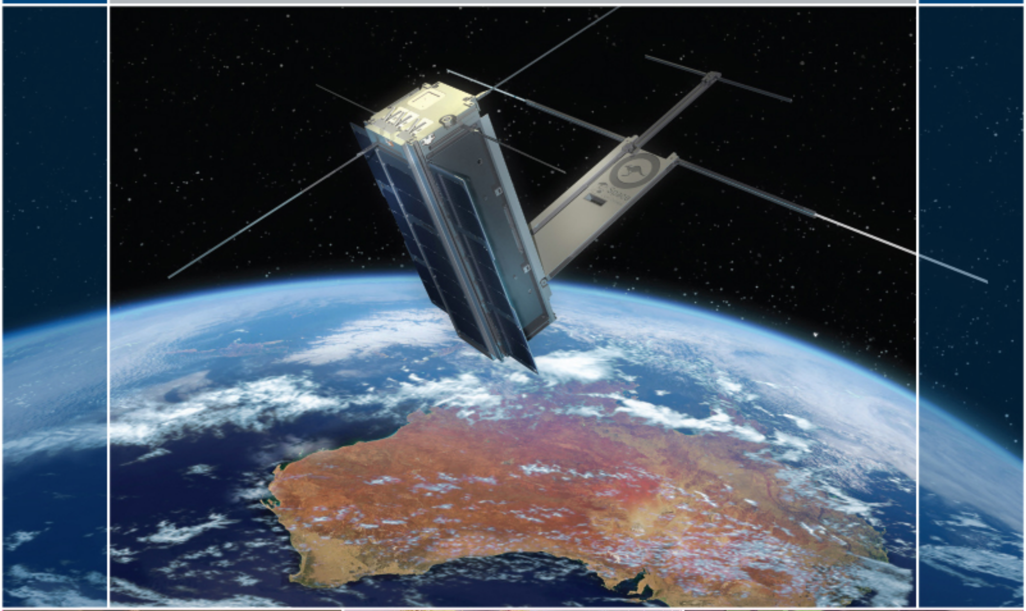
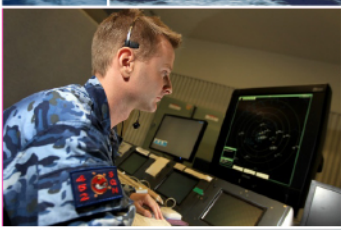
DOCTRINE NOTE SERIES

AIR-SPACE INTEGRATION

AFDN 1-19





AIR FORCE DOCTRINE PUBLICATION

2019

FOREWORD

Air and space power are critical to the conduct of Australian air operations in ADF joint warfighting. Space capabilities can be considered as a joint force integrator that enables joint force effects. Air Force is vectoring its force design efforts towards realising the networked 5th generation Air Force. The communications, intelligence, and networking functions of the 5th generation Air Force are critically dependent on the continued and assured access to space, space situational awareness, and space-based services.

The space domain exists beyond the altitude above the Earth where atmospheric effects on airborne objects are negligible. Space can be considered to be a separate operating domain to the air, land, maritime, and information domains, with its own unique defining characteristics, that shape and influence the designs for ADF combat systems and operations.

The Air Power Development Centre has prepared this doctrine note to enable members to understand the fundamental benefits and constraints of using space effects to support ADF operations. I encourage you to read this doctrine note with a view to better understand your role in a space-enabled military organisation. Empower yourself to contribute to the thinking and concepts that are regularly being reviewed to assure that the current and future designs for Air Force will continue to reliably deliver the air and space power needed in the Joint Force.

Air Commodore Stephen Edgeley, AM
Director General Strategy & Planning

February 2019

ACKNOWLEDGEMENTS

The information and knowledge presented in this handbook was gained from domestic sources that include the DST Group, Air Force Headquarters, and other Defence sources.

Information has also been provided through educational programs and exercises delivered to Air Force by Defence, US Air Force Space Command, Royal Military College of Canada, and the International Space University.

The Air Power Development Centre acknowledges the support provided by SQNLDR Michael Spencer for his research and subject matter expertise and Dr Neal Waddell for his editorial support.

Images used in this handbook have been obtained from various sources and incorporated for educational and informational purposes.

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HIERARCHY OF AIR FORCE DOCTRINE

Air Force doctrine is articulated in the Air Force doctrine hierarchy (see the graphic on next page) that encapsulates Air Force's philosophical, application and procedural doctrine. The Air Force doctrine hierarchy identifies four types of Air Force Doctrine publications (AFDP):

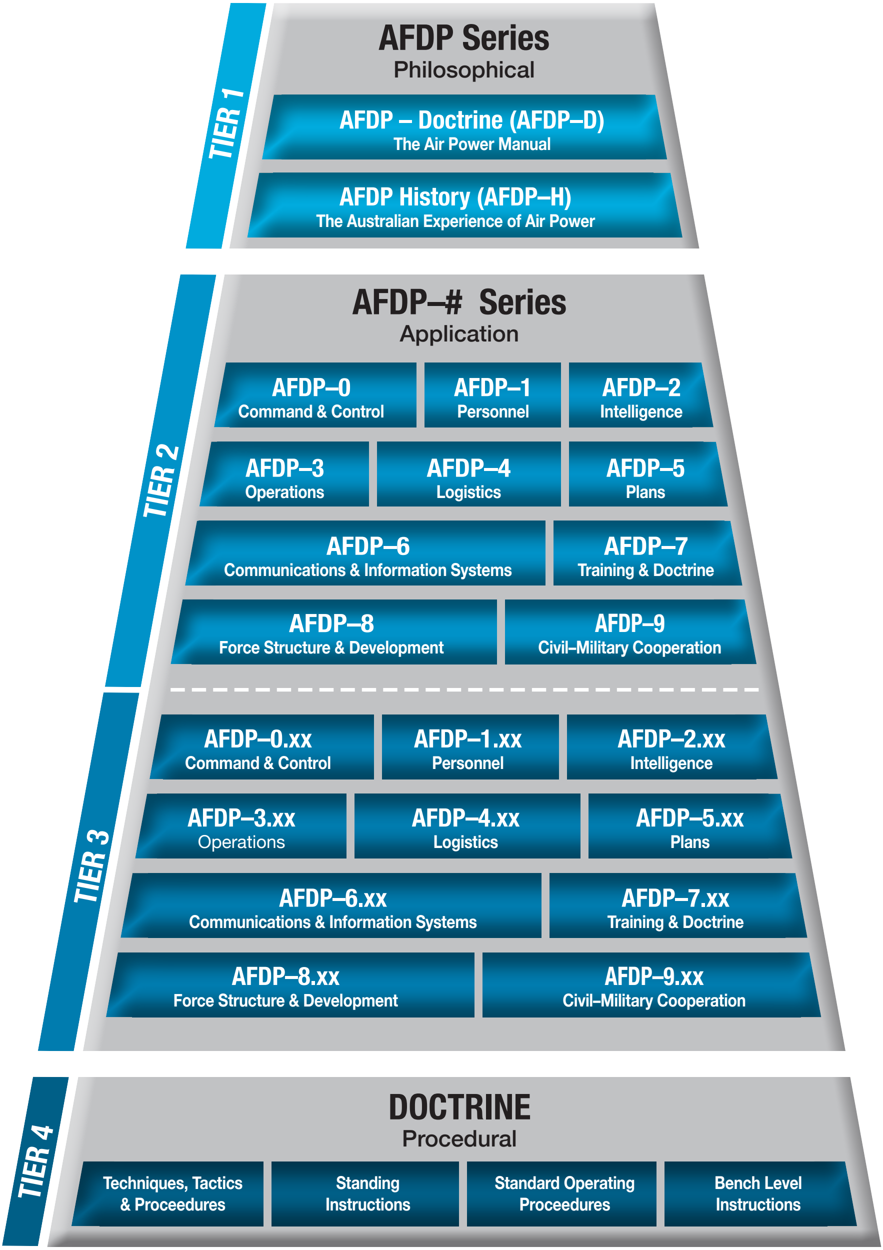
a. **Tier 1**: Philosophical/capstone doctrine explains broad fundamental principles in the form of the AFDP-D that describes the factors and conditions that shape Air Force and air operations. The AFDP-H support this by using historical examples.

b. **Tier 2**: Application/keystone level doctrine explains how the fundamental air power principles are applied. These doctrine publications are arranged by functional grouping and follow the common staff system nomenclature: Command and Control (AFDP-0 Series), Personnel (AFDP-1 Series), Intelligence (AFDP-2 Series), Operations (AFDP-3 Series), Logistics (AFDP-4 Series), Planning (AFDP-5 Series), Communication and Information Systems (AFDP-6 Series) Doctrine and Training (AFDP-7 Series), Force Structure and Development (AFDP-8 Series) and Civil-Military Cooperation (AFDP-9 Series).

c. **Tier 3**: Application doctrine subordinates the framework of functional groupings in Tier 2 and expands on the particular methods and processes that Air Force use to command, support and sustain air operations and is numbered accordingly (AFDP 0.X.X, AFDP 1.X.X).

d. **Tier 4**: Air Force procedural doctrine mainly comprises procedures and handbooks covering specific systems, equipment, or categories/ musterings, SOPs, TTPs, SIs and BLIs. Tier 4 procedural doctrine is locally authorised and controlled.

Air Force Doctrine Note (AFDN). An AFDN promulgates specific doctrinal matters that need to be formally articulated between major doctrinal reviews in the AFDP Series. AFDNs seek to inform and promote discussion on a specific doctrine subject and may not necessarily represent an agreed position. AFDN remain current for a limited time and are either then incorporated into approved doctrine or archived.


TIER 1
AFDP Series
Philosophical
AFDP – Doctrine (AFDP–D)
The Air Power Manual
AFDP History (AFDP–H)
The Australian Experience of Air Power
TIER 2
AFDP–# Series
Application
AFDP–0
Command & Control
AFDP–1
Personnel
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TIER 4
DOCTRINE
Procedural
Techniques, Tactics & Proceedures
Standing Instructions
Standard Operating Proceedures
Bench Level Instructions

INTRODUCTION TO SPACE

Australia's space history

1. In 1967, the Weapons Research Establishment Satellite (WRESAT) was the first Australian-made satellite to be launched into space, using the rocket launch facility at Woomera, South Australia. Australia became the fourth nation to launch a spacecraft into orbit, behind Russia, USA, and Canada, and the third to launch from its own soil. WRESAT was inserted into a low-earth orbit and operated for 14 days, so limited by battery life, on a mission to support upper atmospheric research. After 42 days in orbit, it completed over 630 orbits before re-entering the Earth's atmosphere.

2. Australia's domestic space policy changed direction in the 1970s. Australia has relied mainly on overseas providers for procuring payloads and launch services. Presently, Australia is responsible for 21 resident orbital space objects listed in the space catalogue and shown at table 1. Maintaining awareness of these objects, as well as others we rely upon for national security and prosperity, and their environment (including hostile systems), are important determinants for ADF capability needs for space situational awareness, assured space access and space security.

3. Australia's space infrastructure depends heavily on services owned and delivered by domestic and international commercial providers, and US military systems and cooperative arrangements. Australian space-related capabilities depend on a range of international collaborations and by purchasing products and services in the domestic and global market place.

Space Object Count	Resident Space Object	User	Mission	Launched	Orbit	Status
-	WRESAT	Civil	Science	1967	Decayed 1968	-
1	OSCAR 5	Amateur	Amateur Radio	1970	LEO	Expired
2	OPTUS A1	Commercial	Communications	1985	Graveyard	Expired
3	OPTUS A2	Commercial	Communications	1985	Graveyard	Expired
4	OPTUS A3	Commercial	Communications	1987	Graveyard	Expired
-	OPTUS B2	Commercial	Communications	1992	Launch Fail 1992	-
5	WESTPAC	Commercial	Science	1998	LEO	Operational
6	OPTUS B1 Rocket Booster	Debris	Launch Phase	1992	HEO	Expired
7	OPTUS B1	Commercial	Communications	1992	Graveyard	Expired
8	OPTUS B3 Perigiee Kick Motor	Debris	Launch Phase	1994	HEO	Expired
9	OPTUS B3	Commercial	Communications	1994	Graveyard	Expired
10	FEDSAT	Civil	Science	2002	LEO	Expired
11	OPTUS C1	Commercial/ Defence	Communications	2003	GEO	Operational
12	OPTUS D1	Commercial	Communications	2006	GEO	Operational
13	OPTUS D2	Commercial	Communications	2007	GEO	Operational
14	OPTUS D3	Commercial	Communications	2009	GEO	Operational
15	OPTUS 10	Commercial	Communications	2014	GEO	Operational
16	SKY MUSTER	Commercial	Communications	2015	GEO	Operational
17	SKY MUSTER 2	Commercial	Communications	2016	GEO	Operational
18	INSPIRE-2 (QB50)	Research	Science	2017	LEO	Operational
19	SUSAT (QB50)	Research	Science	2017	LEO	Operational
20	UNSW-ECO (QB50)	Research	Science	2017	LEO	Operational
21	BUCCANEER RMM	Research	Science	2017	LEO	Operational

Table 1 - Australian-owned orbiting objects listed in the US Space Situation Report.

Users of the space domain

4. Traditionally, planned air operations were intended to establish control over the airspace above the operational battlespace as a crucial military objective for enabling mission successes in the air, land and sea environments. The space domain's increased perspective of the battlespace further enables capabilities to extend beyond the terrestrial horizon. Exploiting the benefits of space-based systems enables long range secure satellite communications (SATCOM); precision manoeuvre and strike using global navigation satellite systems (GNSS), eg Global Positioning System (GPS), and an information advantage from intelligence, surveillance and reconnaissance (ISR) satellites.

5. Employing space effects technology and the size of such a coverage area requires thinking that may not logically extend beyond what was traditionally used to operate airpower. Space power needs to be considered differently, but integrated with, air power when developing operational plans, military systems, and international laws.

6. Military planners would typically plan and manage air operations in airspace to control air movements to meet necessary military objectives. Through combining procedural controls with military force enables control of the air, typically by managing the ingress and egress of assets in an operational area. According to international law, unlike the sovereign airspace that any nation uses to conduct its air activities, the space environment must be free of sovereignty and thus available to all nations.

7. The horizontal and vertical spread of space technologies has enabled many nations and interest groups to access and exploit the space domain. Because the ADF shares space with other nations, it should operate its space missions with due regard to the benefits available from cooperation and how the ADF might offer collateral effects to other space missions. Typically, employing space is shared between user groups who, despite being distinctive, also share common needs, interests, and dependencies on space systems and services:

a. **National security users**. Those government agencies that pursue space programs to satisfy national strategic goals, including national security. This includes militaries and the intelligence community conducting missions that typically include satellite communications (SATCOM), positioning, navigation and timing (PNT), ISR, space situational awareness (SSA), environmental monitoring (weather), and space control (or counter-space).

b. **Civil users**. Those government agencies that are not engaged in national security space activities, which may include space exploration, research and development, science and technology, weather, and communications, amongst others.

c. **Commercial users**. Refers to profit-making companies that provide services in, from, or are enabled by, space. These services involve communications, broadcasting, and remote sensing. It is important to note that government agencies, including national security, typically rely heavily upon commercial actors to augment their space systems, especially satellite communications, and increasingly for ISR as commercial capabilities reach, or even surpass, government capabilities.

d. **Other users**. As space becomes more accessible through the decreasing cost and complexity of satellites, systems, launch and operations, there is an increasing number of 'other' users that include academic and amateur actors, eg Radio Amateur Satellite Corporation (AMSAT) and the California Polytechnic State University CubeSat Standard. Most of these use space for training, education and experimentation.

