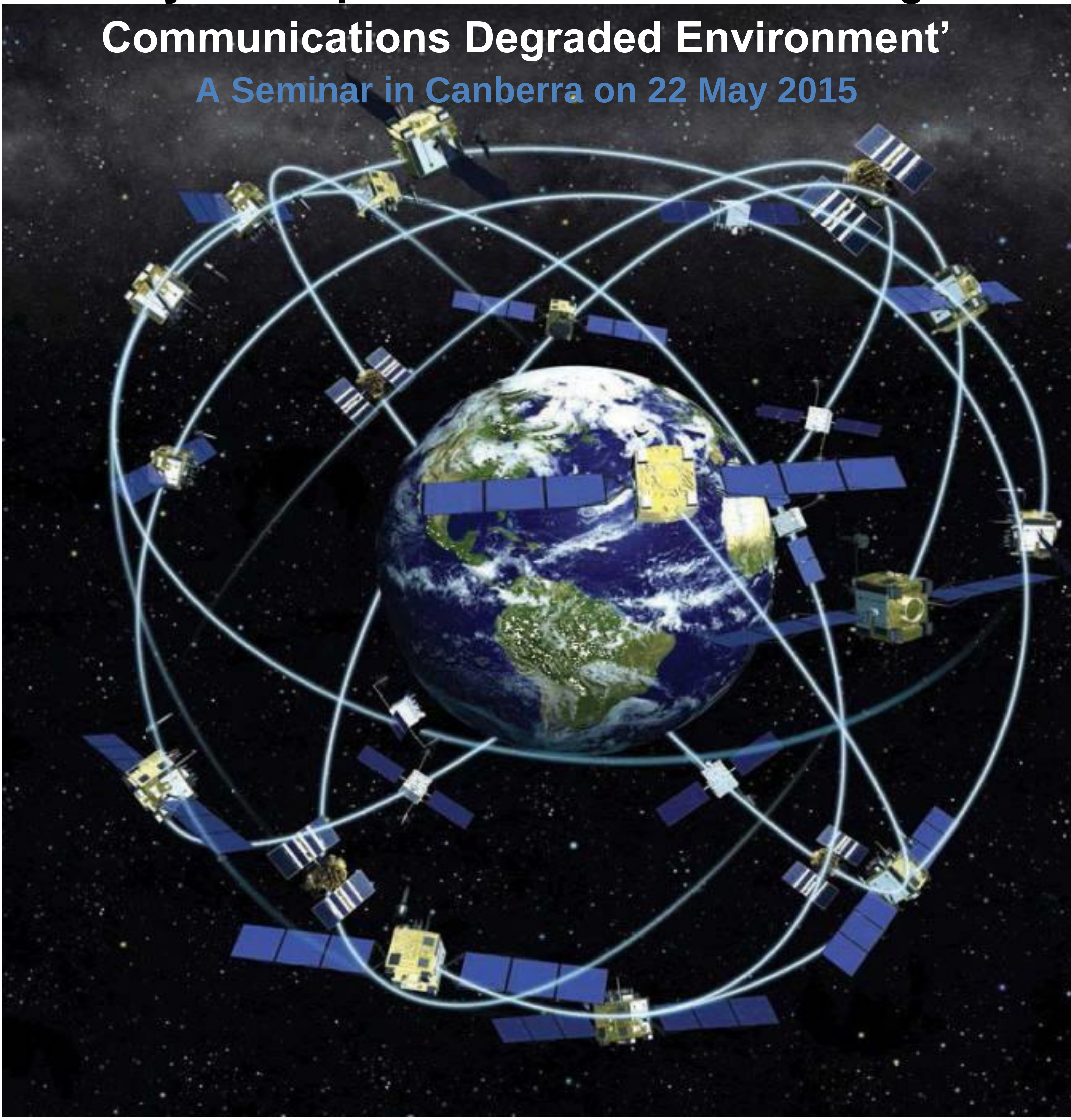
Summary of Proceedings
‘Military/Civil Operations in a Satellite Navigation/ Communications Degraded Environment’

A Seminar in Canberra on 22 May 2015



Edited by
Air Vice-Marshal Kym Osley AM, CSC (retd)
Secretary, Australian Institute of Navigation

Australian Institute of Navigation

Australian Government
Department of Defence
Capability Development Group

Seminar on 'Military/Civil Operations in a Satellite Navigation/Communications Degraded Environment' 22 May 2015

Key Outcomes/Actions

- **Share Information**. Further develop cross-Government GNSS-related forums to better share developments in dealing with GNSS degradation.

- **Plan.** Ensure that natural and human–induced GNSS degradation is adequately addressed in Government and Department contingency plans and risk registers.

- **Education.** Develop a program for better educating the public of the dangers of jamming or interfering with GNSS. This would include educating the public on the laws and penalties that apply to those caught interfering with GNSS/satellite communications signals.

- **Critical Infrastructure.** Seek to have GNSS recognized as critical infrastructure in Australia.

- **Training.** Review cross-Government exercise programs and training courses to ensure that they adequately stresses staff and processes in preparation for responding to a serious degradation in space-based PNT.

- **Detect.** Create an Australian national system (equipment and processes) for detecting and geo-locating GNSS jamming.

- **Ownership**. Defence and the Australian Institute of Navigation to find the most suitable cross-Government group to accept and progress these key outcomes/actions.

SPECTDO

Seminar Program

0800-0830 – *registration*

0830-0835 – *Welcome & Seminar Administration* – **Air Vice-Marshal Kym Osley AM, CSC (retd)**

0835-0850 – *Opening address* – **Air Vice-Marshal Mel Hupfeld AO, DSC,** Acting Chief of Capability Development Group

0850-0930 – *The Threat to Space-Based Services* – **Prof Chris Rizos,** President Australian Institute of Navigation

0930-1000 – *The Risk to Civil Air Operations – Air Services Perspective* – **Ms Margaret Staib AM, CSC**, Chief Executive Officer Airservices

1000-1030 - break

1030 -1100 – *The Risk to Civil Aviation - CASA Perspective* – **Mr Ian Mallett AFC,** Section Head Communications, Navigation and Surveillance, CASA

1100-1130 – *The Risk to Military Air Operations* – **Air Commodore Craig Heap CSC,** Director General Aerospace Development

1130-1200 - *Panel comment and question session*- Civil and Military aviation

1200-1300 – *light lunch outside seminar theatre* (including displays by Defence Science Technology Organisation)

1300-1330 – *The Risk to Critical Infrastructure & Land Operations – Civil Perspective* – **Assistant Commissioner David Mclean,** National Manager High Tech Crime, Australian Federal Police

1330 -1400 – *The Risk to Military Land Operations* – **Major General Gus McLachlan AM,** Head Army Modernisation and Strategic Planning, Army Headquarters.

1400 - 1430 – *The Risk to Commercial Maritime Operations* – **Mr Nick Lemon,** Manager Nautical and Regulation, Australian Maritime Safety Authority

1430-1500 – break

1500-1530 - The *Risk to RAN Maritime Operations* – **Commander Dave Prentice, RAN,** acting Director General Information and Communications Warfare, Navy Headquarters

1530-1600 – *Panel comment and question session*- Land and Maritime

1600-1625 - *What is Defence doing about Navigation Warfare?* – **Captain Don Burningham, RAN**, Director ISREW, Capability Development Group

1625-1650 – *Current NAVWAR-related Developments in Australian Industry* **- Dr Mark Knight**, Cyber and Electronic Warfare Division, Defence Science Technology Organisation

1650-1700 – *Wrap-Up and Closing* – **Air Vice-Marshal Kym Osley AM, CSC** (retd) AIN

To be followed by:

1700-1800 – **Australian Institute of Navigation sponsored networking reception at the ADFA Officer's Mess.**

SUMMARY OF PROCEEDINGS OF

22ND MAY 2015 SEMINAR ON 'MILITARY/CIVIL OPERATIONS IN A SATELLITE NAVIGATION/COMMUNICATIONS DEGRADED ENVIRONMENT'

NOTE: ALL POWERPOINT SLIDES FROM THE SEMINAR WILL BE ACCESSIBLE AT THE AUSTRALIAN INSTITUTE OF NAVIGATION WEBSITE WWW.AIN.ORG.AU IN THE NEAR FUTURE

Introduction – Air Vice-Marshal Kym Osley (retd), Executive Secretary Australian Institute of Navigation

Air-Vice Marshal Osley welcomed the attendees and provided some short introductory remarks. He noted that the Seminar was being conducted in the new Sister Ross-King Theatre, and noted that she was a nursing sister in WW1 who had received a Military Medal for bravery under fire in recognition of her rescuing and tending to wounded Australian soldiers on the Western Front in 1917. Air Vice-Marshal Osley then introduced the first speaker, Air Vice-Marshal Mel Hupfeld.

Opening Address – Air Vice-Marshal Mel Hupfeld, Acting-Chief Capability Development Group, Defence

Air Vice-Marshal Hupfeld thanked the Australian Institute of Navigation and Air Vice-Marshal Osley for initiating the Seminar on a topic of great importance to a wide variety of agencies. He opened the proceedings by acknowledging the Ngunnawal people as the traditional land custodians of Canberra, and he paid his respects to their Elders past and present.

Air Vice-Marshal Hupfeld stated the importance of addressing the risk posed by degradation of satellite navigation and satellite communications. He emphasised the need to be ready to respond proactively to this new emerging threat with a quote from George Orwell '…people sleep peacefully in their beds at night only because rough men stand ready to do violence on their behalf…'.

He explained that the impacts would be widespread and not just affect the military. A future incident that degraded Global Navigation Satellite System (GNSS) position, navigation and time signals (PNT) could result in interruptions to mobile phone communications, financial services, traffic signals, and other critical infrastructure.

He noted recent incidents around the world (eg in the US) where Global Positioning System (GPS) signal degradation had occurred. He said this may have been an inadvertent 'jamming' episode or just the result of Radio Frequency Interference (RFI), but it did highlight the potential problems that could be caused by even relatively localised jamming of GPS signals.

Air Vice-Marshal Hupfeld stated that the instigators of GNSS PNT signal degradation could potentially be either state or non-state actors, and that the jamming or spoofing equipment was relatively low cost and readily available on the internet. He quickly covered the different topics that the speakers would be addressing.

Air Vice-Marshal Mel Hupfeld opening the Seminar

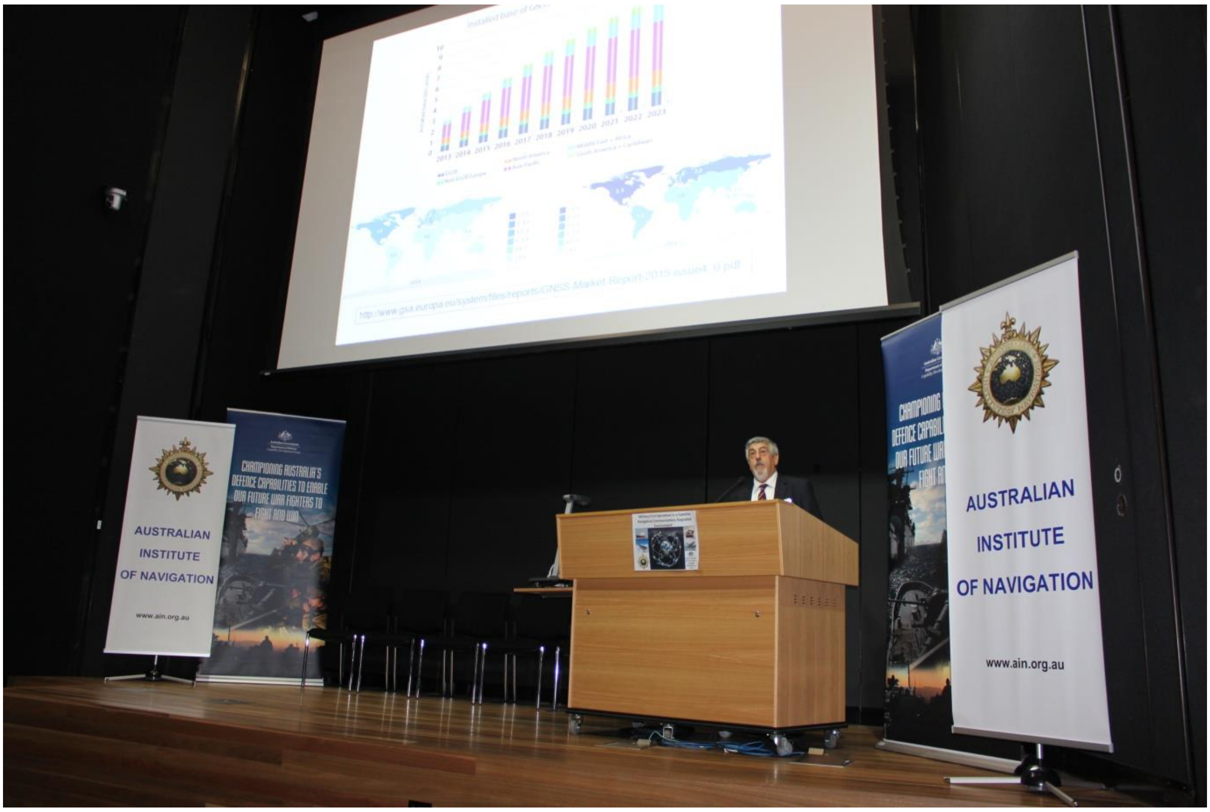
Air Vice-Marshal Hupfeld also mentioned that an expected outcome of the day would be some practical recommendations on the way ahead, which he thought would need to include changes to collective cross Government Department training, a more detailed risk assessment of GNSS degradation on Australia-wide infrastructure and key operations, and perhaps a follow-on war game between the agencies represented at the Seminar.

The Threat to Space Based Service - Professor Chris Rizos, President Australian Institute of Navigation

Professor Rizos noted that the number of GPS-based devices per head of population will double or triple over the next 10 years in many countries, including Australia. This will make Australians increasingly reliant on space-based Positioning, Navigation and Timing (PNT) services. He also noted that the greatest risk to Australia was not necessarily resulting from the wide spread community use of GPS and other space-based services for ‘mass market’ positioning and navigation applications (or ‘apps’).

Perhaps the greater risk arose from the relatively little known ‘hidden’ niche uses of space-based services to support and underpin key infrastructure and civil/military capabilities. The economic and social benefits of these ‘niche’ PNT applications are estimated to be orders of magnitude greater than their percentage component of the GPS/Satellite Communications market “size” (dominated by the ubiquitous ‘smart phone’).

Professor Rizos noted that the US is currently conducting a study into the assessed economic benefits of GPS services. A preliminary estimate is that there is likely to be over $65B in annual benefits in the US. A similar percentage benefit (or impact if space-based services are degraded) to the Australian Gross Domestic Product (GDP) could be expected.



Professor Chris Rizos discussing the threats to GNSS and satellite communications systems

Professor Rizos discussed the extent of GPS dependencies in economic areas, and in critical national infrastructure. 15 out of 18 critical infrastructure areas use GPS timing, while three areas use GPS positioning as well. It is infrequently stated, but it is clear that Global Navigation Satellite System (GNSS) is a critical civilian infrastructure as well as a critical military capability.

He stated that there is general recognition now of the vulnerability of the GPS system and signals. The GPS signals are relatively weak, and can be jammed or spoofed quite easily, unless the GPS receiver has in-built functionality to reduce their vulnerability. Military equipment and associated signals are more robust than civilian/open service signals.

Professor Rizos noted that GPS has been a remarkably reliable PNT technology that as a result has fostered complacency regarding its vulnerability. He then outlined the inherent vulnerabilities of GNSS; which are both natural and manmade. These vulnerabilities are very expensive and complicated to overcome; which is why (noting the reliability of GNSS over the past 30 years) little has been done across the board to address them.

He stated that when the system was developed there was no risk assessment for the civilian GPS service (noting that the military GPS signal was encoded and had some in-built risk mitigation features from the very start). There is a risk of state or non-state actors denying or degrading GPS (and GNSS in general), and the consequences have been assessed as ranging from life threatening to significant economic impact.

Professor Rizos noted that the consequences of GNSS loss, degradation or spoofing depended on the application involved and the duration of signal loss, system degradation or spoofing. The impact could range from minimal (with a fast recovery); through reduced effectiveness and efficiency of operations; to major safety impacts that potentially could result in loss of life or environmental and economic damage.

