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RPAS Integration within an Australian ATM System: What Equipment and which Airspace*

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Abstract— **The Australian Civil Aviation Safety Authority (CASA) currently lists more than 100 separate entities or organisations which maintain a UAS Operator Certificate (UOC) [1]. Approved operations are overwhelmingly a permutation of aerial photography, surveillance, survey or spotting and predominantly, are restricted to Visual Line of Sight (VLOS) operations, below 400 feet, and not within 3 NM of an aerodrome. However, demand is increasing for a Remote Piloted Aerial System (RPAS) regulatory regime which facilitates more expansive operations, in particular unsegregated, Beyond Visual Line of Sight (BVLOS) operations. Despite this demand, there is national and international apprehension regarding the necessary levels of airworthiness and operational regulation required to maintain safety and minimise the risk associated with unsegregated operations. Fundamental to addressing these legitimate concerns will be the mechanisms that underpin safe separation and collision avoidance. Whilst a large body of research has been dedicated to investigating on-board, Sense and Avoid (SAA) technology necessary to meet this challenge, this paper focuses on the contribution of the NAS to separation assurance, and how it will support, as well as complicate RPAS integration. The paper collates and presents key, but historically disparate, threads of Australian RPAS and NAS related information, and distils it with a filter focused on minimising RPAS collision risk. Our ongoing effort is motivated by the need to better understand the separation assurance contribution provided by the NAS layers, in the first instance, and subsequently employ this information to identify scenarios where the coincident collision risk is demonstrably low, providing legitimate substantiation for concessions on equipage and airworthiness standards.**

I. INTRODUCTION

Extant Australian RPAS operations are predominantly segregated, and the transition to full integration, across all classes of airspace, will be a challenging undertaking. Ideally, the chosen pathway will simultaneously minimise the impost on aviation (manned and unmanned) and the safety risk. To manage this requires improved understanding of the event sequences that lead to airborne and terrain collision, the necessary equipment reliability, the complexities of the NAS, and in many cases, the circumstances where it will be acceptable, (and more cost effective) to mitigate, rather than prevent the occurrence of certain hazards. Until this is done, the stance taken by regulatory authorities is likely to be conservative, and coincide with an expectation that RPAS comply with the same airworthiness and equipage expectations currently in place for Conventionally Piloted Aircraft (CPA). In fact, there may be an insistence for greater performance levels in some areas, to compensate for the absent, last minute collision avoidance provided by CPA pilots. The compliance cost will clearly impede the progress of RPAS integration efforts. Consequently, many in the RPAS community advocate for a risk based regulatory approach for determining required equipment, levels of certification rigour, and permissible areas of operations [2].

To date, research dedicated to reducing the risk of RPAS related, airborne collisions has primarily focused on arming RPAS with an on-board ability to sense other traffic, self-separate and avoid collisions. Significantly less effort has been dedicated to understanding how the National Airspace System (NAS) contributes to reducing the possibility of collisions: for both CPA and RPAS, and what elements of the NAS will play key roles in efficient RPAS integration. This is curious given its importance to air transportation throughout the world, and in-built capacity to mitigate key collision possibilities. The NAS/RPAS integration challenge is not expected to abate: in fact, the complexity of the NAS is expected to escalate over the next 10 years [3].

Like the United States NAS (NextGen), and European NAS (SESAR), the Australian NAS will undergo significant change under the "OneSky" program. The implications of this increased complexity on RPAS integration has already been flagged by the US FAA, with their 2013 UAS Roadmap [4] highlighting that "*to avoid obsolescence, UAS developers will need to maintain a dual focus: integration into today's NAS while maintaining cognizance of how the NAS is evolving*". The onus for agility does not just rest with industry: the regulators and Air Navigation Service Providers (ANSP's) must also consider the implications of planned NAS topologies in their deliberations regarding RPAS related regulatory change and modifications.

Available SAA technology does not currently meet espoused Targeted Levels of Safety (TLOS), at least once practical Size, Weight and Power (SWaP) criteria are superimposed. This shortfall only serves to amplify the criticality of the NAS in facilitating short, to mid-term, BVLOS operations. The challenges posed by current SAA limitations were resonated by a US Office of Naval Research (ONR) investigation conducted in 2009 [5]. This study concluded that it could be many years before suitable SAA systems are designed and built to satisfy the currently required levels of SAA performance. The ONR report reached this conclusion after a comprehensive examination of mature and

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developmental SAA solutions.

The reviewed technologies included Automatic Dependant Surveillance-Broadcast (ADS-B), Traffic Collision Avoidance System (TCAS) I and II, radar, infrared, lidar, FLARM, in addition to more futuristic solutions including acoustic systems and optical flow, and a range of hybrid combinations.

The Technical Readiness Level (TRL) determination was based on 20 recognised SAA assessment criteria. After ranking the performance of the listed systems, ONR reached the conclusion that SAA for RPAS in the short to mid-term, would be best addressed by mandating all aircraft (RPAS and CPA) be rendered electronically visible (i.e. cooperative) via a low cost, low SWaP hybrid ADS-B, TCAS and Traffic Information Service-Broadcast (TIS-B) system[1]. They assert that by leveraging off existing technologies, this could be rapidly implemented, and reduce the risk of RPAS related Mid-Air-Collisions, to a more acceptable level, until SAA technology matures sufficiently. Holistically, the suggested approach might actually be the most cost effective pathway for integrating RPAS, but there is likely to be resistance from the CPA community if they are expected to bear an unreasonable portion of the cost for integrating RPAS.

Irrespective of the palatability of this recommendation to the broader aviation community, it does not diminish the criticality of the need for alternative, interim arrangements until SAA technology matures, if BVLOS operations are to progress, and Australia is to realise the potential economic benefits RPAS can provide.

It is notable that in their recently released RPAS Roadmap [4] and plan [7] (2013), the United States detailed intent for a three stage transition to integrated RPAS operations: accommodation, integration and evolution. It is likely that the “accomodation ” stage is a concession to the challenges posed by SAA technology limitation, extant array of legacy platforms, and the critical need to improve the understanding of the NAS/RPAS integration effort, across the spectrum of possible RPAS operations. The successful conduct of this task will ensure RPAS collision risks are maintained at an acceptably safe standard during this transition period.

ADS-B is a key element of the current and future Australian NAS, and is likely to be critical to RPAS integration, if only because recent mandates in Australia require all aircraft operating IFR in controlled airspace to fit ADS-B OUT by February 2017. On the surface, it would appear this mandate will provide an overall net benefit for RPAS separation assurance, as it will increase the number of cooperative platforms and reduce risk in certain airspace. However, it also increases the equipment expectations, and hence cost, for the RPAS community.

