
Chartered Industries of Singapore. Today, it is part of Singapore Technologies Kinetics.

DTP
Defence Technology Prize. This is a prestigious award given out by the Ministry of Defence to foster and encourage technological innovation and excellence amongst Singapore defence scientists and engineers.

DMO
Defence Materiel Organisation. A body responsible for defence system acquisitions, it has since evolved into the acquisition group in the Defence Science and Technology Agency.

DS
The Deputy Secretary (DS) is a senior officer in the civil service who is the deputy to the Permanent Secretary.

DSTA
Defence Science and Technology Agency. This is a statutory board under the Ministry of Defence's supervision that implements national defence science and technology policies and plans. It was previously known as the Defence Technology Group.

DTG
Defence Technology Group, the predecessor of the Defence Science and Technology Agency.

EA
Executive Agency. This is a semi-autonomous status given to certain organisations under the Ministry of Defence, to manage their own operating funds in fulfilling their mission objectives.

ECM
Electronic countermeasure. This refers to any electronic technique designed to deny detection or accurate information to a radar or communication receiver. Examples of ECM techniques are: screening with noise, confusion with false targets and deception by affecting tracking circuits.

ECCM
Electronic counter-countermeasures. This refers to any electronic technique designed to make a radar or communication receiver less vulnerable to electronic countermeasures.

Electronic Warfare (EW)
This refers to the exploitation of the electromagnetic spectrum to search for, intercept, locate, record, analyse or disrupt the use of hostile electronic sensors and communications and conversely, to maintain the effectiveness of the friendly use of the electromagnetic spectrum.

ETC
Electronics Test Centre. This was set up in 1972 by Dr Goh Keng Swee to create the technological edge for the Singapore Armed Forces. It was merged with the Systems Integration and Management Team in 1977 to form the Defence Science Organisation. This was later corporatised in 1997 as DSO National Laboratories, a not-for-profit company limited by guarantee whose mission is to develop technologies and solutions that can provide technological surprises to sharpen the cutting edge of Singapore's national security.

EXCO
Executive Committee. It comprises representatives from the Ministry of Defence and the Singapore Armed Forces, which supervised the Electronics Test Centre and subsequently DSO, to align its R&D focus with the Ministry of Defence and to approve its budget and resource utilisation.

Executive Agency
See "EA".

Gombak
Bukit Gombak. This is where the Ministry of Defence Headquarters is located.

IME
Institute of Microelectronics. This is an institute under the Agency for Science, Technology and Research.

ISO9000
A set of quality standards awarded by the International Organisation for Standardisation to organisations which have achieved excellence in quality management.

ISS
Institute of Systems Science.

kuat
A Malay word that means strong, powerful or forceful, it has found its way into Singapore colloquial English and certain Chinese dialects.

LEO
Lands & Estates Organisation. The organisation is responsible for major construction of defence infrastructure. This has since evolved into the Building & Infrastructure Division of the Defence Science and Technology Agency.

longkang
A Malay word that means drain or ditch. Like *kuat* it has also found its way into Singapore colloquial English and certain Chinese dialects.

LSST
Litton Scientific Support Team. The team was led by foreign consultants engaged by the Ministry of Defence to manage the acquisition of the missile gun boats on its behalf.

LTPG
Long Term Planning Group which was formed to prioritise the Ministry of Defence's long term defence R&D investment.

MCV
The Republic of Singapore Navy's missile corvette.

MGB
The Republic of Singapore Navy's (RSN) missile gunboat. It was the first-generation of RSN ships to be equipped with anti-ship missiles.

MINDEF
The Singapore Ministry of Defence.

Minimi
A 5.56mm light machine gun developed by the Fabrique Nationale of Belgium.

NS
National Service.

NSTB
National Science and Technology Board. This is the predecessor of the Agency for Science, Technology and Research (A*STAR).

Perm Sec
Permanent Secretary or PS for short, he is the highest-ranking civil servant in each government ministry in Singapore.

Plasma
This is the ionic state of a medium, such as air, affecting radio frequency propagation through the medium. It is formed when a high-energy, electrical discharge or current passes through the medium, resulting in the separation of electrons from the host atoms.

PS
See "Perm Sec".

PSC
Public Service Commission. Appointed under the Prime Minister's Office, the PSC decides on the recruitment and promotion of civil servants.

Radar
A device for transmitting electromagnetic signals and receiving echoes from objects of interest (targets) within its volume of coverage. The presence of a target is revealed by detection of its echo or its transponder reply. The word, radar, was originally an acronym for Radio Detection and Ranging.

RF
Radio Frequency. This is part of the electromagnetic spectrum commonly used for communications and radar.

RI
Raffles Institution, one of the premier secondary schools in Singapore.

RPV
Remotely Piloted Vehicle which is able to take off, fly, navigate and land without a pilot onboard.

RSAF
Republic of Singapore Airforce.

RSN
Republic of Singapore Navy.

SAF
Singapore Armed Forces.

SCO
Systems and Computers Organisation. Responsible for information technology in the Ministry of Defence, it has since evolved into the S&C4 (Systems, Command, Control, Communications, Computer) group in the Defence Science and Technology Agency.

SEEL
Singapore Electronic and Engineering Limited. This is the predecessor to the present-day Singapore Technologies Electronics Limited.

SID
Security and Intelligence Division, Ministry of Defence.

SIMT
Systems Integration and Management Team, the group responsible for the integration of mission systems in missile gunboats.

SMG
Science and Management Group. It was established by Dr Goh Keng Swee to handle all new projects for the Ministry of Defence. These included the development of the Changi Airbase and the setting up of the Junior Flying Club.

SPO
Special Projects Office. Responsible for major defence system acquisitions, it later became the Defence Materiel Organisation. It now constitutes the acquisition group in the Defence Science and Technology Agency.

Ultimax
An infantry Light Machine Gun developed indigenously in Singapore.