Professor Rizos stated that a significant potential impact came from the degradation of the timing afforded by GPS/GNSS. If that suffers a longer term outage, then services such as communications, data networks, electricity grids, traffic signals, and could be seriously affected and could cause localised chaos if back-up timing systems are not available.

He opined that many government and commercial authorities may be ill-prepared for GNSS failure, and are reluctant to invest in alternative backup systems because GNSS-enabled PNT is so cost-effective compared to alternatives, and has historically been very reliable.

Professor Rizos posed the rhetorical question – so why do we need more Resilient Positioning, Navigation & Timing (RPNT)? Quite obviously the need for greater resiliency goes hand-in-hand with an increasing dependency on GNSS PNT for many safety-of-life, liability-critical or mission-critical applications. The number of such applications is continuing to grow at a rapid rate.

He indicated that we are in a new ‘design space’; seeking something that was previously mutually exclusive – which is greater integrity of signal at the same time as a higher PNT accuracy. RPNT implies a holistic approach to GNSS vulnerability, by addressing issues that are technical, regulatory, standards/industrial in scope, as well as adopting new frameworks and design methodologies.

An example of the need to move to a new design space that was used by Professor Rizos was the future move to ‘driverless’ vehicles. This will place ‘safety-of-life’ criticality on GNSS positioning in vehicles; and continuity, availability, integrity, interoperability will all be essential. This will impose very stringent positioning requirements on car-based GNSS systems; that will necessitate resilient navigation at three levels of accuracy: road-level (metre resolution), lane-level (sub-metre resolution), and where-in-lane-level (decimetre resolution)

Professor Rizos noted that there has been considerable effort in the international arena to develop new Cooperative Intelligent Transport Systems (C-ITS) positioning and design standards as a forerunner to the widespread deployment of driverless land vehicles. In many environments, such as tunnels, in built-up urban areas, or in the presence of signal interference or spoofing, GNSS performance rapidly deteriorates. GNSSs on their own cannot therefore satisfy the “high performance positioning” needs of applications such as driverless cars that are either liability-critical or life-critical. Fortunately extra ‘local’ navigation technologies can assist by providing collision avoidance capability.

Professor Rizos outlined the potential for and types of interference of the GNSS signals. He classified them as ‘unintentional’ and’ intentional’. Unintentional interference includes Radio Frequency Interference (RFI); ionospheric disturbances; and multipath signal disturbance. Intentional Interference includes direct signal jamming and spoofing (using counterfeit signals). Unintentional interference is generally short term. Intentional interference may also be short term, but could be done in such a way that system damage can be longer term, using for example mobile jammer units that will be hard to detect.

Professor Rizos stated that to the user of GNSS, it really does not matter what is causing the interference as the result is largely the same. Thus a GNSS user needs a system that has “integrity monitoring”; guards against “human or computer error”; is not overly reliant on a single technology; and has a viable backup.

Quite obviously in state-versus-state war-like situation, several nations now have the potential to damage the GPS (or GNSS) constellation through space attack. However, parts of the GPS ground control could be damaged or disrupted through a natural disaster (such as an earthquake) or by terrorist or military action, though the impact is unlikely to be significant because of the highly distributed nature of the ground control elements.

GNSS has always been vulnerable to loss-of-signal-lock (or interference) during extreme ionospheric storms. A very severe storm could disable the satellites themselves, but this is a rare event. The solar event of 1859 has been the largest such natural event in the industrial age. The solar storm of 1859, also known as the Carrington event, was a powerful geomagnetic solar storm.[1]

Studies have shown that a solar storm of this magnitude occurring today would likely cause widespread problems for modern civilisation.[2] The solar storm of 2012 was of similar magnitude, but it passed Earth's orbit without striking the Earth. In June 2013, a joint venture from researchers at Lloyd's of London and Atmospheric and Environmental Research (AER) in the United States used data from the Carrington Event to estimate the current cost of damage of a similar event to the US alone at $0.6–2.6 trillion!

Professor Rizos noted that only very low power is typically required to jam GNSS. The jamming power required at the GPS antenna can be of the order of a Picowatt (10^{-12} watt). Also the jamming of GPS is simplified because there is only a single civilian frequency, and the signal structure is very well known. Many jammer models exist that are effective against GNSS. These are all easy to make and have from a

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[1] A solar coronal mass ejection hit Earth's magnetosphere and induced one of the largest geomagnetic storms on record. The associated "white light flare" in the solar-photosphere was observed and recorded by English astronomers Richard C. Carrington and Richard Hodgson.

[2] In the 1859 event, telegraph systems all over Europe and North America failed, in some cases giving telegraph operators electric shocks. Telegraph pylons threw sparks. Some telegraph operators could continue to send and receive messages despite having disconnected their power supplies.

KWatt to MWatt output, although some that are quite effective have low power (<1 Watt) and can be used in vehicles.

There are a number of jamming signal types, including narrowband, broadband and spread spectrum-PRN modulation. DSTO has developed plots that show the vulnerability of a GPS receiver while acquiring or tracking GPS signal, for varying distance from intentional jammer (for a specific jamming power). Use of 'Controlled Reception Pattern Antenna' (CRPA) seems promising, but is currently quite expensive ($2 000-$20 000), and hence likely to be implemented on high value military assets.

Professor Rizos noted that the impact of even a low powered GPS jammer (eg <1 Watt) on the Sydney business district would be quite significant.

He noted that perhaps of equal concern to deliberate jamming was the threat posed by the ‘casual terrorist’ – people who buy jammers for various reasons and who then inadvertently jam GPS signals in key locations. Two examples were mentioned. One was a truck driver with a GPS jammer who parked near an airport in the US and caused significant issues for aircraft operations. The second example was the recent police apprehension of Melbourne taxi drivers with GPS jammers. This did not interrupt air operations at the airport, but could easily have done so if the jammer had been operating and the taxi was near the airport.

Professor Rizos highlighted the threat from ‘spoofing’. Spoofing can take many forms, but one is ‘meaconing’ which is the delay and re-broadcast of the GPS signal. Spoofing has perhaps a more sinister mode of operation where the signals can be adjusted to actually deliberately drive a GPS receiver from its selected path to another predetermined location. Professor Rizos gave the example of an experiment in the Mediterranean where relatively simple spoofing technology was used to ‘capture’ and then drive off track the GPS navigation system in a super yacht without alerting any systems on board the yacht.

The International Committee on GNSS (ICG) has recognised the issue of GNSS vulnerability and system monitoring and has made the following recommendations:

- determine Service Parameters to monitor;
- determine what gaps exist in current and planned monitoring and assessment; and
- make recommendations to the ICG-10 meeting (Nov 2015) regarding the way forward with respect to an IGMA Service (or similar).

Professor Rizos noted that first there is the need to define what integrity parameters need to be monitored, and to look at current capabilities in this regard before establishing such an international GNSS Monitoring and Assessment task (IGMA) service. He then posed the question of what really needs to be done to protect, toughen and augment GPS (and GNSS in general) systems?

Professor Rizos discussed the inconsistent way that GNSS is regarded around the world; with some nations regarding it as Critical Infrastructure and others not formally doing so. The international characterisation of GNSS can be summarised as follows:

- US. In the US, GPS is not considered a critical infrastructure.

- Russia. While GNSS is not specifically listed as being Critical Infrastructure, navigation systems in the broad are considered critical technology.
- China. The Chinese GNSS (BeiDou) is regarded as Essential Space Infrastructure.
- European Union (EU). The European GNSS (Galileo) will be designated as Critical Infrastructure.
- Australia. There is no mention of GPS/GNSS in the 2010 Critical Infrastructure Resilience Strategy for Australia, and GNSS is not listed as Critical Infrastructure.

<u>Protection of GNSS</u>. To protect the 'clear and truthful' GNSS signals requires a strong legal response to those who seek to buy or use jammers, with significant effort put into pursuing the prosecution of offenders and with penalties that match the severe potential outcomes of jamming key infrastructure. Also a geo-location system is required for GNSS jammers that results in a high probability of apprehending offenders to neutralise the jammer threat. There also needs to be a ban on transmitters in neighbouring frequency bands, eg pseudolites. Finally, Australia should formally designate GNSS as Critical Infrastructure.

Professor Rizos noted that considerable international (and Australian) effort is now going into jamming detection systems. Typical systems, such as the GNSS Environmental Monitoring System (GEMS) II have demonstrated the ability to determine quite accurately the location of jammers. Australia (researchers at the University of NSW in partnership with industry and DSTO) have been involved in recent field trials of the system with promising results. Additionally, there are proposals to use UAVs as platforms for jammer detection and jammer localisation. However they are still some way from being operational.

<u>Toughen GNSS Receivers</u>. Effort also needs to be put into methods to 'toughen' user receivers to make them more resilient to jammers and spoofers. There are many ways to toughen or harden GNSS receivers and antennas, including:

- Improved GNSS signals and receiver signal processing that allow software to better differentiate between genuine signals and any jamming or spoofing.
- Advanced Receiver Autonomous Integrity Monitoring (RAIM) concepts that take a wide variety of inputs to provide a simple warning to the human operator (or machine) of any degradation in the quality of the GNSS PNT solutions.
- A Controlled Radiation Pattern Antenna (CRPA) technique is considered to be the best GPS pre-correlation protection technique against interference. It consists of an antenna array and a processing unit that performs a phase-destructive sum of the incoming interference signals, this process being equivalent to making nulls towards interferers in the array radiation pattern.
- Ultra-tight integration with inertial measurement units and Chip Scale Atomic Clocks (CSAC) (to detect sudden movements in the GNSS position or time outputs due to jamming).
- Multi-GNSS devices that can use some or all of the international GNSS constellations.
- GNSS signal integrity monitoring service(s) provided by external third parties.
- Use of systems such as the GNSS Environmental Monitoring System (GEMS) II to identify the presence of and localise jamming.
- Signal-to-noise ratio checks to differentiate between weak genuine GNSS signals and variable strength (but likely higher) jamming.

Augmentation of GNSS. Australia should also take a whole-of-Government approach to developing suitable ways to augment GNSS PNT capability, by providing alternate ways of delivering a backup PNT capability to critical infrastructure in Australia. Authorities, Defence and industry need to make their critical systems more capable of using alternate GNSS sources (beyond just GPS) and ensure that interoperability and compatibility are key considerations when specifying the PNT requirements of critical infrastructure. Also there needs to be investment in worldwide GNSS integrity monitoring to better warn of the need to transition to alternate PNT sources.

Australia also needs to be a proactive participant in efforts to develop alternate and independent PNT systems. He noted that the US in particular has been considering the use of e-Loran, a hyperbolic navigation aid, as a backup reversionary system. There are also other land-based systems that will seek to provide an alternate capability over particular regions to ensure continuity of PNT, such as the Locata system.

Locata Corporation is a Canberra-based company that has developed a terrestrial PNT system that replicates and augments the signals transmitted by GPS, but at the 2.4GHz frequency band. It is more resistant to jamming because of the higher power signals from the ground emitters. It also enables centimetre- level accuracy. Designs for low-cost dual-mode GPS/Locata receivers have been developed.

Professor Rizos then outlined the plans for the ‘big four’ GNSS, listing current and future satellite numbers. Also he outlined two Regional Navigation Satellite Systems (RNSS), and several current and proposed Space-Based Augmentation Systems (or SBAS). He noted that all will need to be tracked, all orbits, clocks, biases will need to be computed on a regular basis, and commercial and non-commercial data products will support real-time, as well as precise geodetic applications of these GNSS, RNSS and SBAS systems.

The risk to civil air operations: Airservices perspective – Ms Margaret Staib, CEO Airservices

Ms Staib noted that Airservices has responsibility for *inter alia* airspace management, radio navigation aids, and aviation communications. Thus the risk posed by degradation of GNSS PNT services is within the purview of Airservices. She provided a quick overview of the area of responsibility of Airservices, which covers about 11% of the surface of the earth and which includes hundreds of airfields and an increasing amount of air traffic.

She stated upfront that the threat from GPS/GNSS degradation to navigation and aircraft communications was thus a serious risk, but one that Airservices had done much to mitigate.

Ms Staib explained that the use of space based PNT was critical to the delivery of acceptable air traffic services because of the ubiquitous availability of GNSS/GPS, its inherent ‘bounded’ high accuracy, and flexibility of flight path (and attendant savings) that it offered. This requirement will increase and not decrease over time. GNSS/GPS supports very flexible area navigation and most notably has allowed user preferred routing to be used much more than it was possible prior to the introduction of widespread GPS coverage.

Ms Staib answering a question during the panel session. Other panellists from left to right are Mr Ian Mallett, Professor Chris Rizos, Air Commodore Craig Heap, and Air Vice-Marshal Mel Hupfeld.

Ms Staib noted the installation of the Sydney Airport Ground Based Augmentation System (GBAS) located at the southern end of the main runway at Sydney Airport to provide (effectively) differential GPS high accuracy signals to support automatic landing of aircraft at the airport. Essentially GBAS is differential GPS around the thresholds of specific airfields to give the higher accuracy needed for auto-landings by airliners. Up to recently, GNSS/GPS offered an accuracy level that was (more than) adequate for all operations except Precision Approach, and that is now changing with the GBAS.

She also noted that in the next few years there will be mandatory fitment of automatic Position Reporting capability to aircraft using the Automatic Dependent Surveillance Broadcast (ADS-B) system. ADS-B is an air traffic surveillance technology that enables aircraft to be accurately tracked by air traffic controllers and other pilots without the need for conventional radar. ADS-B uses GNSS/INS position transmitted by each aircraft, together with a ground network of radio stations, to acquire and track aircraft and provide controllers with wide area aircraft positional information. Aircraft also communicate with each other to provide pilots with their own situation awareness of other air traffic.

Ms Staib stated that GNSS/GPS has allowed the airlines to achieve very high efficiencies in optimum tracking to allow for wind and weather at the time of the flight, and any GNSS degradation that necessitated reverting to alternate navigation techniques would certainly affect the profitability of any airline operations that were underway.

She explained that there were still adequate backup systems for air navigation, and that pilots/aircrew are still trained in reverting to non-GPS navigation. Thus from a technical and training stand-point, the GNSS degradation at the heart of this Seminar does not pose a critical vulnerability to the Australian Airspace Management System. She did note that the main issue was the potentially insidious nature of space-based PNT degradation. The challenge is in recognising when the GNSS/GPS data may have been jammed or compromised, and warning the aircrew so they can make a timely transition to backup navigation techniques.

Ms Staib highlighted the constant monitoring of air traffic systems that takes place in the relatively new Airservices National Operations Centre that is located in Canberra. She stated that this Centre is the key to coordinating any emergency arising from a detected GNSS/GPS system degradation. The Centre staff monitors the quality and functionality of key systems including GNSS-based systems.

Ms Staib outlined the GPS threats to safe navigation included atmospheric effects such as ionospheric disturbance/storms. This has not recently been a problem, but has the potential for interrupting PNT services and causing particular problems for Precision Approach (and in particular Vertical guidance).

AVM Osley presenting Ms Staib with an AIN plaque

She also indicated that there could be an inadvertent ‘jamming’ of aviation-related GNSS/GPS signals/receivers that may cause a localised incident. All indications are that civil aviation GNSS/GPS systems have not yet been deliberately targeted in

Australia, but it is certainly possible. The more likely sources of GNSS/GPS jamming are those intended for other purposes such as:

- Radio frequency interference arising from an entity trying to deny GNSS/GPS to some application (eg a University experiment, etc)
- Truck drivers who may use a GPS jammer to defeat truck tracking by their employer.
- Taxi drivers who may wish to defeat a taxi dispatch system.
- By those involved in criminal activities who may wish to defeat Police tracking (eg when stealing a car with a GPS augmented security system).
- By those who wish to defeat encrypted communications.

Ms Staib specifically mentioned the example of GPS jammers carried by civilian vehicles to prevent their location being transmitted back to parent companies for various reasons, potentially causing problems with the US equivalent system to the Ground Based Augmentation System. Although Newark is one of the busiest airports on the East Coast, it is shoehorned into a relatively small physical area, which made finding a good site for the GBAS ground station a challenge. All four GBAS type antennas are within 200 meters of heavy traffic (more than 100,000 vehicles passing the location each day) along the New Jersey Turnpike (I-95). The proximity of I-95 had not been expected to pose a problem prior to installation.