8. Despite the vastness of space, it is rapidly becoming very crowded, especially in low-earth and geostationary orbits. In addition to many satellites, the space debris orbiting the Earth has greatly increased. This debris, comprising natural and non-natural space matter, increasingly risks colliding with and damaging satellites:

a. **Natural space debris** comprises passing asteroids, comets, micrometeoroids and cometary debris that have been captured by the Earth's gravitational pull and have entered a permanent geocentric orbit.

b. **Human-made orbital space debris** typically comprises non-functional systems such as derelict spacecraft, the result of spacecraft or upper-stage explosions or collisions, and tiny paint flecks released by thermal expansion, contraction or colliding with larger space objects. Functional debris usually results from launch vehicle upper stages that fail to re-enter, items intentionally released to enable spacecraft separation from its launch vehicle, or arming wires and lens caps jettisoned during mission operations.

9. It is important for space actors to acknowledge their responsibilities and accountabilities for their behaviours in space, including ownership for space objects originating from their space mission. The 'Liability Convention' describes the internationally agreed rules for the liabilities of space actors involved throughout the life cycle of a space mission – from launch through to disposal.

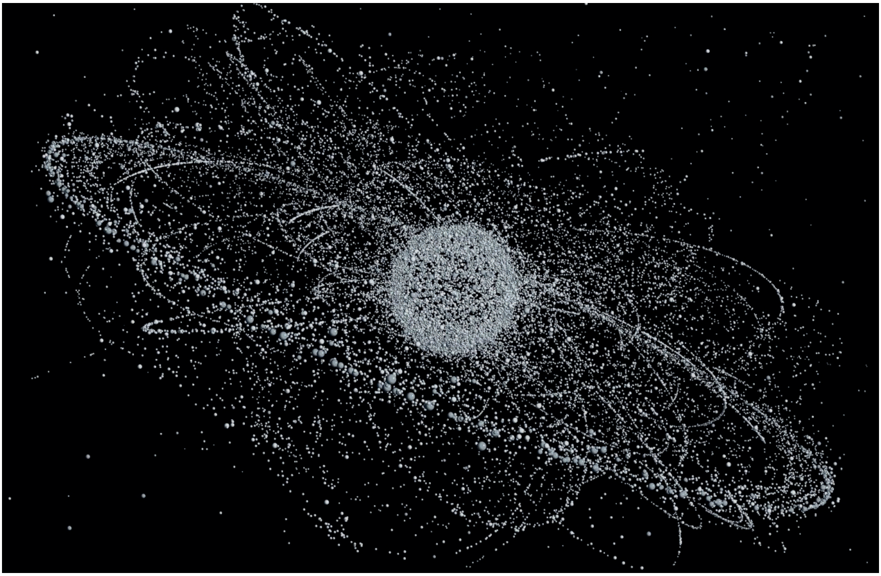

Figure 1 - Artist's depiction of the orbital debris field (objects not to scale)

THE SPACE DOMAIN

The space environment

10. While there is no internationally-recognized legal definition, the boundary that distinguishes space is generally accepted to begin at the Karman Line, at 100 kilometres altitude, named after Theodore von Karman. He calculated that, close to this altitude, the speed required to generate sufficient aerodynamic lift to enable flight in the rarefied air is faster than the speed necessary for an object to remain in orbit . Figure 2 depicts the nature of air and space activities operating at different altitudes.

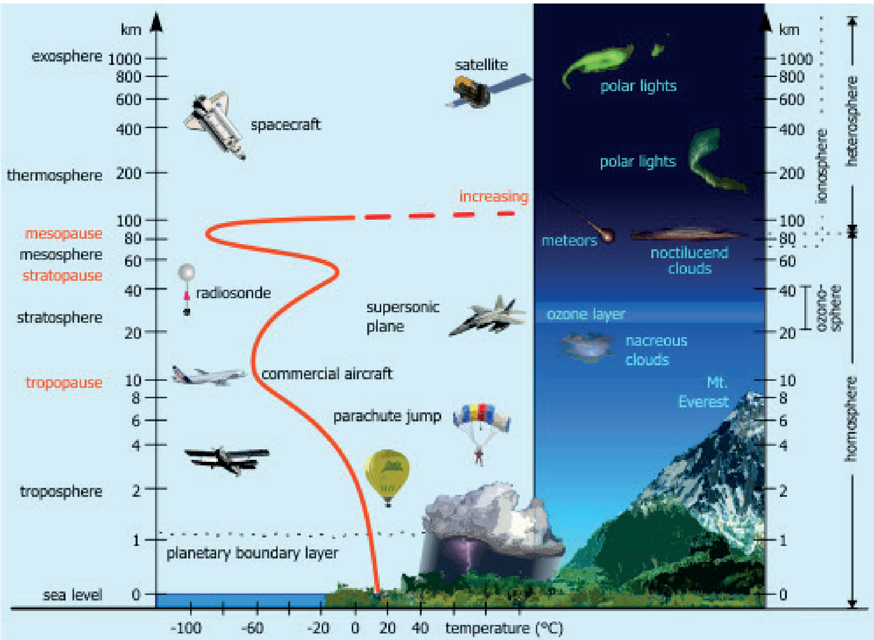

Figure 2 - Air and space activities in the Earth's atmosphere.

11. In accord with international treaty, sovereignty cannot be exercised in space therefore the laws that apply to overflights by reconnaissance aircraft and aircrew do not apply to spacecraft and astronauts operating in space.

12. The Earth is bombarded daily by more than 100 tons of dust and sand-size particles. The atmosphere provides some protection from space hazards to terrestrial activities. It filters cosmic and solar radiation to protect terrestrial life and causes micro-meteorites to burn up before reaching the Earth's surface.

13. Although satellites operating outside the Earth's atmosphere need not consider the effect of wind and atmospheric weather, the effects of space weather do need consideration. Space weather deals with phenomena derived from ambient plasma, magnetic fields, cosmic radiation, solar radiation pressure, solar eclipses and thermal changes, and micrometeoroids. All these effects significantly impact upon the design and operation of a spacecraft to ensure that it survives.

Types of satellite orbits

14. An orbiting spacecraft has its forward movement offset by the pull of the Earth's gravity. Once in stable orbit, free from any significant drag, the spacecraft will remain in orbit unless acted upon by an unbalanced force, such as on-board thrusters or solar radiation pressure. A stable spacecraft will remain in an orbit of fixed dimensions and its orbital speed determines its orbit altitude. Increasing the speed of an orbiting spacecraft will cause it to move to a higher altitude orbit and decreasing the speed has the opposite effect. Figure 3 is a useful perspective to review availability and access to spacecraft from ground locations.

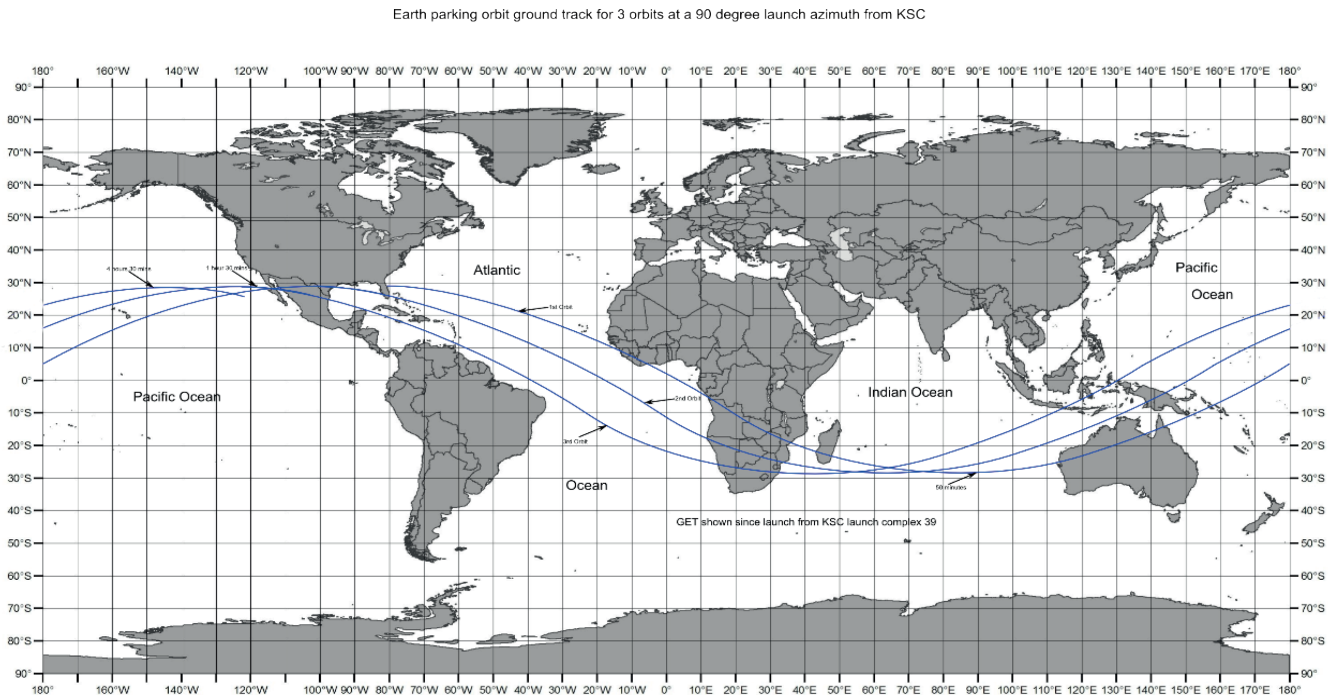

Figure 3 - The ground track view is a useful perspective to review availability and line of sight to the spacecraft.

15. **Low-earth orbit (LEO)**. As shown in figure 4, LEO orbits lie between 150 and 2000 km, but most commonly from 500 to 800 km, with an orbital period of about 90 minutes. LEO are described as:

a. **LEO polar sun-synchronous**. A LEO orbit that crosses both poles in a single orbit and passes all latitudes at the same local solar time each day (through a combination of proper altitude and inclination). Orbits lie within 20 degrees of a 90-degree inclination from the equator. To maintain this synchrony, the orbital plane must rotate about 1 degree per day. The sun-synchronous orbit also includes the dusk-dawn orbit where the spacecraft does not pass into the Earth's shadow.

b. **LEO polar non-sun-synchronous** refers to a LEO polar orbit that does not relate latitude passes to the solar time.

c. **LEO inclined non-polar**. A LEO orbit is one with an inclination angle of less than 70 degrees. Platforms in "inclined non-polar" orbits are not sun-synchronous. For example, the International Space Station is in a 550 km LEO orbit inclined at 51.6 degrees.

d. **LEO retrograde orbit**. An orbit inclination of greater than 90 degrees would mean that the satellite is in a retrograde orbit where part of the motion of the spacecraft is opposite to the Earth's rotation. The launch effort requires significantly more energy to insert a payload into orbit in a retrograde direction compared to a prograde orbit.

16. **Medium-earth orbit (MEO)**. MEO orbits lie between 2000 km to 35,786 km, but most commonly at 20,200 km or 20,650, with an orbital period of 12 hours. Note that the Van Allen Belts of high energy protons lie within the MEO orbital ranges.

17. **Geosynchronous orbit (GSO)**. The orbital period of a geostationary orbit coincides with the direction and period of rotation of the Earth. The spacecraft will appear to the observer always in the same area of the sky. However, it may appear to be ascending and descending in altitude about an average point in the sky due to the orbit's inclination

angle and eccentricity[1]. The GSO is used to enable stacking of spacecraft situated above and below geostationary spacecraft, and relieve orbital congestion.

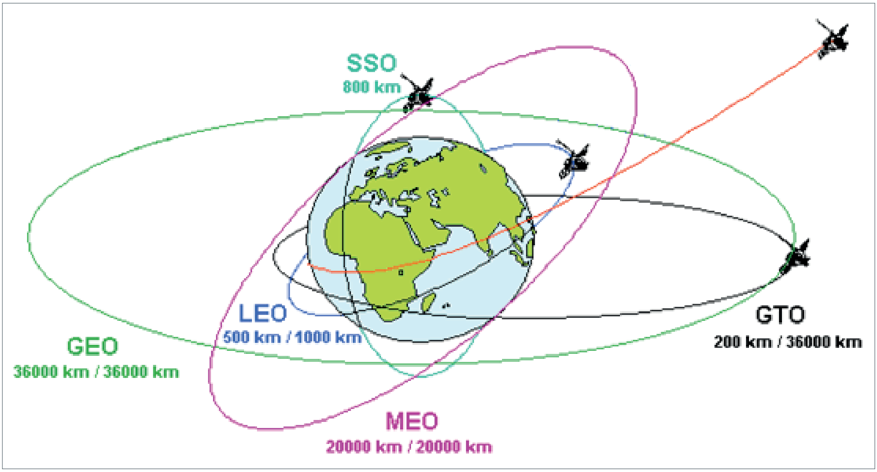

Figure 4 - Commonly used spacecraft orbits.

18. **Geostationary-earth orbit (GEO)**. At an altitude of 35,786 km, GEO is a special case of geosynchronous orbit. GEO describes a circular orbit whereby the satellite remains over the Earth's equator, ie its inclination and eccentricity are zero. In this orbit, the satellite has the same angular velocity as the Earth, and a period of 24 sidereal[2] hours.

19. **Parking or transfer orbit**. This describes a temporary orbit used during the launch phase of a spacecraft. A booster rocket enters the

1 Eccentricity refers to the shape of the orbit. A satellite with a low eccentricity orbit moves in a near circle around the Earth. An eccentric orbit is elliptical, with the satellite's distance from Earth changing depending on where it is in its orbit. https://earthobservatory.nasa.gov/Features/OrbitsCatalog

2 A sidereal day measures the rotation of Earth relative to the stars rather than the sun. It helps astronomers keep time and know where to point their telescopes without worrying about where Earth is in its orbit. https://earthsky.org/astronomy-essentials/what-is-sidereal-time

parking orbit with the payload, and is stabilised to conduct systems testing and activation checks before firing again to enter the final desired trajectory by which the payload is placed into the final desired orbit.

20. **Graveyard orbit**. A super-geosynchronous orbit located a few hundred kilometres above GEO where satellites are relocated after mission expiry to vacate the GEO orbital location for a replacement satellite.

21. **Highly Elliptical Orbit (HEO)**. HEO is an elliptical orbit with a low perigee altitude (within LEO) and a high apogee (outside GEO). These orbits have an inclination between 50 and 70 degrees and high eccentricities, like the Russian Molniya orbit. A Molniya is a semi-synchronous orbit, ie an orbital period of 12 hours, at the critical inclination of 63.5 degrees. HEO is popular for the Earth's magnetospheric measurements, astronomical observatories, and communications in high northern latitudes.

22. **Lagrange Point Orbits (LPO)**. A Lagrange Point is a location in space around a rotating two-body system (such as the Earth-Moon or Earth-Sun) where the pulls of the gravitating bodies combine to form a point at which a third body of negligible mass, for example a spacecraft, would be stationary relative to the two bodies. Growing numbers of spacecraft are being placed in LPO orbits between the Sun-Earth and the Earth-Moon. Characteristics of satellite orbits are described in table 2.

Orbital perturbations

23. Unbalanced forces exist in the space environment, which will act on the spacecraft and cause perturbations in the orbital parameters. These orbital perturbations become apparent with time delays in the expected satellite appearance times and changes in the orbit altitude. Furthermore, spacecraft are configured with on-board fuel-dependent attitude control and manoeuvring systems to maintain the spacecraft in the correct orbit. The finite fuel supply determines the useful mission life for the orbiting spacecraft under three conditions: if the space mission expires when the fuel is expended, if the spacecraft is prevented from maintaining its planned orbit, and if the spacecraft is allowed succumb to atmospheric drag and earth re-entry.