Our attempts to understand the limitations of ADS-B in supporting RPAS SAA, for Australian conditions, unveiled a complex mix of RPAS integration issues. This includes a labyrinth of rules dictating equipment expectations, or which impact on the levels of ATC separation and support services provided to mitigate collision. Many of these expectations and services vary according to airspace classes, whether the flight is VFR or IFR, or vary due to technology and infrastructure limitations. Ultimately, these factors impact on the quality of “cooperation” available to minimise collisions, and serves to reinforce the difficulty associated with RPAS integration and highlights the need for critical, multidisciplinary review. Accordingly, the primary focus of this paper is to collate key, but historically disparate threads of Australian RPAS and NAS related information, and distil it with a filter focused on minimising RPAS collision risk. The motivation for our ongoing effort was to first understand the contribution to separation assurance provided by the NAS layers, and hopefully, employ this information to identify scenarios where the unsegregated RPAS collision risk is mitigated sufficiently to substantiate claims for concessions on equipage and airworthiness standards.

Section II briefly details pertinent elements of the Australian RPAS regulatory environment before Section III expands on the RPAS SAA environment and how NAS layering acts to mitigate and reduce collision risks for aircraft. Relevant aspects of the Australian NAS are presented in Section IV, including the levels of service and separation an IFR or VFR platform can expect to receive across all classes of airspace. Surveillance coverage, and RPAS collision risk across airspace class are then explored in Section V. In Section VI, key details are presented for ADS-B, including mandated equipment dates, equipment compliance expectations and other issues which contribute to the number of cooperative platforms which might be expected in any particular class of airspace. Section VI then examines a suite of manned-unmanned collision risk profiles. Conclusions are drawn in Section VII.

II. The RPAS Regulatory Environment in Australia

The rules governing unmanned aviation activities are contained within Civil Aviation Safety Regulations (CASR) Part 101 (2003)[8], supported by 3 Advisory Circulars (AC’s) [9]. A contemporary overview (2012) of the current regulatory regime is provided at [10], including key limitations and challenges. Airservices Australia has released information on their website at [11], detailing NAS related information pertinent to RPAS and CASR Part 101, in addition to guidance on RPAS Operations near controlled Aerodromes and/or within controlled airspace, and an assortment of relevant maps for low level, VLOS operations. Notably, the levels of ATC oversight necessary to “accommodate” approved RPAS operations, whilst manageable now, will not scale well once RPAS number grow. Importantly, technological advancement means industry is now seeking more comprehensive guidance on the transition pathway to more integrated operations, and in particular, airworthiness standards and equipment expectations to operate Beyond Visual Line of Sight (BVLOS), above populated areas and in controlled airspace.

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[1] TIS-B is broadcast on 1090MHz in the USA. Collected ATC radar information is then transmitted to ADS-B IN equipped aircraft. Airservices Australia has indicated TIS-B will not be implemented in Australia for technical and financial reasons[6]

CASA is addressing this demand via a two-phase process under Project OS 11/20 [12]. Phase 1 has seen a suite of new Advisory Circulars (ACs) drafted, with recent versions tabled for review by selected elements in industry. Phase 2 will consist of a complete re-write of the regulation resulting in a new CASR Part 102 for RPAS. The Australian Aerospace Industry Forum (AAIF) certification and regulation working group, released their review of CASA's recently drafted AC's in April 2012 [13]. Of the 8 draft AC's CASA identified on the Project OS 11/20 website, the AIFF review was restricted to reviewing 5: general, operations, training and licensing, manufacturing and initial airworthiness, and finally maintenance and continuing airworthiness drafts. Three draft AC's currently have uncertain development status: safety management, **operations in controlled airspace**, and Operator Certificate application [13].

This paper does not review the draft AC's content, nor comment on the validity of the AAIF review commentary.

Nevertheless, AIFF did identify critical shortcomings in key elements of the released draft AC suite, highlighting a lack of guidance on "*Initial*" and "*Ongoing*" airworthiness (AC-101-6 & 7). AAIF assert the content should be tailored for the risk and complexity of the RPAS operation, rather than arbitrarily applying a "*lightly tailored*" version of certification and maintenance standards in force for CPA [13]. The ideal of "*tailoring to address risk*" underpins the approach taken in this paper, where the inter-relationship between NAS and platform separation are scrutinised to identify possible avenues for risk mitigation, in lieu of arbitrary, and possibly unnecessary imposition of equipment expectations. AAIF also observed that there is little advice on the expected scope and structure for Safety Cases: a key element used to assess applications for UAS Operating Certificates. This is also an extant issue for RPAS approval under the current regulations. Since receiving AAIF feedback, CASA has dedicated significant resources to addressing industry concerns in the amended drafts. Informal advice suggests public release will occur in the latter part of 2014. It is hoped these updates will address key questions such as:

- What is the roadmap for transitioning RPAS into all classes of airspace?,
- In which airspace are BVLOS operations likely to be permitted first: controlled or uncontrolled?,
- If all RPAS operating BVLOS are classed as flying IFR, will they be required to meet the equipment (ADS-B, GNSS) and pilot training expectations for manned IFR operations?,
- What software assurance standards will be enforced for the RPA and the Remote Pilot Stations (RPS's) sub-systems which enable Flight Termination, ADS-B control, and dangerous payload control?

The remainder of this paper underpins the motivation for posing these questions.

III. THE RPAS SEPARATION CHALLENGE

A. *Key Considerations for Sense and Avoid*

Two key considerations in the SAA challenge are the degree of cooperation provided by other platforms, alongside the detection technique employed by the RPAS. In [14], Muraru organises these variables to identify four key SAA scenarios which are often referred to in SAA literature:

- **Active-Cooperative**: active, airborne interrogation of the transponder of other (Cooperative) aircraft e.g Traffic Collision Avoidance System (TCAS),
- **Active-Uncooperative**: Actively scanning to detect all traffic, whether transponder-equipped (cooperative) or not (uncooperative), e.g RADAR, LIDAR,
- **Passive-Cooperative**: reliant on everyone having a transponder (cooperative), which broadcasts position, altitude and velocity data such as Secondary Surveillance Radar or Automatic Dependant Surveillance-Broadcast (ADS-B),
- **Passive-Uncooperative**: Most challenging problem space, requiring a sensor to detect and assess the threat posed by oncoming, electronically "invisible" traffic.

Each scenario/approach has advantages and disadvantages and presents specific challenges. A significant disadvantage for both active scenarios is SWaP, and/or cost. As will become clear throughout this paper, the structure, surveillance and separation services provided by the NAS all impact on the degree of cooperation provided by other platforms, in addition to the instances where "passive" measures are less effective for maintaining separation. A key example is uncooperative, VFR manned platforms operating in uncontrolled airspace. This challenging scenario is one which on-board and off-board RPAS SAA technology has still not adequately mitigated, and the delays underpin the recommendations made by the US ONR report [5], discussed in Section I.