During testing after installation in late 2009, however, the system went into "alarm" mode, requiring system shutdown and loss of service. These events were confirmed to be caused by RFI coming from the direction of I-95 and caused by GPS jammers on passing vehicles. Prior to further software and site modifications PPD interference was observed as often as several times per day. The RFI remains present there today, but the mitigations applied thus far have reduced the frequency of GPS jammer-related incidents to several per week on average.

Ms Staib stated that the solution is to have systems and processes to rapidly identify the GNSS/GPS jamming/interference and to get the aircrew to transition to backup methods of recovery on the ground. All air traffic control officers are able to recover the traffic if there is an incident. It is not expected that alternate Australian air traffic services would need to be provided over a long period in the presence of intensive and widespread GNSS/GPS jamming.

The instances of jamming are expected to be relatively short term; where Airservices would assist where possible in warning aircrew of the threat, safely transitioning the aircraft airborne to alternate means of navigation and air traffic management, assist in tracking down the source of jamming, and work closely with the Australian Communications and Media Authority (ACMA) and the Australian Federal Police (AFP) to resolve the issue. Airservices also recognises that they have a role to play in mitigating the risk of GNSS/GPS degradation through better education of the general public to reduce the instance of inadvertent interference to air navigation.

Ms Staib stated that Airservices already differentiates between those flying with and without GPS integrity monitoring. Those without Receiver Autonomous Integrity Monitoring (RAIM) are given greater separations from airspace and other traffic than those with RAIM.

Ms Staib then outlined the steps that Airservices would go through in the event of GNSS/GPS degradation being detected. She reiterated that the key to an effective risk mitigation and reversion to safe navigation was timely detection of the incident. Detection could occur through identification of abnormal GPS signals (eg signal too strong, a delay in the signal from some satellites, or an inconsistency that is detected by the RAIN test, a step change in position, or mismatch between GPS and INS or radar position, etc).

She explained that once a pilot(s) or the Airservices operations staff detected a GPS-related 'event' aircrew would be advised to revert to alternate methods of navigation, and ATC staff would revert to non-GPS dependant air traffic control procedures. Australian aircrew had adequate training and access to alternate means of navigation to safely navigate in oceanic airspace, domestic overland airspace and in the terminal area. If the event was severe enough the aircraft would be recovered and the GPS degradation would be investigated and corrected before continuing with normal operations.

Ms Staib took the opportunity to briefly explain the 'One Sky' initiative that will 'harmonise' Civil–military airspace management within Australia.

Ms Staib also highlighted the 'social problem' associated with GPS/GNSS jamming and spoofing. GPS is not just used for essential 'high end' navigation and communications – it is ubiquitous, and is used in many non-essential 'nice to have' applications. The general public does not see it as critical infrastructure, but more as a non-essential commodity.

Many people actually see many GPS applications as an invasion of their privacy. Some specific applications (such as GPS use to see where and how truck drivers and taxi drivers drive) are actively disliked, and it is seen as acceptable to procure and use a GPS jammer (in these cases marketed as a personal privacy device) to defeat the GPS. The jamming signals from Personal Privacy Devices may of course cause inadvertent collateral jamming of safety critical GNSS/GPS applications – at locations such as airports.

Ms Staib noted that the General public may have sympathy for some who would use GPS jammers, and might see buying and operating a GPS jammer as a relatively minor issue – when it has the potential to cause potentially life threatening outcomes. Internet usage and norms have led to the situation where some 'hacking' or 'spoofing' of electronic systems is considered a minor issue, or even 'cool' to do. Also jamming and spoofing can currently be done with anonymity and with low risk of being caught. And the penalties are quite low if you are caught. The internet also provides ready access to jammers and ideas, knowledge, parts, equipment, instruction.

Ms Staib stated that we have a challenge ahead in educating people on the potential risk and to ensure that people understand that it is not legal or socially acceptable to jam or spoof GPS. Addressing these social aspects is not going to be easy, especially for a group of technocrats – which is largely what the aviation community is.

Ms Staib concluded by noting that there was also a need to continue to conduct exercises and practice in GNSS degradation procedures, in conjunction with both civil and military users of the airspace. She reiterated that GNSS/GPS use in aviation will expand and not contract because of the low cost, high quality PNT it provides. GNSS/GPS has proven over time to have remarkable performance accuracy, availability, continuity and integrity and has been so good that many consider it infallible. Airservices is actively mitigating the risk of GNSS/GPS degradation, and there is relatively modest risk if the degradation is detected early and a transition made to alternate navigation/communications methods. A key risk however, is the social aspects of GNSS/GPS use and jamming/spoofing – and we all have a role to play in addressing and mitigating this risk.

Managing Risks in the Transition to Satellite Based CNS – Mr Ian Mallett, CASA

Mr Mallett noted that in addition to having a long history in aviation himself, his family connection in aviation went back a significant way – to his Grandfather who served in the Royal Flying Corps in the UK.[3] Mr Mallett stated that he had been working GPS issues with CASA for a couple of decades.

He outlined the topics he would cover, including Position Navigation Timing (PNT) architecture, GPS and augmentations, aviation Communications Navigation Surveillance (CNS), aviation CNS risks, GNSS vulnerabilities, mitigations, and scenario considerations.

Mr Ian Mallett at the podium during his presentation to the Seminar

[3] In fact his grandfather had been a balloon pilot early on and had pilot number #17 dating from 1912.

Mr Mallett stated that GPS had been authorised for civil IFR use since early 1990s. While initially the military were the only ones with access to the highest accuracy, this limitation on access to Selective Availability (SA) was eventually removed in 2000 in the face of civil public pressure. To ensure that potential adversaries do not use GPS, the US Government and US military is dedicated to the development and deployment of regional denial capabilities in lieu of global degradation of the GPS system. To date, GPS has provided excellent performance with continued improvement in accuracy and availability.

The US has made a commitment to the International Civil Aviation Organisation (ICAO) that it will continue to support and fund GPS and the Wide Area Augmentation System (WAAS). Currently, GPS alone does not meet international standards for air transport navigation requirements for accuracy, integrity and availability. WAAS is a US ground based system that monitors and corrects the GPS signals for GPS signal errors caused by ionospheric disturbances, timing and satellite orbit errors, and it provides vital integrity information regarding the health of each GPS satellite.

At this time the US has funding for the introduction of the next generation of GPS satellites known as GPS III.[4] This system will introduce a second civil frequency to reduce the potential for ionospheric error and interference potential. Of note there has been no GPS system wide failure in 25 years.

Mr Mallett noted that over the years there have been many GNSS augmentations and improvements. These have included the following:

- Hybrid GPS/INS Systems. The linking of GPS and inertial navigation systems has matched the independent and autonomous advantages of INS with the accuracy and bounded error advantages of GPS.
- Autonomous Integrity Measurement Extrapolation (AIME). AIME technology compensates for the inherent deficiencies of GPS by integrating GPS and IRS in a unique, patented algorithm. AIME continuously analyses available satellite and inertial signals. If the data's integrity is compromised, AIME automatically uses the aircraft's position history to maintain accuracy and integrity.
- Receiver Autonomous Integrity Monitoring (RAIM). RAIM programs are located alongside the receivers on board the aircraft and monitor the health of the GPS solution and provide warning to the aircrew of degradation.
- Advanced RAIM. A more advanced version of RAIM currently under development.
- Satellite-based augmentation systems (SBAS). SBAS complement existing global navigation satellite systems (GNSS). SBAS compensate for certain disadvantages of GNSS in terms of accuracy, integrity, continuity and availability. For example, neither the USA's GPS nor Russia's GLONASS meet the operational requirements set by the International Civil Aviation Organisation (ICAO) for use during the most critical phases of aircraft flight, in particular final approaches. To solve it, ICAO decided to standardise several GNSS augmentation systems including SBAS. The SBAS concept is based on GNSS

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[4] GPS III is the next generation of GPS satellites, which will be used to keep the Navstar Global Positioning System operational. Lockheed Martin is the contractor for the design, development and production of the GPS III Non-Flight Satellite Testbed (GNST) and the first eight GPS III satellites. The United States Air Force plans to purchase up to 32 GPS III satellites. GPS IIIA-1, the first satellite in the series, was projected to launch in 2014, but significant delays[3][4] have pushed the launch to no earlier than 2017.

measurements by accurately-located reference stations deployed across an entire continent. The GNSS errors are then transferred to a computing centre, which calculate differential corrections and integrity messages which are then broadcasted over the continent using geostationary satellites as an augmentation or overlay of the original GNSS message. SBAS messages are broadcast via geostationary satellites able to cover vast areas. One of the safety risks becoming apparent is that most intelligent transport systems have SBAS as part of their design and assume it is available - Australia being the largest land mass (shortly) that will not have SBAS.

- Multi-GNSS Receivers. These receivers take the signals from multiple international constellations such as GPS, GLONASS, GALILEO, and Beidou.
- Regional augmentation. Regional systems can provide augmented (eg differential GPS accuracy) GPS performance over specific areas.
- Ground Based Augmentation System (GBAS). GBAS has been installed at various locations around the world, including at Sydney Airport. GBAS is differential GPS around the thresholds of specific airfields to give the higher accuracy needed for auto-landings by airliners.

Mr Ian Mallett at the podium during the Seminar

Mr Mallett noted that there had been several equipment and policy improvements to aviation GPS systems, including:

- Minimum Operational Performance Standard (MOPS) DO-253 provides standards for GPS/GBAS.
- Technical Service Orders (TSOs) have been introduced that provide direction on how to install and maintain GPS/GBAS.
- Multi-mode Receivers have been introduced that allow for multiple constellations, and which allow for integration with inertial navigation systems.

  - Integration with inertial systems
- There are policies now on the amount of fault detection required in GPS systems.
- There are also some standards for the interference resistance of GPS antennae

Mr Mallett gave a short history of air navigation improvements. For the first 80 years of aviation, there was almost a sole reliance on dead-reckoning and celestial navigation for overwater area navigation, and Automatic Direction Finding to Non-Direction Beacons for overland and terminal area Instrument Flight Rules navigation.

From the 1960s onwards, the inertial navigation system took over from celestial navigation for area navigation. The advent of triple high accuracy inertial navigation systems effectively removed the requirement for a human specialist navigator on airliners/transport aircraft. The INS was generally the sole means of navigation with no backup beyond dead reckoning.

Mr Mallett stated that since 1995, GNSS/GPS has progressively been approved for increasing use in IFR conditions. It was approved for enroute IFR (with a DME/VOR backup) from 1995. GNSS approaches were progressively introduced from 1998. In 2001 Required Navigation Performance (RNP) approaches were introduced as an alternative to inefficient non-precision approaches. The RNP equipment is GPS based and provides onboard navigation capability that allows crews to fly aircraft along a very precise flight path with an optimum descent profile to an airfield.

Mr Mallett noted that with the rollout of newer GNSS infrastructure that some ground-based air navigation aids were planned to be removed, with more than 200 NDBs, VORs and DMEs to be removed by mid-2016. The remaining ground aids are required to be maintained to support TSO C129 GPS + provide (limited) backup. He noted that TSO C129 require conventional aid alternate. However, Mr Mallett commented that while there may be residual terrestrial nav aids being left as a backup; many aircraft nowadays are not being fitted with ADF/DME/VOR.

In 2006 the sole use of GPS-based systems for IFR flight was approved. To meet requirements you do need a TSO C145/6 receiver and TSO C144 antenna. However, this means that an aircraft equipped this way does not need any alternative DME/ADF/VOR or other navigation equipment on board. This raises the obvious question – what happens if the GNSS/GPS is degraded while enroute in IFR and you are in an aircraft solely fitted with GPS navigation systems.

Mr Mallett explained that the safety analysis done at the time of the 2006 approval showed that even when you take the potential of total GPS failure and other risks into account, using a TSO 145/66 receiver is considerably more reliable than the long standing dependence on ADF. He noted that there never was any requirement for a back up to ADF - despite numbers of total failures.

Mr Mallett highlighted the ubiquity of GPS by noting that after the first GPS approaches were introduced in 1998, there were now 272 airfields with GPS-based Route Navigation procedures and more than 600 RNAV (GPS) Approaches in Australia.

There is no sign of the proliferation of GPS abating, with ADS-B being introduced to Australia and increasing ATC mandates; such as GNSS becoming a mandatory requirement for IFR flight from February 2016. ADS-B will be mandatory from February 2017.

On the communications side, HF remains in service while data link is being used more often along with satellite comms for voice.

Mr Mallett noted that over one billion GNSS units are now in use worldwide. Many of these are multi system with augmentation. Aviation is only a minor user with less that 0.1% being for aviation purposes.

Australia has been a member of the ICAO GNSS panel since 1993. The GNSS panel has very sub-panels that look at the various vulnerabilities and issues associated with using GNSS for PNT. The GNSS panel has a Navigation System sub-Panel (NSP), which includes a 'GPS vulnerabilities' Working Group.

There are many new GNSS core systems that provide the potential for significant redundancy and resilience over a single constellation system. These include:

- GPS III with upgraded satellites and dual civilian frequencies.
- GLONASS, which is being upgraded and which will become GPS compatible.
- GALILEO is an EU satellite system that will start offering first services from 2016. Full completion of the 30-satellite Galileo system (24 operational and 6 active spares) is expected by 2020. It is expected to offer higher accuracy at higher latitudes than the other systems. Low accuracy signals will be available to all, and high accuracy signals (less than a metre accuracy) will be provided to paying customers.
- COMPASS is the second generation version of the original Chinese BeiDou Satellite Navigation System (BDS). COMPASS or BeiDou-2, will be a global satellite navigation system consisting of 35 satellites, and is under construction as of January 2015. It became operational in China in December 2011, with 10 satellites in use, and began offering services to customers in the Asia-Pacific region in December 2012. It is planned to begin serving global customers upon its completion in 2020.

Mr Mallett noted that the end result of this proliferation of international GNSS constellations is that it makes increasing sense to achieve resilience through having a multi-constellation 'hybrid' receiver that can use all satellites in view. Of course this leads to design and certification issues, and the need to retrofit aircraft fleets. Also many of these hybrid receivers are still being developed in concert with development and rollout of the constellation satellites.

Mr Mallett stated that there are aircraft safety issues arising because of aircraft GNSS installations. To date, almost all the GPS 'failures' experienced have been due to aircraft installation problems, or poor filtering , incorrect antenna position or out of date software. New rules have had to be introduced to address the problems with non up to date data bases and data integrity. He said that some of the blame should also go to GPS manufacturers, who have complicated the use of GPS – and quoted the example of at least one case a GNSS pilot's manual of 220 pages, which exceeded the size of the whole flight manual for the aircraft it was installed in!

Also from a human factors point of view, there are also differences in how to operate different GPS receivers for those transitioning between aircraft. Also many civil pilots may be unaware of the susceptibility of GNSS to external threats such as jamming and spoofing, as well as GNSS vulnerabilities such as Interference, and solar flares. Pilot training at most civil pilot training schools rarely includes lectures in GPS susceptibility and degradation, and air training infrequently addresses insidious GPS/GNSS failures.

Mr Mallett highlighted the risk posed by the potential for the US Government at some point in the future to curtail GNSS satellite funding, despite their assurances and best intentions at this time. This could significantly affect the accuracy and resilience of the system if the number of GPS satellites reduced below 24 satellites. In addition to reduced funding, this satellite reduction could also occur very quickly if a peer adversary with anti-satellite capability engaged in conflict with the US.

Mr Mallett also briefly mentioned the risk associated with solar flare and solar disturbances. He noted that a major solar flare activity (reported in the media in 2014 as predicted as a possibility by NASA and known as Solar Max) could potentially occur as soon as 2016, but also noted that there were few GPS issues with recent solar flare activity since the inception of GPS.

Mr Mallett outlined Australia’s position on GPS jammers. He noted that they were illegal in Australia, and that Australia had a very good spectrum regulator and thus protection in ACMA. He noted that other countries are not so fortunate, and signalled Italy out as an example where the spectrum protection was quite weak. In the United Kingdom, the purchase of jammers is legal, although the devices’ use is prohibited.

Despite the Australian ACMA protective measures and associated laws, the GPS jammers continued to be available on the web for about $40 upwards as ‘personal privacy devices’ and were being bought by cab drivers and truck drivers to circumvent and render inoperative the GPS tracking devices in taxi-cabs and trucks for various reasons.

He mentioned the interruption in GPS services around Sydney airport recently, as well as other examples from overseas. While predicted interruptions to GPS services (eg due to constellation issues, or outages in specific satellites and ground systems) can be accounted for and warnings provided to pilots to not use the GBAS Landing System (GLS) approaches; there is still a risk of an intermittent and not predicted error being induced into the system by deliberate or inadvertent jamming.

He reiterated that not all GPS problems arise from jamming or spoofing and that more common was problems arising from poor GPS installations or failure to update system software. Also he noted that the Airservices inflight publication mentioned that any CNS(GPS) interference or suspected interference was to be reported.

Mr Mallett noted that one solution for potential errors in GNSS systems was to ‘bound’ them with other independent and self contained navigation aids or to provide backup systems. He discussed the potential backup navigation/PNT systems including:

- Existing ground-based navigation aids including DME, VOR and RNAV.
- Smaller, cheaper and more accurate inertial navigation systems.
- E Loran, which he considered could take up to 15 years to get into operational service.
- Various hybrid GNSS receivers are being developed that can see Multiple GNSS systems, and would track all satellites in view.

Also there was the potential to make GPS systems more resilient through better antennae design, and through the wider use of hybrid multi-frequency/multi constellation receivers.

However, a problem was that even if a decision was made today to change the policy on essential ‘backup’ navigation systems in aircraft, it would require about 15 years to have the world aircraft fleet modified due to the expense and long lead times associated with developing installations and upgrading aircraft.

Overseas alternate/backup navigation solutions are not viable in Australia. For example the US uses a VOR every 100nms as an interim backup solution. This is to provide an emergency safe recovery system only if GNSS is degraded while aircraft are inflight. It would be cost-prohibitive for Australia to have a VOR-like system installed every 100nms!

Mr Mallett indicated there were other solutions, including local Australian ones that were worth looking at. He specifically mentioned Locata Technology in Canberra. Locata has developed a backup ground system that replicates the signals issued by GPS at the 2.4GHz band. With much higher power levels in a non-interfering frequency band and centimetre accuracy, while still working with GPS, this seems to make for a really suitable potential candidate for GPS back-up in the event of jamming, among many other potential applications. With little further development there could be low-cost dual mode GPS/Locata receivers available.

Mr Mallett noted that as of today there was not a good system for the reporting and characterisation of incidents. The current system lacked mechanisms to make people comply and report incidents in a timely manner, and it has limited means of identifying where the source of the jamming or spoofing might be. Notwithstanding, Mr Mallett noted that most airline aircraft and ATS have protection and/or alternatives to GNSS disruptions whether intentional or unintentional.

Mr Mallett provided some suggested actions to mitigate the risk to Australian aviation posed by degradation of GNSS. Specifically he suggested:

- Developing an Australian common, agreed and standardised GNSS reporting system.
- Develop a national interference identification and location system.
- Participate in international efforts to protect the integrity of spaced-based GNSS navigation systems and to prevent encroachment on associated frequencies in the spectrum. This would also include an international standardised way of reporting of GNSS degradation issues. Supporting international efforts to improve GNSS receiver/antennae designs and to develop viable, cost-effective GNSS alternatives

Mr Mallett summarised by stating that Australian IFR aircraft have good protection against most GNSS threats. He opined that the Air Traffic Management system in Australia, and Airservices, was reasonably well prepared to deal with the threat, but there were several initiatives that would further enhance the Australian and international response. This included introducing a national reporting and geo-location system for GNSS interference and continued research and development into alternate technologies and multi-constellation solutions for all users.

The Risks to Military Air Operations – Air Commodore Craig Heap, Director General Aerospace Development

Air Commodore Heap used an indicative scenario to illustrate the impact of GNSS degradation on military air operations. The hypothetical scenario was in the South China Sea, where a relatively minor increase in tension in the region could lead a state or non-state actor could potentially cause deliberate or inadvertent disruption to GNSS in the area, as well as potentially localised jamming of GNSS within the Australian region.

Air Commodore Craig Heap engaging with the participants at the Seminar

He outlined the likely impact on military air operations, including the need to revert to less accurate navigation techniques, and the complexity that would add to military air and maritime operations in and around the various overlapping international borders, exclusion zones and sea boundaries. Also the compilation of common air and surface pictures would be greatly complicated without a ubiquitous common time and an agreed position reference system, and search and rescue operations may be compromised, especially in the presence of spoofed or erroneous beacon positions. A significant portion of military communications would be degraded, including satellite communications and some secure communications where a common time signal was critical.

Air Commodore Heap noted that from a military perspective, a key issue would be positively identifying the source of the interference, as it may constitute an act of war, or at least be a consideration in the Rules of Engagement being used by the Coalition/Australian forces in the hypothetical scenario. Much effort would need to be applied to determining the method and characterisation of the interference. Is it localised or broad area? Is it jamming locally with noise, or attacking satellite and denying broad area? Is the interference due to RF jamming or a cyber attack?

If spoofing is used, it may take considerable time to determine that it is not natural interference or a system problem. If the GNSS degradation is to be considered a potential act of war, then a system of detecting and characterising the interference will need to be done to a level to meet international and media scrutiny.

Air Commodore Heap stated that military aircraft were designed to be resilient in adverse Radio Frequency (RF) environments, and to have several reversionary modes in case of electronic warfare or battle damage denying them their prime means of operation.

He also explained that military aircraft have hybrid/backup navigation systems such as GPS/Inertial Navigation Reference Systems with Kalmann filters and other sophisticated technologies to automate the reversion to an alternate means of navigation as prime means are denied. The GPS systems used are more resistant to jamming than civilian systems and have enhanced antenna design and military software code.

Air Commodore Heap noted that this software includes selective availability and anti-spoof modules. Many military aircraft have ground mapping radar which can be used to check and calibrate the navigation and targeting solution. Additionally they can compare navigation and timing references over extended line-of-sight ranges through the use of Link 16 to exchange key parameters.

Safety-of-life systems are heavily dependent on GPS and satellite technology. If GPS denial or degradation activities are present the potential for shipping accidents in such a high traffic environment as the region to Australia’s north is high. Merchant vessels rely heavily on GPS with very few fitted with Inertial Navigation Systems. They do possess radar fixing functionality but this is of little use in blue water.

Most have Automatic Identification System (AIS) which is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships, AIS base stations, and satellites. When satellites are used to detect AIS signatures then the term Satellite-AIS (S-AIS) is generally used. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport. Thus if GNSS is degraded then the AIS picture and collision avoidance functionality is not available beyond VHF line of sight.

Air Commodore Heap noted that most military aircraft were designed to minimise the potential effects of jamming and spoofing of RF signals. In the case of GNSS and satellite communications degradation they could use High Frequency radio communications for Beyond Line of Sight communications, as well as Line of Sight relays through manned and unmanned platforms. Also the military antenna design for GNSS was such that it semi-directional and limited the impact of terrestrial GNSS jamming.

He also indicated that the resilience of military aircraft communications and navigation meant that it was likely that a role for military aircraft would be to support the continuity of some civilian operations through:

- re-establishing and maintaining a common operating picture for air and surface civilian traffic in remote localities where civilian surveillance and navigation becomes degraded.
- Providing communications support for civilian search and rescue operations at sea.

While the GPS Timing reference is the prime means of referencing secure communications systems, and satellite communications was important for operational command, the Australian Defence Force (ADF) could operate tactically without it, and could use other means to generate a time reference.

Air Commodore Heap asked the rhetorical question; so what is the ADF reaction/response to a GNSS degradation incident or a scenario such as the one posed earlier? He noted that the key issue up front would be determining who was responsible for the jamming/spoofing and how this now impacted the ROE and whether it constituted an act of war under International Law. This would largely determine the immediate military response. Quite obviously, given the potential risk to civilian lives, and economic impact, the ADF and Australian Government would be closely considering responses along the lines of self protection and collective self defence.

Tactically, much effort would go into detecting and localising any persistent jamming. The ADF has the ability to then conduct either kinetic or non-kinetic action on the source of the threat. At the same time, the civilian and military air and maritime operators would be warned of the threat through the normal Notice to Airmen and Notice to Mariners system. At the strategic level there would be a number of Whole of Government options that might be pursued, including diplomatic pressure, approaching the relevant areas within the UN, and applying pressure at the Coalition level.

Air Commodore Heap raised the question - so what can we do to mitigate these risks? The answer lay in increased redundancy. The fragility of space reliant systems may mean that deliberate GNSS jamming or disruption may not be obvious or detected immediately. Thus the ADF needs to plan on working in a GNSS degraded environment for at least a reasonable time period of several days. Thus there needs to be an ongoing emphasis on reversionary navigation and communications training, and the development of GNSS degradation tactics and procedures for use across military and commercial stakeholders.

Air Commodore Heap did note that the Air Force approach to air operations – namely mission command – did provide some resilience to GNSS disruption of longer range communications. Mission command relied on the Coalition Force Air Component Commander issuing direction on what he wanted the various air elements to do, who were then responsible for executing the mission – even in the absence of further direction.

He opined that any adversary would be reluctant to target systems that impact their own military capability. The utilisation of civil systems may appear to provide greater risk, however if hostile actors are reliant on those same systems for themselves then they may actually target military systems but leave some civil systems unhindered. This also indicated why a GNSS receiver that can interrogate most international constellations would probably continue to be useful despite hostile action.

Air Commodore Heap stressed the need to integrate Defence and civilian efforts in the area of mitigating the GNSS degradation risk. This includes the need to take a Whole of Government approach where the capabilities and expertise of the various departments, such as AFP, Defence, Airservices, Attorney-General, CASA, AMSA, etc are used optimally to respond to any GNSS degradation event, and a common and interoperable planning and operations environment is used. A regular review of ADF, Defence and WOG operational plans is required to validate the actions in the event of a space denial, and educate key areas of government. Exercises, initially desk top, potentially followed by more realistic 'counter terrorism' like exercises will be required to ensure the nation is prepared for a spaces systems denial event.

Air Commodore Craig Heap making a point during the panel session

Air Commodore Heap noted that GPS/SATCOM was fundamental to the economy. Australia was critically dependant on maintaining cost-effective sea lines of communication. In Europe it was assessed that 6-8% of GDP was reliant on GPS, and Australia would likely approach that figure in the future if not already.
Thus the impact of a scenario similar to what he had outlined would be felt at national level.

Military aircraft are generally better equipped than most to deal with environment, and could actually provide some support to Government agencies and commercial entities to improve business continuity if a GNSS degradation incident occurred. For example, an AP-3 and Wedgetail Airborne Early Warning and Control (AEW&C) aircraft operating around the Australian coast during a GNSS degradation event could assist with compiling an air and maritime common operating picture that could be passed to Airservices and AMSA. Training and exercising space denied environment will provide more a more robust whole-of-Government capability and response.

Police and emergency operations in a space-denied scenario: An AFP perspective - Commander David McLean, Acting National Manager High Tech Crime Operations, Australian Federal Police

Commander McLean opened by noting that the hypothetical scenario of having GNSS and satellite communications degraded over mainland Australia would present a significant challenge for the AFP at this time and for Australia's 'first responders'/emergency services more broadly. He noted that there was a very real risk posed to AFP (and other emergency) operations by the intentional or unintentional use of GPS jamming or spoofing.

He stated that the key questions that the AFP would need to address in order to optimally respond to a similar scenario in the future would be:

- How do we define the risk in terms that are meaningful and can be addressed?
- What is the likely effect on AFP (and more broadly Government) Business Continuity Planning (BCP)
- What mitigation strategies do we potentially have?
- What could the AFP contribution be within the overall Whole-of-Government response to GNSS degradation?

Commander McLean noted that the AFP had only made a nascent start on formally defining and addressing the risks to AFP operations associated with GNSS/Satcom degradation over Australia. He stated that there was a lack of an AFP centrally-based register for such events. What eventually needed to occur was that the potential vulnerability of AFP geo-reference, IT and communication systems should be examined holistically to determine the risk.

However, he stated that based on initial analysis the AFP believed that the AFP radio network should still function, with most systems able to revert to an internal clock, at least for operations in the shorter term. The AFP would maintain a 24 hour national technical capability response, and would continue to liaise with communications system hardware manufacturers to ascertain the likely effects of GNSS/PNT degradation on extant and future communication systems.

Commander David McLean presenting at the Seminar

Commander McLean stated that extended outages could potentially cause problems with AFP communications due to timing drift or system shut down. ACT Policing is highly dependent on communications to respond effectively and so this is a significant concern. Also such an outage could cause problems with AFP technical surveillance and monitoring. GNSS /GPS outage would hinder online surveillance and tracking as it is GPS dependent.

However, he noted that there are alternatives available such as physical surveillance options. Physical surveillance options, while possible, are expensive and personnel intensive. They also have workplace health and safety implications. The AFP may need to explore alternatives that involve the mobile network.

Commander McLean stated that there may potentially be issues with the admissibility of evidence due to timing drift. There have been recent cases around the world where evidence provided from two sources (one using GPS trimming and the other using a wristwatch timing that was out by several minutes) resulted in evidence being not admissible. This focus on exact timing tags for evidence is likely to become more important given the prevalence of GPS linked to phones and cameras. The AFP can tolerate short-term outages but longer-term is more problematic.

The impact of GNSS outages at airports and other transport hubs is likely to be significant for AFP operations, as discussed by previous speakers. He noted that more work is needed on specific Standard Operating Procedures or emergency management plans for this issue. Also there could be significant impact on offshore/remote AFP deployments with degraded positioning/situational awareness and communications.

Commander McLean stated that a key mitigation strategy would be to work with Defence and other agencies to determine ways to better characterise the risk from GNSS degradation, and optimise the response from a whole of Government perspective, and then to practice the scenario regularly. The risk posed by a degradation in communications can be somewhat mitigated by embedding command decision makers and technical expertise in the field. Also the AFP may need to reinvest in close range UHF and longer range VHF.

A situation where a potential adversary may seek to confuse and deny AFP may occur with a Close Personal Protection (CPP) situation. A GNSS/communications denial event could impact this scenario, but could be mitigated by advance pre-planning and the practice of techniques including non-technology based communication.

Commander McLean indicated that the AFP would use extant risk management processes to minimise *ad hoc* responses. The AFP data network has its timing capability delivered through external provider and so Voice Over IP (VOIP) was likely to be adversely affected. Alternate communications infrastructure could be stood up, but first the AFP needs to define what is mission critical - such as voice being essential, but data secondary and video just ‘nice to have’.

Commander McLean stressed that a collaborative response to the risk was essential across the Government agencies. The AFP international operations are critically dependent on interaction with other Government entities, and they needed assured access to entities such as the Attorney General.

For the way ahead, Commander McLean said the AFP would leverage technical contacts, and would seek to address this risk *inter alia* in Joint forums and planning exercises. There was a need for the AFP to have access to systems that could provide an alert for GNSS degradation, and which could detect those who might be involved in jamming or spoofing. Thus the AFP would need to consider interoperability with any jamming geo-location technologies and capabilities implemented by Defence or other Government agencies. The AFP also needs to do effective mapping of the technical and organisational implications of an outage, and ensure this is addressed in the AFP risk register.

Any domestic GNSS jamming or spoofing event would be clearly within the judicial zones of Australia, and thus implies potential Commonwealth and State policing responsibilities and responses. The AFP should aim to develop the capability to locate shutdown any GNSS jamming or spoofing agent as soon as possible due to the risk to life and property. The AFP Technical Operations staff would be at the forefront of any AFP response, and the AFP more broadly would back them up with other law enforcement methodologies while mitigating any risk posed to other AFP operations.

Air Vice-Marshal Osley presents Commander McLean with an Australian Institute of Navigation plaque in appreciation of his support to the Seminar

Commander McLean closed by stating that there are many challenges ahead in combating the enduring threats of cybercrime. He feels that the AFP is up to the challenge, but that they also need to continue working on their capacity and capabilities to remain one step ahead of criminal groups.

Risks to Military Land Operations in a Space-Degraded Environment – Major General Gus McLachlan, Head of Army Modernisation and Strategic Planning

Major General McLachlan noted that the Australian Army was reliant on decision superiority, rather than mass or technical superiority, for its decisive edge. To prevail in future land/Joint conflicts, the Australian Army would need to match, and preferably exceed, the 'localised' adversary through decision superiority and the effective delivery of precision fires. Any adversary would know of the importance of decision superiority for Australian forces, and could be expected to target the capabilities that enhance situational awareness – including space based systems.

Major General McLachlan stated that the ADF already had some experience in the Middle East with an enemy that tried to disrupt navigation and communications capabilities. However, we should expect this to occur on a more significant scale in any future conflict, where the enemy will see it as having an asymmetric effect on the capabilities of Coalition/western combat forces.

Major General McLachlan discussed the vulnerability and resilience of land military capabilities from both a tactical and a strategic level. His overall summary was that the Army had made a start on building in resilience to the effects of degradation of space based systems, but the Army did not yet have a complete answer and that there was much more work to be done.

Major General Gus McLachlan presents to the Seminar

Major General McLachlan indicated that resilience could only be built in by providing some redundancy in systems, and through appropriate exercise and training. He used the tactical communications net for Australian armoured vehicles as an example where some redundancy and thus resilience was being built in by having a hybrid system for communications (that included a terrestrial web). He also noted that the Australian Army was returning to use of the HF radio system as a non-space based ‘backup’ for longer range tactical and strategic communications. He also used the example of the US Army which is testing a localised 4G network.

Junior leaders must be able to navigate without GPS. Australian armoured vehicles still have inertial navigation systems in them. In the ISR sphere there have been several uncoordinated advances. We need a commonwealth of systems, and not a federated system. Need a core of Force Design.

Major General McLachlan rhetorically asked the question…how willing are we to disrupt major exercises and high fidelity training to test our forces for space-denied operations? For example, after getting significant high end US and Australian forces together at great expense for Talisman Sabre there would be a great reluctance to have Exercise Control turn off the satellite communications and space-based timing and positioning.

However, Major General McLachlan stated that we will have to bite the bullet and test ourselves in high and low end exercises and training drills. The only way we will be able to deter an adversary is by being able to fight through any disruptions – including demonstrating this in open forums that we can do this in exercises. He also stressed the importance of ensuring that land forces practice this in exercises with Allies and with organisations such as the AFP.

In question time, Major General McLachlan noted that a 'space free day' was inadequate to test the resilience of a military force, and that there needed to be at least a period of 72 hours of degraded space based services to test the forces. Also this drive for resilience, and the testing of it in exercises at the Joint level belonged in the domain of VCDF and CJOPS.

Maritime operations in a satellite navigation/communications degraded environment – Mr Nick Lemon, Australian Maritime Safety Authority

Mr Nick Lemon stated that his presentation would cover the increasing need for (and importance of) resilient positioning…and modern communications; e-navigation - a new paradigm for maritime navigation and communications; and innovations and the future.

He noted that there had been an exponential improvement in navigation techniques and technology, along with accuracy, over the last few hundred years. The maritime sector today comprised many sectors (e.g. shipping, offshore oil and gas, fishing and recreational users). A wide variety of ships carry solids and liquids in bulk, break bulk, containers, vehicles (roll-on roll-off), LNG and people (cruise ships). High value and high risk cargos such as oil, gas and people tend to lead to more rigorous attention to safety standards.

Mr Lemon takes the podium at the Seminar

A modern trend was to reduce crew numbers as much as possible, and this had resulted in issues including lack of rest and fatigue, competency of crews and the need to crews to work in cross-cultural situations.

The complexity of enhancing maritime safety was increased by the relatively large numbers of stakeholders, including ship builders, owners/operators, crewing agencies, cargo interests, insurers, classification societies, training institutions, regulators and authorities, financial institutions, the general public etc.

Mr Lemon stated that shipping commodities from Australia represents about a fifth of the global shipping task. Australia's ports handle around 10% by value of the world's seaborne trade. Over $400 billion worth of international cargo is moved annually (2013-14 data) - 99% of this by sea. At any one time, some 7,000 ships are in Australia's EEZ.

Maritime activities that rely on dynamic positioning place a high demand on high accuracy GNSS PNT. A wide variety of craft such as work boats, Anchor Handling Vessels, Remotely Operated Vehicles, shuttle tankers, Floating Production and Storage Off-take vessels, cable-laying vessels and drill rigs. The main challenge is to maintain position, move along a predetermined track or precise location of infrastructure. The driver for precise/accurate positioning is more efficient operations, reduced fuel consumption, optimal deep water drilling, pipe laying on track, precise anchor placement.

Some operations now cannot be performed by humans without precise navigation instruments and indicators. Manoeuvring large gas carriers and cruise ships requires precise measurement of movement (e.g. rate of turn and lateral velocities of the bow and stern). This means the pilots manoeuvring such vessels need GNSS enabled technology, combined with Inertial Motion Units and rate gyros, in order to measure movements that the human eye cannot perceive.

Mr Lemon outlined some of the maritime industry concerns and challenges, which included risk of losses and groundings due to navigation failings of various kinds. The Allianz Safety and Shipping Review 2015 indicated that 2014 losses (75) were down 32% on 2013 (110), but the primary cause of losses remained avoidable and related to poor navigation, including foundering (65%) and groundings (17%).

An overreliance on electronic navigation was a rising safety concern. Some lessons were being learned with respect to ECDIS that needed to be fed into training and into the design of new systems. Of note, it was seen that automation, while improving the economics of shipping, was also a pathway to new types errors. The factors that degraded safety including automation bias, an overreliance on automation, attention tunneling, loss of human situation awareness (SA). A study was cited that showed a positive correlation between loss of SA and increasing level of technology.

Mr Lemon gave some examples of GPS vulnerability in the maritime environment. The first example was failure of a GPS satellite clock in January 2004. On January 1st, 2004, a GPS clock failure occurred suddenly onboard a GPS satellite with the signal being transmitted for hours after that. The unhealthy flag of its navigation message, used by the receivers to discard its measurements from the navigation position computation, was only raised several hours after the occurrence. GPS receivers were affected differently depending on their type and location, but some of them were affected significantly without any warnings being displayed.

Mr Lemon also noted that natural phenomena can affect space-based services, and that in December 2006 a solar flare affected GPS receivers.

He also mentioned a more recent GLONASS outage that occurred on April 1, 2014, when all GLONASS satellites started to transmit wrong Broadcast Messages (BM). The satellite positions derived from these BM were wrong by up to ± 200 kilometers in each of the three coordinates. The problem disappeared after an hour (after two erroneous BM) for two GLONASS satellites; for other satellites, the problem lasted much longer: up to 10 hours. The GLONASS event was one that we might have described as “such a thing can never happen.”

Another incident raised by Mr Lemon was the 1995 grounding of the ship the ‘Royal Majesty’. It was a 32,000 DWT, 600 foot long cruise ship that was en route from Bermuda to Boston in June 1995. A loose GPS cable connection from flying bridge to wheelhouse was found to be at fault. The vessel was on DR mode for several hours and ran aground on shoals 10 nm from Nantucket Island, off Boston. The lessons to be learned from this incident centre around a ship’s bridge staff being able to detect when automated position inputs start to fail.

Mr Lemon outlined a typical scenario where a large, modern container ship is making port after an ocean passage. If GNSS is denied there would be an Electronic Chart Display and Information Systems (ECDIS) alarm and an indication of ‘loss of position fixing’. The unit would revert to dead reckoning mode. The Automatic Identification System (AIS) would provide degraded position information and due to the reliance AIS places on GPS timing to operation the AIS system would eventually fail. As a result there would be a lack of ship position reporting and Vessel Traffic Services (e.g. harbour traffic control systems) would have vastly degraded information to work with. The Global Maritime Distress and Safety System (GMDSS) equipment would have reduced efficiency of safety and distress communications.

Ships would still be able to navigation with radar and compass information and the speed log would provide speed through the water. Gyro compasses would continue to work – but with no automatic speed and latitude inputs. What is likely to be a major issue is the human response to alarms and how the reversion to manual methods is affected. This has tended to be the weak link in the safety chain.

Generally, once the navigation degradation has been recognised, the crew’s main challenge will be to successfully revert to a safe mode of manual navigation. Given that in many ships manual navigation techniques are seldom practiced this is a major problem area.

Mr Lemon stated that if there was an interruption to GNSS then the maritime authorities would be faced with more complex and less accurate vessel tracking, which would have an impact on the flow of services. The Vessel Traffic Services would probably be unable to maintain a highly accurate maritime surface picture of vessel movements. There may also be some degradation of terrestrial based maritime navigation aids such as synchronised lights (e.g. port and starboard channel markers that used in many ports today).

The GNSS degradation would be a particular concern in the oil and gas industry where precise positioning is very important and would be jeopardised. It would also complicate and degrade sub-sea survey and construction, and the establishment phases of any drilling and sub-surface operations.

The impact on the dynamic positioning maritime industry would be less profound, as they have established mitigation and reversionary methods. However, they may have to stop operations if they rely on only one system with implications for cost-effectiveness of operations.

There is a growing awareness in Australia of the increasing reliance being placed on space-based PNT services:

- Attorney General's Department (Space Community of Interest)
- Geoscience Australia (PNT Working Group)
- Geoscience Australia (National Positioning Infrastructure – Advisory Board)
- IGNSS Conferences – e.g. next one being held in July 2015 in Queensland.

E-navigation is a Strategy developed by the International Maritime Organization (IMO), a UN specialized agency, to bring about increased safety of navigation in commercial shipping through better organization of data on ships and on shore, and better data exchange and communication between ships and the ship and shore.

The core objectives of e-navigation are to achieve:

- mutual compatibility and interoperability of equipment, systems, symbology and operational procedures,
- safe and secure navigation of vessels,
- vessel traffic organization,
- enhanced communications, and
- enhanced management of information.

Mr Lemon noted that e-navigation is also about the IMO exercising coordination over the increasingly rapid introduction of digital technology for the navigation of vessels. Further, as the process of navigation has become less taxing due to automation, e-navigation is less about navigation and safety, and more about opportunities for global supply chain efficiency. In essence, we are no longer just concerned about 'where we are', but more about 'where everyone is, and what are they doing'. In 2020, the issue will all be sea traffic management (STM). STM will require a common and shared situational awareness about how all users of the maritime domain will interact.

E-navigation and modern maritime operations in general places a heavy load on resilient and high bandwidth communications. There is an increasing demand for digital data exchange in maritime radio communications to service new functionality. The systems used include:

- Automatic Identification System (AIS) detection by terrestrial receiving stations and also by satellite
- Digital Selective Calling (DSC) is a semi-automated means of establishing initial contact between stations. Once contact is made, communications on a nominated VHF or HF frequency should be used to pass messages.
- Navigational Telex (NAVTEX) is an international automated medium frequency direct printing service for the delivery of navigational and meteorological warnings as well as urgent maritime safety messages for ships.
- INMARSAT & potentially IRIDIUM (Satellite) are commercial satellite communications systems.
- HF and VHF can be used to pass data and for voice transmissions.
- 3G and 4G are wireless internet standards. The G stands for 'generation', with 4G being up to 10 times faster than 3G for the transfer of data. 4G networks cover a smaller area than 3G and sometimes have shorter range. But all 4G receivers can operate in a backup mode on 3G.
- WIMAX refers to interoperable implementations of a family of wireless network standards ratified by the WIMAX Forum.

Mr Lemon suggested that e-navigation may result in more resilient PNT options, to provide:

- Independent and dissimilar (low frequency, high power) to GNSS
- Similar levels of performance to GNSS
- Support all phases of navigation
- Potential for world-wide deployment

Mr Lemon addressing the participants at the Seminar

One such system, e-LORAN, has been developed and trialed by Trinity House, UK in 2013. The trials were considered a success and demonstrated the automatic and seamless transition of various critical applications.

Mr Lemon opined that what is needed is a variety of systems, optimized for different tasks and parts of the voyage. He raised the concept of the 'maritime cloud' which he stressed was not a storage cloud ..nor is it cloud computing. It is an emerging communication framework for efficient, secure and reliable electronic information exchange between authorised stakeholders. This 'maritime cloud' concept fits in neatly with the IMO's vision for e-navigation.

Mr Lemon stated that AMSA recommends the use of independent information to check and confirm navigation information from GNSS. An independent terrestrial PNT system for maritime use, such as e-LORAN could provide increased resilience for positioning in terms of accuracy, integrity, availability and continuity. An alternative system could provide a seamless transition to a complementary service if GNSS happens to be unavailable.

Mr Lemon said that while we may understand some terrestrial back-up systems are being considered around the world, we need to exercise caution against the use of differing PNT systems in different regions. This would cause new risks for marine navigation, as mariners would need to change their methods and practices when navigating between different regions. AMSA recommends such solutions should as far as practicable be applicable worldwide and not result in regional differentiation.

Mr Lemon receives an Australian Institute of Navigation plaque from Air Vice-Marshal Kym Osley at the conclusion of his presentation

Satellite systems are not infallible – they can and will fail. So there will be an ongoing quest for resilient and backup positioning, navigation and timing services. There is the potential for other systems to provide some reversionary capability such as e-Loran, which is a modernised version of LORAN. This is a terrestrial system – that is independent and dissimilar to GPS. However, it would still need to meet the IMO accuracy, availability, continuity and integrity requirements. AMSA's existing Differential GPS (and AIS) infrastructure could also potentially provide ranging and timing services as a backup.

In closing, Mr Lemon stated that at the start of a period of degraded PNT – there is significant potential for accidents and incidents (due to the role of technology (ECDIS and ARPA radar) and the human factors aspects of situational awareness. Once users are aware of the problem, and with some time to adapt, general ship navigation can continue relatively safely, perhaps with the exception of some high accuracy dependent operations (e.g. oil/gas, limited port operations with tight tolerances etc).

VTS and maritime authority situational awareness, including AMSA's Rescue Coordination Centre, could potentially be degraded (due to increasing reliance on satellite and terrestrial AIS information). The impact on VTS and maritime authorities is likely to be worse in the future due to e-navigation developments, such as a maritime digital infrastructure with increased reliance on satellite PNT and communications. There would be implications for some supply chains, but it is hard to quantify. If no catastrophes occur at the start of a period of PNT degradation, then the impacts are likely to manageable.

Seminar participants during the Seminar lunch break

Seminar Participants during the lunch break

Risk to Maritime Operations – A Navy Perspective – Commander David Prentice, RAN, Acting- Director General Navy Communications and Information Warfare

Commander Prentice highlighted the progress Navy had made in moving to a highly networked force, but one that was perhaps now more vulnerable to the risk posed by GNSS and satellite communications degradation.

The maritime capability being developed by Navy was underpinned by secure networks that rapidly allowed information to be transferred tactically between ships, as well as to other ADF and Coalition assets, and strategically back to headquarters. This rapid transfer of information results in increased situational awareness.

To achieve this situational awareness and networking requires the effective use and linking of a number of systems that all depend at some point on accurate position, navigation and timing signals; most of which are normally obtained from GNSS. These RAN onboard systems include NDS/WECDIS, Command Support/Combat System, Weapon Systems, Surveillance Systems, Radios and Crypto. Commander Prentice noted that 116 separate systems have a GPS feed in the LHD. The Battle Space needs to be networked to allow all source information exchange.

Commander Prentice highlighted how the RAN fleet network would degrade under circumstances where GNSS degradation caused navigation and communications systems to go offline.

Under the situation where there was no jamming or interference, the fleet would operate in the fully networked mode. This was seen as ‘Normal Operations”. This scenario incorporates all information links as operational. Traffic flows via "least cost paths"

Commander Prentice at the podium

Under less severe GNSS degradation, operations could continue in a Restricted Environment – one or more of the units participating in the LOS/BLOS Subnets do not have organic access to SATCOM for reachback and therefore must use the LOS/BLOS connection to use a SATCOM connected ship to bridge them back to the shore.

In a Satellite denied environment, no participant within the LOS/BLOS subnet have access to shore. Requirement to share information between the TG remains.

To mitigate the risk in these scenarios, there needs to be not only effort put into resilient equipment and training, but also appropriate policy and doctrine. This is being progressed in the areas of C2D2E, MODILE, MANET and PNT.

Commander Prentice stated that resilience and alternatives to GNSS PNT were being explored through the the Five Eyes community. The Five Eyes community in particular was "…putting new physics, new devices, and new algorithms on the job so our people and our systems can break free of their reliance on GPS…'. Some examples of how this is being achieved includes:

- Adaptable Navigation Systems – ANS
- Microtechnology for Positioning, Navigation and Timing - Micro PNT
- Quantum Assisted Sensing and Readout (QuASAR)
- Programme in Ultrafast Laser Science and Engineer (PULSE)

- Spatial, Temporal and Orientation Information in Contested Environments (STOIC)

Adaptable Navigation System (ANS). ANS aims to create better inertial measurement device by using cold-atom interferometry, which measures the relative acceleration and rotation of a cloud of atoms stored within a sensor. ANS addresses three basic challenges through its Precision Inertial Navigation Systems (PINS) and All Source Positioning and Navigation (ASPN) efforts: 1) better inertial measurement units (IMUs) that require fewer external position fixes; 2) alternate sources to GPS for those external position fixes; and 3) new algorithms and architectures for rapidly reconfiguring a navigation system with new and non-traditional sensors for a particular mission.

Commander McLean, Major General McLachlan, Commander Prentice and Mr Nick Lemon during the afternoon Panel Session at the Seminar

Micro-Technology for Positioning, Navigation and Timing (Micro-PNT). The goal of the program is to develop technology for self-contained, chip-scale inertial navigation and precision guidance for munitions as well as mounted or dismounted soldiers. Size, weight, power, and cost are key concerns in the overall system design of compact navigation systems. Breakthroughs in micro-fabrication techniques may allow for the development of a single package containing all of the necessary devices (clocks, accelerometers, and gyroscopes) incorporated into a small (8 mm^3) low-power (1 W) timing and inertial measurement unit. On-chip calibration should enable periodic internal error correction to reduce drift and thereby enable more accurate devices. Trending away from ultra-low drift sensors towards self-calibrating devices will allow revolutionary breakthroughs in PNT technology.[5]

Program in Ultrafast Laser Science and Engineering (PULSE) . This Program uses pulsed laser technology to significantly improve the precision and size of atomic clocks and thus enhance navigation and timing accuracy as an alternative to GPS. The expected outcome of the program is to develop novel sources of radiation that improve upon existing state-of-the-art performance, size, weight, and power. In particular, PULSE aims to develop devices and techniques that will result in low phase-noise microwave oscillators, practical optical time/frequency transfer techniques, tabletop sources of high-quality secondary radiation and high flux isolated pulses, and other Defence -relevant applications.

Spatial, Temporal and Orientation Information in Contested Environments (STOIC) is a Defense Advanced Research Projects Agency (DARPA) program that is currently under development. DARPA is soliciting proposals for the STOIC program to develop PNT systems that provide GPS-independent PNT with GPS-level timing and positioning performance. STOIC comprises three primary elements that when integrated have the potential to provide global PNT independent of GPS: 1) long-range robust reference signals, 2) ultra-stable tactical clocks, and 3) multifunctional systems that provide PNT information between cooperative users. When complete, the STOIC program will provide GPS-like and better PNT for contested environments where GPS performance is degraded or unavailable.

Commander Prentice concluded by noting that Position, Navigation, and Timing are as essential as oxygen for our military operators and we must protect them and have alternative backups where vulnerabilities exist.

Future of NAVWAR – Captain Don Burningham, RAN, Integrated Capability Development Branch, Defence.

Captain Burningham outlined his presentation scope as including current acquisition activities, capability development activities (including Joint Project 9380 and the Concept Technology Demonstrator (CTD) program), and ongoing international engagement. He noted that the current acquisition program was primarily JP5408 'GPS Enhancement for Legacy Platforms' which included a number of phases. The expectation is that the equipment procured under this project will be military off the shelf, including systems and capabilities such as:

- GPS Antenna System 1 (GAS-1). This is a basic anti-jam antenna system.
- Controlled Radiation Pattern Antenna (CRPA).
- Defence Advanced GPS Receiver (DAGR). Is a handheld anti-jam GPS.

[5] In January 2010, DARPA launched a coordinated effort focused on the development of microtechnology specifically addressing the challenges associated with miniaturization of high-precision clocks and inertial instruments. The Micro-PNT program is comprised of three thrust areas: Clocks,Inertial Sensors, and Microscale Integration. Each area is made up of various efforts exploring new fabrication techniques, deep integration, and on-chip self-calibration, which go hand-in-hand with the development of "plug-and-test" architectures. The developments consider a number of operational scenarios, ranging from dismounted-soldier navigation to navigation, guidance and Control (NG&C) of Unmanned Air Vehicles (UAVs), Unmanned Underwater Vehicles (UUVs), and guided missiles. The micro-PNT initiatives seek to increase the dynamic range of inertial sensors, reduce long-term drift in clocks and inertial sensors, and to develop miniature chips providing position, orientation, and time information.

- Fixed Reception Pattern Antenna (FRPA). Provides resistance to jamming for air and ship receivers.

Captain Burningham noted that Phase 2B would provide greater resilience and anti-jam/spoof to the ANZAC, Adelaide, F/A-18A, and M113 platforms. Under Phase 3 both handheld and platform systems (for CCSM, CSSF, Minehunter, Hydrographic ships, AMSTAR, PSTAR-ER, RBS-70 surface to air missiles, and Special Forces RHIB) would be procured.

Captain Burningham explained that the proven technology to be used under JP 5408 Phase 3 is the GPS Anti-jamming System 1 (GAS-1). The GAS-1 is an analogue system comprising of a CRPA and associated antenna electronics (AE). This system is being installed on ANZAC and Adelaide Class Frigates and F/A-18A Hornet aircraft under JP 5408 Phase 2B. The DAGR is the new military code handheld GPS receiver which is the next generation of technology after the Precision Lightweight GPS Receiver (PLGR) currently used by the ADF. DAGR can be used in a handheld role for Land Forces or mounted in a Platform. A combination of CRPA and DAGR protection is suitable for the GPSE of Maritime platforms.

He went on to note that the new Fixed Reception Pattern Antennas (FRPA) to replace currently fitted FRPAs to achieve compatibility with the DAGR. A common marinised housing, antenna control box and jamming indication unit plus other ancillary items are being used across some Maritime platforms to house the CRPA and provide integration into the platform services and systems. These items are collectively termed the GPS Enhancement System (GES).

Captain Burningham provided a short situation update on Phase 2, and noted that the project completion date is now forecast as mid-late 2016, dependant on the availability of M113AS4s. He stated that the Phase 3-Handhelds achieved 2nd pass approval in the fourth quarter of 2011 with the Phase 3 (Platforms) achieving 2nd pass approval in late 2014. Final Operating Capability is scheduled for end 2021.

Captain Burningham stated that the current capability development activities included the following JP9380 (previously 5200) ‘PNT in a Contested Environment’ related activities.

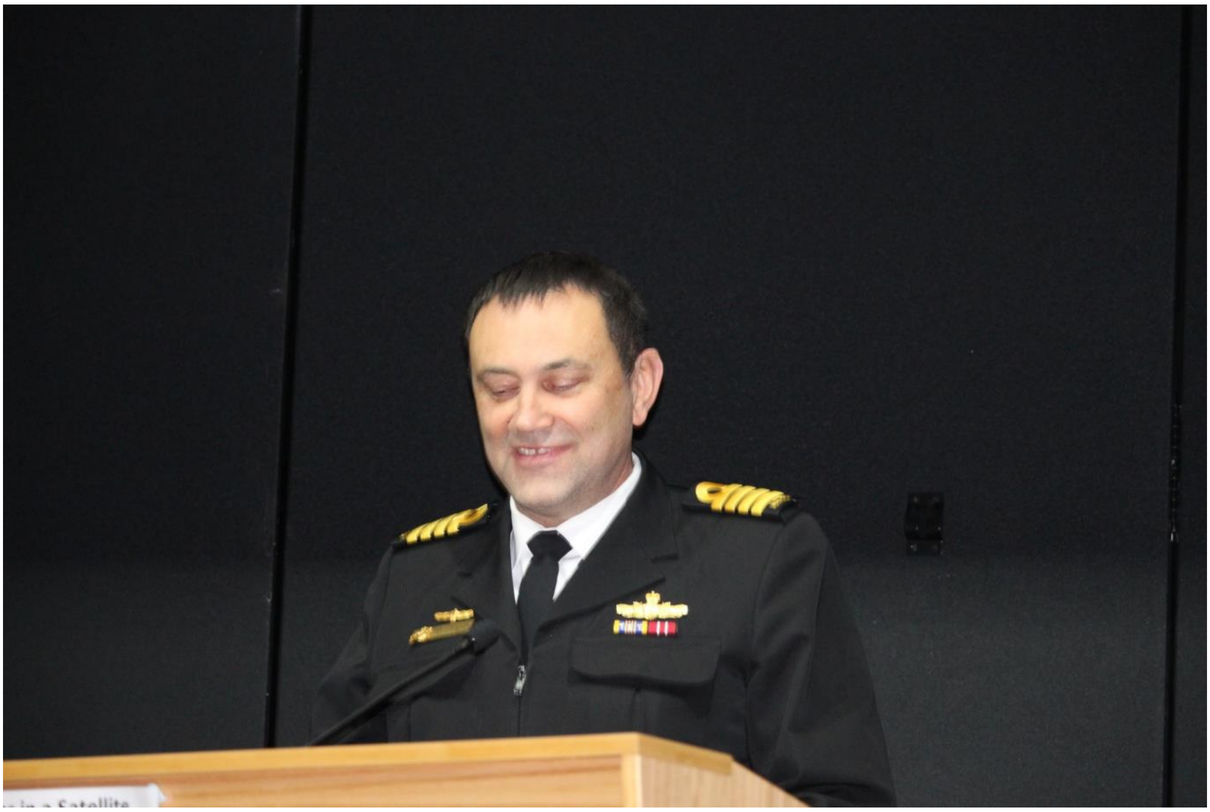
- Survey of ADF PNT/GPS receiver users
    - Commencing in July 2015
    - Collate database of equipment & users
- Understand user accuracy requirements
    - Industry/technical study
    - Commencing May 2016
    - Outcome to inform project scope
- Project initiation ~ second half of 2017.
- Year of Decision would be early 2020s

Captain Burningham explained that the survey phase of the project would be a 10 month effort commencing in July 2015 with the expectation that the final report would be delivered by end April 2016. The plan was to use the DCAF-sponsored Air Force “GPS Denial” survey conducted by DSTO in 2014 as the baseline. There would then be a need to survey Army and Navy users, and capture any additional data required from Air Force. The program is budgeted for contractor support; but may utilise DSTO personnel for the task.

He also provided an overview of the study phase of the program which is a 12 month effort commencing in May 2016 that aims to deliver a preliminary report by end March 2017, and final report by the end of May 2017. The timelines are to support the Project Initiation Review Board document preparation requirement. Directed by outcomes of survey, the study will recommend PNT technology/ methodology/ acquisition strategy relevant to ADF in-service and future capabilities operating in a GPS denied/deception environment. The outcomes will inform project scope and options development. There is the potential to have the Rapid Prototyping and Development team involved. The project is budgeted for contractor support.

Captain Burningham outlined the CTD program. It includes a RF Interference Geolocator that is being developed by GPSat Systems Australia, and which aims to provide geolocation of GPS RF interference to support Defence operations. He noted that the next presentation by Dr Mark Knight will provide more details about this topic.

Captain Burningham noted that there was ongoing international engagement in this field. There are a variety of forums attended by CDG, DSTO and DMO. There is also a risk reduction activity being conducted in support of JP9380. This will keep us informed of US and Allied GPS / GNSS constellation developments, as well as collaborative trial/development opportunities, and give Australia a foot-in-the-door purchasing power.



Captain Don Burningham addressing the Seminar

CDG, DSTO and DMO also participate in a number of international forums, which allow Defence to keep abreast of ongoing and future activities as they relate to NAVWAR in both sustainment and capability design activities. Participation in MOUs is a risk reduction activity for JP9380 (5200), and keeps Defence informed of US and Allied GPS constellation developments & GPS user equipment developments. It also provides collaboration opportunities on equipment trials to determine performance and vulnerabilities, and provides an opportunity for collaborative development of future receiver technology that will satisfy ADF capability needs.

Finally, Captain Burningham stated that it provides an opportunity to purchase technology developed under the MoU umbrella. There are 11 Nations GPS & NAVWAR RDT&E MoU. These are Australia, US, UK, Canada, France, Denmark, Sweden, the Netherlands, Italy, Germany, and the Republic of Korea.

Australia is also involved in a GNSS Project Agreement (PA) that covers the GNSS receiver / algorithm development, and which will involve the testing of capabilities and collaboration in the area of Test / simulation. There is also a proposed SPACEJAM PA. This is a Simulated Programmable Aircraft Embedded Jammer that would allow for aircraft to have a built-in GPS denied/degraded training environment simulator.

NAVWAR Collaboration Between DSTO and Australian Industry - Dr Mark Knight, Cyber & Electronic Warfare Division, DSTO

Dr Knight noted that the main way in which DSTO collaborates with industry and academia in the area of NAVWAR is through the Capability and Technology Demonstrator Program, although Defence has in the past had a number of small contracts with the University of Adelaide in the area of NAVWAR EP.
The Capability & Technology Demonstrator (CTD) Program is sponsored by Capability Development Group but managed by the CTD Program Office within DSTO.

CTDs are *"A collaborative activity conducted under contract between Defence and industry to deliver a demonstration of the capability potential of new technology"*. CTDs typically develop demonstrators to around the TRL 3-6 level.
Each year a new round is opened with a call for proposals around April/May. Announcement of the successful proposals is made in April the following year.
In round 18 (2014), GP-Sat Systems Australia submitted a successful bid to develop a capability to detect and geo-locate GPS jammers and spoofers – Project CTD 2014-03.

In round 12 (2008), BAE Systems Australia successfully bid for a project to develop a miniaturised GPS anti-jam system with jammer DF capability – Project CTD 2008-05. That project culminated in a successful demonstration of the mini-GISMO Space-Time Adaptive Processor (STAP) anti-jam unit at Woomera in 2010.

CTD 2014-03 – The Geo-location of GPS RFI to Support Defence Operations

GP-Sat Systems Australia is developing a capability to detect, geo-locate and track GPS interference signals, including jamming and spoofing signals within the GPS L1 and L2 bands (20 MHz bands centred on 1575.4 MHz and 1227.6 MHz). The system will consist of sensor nodes deployed around a facility, such as an airfield or military base, and a central processing unit connected to the nodes via WiFi or fibre. Jammer geo-location will be via a combination of Angle of Arrival, AOA (each sensor node includes an antenna array) and Time Difference of Arrival, TDOA. Although some aspects are unique to GPS – frequencies, bandwidths, spoofer detection – the system could be extended to other signal types, including other GNSS signals.

Antenna arrays at each sensor node will produce high gain steerable beams to search for weak jamming and spoofing signals. When a signal is detected, each node will be tasked to steer a beam towards the signal. Initial geo-location may be derived from these Angles of Arrival, AOAs. Time stamped data sets will then be sent back to the central processor to form Time Differences of Arrival, TDOAs. AOA and TDOA information will be combined to form the final geo-location solution – AOA and TDOA have natural synergies; AOA works well with narrowband signals. TDOA works well with wideband signals.

Dr Mark Knight at the podium

Real GPS signals arriving from valid directions will be removed from the received signal to allow extremely weak jamming signals to be detected – i.e. TDOA processing will not be contaminated by valid GPS signals. This also allows spoofing signals to be detected – the only GPS like signals remaining.

The performance goals for the system are:

- Signal detection down to GPS signal levels (–130 dBm into a 0 dBi gain antenna). Weak signal detection is necessary to detect weak jammers and spoofers at long range.

- Target position error less than about 10 m, 95% for sensors up to 5 km from the jammer or spoofer (assuming HDOP < 2).
- Concurrent operation against 2 spoofers, or 2 jammers and 1 spoofer.
- Portable and deployable within a few hours.
- Map display with moving tracks for jammers/spoofers.
- Geo-location speeds of the order of 10's of seconds.

Field demonstration and project completion is expected within 24 months of contract signature, which is planned for mid-August 2016. The partners in the project are:

- GP-Sat Systems Australia – Prime.
- UNSW – GNSS algorithms and signal processing.
- University of Adelaide – Array processing and weak signal detection.
- Others – RF, digital and antenna hardware development.

Dr Mark Knight outlining the CTD program to Seminar attendees

A prototype civilian system was developed by GP-Sat Systems Australia and the Universities of Adelaide and NSW using ARC funds. That system had a 2 MHz bandwidth at the GPS L1 frequency only. A civilian system designed to cover the GPS L1 (C/A-code), GPS L2 (L2C) and perhaps L5 bands could be developed to protect civilian infrastructure that has a dependence on GNSS, including airports, water-ports and harbours, city centres, etc. A permanently installed system should allow the nature and location of any potential interference or jamming events to be determined within seconds, allowing the event to be responded to while it is still happening.

CTD 2008-05 – Miniature GPS Anti-Jam System

Between 2008 and 2010, BAE Systems Australia developed a Space-Time Adaptive Processor (STAP) beam-former to protect GPS receivers against multiple broadband L1 and/or L2 GPS jammers.

Key design objectives for this project were:
- To minimise size, weight, and power for employment within space, weight and power constrained platforms such as mini-UAVs, dismounted soldiers, etc.
- To interface with a wide range of GPS receivers by replacing existing Fixed Reception Pattern Antennas.
- To provide jammer AOA information relative to the platform body.

Anti-jam protection is provided through adaptive null steering using an eight element antenna array:
- Provides Protection is provided against narrowband (CW) to broadband (24 MHz) GPS jammers.
- Multiple modes are offered to optimise resource usage: 4+4, 7+1, 1+7, 8+0, 0+8, where the two digits represents the number of channels dedicated to the GPS L1 and L2 bands, respectively.
- Provides protection against up to seven broadband jammers.
- Through the use of STAP, protection may be provided against even more narrowband jammers.

Dr Knight stated that when calibrated, the system can provide quite accurate (3 to 8 degrees) Angle of Arrival (AOA) measurements for multiple GPS jammers. The system's anti-jam and jammer AOA performance is classified, but is comparable to much larger Military Off-The-Shelf systems. It is relatively small and light weight (about 0.5 kg) and is low power (9.7 Watts). A reduced bandwidth civil version might be developed for the GPS L1 C/A-code and L2C to protect civilian infrastructure that has a dependence on GNSS, such as GBAS for airports, power distribution systems, communications systems, etc.

Seminar Wrap-up – Air Vice-Marshal Kym Osley (retd), Executive Secretary Australian Institute of Navigation

Air Vice-Marshal Osley noted that all the speakers had highlighted the critical risk associated with a potential deliberate or unintentional GNSS outage and the significant impact it could have on the continuity of civilian and military operations in the air, land and on the sea. He noted that Air Vice-Marshal Hupfeld in his opening remarks had highlighted the need for a whole-of-Government approach to the issue, and that more needed to be done to develop the capability to detect, localise and respond to GNSS degradation incidents, and that this needed to be practiced in regular cross-Government department exercises.

Professor Rizos highlighted the types of threats to GNSS continuity, including solar storms, jamming and spoofing. Particularly worrisome is the 'inadvertent jammer' and the risk of difficult to detect 'spoofing'. He stressed the need to protect, toughen and augment.

Ms Margaret Staib, Mr Ian Mallett and Air Commodore Craig Heap all addressed the risk to air operations from a civilian and military perspective. It is clear that air operations will proceed in spite of GNSS degradation, but in some areas air operations will be much less efficient. In both the military and civilian sectors, there is still adequate training in reversionary navigation and communication measures that will allow operations to safely continue. However, the main risk comes from a late detection of the jamming or spoofing, with an attendant breakdown in navigation, or aircraft separation and thus safety. In the military realm, a late detection of GNSS degradation could result in poor weapon effectiveness, or inadvertent penetration of national borders or no-fly areas. All speakers thought that there is a need for a system of identifying and localizing the jamming, and for positively informing airmen of when GNSS and communications may be unreliable.

Major General McLachlan and Commander McLean discussed the risk to land operations for both the military and civilian applications respectively. Commander McLean noted that the Australian Federal Police (AFP) needs to do a more holistic review of the risk represented by a GNSS degradation to their operations and to address this as they would any other risk.

The AFP can cope with a shorter term interruption to services, but a longer term interruption would present a more challenging problem. Commander McLean stated that there should be a collaborative approach across Government to addressing the risks.

Air Vice-Marshal Osley addressing the Seminar

Major General McLachlan noted that Army have started the journey to address the challenges inherent in GNSS degradation, but much more needs to be done.

Exercises will need to be conducted to test the readiness to operate in a GNSS degraded environment, and these exercises would need to be several days long to ensure the correct lessons were learned.

The risk to maritime operations was also looked at through both a commercial and a military lens by Mr Nick Lemon and Commander Prentice. 10% of shipping trade is through Australian ports, and precise navigation is now essential for some large ship operations, and for some drilling and other high accuracy operations. An over-reliance on electronic navigation can be a safety issue, and lessons from this over-reliance need to be fed into training.

A key issue is the human factors-related issue of how to warn of GNSS failures and prompt the crew to revert to backup means of navigation. The issue is very much less about the technology of navigation and the GNSS degradation, and more about understanding the human interface on the ships.

Commander Prentice explained the criticality of GNSS-based PNT to achieving the networked maritime force, and the fact that in the ‘all up’ system of systems, many of the systems on a naval vessel rely on some direct or indirect link to GNSS. There are 116 systems on the LHD that require a GNSS feed.

Graceful degradation through the limited to the denied operational environments is required and must be planned and trained for. The way ahead is to reduce the reliance on GPS by providing some reversionary systems and alternatives to ensure that situational awareness can be maintained for as long as possible.

Air Vice-Marshal Osley stated that Captain Don Burningham had outlined a number of projects that Defence has initiated to reduce the risk from GNSS degradation. But Captain Burningham had warned that there are no quick fixes. There are a number of Concept and Technology Demonstrators that are underway under the auspices of Capability Development Group and DSTO. There is also significant ongoing level of international engagement in the field of GNSS, particularly in the Five Eyes Community. As a result, Australia is gaining good access to risk mitigation activities that other partners in the Five Eyes Community are working on.

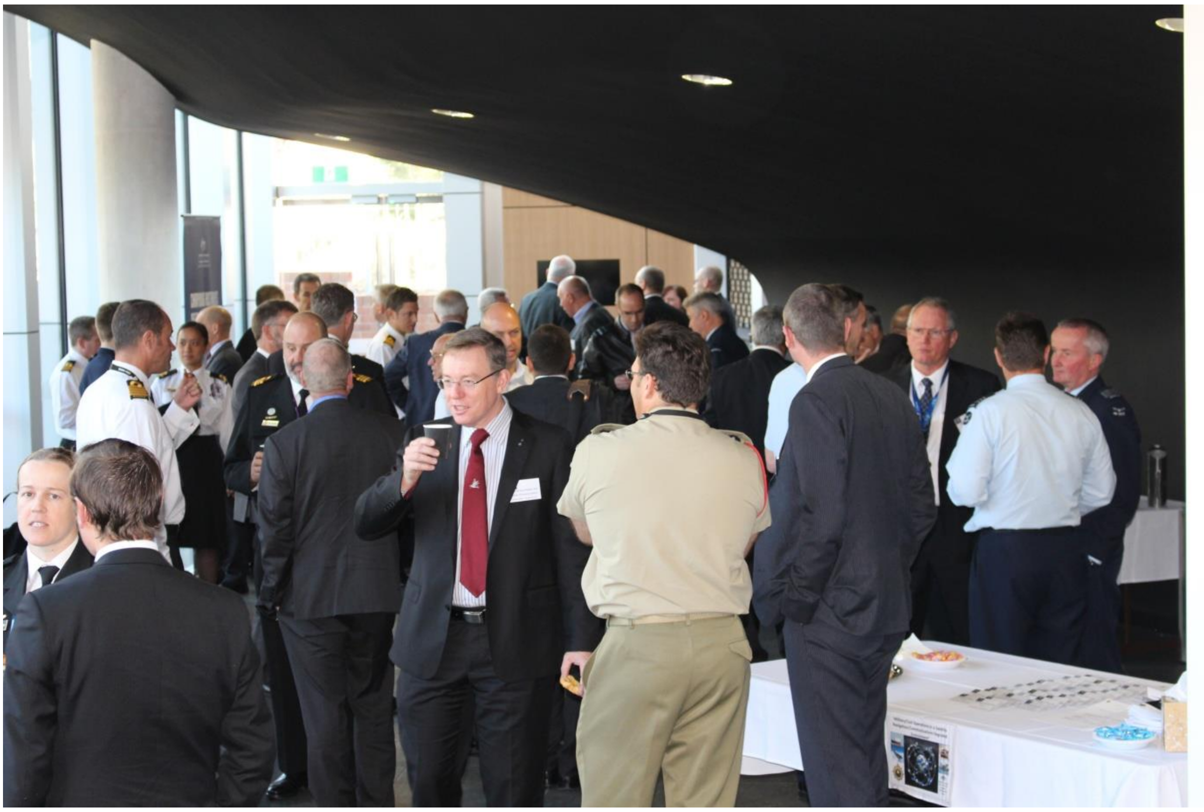
Dr Mark Knight highlighted the strong links between Defence/DSTO and industry through the Concept and Technology Demonstrator (CTD) program. Again there are a number of CTDs underway, but these will not necessarily be quick fixes and much work still needs to be done. Key CTDs are addressing the vulnerability of current receivers, and also are seeking to allow for tactical level geo-location of GPS jamming systems. These CTDs have application in both the Defence and civil sectors.

Air Vice-Marshal Osley concluded by stating that the next step is for the Agencies represented at the Seminar to build on the discussions and develop an effective risk mitigation strategy. At a minimum this should include:

- Further develop cross-Government GNSS-related forums to better share developments in dealing with GNSS degradation.
- Ensuring that natural and human–induced GNSS degradation is adequately addressed in Government and Department contingency plans and risk registers.

- Developing a program for better educating the public of the dangers of jamming or interfering with GNSS. This would include educating the public on the laws and penalties that apply to those caught interfering with GNSS/satellite communications signals.
- Seeking to have GNSS recognized as critical infrastructure in Australia.
- Reviewing cross-Government exercise programs and training courses to ensure that they adequately stresses staff and processes in preparation for responding to a serious degradation in space-based PNT.
- Creating an Australian national system (equipment and processes) for detecting and geo-locating GNSS jamming.

Air Vice-Marshal Osley thanked Air Commodore Clements, the Commandant of ADFA, and Ms April Barrett for making the Ross Theatre available for the Seminar. He also thanked the attendees and speakers for taking the time to share their views at the seminar, and he finally thanked the key sponsors of the day – Capability Development Group and the Australian Institute of Navigation. He then drew the Seminar to a close.



Seminar Participants outside the Ross Theatre

The Australian Institute of Navigation

The Australian Institute of Navigation (AIN) was established on 12th April 1949, at about the same time as the US Institute of Navigation and the Royal Institute of Navigation (UK) were formed. The idea to form an Australian Institute came from Captain Brett Hilder, and the first meeting place was the Richmond Nautical School in Sydney.

A series of Technical Meetings was set up, the first being conducted in the Hall of Tropical Medicine at Sydney University. Meetings were later held at the Science House, which was to become the home for the Institute for the next 18 years. The first Annual General Meeting was held at the Science House on 31 January 1950, and a formal Council was elected with Captain E.G. Bowen as the first President.

In 1958, Vice-Regal Patronage was sought and members were delighted that Sir William Slim, the then Governor General of Australia accepted the invitation. Since that time all Governor Generals have honoured the Institute with their Patronage, and Sir Peter Cosgrove is the current Patron.

In 1987 the Institute became an incorporated body.

The first edition of the AIN Newsletter 'Navigation' was sent to members in 1959, and this continues on a quarterly basis today.

In 1975, the various Institutes of Navigation around the world agreed to form the International Institutes of navigation, of which Australia remains a proud member to this day.

The objects of the Institute are -

- To unite in one society persons interested in the science and practice of navigation.
- To advance the science and practice of navigation. Several AIN Fellows and members have considerably contributed to the study of navigation over many decades, including Professor Brian O'Keeffe, AO, who in 2004 was awarded the highest award by the International Civil Aviation Organisation for his leading role in the development of air navigation systems.
- To examine and review results of navigational research and invention and to advise on achievements which promise advancement in the standards of navigational performance.
- To co-operate, for the advancement of navigation, with other scientific institutions in related fields. The AIN is a key sponsor of the July 2015 International Global Navigation Systems Society Conference at the Gold Coast.
- To establish awards in recognition of navigational excellence (the AIN sponsors prizes at the RAN Navigation Courses and the RAAF Air Combat Officer Courses).

The Institute can be contacted via the Executive Secretary, Air Vice-Marshal (retd) Kym Osley AM, CSC, on kym.osley1@gmail.com.

Biographies

Air Vice-Marshal Mel Hupfeld, AO, DSC
Head Capability Systems, Capability Development Group

Air Vice-Marshal Mel Hupfeld was born in Sydney in 1962. He joined the Royal Australian Air Force (RAAF) as an RAAF Academy Cadet in January 1980, winning the Flying Prize for his year and graduating with a Bachelor of Science degree in 1983. Air Vice-Marshal Hupfeld's early career was spent in a variety of flying positions on Mirage and F/A-18 aircraft, primarily with No 3 Squadron (3SQN) and No 2 Operational Conversion Unit (2OCU), before qualifying as a Fighter Combat Instructor in 1989. Following a period of service as B Flight Commander, 3SQN, Air Vice-Marshal Hupfeld was appointed as the Executive Officer of 2OCU in 1995.

In 1997 Air Vice-Marshal Hupfeld was selected to attend the Royal Air Force Advanced Staff Course, graduating with a Master of Arts in Defence Studies from King's College in London, before taking up post as a Deputy Director in the Aerospace Development Branch.

In 2001 Air Vice-Marshal Hupfeld took command of No 75 Squadron (75SQN) and led the Squadron in operations in Middle East on Operations BASTILLE and FALCONER. In 2003 Air Vice-Marshal Hupfeld was awarded a Distinguished Service Cross in recognition of his performance as Commanding Officer 75SQN on Operation FALCONER, and his Squadron was awarded a Meritorious Unit Citation. On promotion to Group Captain in January 2004 he was appointed Director Aerospace Combat Development in the Australian Defence Headquarters, before accepting appointment as Officer Commanding No 81 Wing in January 2006.

Promoted to Air Commodore on November 2007, he became the Director of the Combined Air Operations Centre in the Middle East Area of Operations, before returning to Australia as the Director-General Air / Director General Air Command Operations in March 2008. In December 2009, he took command of Air Combat Group where he oversaw all of the RAAFs fast-jet combat aircraft to deliver Australia's capability to control the air and conduct precision strike. Air Vice-Marshal Hupfeld was promoted and appointed as the Air Commander Australia on 3 February 2012. In this position he provided specialist air advice on raise, train and sustain issues to the joint environment.

In September 2014 he was appointed Head Capability Systems Division in the Capability Development Group. In 2015 Air-Vice Marshal Hupfeld was awarded the Order of Australia for distinguished service to the Australian Defence Force in senior command and staff appointments.

Air Vice-Marshal Hupfeld is married to Louise, and his interests include mountain biking, running, fishing, light aircraft, and sailing.

Professor Chris Rizos
President of the Australian Institute of Navigation

Professor Rizos gained his Bachelor of Surveying from the University of NSW in 1975 with First Class Honours. He remained as a post-graduate student in the School of Surveying until 1980, when he gained his PhD for a thesis entitled "The role of the gravity field in sea surface topography studies". From 1981 he took up a position as a Visiting Research Fellow at the German Geodetic Research Institute (DGFI), Munich, Germany, supported by an Alexander von Humboldt Fellowship. In 1987 he returned to Australia as a Professional Officer at the School of Surveying, UNSW, working under Assoc. Prof. Art Stolz and his team carrying out research into the new Global Positioning System (GPS) technology.

From late 1987, Professor Rizos was appointed a lecturer at the School of Surveying, UNSW. He continued research in GPS/GNSS software and modelling problems for static applications. His major teaching interest was (as it still is) GPS/GNSS for undergraduate and postgraduate students. In late 1989 he was promoted to a Senior Lecturer position, as well as being Manager of the Geodesy Laboratory, and also establishing the Satellite Navigation & Positioning Group. In early 1996 he was made an Associate Professor, and in January 2001 a Professor at the renamed UNSW School of Surveying & Spatial Information Systems.

In mid-2004 Professor Rizos became the Head of the School of Surveying & Spatial Information Systems (in 2012 the School was renamed the School of Surveying & Geospatial Engineering). Since the start of 2013, he has been the Professor, School of Civil & Environmental Engineering.

Academic Qualifications and Awards:

- BSurv (Hons.1), UNSW, 1975
- PhD, UNSW, 1980
- University Medal, UNSW, 1975
- Institution of Surveyors (N.S.W. Division) Gold Medal, 1975
- Commonwealth Postgraduate Research Scholarship, 1975-78
- Fulbright Fellowship (Postgraduate Category), 1977-78
- Rothmans Fellowship, 1979
- Alexander von Humboldt Fellowship, 1981-83, 1991
- Fellow of the Australian Institute of Navigation
- Fellow of the U.S. Institute of Navigation
- Fellow of the International Association of Geodesy
- Associate Member of the International GNSS Service (IGS)
- Member of the Governing Board of the IGS, 2004-2013
- Australian/Asian representative on the Executive of the U.S. Institute of Navigation Satellite Division, 2004.9-2006.9
- Japan Society for the Promotion of Science, 1999, 2003
- Senior Fellow, Nanyang Technological University, Singapore, 1999
- Honorary Professor, Wuhan University, P.R. China, 2006

Ms Margaret Staib AM, CSC
CEO Airservices

Ms Margaret Staib commenced in the role of CEO at Airservices on 15 October 2012 after a distinguished career over three decades in the Royal Australian Air Force.*

From January 2010, she held the position of Commander Joint Logistics. In 2000, Ms Staib's contribution and leadership in the field of ADF Aviation Inventory Management was recognised when she was awarded the Conspicuous Service Cross. Ms Staib was a member of the Chief of Air Force Advisory Committee.

A posting with the United States Air Force at the Pentagon furthered her experience of logistics transformation, including strategic procurement initiatives with industry, supply chain integration and technology. Her service during this period was recognised with the United States Meritorious Service Medal.

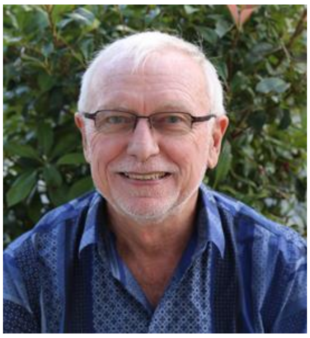
In January 2009, Ms Staib was appointed as a Member in the Military Division of the Order of Australia.

Ms Staib was also recognised by Australian industry when she received the Outstanding Contribution to Supply Chain Management in Australia award at the 2011 Smart Supply Chain Conference.

Ms Staib is a member of the Industry Advisory Board for the Centre for Aeronautical & Aviation Leadership of Embry-Riddle Aeronautical University, a Certified Practicing Logistician, and a Fellow of the Chartered Institute of Logistics and Transport.

Ms Staib holds a Bachelor of Business Studies, Master of Business Logistics and Master of Arts in Strategic Studies.

Ms Staib holds the rank of Air Vice-Marshal in The Royal Australian Air Force Active Reserve.



Mr Ian Mallett, AFC
Head CNS Section, Civil Aviation Safety Authority

Mr Ian Mallet joined the RAAF in 1967 as a pilot and served in transport, instructional and staff positions including commanding officer of No 33 Squadron flying Boeing 707 VIP/tanker aircraft.

Mr Mallet joined CASA in 1990 as a flying operations inspector and has been involved in GPS adoption since then. This work has included considerable involvement with ICAO on the navigation systems panel and as chair of the regional performance based navigation task force (PBNTF) and ASTRA.

Mr Mallet is currently head of the CNS section in CASA, involved with the transition to satellite based performance based navigation (PBN), with the mandates for GNSS and ADS-B, the transition to vertically guided approaches (APVs) and investigation into a possible satellite-based augmentation system (SBAS) for Australia.

Assistant Commissioner David Mclean
National Manager High Tech Crime Operations, AFP

A/Assistant Commissioner David McLean is currently performing the role of National Manager for High Tech Crime Operations, AFP. He previously held the position of Manager Cyber Crime Operations within the Australian Federal Police High Tech Crime Operations portfolio.

In that capacity A/Assistant Commissioner McLean is responsible for the investigation of significant criminal acts which may compromise high technology infrastructure in Australia, including computer systems, GPS systems, high-tech communications systems that Australian critical infrastructure.

A/Assistant Commissioner McLean has previously been responsible for Child Protection Operations and the targeting of offenders use the internet to facilitate the sexual exploitation of children or who travel offshore and commit sexual offences against them.

Previous senior executive roles occupied by A/Assistant Commissioner McLean include Manager Professional Standards responsible for internal investigations and maintenance of the AFP integrity framework; Deputy Chief Police Officer, ACT Policing, the AFP's community policing arm; and Chief of Staff, responsible for the coordination of information, administrative and support services provided to the Commissioner and AFP Executive.

From 2004 to 2007, A/Assistant Commissioner McLean was stationed in Washington DC where he served as the AFP Senior Liaison Officer responsible for cooperation with the United States and Canada on policing issues.

A/Assistant Commissioner McLean is a graduate of the AFP Management of Serious Crime Program, the AFP International Senior Command Program and the Australian Institute of Police Management. He holds a Bachelor of Business and a Graduate Diploma of Executive Leadership.

Major General Gus McLachlan, AM
Head Army Modernisation and Strategic Planning

Major General Gus McLachlan, AM, was born in Papua New Guinea while his parents served with the Australian administration. He entered the Royal Military College, Duntroon, in 1982. He is a proud Armoured Corps officer whose Regimental service concluded with his appointment to command the 1st Armoured Regiment, Australia's only tank unit, in 2001/02.

Major General McLachlan has also served on exchange with the United States Military. In 1999 he was posted to the United States Marine Corps Warfighting Laboratory in Quantico Virginia, where he worked for two years on the US Marine Urban Warfare development teams – Urban Warrior and Project Metropolis.

Major General McLachlan has deployed on operations in the Israeli Occupied Territories, Lebanon and Iraq. Most recently he completed a 12 month tour in Afghanistan with the International Security Assistance Force in Afghanistan where he was the senior campaign planner.

In 2009 Major General McLachlan was selected to represent the Australian Defence Force for a placement in the Office of the US Secretary for Defense to work on the first Quadrennial Defense Review of the Obama Administration. He returned to Australia to assume command of the Army's 1st Mechanised Brigade in Darwin. He served for three years as the Commander of the 1st Brigade during which time the Brigade deployed personnel for operational service in Afghanistan, East Timor and the Solomon Islands.

Major General McLachlan's roles as a General Officer have included operational planning in Afghanistan and Joint Capability Coordination for the Vice Chief of Defence where he was responsible for generating Australian Defence capability in cyber space, electronic warfare, joint command and control and counter IED capabilities. He assumed his current appointment as Head of Army Modernisation and Strategic Planning in December 2014.

Major General McLachlan is married to Maree and has two adult sons. His interests include sailing, bike riding and age group triathlons. He aspires to master long board surfing.

Mr Nick Lemon
Manager, Ship Safety, Australian Maritime Safety Authority

Nick joined AMSA in 2003 after a career in the Australian Navy as a seaman officer and hydrographic surveyor. Since joining AMSA Nick has worked in the areas of Aids to Navigation and navigation safety, nautical advice and policy, and with the maintenance of AMSA's delegated legislation (Marine Orders). Nick represents AMSA domestically and internationally on navigation safety and related technical matters and in particular at the International Maritime Organization's (IMO) Navigation Communications and Search and Rescue Subcommittee.

Nick has a Bachelor of Surveying degree and graduate diplomas in Hydrography and Business Administration and is a member of the Hydrographic Society and The Nautical Institute.

Captain Don Burningham, RAN
Director Joint Intelligence, Survveillance & Reconnaissance, & Electronic Warfare, Integrated Capability Branch

CAPT Burningham joined the RAN as an Undergraduate Midshipman in 1984. He completed Engineering studies in 1988, was promoted to Lieutenant and undertook Single Service/Engineering training in 1989, qualifying as a Weapons Electrical Engineer.

His first sea posting was as Deputy Weapons Electrical Engineering Officer (DWEEO) in HMAS DERWENT. He then spent time at CDSC before being posted as DWEEO in HMAS BRISBANE in 1993. This was followed by promotion to LCDR in 1995 and a posting to the USA where he was the DDG Liaison Officer in the USN NAVSEA organisation and then Project Liaison Officer on the Naval Attache's Staff.

On return to Australia he had postings as Assistant Director of Engineering Policy - WE and as Deputy Fleet Weapons Electrical Engineering Officer (WEEO) prior to joining HMAS HOBART as WEEO in December 1998. After decommissioning HMAS HOBART, he moved to the Capability Development cell of the Surface Combatant Force Element Group before returning to Canberra as the Staff Officer to DG Navy Systems and DG Navy Certification, Safety and Acceptance Agency.

In 2002, he undertook the Australian Command and Staff Course and was promoted to Commander in July 2002. On course completion he was posted as the Combat Systems Manager for the AWD project within DMO. CAPT Burningham then served as the Deputy Director Navy Establishments, before taking up the role of Deputy Director Systems within Maritime Development Branch. He was then sent as the National Deputy for Australia in the NATO Seasparrow Project, based in Washington.

In Jan 2010 he was promoted to CAPT and returned to Australia to take up the position of Director Weapons Systems in the Weapons Technical Intelligence Branch. He then took up the position of Director Intelligence, Surveillance & Reconnaissance & Electronic Warfare within the Integrated Capability Development Branch.

CAPT Burningham is a keen sportsman having represented at Combined Service level for soccer and inter-service level for volleyball. He is interested in wine and enjoys entertaining and travel in his spare time. CAPT Burningham is married to Amanda, a Business and Project Manager with Centre-link.

Air Commodore Craig Heap CSC
Director General Aerospace Development (DGAD)

Air Commodore Heap joined the RAAF in 1984 as a Direct Entry pilot. On graduation from 132 Pilots Course in June 1985, Group Captain Heap was posted to 34 SQN as a VIP copilot for 12 months. He then completed the Aircraft Systems Course at the School of Air Navigation before posting in 1987 to 5 SQN as an Iroquois helicopter pilot. In 1989, with the demise of the RAAF helicopter fleet, Air Commodore Heap was attached to 292 SQN for P-3C conversion and subsequently served at 11 SQN until 1993.

In 1993 Air Commodore Heap was posted to 2FTS as a Qualified Flying Instructor (QFI), after completing the Central Flying School, Flying Instructors Course. Returning to 292 SQN in 1994 as a P-3C Qualified Flying Instructor, he instructed at 292 SQN for 18 months before returning to 11 SQN as the SQN Qualified Flying Instructor, and later as a Flight Commander.

In late 1998 Air Commodore Heap was posted to the Central Flying School as the A Flight Commander, in charge of the RAAF Flying Instructors Course. He also joined the RAAF Flying Display Team, the Roulettes. In 2000, he was appointed as the Chief Flying Instructor. In 2001, Air Commodore Heap was selected to attend the Canadian Forces Command and Staff Course in Toronto, Canada. On return to Australia in mid 2002 was posted to Weston Creek, Canberra as member of the Directing Staff of the new Australian Command and Staff College. In 2005 he was awarded the Chief of Defence Force Commendation for his service to the Australian Command and Staff College.

Air Commodore Heap returned to 92WG in January 2005 as the incumbent Commander of the AP-3C Task Group in the Middle East. For his command of this Task Group he was awarded the Vice Chief of Defence Force commendation. On return from the Middle East in late 2005 until mid 2007 he served as the Commanding Officer of No 10 SQN.

In 2007 Air Commodore Heap was posted as the Director of Studies Air and Chief of Operations at the Australian Command and Staff College. In November 2008, Air Commodore Heap commenced duties as the Chief of Staff to the Chief of Defence Force, from which he was posted to the Centre for Defence and Strategic Studies in January 2010, completing a Master of Arts (Strategy). From November 2010, Air Commodore Heap returned to the Middle East as the Joint Task Force 633 Air Component Commander until June 2012, for which he was awarded the Commendation for Distinguished Service in the 2012 Queens Birthday Honors' list. In October 2011 Air Commodore Heap assumed the post of Officer Commanding 92WG. In July 2014, Air Commodore Heap assumed the post of Director General Aerospace Development on promotion to Air Commodore.

Air Commodore Heap is married to Wendy, and has three children, James (18), Stuart (16), and Alyce (14). He enjoys scuba diving, rugby and mountain biking.

Commander David Charles Prentice, RAN
Director General Information and Communications Warfare

CMDR Prentice joined the Royal Australian Navy in January 2011 as a lateral transfer following a 32 year career in the Royal Navy. His current posting as the Director for Navy Information Warfare follows an original posting as the Director of Navy C4.

He is currently Acting DGNCIW and is responsible for the Capability Management of all Communications and Information Warfare related issues within the Australian Navy. His last appointment before transferring to Australia was as the Branch Head for Allied/Coalition Maritime Interoperability within OPNAV N2/N6, as a UK exchange Officer in the United States. During this appointment he was also the Chairman of the Permanent Support Group to AUSCANNZUKUS, the Five Eyes maritime organisation and the US representative to the NATO Maritime C3 Group.

His time in the Royal Navy was primarily spent in Operational areas as a Principle Warfare Officer Communications and Electronic Warfare and on Fleet Battle Staffs. He was Executive Officer of HMS NEWCASTLE for three Deployments and appointed as Commanding Officer during the final deployment as part of Operation Active Endeavour in the Mediterranean.

As such his exposure to the business of Network Enabled Warfare and Naval Operations has been full and varied.

Dr Mark Knight
Cyber and Electronic Warfare Division

Mark Knight graduated from the University of Adelaide, Department of Electrical and Electronic Engineering with a Bachelor’s degree in Electrical & Electronic Engineering. He commenced a Master of Engineering Science in 1995, and then in 1998 commenced his PhD. He completed his Ph.D. in Engineering Science in December 2000. The subject of his PhD thesis was "Ionospheric Scintillation Effects on Global Positioning System Receivers”.

He currently works as a Senior Research Engineer with Cyber and Electronic Warfare Division of the Defence Science & Technology Organisation (DSTO) in Position Navigation and Timing Technologies & Systems (PNTTS) group.

Air Vice-Marshal Kym Osley (retd) AM, CSC
RAAF Reserve Staff Group

AVM Osley joined the Air Force in January 1977. He flew as an Air Combat Officer in F-111 strike aircraft with No 1 Squadron before being posted on exchange to fly in reconnaissance Phantoms with the USAF in Texas. On return to Australia in 1988, he flew reconnaissance RF-111C aircraft with No 6 Squadron.

In the period 1990-93, AVM Osley was responsible for major strike-reconnaissance projects within Capability Development (Air) Branch. Following staff training in 1994, he was the Air Force strategic planner for three years before taking command of No 1 Squadron (F-111).

On promotion to Group Captain in late 1999, AVM Osley was posted to the United Kingdom as the Air Force Adviser. In 2002 he undertook senior staff studies before being appointed Officer Commanding No 82 Wing. In August 2004 he was posted on promotion to Director General Capability and Plans, Canberra. In this position he assisted with planning the future force structure for the Australian Defence Force.

AVM Osley deployed as Director of the Combined Air Operations Centre in the Middle East in the period November 2006 to March 2007. In this position, he directed all Coalition air operations over Iraq and Afghanistan. He took up the appointment of Commander Air Combat Group in July 2007. Following studies at Harvard Business School in early 2008, AVM Osley was promoted to his current rank and appointed as Head of Australian Defence Staff (Washington) in July 2008. In December 2010, AVM Osley returned to Australia to take up the position of Program Manager New Air Combat Capability (PM NACC). In December 2013 he was posted to Air Force Headquarters as Head Capability Transition – Air Force; where he coordinated the planning for the transition of the F-35 and other Air Force capabilities into RAAF service. He retired from the Permanent Air Force on 31 August 2014.

In addition to full-time employment as a Director in Pricewaterhouse Coopers, AVM Osley continues to support RAAF senior international engagement activities in uniform and recently conducted a review into leadership and ethics education. He is also the Patron of the Australian Federation Guard, Patron of the 467/463 Squadrons (Qld) Association, Vice President of the WW2 Pathfinders (Qld) Association, and Executive Secretary and Fellow of the Australian Institute of Navigation.

AVM Osley has a BSc (Physics), Master of Arts, Master of Def Stud, Grad Dip Mngt, Grad Dip Mil Av, is a Fellow of the Centre for Defence and Strategic Studies, is a graduate of the Harvard Business School (Advanced Management Program) and a Graduate of the Australian Institute of Company Directors. He is married to Debbie, has three grown children, and his interests include writing military biographies, history, classic car restoration, road cycling, and travel. He was awarded a Conspicuous Service Cross for Services to Air Force in 1997, and made a Member of the Order of Australia in 2008.