Orbit Type	Typical Inclined Angle (deg)	Typical Perigee Height (km)	Typical Apogee Height (km)	Typical Orbit Period	Orbits per Day	Typical Repeat Cycle (days)	Space Missions
Low Earth Orbit-Inclined	0 to 70	350 to 2,000	same as perigee	90 to 110min	13 to 15	3	Science, Earth Observation
Low Earth Orbit-Polar, Sun-Synchronous	85 ± 5	350 to 2,000	same as perigee	98 to 103min	13 to 15	1 to 45	ISR, Remote Sensing, Communications, Science, Earth Observation
Low Earth Orbit-Polar, Sun-Synchronous, Retrograde	95 ± 5	350 to 2,000	same as perigee	98 to 103min	13 to 15	2 to 45	ISR, Remote Sensing, Communications, Science
Low Earth Orbit-Polar, Non-Sun Synchronous	90 ± 20	350 to 2,000	same as perigee	90min	13 to 15	24	Science, Earth Observation
Medium Earth Orbit	various	20,000	same as perigee	12hrs	2	Varies	PNT, Communications
Geosynchronous Orbit	≠0	35,786	same as perigee	24 sidereal hours	1	n/a	Meteorology, Communications, Early Warning, Earth Observation
Geostationary Earth Orbit	0	35,786	same as perigee	24hrs	1	n/a	Meteorology, Communications, Early Warning, Earth Observation
Highly Elliptical Orbit	50 to 70	~1,000	> 35,786	12 or 24hrs	1 or 2	0.5 to 1	Communications, Early Warning

Table 2. Characteristics of typical operational orbits.

24. **Conservative forces** have a perturbing effect that depends on the position only of the orbiting spacecraft, and are typically attributed to:

a. variations in the Earth's geopotential resulting from its non-spherical shape.

b. variations in the Earth's gravity resulting from the uneven distribution of its mass, tidal effects from the ocean masses caused by the Moon, and tidal effects from the movement of mass within the solid Earth.

c. third-body interactions from outside the Earth-spacecraft situation and attributable to gravitational forces from third bodies such as the Moon and Sun.

25. **Non-conservative forces**. Non-conservative forces have a perturbing effect that is dependent on both the position and velocity of the spacecraft, creating unwanted drag and torque forces.

a. Aerodynamic drag is the pressure of the atmosphere affecting the spacecraft, especially in lower altitude orbits. This drag is greatest during launch and re-entry. The amount of solar activity can affect the atmosphere, causing it to expand and contract with the solar cycle.

b. Solar radiation pressure is a force applied to the spacecraft from the Sun, a pressure causing periodic variations in all orbital parameters. The intensity of the solar pressure depends on the level of solar activity.

c. Solar wind consists of particles ejected from the Sun, mainly ionised nuclei and electrons, thereby impacting upon the spacecraft and causing drag.

THE SPACECRAFT LIFE CYCLE

Defence Capability Life Cycle

26. The capability life cycle (CLC) is the 'end-to-end' approach that spans across Defence programs for the development and delivery of capability. The CLC is the process of introduction, sustainment, upgrade and replacement of a Defence capability. The process is owned by the Secretary and Chief of the Defence Force (CDF) on behalf of the Commonwealth; Vice Chief of the Defence Force (VCDF), as the chair of the Investment Committee, operates the CLC on behalf of the Secretary and CDF, and is the Joint Capability Authority accountable for strategy and concepts, future force structure, and integration of the joint force.

27. **Australian Defence Force Headquarters (ADFHQ) management of joint capabilities**. The ADFHQ organization has established a strategy-led and integrated approach to managing ADF capabilities. Under the ADFHQ implementation of CLC process, the authority and accountability for the delivery of different capability outcomes, including space-related capabilities, have been assigned to different individual Defence appointees, as follows:

a. **ADF Capability Managers**, distributed across the Defence programs, lead the deliveries of the capabilities within their programs; including raising, training, and sustaining assigned capabilities. The Capability Manager appointments are:

    i. Vice Chief of Defence Force - Joint

    ii. Deputy Secretary Strategic Policy & Intelligence –

    - Strategic Intelligence & Cyber Programs
    - Geospatial Intelligence & Information and Services

    iii. Chief of Navy - Maritime

    iv. Chief of Army - Land

    v. Chief of Air Force – Air & Space

b. **ADF Capability Stream Leads** co-ordinate the development of capabilities within their assigned capability streams, in order to balance joint capability across the Defence Portfolio. They also provide cross-program prioritisation advice to the Investment Committee, for their respective streams, to ensure joint force integration and interoperability. The Capability Stream Lead appointments and their assigned capability streams are:

   i. Chief of Joint Capabilities – ISREW, Space and Cyber

   ii. Chief of Air Force – Air & Sea Lift

   iii. Chief of Army – Land Combat & Amphibious Warfare

   iv. Chief of Air Force – Strike & Air Combat

   v. Chief of Navy – Maritime & Anti-Submarine Warfare

   vi. Chief of Joint Capabilities/Associate Secretary – Key Enablers

28. **Air Force capability management**. Deputy Chief of Air Force (DCAF) leads the coordination of Air Force doctrine, strategy, policy, capability and planning to determine current and future Air Force activities and priorities. Thus, DCAF leads future changes that affect, or are affected by, issues relating to Air Force responsibilities and resources to raise, train, and sustain Air Force resources.

29. **Space science and technology**. Defence Science and Technology (DST) Group is the lead government agency responsible for applying science and technology for Defence and national security. DST provides expert and impartial advice and support for the conduct of operations, for the current force and for acquisition of future Defence capabilities, including ground and space-based technology and systems for space missions.

Space capability life cycle

30. Defence is responsible for forecasting new requirements for capabilities that are needed for the future force and managing current requirements for existing capabilities that enable the current force to fulfil Defence outputs. Defence applies a philosophy for managing the introduction of a new capability, or a modification to an existing capability, in a process that is appropriate to the CLC phase. Figure 5 illustrates mapping the CLC to a space capability, which would comprise the following life cycle phases that are managed in a linear sequence:

a. **Strategy and Concepts**. This phase will identify and prioritise capability needs that are informed by assessing the ability of current Defence space capabilities to meet its missions as guided by strategy. This phase addresses both threats and opportunities: gaps in the ADF capability to perform a mission or a task; and opportunities to take advantage of, for example, emerging technologies to better perform a mission or task.

b. **Risk Mitigation and Requirement Setting**. This phase involves developing and progressing capability options through the investment approval process that leads the Government to decide to proceed to acquisition.

c. **Acquisition**. This phase involves placing a contract or agreement with industry and/or other partners to acquire the required capability, executing that contract, and introducing the capability into service. This phase thus involves launch, space, terrestrial (eg air, sea and land), and user segments.

d. **In-service and disposal**. The in-service and disposal phase involves supporting a capability throughout its in-service life. Disposal involves withdrawing the capability from service, managing the transition to any replacement, and ultimately disposing of the equipment, ie considerations for system-derived products, eg space-derived products and space-situational awareness data.

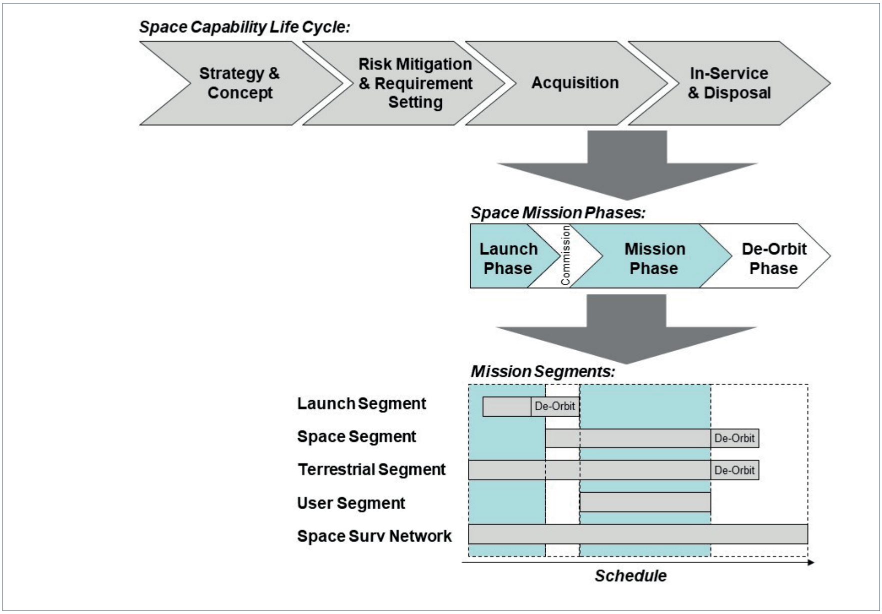

Figure 5 - Transformation of Space Capability Life Cycle into Space Mission Segments.

Space systems operations

31. The Space System Operation, illustrated at figure 6, can be considered as comprising four operational phases:

a. **Launch phase**. Launches are performed by a service provider. Spacecraft owners must design the spacecraft to comply with the launcher interface specifications. They thus ensure survivability in the shock, thermal, and vibration environments experienced during a launch. Launch vehicles are configured to carry one or two large satellites, and have options for inserting microsatellites into spare space in between. The launch vehicle inserts the dormant spacecraft into a temporary parking orbit. The spent stages are either manoeuvred into a controlled re-entry, or will succumb to atmospheric drag and re-entry to mitigate space debris. Launch vehicle technologies are:

i. ground launched multi-stage rockets,

ii. sea-launched multi-stage rockets,

iii. rockets launched from high altitude balloons,

iv. rockets launched from aircraft,

v. shuttle transfer systems, or

vi. parasite launch, ie for hosted payloads.

b. **Commissioning phase**. During this phase of complex space systems, the dormant spacecraft is activated, and subsystems are deployed and acceptance tested before being boosted into its operational orbit.

c. **Mission phase**. Once in this phase, the spacecraft is managed according to a mission schedule that allows for payload operations, system power re-charging (eg solar power), payload-data downlinking and telemetry, and ground-station uplinking of mission control commands. The spacecraft may need to conduct attitude changes to point communications equipment towards a ground station, which may prevent normal operations of the primary payload. Spacecraft may be designed to perform orbital manoeuvres and attitude changes to protect itself against environmental factors, collision avoidance, and station-keeping. Simulation and visualisation software tools support mission planning.

d. **De-orbit phase**. Typically, the mission expiry is determined when the fuel remaining for orbital manoeuvres reaches the minimum reserve required for a controlled de-orbit manoeuvre. Consequently, the spacecraft is either boosted into a higher graveyard orbit away from the more important operational orbit. Otherwise, retrograde thrust is used for a controlled re-entry and burn-up in the atmosphere. Other spacecraft in low-earth orbit succumb to uncontrolled re-entry caused by atmospheric drag.

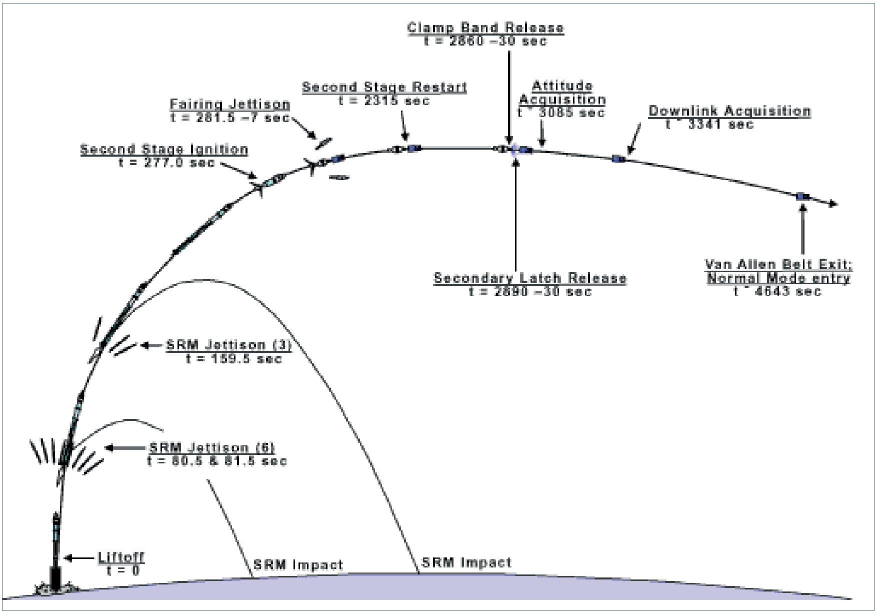

Figure 6 - Example launch ascent profile.

Space systems architecture

32. Space system architecture refers to how the people who undertake employed during the terrestrial, launch, space, and user segments use the equipment to coordinate tasks that achieve the space mission objective. A notional architecture is illustrated at figure 7 and comprises the following user segments:

a. **The terrestrial segment** of a space mission can entail satellite control networks, satellite communications terminals, satellite operations centres, geographically dispersed remote tracking stations/terminals, antennas, and networks to connect terrestrial elements, eg ground, air, and sea-based stations.

b. **The launch segment** occurs when the spacecraft is transported from the ground to its operational orbit. This segment entails the launch vehicle, launch insurance, launch-related ground support equipment, launch pad facilities, range safety systems, and launch control operations by the launch service provider.

c. **The space segment** of the space mission involves the spacecraft, post-launch manoeuvring system, and any other space-based systems needed to perform the identified tasks during the space segment. The spacecraft design typically comprises:

    i. **A satellite bus** designed to aid the satellite components to survive thermal, vibration and shock stresses experienced in the launch event and provide a structure that keeps all components connected and interfaced correctly.

    ii. **The payload** is the mission-specific component of the spacecraft and typically includes the sensors, radar, communications relay modules, and a science experiment.

    iii. **Telemetry, tracking & control subsystem (TT&CS)**. The satellite must regularly confirm its location and operations status to the ground station. Typically, a simple transponder beacon system enables a ground station to track the satellite, while TT&C commands are used to maintain the onboard systems and orbit.

    iv. **Electrical power subsystem (EPS)**. Solar panels are commonly combined with electrical storage cells to enable the EPS to provide a constant source of electrical power as the satellite travels the dark and sunlit parts of its orbit. LEO satellites have a greater need to use batteries, unlike GEO satellites that are exposed to the sun for substantially longer periods.

    v. **The propulsion subsystem** is fitted to propel the satellite into the final operational orbit when a mission begins and, at the end of a mission. At the end, this subsystem can be used in three ways: to boost the satellite into a higher graveyard orbit; to retard it so it re-enters the Earth's atmosphere for disposal, or for orbital station-keeping.

vi. **The communications subsystem** typically comprises transmitters, receivers and transponders or beacons to support all communications functions.

vii. **The thermal subsystem** regulates the temperature of the satellite's components using both passive and active mechanisms. The extreme and rapid temperature variations that occur in space can degrade the useful life of a satellite.

viii. **Attitude determination and control subsystem (ADCS)**. Depending on the mission, the satellite may need to maintain itself or a specific component in a specific attitude, eg pointing to the subpoint or towards the Sun. Attitude determination is typically managed using a gravitometer, magnetometer, earth horizon, and/or star tracker systems. Because its attitude may need to be corrected, a satellite often uses very small chemical or electrical thruster motors. A satellite also make small manoeuvres to maintain itself in the correct orbit when either atmospheric drag, magnetic fields, or the solar winds move the satellite out of its correct orbit.

ix. **The navigation subsystem** enables a spacecraft's position to be accurately determined. Typical systems employ GPS, GNSS, earth mapping, astrometry and star trackers.

x. **The life support subsystem (LSS)** assists any human occupants to perform a prescribed space mission by providing a managed environment to control pressure, temperature, radiation shielding, lighting, food and water. LSS may or may not collect, dispose, or reprocess waste products such as carbon dioxide, water vapour, and human waste. It may also include an armour-plated enclosure to shield against space debris.

d. **The user segment** of the space mission describes the collection of organised entities and individuals who use and control the space segment payload and its products. This segment can entail the data-receiving and processing equipment, the raw or processed data, and the distribution system used to transfer the data to the user.

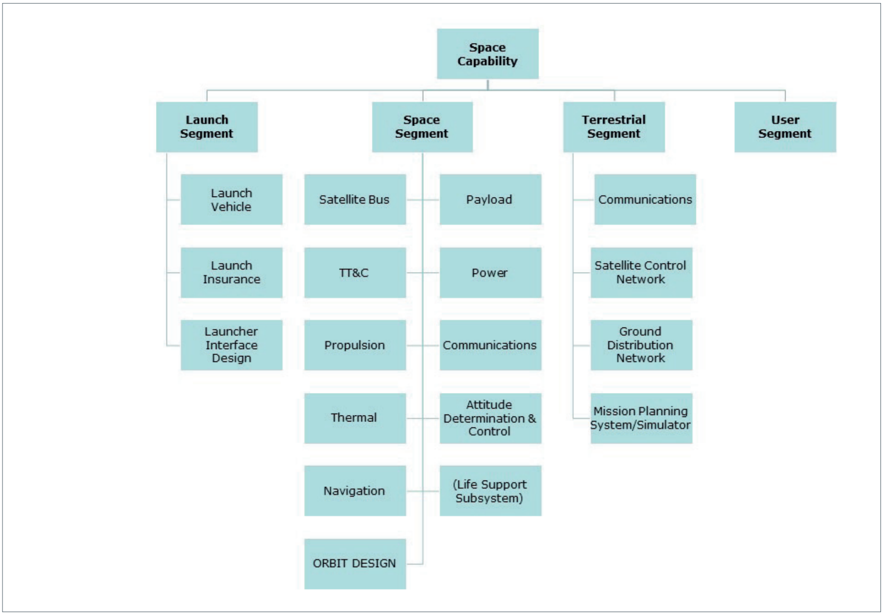

Figure 7 - Example spacecraft system architecture.

Spacecraft categories

33. Spacecraft can be categorised varyingly, including user type, mission, wet/dry mass:

a. **Spacecraft categories by user**. Spacecraft missions and designs can be categorised by the profiles of the user:

   i. **National users**. National users represent the state owners of space assets. They involve government and military organisations that typically achieve space effects and enable space research, eg Bureau of Meteorology, Geosciences Australia, CSIRO, NASA missions, COSPAS-SARSAT, InMarSat, Tracking & Data Relay Satellite.

   ii. **Commercial users** describe users who employ space systems for profit-making, eg Optus, Intelsat, Iridium.

iii. **Civilian/amateur users** seek to promote engagement in space interests and the utility of space, eg Amateur Satellite Corporation, and University CubeSat Programs.

b. **Spacecraft categories by mass**. Being categorised by mass is useful because it relates directly to launcher capability and cost. Table 3 shows a commonly used scheme for categorising spacecraft by the mass deployed into orbit. The listed masses refer to the fully-fuelled, ie wet mass configuration, where the satellite includes an onboard propulsion or manoeuvring system and fuel store. Satellite miniaturisation can reduce the program cost: heavier satellites require larger launch vehicles at higher costs; and smaller and lighter satellites require smaller and cheaper launch vehicles. The smaller, lighter spacecraft can sometimes be launched together as multiple units in a launch payload by being configured to rideshare in the spare space in or around a large payload satellite, or as a hosted payload mounted onto the mainframe chassis of a large satellite in a 'piggyback' configuration.

Satellite Size	Wet Mass (kg)
large satellite	> 1,000
medium satellite	500 to 1,000
mini satellite	100 to 500
micro satellite (microsat)	10 to 100
nano satellite (nanosat)	1.0 to 10.0
pico satellite (picosat)	0.1 to 1.0
femto satellite	< 0.1

Table 3. Satellite classes by wet mass (ie including fuel).

c. **Spacecraft categories by mission**. Table 4 lists missions commonly performed by spacecraft. A spacecraft may be designed to perform one or more missions concurrently for one or more users. Each mission has unique requirements that call for different component capabilities in the spacecraft design.

Mission	Mission Type	Typical Orbit	Key Payload Design Requirements
Missile Warning	Military	HEO/GEO	Sensor matched to missile signature, staring sensor, coverage area, COMMS antenna pointing, and navigation.
Communications & Broadcasting	SATCOM	MEO/HEO/GEO	Beam-shaped antennas, antenna pointing.
Communications Relay	Military	LEO/GEO	Antenna pointing, navigation, bandwidth.
Disaster Surveillance	Rem Sens Science		Sensor pointing, coverage area, navigation, COMMS.
Earth Observation	Rem Sens Science	LEO/GEO	Sensor/observation matching, sensor pointing, data store.
Earth Weather	Science	LEO/GEO	Sensor pointing, data store
Global Navigation Satellite System	Military PN&T Science	MEO	Space navigation, accurate clock, coverage area.
Intelligence, Reconnaissance & Surveillance	Military	LEO	Sensor matched to target signature, attitude control, pointing sensor, navigation, COMMS antenna pointing, data store, high data rate & wide bandwidth COMMS.
Interplanetary Exploration	Science	Deep space	Autonomous operation, pointing COMMS antenna, space navigation, non-solar power, propulsion, long mission life.
Manned Space Flight	Science	LEO	Life support system (eg, ISS, transfer vehicle).
Nuclear Detonation Detection	Military	LEO/MEO/HEO/GEO	Sensor match to detonation signature, staring sensor, coverage area, navigation
Scientific Research	Science	LEO	Payload design, orbit design, data storage.
Search & Rescue	SATCOM	LEO/MEO/GEO	Coverage area, navigation
Space Weather	Science	LEO, Lagrange & heliocentric	Pointing sensor, navigation
Space Based Surveillance	Military Science	LEO/GEO	Pointing sensor, navigation, target ephemeris, pointing COMMS antenna.
Space Telescope	Science	LEO	Attitude control, pointing sensor, navigation, target ephemeris, high data rate & wide bandwidth COMMS.
Spacecraft Disposal	All types	Super-LEO; Super-GEO	Propulsion

Table 4. Summary of typical space missions and design characteristics.

1967 launch of the Australian WRESAT from Woomera, South Australia.

OPERATIONAL APPLICATION OF SPACE

Types of satellite missions

34. Satellite designs can be categorised according to the six space missions that satellites undertake: scientific research; weather observation; satellite communications; position, navigation and timing; Earth observation; and military purposes.

Scientific research

35. Scientific research missions have satellite payload data for analysis. These missions are usually designed to:

a. gather information about the composition and effects of space near the Earth that affect its climate and weather, and the orbits of satellites.

b. record temporal changes in the Earth and its atmosphere.

c. observe near-earth objects, asteroids, planets, stars, and other distant objects.

d. test and evaluate the performance of new space systems and technology.

Terrestrial weather observation missions

36. Spaceborne Earth observations primarily support the study and predictions of terrestrial weather. Satellite-based sensors have the benefit of observing atmospheric conditions over large global areas and where weather information may not necessarily be accessible from local sources. Onboard instruments can measure cloud cover, temperature, air pressure, precipitation, surface wind, and the sea-state and chemical composition of the atmosphere.

Figure 8 - Minister for Defence, Senator Marise Payne, reviews the Buccaneer satellite built by DST Group and UNSW for space-based calibration experiments with Jindalee Operational Radar Network.

Satellite communications

37. Communications satellites serve as relay stations that enable surface, air and space systems to communicate over the horizon. A communications satellite function of receiving transmission signals uplinked from one location and then downlinking them to another occurs on the ground, in the air, or in space. A single communications satellite can simultaneously relay multiple television and telephone signals on separate channels.

38. Military satellite communications (MILSATCOM) is a term used to describe the mission efforts that support military operations with effective global, real-time, and continual communications that can support the different demands of voice and data requirements. Future systems are currently being considered with shaped transmission beams, network-centric connectivity, and laser communications for increased

bandwidth and data-rates. Military-specific systems are often protected and designed with features for anti-jamming and nuclear survivability.

39. Example communication missions and systems are:

a. **Wideband global SATCOM (WGS)** is a constellation of six communications satellites providing services in both the X- and Ka-band[3] frequency spectrums. WGS provides communications services that are essential to allow tactical commanders (HQ, air, land and sea) to exercise command and control. Tactical forces rely on WGS to provide high-capacity connection to the terrestrial ground stations.

b. **International maritime satellite (INMARSAT)** was the first global mobile satellite communications system, developed to provide merchant ships with global communications. INMARSAT supports mobile voice and data communications on land, at sea or in the air. It comprises three global constellations of 11 geosynchronous communications satellites.

c. **Iridium**. The Iridium system was developed as a global mobile phone network comprised of 66 LEO communications satellites, plus spares. Communications between Iridium handsets passes via satellites whereby calls to other telephone systems first pass through the US Satellite Earth Station and are then connected to terrestrial telephone networks.

d. **Intelsat 22 (IS-22)** was launched in April 2012 as part of the Intelsat constellation and located at 72° east longitude covering the Indian Ocean region. IS-22 has a specialised UHF hosted payload with dedicated communication channels reserved to support the ADF.

e. **Singtel/Optus C1 satellite with military communications payload**, owned by Singtel/Optus, was launched in 2003 as a commercially operated geostationary communications satellite. It is a hybrid configuration with X-Band, Ka-Band and UHF payloads that are leased exclusively for Australian Military use. The satellite

3 X Band: 8-12 GHz, Wavelength: 7.5–3.75 cm; Ka Band: 27–40 GHz Wavelength: 11.1–7.5 mm

provides medium to high data rate theatre coverage and duplex video, along with voice and data communications. It is controlled by the Optus satellite earth-station in Sydney.

Positioning, navigation & timing

40. The Global Positioning System (GPS) is a constellation of over 24 US Government satellites operating in six different orbital planes in MEO. GPS enables highly accurate positioning, navigation, and timing (PNT) continuously to civilian and military GPS receivers globally in all weather. Each satellite carries a precise atomic clock and repeatedly and simultaneously broadcasts its identity, position, and transmission time. US Air Force controllers work constantly to recompute the satellite positions, to adjust positions for orbital perturbations.

41. PNT combines three distinct capabilities:

a. **Positioning**. Determining a receiver's location in three dimensions.

b. **Navigation**. Determining best routes to projected positions using maps and algorithms to correct course, orientation, and speed to attain a position projected anywhere in the world, from sub-surface to surface, to space.

c. **Timing**. The GPS provides an accurate and coordinated timing signal, based on precise atomic clock measurements in UTC.

42. The GPS signals[4], moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others. The GPS receiver calculates the distance to the GPS satellites by estimating the time for their signals to arrive from all that are visible.

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4 Each GPS satellite transmits three carrier signals in the microwave range of the electromagnetic spectrum, designated as L1, L2, and L5 (frequencies located in the L-band between 1,000 and 2,000 MHz of the spectrum). The L1 frequency is 1,575.42 MHz (wavelength 19.05 cm), the L2 frequency is 1,227.60 MHz (wavelength 24.45 cm), and the L5 frequency is 1,176.45 MHz (wavelength 25.48 cm). L band waves penetrate clouds, fog, rain, storms, and vegetation and, as such, GPS units can receive accurate data in all weather conditions, day or night. https://ascelibrary.org/doi/pdf/10.1061/9780784411506.ap02

The receiver needs a minimum of four GPS satellites to determine its position in three dimensions (see Figure 9).

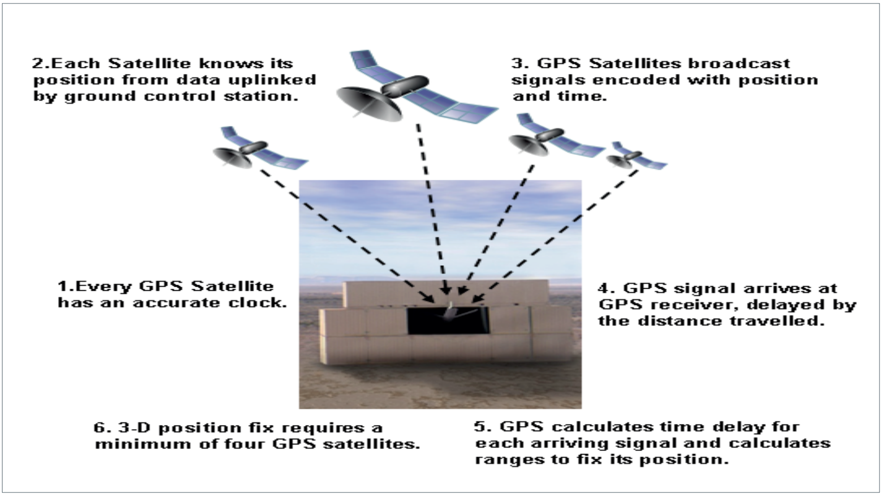

Figure 9 - GPS satellite operation with AGM-158 JASSM

43. The ADF has a long-standing partnership with the USA for access to military encrypted GPS signals and receivers. Because of this access and the benefits it provides, ADF policy holds that GPS is the sole source of satellite navigation signals to be used in ADF operations. While acquiring civilian GPS receivers has enabled quick and easy PNT information to be freely available to the war fighter, they do not protect against GPS interference and are less accurate than military GPS receivers. Military GPS receivers accept two signals that correct for atmospheric model errors, thus allowing a more accurate position to then be calculated. However, the most important feature is the encryption of those signals. It significantly reduces the effects of interference and provides mission assurance. It should also be noted that a military receiver that is not encrypted is as susceptible to GPS interference as a civilian GPS receiver and thus offers no protection.

44. With civilian GPS signals being freely available, many commercial and military uses of its position and timing signal have been developed.

Military users need to be aware that GPS interference or signal disruptions can ramify on much more than merely the ability to navigate. The precise atomic clock time is transmitted by each satellite to encrypt or frequency-hop communication synchronisation, to align the inertial navigation systems within GPS, and more evasively, affects every ATM transaction globally. The positioning information allows navigation by aircraft and ground-based vehicles, and automation and tracking of logistical supplies. The dependency on GPS permeates all layers of defence, and the critical infrastructure which supports raise, train and sustain functions. With that dependency comes vulnerability, the depth of which, in some cases, is not well understood.

45. **Other operating GNSS**. GPS is not the only available satellite navigation system; five others are currently available, or emerging:

a. **GLONASS (Russia)**. Russia commenced launching satellites for the GLONASS constellation in 1982, with the complete constellation of 24 satellites in place by December 1995. Those responsible for the constellation did not maintain a minimum level of six operational satellites until GLONASS was fully restored in 2011. The satellites operate at 19,100 km at an inclination of 64.8 degrees, which is better suited to higher latitude countries such as Russia. GLONASS initially functioned on two frequency bands like GPS, but the L2 frequency band also carries an encrypted, or high precision, signal. Its latest satellites also transmit on the L3 and a L5 (safety of life) frequency band and on common frequencies that are used by GPS and Galileo to allow for standardised multi-GNSS receivers.

b. **BeiDou Navigation Satellite System (BDS) - China**. BeiDou, meaning compass in English, began as a navigation payload on four GEO communications satellites that serviced only China and surrounding countries. The BDS constellation is planned to be completed by 2020 and will consist of five GEO satellites, three inclined GSO satellites, and 27 MEO satellites that will not only service the Silk Road Economic Belt but provide global coverage to Beidou users. The system uses signals on similar frequencies to GPS and offers free services for civilian use and restricted services for subscriber use, eg commercial/military formats. BDS receivers determine position coordinates in reference to the China Geodetic Coordinate System.

c. **GALILEO - European Union**. Galileo is Europe's GNSS, providing improved positioning and timing information with significant positive implications for many European services and users[5]. Unlike GPS or GLONASS, Galileo is civilian-controlled and the program is designed to be compatible with all existing and planned GNSS, including GPS and GLONASS. It also has freely available an encrypted more accurate signal (pay per access arrangement), a search and rescue, and a safety of life signal. Two satellites of the planned 30 satellite MEO constellation have been launched and are currently operational on orbit at 23,222 km.

d. **Quasi-Zenith Satellite System (QZSS) - Japan**. QZSS is a Japanese government owned system but operated by QZS System Service Inc. QZSS aims to enhance GNSS by complementing GPS and improve coverage for users in East Asia and Oceania. Japan plans to have an operational constellation of four satellites in 2018 and expand it to seven satellites for autonomous capability by 2023.

e. **Navigation Indian Constellation (NavIC) - India**. Originally designated as the India Regional Global Navigation Satellite System but later renamed, NavIC provides real-time PNT services to users in and near India, with signal coverage up to 1,500 km from its borders. The satellite constellation consists of seven satellites; three in geostationary earth orbit (GEO) and four in geosynchronous orbit (GSO). The NavIC signals will use an open format for civilian use while the more accurate PNT signals will be encrypted for Indian military and government users.

5 https://www.gsa.europa.eu/european-gnss/galileo/galileo-european-global-satellite-based-navigation-system

Earth observation (remote sensing)

46. The Canadian Government has defined remote sensing as "the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing, and applying that information."[6]

47. Sensors may be either passive, to detect incident radiation which originates from the target or active, to illuminate the target to detect reflections. Depending on the properties of both the incident radiation and the target, the changes in the reflected radiation can be used to characterise the target object, provided it can travel through the atmosphere to the satellite sensor. Interpreting and analysing techniques are then used to discriminate and extract information about the required targets.

48. Remote sensing is used to map and monitor the status and changes in the Earth's resources, climate, oceans and chemical life cycles. Satellites designed for earth observation missions typically follow sun-synchronous, polar orbits. Under consistent illumination from the sun, they take pictures in different colours of visible light and non-visible radiation with computers on Earth combining to analyse the pictures. Scientists use earth-observing satellites to; locate mineral deposits, determine the location and size of freshwater supplies, identify sources of pollution and study its effects, and detect the spread of disease in crops and forests. Military analysts use remote sensing to support strategic ISR.

49. Remote sensing payloads can be categorised in four ways according to the characteristics of the target that is being observed and enhanced to enable detection, discrimination and measurements:

a. **Spatial analysis** describes acquiring and measuring spatially organised data/information, most commonly, geographically distributed objects. Spatial resolution refers to the size of the smallest possible feature that can be detected.

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6 Natural Resources Canada (2015). *Fundamentals of Remote Sensing – Introduction*. Online at http://www.nrcan.gc.ca/node/9363. Accessed on 26 June 2018.

b. **Temporal analysis** may refer to the observations of discrete events, eg lightning strike locations, or the frequency of observing to detect and study change trends. The temporal resolution refers to how often a satellite overflies a specified target location.

c. **Spectral analysis** identifies and measures the bands in the electromagnetic spectrum that characterise reflections or emissions from specific matter. Spectral resolution specifies the number of bands in which the sensor can collect reflected radiance from the target. Both the number of spectral and wavelength band are important. Presently, hyper-spectral imaging sensors best detect the character of the unique elements in the battlespace.

d. **Radiometric analysis** uses a sensor to measure the intensity of the electromagnetic energy radiated by a target object or area. Radiometric resolution refers to the minimum number of different intensities of radiation that the sensor can distinguish and is a measure of the sensitivity of the sensor. Differences in radiometric signatures can be used to characterise the object or area in comparison to their surrounds.

50. Many types of imaging sensors are used on remote sensing platforms, most commonly operating in the visual or infra-red (IR) spectrum. Most modern systems have digital sensors that provide a picture using panchromatic, multispectral or hyperspectral techniques. Processing of multispectral images can provide evidence of disturbed earth or the presence of individual chemicals or minerals, where hyperspectral imaging techniques are useful in prospecting, environmental monitoring, or agriculture. They are as follows:

a. **Panchromatic imaging**. Black and white digital sensors are best suited when greater sensitivity is needed. The images they produce are commonly known as panchromatic. However, a disadvantage of this type of imaging is that the colour information is not present, which can be useful in any analysis of the image.

b. **Multispectral imaging** is created through combining separate monochromatic images, typically using red, green and blue filters to create a single multispectral image. In a multispectral system, the detectors may also be optimised for the near, mid and far IR bands. The image produced will have many colours that represent the different frequency bands chosen, rather than the visual image that would be seen by the eye.

c. **Hyperspectral imaging**. This technique collects the information as a set of images. Each image represents a range of the electromagnetic spectrums or spectral bands, rather than the discrete frequencies that comprise a multispectral image.

d. **Infra-Red imaging**. IR detectors have traditionally been much harder to make and operate than visual systems. Producing reliable, high performance, staring IR arrays is a relatively recent achievement. While IR detectors can function in daylight, they can be specifically applied to night surveillance because they are ideal for differentiating temperature. Images produced using IR sensors are excellent for determining the status, or even presence, of factories and power plants, ships or submarines, and natural events such as water flows and forest fires.

51. Radar payloads are used extensively by both military and civilian satellites and require significantly more power to operate than passive systems, ie visual and IR). Synthetic aperture radar (SAR) can penetrate through cloud and provide high-resolution images of ground features, which provide similar information to a visual image. SAR is also able to detect oceanographic features such as fronts, wave velocity and wave height. Another mode of SAR can detect moving targets such as vehicles, ships and helicopters.

Other space missions

52. Dedicated military missions play an increasing role in Australian military operations. Whereas Australia is capable of independently exploiting the services provided by some US space missions, other mission areas require that Australia continues to depend on US-managed tasks and priorities. Space areas for mission interoperability are:

a. **Intelligence, surveillance and reconnaissance (ISR)**. Intelligence describes information and knowledge obtained through observation, investigation, analysis, or understanding. Surveillance and reconnaissance by satellites refers to how satellite sensors can make observations, eg optical, radar, and electronic. Surveillance involves systematically observing to collect whatever data is accessible and available, while reconnaissance involves a deliberately planned mission to obtain specific intelligence.

b. **Missile warning (MW) and Nuclear detonation (NUDET) monitoring**. The space-based infra-red system (SBIRS) satellite constellation comprises infrared sensor payloads in various SBIRS orbits as well as fixed and mobile ground-based assets. They globally detect and warn of missile and space launches, and nuclear weapons detonations. Knowing the infrared signatures that are unique to different systems enables the characterisation of such events (see Figure 10).

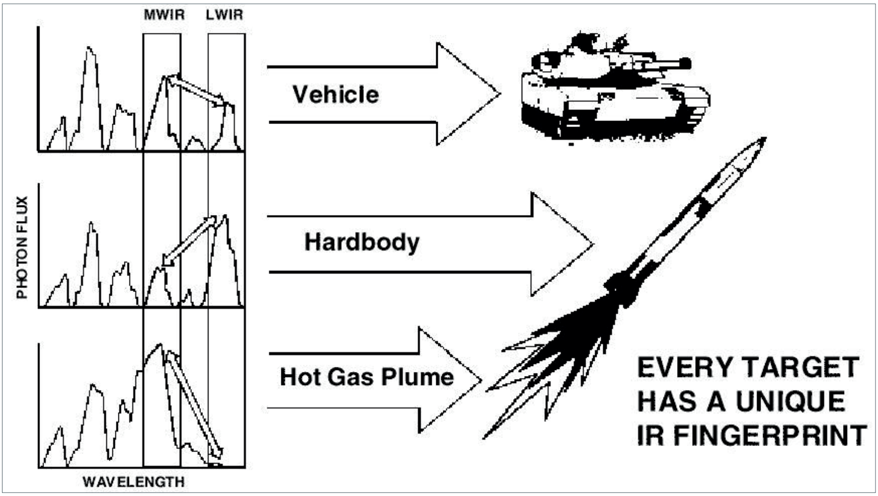

Figure 10 - Space based surveillance of terrestrial targets.

c. **Space-based surveillance** missions are typically designed to employ electro-optical systems to support near-real-time space situation awareness. Space-based surveillance searches for lost objects, seeks to detect unknown objects, and identify those that are found. Operating a sensor from orbit will aid users to overcome the limitations for terrestrial based optical and radar sensors caused by the atmosphere, terrestrial weather, and the constraint of making night observations with solar illumination.

d. **Space Situational Awareness (SSA)**. SSA is defined as the requisite current and predictive knowledge of space events, activities, conditions and space systems status, capabilities, constraints and employment to enable commanders, decision-makers, planners and operators to gain and maintain freedom of action, in space, throughout the spectrum of conflict[7]. Situation awareness enables decision superiority in the battlespace. Endsley[8] suggests that situation awareness requires three tasks:

   i. perceiving entities in the environment, eg space objects;

   ii. understanding their meaning, eg space objects and their missions;

   iii. projecting their status into the near future, ie as it may affect friendly mission outcomes.

53. A commander needs the expertise to perform these three tasks as they are important in achieving the desired outcomes of a system supporting SSA (see Figure 11).

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7 Australian Defence Headquarters, 2016,Australian Defence Doctrine Publication 3-18 *Operational Employment of Space*, Canberra, Second Edition, p3-5.

8 Endsley, M., 1995. T*owards a theory of Situation Awareness in Dynamic Systems*. Human Factors. Special Issue of Situation Awareness. Vol 37, no 1, pp32.64, March 1995.

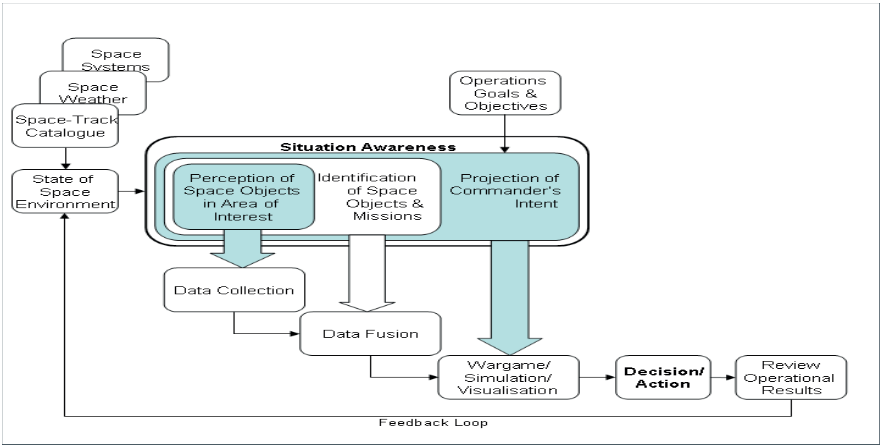


Figure 11 - A system description for situational awareness.

54. Presently, the US uses its global Space Surveillance Network (SSN) comprised of optical and radar sensors, including sites in Australia, to conduct space surveillance (see Figure 12). SSN observations are used to make determine orbital parameter for use in predicting future positions of space objects for pointing the SSN sensors and for predicting likely orbital collisions between space objects. Effective detecting and identifying space objects by current sensors is limited to a minimum cross-section size of about 10cm.

55. The accumulated observations of functioning and expired satellites, spent rocket boosters, and space debris are listed in the US Strategic Command (USSTRATCOM) satellite catalog. In mid-2018, the US managed satellite catalog lists over 43,500 orbiting objects that have been uniquely tagged and are being tracked in the LEO to GEO orbits. The SSN also supports predictions for likely time and upper atmospheric location where low-orbiting expired and uncontrolled space mission systems slowly reduce altitude and are captured by atmospheric drag; whereupon they exit the orbital environment and re-enter the atmosphere to burnup or impact the Earth.

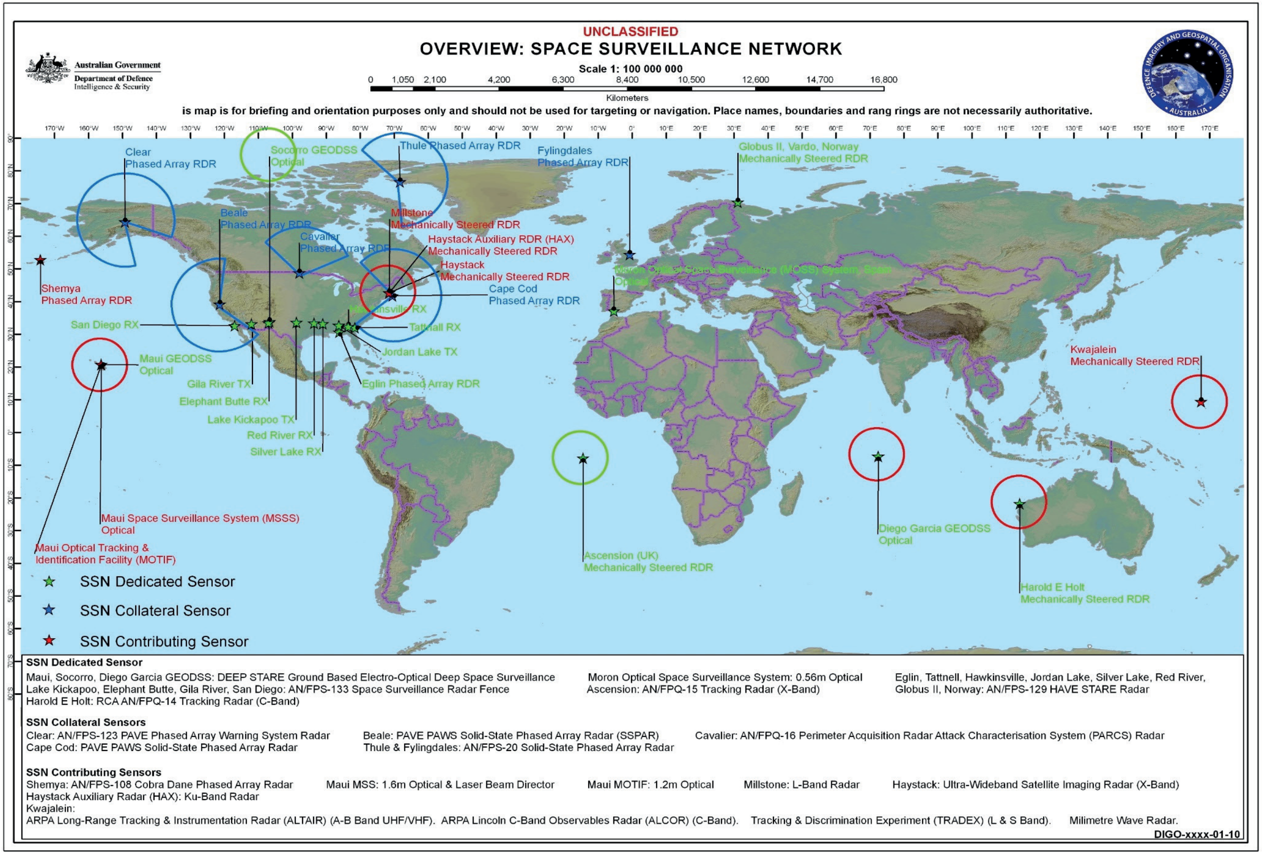


Figure 12 - US global Space Surveillance Network.

TENETS OF SPACE EMPLOYMENT

The space policy framework

56. The laws of armed conflict (LOAC) and ADF rules of engagement are ultimately derived from a set of international treaties, principles, arrangements, and domestic laws. Australia regards international law to apply to outer space. This means that LOAC, as they relate to the use of force and non-interference, apply to activities conducted in outer space. While these laws were not developed specifically with outer space in mind, they can be reasonably interpreted by specialist legal staff as guiding the space domain.

57. The term "outer space" was first introduced in the 1950s in debates on where the "air space" ends and "outer space" begins. The 1957 launch of the Sputnik satellite was used to drive international agreement on the principle of freedom of space and to treat "outer space" differently to "air space." The term "outer space" was widely adopted in the first international treaties that were initiated for the early space programs by individual nations, knowing that the "outer space" trajectories would overfly other countries.

58. To this day, it is important to understand the importance of the separation of "air space" and "outer space" because different laws are applicable to each domain. The use of the term "space" is commonly used in reference to "outer space." Even though there is not a clear physical boundary to separate air and space, it can be inferred from Australian Space Activities Act (1998) which defines a "space object" as a thing consisting of a launch vehicle and a payload that carried to or from an area beyond the distance of 100 km above mean sea level.

59. Guidance as to the law affecting space operations can be found in ADDP 06.4 *Law of Armed Conflict*[9] and AAP1003 *Operations Law for*

9 Australian Defence Headquarters, 2016,Australian Defence Doctrine Publication 06.4 *Law of Armed Conflict*, Canberra, First Edition.

RAAF Commanders[10]. The Australian Defence Organisation space policy framework is also derived from:

a. International space-related treaties, laws and guidelines

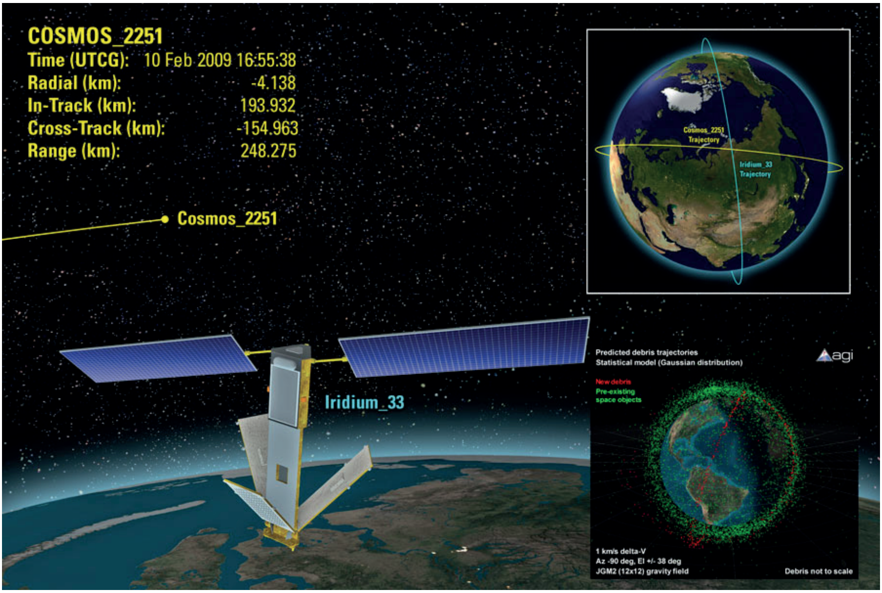
b. Australian domestic laws

c. Australian bilateral and multilateral agreements

d. National policy and plans

e. Defence policies, plans, and guidance

f. Defence contracts



The 2009 collision between an Iridium and a COSMOS satellite has been used to test international space laws.

10 Air Force Headquarters, 2004, Australian Air Publication 1003 *Operations Law for RAAF Commanders*, Canberra, Second Edition.

International space-related treaties, laws and guidelines

60. After the launch of Sputnik I in 1958, the United Nations (UN) established the Committee on the Peaceful Uses of Outer Space (COPUOS) in 1959 to govern the exploration and use of space for the benefit of all humanity: for peace, security and development. The Committee was tasked with reviewing international cooperation in peaceful uses of outer space, studying space-related activities that could be undertaken by the United Nations, encouraging space research programmes, and studying legal problems arising from the exploration of outer space[11].

61. Australia is a signatory to six UN treaties and agreements on space:

a. **Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 1967 (Outer Space Treaty)**. This outer space treaty requires that exploring and using outer space shall be for the benefit and interests of all countries. The treaty prohibits the national appropriation of outer space; prohibits placing weapons of mass destruction (WMD) in orbit around the Earth, on celestial bodies, or stationed in outer space; and states that the Moon and other celestial bodies shall be used exclusively for peaceful purposes. It does not specifically ban the deployment of conventional weapons in space, nor prohibits the temporary employment of WMD through space, eg ballistic missile nuclear warheads, providing they are not permanently placed in orbit.

b. **Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, 1968 (Rescue Agreement)**. This agreement calls for the rendering of all possible assistance, rescue, and return of astronauts and spacecraft in the event of accident, distress or emergency landing in unplanned areas.

c. **Convention on International Liability for Damage Caused by Space Objects, 1972 (Liability Convention)**. This convention

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11 United Nations, *Committee on the Peaceful Uses of Outer Space*, viewed 30 October 2018, http://www.unoosa.org/oosa/en/ourwork/copuos/index.html

expands the liability provisions originally found in the 1967 Outer Space Treaty to address the issue of collateral damage that space objects may cause on the surface of the Earth, in flight, or in space. It was amended by the 'Space Liability Convention' to expand the rules for a state to bear international responsibility for all space objects that are launched within its territory. However, it may seek to indemnify itself from the state who owns the spacecraft being launched.

d. **Convention on Registration of Objects Launched into Outer Space, 1976 (Registration Convention)**. This convention requires that states launching objects into space maintain an appropriate registry of launched objects and inform the UN of the establishment of such a registry and notification, as soon as practicable, after any space launch.

e. **Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1984 (Moon Agreement)**. This agreement states that the Moon shall be used by all states exclusively for peaceful purposes. Additionally, any benefits derived from the Moon's resources shall be shared equitably among all states that are party to the treaty regardless of the status of their involvement in an event.

f. **International Telecommunications Union Convention and Radio Regulations, 1994**. This legal framework applies to terrestrial and space-based telecommunications activities and provides a basis for allocating and spacing satellite locations, and thus prohibit new satellites from causing harmful interference.

62. The UN also made declarations on the following legal principles to guide international forums and domestic law-makers in developing policies and laws on space activities:

a. "The Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space", 1963;

b. "The Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting", 1982;

c. "The Principles Relating to Remote Sensing of the Earth from Outer Space", 1986;

d. "The Principles Relevant to the Use of Nuclear Power Sources in Outer Space, 1992"; and

e. "The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries", 1996.

63. The UN has also prepared two other international treaties and agreements on space, as follows:

a. **Draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects, 2008**. This treaty seeks to prevent any type of weapon from being placed into earth orbit or installed on celestial bodies, and to prevent threats or the use of force against outer space objects.

b. **Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, 2007**. These guidelines manage the risks posed to life and space missions by man-made objects, including debris fragments and elements thereof, in earth orbit or when re-entering the atmosphere.

64. Additionally, Australia is a signatory to the following treaties and agreements:

a. **Wassenaar Arrangement (WA) on Export Controls for Conventional Arms and Dual-Use Goods and Technologies, 1993**. The WA was established in order to contribute to regional and international security and stability, by promoting transparency and greater responsibility in transfers of conventional arms and dual-use goods and technologies, thus preventing destabilising weapon accumulations. Participating States seek, through their national policies, to ensure that transfers of weapons do not contribute to the development or enhancement of military capabilities that undermine these goals, and are not diverted to support such capabilities[12].

b. **Missile Technology Control Regime, 1987**. The MTCR is an informal and voluntary association of countries that share the goal of not proliferating unmanned delivery systems capable of delivering WOMD. The MTCR thus seek to coordinate national export licensing aimed at preventing such proliferation. Because missiles with a range of 300km or greater, capable of carrying a payload weighing 500kg or more, can deliver nuclear, biological or chemical weapons, they need to be export-controlled.

c. **Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD Convention), 1977**. The ENMOD Convention is specifically intended to prevent use of the environment as a means of warfare, by prohibiting the deliberate manipulation of natural processes that could produce phenomena such as hurricanes, tidal waves or changes in climate[13].

d. **Treaty on the Non-Proliferation of Nuclear Weapons, 1973**. The 'Non-Proliferation Treaty' objectives are to prevent the spread of nuclear weapons and weapons technology, to promote co-operation in the peaceful uses of nuclear energy, and to achieve nuclear disarmament and general complete disarmament.

e. **Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, 1963**. To slow the arms race and reduce the spread of nuclear contamination in the atmosphere, this treaty prohibits all test detonations of nuclear weapons, other than those occurring underground.

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12 Wassenaar Arrangement Secretariat, 2017, *Wassenaar Arrangement On Export Controls for Conventional Arms and Dual-Use Goods and* Technologies, Viewed 30 October 2018, https://www.wassenaar.org/app/uploads/2015/06/WA-DOC-17-PUB-001-Public-Docs-Vol-I-Founding-Documents.pdf

13 International Committee of the Red Cross, Factsheet, *1976 Convention on the Prohibition of Military or any Hostile Use of Environmental Modification Techniques*, Viewed 30 October 2018, https://www.icrc.org/en/document/1976-convention-prohibition-military-or-any-hostile-use-environmental-modification

Australian domestic laws

65. The Australian Government has enacted the following domestic laws and regulations to manage Australian space-related activities:

a. **The Space (Launches and Returns) Act, 2018** established a regulatory framework for the licensing and safety requirements for space activities in Australia or involving Australian interests and reduce barriers to participation in the space industry by streamlining processes and insurance requirements for launches and returns. The Act defines a space object as:

   i. an object the whole or a part of which is to go into or come back from an area beyond the distance of 100 km above mean sea level; or

   ii. any part of such an object, even if the part is to go only some of the way towards or back from an area beyond the distance of 100 km above mean sea level.

b. **The Australian Communications and Media Authority (ACMA) Act, 2005** states that the ACMA has two obligations: first, to regulate telecommunications in accordance with the Telecommunications Act 1997 and the Telecommunications (Consumer Protection and Service Standards) Act 1999; and second, to manage the radiofrequency spectrum in accordance with the Radiocommunications Act 1992.

c. **The Space Activities Regulations, 2002** cover the licensing of a launch facility and its events, requirements for launch certification and registration with the UN registrar, certification that payloads and launch vehicle do not contain a nuclear warhead or WOMD destruction, and how a foreign owner recovers space debris from Australian territory.

d. **The Radiocommunications (Australian Space Objects) Determination, 2000** specifies when a space object can be considered Australian and brings Australian space objects into the scope of the Radiocommunications Act 1992, so that they can be licensed and identified as stations that the ACMA has jurisdiction over in all places at all times[14].

e. **The Australian Radiation Protection and Nuclear Safety Act (ARPANSA), 1998** protects the health and safety of people and the environment from the harmful effects of radiation, and provides special provisions for Defence[15].

f. **The Space Activities Act, 1998**, **Space Activities Regulations 2001 (Regulations), and the Space Activities (Scientific or Educational Organisations) Guidelines 2015** create a regulatory framework for civilian space activities conducted from Australia, or by Australian nationals outside Australia (in certain circumstances). The Act and Regulations deal primarily with the launch and return of space objects[16], and includes the definition of space object as:

   i. a launch vehicle; and

   ii. a payload (if any) that the launch vehicle is to carry into or back from an area beyond the distance of 100 km above mean sea level, or any part of such a thing, even if:

      - the part is to go only some of the way towards or back from an area beyond the distance of 100 km above mean sea level; or
      - the part results from the separation of a payload or payloads from a launch vehicle after launch.

g. **The Radiocommunications Act, 1992** provides the ACMA with powers to regulate the use of Australian spectrum for space systems or satellite networks and stipulates operating any

14 ACMA, *Australian Space Regulations*, viewed 30 October 2018, https://www.acma.gov.au/Industry/Spectrum/Spectrum-planning/Space-systems-regulation/australian-space-regulations-space-systems-regulation-acma

15 ARPANSA, *ARPANS Legislation*, viewed 30 October 2018, https://www.arpansa.gov.au/regulation-and-licensing/regulation/about-regulatory-services/why-we-regulate/arpans-legislation

16 Department of Industry, Innovation and Science, *Space Regulation*, viewed 30 October 2018, https://www.industry.gov.au/regulation-and-standards/space-regulation

radiocommunications device within Australia must be authorised by an appropriate radiocommunications licence[17].

h. **The Telecommunications (Interception and Access) Act, 1979** regulates access to telecommunications content and data in Australia and prohibits the interception of telecommunications except where authorised in special circumstances, to trace the location of callers in emergencies, and to collect foreign intelligence relating to national defence[18].

i. **The Defence Special Undertakings Act, 1952** states the Commonwealth law for protecting works and undertakings that are carried out to defend Australia, including prohibiting aerial photo-reconnaissance missions over gazetted restricted areas.

Australian bilateral/multilateral agreements and arrangements

66. Governments may conclude agreements or arrangements on the mutual exchange of services. For space capabilities, this usually means an exchange to enable access to another nation's space capabilities and/or related products and services, including, for example:

a. The (2014) Space Situational Awareness (SSA) data-sharing agreement with US Strategic Command for the Combined Space Operations initiative to enhance multinational space cooperation and give participating nations an understanding of the current and future space environment, an awareness of space capability to support global operations.

b. The (2007) Australian/US partnership for the Wideband Global SATCOM (WGS) program.

67. All of Australia's treaty obligations are set out in the Australian Treaty Series (www.austlii.edu.au/au/other/dfat/). In addition, numerous

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17 ACMA, https://www.acma.gov.au/Industry/Spectrum/Spectrum-planning/Space-systems-regulation/australian-space-regulations-space-systems-regulation-acma

18 Department of Home Affairs, *Overview of Legislation*, viewed 30 October 2018, https://www.homeaffairs.gov.au/about/national-security/telecommunications-interception-surveillance/overview-legislation

non-legally binding arrangements exist, updated information on which can be obtained from the Directorate of International Government Agreements and Arrangements in Defence Legal.

National policies, plans and guidance

68. The newly established Australian Space Agency[19] commenced operations on 1 July 2018 with six primary responsibilities:

a. Setting national policy and strategy for the civil space sector.

b. Coordinating Australia's domestic space sector activities, including regulatory and licensing activities under the Space (Launches & Returns) Act 2018.

c. Leading international space engagement.

d. Supporting the growth of Australia's space industry.

e. Sharing our expanding role in space and importance to the national economy.

f. Inspiring the Australian community and the next generation of space entrepreneurs.

69. The Australian Government has previously prepared space-related policies, plans and guidance within and among departments that are pertinent to Defence interests and capabilities:

a. **Australian Satellite Utilisation Policy**[20]. In 2013, the Department of Industry, Innovation, and Science was given a mandate to create an Australian Satellite Utilisation Policy for consideration by Government. The policy covers Australian civil uses as well as defence use of space. It addresses how Australia uses space to tackle

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19 Australian Space Agency, *Australian Space Agency – Our Role*, viewed 4 October 2018, www.industry.gov.au/strategies-for-the-future/australian-space-agency.

20 Australian Space Agency*, Australia's Satellite Utilisation Policy*, viewed 4 October 2018, https://www.industry.gov.au/sites/g/files/net3906/f/May%202018/document/pdf/australias_satellite_utilisation_policy.pdf

climate change, weather forecasting, natural resource management, forestry and agriculture, disaster management, and national security.

b. **Australian Government Space Re-entry debris plan – AUSPREDPLAN**[21]. Emergency Management Australia (EMA) prepares and maintains the plan to coordinate Australian Government support to states and territories to respond to a space debris re-entry threat.

Defence policies, plans and guidance

70. Defence strategic guidance shapes decisions and plans for major defence strategy and policy decisions, including intelligence policy, military capabilities, operational concepts, and military operations. Air Force Headquarters develops air and space concepts, guidance and policy to shape the Air Force to be better prepared for future force structures, organisations, and systems. Air Force concept development is also guided by the ADF narratives for Joint Concepts, for guiding forces designs in current and future operations, and assessments of future operating environments. Defence has similarly prepared space-related policies, plans and guidance from:

a. **Defence White Paper (DWP)**. The Department of Defence is mandated by Government to produce the DWP to account for the Government's approach to defending Australia and its national interests.

b. **Integrated Investment Program (IIP)**. The IIP describes major Defence capital equipment proposals that are currently planned for Government consideration. The proposals relate to procuring new or improved capabilities over the period specified for the approved IIP.

c. **Defence Space Policy**. The Strategic Policy and Intelligence (SP&I) Group builds the strategy for that provides the framework for capability planners to derive the Defence roles and functions needed for space in military and defence strategies.

21 Department of Home Affairs, *Emergency Response Plans*, viewed 30 October 2018, https://www.homeaffairs.gov.au/about/emergency-management/response-plans

d. **Joint Concepts Framework**. The Joint Concepts Framework (JCF) Directive provides the structure, process and coordinating mechanisms to develop and unify joint concepts across Defence. The JCF ensures a consistent approach to achieve a joint and integrated force aligned to strategic guidance[22].

e. **Australian Defence Doctrine Publication 3.18—Operational Employment of Space**. ADDP 3.18 provides guidance for the employment of space-based capabilities in support of ADF campaigns and operations. It is structured to provide fundamental knowledge about the space environment and an understanding of the way space permeates the planning and activities of joint operations. As joint doctrine, ADDP 3.18 informs Air Force doctrine, which in turn explains how fundamental air and space power principles are applied.

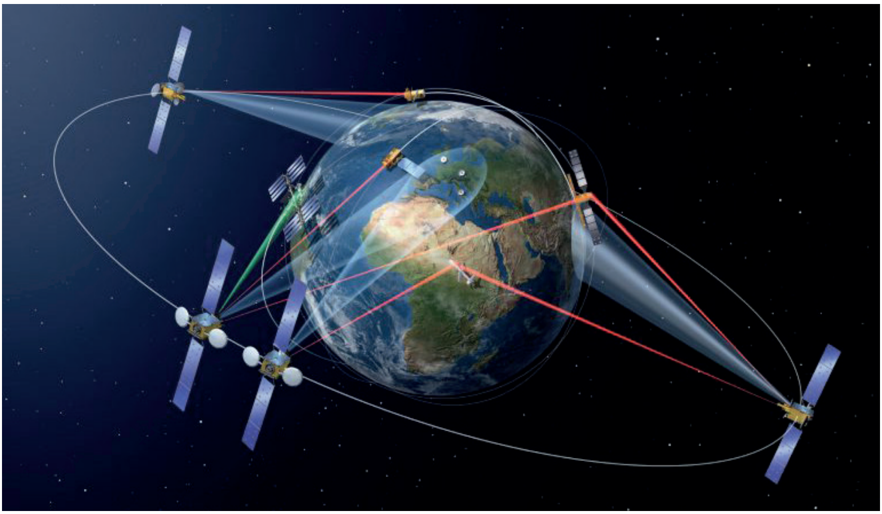

Figure 13 - The laws applicable to satellites and the space domain are different to those controlling airspace and airspace users.

22 Joint Concepts and Futures Branch, VCDF Group, *Joint Concepts Framework Directive*, viewed 31 October 2018, http://drnet/vcdf/FD/FA/Concepts/Pages/home.aspx

COMMAND & CONTROL (C2) FOR SPACE EFFECTS

Centralised C2 for air and space effects

71. The characteristics of air power, including perspective, speed, reach, flexibility and precision, shape the conduct of air operations and the delivery of mission effects. Air power needs C2 systems that are organised to plan and manage individual air missions with durations measured in hours, as a part of operations that may endure for weeks, or months and reaching out to force element deployed to operate from their home base or over intercontinental ranges to forward locations. Air operations may temporarily push up air mission rates of effort until they ramp down at the end of the operation. However, space missions are planned with continuously operating mission payloads with mission durations that can be up seven years or more, necessitating a specialised, continuously operating and dedicated C2 system for space power.

72. Access to the space domain enhances the application of air power; the high ground advantage provides increased coverage over areas of interests and communications linkages to sensors and force elements situated beyond the horizon. Whilst the availability and applied rates of effort for air power may vary between operations, orbital space missions provide capabilities with continuous operational resources providing 24/7 data output to users. Space missions also deliver effects that support one or many operations concurrently, and in geographically remote and dispersed locations. Additionally, the space domain poses different challenges in respect of space traffic management, collision avoidance, space mission availability, fixed orbital trajectories over operational areas and competitor/adversary nations, etc, which are separate and different to the needs for an air power focused C2 system.

73. Space situational awareness (SSA) is therefore a key role for a space C2 system. The C2 of space operations faces four challenges:

a. access to space capabilities because it is shared between military and commercial service providers

b. the interdependence between tactical and theatre space forces

c. different national and coalition forces priorities

d. national and international government needs

74. Another level of complexity occurs because some space-derived information and services that can support military interests may come from organisations outside of the ADF, which sometimes use non-traditional lines of ADF command or Defence management. In some cases, authority may be split between organisations owing to shared interagency responsibilities for the same or different mission payloads configured on the same satellite or satellite system.

75. The C2 system is also required to maintain an awareness of the current and future availability of space missions, analyse the dynamics of the space environment and their effect on space missions, monitor benign space missions, and determine when, where, and how space missions are needed and tasked to support ADF operations. A centralised C2 organisation is necessary to understand when orbiting space missions are available and accessible to support terrestrial operations and then coordinate and synchronise the sharing of the limited available space missions to support multiple ADF force elements that may be dispersed over multiple locations, at different times, throughout a geographically distributed Joint Task Force.

76. This situation creates the need for a dedicated space C2 workforce, staffed accordingly with the personnel numbers and expertise to match the specialist capabilities and rate of effort required for space missions. It must also be scalable to support a single force element or multiple joint task forces deployed over vastly different geographical locations. As such, C2 for space missions needs to be centralised in order to effectively provide concurrent support that is both horizontally scalable for single missions and multiple deployed task forces, and vertically scalable to inform decision-makers from the tactical to strategic levels.

Air Force space capability management

77. **Defence capability coordination**. Chief of Air Force (CAF) is the coordinator of Defence space capabilities. Other responsibilities for coordinating space-related Defence capabilities are delegated as follows:

a. Chief Information Officer Group (CIOG) is the capability coordinator for Defence satellite communications, command and controls systems, and networks; and

b. Deputy Security for Intelligence and Security, within Strategic Policy and Intelligence Group, is the capability coordinator for Defence geospatial information and services within defence.

c. Vice Chief of the Defence Force (VCDF) acts as the chair of the Investment Committee, operates the Capability Life Cycle on behalf of the Secretary and CDF, and is the senior officer accountable for the future force structure and integration of the joint force.

78. **Capability management**. Deputy Chief of Air Force (DCAF) leads the coordination of Air Force doctrine, strategy, policy, capability and planning to determine current and future Air Force activities and priorities. DCAF thus leads future changes that affect, or are affected by, issues relating to Air Force responsibilities and resources to raise, train, and sustain Air Force resources.

79. **Future strategy and concepts analysis**. Director General Strategy and Planning—Air Force (DGSP-AF) leads for Air Force during the strategy and concepts stage of the capability life-cycle for strategic planning, and devising future concepts, doctrine, and designs for air and space power. DGSP-AF is supported by the Air Power Development Centre (APDC), which provides practical analysis and advice on strategic developments in air and space power, and thus contributes to Air Force doctrine, education, and knowledge systems.

80. **Requirements and acquisition management**. Director General Air Combat Capability—Air Force (DGACC-AF) and Director General Air Capability Enablers—Air Force (DGACE-AF) both act as the Air Force sponsors for separate programs during the requirements setting and acquisition stages of the capability life-cycle for the capability programs for which CAF is the Capability Coordinator.

81. **Space capability systems management**. Wide Area and Space Surveillance Systems Program Office (WASSSPO) is assigned by CAF as the group responsible for managing the space capability systems of Air Force. Air Force operates Australian-based SSA sensors and mission processors in cooperation with US AFSPC, which owns these space systems, after certification standards have been mutually agreed upon.

Planning and managing space effects

82. The ADF way of warfighting critically depends on space missions. The ADF has responded to this need by integrating its space operations within the Headquarters Joint Operations Command (HQJOC) C2 system and the Air Force resources assigned to its air operations. Regardless of the type of space support required, ADF operational planning starts with HQJOC. Given that many of the space capabilities that the ADF relies upon are not under direct ADF command or control, much of the space effort within the ADF focuses on managing a productive relationship with US Department of Defense (US DoD) and its Combined Space Operations Centre (CSpOC).

83. **Australian Space Operations Centre (AUSSpOC)**. HQJOC is responsible for processing space support requests and does so using the specialist resources of the AUSSpOC, which is established within HQJOC's Air & Space Operations Centre (AOC), to provide:

a. analysis of satellite vulnerability reports (SATVULREP) for force elements in training or as deployed on operations and exercises.

b. warning reports of space debris re-entry over areas of interest and liaisons with EMA.

c. monitoring of the impacts of space weather forecasts on operational space capabilities.

d. dissemination of space situational awareness advice

e. liaison with the US CSpOC

Figure 14 - US Combined Space Operations Centre (CSpOC).

84. **US Combined Space Operations Centre (figure 14)**. The CSpOC acts as the clearing house for space operations for US DoD and coordinates space support to its US combatant commanders. AUSSpOC and CSpOC interdependently coordinate tasking for the Australian-based SSA sensors. AUSSpOC also relies on CSpOC derived information to provide space support to ADF operations. The ADF has an exchange officer attached to the CSpOC.

Integrating space operations into the Joint Force

85. **Operational Control (OPCON) of space systems**. Located within HQJOC is a single dual-roled Air Force appointment for directing air and space operations. The Director General Air Command Operations (DGACOPS) appointee who is responsible to the Air Commander Australia for Air Force "raise, train, and sustain" activities. The incumbent also acts as Director General Air (DGAIR) in their second role, where the appointee is responsible to Chief of Joint Operations, who commands HQJOC, to manage those Air Force assigned air and space force elements employed in joint force operations. This includes the Air Force operations

C2 force element, the Air & Space Operations Centre (AOC) established at Headquarters Joint Operations Command and depicted in Figure 15.

86. **Air & Space Operations Centre**. The AOC is permanently force assigned to HQJOC to plan and direct air and space operations as part of air campaigns and exercises conducted by the ADF. The AOC provides centralised air and space operations planning and execution, although the execution of specific tasks may be delegated to other operational Task Force elements. The AOC is comprised of a central group of personnel who have the professional mastery to plan and execute an air campaign, including employing space capabilities based in Australia or from allied or commercial space-based services.

87. **Senior space adviser to Chief of Joint Operations (CJOPS)**. The Chief AUSSpOC appointee is the senior appointed space representative within the AOC and, as such, to HQJOC. This officer is responsible to advise, plan, and conduct Australian space operations for CJOPS, through DGAIR.

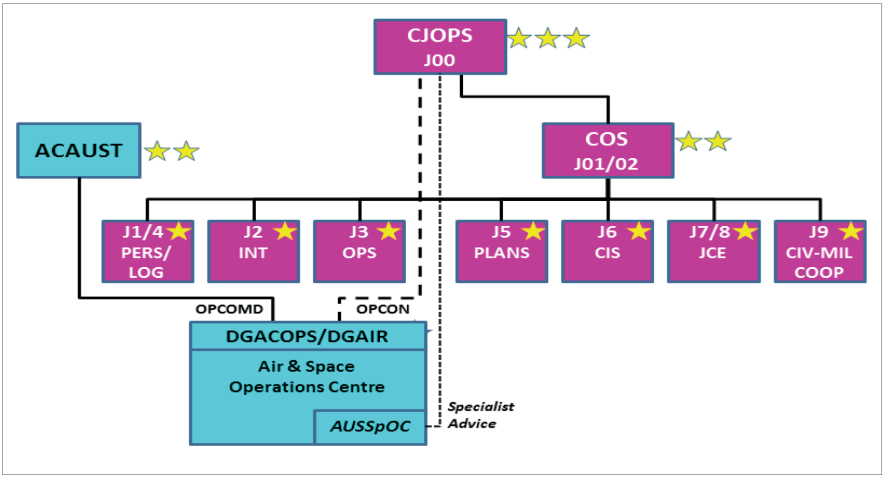

Figure 15 - C2 arrangements for ADF space operations.

88. **Technical Control (TECHCON)** is the provision of specialist and technical advice by designated authorities for the management and

operation of forces. Technical control is exercised by capability managers and is not normally delegated. Technical control is exercised through the CJOPS for assigned forces[23]. TECHCON for Air Force SSA systems is provided by the Wide area and space surveillance systems program office (WASSSPO), who are responsible for maintaining and supporting Air Force SSA systems. Australian-based SSA sensors and mission processors are operated by Air Force using certification standards that are recommended by US Air Force, as the asset owner.

89. **Commercial and non-commercial satellite services**. The ADF is dependent on space-derived products and space-based services that are delivered under international Defence agreements with non-commercial partners and commercial contracts.

a. **Government imagery and geospatial data**. The Australian Geospatial-Intelligence Organisation (AGO) is the Australian government organisation responsible for providing geospatial intelligence from imagery and other sources in support of Australia's defence and national interests.

b. **Military and commercial satellite communications (SATCOM) services**. Chief Information Officer Group manages the provision of satellite communications services, including wideband SATCOM, through the Defence Network Operations Centre (DNOC) at HMAS Harman.

c. **Government meteorological services**. The Defence Meteorological Services Unit, located at HQJOC, provides meteorological support to the ADF using meteorological satellite data managed by the Bureau of Meteorology.

d. **US Foreign Military Sales (FMS)**. FMS enables foreign governments to purchase military goods and services from the US Department of Defense. Australia uses FMS contracts to procure US military products and training courses

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23 Australian Defence Headquarters, 2018, Australian Defence Doctrine Publication 00.1 – *Command and Control*, Second Edition, p 5-11

SPACE POWER AND 5TH GENERATION AIR FORCE

Space situational awareness

90. Air Force has evolved into a modern force that relies on timely and accurate observations and communications taken from space-based systems, about space-based systems, and of the space environment. Securing access to the space environment relies on being aware of systems, events and threats in space so that Air Force can successfully plan and conduct operations that critically depend on space. Accordingly, Air Force is acquiring space situational awareness (SSA) capabilities to better understand potential risks to Australian space-related interests in ground infrastructure and orbiting systems. This understanding is also essential so that Air Force can contribute to ADF joint warfighting and coalition or combined operations.

91. Australia is vast, with many remote regions of national security importance, and our Defence operations supporting our national interests are invariably undertaken at vast distances from home bases. This distance makes it essential that Australia maintains reliable access to space and space-derived products, and services for information and communication. While Australia owns geostationary communications satellites to service the Australian domestic population and ADF military operations, many space services are provided under allied military agreements and commercial arrangements with foreign satellite owners. Air Force provides SSA capabilities to help assure both Australia and its allied partners about the nature and status of risks from space to any of those systems.

92. Australia and its allies conduct surveillance of space to contribute to both a catalogue of satellites currently resident in orbit, whether functioning or not, and objects that have previously orbited the Earth and are known to have re-entered the atmosphere. Because some of these objects are too small or too far from Earth to be detected by SSA sensors, the catalogue cannot provide tracking data on all the man-made objects that are known to be orbiting the Earth.

Air Force SSA elements

93. Air Force SSA capabilities are ground-based surveillance sensors that detect and track objects orbiting the Earth, including functional satellites and debris. Ultimately, Air Force SSA will enable the detection, prediction, and assessment on the risk to life on the ground, equipment in orbit and on the ground, and disruptions to ADF operations. Air Force SSA elements comprises:

a. **No 1 Remote Sensor Unit (1RSU)**. 1RSU is the only Air Force operational unit whose role includes operating and supporting Air Force space capabilities. In addition to operating the Jindalee Operational Radar Network (JORN) of high frequency (HF) over-the-horizon radars (OTHR), 1RSU is responsible operating the C-band space surveillance radar, the Space Based Infra-Red System - Australian Mission Processor (SBIRS-AMP) and, in the future, the Space Surveillance Telescope (SST), to support ADF's SSA (see figure 16). These sensor systems detect and track objects orbiting the earth, including functional satellites and debris. The space object tracking data obtained is shared by 1RSU, under partnering arrangements, with the US to contribute to the US global Space Surveillance Network. Air Force operators have also been, and continue to be, part of an exchange program with the USAF 2nd Space Warning Squadron, based in Colorado, USA.

b. **Space Surveillance Telescope (SST)**. SST is a first of type, highly advanced US-owned ground-based optical telescope that is being relocated to a new purpose-built facility located at NAVCOMSTA Harold E Holt. 1RSU will remotely operate SST, in collaboration with US AFSPC to provide awareness of space activities.

Figure 16. Australian-based space situational awareness sensors: (left) Space surveillance telescope; (right) C-band space surveillance radar.

c. **C-band space surveillance radar**. The C-band radar is a USAF-owned radar system that has been relocated from Antigua to an Australian modified facility at NAVCOMSTA Harold E. Holt in Western Australia. 1RSU remotely operates the radar in collaboration with US Air Force Space Command (AFSPC). The radar tracks spacecraft, space debris, and contributes space-tracking data to the US global space surveillance network.

d. **Space Based Infra-Red System—Australian Mission Processor (SBIRS-AMP)**. SBIRS is a US AFSPC-deployed constellation of earth-observation satellites that provides global coverage for detecting ballistic missile launches and battlespace awareness events. 1RSU operators have access to this system, with US AFSPC collaboration provided under a Memorandum of Understanding with USSTRATCOM.

Other Australian-based SSA elements

94. Other Australian ground-based sensors, which also contribute to SSA, include:

a. **Learmonth Solar Observatory (LSO)**. The LSO is jointly operated by Australia's Bureau of Meteorology, DST Group, and US Air Force. LSO is part of the US-established global network that monitors, analyses and predicts solar activity to ascertain space and terrestrial weather.

b. **Falcon Telescope Network (FTN)**. The FTN is a global network of small-aperture, optical telescopes developed by the US Air Force Academy in collaboration with international educational partners. These partners include the University of New South Wales in Canberra. FTN supports undergraduate research, education, and community outreach programs that promote space capabilities.

Challenges to assuring space access

95. Space systems are integral to the overall ADF combat capability. ADF warfighting effectiveness depends on having assured access to space and this dependence will continue to increase, particularly related to networked operations. The 5th generation Air Force will critically depend on the network connectivity enabled by satellite communications to extend the reach of distributed air power control and share battlespace situation awareness. Air Force SSA capabilities are vital to support Air Force force-level designs.

96. Air Force depends on robust, dependable and fit-for-purpose communication and information systems (CIS). This emphasises the prominence of SATCOM and CIS in Air Force thinking of those things which it must 'get right' if Air Force is to continue to be effective. Because the 5th generation integrated, networked force will more greatly rely on resilient and capable communications systems, Air Force needs a good understanding of the risks and opportunities associated with:

a. network resilience of future integrated terrestrial and space-based systems.

b. future network bandwidth of the ADF.

c. future ADF employment of space-based remote sensing and communications systems.

d. assured continuing access to space.

e. the growing risks of space debris (see Figure 17).

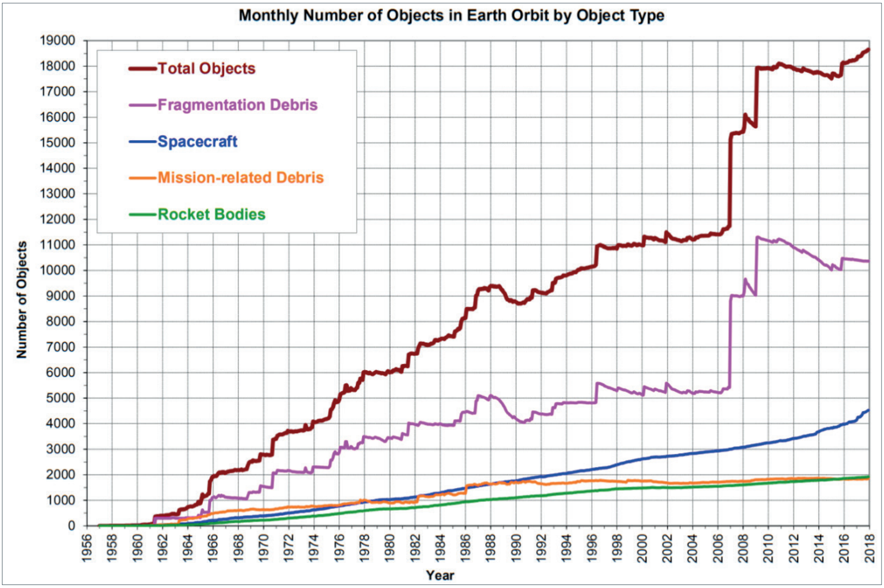

Figure 17 - Monthly statistics for objects in Earth orbit, by object type.[24]

Integrating space power into the 5th generation Air Force

97. Doctrine states the fundamental principles by which forces are guided in their actions to achieve desired goals. It is, by design and historic practise, intended to assist practitioners approach complex,

24 NASA, Orbital Debris Quarterly News, Volume 22, Issue 1, February 2018, viewed 4 October 2018, https://orbitaldebris.jsc.nasa.gov/quarterly-news/newsletter.html

dangerous and unfamiliar situations with clarity of thought through practical and useful guidance[25]. An Air Force doctrine note (AFDN) seeks to promote discussion on a specific doctrine subject seeking views and commentary on its application in Air Force. At this time, Air Force is embarking on a pathway to develop a 5th generation Air Force that will introduce and test new concepts in the way we operate. As we move forward it is also important to consider the way new domains will shape future Air Force, therefore the discussion on the integration of space into our 5th Generation Air Force is necessary to identify the concepts that, once tested, will become future doctrine.

98. A 5th generation air force is more than a collection of highly-capable platforms, it a force that is designed, trained, and equipped to generate and employ integrated air power effects. The purpose of this integration is to combine the effect of individual platform capabilities to generate an agile, informed, collaborative, and resilient force that excels on the delivery of air power effects in the joint force across multiple domains (see figure 18). Space enables the fifth-generation air force. Accordingly, it is important for airmen to understand the relationship between a fifth generation force and space power.

Figure 18 - Attributes of the 5th generation Air Force.

25 AAP 1000-D – *The Air Power Manual*, p3

99. The **integration** of air and space power enables assured and persistent access to satellite communications and surveillance over an entire theatre of operations or concurrent theatres of operations. Space enables monitoring of terrestrial activities from above the engagement ranges of conventional weapons thereby contributing to improved situational awareness and situational understanding. The high-ground advantage of orbiting sensors enables the warfighter to extend their communications connections beyond the physical limits of the Earth horizon by connecting into a global network system with and without terrestrial networks. Space-enabled global networks are essential for commanders to integrate with dislocated units to exchange data and/or control signals to integrate decision systems, warfighters, and combat systems.

100. **Agility** refers to the ability to quickly and easily adjust and adapt to exploit emerging opportunities and maintain warfighting advantage in dynamic and uncertain environments. Space missions provide a whole-of theatre perspective permitting the joint force to observe and dominate surface activities and enhance decision superiority[26], which enables quicker and agile responses. Additionally, the growth in the diversity and availability of deployed space missions facilitates agility in the battlespace, such as responding to changes in an adversary's signatures[27], communications, and manoeuvres within different domains.

101. **Communication** networks, enabled by space missions, create the network through which capabilities and effects are integrated. The network acts as a force-multiplier, building and extending the capability of the human operator in the cockpit, or a ground-based mission control system, by providing them with real-time data fusing and, concurrently, sharing their activities and information with collaborating intelligence analysts and data fusing systems. Satellite communications enables operational decision-makers to utilise these networks and synergise information resources quickly, providing them with a holistic view

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26 Decision Superiority – *The ability to make and implement more informed and more accurate decisions at a rate faster than the adversary*.

27 Conventional military equipment emits a wide range of detectable signatures, including visual, thermal, infra-red, acoustic, seismic, magnetic, electronic, laser and ballistic.

across a broad spectrum of battlefield intelligence sources and enhanced decision-making.

102. National security challenges are becoming increasingly complex; demanding cross-functional teams to resolve. To meet that end, our people will have to develop strong personal networks across Air Force, as well as the broader defence, government, allied, industrial and academic communities[28]. The space-enabled communications network enables deployed warfighters to reach-back to well-established and long-term mission support capabilities and human infrastructure established in home territory. Space enabled **collaboration** is a force multiplier, enabling mission specialists and deployed aircrew to consult and collaborate in real-time with subject matter experts and mature well-established information systems, either in direct contact or through a cloud-type system architecture for sharing situational awareness, intelligence, and decision making. Reducing the need to forward deploy elements reduces operational risks and improves the resilience of the deployed

103. Operations based on the use of air platforms and their technological advanced systems can be vulnerable to fragilities[29]. Collaboration creates **resilience** and Air Force mitigates fragility by planning and conducting operations to leverage strengths across the ADF and its partners to provide systemic depth[30]. Air Force relies on space enabled missions and networks to facilitate this communication and collaboration between our partners in order to mitigate the fragility of air power. However, Air Force reliance on space missions creates a vulnerability for air power. Space missions are vulnerable to conventional attack on ground support and launch facilities; non-kinetic attack through jamming of the electro-magnetic spectrum to degrade or deny ground-to-satellite links; or exploitation of GPS, communication, or network signals by adversaries.

104. The management of assured space support is built on three elements; space situational awareness (SSA), space control, and assured access to space capabilities. SSA provides timely and actionable information will enable commanders and their staff to gain and maintain

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28 Turnbull, G. AVM, 2018, Deputy Chief of Air Force, *Air Force: Next! The Reformation of the Air Force and its Transformation into a Networked Force*, Air Power Conference

29 Fragility: *the vulnerabilities inherent in the sophisticated materials of which air platforms and technological advanced systems are composed.*

30 AAP 1000-D – *The Air Power Manual*, p145

freedom of action in space across the spectrum of ADF activities. Space control supports freedom of action in space by employing offensive and defensive space control measures that mitigate the adversaries' ability to interfere with or attack our space systems. Offensive space control involves preventing adversaries from exploiting space by attacking their capabilities through deception, disruption, degradation, denial or destruction. Defensive space control includes measures to preserve our ability to exploit space by using active or passive measures while protecting our space capabilities from attack or interference[31].

105. Assured access to space is a joint force responsibility; however, the current and future Air Force SSA capabilities and its coordination and collaboration networks not only integrates those networks and activities into the 5th generation Air Force but the integration of air and space supports the resilience and requirements for the integration of space into the joint force.

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31 Australian Defence Headquarters, 2016, Australian Defence Doctrine Publication 3.18 – *Operational employment of Space*, Second Edition, p 3-7

LIST OF ABBREVIATIONS

Abbreviation	**Meaning**
1RSU	(RAAF) No 1 Remote Sensor Unit
ACMA	Australian Communications and Media Authority
ADDP	Australian Defence Doctrine Publication
ADF	Australian Defence Force
ADFHQ	Australian Defence Force Headquarters
ADO	Australian Defence Organisation
AEHF	Advanced Extremely High Frequency
AFSPC	(US) Air Force Space Command
AGO	Australian Geospatial-Intelligence Organisation
AJOC	Australian Joint Operating Concept
AOC	Air and Space Operations Centre
AUSSpOC	Australian Space Operations Centre
AUSPREDPLAN	Australian Space Re-entry Debris
C2	Command & Control
CAF	Chief of Air Force
CIS	Communications and Information Systems
COE	Classical Orbital Elements
COPUOS	(UN) Committee on the Peaceful Uses of Outer Space
COSPAS	(Russian) Space System for the Search of Vessels in Distress
CSpOC	Combined Space Operations Centre
DGACC	Director General Air Combat Capability
DGACE	Director General Air Capability Enablers
DGSP	Director General Strategy and Planning
DIRSPACEFOR (DS4)	Director of Space Forces
DNOC	Defence Network Operations Centre

DST	Defence Science & Technology Group
DWP	Defence White Paper
EMA	Emergency Management Australia
EMP	Electro-Magnetic Pulse
FJSC	Future Joint Space Concept
FMS	(US) Foreign Military Sales
FTN	Falcon Telescope Network
GEO	Geostationary Earth Orbit
GEODSS	Ground-based Electro-Optical Deep Space Surveillance
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
GSO	Geo-Synchronous Orbit
GTO	Geostationary Transfer Orbit
HEO	Highly Elliptical Orbit
HQJOC	Headquarters Joint Operations Command
IIP	Integrated Investment Program
ISREW	Intelligence, Surveillance, Reconnaissance, Electronic Warfare
ITU	International Telecommunication Union
JFC	Joint Force Commander
JOC	Joint Operations Command
LEO	Low-earth orbit
LOAC	Laws of armed conflict
LPO	Lagrange-point orbit
LSO	Learmonth solar observatory
MEO	Medium earth orbit
MILSATCOM	Military satellite communications
MOA	Memorandum of agreement
MOU	Memorandum of understanding
NASA	National Aeronautics and Space Administration

NPT	UN Treaty on the Non-Proliferation of Nuclear Weapons
OSCAR	Orbiting Satellite Carrying Amateur Radio
PAROS	UN Treaty on Preventing an Arms Race in Outer Space
PNT	Positioning, Navigation and Timing
PPWT	UN Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects
SARSAT	Search And Rescue Satellite Aided Tracking
SATCOM	Satellite Communications
SBIRS	(US) Space Based Infra-Red System
SBIRS-AMP	Space-Based Infra-Red System—Australian Mission Processor
STSS	Space Tracking and Surveillance System
SCA	Space Coordinating Authority
SSA	Space Situational Awareness
SSN	Space Surveillance Network
SST	Space Surveillance Telescope
UN	United Nations
USSTRATCOM	US Strategic Command
WASSSPO	Wide Area and Space Surveillance Systems Program Office
WGS	Wideband Global SATCOM

GLOSSARY

Altitude	Height of the object above the Earth's surface.
Apogee	Point in the orbit where an Earth satellite is farthest from the Earth. Opposite of perigee.
Disruption	A person or thing that prevents something, especially a system, process, or event, from continuing as usual or as expected; also, a specialized business that changes the traditional way an industry operates, especially in a new and effective way.
Eccentricity	The shape of the orbit, describing how flattened it is compared to a circle.
Geocentric	An orbit with the Earth at the orbit centre (circle) or one focus (ellipse).
Heliocentric	An orbit with the Sun at the orbit centre (circle) or one focus (ellipse).
Inclination	Angular distance of the orbital plane from the plane of the planet's equator, stated in degrees. [Geocentric angle between orbit and equator].
Kessler Syndrome	If the growth of orbital debris in LEO continued unchecked, the density of objects could become so great that the objects would increasingly collide, with each collision generating more debris, which would cause access to space to become more hazardous.
Liability treaty	UN Convention on International Liability for Damage Caused by Space Objects.
Moon treaty	UN Agreement Governing the Activities of States on the Moon and Other Celestial Bodies.
Non-Proliferation Treaty	UN Treaty on the Non-Proliferation of Nuclear Weapons.

Orbit	The path of an object that is moving around a second object or point under the influence of gravity.
Orbit Period	Time taken for a platform to complete one full orbit.
Outer space treaty	Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space.
Perigee	Point in the orbit where an Earth satellite is closest to the Earth. Opposite of apogee.
Registration treaty	UN Convention on Registration of Objects Launched into Outer Space.
Repeat cycle	Time for a satellite to pass vertically over the same location.
Rescue and return agreement	UN Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space.
Space power	The total strength of a Defence Force to conduct and influence activities to, in, through, and from space to achieve its military objectives.
True anomaly	The geocentric angle between the spacecraft position and the periapsis.

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THE AIR POWER DEVELOPMENT CENTRE

Email: apdc.doctrine@defence.gov.au

Internet: http://www.airforce.gov.au/airpower

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