B. *The NAS Contribution to Separation Assurance*

Section I highlighted non-segregated RPAS operations are a high priority for the RPAS community, however the challenges associated with non-segregated operations will quite likely necessitate a stepped transition. This prompts an immediate question: which airspace is the ideal place to commence those operations and what are the corresponding airworthiness requirements. In considering these questions, CASA may draw on the recently released (2013) European RPAS Roadmap [15] or the US FAA RPAS Roadmap [4] to inform their decision making process. Both documents incorporate a suite of high level goals and identify an array of enabling research focus areas. However via Annex 2 to the Roadmap, the Europeans provide more detailed sequencing and milestone information and in particular, greater granularity regarding their near, mid and long term priorities. Their short to mid-term focus will be on integrating RPAS into **controlled airspace, under IFR rules**. They assert that integrating RPAS into uncontrolled airspace, amidst an array of uncooperative VFR/IFR CPA platforms, is an environment that current SAA technologies are not yet equipped to

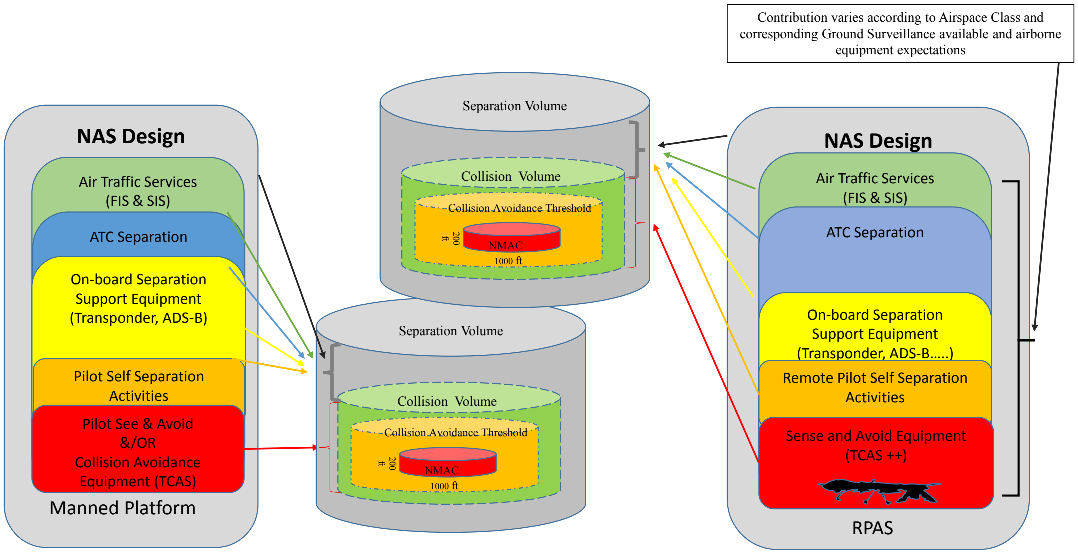

Fig. 1: Contributing factors to Separation and Collision Avoidance

mitigate. The US Roadmap [4] and plan [7], have a large number of overlapping goals with the espoused European approach, however the documents are silent in regard to any preference for transition sequencing of RPAS operations.

CASA, is yet to publicly declare a preference or priority for initial BVLOS operations, however recent draft updates to CASA Advisory Circulars discussed in Section II suggest an alternative view may be forming, where RPAS integration efforts will begin in Class G airspace, well away from populated areas, before moving progressively to controlled airspace and correspondingly higher complexity air traffic.

It is conceded that in Australia, there are a range of large economic benefits coinciding with RPAS enabled surveillance activities including defence, bushfires, power lines, agriculture and mining. These operations are more frequently conducted over rural/regional or unpopulated areas, and corresponding tracts of Class G airspace. Consequently, Australia's political and economic imperatives for RPAS progress may be completely divergent from our European and US counterparts.

Notwithstanding the importance of economic motivations, safety should always be paramount, and there is some evidence to suggest that IFR operations in controlled airspace is the safer alternative for initial RPAS BVLOS operations. Consequently, our research sought to objectively consider the environmental variables, for "Australian" conditions, which should "ideally" underpin any determination about priority sequencing for RPAS BVLOS operations. Section III-A and V will expand on this assertion.

A secondary motivation for this work was the suspicion that emergent findings might identify operational situations within the NAS, where the coincident collision risk is demonstrably low, and may justify claims for concessions on equipage and airworthiness standards. In pursuing this research "thread", our research drew inspiration from work previously presented by Lacher *et al* from the MITRE corporation in [16], and more recently by Korn *et al* [17]. In Korn's study, he highlights that the current NAS incorporates several layers which combine to provide separation assurance and reduce the collision risk below a Targeted Level of Safety (TLOS). This aligns with the international regulatory approach to ATM [18], which describes a three-tiered, layered approach to maintaining separation as follows:

- **Strategic Conflict Management (SCM)**: structuring airspace design to enable separation for all aircraft classes and capabilities, alongside the use of ATM to maintain efficient flows and manage the overall traffic structure,
- **Separation Provision (SP)**: ensures separation minima are maintained if strategic management is compromised, alongside rules for flight planning and right of way, desired headings, ATC separation services (radar and procedures) and a tiered arrangement of Flight information and Surveillance services,
- **Collision Avoidance**: This coincides with breaching the Collision threshold shown in Figure 1, with the desired outcome to avoid collision via emergency action. In manned aircraft this is achieved via the pilot's ability to take SAA action, possibly with support from a Traffic Alert & Collision Avoidance Systems (TCAS).

Figure 1 is a tailored hybrid of the layering principles described in [17], [16], [18], but also includes RPAS related elements derived from [5] and [19] and the Separation and Collision Avoidance volume concepts presented in [20]. Discussion regarding the contribution of ATM related aspects such as FIS/SIS and ADS-B is deferred until Sections IV and VI respectively.

As highlighted by Lacher, the NAS provides a *defense in-depth* layering that requires failures at multiple layers before a system failure can progress to a Loss of Separation (LOS)

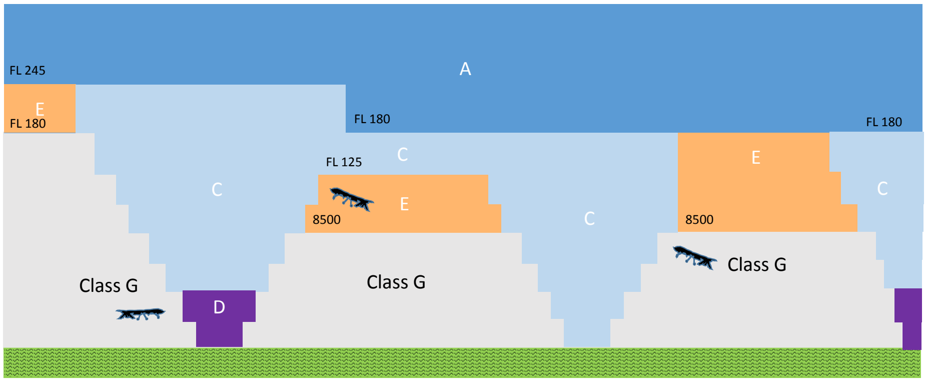

Fig. 2: Permutations of Airspace Classes A, C, D, E and G in Australia with typical Lower Limits

and then ultimately, a Mid-Air Collision (MAC). Arguably, the first two layers (SCM and SP) play a much larger role in reducing the risk of MAC, in comparison to the last layer of Collision Avoidance.

Korn expands on the concept where the ATM layering provides significant risk mitigation, arguing that the individual Equivalent Levels of Safety (ELOS) for "**each of the layers**", does not necessarily need to coincide with the individual elements expected for CPA. Instead, he suggests the goal should simply require that the collective or "**Overall**" ELOS expected for CPA (1×10^{-9} for a MAC) be maintained, and each of the subordinate components in the event chain could be adjusted for the platform, and its expected area of operations. Of particular relevance is Korn's inference that by restricting the **RPAS operations to controlled airspace**, where the NAS contributes significantly more to separation assurance, you could still maintain an overall ELOS.

This reinforces the view that controlled airspace may actually be the safer place to commence unsegregated RPAS operations, because the NAS compensates for many of the extant SAA system limitations. However, one key caveat emerges: the contributing elements of Strategic Conflict Management (SCM) and Separation Provision, **are not constant in the support they provide to conflict prevention**. This varies according to airspace class: variability in applicability of rules and regulations, surveillance equipment, the distribution of aircraft operating in proximity of each other, and required levels of aircraft equipage.

IV. KEY ELEMENTS OF THE AUSTRALIAN NAS

This section provides a brief overview of key contributing NAS elements to support subsequent discussion points.

A. *Overview of Airspace Classes*

The Australian Airspace Policy Statement (AAPS) [21] details that Australian airspace is classified as either controlled (Class A, C, D, E) or uncontrolled Class (G), subject to the level of service required to manage traffic safely and effectively. Class B and F are not used. The administration and prescribed services for airspace classes is aligned with the standards detailed by ICAO in [22]. An easily digestible summary of Australian Airspace is provided at [23], whilst more authoritative guidance is available in the Manual Air Traffic Services at [24] and CASA Regulations at [25], [26].

Figure 2 incorporates the typical permutations of airspace design in Australia. The breakdown of Class C and D Control Zones (CTR) and Control Areas (CTA) for Australian cities and regional areas is as follows:

- **Class C Control Zones**:
  - **Civilian Aerodromes**: Canberra, Melbourne, Sydney, Adelaide, Brisbane, Perth, Gold Coast, Cairns, Coffs Harbour.
  - **Military or Shared**: Amberley, Darwin, East Sale, Edinburgh, Cairns, Curtin, Gold Coast, Learmonth, Nowra, Oakey, Scherger, Tindal, Townsville, Williamtown
- **Class D Control Zones**:
  - **Metropolitan or GA Aerodromes**: Archerfield, Avalon, Camden, Bankstown, Jandakot, Launceston, Mackay, Rockhampton, Sunshine Coast, Moorabbin, Parafield,
  - **Regional Aerodromes**: Albury, Alice Spring, Hamilton Island, Karratha, Tamworth, Broome.

Section V will highlight that the greatest risk for MAC in the UK occurred in Class G airspace below 3000ft, and around aerodromes (in and out of controlled airspace). With this in mind, consider Figure 2. It is clear that RPAS operating in Class G at low levels (with possibly lower certification standards), can be short flight times away from Class C/D CTR/CTA and aerodromes. Importantly, these low level areas on the fringe of controlled airspace, often coincide with low levels of surveillance coverage, as will be highlighted in Section IV-F.

This combination of factors warrants scrutiny of the variability in RPAS Lost Link and Flight Termination procedures, in particular, their suitability for dealing with the wide spectrum of NAS permutations that will arise. Prudent determination of acceptable intervals before ATC and surrounding traffic are made aware of a lost link occurence is also a short term requirement, in conjunction with deliberations regarding how and when Recovery Actions[2] will be communicated to ATC.

All of these factors amplify the critical need to determine the desired standards for RPAS airworthiness, and the necessary precision, integrity and reliability of navigational and barometric equipment. This includes guidance and regulation regarding the required levels of software assurance for both the Remote Platform (e.g. RTCA DO-178C[27]) and its corresponding Remote Piloted Station (e.g RTCA DO-278C [28]).

B. Air Traffic Service

The purpose of Air Traffic Service (ATS), as described in the Airservices Manual of Air Traffic Services (MATS) [24], is to prevent aircraft collisions (on the ground and in the air), ensure orderly flow of traffic, provide advice and information useful for safe and efficient flights, and provide SARWATCH. MATS details that ATS contains 3 key elements:

1) **Air Traffic Control Service** which includes:
    - Area Control,
    - Approach Control (Sect 11 of [24]), and
    - Aerodrome Control (Section 12 of [24]).
2) **Flight Information Service** (FIS), and
3) **Alerting Service**.

For aircraft operating in controlled airspace, ATC separates and segregates aircraft to ensure the separation and collision volumes illustrated in Figure 1 are not breached. Further details on ATC separation, FIS and SIS are provided below to reinforce how the Australian NAS provides a layered collision support service.

C. ATC Separation

In summary, clearances issued by air traffic control units will provide separation:

- Between all flights in class A airspace,
- Between IFR flights in classes C, D and E airspace,
- Between IFR flights and VFR flights in Class C airspace,
- Between IFR flights and special VFR flights, and
- Between Special VFR flights when the visibility is less than VMC.

Lateral, horizontal and vertical separation minima are maintained in accordance with [24] and can vary subject to a number of considerations. When an aircraft is within radar coverage (Primary Surveillance Radar (PSR) or Secondary (SSR)), aircraft can be separated according to much tighter margins, typically 3 or 5 NM, subject to the type of radar used. Vertical separation minima in accordance with [24], [25] and [26] can vary between 500 and 3000 feet. When radar surveillance is not available, the aircraft will be placed under Procedural Control and cleared onto a predetermined route. Any other aircraft flying on the same or intersecting routes, at the same level, cannot be within a predetermined minimum flying time (typically 10 minutes) from the other aircraft. Other variables which can influence the allowable distance between aircraft include the speed of the aircraft, and the method and assessed accuracy for which aircraft and or ATC use to determine the aircraft position. Circumstances which trigger a requirement for procedural control (such as an RPAS not adequately equipped), can necessitate separation distances up to 75 NM. This is a situation which has undesirable implications for traffic flow optimisation that form part of the SCM discussed in Section III-B.

D. Flight Information Service(FIS)

Section 9.1 of [24] provides a comprehensive description of the elements available under the FIS. Broadly, a FIS includes [24]:

- Pre-flight information,
- Operational informational including meteorological data, changes to air routes, nav and approach aids and facilities,
- Traffic Information (to Class C, D, E & G),
- ATS Surveillance information (to Class E and G), and
- Information likely to affect safety.

The ATC Centre in either Brisbane or Melbourne, provides both the Area Control Service in controlled airspace and the Flight Information Service (FIS) for Class G airspace. This FIS service is delivered by a Sector controller via VHF or HF communications (Flightwatch).

E. Surveillance Information Service (SIS)

Section 9.8 of [24] describes SIS as an "*on request*" traffic, position or navigation information service provided to assist pilots of VFR flights, **within** ATS surveillance system coverage, in Class E and G airspace, enabling them to avoid other aircraft and/or assist in navigation. Provision of SIS is subject to ATC workload, and according to 9.8.9.3 of [24], aircraft must be equipped with direct VHF communications and a serviceable Mode S transponder (with or without Extended Squitter). This suggests VFR aircraft only equipped with a Mode A/C transponder do not receive SIS. SIS can also include Flight following, which assists transponder equipped recreational aircraft operating around a control zone, providing a risk mitigation tool for minimising unintentional violation of controlled airspace.

F. Surveillance Coverage

There are four key surveillance technologies used to support air traffic control separation and services. These include:

- Radar (Primary & Secondary),
- ADS-B alone,
- Wide Area Multi-lateration (typically with ADS-B but may be supplied without), and
- ADS-Contract (ADS-C)(Not discussed further in this paper).

Recent completion of the AMSTAR Project [30] means all capital cities[3] have Primary and Secondary Surveillance

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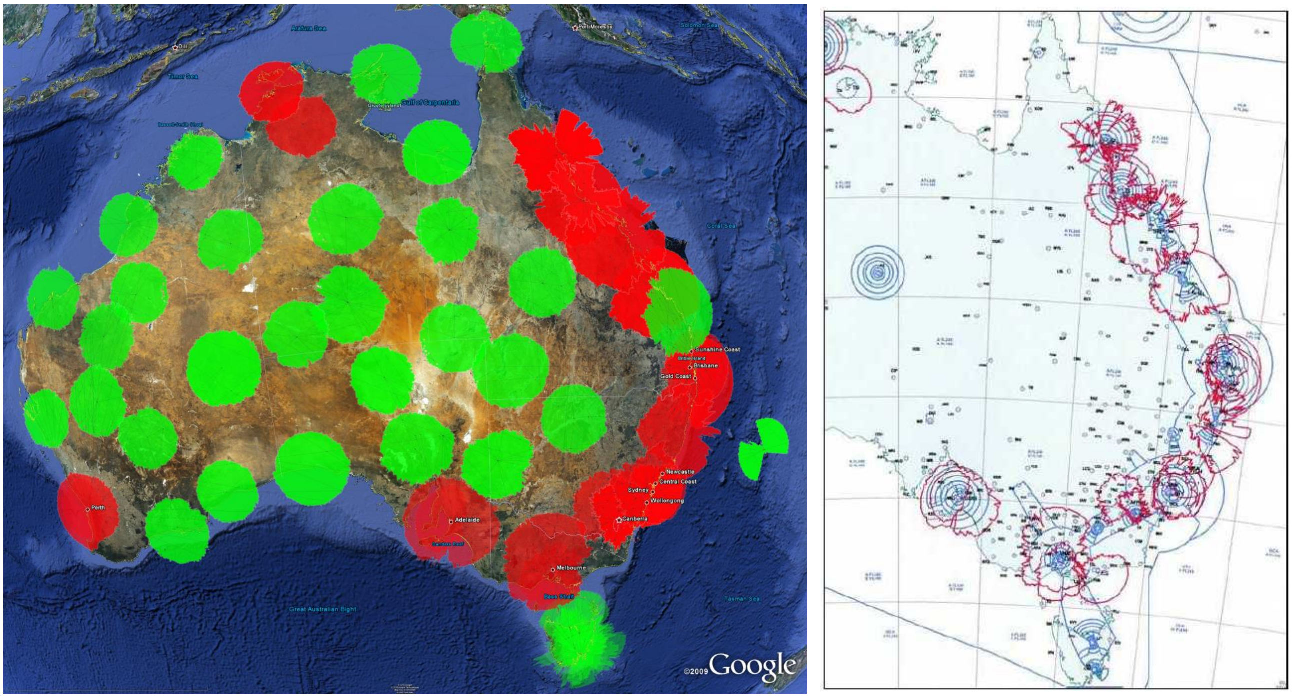
[2] Return to Base, variation in turn and decent solutions

[3] Plus Coolangatta and Cairns minus Hobart



(a) PSR, SSR and ADS-B at 5000 feet: ADS-B shown in Green

(b) SSR Only Coverage at 3000ft

Fig. 3: PSR/SSR & ADS-B Coverage **Source**: *Airservices Australia*

Class D Airport	Class D CTR/CTA Details	Surveillance Coverage (CTR & CTA)	Class D Airport	Class D CTR/CTA Details	Surveillance Coverage (CTR & CTA)
Albury	SFC-2000ft 3 steps to 4500 ft and 20 NM DME	SSR only avail >8000ft via Melbourne. TSAD Avail, Melbourne provides radar >8000 ft	Launceston	CTR SFC-1500ft 3 steps to 4500 ft out to 20 NM DME	0-4500ft via WAM fed to Melbourne
Alice Springs	CTR SFC-3500ft 3 steps to 4500 ft out to 15 NM DME	No RADAR Coverage & TSAD Not Available	Mackay	CTA SFC-1000ft 3 steps to 4500 ft out to 22 NM DME	SSR Coverage for CTR, (Some radar shadowing to North) TSAD Available
Coffs Harbour	CTR SFC-1000ft 3 steps to 4500 ft out to 22 NM DME	No SSR. Brisbane radar available > 6000 ft.TSAD Available	Rockhampton	CTR SFC-1000ft 3 steps to 4500 ft out to 22 NM DME	SSR for entire CTR. (SFC-1000) Brisbane Radar Service >4500 ft.
Hamilton Island	CTR SFC-1000ft 4 steps to 4500 ft out to 22 NM DME	SSR coverage > 2500 ft within CTR. Brisbane provides radar coverage > 4500, TSAD	Sunshine Coast	CTR SFC-1500ft 3 steps to 4500 ft out to 20 NM DME	SSR adequate to 1000 ft. Brisbane provides radar service > 4500ft
Hobart	CTR SFC-1500ft 3 steps to 4500 ft out to 25 NM DME	1000 to 4500 ft, WAM fed to Melbourne	Tamworth	CTR SFC-3500ft 1 Step out to 23 NM to Sth	SSR only avail > 6000ft via Brisbane Centre. TSAD Available

TABLE I: PSR and SSR Coverage at Selected Class D CTR/CTA, **Source**: [29]

radars, with 60 and 256 NM coverage respectively. Simultaneously, Route Surveillance Radars (RSRs) provide radar coverage for aircraft operating along the east coast of Australia and also parts of Western and Northern Australia. The RSR's also provide augmentation or backup to the nearby Terminal Approach radars (PSR/SSR), however their primary role is providing service to the high level airspace. This service is being enhanced under the En-route Radar Replacement Project (ERRP) which includes the replacement of nine of the eleven aging RSRs, including new radomes at seven sights, alongside various other improvements.

The coverage provided by PSR and SSR at 5000 feet is depicted in red in Figure 3a, with the distinct ”J Curve” down the eastern seaboard clearly evident. It is well acknowledged that the existing PSR and SSR equipment does not provide coverage for all Australian airspace; with [31] noting large sections over the middle, north and west of Australia (including the mining areas north of Perth) lacking radar coverage.

The lack of radar coverage necessitates an increased longitudinal enroute separation distances of 50 NM between aircraft, rather than the 5 NM if radar or ADS-B surveillance is available to air traffic control. To address this, Airservices

Australia awarded Thales a contract in 2004 to install 56 ADS-B Ground Stations [32]. The work is still in progress, with 29 duplicated ADS-B ground stations implemented, alongside 14 ADS-B capable multi-lateration sites in Tasmania and 16 in Sydney. Once completed, the combination of radar and ADS-B will provide almost complete surveillance coverage of Australia [6] at 30,000 feet.

However, low level coverage is significantly less comprehensive, and **this coincides with the likely operational areas for many RPAS**. Terrain shadowing, the environment, elevation of the radar dish (for PSR and SSR), range limitations for ADS-B receivers and variability in aircraft transmission signal strength all serve to degrade practically realisable coverage. For example, PSR radar dishes are elevated at 0.5 °. Consequently, at the 60 NM limit of the PSR, nothing below 3000 ft is detectable. Figure 3a highlights the significant coverage gaps for ADS-B (shown in Green) at 5000 ft, notable because there is full coverage at 30,000 ft. Nevertheless, many of the gaps coincide with low traffic density, "*en-route*" tracks between regional Class D aerodromes, so the impact of non-existent ADS-B coverage will be lower.

Figure 3b depicts the SSR coverage at 3000 feet across Australia (as detailed in [29]), highlighting that even in the "J-Curve", surveillance coverage is fragmented and gaps exist. Many of these coverage gaps appear to be well within the bounds of CTA steps surrounding Class C and Class D CTR's. For CPA, the tiered (upside-down wedding cake) system of CTR/CTA mitigates the fragmented coverage, and airspace design ensures IFR and VFR routes into aerodromes coincide with regions of maximum coverage. Moreover, CPA have the added benefit of See and Avoid.

However, these gaps presents challenges for RPAS and CPA separation because they both lose "electronic" visibility, even if fitted with an appropriate ADS-B/Mode S-ES transponder, unless both have TCAS and ADS-B IN. Importantly, these regions with reduced surveillance coincide with reduced levels of Air Traffic Separation and Services, and where there is no legal requirement for VFR aircraft to carry ADS-B, or a transponder. For this reason, further attention was paid to Class D CTA/CTR.

G. Coverage in Class D

A report commissioned by CASA in 2010, examined the airspace surrounding 10 Class D aerodromes [29], providing useful surveillance and ATC coverage information. Table I consolidates pertinent aspects for the investigated aerodromes. Perusal of Table I reveals deficiencies in low level coverage for Tamworth, Coffs Harbour, Albury, Alice Springs and Hamilton Island.

It is uncertain whether the Surveillance Approach Control Services to Regional Airports (SAFRA) project [33], AMSTAR [30] and En-Route Radar Project (ERRP) [34] have served to improve the surveillance coverage. Most of the reviewed aerodromes employ a Tower Situational Awareness Display (TSAD). TSAD derives its information from en-route SSR feeds to the ATC Centre in either Brisbane or Melbourne, however it does not meet the engineering performance requirements for a radar control service, due to latency and shortfalls in functionality [29]. Consequently, Tower controllers cannot use TSAD to separate aircraft, and instead must employ procedural control. For IFR aircraft, this means much greater separation spacing, so technically, a significant increase in BVLOS RPAS operations around these particular aerodromes, may complicate traffic flow optimisation for ATC.

V. RPAS COLLISION RISK IN DIFFERENT AIRSPACE CLASSES

Section III-B highlighted that the introduction of unsegregated, BVLOS RPAS operations in Europe is likely to begin in controlled airspace. There is considerable evidence to suggest this is a safer option compared to commencing initial operations in uncontrolled airspace. For example, in a study commissioned by the Guild of Air Pilots and Air Navigators (GAPAN) [35], the 32 million flying hours flown in the UK between 1999 and 2008, were analysed to establish the overall risk of Mid-Air Collisions (MAC). The figures were subsequently analysed across various classes of airspace and operations with notable findings as follows:

- Commercial Aircraft operations (14.75 M hours) did not result in a single Mid Air Collision (MAC),
- General Aviation (GA) accounted for 86% of MAC's,
- Operations in uncontrolled airspace were **400 more times likely to result in a MAC**, and
- The highest risk of MAC was in Class G, especially around 3000ft in conjunctions with the area surrounding airfields, inside and outside controlled airspace.

The report highlights that in Class G airspace, the primary mechanism for avoiding a MAC in manned platforms is via pilot lookout and decision-making, but the "*perceived level of safety gained from this ability is **overestimated***". By contrast, in controlled airspace, this ability is complemented by the layered NAS described in Section III-B, and this system acts to significantly reduce the likelihood that an aircraft will breach the separation or collision volumes illustrated in Figure 1, where last minute avoidance would be required. For the UK, the NAS contribution to separation assurance is several orders of magnitude more effective than pilots obtain when operating alone in uncontrolled airspace. Our scrutiny of an Australian Air Transport Safety Bureau (ATSB) study [36], dedicated to examining loss of separation between 2008 and 2012 noted that there have been no MAC occurrences for aircraft separated by ATC in Australia. A less detailed review of MAC statistics available on the ATSB website also reinforces the theme of higher percentages of GA involvement in both LOS and MAC.

Section IV-F and IV-G illustrated that in certain parts of Australia, particularly at lower altitudes, there are gaps in ADS-B, PSR, and SSR coverage. Section IV-B will expand on the requirements for aircraft operating under Visual Flight Rules in Class D, E and G, and how they coincide with less desirable less stringent requirements for equipment, in addition to reduced levels of ATC separation and service. For future BVLOS RPAS operations, one of the more ominous combinations is VFR CPA (or RPAS), operating in Class E in Australia, where:

- No requirement for a clearance to enter exists, and ATC are not required to provide a separation service, although the aircraft can receive a Flight Information Service or Surveillance Information Service on request,
- There is no current or planned requirement for existing aircraft to fit ADS-B, and VFR aircraft only require a **Mode A/C transponder**, and
- IFR aircraft operating in the area are only separated from other IFR, **not VFR**, although an Air Traffic Service and Traffic Information is provided on VFR flights, **if practicable**.

The diminishing safety buffer this environment presents, even for CPA platforms, was compellingly highlighted in the CASA report [29] discussed in Section IV-G. They noted that selected major airlines, flying between Melbourne/Sydney and Mackay, deliberately track via Rockhampton in order to stay within the confines of Class C and Class D airspace, "**rather than risk flying at low level in Class E airspace**".

In their view, there is a significantly greater risk of conflict with unannounced or unidentified aircraft operating under Visual Flight Rules, and this mitigation was considered necessary, despite the additional track miles, additional fuel, time and ultimately cost. The fact this risk is acknowledged and mitigated by the commercial passenger transport community, even though typically equipped with TCAS-II and ADS-B (which coincides with two key elements of the ONR recommendation), in addition to human ability to See and Avoid, reinforces that the European concerns are not specific to their airspace. The evolution of local Australian behaviours to mitigate the risk strengthens the "international" case for conducting initial BVLOS RPAS where greater levels of surveillance and ATC control are available.

VI. ADS-B AND TCAS-II IN AUSTRALIA

This section explores the contribution ADS-B makes to separation assurance within the Australian NAS, and the implications for RPAS. Knowledge regarding the fundamentals of ADS-B is pre-supposed, although a brief overview is provided to facilitate emphasis on selected points. The lack of consideration for TIS-B, despite its contribution to situational awareness and risk reduction, is justified because the Australian ANSP has indicated TIS-B will not be installed. TCAS-II, whilst similarly important, was also not considered because the requirements for RPAS SAA, are unlikely to be met by TCAS-II, as indicated in [37].

There are two key on-board ADS-B systems: ADS-B OUT and ADS-B IN. Only ADS-B OUT is mandated in Australia. An ADS-B OUT equipped aircraft contributes to the safety of the NAS, by being electronically visible to other aircraft equipped with ADS-B IN, and ATC, when in range of an ADS-B ground receiver[4]. Section IV-F highlighted the limitations of ADS-B coverage in Australia. An ADS-B OUT equipped aircraft is not capable of receiving information about other "*intruder*" traffic, unless this information is relayed verbally from ATC. In contrast, an ADSB-B IN aircraft can receive information on other ADSB-OUT (or IN) aircraft via a Cockpit Display Traffic Information (CDTI) device. Notably, in Australia, the information received by ADS-B IN equipped aircraft is reduced compared to that available on US systems. This is because the US employs ADS-Rebroadcast (ADS-R), where an ADS-B ground station receives ADS-B transmissions on one link (UAT or 1090 MHz), and re-transmits traffic information on 1030 MHz up-link. This traffic information includes any PSR and SSR derived information received by ATC, in addition to ADS-B OUT transmissions from other aircraft in range. It enables ADS-B IN equipped aircraft to see all electronically within a specific transmission volume. However, in Australia ADS-R and TIS-B are not employed, meaning the only information available is that relayed verbally by ATC regarding other aircraft, or directly via ADS-B OUT transmissions. The key takeaway is that safety determinations made in the US regarding separation assurance for CPA/RPAS, **may need reconsideration for Australian ADS-B infrastructure**.

A. ADS-B Key Dates

All IFR operating in controlled airspace in Australia will be required to install and operate ADS-B OUT by Feb 2017, compliant with the standards contained in [38]. The mandate does not stipulate a requirement for an ADS-B IN capability. THE ADS-B equipment mandate has been staged according to the following schedule [39]:

- **IFR above FL 290** - 12 Dec 2013: all IFR aircraft flying at, or above 29 000 ft, in Australian airspace,
- **IFR Forward fit** - 6 Feb 2014: Aircraft first registered on, or after 6 February 2014, and operated under IFR, must carry serviceable ADS-B transmitting equipment compliant with [38],
- **IFR for Western Australia** - 4 Feb 2016: Aircraft operated under IFR in Class A, B, C or E Airspace, and within the arc of a circle that starts 500 NM true north from Perth aerodrome and finishes 500 NM true east from Perth Airport,
- **All IFR aircraft** - 2 Feb 2017: Any aircraft first registered before 6 Feb 2014 and operated under IFR.

In addition to all IFR aircraft, "*VFR aircraft imported or manufactured from Feb 2014 and operating in controlled airspace*", or above 10000 feet in Class G, are also required to install an ADS-B "*capable*" transponder. Section VI-B will expand on the details.

B. ADS-B Equipment Compliance

The key elements necessary for a CASA compliant ADS-B system, in accordance with [38] are:

1) ADS-B transmitting equipment must be of a type that is:
    - authorised by either the FAA in accordance with FAA TSO-166 (2004) [40] or by CASA in accordance with ATSO-C1004a or ATSO-C1005a,

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[4] Recall the ADS-B coverage shortfalls identified in Section IV-F

    - accepted by CASA as meeting the specifications in RTCA DO-260 (2000) [41][5], or a later version,

2) Subject to the date of manufacture of the aircraft, an ADS-B compliant GNSS receiver must be certified in accordance with either FAA TSO-C129 [42], TSO-C145a [43], TSO-C146a [44], or TSO-C196 [45]. Aircraft undertaking flight with TSO-C129 compliant systems must plan for an alternate that has a conventional navigation aid and hence, carry suitable equipment e.g. VOR or ADF, thus incurring a SWaP penalty,
3) Pressure altitude must be determined by a barometric encoder authorised by FAA or EASA in accordance with TSO-C88a[46], or equivalent, and
4) The system must allow the pilot to activate and deactivate transmission during flight.

In addition to the listed items, aircraft carrying a compliant ADS-B System must operate it, and lodge a flight plan before each flight. Airservices has indicated all ADS-B equipped aircraft in range of ground receivers, will receive a separation service. Notably, there are circumstances where VFR aircraft also need to "*carry*", but not necessarily operate, an ADS-B capable Mode-S-Extender Squitter transponder (Section 9E of [38]): essentially a case of "*fitted for, but not with*" where subsequent installation of a compliant GNSS (and presumably barometric source) would render the previously "*ADS-B capable*" device, compliant for operation against [38].

Compliance with GNSS requirements for ADS-B is also an enabler for Performance Based Navigation (PBN) requirements, where PBN defines the aircraft navigational requirements in terms of accuracy, integrity, continuity and functionality for the proposed operations. Assuming all BVLOS RPAS operations are deemed IFR, a lack of compliance with the PBN equipage expectation pose concerns regarding how RPAS are meeting RNP 1 (SIDS and STARS), RNP 2 (Enroute) and RNP APPCH operations under PBN.

No guidance has yet been released in regard to qualification standards for equipment/software on both the RP and the RPS, noting the RP must be able to activate or deactivate the ADS-B system, (identified above in Item 4), initiate flight termination and change transponder codes. Arguably, this would need to be compliant with the software standards described in RTCA DO-178 [27] for the RPAS, and or DO-278 [28] for the RPS.

Compliance with these standards are a significant financial impost on operators. For example, consider the suite of extant aircraft systems that will be required to interface with the ADS-B system (antennas, barometric, GPS, weight-on-wheels switch, and possibly displays) all of which imply an update to the Supplemental Type Certificate, or whatever equivalent processes emerges for RPAS at the completion of CASA AC-101 updates.

The requirements associated with ADS-B compliance, including the GNSS and Barometric equipage expectations, represents a double edged sword. On one hand, it will render all IFR and a subset of VFR aircraft operating in controlled airspace, "*cooperative*", with accurate positional data regarding their location. The key disadvantages are cost, and to a lesser extent SWaP. In the long term, these disadvantages are not as onerous as is currently perceived, particularly if the mandates subsequently underpin larger volume requirements for manufacturers, supporting lower costs and iterating SWaP to more manageable levels. Notably, a recent teaming arrangement between MITRE FreeFlight Systems [5] managed to create a portable, low cost, light weight, low power, standalone (self contained GPS and barometric sensor and RF antenna) system that utilizes ADS-B and UAT frequencies capable of receiving signals at ranges in excess of 20 miles, 14 hours operation on 4 AA batteries, and weighing as little as 6 ounces. Similar efforts from Honeywell and DARPA were also cited in [5].

C. Combined ADS-B/NAS impact on SAA

Table II consolidates the ATC and ADS-B related information presented thus far, encompassing consideration for the type of flight (VFR, IFR), the class of airspace and ADS-B equipage expectations. It illustrates the varying levels of confidence in traffic electronic visibility, and surveillance and separation assurance provided by the NAS and ADS-B. The Table has been colour-coded using Green, Amber and Red to reflect the level of confidence to be gained, given the expected equipage and ATC services and separation which are available.

Scrutiny of Table II highlights VFR operations, particularly those OCTA, do not compel operating aircraft to install ADS-B (unless newly registered), and accordingly, those platforms may not be "electronically" visible. This is exacerbated in Class D and G, where a transponder is not required [48][38], and compounded further for RPAS because those conditions typically coincide with reduced levels of separation and ATS service, degrading to "*service on request*", or "*subject to ATC workload*" support.

In contrast, IFR aircraft, with the exception of Class G operating below 10000 feet, will require ADS-B by 2017 (and hence a mode S transponder), will be separated from most IFR and VFR traffic (except Class G), and also have access to FIS and SIS on request. The only degraded aspect of the NAS layering in controlled airspace, occurs because of surveillance gaps, as highlighted in Sections IV-F and IV-G, and the flow on implications to ATC service and separation support in Table II.

D. ADS-B latency and Separation Standards for RPAS

The separation standards for CPA have been iteratively refined over many years. They incorporate consideration for communication latency between ATC and the pilot, and estimates for acceptable response times for pilots after receiving ATC directives. For the trifecta of RPAS/CPA/ATC communication, the relevance of these time-frames is compromised, because, as noted in RTCA DO-304 [49], RPAS employ more complex, and variable communications pathways. For

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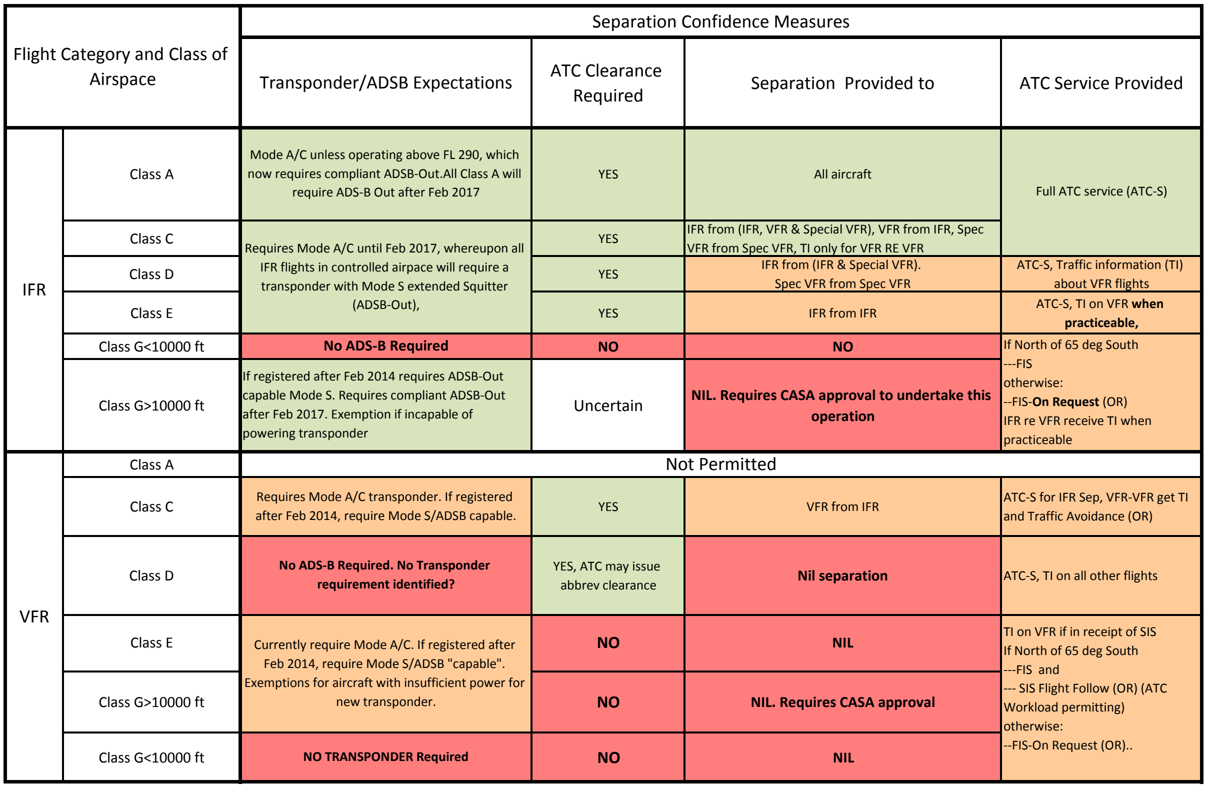
[5] RTCA DO-260B and TSO-166b reflect the most recent update status for ADS-B, released in 2009



Flight Category and Class of Airspace		Separation Confidence Measures			
		Transponder/ADSB Expectations	ATC Clearance Required	Separation Provided to	ATC Service Provided
IFR	Class A	Mode A/C unless operating above FL 290, which now requires compliant ADSB-Out.All Class A will require ADS-B Out after Feb 2017	YES	All aircraft	Full ATC service (ATC-S)
	Class C	Requires Mode A/C until Feb 2017, whereupon all IFR flights in controlled airpace will require a transponder with Mode S extended Squitter (ADSB-Out),	YES	IFR from (IFR, VFR & Special VFR), VFR from IFR, