ROYAL AUSTRALIAN AIR FORCE
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01

Space Observations: An Australian Perspective[1]

by Scott Wallis and David Fogg

ABOUT THE AUTHORS

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1 This paper was written for the 5 May 99 meeting of the Air Force Research and Development Review Committee. Although some information is dated the underlying themes and recommendations remain relevant.

BACKGROUND

> *Australia's future strength and success depends on our ability to become more innovative and imaginative in the way we do business. What better way to demonstrate our commitment to take on the challenges of the future, than by embracing the challenges of space?*
>
> The Honourable John Moore[2]

Evolution

Space is the natural extension of the air environment. Early military use of the air medium was limited to relatively low altitudes with a focus on reconnaissance and an aircraft's ability to provide a broader perspective of the battle area. Technological advances enabled aircraft to fly at higher altitudes and to achieve even greater reconnaissance capabilities over a theatre of operations. Like the aircraft early space development concentrated on reconnaissance and intelligence. From this limited beginning, as with aircraft, the capabilities of space vehicles have expanded into other areas. Space systems are now becoming an integrated part of the overall combat capability of many nations, exploiting the air environment to the full extent.

Australian Activity and Dependence on Space

In the 1960s Australia was one of the first nations to launch a satellite from its own territory, the Weapons Research Establishment satellite known as WRE-SAT.[3] However, since that time Australia's involvement in satellite development and space launch has been more at the level of a part-time reserve player or observer, rather than an active participant. Despite this, Australian organisations and individuals are now becoming dependent on space-based communications, navigation, timing, surveillance, earth resource monitoring and weather observations. Space capabilities are vital components of the information revolution and are thus critical to both military and civilian activities. Space is emerging as a centre of gravity for information-dependent forces, businesses, and society as a whole. Increasing economic and military dependence on space related systems makes it highly probably that continued and assured access to space will be a major determinant of national power.

Australian Defence Force Space Policy

Australia's Strategic Policy 1997 provides the foundation for the integration of space-based systems into the core capabilities of the Australian Defence Force (ADF).[4] A number of the Defence Executive's Key Objectives for 1998 and 1999 were also related to space systems.[5] However, there is still no overarching Defence strategic space policy or doctrine. This could be in part due to the absence of any Service formally being allocated responsibility for space.[6] Given Defence's growing dependence on space it is surprising that there is a lack of policy associated with the military use and exploitation of space systems. The absence of a clear space policy makes it difficult to justify space-related research and it could mean missing unique opportunities for early involvement and influence over collaborative space programs.[7]

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2 Statement to the 5th Australian Space Development Conference in Sydney on 27 July 1998 by John Moore, then Minister for Industry, Science and Tourism and subsequently Minister for Defence.

3 The Weapons Research Establishment (WRE) Satellite (WRE-SAT) was launched from Woomera on 29 November 1967. WRE was absorbed into what is today the Defence Science and Technology Organisation (DSTO).

4 Maintenance of a Knowledge Edge will require utilisation of satellite communication and access to space-based surveillance capabilities. Precision strike will require GPS for precise navigation.

5 Goal Two 'Stronger Future Capability' and Goal Three 'Closer Alliances and International Strategic Relationships' both have key objectives that relate directly to the use of space.

6 The RAAF has not laid claim to space being its area of responsibility. The Third Edition of *The Air Power Manual* only has scant mention of the space/aerospace environment with a number of references seeming to be added as afterthoughts.

7 For example, given Defence's investments in JORN and Project *Wedgetail*, what would Defence's position be if asked to quickly respond to a request to become part of an Allied space-based radar program?

Part ownership of a space system also provides long-term benefits of reduced access costs and increased user priority. Tardy appreciation of the need for space access could mean Defence would have to compete with the media and others for communications channels during a conflict. Similarly if a conflict is widespread, it can be anticipated that other military forces will be seeking increased access to national and commercial systems.

Space Collaboration

It is not practicable for Defence to own or develop independent space systems that will meet *all* its needs. However, through well-targeted participation in collaborative space programs there could be significant potential for Defence to improve its capabilities in a cost-effective manner. Collaboration in the development of space systems is consistent with Goal Three of the Defence Executive's Priorities for 1998-1999. Collaboration can enable personnel to gain pertinent expertise as well as developing Defence research capabilities in space systems. Also Australian industry may be able to gain a foothold in relevant niche areas as a result of support to collaborative programs. The United States (US) is considered the key nation for collaboration on space systems because of its intention to maintain its dominant position in space.[8] However, efforts should be made to balance international collaboration with other traditional allies[9] and regional countries.[10] The absence of Defence space policy makes it very difficult for the US (and other nations) to have a clear understanding of Defence's long-term approach to collaborative space efforts.[11]

Technology Trends

The major developer of space is the US, while Europe is attempting to increase its involvement and Japan is in a position to make significant contributions. A key issue is that growth in the commercial space industry is outstripping government-sponsored development with the margin expected to increase. Just as the explosive growth of commercial aircraft in the 1930s and 1940s led to many new capabilities for aircraft, the commercial space industry's rapid advance in the last decade is spurring the development of future space capabilities. Finance for space development is growing (for example, the unprecedented $US 2,951 million expenditure by US satellite communications companies in the month of January 1999).[12] Australia is committed to achieving regional technological defence superiority[13] and will need to consider the consequences of an exploding commercial satellite growth in relation to the acquisition of space-based capabilities. Also Australia's geographical and political circumstances, and commercial infrastructure, give rise to issues that require uniquely Australian solutions in space development.

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8 The US Space Command's Long Range Plan 1998 pronounces that: 'USCINCSPACE's ability to "shape the space environment" from a position of authority and expertise will play a major role in retaining US Superiority in military space operations and technology. In keeping with the National Security Strategy, the DoD and USCINCSPACE must ensure we retain the right (and capability) to act unilaterally in support of national interests.' This raises the question of how the US might react to a perceived loss to Allied interests (government or commercial) of technical superiority considered important to US national interest?

9 The US could change its stance on collaboration or may not be as forthright as Australia desires in regard to space systems. It may be in Australia's interests to not only collaborate with the US but also work independently with other Allied organisations. Navigation Warfare (Navwar) is an area that Australia might harmonise its activity with the United Kingdom (UK). The US has been very slow in developing a multi-national collaborative program on Navwar. Given Australia's and the UK's strengths in this field, and rapidly changing technology, it could be useful for both countries to work collaboratively while the US continues to develop multi-national agreements on Navwar.

10 Regional countries have a similar area of interest to Australia. There are likely to be a number of future opportunities to share the costs of some national space systems with regional countries.

11 During his postings to the USAF Space and Missile Systems Center (1992-95) and the Space and Joint Systems Project Office (1996-98) Wing Commander Wallis had regular discussions with US space acquisition specialists. During these meetings the US perception of the ADF's space capabilities was sought. Many US representatives perceived Defence had significant space research capabilities at DSTO; however, the lack of a policy on space made collaboration in some programs difficult.

12 *Space News*, Vol 10, No 5, 8 February 1999.

13 Australia's Strategic Position 1997.

Paper Outline

This paper is intended to be forward-looking with the aim of identifying aspects of space operations that might be expected to play an influential role in the operation and/or effectiveness of the ADF in the future. It was written for consideration at the 5 May 99 meeting of the Air Force Research and Development Review Committee. The major limitation affecting the preparation of the paper was the lack of any documented vision or overarching policy for the research, development and utilisation of space systems by Defence. Significant research has been undertaken on space operations over the last five years, predominantly by various organisations within the US. The most recent, and possibly most influential, publication on the topic is the US Space Command (USSPACECOM) Vision 2020, published in August 1998. Vision 2020 has been assumed as a starting point for the paper in the absence of Australian guidance for space operations.

THE FUTURE AUSTRALIAN AEROSPACE ENGAGEMENT ENVIRONMENT

> *Space systems and capabilities enhance the precision, lethality, survivability, and agility of all operations – air, land, sea and special operations. Space operations are key elements in achieving global awareness and maintaining information superiority. Space assets contribute significantly to overall aerospace superiority and support the full spectrum of military actions in theaters of operations.*
>
> USAF Doctrine[14]

Future Forecasting

*Oracle 2030***.** The ADF has been researching future concepts up to 30 years ahead in an attempt to avoid any planning surprises.[15] Air Force *Oracle 2030* is working to identify and assess key drivers of change that will impact Australia, the ADF, the Royal Australian Air Force (RAAF), and the Asia-Pacific region. In project *Oracle 2030*, four extreme imaginary alternate future 'worlds' or scenarios at the vision horizon of 2030, have been created to assist the RAAF in planning for operations in the 21st Century (Annex A refers). As each of these worlds is different, so too in each there is a difference in the global utilisation of space and indeed Australia's involvement in space. Similarly, the proportion of military and commercial use of space varies across the four worlds. In one world, Splendid Isolation, the major powers maintain a significant military space presence while in another, Rainbow Dynamo, space-based surveillance along with other space-based services are largely commercial operations operated at tight margins. In contrast, space does not play a significant part in the future world of Dissonant Arcadia. However in the fourth world explored, New Balance, Australia is a significant player in space with not only military space assets, including Trans Atmospheric Vehicles, but also a commercial spaceport in the north.

*Air Force 2025***.** Prior to the development of *Oracle 2030* the United States Air Force (USAF) also undertook an extensive study[16] that looked 30 years ahead to identify the concepts, capabilities and technologies the US will require to remain the dominant air and space force. The *2025* study used Alternate Futures[17] to describe various plausible future worlds, each separate and distinct, and each offering different security and planning challenges. In the first world, the US's military might is constrained by many world players with other forms of power. A second world depicts the extreme impacts of a future dominated by multinational corporate giants. A third

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14 Foreword to *Space Operations,* Air Force Doctrine Document 2-2, USAF Publication, 23 August 1998.

15 The two major studies are *Oracle 2030* and Project *Sphinx*. Project *Sphinx* is addressing future ADF warfare concepts.

16 The study was titled Air Force 2025; however, in the USAF it is termed just ***2025.***

17 The procedure to develop Air Force 2025 Alternate Futures was very similar to that used for Oracle 2030.

world is a 'scary' future in which information and biogenetic technology is dispersed, giving individuals and small groups untold power. In a fourth world, the US loses its status as a superpower to an Asian colossus. A fifth future envisions a world marked by fundamental changes in the social structure, environment and the international security system, making it difficult for the US to determine how best to exert its power and influence. The final world depicts how a major conflict in 2015 could shape events in 2025. Space related systems are commonly used in all these worlds.

Future Trends. *Oracle 2030* and *2025* identified future trends that will directly impact future military operations. Both studies highlighted the following trends that are likely to have a significant impact on each country's air forces:

1. humans will move from being more in the cockpit to being more in the loop;
2. the medium for air force operations will move from the air and space toward space and air;[18]
3. development responsibilities for critical technologies and capabilities will move from government toward industry;
4. influence will increasingly be exerted by information more than bombs; and
5. military education will move from being rigid to responsive.

Long-Range Planning

*Air Force 2015 Plan***.** Air Force Headquarters is developing a strategic plan covering the period to 2015, *Air Force 2015 Plan*. The year of 2015 was selected as it is near the expected crossover point between the *Oracle 2030* future worlds and the retirement of many in-service systems. The *Air Force 2015 Plan* will address the RAAF's future activities as derived from *Oracle 2030*. Fundamental to this plan is an understanding of the expected aerospace environment. The migration to space of traditional air-based sensors will increase the options available for the provision of military capabilities. Also further developments of Uninhabited Aerial Vehicles (UAVs), with the possible development of Uninhabited Combat Aerial Vehicles, could present alternative systems to the traditional manned aircraft. While these developments mature, aging RAAF aircraft are likely to require increased levels of maintenance funding. In addition, defence budgets are likely to remain tight with increased pressure to reduce manpower. Timely decisions will be required about the retirement of current systems and the acquisition of future capabilities. Good awareness of the range of options for these systems is necessary if Defence is not to miss opportunities to maximise capabilities. Decisions made during the next couple of years about space systems and space operations are likely to significantly shape Defence space capabilities in 2015 and beyond.[19] Unfortunately Air Force has not comprehensively studied how present and evolving space systems and space operations are to be integrated with new and longer term activities.

The Five and Ten Year Defence Plans. Acquisition lead-times for major capital equipment from concept to operational capability are often greater than ten years. The time-consuming Defence acquisition process reduces the flexibility to quickly acquire new capabilities through traditional approaches. It also locks in the majority of capital spending and reduces flexibility for replanning to account for new technologies. Often commercial developments can provide the opportunity to acquire a new capability much quicker. The military Global Positioning System, or GPS, receiver is an example of commercial technologies driving military equipment

18 Over time, many surveillance capabilities that are currently delivered by surface and air-based platforms are expected to migrate to space-based platforms. This is likely to occur in phases as technologies mature and are incorporated into new systems. There is likely to be new families of systems that provide different space-based capabilities: one similar to Airborne Warning and Control System for missile and air surveillance, and another similar to Joint Surveillance Target Attack Radar System for mobile and fixed surface targets. USSPACECOM Vision 2020.

19 The *Air Force 2015 Plan* needs to incorporate the maintenance of near-term capabilities while simultaneously planning for the transformation required to prepare for the future. Planning needs to strike the correct balance between maintaining current force structure and capabilities on one hand and modernising with innovation on the other.

developments. Over the last decade there have been five generations of hand-held GPS receivers.[20] Yet the planned life of type for hand-held GPS equipment being acquired by the ADF's GPS project is ten years.[21] A new generation of hand-held GPS receivers are to be fielded by the US within a year of the ADF's procurement.[22] Continuous reappraisal on the impact of technology changes to planned capabilities and acquisitions must be conducted if a new capability is not to be a legacy system within a couple of years of it becoming operational. Ongoing in-depth appraisal should also apply to proposed revolutionary systems. High Altitude Endurance UAVs have been seen as a cost-effective alternative to manned aircraft. However, changes in US program priorities could affect timely developments of these types of systems.[23]

Long-Range Trends. Future forecasting can provide indications as to underlying trends; however, for long-range planning more immediate trends need to be considered. Suggested trends likely to propagate increased uncertainty and global instability include:[24]

- The globalisation of markets is likely to cause unprecedented economic growth in some sectors, while widening the gap between the 'haves' and 'have-nots'.
- Numerous transnational issues in the areas of population, health, transportation, and environment will demand greater international attention and interaction.
- The information technology revolution will enhance Allied military wartime performance, and will potentially increase Allied vulnerability to asymmetric means of attack.
- Commercial competition and increased technological capabilities in the private sector will make advanced technology more widely available to both friends and adversaries.
- Non-state actors such as international business conglomerates, religious and ethnic groups, and crime syndicates will gain prominence and influence.
- The growing sensitivity toward ecological degradation will strengthen popular appeal for environmental protection efforts.
- The size of the military budgets expressed as a percentage of Gross Domestic Product are likely to remain constant or decrease slightly in the wake of changing domestic priorities.

High Leverage Technologies. The *2025* study found the keys to preserving the military security of the US are the integration of information technologies with air and space capabilities, and the connectivity for distributed, demand-driven systems. These capabilities can be achieved by investments in technologies that enhance vigilance, decision-making capabilities and communication architectures. These technologies can also provide a 'Knowledge Edge'[25] over an opponent.[26] Maintenance of an edge can be achieved by early identification and investment in high leverage technologies.[27]

20 The rapid change occurred because of the revolutionary advance in radionavigation and timing that GPS provided to non-military users. This provided a very buoyant commercial market. Similar changes have occurred in satellite communications.

21 Phase 3B of Joint Project 5195 NAVSTAR GPS for the ADF is acquiring GPS hand-held equipment.

22 The next generation of hand-held GPS equipment is called the Defense Advanced GPS Receiver, DAGR.

23 The US has decided to cancel the stealthy Darkstar HAE UAV. The non-stealthy Global Hawk despite problems still remains an active program, possibly due to foreign involvement. The cost of operation of UAVs might not be significantly different to that of manned aircraft. Like manned aircraft UAVs require clearance for overflight of territory. Also the mixing of UAVs in airspace occupied by civilian manned aircraft is likely to cause legislative and legal problems.

24 These trends were derived from the USAF Long Range Plan. The trends are believed to be generic and are consistent with trends being analysed for the *Air Force 2015 Plan*.

25 ASP-97 calls for a 'Knowledge Edge' capability for Australia.

26 The *2025* study refers to a Vigilant Edge akin to the Knowledge Edge.

27 High leverage technologies that *2025* identified for the USAF were: 1) Data Fusion, 2) Power Systems, 3) Micro-mechanical Devices, 4) Advanced Materials, 5) High Energy Propellants, and 6) High Performance Computing.

OPERATIONAL CONCEPTS FOR SPACE TO EXPAND THE BATTLESPACE

> *Electricity and oil were critical parts of the industrial revolution; space capabilities are emerging as vital to the information revolution. Today, military operations depend critically on space capabilities. In the 21st Century, they'll rely even more on such services.*[28]

The Space Environment

Military and commercial uses of space will become vital to national interests as space capabilities proliferate around the world. Currently more than 1,100 commercial companies across 53 countries are developing, manufacturing, and operating space systems. Many traditional military missions for land, sea, and air have started to migrate to space, for example communications and surveillance. The advantage of space-based platforms is that there are no restrictions on overflying a nation from space. This advantage is expected to endure, although sovereignty will remain a concern. However, the rapid increase in the number of satellites is likely to bring competition for orbit parking locations, frequency allocation, and 'basing rights' to distribute uplinks and downlinks to/from ground stations. Over the last decade there has been a convergence of the military, civil, and commercial space sectors with the shift in the US continuing from the military to the commercial sector as the dominant receiver and provider of space services. In 1996 US commercial launches exceeded military launches and commercial space revenues outstripped government space expenditures. Military resources are shifting from sustaining current systems, research and development to buy-and-lease services that are always state of the art. However, this shift could be a vulnerability to national security. Also appropriate responses will need to be developed if there is intentional interference with Allied satellites.

Space Superiority

Space superiority will be achieved through the integration of space capabilities, comprehensive awareness and situational control. Space-based capabilities (collecting, generating and transmitting) are critical to the uninterrupted flow of information throughout the battlespace. The protection of space capabilities and the denial of the enemy's use of space are integral to information superiority. Space-based satellite communications, navigation, surveillance, earth resource monitoring and weather data provide significant contributions to battlefield awareness and a common integrated battlefield operating environment.

Four operational concepts are suggested for the achievement of space superiority:

- Control of the Regional Space Environment (CRSE);
- Regional Engagement Augmentation (REA);
- Complementing Full Force Integration (CFFI); and
- Space Collaboration (SC).[29]

Control of the Regional Space Environment

The CRSE is the ability within Australia's region of interest to assure access to space, freedom of operations within the space medium, and an ability to deny others the use of space, if required. CRSE assumes the achievement of the following five interrelated objectives:

1. *assure* the means to get to space and operate once there;
2. *exercise surveillance* of the region of space to achieve and maintain situational understanding;

28 Introduction to USSPACECOM Vision 2020.

29 These concepts are developed from the USSPACECOM Vision 2020 and are intended to only provide a conceptual framework. Although discussion of the concepts is limited, significant amplification and tailoring of Vision 2020 to Australian conditions is possible.

3. *protect* critical space systems from hostile actions;
4. *prevent* unauthorised access to, and exploitation of, Allied space systems and, when required,
5. *negate* hostile space systems that place Allied interests at risk.

Regional Engagement Augmentation

The REA concept advocates integrated regionally-focused surveillance of space, air, and surface areas; a defensive umbrella against missile attack; and a force application capability for certain high-priority targets. Through REA theatre commanders should have greater situational awareness and more reaction time by the provision of an effective forward presence in space. Built on information superiority, it takes advantage of leap-ahead technologies[30] that bring unprecedented speed, flexibility, and perspective to an increasingly lethal battlespace. REA faces significant challenges, including the development of a regional, integrated system for command and control, surveillance of all environments day and night, the need to develop national and international space policies, and enough analysis to support critical trade-offs of technology, systems, and architectures. The following are the specified objectives for REA: Integrated Focused Surveillance, Missile Defence, and Force Application.

Complement Full Force Integration

CFFI means integrating space forces and space-derived information with their counterparts on land, sea, and air. If this integration is thorough enough, operational commanders can use space assets as intuitively as the more traditional ones. CFFI means the right forces will have the right information at the right time, with a coherent common operating picture shared across the battlespace. **Policy** should be developed to enable joint integration of commercial, civil, and Allied space systems into the ADF. **Doctrine** should ensure space operations fully integrate with other mediums of warfare. Clearly defined space policy and doctrine should be developed to realise the full potential of space and the complex issues associated with space operations. **Personnel** need a greater understanding of space. Greater emphasis is necessary at every level for improved space education and training. Although space support is already essential to military operations, most personnel do not always understand it. **Information networks** need to integrate space information, operations and forces to enable easy access by commanders at all levels. **Organisational relationships** and partnerships among the civil, military and commercial communities should be developed and defined if space assets are to be fully integrated into Defence capabilities.

Space Collaboration

The SC concept strengthens military space capabilities through leveraging with commercial, national and international space systems. Without SC many potential Defence space related projects might not be economically justifiable. Partnerships provide more opportunities to share costs and risks. Collaboration in space programs can also enable interoperability between coalition forces. In the near-term most opportunities for SC will be associated with foreign programs that are likely to have completed initial requirements analysis. When investigating the potential to join these programs, careful consideration should be given to whether core Defence requirements can be met through SC.[31] This is especially relevant as the cost of space systems continues to drop and the feasibility of owning indigenous systems improves. Once a determination is made for SC a single Defence point of contact, such as an acquisition project office, should be established very early. Rapid involvement will increase the potential to influence the system requirements in favour of the Australian capability. Close liaison with Australian and regional space industries can provide Defence with a good understanding of industry planning and investment considerations. Cooperative planning could develop architectures or system designs that satisfy both partners' requirements at a lower cost.

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30 Some of these technologies are discussed later in this paper.

31 Australia might not be able to afford the cost of joining a large collaborative space program.

TRENDS IN SPACE TECHNOLOGIES - AUSTRALIAN MILITARY SPACE SUPPORT

> *Industry, not government, will be responsible for developing critical new technologies, and government more often than not will borrow, licence, or lease systems rather than buy or develop them on its own.*[32]

Basic Technology Improvements Applicable to Space Operations

The currently perceived high return goals of commercial space development are miniaturisation, increased power, and reduced weight; all at lower cost. It is advantageous to ensure that leverage can be obtained for military uses from these developments. The most significant military specific goal that can be added to the commercial vision is in the area of sensor improvement; including sensitivity, resolution, coverage, and longevity. Defence should maintain a clear understanding about the directions of commercial space research and commercial programs that could have direct military applications.[33] Early identification can enable harmonisation of requirements and targeted seed funding in ventures that could provide long-term military and cost advantages.

Reduced Size of Electronic Components and Increased Speed of Computation

The history of increasing clock cycle rates of affordable desktop microprocessors and the associated need for reduction in size is well documented.[34] Desktop computers are now operating in the region of hundreds of MHz and are predicted to typically exceed a GHz by 2005. Silicon based microprocessor technology may have to be replaced to progress significantly beyond this. Teraflop[35] computing can only be achieved today by parallel computing operations. However, there are programs to explore terahertz technologies for wider bandwidth communications and sensing for satellite systems and upper atmosphere imagery. Helping to achieve these speed gains are the size reducing nano-scale[36] technologies.

DARPA Terahertz Program. The US Defense Advanced Research Projects Agency (DARPA) has established a program in terahertz technology[37] for sensing and satellite communications. The goal of the program is to explore terahertz technologies for wider bandwidth communications and sensing for satellite systems and upper atmospheric imagery. More specifically the objective is the development and demonstration of solid-state terahertz sources and detectors for operation in the range between 0.3 THz to 10 THz (1 millimetre to 30 micrometre), mainly for space-based communications and atmospheric sensing, and potentially, short-range terrestrial and airborne communications and near object analysis.[38] One means by which these improvements may be achieved is photonics, the science and technology of using light to transfer and manipulate information within high performance systems. It requires the development of unique optical devices, multi-wavelength laser sources, integrated optical-electronic components, improved materials, and the nano-scale structures required to realise these devices. A DARPA goal for the next generation real-time synthetic aperture radar imaging is 'a processing

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32 Tirpak, J.A., 'Air Force 2025: A massive study considers the US Air Force's place in a future that will be much different from today', *Air Force Magazine*, December 1996, p 22.

33 A Defence Space Systems Centre of Expertise could be charged with the monitoring task.

34 Hospodar et Alia, Proc IEEE 81(4):586-594, 1993.

35 1 teraflop = 10^{12} cycles per second.

36 1 nanometre =10^{-9} metre.

37 1 Mega-Hertz (MHz) = 10^6 cycles per second, 1 Giga-Hertz (GHz) = 10^9, 1 Tera-Hertz (THz) = 10^{12}.

38 DARPA Broad Area Announcement for Terahertz Technology Program.

system weighing less than 25 kilograms, occupying a 0.3-metre cube, and capable of executing 0.25 teraflops with an aggregate input/output bandwidth of 256 gigabytes/sec, consuming less than 800 Watts of power.'[39]

Micro-Electromechanical Systems. A further improvement in space systems may come from the field of Micro-electromechanical Systems (MEMS).[40] This is a revolutionary and enabling technology. It is expected to merge the functions of compute, communicate and power together with sense, actuate and control to change completely the way people and machines interact with the physical world. Using an ever-expanding set of fabrication processes and materials, MEMS will provide the advantages of small size, low power, low mass, low cost and high functionality to integrated electromechanical systems, on the micro as well as on the macro scale. MEMS should enable the development of very small satellites that have similar capability to today's satellites but are one to two orders of magnitude greater in size.

Improved Power Systems (Increased Power). Developments in advanced power technology will enable improved earth observation (especially active sensing using lasers and radar), enhanced communications, and the possible use of electric propulsion (arcjets and ion thrusters) to minimise propellant requirements, orbit transfer and on-orbit station keeping. Applicable areas of technological development are: efficient, lightweight, high-capacity solar arrays that are easy and inexpensive to manufacture; advanced and improved power storage technology, including nickel hydrogen battery and advanced flywheel technology;[41] and improved power management and distribution technologies, that can reduce the part numbers and complexity of spacecraft power systems. Current efforts in advanced photovoltaic solar arrays, advanced batteries, and advanced power management and distribution (including switching, control technology and power integrated circuits) are being explored. Improvements in battery performance technology are expected to see a ten-fold improvement in charge/discharge cycle life, which is of critical importance to Low Earth Orbit (LEO) missions that spend part of each orbit in the shadow of the earth. Battery technology developments have direct application to all space missions, and could be critical to missions requiring high power capabilities, such as future radar missions. Significantly lighter, more efficient power systems also allow for more of the satellite mass to be dedicated to the primary payload.

Sensor Developments

Space-based Radar. The Discoverer II program is a joint initiative between DARPA, the US Air Force and National Reconnaissance Office (NRO). It is expected to develop and demonstrate an affordable Space-Based Radar (SBR) with High Range Resolution Ground Moving Target Indication (HRR-GMTI), Synthetic Aperture Radar (SAR) imaging capabilities, and Digital Terrain Elevation Data (DTED) that will revolutionise reconnaissance, surveillance, and precision geolocation support to the tactical warfighter. The operational constellation is expected to have 24 satellites each costing no more than US$100 million each, and with a 20-year operating life. The platforms will fly circular orbits at a height of 770km. The SBR will operate in X-band (10 GHz) with a peak power of 600 Watts. When operating in the GMTI mode, the radar must be able to perform wide-area surveillance over an entire theatre of responsibility covering 500,000km^2 in 15 minutes. It should also be able to detect and track small targets, the size of a light utility vehicle travelling at low speeds. Also it should be able to provide precise geolocation of stationary targets with 3m accuracy.[42] In addition to Discoverer II, NASA is also seeking to develop a Lightweight Synthetic Aperture Radar for operation in LEO.

Lidar (Ladar). Space-based lidars enable additional measurements of the near-ground and atmospheric environment. Using tuneable, narrow-band sources, they can detect specific chemical and biochemical signatures associated with weapons manufacturing. Enhanced target information can be obtained through a wider range of source wavelengths and through the analysis of the time response of signals

39 VLSI Photonics Program, http://www.arpa.mil/ETO/VLSI/index.html.

40 The DARPA MEMS projects are listed at http://www.arpa.mil/eto/mems/projects.

41 A flywheel energy system may be developed that stores one kilowatt-hour of extractable energy, which is then delivered at the rate of 100 watts for ten hours.

42 *Janes International Defence Review*, 1/1999.

stimulated by pulsed illumination. Short-pulse lidar can provide highly accurate target ranging, for track generation, and can even generate a range profile of a target, which is useful for target identification. Lidars can also provide accurate height profiling of atmospheric parameters such as pressure, temperature, humidity, wind speed and direction, and return profile information on airborne aerosols and clouds. In general, the analysis of spectral and temporal characteristics of the returned signal can provide enhanced information over that obtained passively with solar illumination alone.

Hyperspectral Sensors. The US Air Force Research Laboratory (AFRL) is currently soliciting proposals for a Brassboard Overhead Spectral Sensor System Specification (BOSS) program to develop day and night global surveillance hyperspectral imaging (HSI) technology capable of rapid precision targeting against ground and aerial targets. The BOSS program is focused on support to military operations, including precision targeting, intelligence preparation of the battlefield, and battle damage assessment. The program will enhance military operations by developing the capability to perform wide area search/detect/target for low contrast ground and air targets, provide automated target/material recognition, fuse information with other assets, and operate in synergism with airborne reconnaissance assets. The goals are to mature the technology to the point that a successful air and/or space demonstration is viable, and to develop integrated air and space system concepts that are optimised to meet the critical needs of the above military missions. Current and near-term space HSI sensors are predominantly limited to the following characteristics: daytime-only, intelligence exploitation focus, stand-alone systems, and space-only solutions. In order to support the objectives stated above, the following key areas of research and development will be performed:

1. day/night (thermal infra-red spectral region) performance, including underlying target/background phenomenology and sensor system specification and development,
2. near real time support to military operations including development and systematic evaluation of semi-automated target detection and recognition algorithms and insertion into operational exploitation systems,
3. multi-sensor information fusion, encompassing relevant air and space signals and image intelligence collection assets, and
4. development of synergistic, joint air/space solutions.

Of note, Australia is also planning to use hyperspectral sensors in space on board the Australian Resource Information and Environment Satellite (ARIES). ARIES-1 will be a commercial operation using a spaceborne imaging spectrometer with visible and near infra-red and shortwave infra-red capabilities. The 400kg satellite should be launched within a couple of years and orbit at 500km in a sun synchronous orbit.

Infra-Red. One of the most promising new infra-red technologies emerging is the silicon- and gallium-arsenide-based Quantum Well Infra-red Photo-detector (QWIP) technology. QWIP technologies offer superior uniformity than current detectors. They are also much easier to fabricate, which should make them much less expensive. A valuable capability of QWIP technology is that because the spectral response bands can be made fairly narrow, it is possible to achieve simultaneous imaging in multiple spectral bands by stacking multiple layers of stepped spectral response. This effectively provides three-dimensional, hyperspectral data in a staring mode. Sensor cooling is another method of improving detector sensitivity. In general, the detection of weak or low-contrast IR signals beyond a few microns requires active cooling of the detector to reduce the dark current noise below signal levels. To date there has been little commercial incentive for the development of such coolers. High-resolution imaging also requires very accurate and stable pointing. Mechanical coolers present a particular challenge in this regard, and vibration-free coolers or active vibration suppression technologies remain an exclusive military requirement.

Visible Sensors. Charge coupled device (CCD) arrays have achieved performance close to 100 per cent quantum efficiency. CCD arrays are continuing to improve and there is significant motivation to search for less expensive approaches to achieve large-format, high-efficiency arrays. Array technologies such as the active pixel sensor that can be manufactured on any standard microelectronics fabrication line are interesting since they can reduce the cost of future sensor systems.[43] Defence applications may require the implementation of emerging on-chip micro-lens array technology that can focus the light on the active portion of each pixel.

Communication and Navigation Developments

Military Communication Satellites. Communications bandwidth used to be limited and at a premium. However, with the onset of digital compression and multiplexing, bandwidth is exploding as communications begin to work in the upper Super High Frequency and the Extremely High Frequency bands, exploiting frequencies in bands with data transmission rates in the gigabit range. Advances in cross-linking will also allow satellites to talk to one another without ground stations. The NRO has started development of a communications technology demonstration satellite, the Geosynchronous Lightweight Technology Experiment (GeoLITE). The GeoLITE is planned to have a laser communications experiment and an operational Ultra High Frequency communications mission. A major problem for communications at dramatically high frequency levels is the need for improved antenna pointing and tracking accuracy. The most challenging task is to maintain laser communication to, from and between LEO satellites moving at very high velocities. Although there have been problems, the expectation is that such communications are achievable. Once obtained there is then significant scope to also communicate directly with aircraft from space using laser. This should greatly improve data flow and the stealthiness of communications when conditions for use are favourable.

Civilian Communication Satellites. A by-product of the explosion of information is the migration of communications needs away from dedicated military satellite communications to wide-band high data rate commercial transponders. Some communications were off-loaded to leased systems in *Desert Storm*, and leased transponders on commercial satellites were also used for Bosnian support. Commercial systems have reliability, high capacity, anonymity - and they are cost-effective. They could also handle 70 to 80 per cent of future space communications needs. The emerging use of low orbiting communications systems provides instantaneous voice and messaging connectivity in the field. Just as soldiers have been provided with GPS receivers, it would not be difficult to have wireless communication devices issued as well. This would do two things for the military. First, it would assure communications connectivity at all levels of command; and second, it would enhance survivability through proliferation. However, the location of the user is likely to be known by the communications carrier. Satellite broadcast systems such as the Australian Theatre Broadcast System (TBS) can avoid this potential for compromise through a broadcast only mode. TBS also has the potential to be used on civilian and military communication satellites.

Navigation. The prime satellite navigation system is GPS. The development and utilisation of GPS are similar to those associated with radar. Starting as a purely military system GPS has evolved into a US-owned public utility used throughout the world. Significant changes are forecast to the GPS infrastructure to enable more accurate and reliable civil use. However, to maintain the military effectiveness of the systems and to deny its use by hostile forces, the US has been developing a program for navigation warfare (Navwar). Australia has been a key player in the developments for GPS over the last 15 years, including Navwar. New signal strengths, signal structures and transmission platforms are planned for introduction over the next ten years. In addition there is strong potential for communications satellites to broadcast a GPS like overlay signal to increase system robustness, availability, integrity and accuracy. Australia is well positioned to maintain an edge in the development and testing of satellite navigation technologies. Testing jamming systems is an area where Australia could excel given that Woomera is the only land site where unrestricted full spectrum Navwar can be undertaken.

Global Air Traffic Management. The tremendous growth in air traffic is straining airspace capacity and airport resources. The air traffic system requires significant upgrades to increase system capacity and flight efficiency while continuing to meet flight safety standards. The International Civil Aviation Organization (ICAO) and other civil aviation authorities plan to implement a new air traffic architecture to meet this need. This new architecture takes advantage of emerging technologies in communication, navigation, and surveillance to improve air traffic management. The current plan is for the new air traffic environment to culminate in 2010 with the attainment of dynamic routing, commonly referred to as 'free flight'. The civil aviation community refers to these changes as

43 There is significant industry interest in this area as an inexpensive technology for commercial electronic camera applications.

Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM). Many Allied militaries refer to the new concepts as Global Air Traffic Management (GATM). The most critical technology elements of the new CNS/ATM environment are satellite-based navigation, increased use of data links rather than voice for pilot/controller communication in oceanic/remote airspace as well as en-route and terminal environments, and improved surveillance that will enhance both ground and cockpit situational awareness. The new CNS/ATM architecture will have a major impact on military aircraft flying in civil airspace and require potentially significant aircraft modifications. A GATM system could also be expanded to manage international space traffic. However, establishment of such a system could take at least ten years given the international coordination and approval process. As an interim Australia and the US could start to trial a Global Air and Space Traffic Management system in a similar way that CNS/ATM trials were conducted over the Pacific.

Antenna Developments

The longer wavelengths in the microwave region (as compared to the visible and near infra-red) require correspondingly larger apertures in space in order to obtain the necessary resolution. In the nearer term, technology developments are needed to provide large antennas and structures that are lightweight (less than $20kg/m^2$), foldable and deployable, and with high surface metric accuracy that can be actively controlled and corrected. In the longer term, the desire to place microwave sensing systems in GEO (which requires considerably more energy to obtain) places greater demands for reducing the mass of the antenna system. GEO platform-based microwave antenna structures should be ultra-lightweight, with mass less than $5kg/m^2$. These ultra-light antennas could be either deployed directly at GEO, or erected in LEO and boosted to GEO. Inflatable structures[44] could be used as large antenna reflectors. The stowed volume of the inflatable device is about one tenth that of the equivalent mechanically deployed reflector. This gives rise to a smaller launcher resulting in significant cost reduction. Antenna pointing accuracy is another problem affecting most space-based antennas. However, there is scope to utilise MEMS technologies to overcome some of the antenna problems.

Satellite Constellations

GEOs/LEOs. In comparison to GEO satellites there has been a dramatic increase in LEO satellites and constellations. This is mainly driven by the communications industry. Technology hurdles had delayed moves into this area. However, improvements in satellite positioning, orbit predictions, satellite vehicle stabilisation and tracking equipment (both to/from ground and space to space) have made LEO satellites more attractive. It is also cheaper to launch into LEO than GEO. Shorter distances to users from LEO satellites can mean lower power/signal strength requirements, which is good for communications and sensors' sensitivity. However, the increased height of GEOs means they provide greater coverage but their signals must travel further distances and are subject to greater signal loss. GEO satellites tend to be larger than their LEO counterparts.

Tailored Constellations. There have been a number of academic and commercial studies undertaken to determine the optimal mix of satellites for a particular situation, be it for a specific geographic area or for optimisation of revisits and areas of coverage.[45] Since satellites can be small and cheap as well as highly capable, it is expected that LEO constellations will be populated with sufficient numbers of satellites that there will always be one in the part of the orbit required to observe the battlespace. A Singaporean study[46] found that with six or more satellites at Low Equatorial Orbit (LEQ), continuous coverage could be provided for countries lying between the Tropic of Cancer and the Tropic of Capricorn. Six were required for a satellite on the horizon or up to 15 satellites for 30 degree or above elevation angles. This is a great deal less than that required for global systems.

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44 Inflatable structures can be used on space platforms for many purposes including deployment and support of solar arrays, solar concentrators and as complete, large antenna reflectors.

45 Science Applications International Corporation has developed a proprietary program to optimise a combination of GEO and LEO surveillance satellites to provide coverage over a specific area at varying latitudes. Using a GEO/LEO combination enables a significant decrease in the required number of satellites.

46 E. Steve Seumahu, *Investigation of the Equatorial LEO Orbit for Small Satellite Applications,* Nanyang Technological University, August 1996.

Pico to Micro Satellite Vehicle Clusters.[47] One way to perform missions from space is to use the concept of clusters of Pico to Micro satellites that operate cooperatively to perform the function of a larger, single satellite. Each smaller satellite communicates with the others and shares the processing, communications, and payload or mission functions. The cluster of satellites forms a 'virtual satellite'. This technology will lead to new exploitation of capabilities in space. The concept promises many benefits, including greater utility and flexibility by permitting the cluster to reconfigure and optimise its geometry for a given mission, enhanced survivability, and increased reliability. It is expected that clusters will reduce life-cycle cost by using mass-produced satellites and minimising the launch cost by optimising the launch vehicle's cargo capacity. The cluster concept also eases performance upgrades by allowing upgraded satellites to join a cluster, increasing the overall performance of the virtual satellite rather than replacing a single, large satellite or the entire cluster.

Space Based Radar Micro Satellites. The US AFRL is exploring the new paradigm of using satellite clusters for performing space missions in a coordinated effort dubbed Technology Satellite of the 21st Century (TechSat 21). Under this work, a variety of application missions are being considered including surveillance, passive radiometry, terrain mapping, and communications. The space-based radar mission for Ground Moving Target Indication was chosen as a stressing case and is the focus of this initial investigation. An innovative concept has been devised that can potentially satisfy most or all of the desired mission requirements while minimising weight, power, and cost. The key to this concept is a cluster of micro satellites orbiting in close formation, each with a receiver to detect coherently not only the return from its own transmitter, but the bistatic responses received from the orthogonal transmit signals of the other satellites as well. This allows for a wealth of independently sampled angle of arrival data to be collected as the constellation forms a large but sparse coherent array. By virtue of its sparseness, the independent apertures look through different parts of the ionosphere, thus temporal and spatial variations on the scale of their separation could adversely affect their operation. Furthermore, the concept is not viable unless each micro satellite has extremely low weight and cost, while being very capable.[48]

Communication Nano Satellites. The Technical University of Berlin (TUB) is undertaking a research project TUBSAT-N to demonstrate that it is possible to realise ultra low cost space access very quickly. The TUB has launched two Nano satellites as a satellite cluster.[49] Both satellites were separated together from the payload capsule of the rocket. In orbit TUBSAT-N received a command from the ground station to separate the smaller Nano satellite TUBSAT-N1. TUBSAT-N has a total mass of only 8.5kg. Four independent communication channels, two in the 2m frequency band and two in the 70cm frequency band, are available. All communication channels use FFSK (Fast Frequency Shift Keying) modulation with baudrates of 1200 and 2400 baud. An additional downlink transmitter with 9600 Baud GMSK (Gaussian Minimum Shift Keying) modulation was used to transmit the collected messages to the ground station. The smaller satellite TUBSAT-N1 has a total mass of less than 3kg. It has two independent communication channels in the 70cm frequency band.[50]

Remote Sensing Using Micro and Mini Satellites. The field of Earth remote sensing from space is in the process of rapid change. It is moving from one involving large, complex, expensive governmental civil and military systems owned by a few countries to one involving increasing commercialisation, international proliferation, and the use of small satellites with focused missions. At the beginning of 1995, only seven nations were capable of constructing free-flying remote sensing satellites, and only nine nations were operating them. By the end of 2001, according to current planning, there will be 23 countries operating their own remote sensing satellites. The satellites enabling these new countries to enter the field are almost entirely Mini and Micro satellites.[51]

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47 A satellite can be defined in terms of its deployed mass: Pico satellite is less than 1kg, Nano satellite = 1 – 10kg, Micro satellite = 10 – 100kg, Mini satellite = 100 – 500kg, Medium satellite 500 – 1000kg, and a Large satellite is greater than 1000kg.

48 R. Cobb and K. Denoyer, *TECHSAT 21: Developing Low Cost, Highly functional Micro-satellite Clusters for 21st Century Air Force Missions,* AFRL, Kirtland AFB, NM, April 1999.

49 The Nano satellites were launched on 7 July 1998 using a convertible Russian military SS-23 rocket fired from a submarine.

50 R. Schulte, *TUBSAT-N, A Global Communications Satellite System Based on Nanosatellites,* Technical University of Berlin, April 1999.

51 D.I. Glackin, *Smallsat Concepts Enabling Proliferation of Commercial & International Earth Remote Sensing,* The Aerospace Corporation, April 1999.

Imagery Issues[52]

Commercial Imagery. It is important to note that in addition to communications industry also rapidly developing imagery capabilities. Commercial imagery from space is becoming widely available. A very large number of commercial and civil imaging systems could be launched within the next several years to provide subscribers with electro-optical, radar, multi-colour, multi-spectral imagery with one metre resolution or better. In some cases, customers will be able to receive their precision planning and targeting capability digitally. No longer the sole purview of the military and intelligence communities with accompanying classification restrictions, readily available earth observation systems in the 21st Century will fundamentally change the way air forces plan and conduct operations.

Low Contrast Targets. A challenge for space-based surveillance and reconnaissance is the low contrast presented by many military assets with respect to background, especially when enemy assets are consciously hidden, camouflaged, or placed under foliage or below ground. This drives the military to seek more subtle target signatures using an expanded set of measurement parameters, and to fuse information from a variety of different measurement sources (including airborne and in-situ platforms). This translates into a need for detector arrays across wider spectral ranges, and the use of hyperspectral imaging systems operating across this expanded range. For the foreseeable future, military requirements for hyperspectral sensing and data fusion will exceed those in the commercial sector, requiring continued government investment in these areas. Another powerful approach for detecting low-contrast targets is active sensing. Control of the illuminating source properties (wavelength, phase, and modulation or pulse length) provides additional parameter spaces that aid in target discrimination.

Data Latency. The return of information for military applications is typically more time-critical than for most commercial uses. On-demand global knowledge can be achieved only through the deployment of multiple, distributed space platforms. Distributed assets also offer inherent advantages for survivability. Providing this capability at an affordable cost will place stringent constraints on the cost of individual sensor platforms, driving towards significant miniaturisation of space sensor systems.

Satellite Vehicle

Satellite Size Reductions. Improved technology has enabled significant reductions in the size of satellite payloads. The technologies discussed earlier should lead to a further decrease in payload volume and weight. Lower weights are directly related to cheaper launch costs and can significantly reduce overall program costs.

Satellite Buses. Traditionally buses for unique missions were crafted. However, large constellations and commercialisation have enabled the establishment of a manufacturing line for common buses, both for small and large satellites. This leads to significant cost savings.

Increased Satellite Life. The demonstrated and planned life of satellites has been increasing, for example GPS satellites now have a life expectancy of 12 to 15 years. This means lower sustainment costs because of less launches. However, it is very rare for satellite hardware to be changed once it is in orbit. This means that new technological advances cannot be inserted into the system. However, the life of LEO satellites tends to be dependent on their orbit altitude with many not expected to last more than five to seven years. This lower life necessitates repopulation of constellations with newer more capable satellites.

Multi-Role Platforms. The USAF is investigating conceptual architectures to satisfy multiple Mid-Earth Orbit missions. The catalyst for this effort is the strategic planning for the next generation GPS. By taking advantage of the need for a next generation GPS, the USAF is exploring what other mission capabilities could be integrated within the same platform to yield increased mission efficiencies and significant overall cost savings. In addition to GPS, communication and intelligence functions could be added to the satellite. The NRO, in conjunction with US Space Command and Air Force Space Command, is also looking at ways to bring together signals intelligence data and Space Based Infra-red System satellite warning data (SIGINT and SBIRS), both now and in the future. This combination of source data should provide better situational awareness.[53]

52 Most of the information in this section was derived from New World Vistas.

53 From a speech given by Keith Hall, Director of the NRO, on 9 April 1998.

Launch Developments

Access to Space. A number of commercial projects are underway to develop small and medium launch vehicles and there is strong competition from the international providers of large vehicles. Full integration of space capabilities into routine military operations is likely to only be realised when space launch is no longer a significant operational constraint. Although expendable vehicles may continue to provide limited, unique services, over time, dramatic improvements in cost and capability will come through a reusable operational system for all orbital regimes. The same technologies and operational concepts needed for reusable space launch will support transatmospheric systems that could provide presence anywhere on the globe in under two hours. In time there may evolve a need for military staff to provide on-orbit support of complex systems.

Cost of Launch. A key aspect to reducing the cost of spacelift is enlisting industry support in the commercial sector for the development of new systems. The NASA administrator is attempting to build such a partnership with the private sector for reusable launch vehicles. After experiencing an order of magnitude reduction in satellite cost per bandwidth over the last decade, NASA is teaming with industry to realise a $10,000 per pound to $1,000 per pound reduction in the cost of launch.[54] Looking a generation beyond the $1,000-per-pound barrier, the $200-per-pound mark further enables commercial uses of space into such areas as entertainment and space tourism.[55]

Developments in the United States. The USAF is strongly promoting a new unmanned launch vehicle, the Evolved Expendable Launch Vehicle (EELV), which will be fielded in 2001. The EELV will be a family of medium and perhaps heavy launch vehicles, evolved from existing designs with enhanced operability and reliability. The EELV will be the workhorse for the US Department of Defense and the commercial sector well into the 21st Century. It is expected to lower operating costs at least by 25 per cent by reducing infrastructure, adopting commercial practices and standardising interfaces. Possibly the right way to launch satellites in the future will be to fly manned, reusable launch vehicles. These vehicles will be different than the current space shuttle program with its enormous infrastructure and costs. However, there is a considerable technology challenge in building a reusable launch vehicle, particularly in the area of engines, fuels, materials, payload capacity, and cost. Nevertheless, the US goal remains for affordable, reusable access to space using routine operations, just like an aircraft.

Proliferation of Launchers. The large increase in planned commercial launches over the next decade has created a significant market for launch vehicles. A number of new ventures have started. Some use old and proven technology while others are breaking new ground. The aim for most launch companies is to capture market share by providing lower launch costs. An example of the launch developments in the US that could have early application for Australia is the Microcosm Scorpius low-cost launch vehicle. The Scorpius is intended to reduce the near-term cost of launch-to-orbit by a factor of 5 to 10. The program is funded by multiple contracts from the US AFRL, NASA, and Microcosm internal funding. Microcosm has successfully completed the first test flight of the Scorpius SR-S single engine sub-orbital rocket.[56]

Australian Launch Activity. Over the last decade there have been a number of potential Australian based launch programs that have not proceeded. Most did not materialise because of a lack of funding, be it commercial backing or Government support with infrastructure. However, it appears that at least a couple of programs will have launches over the next few years. Currently the highest profile activity is the Kistler Corporation development at Woomera in South Australia for reusable launch vehicles. The Kistler launch vehicle could provide significant potential to deploy Australian military satellites. Astrotech, in conjunction with the University of Queensland and the Australian Space Research Institute (ASRI), plans to launch two flight test rockets with a test Hyshot scramject payload. Hyshot is a hypersonic technological demonstration and development project that has the potential to support the development of an Australian military space launch vehicle. Other organisations that have recently shown interest in basing launch activities in Australia include United Launch Systems International

54 Daniel S. Goldin, 'Viewpoint', *Aviation Week*, 26 February 1996.

55 National Aeronautics and Space Administration, *Space Propulsion Plan* (Draft), Marshall Space Flight Center, 22 January 1996.

56 The flight was conducted on 27 January 1999 at the White Sands Missile Range, New Mexico.

and Asia Pacific Space Centre. ASRI has also been developing a series of rockets (AUSROC) that are hoped to eventually lead to the capability of launching LEO satellites.

INTEGRATION OF SPACE INTO CAPABILITIES AND PLANNING

> *Integration is a key task facing everyone in the space business. Integration drives our national efforts to partner, our military efforts to enhance jointness, and our Service efforts to operate in a seamless vertical dimension. Integration acknowledges the growing networks and connections throughout all levels of society as space fuels the evolving Information Age.*[57]

Space Operations Education and Personnel

Space Training for Defence. To properly exploit space and space-related systems Defence personnel need an understanding of the space environment and what benefits and vulnerabilities space systems bring to a conflict in a similar way the contributions of air, land and sea are understood. This knowledge is essential if competent capability analysis and planning are to be done. Some efforts have been made by Defence to provide space training. External consultants have given limited training in the concepts of space to Defence members. In 1995, a Space Systems Short Course was developed by Force Development (Aerospace). A lack of experienced staff has meant that external consultants have taught this course. In addition a number of military courses teach different aspects of space systems. However, there are no common syllabi requirements across Defence for developing a common understanding amongst personnel. In contrast to Australia the US Department of Defense (DoD) is undertaking a comprehensive program to ensure military education organisations provide a common understanding of space for all ranks.[58]

Personnel with Space Experience. Defence personnel have gained experience in space systems generally from either a tour at No 1 Joint Communications Unit or from an overseas exchange posting. Often after their tour concludes these Defence members are posted to non-space related positions where they do not have the opportunity to develop their scarce skills. The Concepts and Capability Committee in May 1996 identified that Defence did not optimise the use of personnel with experience in space systems. Personnel organisations were not identifying and tracking the limited staff with space systems experience. Although recommendations were made to correct this loss of experience the absence of any clear space policy makes it difficult to develop Australian military space-related centres of expertise. Development of future space capabilities will require a cadre of experienced personnel to plan, acquire, manage and operate these capabilities.

Space Weaponry and Natural Phenomena Effects on ADF Space Functions

Space Weaponry. There is a continuum of weaponry effects that can be applied to an adversary's space systems to deny their space-related capabilities. Attacks on space systems can include soft or hard strikes against satellites, control networks, and the end user's satellite equipment and intermediaries systems. Many attacks are likely to employ similar mechanisms as those used for air superiority, modified for use against space systems. The US aim for Control of Space is based on development and deployment of weapons into space, although a number of treaties restrict the ability of the US to legally deploy and use space weapons. However, the USSPACECOM in Vision 2020, while recognising the legal restrictions, calls for research and development of space related weapons. This is to allow the option for later use either with or without international legal authority. Australian systems,

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57 General Richard Myers, *Integrating Space In An Uncertain Era,* Speech to the Air Force Association, Los Angeles, 13 November 1998.

58 The first goal of the 1997 USAF Long Range Plan is for the USAF to fully integrate space and air operations. To achieve this goal the first end state is to ensure all personnel are educated, and all operators are trained to exploit air and space assets in an integrated manner.

and international systems used by Australia, will likely be to varying degrees more vulnerable to attack than US space systems. The key to defending against possible attacks is to understand system vulnerabilities through study and analysis. Knowledge of real and potential vulnerabilities can allow Defence to implement strategies to mitigate or eliminate risks. Unfortunately the lack of clear policy in this area means that it is unlikely the required level of analysis has been performed.

Natural Effects. The importance of weather to military operations is historic. Knowledge of the weather, or more importantly discrete windows[59] of opportunity in the weather, has been demonstrated in many theatres of warfare. Information derived from space can help predict weather effects on satellites as well as terrestrial based systems. Of particular interest are solar and interstellar effects on the radiation bands around the Earth and in particular effects on the ionosphere. Changes in the ionosphere can degrade space-based communications, navigation and radar. The regular day/night effect on the ionosphere is caused by Earth rotation varying solar radiation. Similarly, satellites are effected by a lack of available sunlight for charging power systems. LEO satellites will be more effected by solar eclipsing than those at higher altitude; however, the degree of impact will be less when improved power storage systems become available. The US has also conducted research into methods to alter the ionosphere and weather. The High Frequency Active Auroral Research Program (HAARP)[60] facility in Alaska aims to actively vary the ionosphere through focusing ground-based energy at a specific area within the ionosphere. The US has also considered using large mirrors in space to redirect sunlight onto areas of the Earth that are in darkness. These mirrors could also be used to heat certain areas.

Effectiveness of Space Systems in Various Environments

Joint Force Enhancement Future. Future combat operations are likely to be joint and/or involve coalition forces. The use of space will be crucial to a successful conclusion of these operations. The effective use of space requires a space-knowledgeable cadre of dedicated and motivated military officers and civilians. Future conflicts should be fought by a holistic force to leverage the synergism between integrated land, seas, air and space elements and depends on the type capabilities in which Defence now invests. Any information that is not readily available to the warfighter, the one with the ultimate responsibility, is irrelevant. The battlefields of the future, across the entire range of situations whereby military forces might be committed, will be ever increasingly dynamic, faster paced and of greater dimensions. There will be a requirement for continuous global, three dimensional positional situation awareness, under day/night and all weather conditions, with less than one metre accuracy and temporal data tethered to GPS time. Space should act as the medium from which to acquire the information that can only be achieved from space or can be obtained more economically from space. Space provides broader area coverage than any other means for a plethora of sensors to support a wide range of missions. Space systems of the future must be a part of a 'system of systems' that can provide the warfighters with all of the information necessary for 'information dominance' of a unified battlefield. This 'system to system' architecture should be an integration of a wide array of space capabilities that includes, among other things; SAR imagery, multi-spectral imagery, GPS, or its successor, meteorological and oceanography information, ELINT, satellite communications, and the other potential space capabilities that await exploitation. There is a need for a 'system of systems' space doctrine that contains existing and planned space capabilities that can be critically analysed during exercises and through modelling and simulation to improve its architecture and effectiveness.

Land. In the future, space assets, capabilities, and products will critically affect the conduct of land military operations across the entire spectrum of those operations. Access to military, Allied, civil, and commercial space capabilities and products will be essential to successful land operations. The use of space products and application of those products will be embedded in land force doctrine, training, simulations, war games and plans, and will be part of all preparations for and conduct of assigned missions of land component commanders

59 Atmospheric absorption also creates windows where some frequencies are more useable than others.

60 HAARP aims at studying the properties and behaviour of the ionosphere, with particular emphasis on being able to understand and use it to enhance communications and surveillance systems for both civilian and military purposes. The HAARP Ionospheric Research Instrument (IRI) is a high power transmitter facility operating in the HF frequency range. The IRI will be used to temporarily excite a limited area of the ionosphere for scientific study.

and warfighters. Space-based capabilities in support of ground operations can be grouped generally into the following categories :

Communications

- Provides reliable transmission of command and control information between and among formations conducting ground operations.
- Provides long-haul communications links for intra and inter theatre combat and support activities.
- Moves sensor data from space-based and non space-based sensors to support intelligence and targeting processing systems.

Position, Navigation, and Digital Mapping

- Provides three-dimensional position, location, and navigation.
- Assists synchronised operations through precision timing and locating.
- Provides information to determine precise enemy location and target acquisition.
- Provides the digital terrain data to support the digital transmission and integration of topographic and feature data to one metre resolution for anywhere in the world.

Reconnaissance, Surveillance, and Target Acquisition

- Provides global and local observation of both friendly and enemy activity and facilities.

Weather, Terrain, and Environmental Monitoring

- Permits advanced knowledge of the environment and its effects on friendly and enemy soldiers, formations, and systems to support mission planning, situation awareness, and synchronised battle management.

Missile Defence

- Provides early warning of missile attack.
- Cues tactical missile defence systems to missile attack.
- Targets enemy launch systems.
- Provides counter-proliferation surveillance.

Maritime. Navy has unique space needs, as it must be able to operate over 70 per cent of the Earth's surface where there is likely to be little commercial satellite support. Commercial communications satellites, particularly the overcrowded Ku and C bands, are focused over land and primarily high-density, populated areas, limiting these communications satellites utility to Navy. Navy's operating environment includes all mediums.61 These environments will not change, nor will Navy missions significantly change for the next 20 years, but there will be major increases in the support required from space. That space support must enable Navy to carry out its missions with shorter time lines and greater accuracy and lethality. Navy's surveillance and warning requirements cover the ocean and littoral areas and include the detection, tracking, and targeting of non-cooperative air and ground targets (aircraft, cruise and theatre ballistic missiles, mobile launchers, etc.) in near real time. Navy communications are likely to be dependent on satellite communications for many of its missions. Although High Frequency radio has been the main communications medium, future data requirements are likely to mean increasing dependence on satellite communications. At sea, naval commanders must have access to large reservoirs of information that contain information about friendly and enemy weapons systems, platform capabilities, enemy order of battle, satellite ephemerides, enemy signals, etc. Every Navy ship and aircraft should have GPS time and position information embedded in its navigation and weapon systems. Navy has a myriad of requirements for accurate and continuous weather information spanning the spectrum from evading storms and heavy seas to avoiding ship

61 The mediums of air, ground, sea, sub-surface and space all can potentially affect Navy's capability.

damage, to making weapon systems more effective, to using winds and tides for economical steaming or flight operations. Weather is a major, if not a determining factor, in every dimension of naval warfare. The commander at sea requires information on sea surface topography, sea state, sea surface temperature, sea surface wind vectors and velocity, sound velocity profile, and cloud opacity, bottom height, thickness and particle size and be able to observe, measure and record temperature, humidity and atmospheric pressure.

Aerospace. Aircrews have a requirement for information which is accurate, relevant, and timely and a concomitant requirement to interfere with an adversary's information such that, in varying degrees at various times, it is none of these. Space systems are uniquely suited to meeting these requirements. They can produce information of extraordinary accuracy, allow access to denied areas, and they can be employed to interfere with information flows. The special risks of operating in all weather by day and night have always challenged aircrew. The three dimensions in which they operate require characterisation just as the ocean must be characterised for the Navy. Space-based weather information has long supported air operations and this support will be required into the foreseeable future. Further requirements, in timeliness, accuracy, and access will grow as air operations extend away from Australia. Since an air force can range over the entire globe its area of operation is virtually unconstrained. This drives the situational awareness requirements for future air forces to very high levels. First they must understand the terrain over which they will operate. This implies a significantly expanded earth surface and cultural features database. Most of the world today is mapped and charted to an accuracy insufficient to support the intrinsic capabilities of future air forces. The inability of aircrew to correlate tactics to the terrain will reduce effectiveness and increase potential losses. Second, they must understand the targets against which they are operating. As weapons technologies allow the movement to general 'one shot, one kill' operations, aircrew must be afforded target situational awareness of comparable accuracy. Third, the essentially unlimited range of air forces implies a new concept for communications. The ability to move the information required for acceptable situational awareness is fundamental to future air warfare. This implies not only requirements for masses of data into a theatre, it implies the ability to move situational awareness information directly into the cockpit. To a lesser degree, the aircrew on the scene is an important part of the air component commander's situational awareness.

The ability of air forces to get to the target has outstripped the ability of the forces that support them to provide the information necessary to the successful conduct of operations. Future air forces will require support that keeps pace with the overall tempo of the operation. The natural extension of air into space leads to the natural opportunity to extend air operations into space. Doing so complicates the adversary's strategic, operational, and tactical challenges, and may afford an entirely new method of projecting force.

Capability Management Trade-offs. Many terrestrially-based systems can be complemented by equivalent space-based systems. A number of military capabilities can now be achieved using space. As more of these space systems mature there will be greater justification for considering space-based systems to either complement or replace some aging less capable terrestrial systems. The capability options for replacements/upgrades should include equivalent space systems. However, to achieve meaningful comparisons Defence needs to improve its knowledge base and familiarity with concepts and capabilities associated with space systems.

Intelligence, Surveillance, Reconnaissance, Acquisition and Tracking/ Battle Damage Assessment [62]

Commercialisation of Space. The rapid developments in satellite systems enable a greater amalgamation of military tasks. Intelligence, Surveillance, and Reconnaissance (ISR) is likely to be captured as part of a more holistic approach to warfare. ISR can form part of a seamless attack support system with almost real-time parallel feedback of information from multiple sources. The Surveillance, Acquisition, and Tracking/Battle Damage Assessment (SAT/BDA) requirements fall into the general mission category of force enhancement. The impact of cost constraints and rapidly developing technologies on militaries are moving the initiative in these areas toward the commercial sector. GPS is a prominent example, with commercial receivers being bought by the thousands to support Operation *Desert Storm*. It is very likely, therefore, that a significant amount of SAT/BDA will depend on commercial concepts or commercial assets in the future. This will be an important

62 Most of the information in this section was derived from New World Vistas.

factor in two ways. First, a great amount of equipment will be available 'off the shelf' around the world. Second, given the high cost of satellites, space assets will probably be shared, and not always by allies. This raises the question of who will be in control.

Information Networks. A future global information network (GIN) is probably the only affordable place to perform most of the SAT/BDA function. If relatively limited[63] military computers, sensors, and dedicated communications are not linked to the GIN, it will be impossible to assemble an accurate 'digital picture of the battlefield' in real time. Linkage to the GIN will also provide ready access to rich sources of information unavailable to current warfighters.

Surveillance. Surveillance can be defined as the systematic observation of aerospace, surface, or sub-surface areas, places, persons or things by visual, electronic, photographic or other means. The requirement for this information seems critical today, but in the much faster world of tomorrow, real-time information will be an absolute imperative. The most survivable and effective way of obtaining real-time surveillance will involve networking and fusing sensory data from a wide variety of military, civil, commercial, and Allied assets. This exciting possibility awaits technical advances in wide-band communications, wide-area networks, data fusion, and above all a far greater number of fielded sensors. Industry is already moving into the area of satellite high-resolution remote sensing. In the future surveillance systems operating from space will provide the war fighter with indispensable real-time, accurate, pre-processed information. Fusion and dissemination of surveillance data will be handled by a distributed, wide-area network of computers (probably based on microprocessors in a parallel architecture) linked by the communications system. The warfighter and his weapon systems, whether air, sea, land, or space-based, will be able to access this information on demand, probably in a graphically oriented format. The real challenge will not be the collection of sufficient data, but its processing into secure, useful, and easily digested forms. This will be an ever greater challenge as the amount of types of available information grows.

Acquisition and Targeting. The dispersion of assets into the civilian arena should be an advantage, since properly designed, distributed systems are much more survivable than centralised, dedicated systems, and because it may be impossible to determine which portion of which physical asset is being used by the military at any one time. Surveillance and acquisition functions can and should be provided by 'off platform' distributed systems. Targeting is a more complex and specialised function. Automated target acquisition and identification is likely to become a reality. The necessary databases and specialised information processing assets can be made available through the GIN, which will also be linked to any specialised military sensor data that might be required to deal with particularly difficult targets. Automated target acquisition and identification is the subject of intense research today, and many promising approaches are being investigated on conventional supercomputers and clever, proprietary combinations of electronic and optical computers. The results of the primarily off platform acquisition and targeting functions will then be handed off to the weapon platform, which will provide the tracking and force-application functions. Using appropriate algorithms and beam selection, it is conceivable that the entire sensor constellation could be available for collection all the time. Fusing of the reflected data from a single look could take place on a central platform, probably in geosynchronous orbit. With the continual miniaturisation of computers and electronics, improved network hardware and software, and redundant wide-band communication links (both optical and RF) these data collection and fusion tasks can and should be shared among a variety of platforms, space and earth-based.[64] This approach has the enormous advantage of eliminating critical nodes in the information system.

Battle Damage Assessment. BDA has historically been a task of considerable difficulty because the wide range of munitions utilised, the target types attacked and the modes of attack have precluded the application of any single, reliable method. Over time the solution to this problem will be evident in the 'digital picture of the battlefield' assembled from the fused input from a myriad of sensors of different types linked wirelessly to the GIN. The very system needed to survey and acquire targets will be used to assess battle damage. The advantages are: cost effectiveness through elimination of redundant sensors and communications, nearly instant assessment of the need for restrike, and economy of force by avoiding the expenditure of unnecessary strikes. Additionally,

63 Limited by a matter of funding, not ingenuity.

64 Air Force 2025 Concepts.

accomplishing BDA through the GIN would provide instant, automatic feedback to the logistics system of the number and nature of resources expended.

Australian Space Research and Development

Australian organisations undertake significant activities that are directly related to space research and development. Space research is conducted at many Australian universities. Several Cooperative Research Centres (CRCs) have been founded on space research business opportunities. The most recently established space CRC is the Cooperative Research Centre for Satellite Systems (CRCSS). The mission of the CRCSS is to deliver a new, sustainable advantage for Australian industries and government agencies involved in services based on the applications of future generations of small satellites. The newer 'smaller, cheaper, faster' approach to satellite systems has begun to open space markets to a wider range of public and private sector players; and new small satellite technology is well within the capability of Australian industry to produce.[65] Another CRC working in fields related to space surveillance and navigation is the CRC for Sensor Signal and Information Processing. A number of Australian companies are also actively involved in developing space hardware, primarily for overseas corporations. Also a good deal of the research work done by Defence Science and Technology Organisation (DSTO) is very relevant to military space capabilities. Surprisingly there is no specific focus for space research and development within DSTO.

Australian Space Test and Evaluation

There is little space test and evaluation expertise in Australia. ASRI has conducted a number of launch campaigns at Woomera and British Aerospace Australia has provided support to international space activities launching from Woomera. Some work has also been done on testing satellite user equipment, such as GPS receivers, by the Aircraft Research and Development Unit (ARDU). However, there has not been a need to develop a comprehensive military space test and evaluation capability that would also cover space launch. If Defence does decide that it requires an Australian military launch capability then it will be essential that an organisation like ARDU be given the charter to undertake this support very early in the acquisition process. It will take a number of years to train appropriate staff and develop a space test and evaluation capability. The US military has relied on its specialised test organisations to plan, conduct, and report developmental test and evaluation in order to ensure the effectiveness and suitability of space systems prior to their delivery to the user. The Aerospace Corporation[66] also provides specialised support to the test and acquisition communities. This support includes the provision of independent review and advice on space systems. DSTO or CSIRO are possibly the only two Australian organisations that could provide similar support for any future Australian military space launch capability. The development of a specialised space support agency is essential if Australia is not to risk launch failures. CSIRO could argue that it has filled the void left when the Weapons Research Establishment [67] was absorbed into what is now DSTO and Defence interest in space launch vehicles evaporated. The CSIRO Office of Space Science & Applications (COSSA) is a primary participant in the CRCSS.

Collaboration

The Need for Space Policy. Well considered collaboration has the potential to significantly improve Australia's capabilities. However, before any future collaborative investments are made in space systems an overarching space policy should be developed for Defence. Without such a policy there is a risk that Defence could be drawn in to projects that may not fit into future capabilities or may divert scarce resources away from more relevant areas.

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65 CRCSS will play a significant role in its first three years in assisting industry partners to take commercial advantage from special-purpose remote sensing satellites such as ARIES, and to competitively supply ground station equipment and services for down-linking of remote sensing data from satellites to Australian ground stations. By the end of 2001 CRCSS will help commission and assemble a small, innovative research satellite (FedSat-1) which will be operating in orbit and delivering useful scientific and prototype operational data to business customers, the education market, and to R&D groups.

66 The Aerospace Corporation is a semi-government not for profit organisation that provides specialised advice on military space systems.

67 WRE provided support to the British and European launch activities at Woomera in the 1960/70s.

US Collaboration. The majority of military related space developments are being undertaken in the US. The USSPACECOM Vision 2020 advocates actively seeking international partners and the Defence Executive Priorities have the goal of closer coordination with the US. It is essential that Defence is very familiar with the US DoD space programs if it is to make wise decisions regarding collaborative ventures. Personnel working in USAF space acquisition programs or with space planning staff are probably the best sources of knowledge regarding compatibility of US developments with Australian space policies and plans. Consideration should be given to augmenting liaison at the Space and Missile Systems Center and the Pentagon through posting of Air Force officers to those organisations.[68] Given the high level liaison required for identification and negotiation of collaborative agreements consideration should be given to posting Wing Commanders with appropriate domain experience in space systems or acquisition.

Other Areas of Collaboration. There are many other domestic and international organisations that Defence could collaborate with on the acquisition of space related capabilities. A list of potential organisations that Defence might consider investigating collaboration on development of space systems is given in Annex B.

Commercial Space Opportunities Studies

The USAF is seeking industry recommendations and comments for developing a comprehensive strategy for integrating commercial space (ground segments and space segments) ventures into both the near-term and future Air Force space architectures. All commercial space ventures were encouraged to participate, including communications, launch, navigation, remote sensing, and satellite command and control. The CSOS team was to detail the operational effectiveness, cost, risk, and benefits of various options for each opportunity identified in order to establish a time-phased investment strategy. Commercial options were anticipated to occupy a continuum ranging from simply adopting commercial acquisition processes and using commercial sub-systems, to buying/leasing/operating commercial systems, procuring commercial services directly, and outsourcing to commercial vendors. The CSOS Team commissioned five separate panels to look at the following areas: 1) Remote Sensing, Surveillance and Meteorology, 2) Launch Services, 3) Navigation, 4) Communication, and 5) Range and Satellite Command and Control. As a result of CSOS Australia may have an opportunity to join, or learn from, the US military programs derived from the study findings.

Implications of Not Conducting Coherent and Planned Space Operations

It is almost certain that Defence reliance on space will grow and with it will come the need to have a well established and comprehensive system for managing the environment to maximise the effectiveness and efficiency of this medium. Defence space capabilities are currently developed and managed by individual functional areas and specifically formed offices. This approach is likely to lead to fragmented development of Defence space capabilities. There are limited windows of opportunity for collaboration. Missing these opportunities can create increased life cycle costs and potentially rob Australian industry of the potential to provide valuable support work that could lead to export work. Some of the implications of not planning for coherent space operations include:

- Loss of cost savings derived from the early recognition and use of commercial developed space capabilities.
- Potential to loose regional credibility because Australia has not been able to demonstrate active involvement in technology areas directly related to achieving a Knowledge Edge.
- Regional countries may gain faster more reliable access to information; obtaining a better ability to Observe, Orient, Decide, and Act; because of Defence's slow adoption of space related technologies.
- Continued under utilisation of space experienced personnel.
- Lack of appropriate space related training could mean personnel are not able to fully exploit space systems.

68 The RAAF currently has a Squadron Leader at the Space and Missile Systems Center (SMC) working at the GPS Joint Program Office. However, the scope of future Australian space programs is likely to require a significantly greater presence at SMC.

CONCLUSIONS

The stakes in space go beyond the strict definition of defence. They are national. Not to possess this capacity would affect the very status of the nation.[69]

Need to Support Operational Concepts

Space Policy Development and Implementation – A Vision for Space. Space operations cut across a wide range of Defence activities and the availability of data together with the development of new applications for space-based products is growing rapidly. Accordingly, the use and development of space should be planned at the highest level. Such a strategic approach would involve establishing and maintaining liaison between the ADF and other military and civilian users of space-based systems. An essential component of the strategic planning process is the articulation of a vision and range of policies for the use, development and exploitation of space-based systems. The vision and policies should provide the framework and guidance within which the other elements of Defence will operate and give direction to development and application of a coherent space support system. An effective strategic direction framework will enhance priority determination and associated resource allocations, promote synergy and cohesion between traditional and space-based systems, and ensure that future relevant space technological developments are considered for use across Defence. The space operational concepts given in this paper could be the first step in developing clear and coherent guidance for achieving space superiority.

Carriage of Space. A single organisation should have carriage for space within Defence. As space is a logical extension of the air environment a strong case should be made for Air Force being given responsibility for the space environment. However, Air Force must be aware of the breadth of this responsibility and the resource implications before space becomes a core responsibility.

Technology Opportunities

During the period from 1998 to 2001 the US DoD will be undertaking fundamental changes to its space operations. These changes are occurring after significant research on the future of US space operations. New programs[70] and technological concepts[71] are being developed as a result of a change in strategic thinking and new technological developments arising from commercial and US DoD research[72] present significant opportunities for Defence as it defines its future space policy. To maximise these opportunities, Defence should ensure a close watch is maintained on technologies that will affect Australia's future space-related programs. Where appropriate, research centres of expertise should be developed in these technology areas.

Space Research and Development

Australia has unique research requirements caused in part by its geography, economy and regional threats. Foreign studies on space are not always directly applicable to Australia. However, overseas studies are likely to have canvassed many of the issues facing Defence and may only need tailoring to the local environments. By applying space studies to Australia, Defence could quickly derive an appreciation of the necessary action required to implement an Australian vision for space operations and research. In undertaking space research there should be an identifiable space focus in DSTO. Currently DSTO has a number of research areas that directly relate to the use of space; however, there is no central point of contact for space research and development. Defence should consider establishing a centre of expertise for space research and development within DSTO.

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69 Pierre Joxe, French Defence Minister, in *France: Emphasis of Defence Programmes Switches to Space Capability.*

70 Space based radar, hyperspectral and multi-role platforms, etc.

71 Nano and micro satellites and satellite clusters.

72 MEMS, Terahertz Program, etc.

Space Test and Evaluation

There is some expertise in Defence for testing space-related user equipment such as GPS receivers. However, there is no experience or expertise in testing and evaluating space launch systems or satellites. If Defence decides to acquire satellites or launch systems, early consideration should be made on developing a capability at ARDU to undertake the appropriate test and evaluation. Even if Defence does not decide in the short term to develop a full space test and evaluation capability, this capability should still be identified as a long term goal for a Defence Test and Evaluation Long Range Plan.

Collaboration

Collaboration on the development of space systems is considered essential. In the short term, immediate efforts should be undertaken to clearly understand US and Allied space programs. Australia needs to be proactive in identifying collaborative programs that will be consistent with its Defence space policy. Early identification will enable Defence to attempt to influence the requirements of the collaborative programs in favour of Australia. If Defence waits to be asked to join then it will have less chance to vary the fundamental system design to reflect possible unique Australian requirements.

Industry Involvement

Significant local benefit could be derived from early involvement of Australian industry in space-related projects. An overarching plan for Defence space activities, operations and acquisitions will enable the development of a Defence Space Industry Policy. This policy should enable Australian companies to harmonise their space-related research with Defence's long term goals for space.

Defence Interfaces with National and International Bodies

There is a strong need for Defence to coordinate its space policy requirements with both national and international organisations.[73] The rapid advances being made by commercial corporations mean that there is increasing pressure to encroach on traditional military capabilities. Defence needs to be aware of future civilian requirements, and where necessary act to defend its position. There may also be synergistic benefits from Defence involvement with external organisations.

Space Training

Development of future space capabilities will require a cadre of experienced personnel to plan, acquire, manage and operate these capabilities. Syllabi for standard space training across all three Services should be developed to ensure Defence members acquire a common understanding of space systems, their capabilities and vulnerabilities. In addition, staff with space systems experience should be identified to enable appropriate utilisation of their limited skills.

Consequences of Not Actively Managing Space

Some of the implications of not planning for coherent space operations include:

- Loss of cost savings derived from the early recognition and use of commercially-developed space capabilities.
- Potential to lose regional credibility because Australia has not been able to demonstrate active involvement in technology areas directly related to achieving a knowledge edge.
- Regional countries may gain faster more reliable access to information, obtaining a better ability to Observe Orientate Decide and Act, because of Defence's slow adoption of space related technologies.
- Continued under-utilisation of space experienced personnel.

73 Liaison should be done with both civil and military organisations.

- Lack of appropriate space-related training could mean personnel are not able to fully exploit space systems.

Areas Requiring Additional Study

Defence needs to undertake additional space-related studies to be able to choose what it needs for the 21st Century rather than relying solely on research conducted for the US DoD and other Allied militaries. Studies should be conducted on the following topics.

- Development of a Database of Australian Space Activity.
- Liaison with International Programs.
- Collaboration on Regional Space Systems.
- Development of Australian Pico to Micro Satellites.
- Development of a Defence Satellite Launch Capability.

RECOMMENDATIONS

Recommended Studies

The limited time available to complete this paper meant that only a cursory review was possible of a number of areas. Many of these areas are of significant importance to future ADF space operations. It is recommended that additional studies be undertaken on the following topics:

1. Investigate international programs that could support a revolutionary jump in future capabilities.
2. Review potential regional collaboration for common space systems, for example an equatorial LEO radar satellite program or joint military communication satellites.
3. In order to cater for Australia's unique requirements associated with space-based capabilities, caused in part by its geography and economy, the results of overseas studies need to be reviewed and modified. Currently DSTO has a number of research areas that directly relate to the use of space; however, there is no central point of contact for space research and development. Defence should consider establishing a centre of expertise for space research and development within DSTO to act as a single point of first contact and centre of coordination.
4. Review Australia's commercial space activities to determine the benefits of possible early participation in those programs, and where appropriate consider Defence funding.
5. Investigate the development of Australian Pico, Nano and Micro satellites to complement Defence communications and ISR.
6. Further investigate the potential for development of a capability to launch military Nano and Pico satellites from Australia, including consideration of the application of hypervelocity engine technology.

Action Implementation

The lack of a coherent Defence space policy over the last decade has meant that Defence is not ready to make fully informed decisions that will affect its fundamental approach to future space operations. There is an immediate need to undertake additional research associated with space operations. It is recommended that Defence commence a formal review of its requirements for space operations. This review should also recommend a single service for the carriage of space responsibilities.

ANNEX A
FUTURE FORECASTING - ORACLE 2030

Regardless of what the future will look like, change will be necessary. In May 1998 the Royal Australian Air Force commenced 'Project Oracle 2030', a study effort intended and designed to gain an insight into the future by use of Alternate Futures Planning Methodology. This methodology involves the creation of a range of possible futures or scenarios at the vision horizon of 2030, and the exploration of these futures for their significance for the RAAF. The aim of the project is to ensure the RAAF of the future is prepared to conduct and sustain effective operations to promote Australia's security and interests. Phase One of the project involved the development and initial exploration of plausible future environments. This will enable the RAAF to formulate broad strategies to counter the risk of strategic surprise inherent in what will be a diverse and unclear future. Phase Two of the project will further develop the planning challenges and strategic issues arising from the scenarios.

The RAAF has retained the services of Toffler Associates, a strategic advisory firm founded and led by the futurists Alvin and Heidi Toffler, to assist in Project Oracle 2030. The project is an innovative and exciting one, and allows the RAAF to look thirty years into the future. Through the course of Phase I of the project, interviews and workshops were undertaken with a wide range of personnel internal and external to the RAAF. One of the first tasks was to develop a focal question that would encapsulate the key issue(s) and focus for the study. The development of the focal question relied on several fundamental components, including the use of a Future Value Analysis Model. This process was used to elicit the key values of senior RAAF decision-makers and actors in other relevant communities. It was decided that the focal question to be addressed throughout the project would be: 'What are the future activities and force qualities that enable aerospace power to enhance Australia's security and international interests in 2030?'

The next step of the project involved the identification of key drivers that will affect Australia in the future. A significant amount of research was undertaken to determine what the potential drivers for the future could be. Through this process 12 main groups of ideas were identified, ranging from the environment, to social dynamics and regional relations. These were subsequently synthesised into three drivers.

Perhaps the most salient insight in the course of this component of the analysis relates to the importance of the combination of environmental, population and economic considerations. These three idea groups coalesced to form the driver known as Ecothropism.[74] A second driver group, Connect-Ability,[75] consisted of social dynamics, human values and microeconomics-related considerations. The third driver, Regional Powershift,[76] consisted of a cluster of ideas emerging around the topic of regional relations.

These three drivers serve as the foundation for Phase One of the project. Each alternative future world was created according to the level of driver impact. Eight possible worlds were identified depending on whether: Ecothropism was integrative or dissipative, Connect-Ability was stronger or weaker, and Regional Powershift was fast or slow. These extremities determined the characteristics and features of each alternate future world.

The process of identifying and developing the eight alternate future worlds involved several components, including seminars and discussions with a contact group. The naming, selection and development of the worlds were reviewed by CAF and DCAF. Four of the eight worlds were selected according to how challenging they would be to inform RAAF strategic planning. The four worlds that were eventually selected were named Rainbow Dynamo, Splendid Isolation, New Balance and Dissonant Arcadia.

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74 The name 'Ecothropism' is derived from the 'Anthropic Principle', which refers to the observation that many of the fundamental constants of nature are uniquely balanced to support and sustain human life. Thus, Ecothropism refers to the balance that emerges among the environment, population and economics.

75 Connect-Ability specifically refers to the will and ability of Australia and Australians (ie. desire reflected in capacity and actions) to be actively inter-connected on a variety of levels with each other, with other actors in the Asia-Pacific region, and with other actors throughout the world.

76 Regional Powershift has to do with power in the Asia-Pacific region and the implications of how the definition and exercise of power is changing.

There are a myriad of possible ramifications and implications for the RAAF arising from the scenarios described in each of the four worlds. In 'Rainbow Dynamo' the predominance of the nation state is waning. Australia is a vibrant actor in the region and throughout the world. Change is constantly occurring, and the RAAF and the ADF are affected by these major changes and by technological advances. In fact, the force bears little resemblance to that of the twentieth century.

In 'New Balance' Australia is very much in order. Australians are extremely passionate about connecting within the continent and externally, and many young Australians have migrated overseas. The population has declined as a result. The RAAF has a large task in terms of planning and strategic issues.

'Splendid Isolation' represents Australia as a country that is unwilling to be connected with the rest of the world. Consequently, Australia takes little action and exerts little influence in regional affairs. Due to the nation's withdrawal from regional interests, the Australian military has returned to a 'Continental Defence' focus. ADF planners are wary of the outside world and are predominantly a watch-look-listen force.

'Dissonant Arcadia' is a world of disharmony and contradiction. Australians are extremely focused on the protection of the natural environment, yet there is little perception of or dedication to a common good. The Australian people are disconnected from one another, and live in 'high-tech' and 'low-tech' enclaves. The absence of unity and balance is a challenge for the RAAF and the ADF.

The RAAF does not believe that the real future will be like any of the notional future worlds. The Chief of Air Force, Air Marshal Errol McCormack, said, 'Project Oracle 2030 is not designed to predict the future. It is designed to reveal a wide range of plausible environments which will equip the RAAF with the necessary knowledge to stimulate strategic thinking and planning for the future'. Whatever the future becomes, it will not be as exactly as described by any of the alternate future worlds that the exercise identifies. The process of long-range planning for the RAAF is not about predicting the future but rather about illuminating the full range of credible future operating environments that might come to pass, and the different kinds of capabilities and force qualities that might be important. Through this important new endeavour, the RAAF will begin now to do the strategic thinking necessary to respond to emerging challenges in a future world certain to be very different from today.

The RAAF's functions and the way it operates will change by 2030. It can be anticipated that Project Oracle 2030 will have a significant impact on the RAAF's air power doctrines in the future. There is a need to continually develop our application of air power, and Project Oracle 2030 will provide the RAAF with the ability to apply potential problems and situations to policy, doctrine and operation procedures. The Chief of Air Force, Air Marshal Errol McCormack, said, 'together with other military and civilian authorities, the RAAF is responsible for monitoring and protecting a very extensive area of land and ocean. If the RAAF is to maintain this role in the future, then we need to undertake the necessary strategic thinking now'.

ANNEX B
AREAS OF COLLABORATION

Introduction

As space systems become more affordable and plentiful a myriad of organisations are investigating either using or acquiring various types of space systems. This annex aims to give an overview of some of the various organisations Defence might consider working with on space developments.

Australian Government

A number of Federal and State Government departments are actively involved in space-related programs. Defence has had some liaison with some of these departments; however, a review of Defence relationships with all potential stakeholders should be undertaken before completion of a Defence space policy. Collaboration with the following organisations is likely over the next decade:

- Department of Transport and Regional Services (Global Navigation Satellite Services Board, Airservices Australia, Civil Aviation Safety Authority, Australian Maritime Safety Authority).
- Department of Industry, Science and Resources (Space Policy Unit).
- Cooperative Research Centre for Space Systems.
- Cooperative Research Centre Sensor Signal and Information Processing.
- Commonwealth Science and Industrial Organisation.

United States Government

There are a large number of US Government organisations involved in developing space systems. Local contact at a number of key sites can help ensure Defence is aware of potential collaborative programs at a very early stage. Suggested locations for close liaison include:

- **Space and Missile Systems Center (SMC).** Most US military space programs are acquired by SMC. Program offices at SMC include: Space Based Radar, GPS, MILSATCOM, Space Based Infra-Red System, Defense Meteorological Satellite; Evolved Expendable Launch Program, Airborne Laser Program, and the Satellite & Launch Control Program.
- **Defence Advanced Research Projects Agency (DARPA).** A number of key technology programs are being conducted at DARPA, including MEMS and the Terahertz Program.
- **Air Force Research Laboratory (AFRL).** The USAF is undertaking a number of key programs at the AFRL, including hyperspectral sensor development.

Other International Government Opportunities

Australia should consider investigating the potential for collaborative programs on surveillance, communications and earth resource monitoring with the United Kingdom, Canada, France, Italy, and Japan. Regional countries should also be contacted to determine their level of interest in joint space programs. Space-based radar in the equatorial area could be very useful for monitoring illegal trade and ship movements.

Australian Industry[77]

Many Australian companies have been involved with space research and development. A number are subsidiaries of multi-national corporations that have extensive experience in space. Listed below are a number of companies that Defence could work with on future space projects.

- Auspace
- British Aerospace Australia

77 Note that the list is not exhaustive but only representative.

- Boeing Australia Limited
- CEA
- Electro Optic Systems

International Industry

Defence should also consider direct liaison with overseas companies involved with the manufacture of satellites, both large and small.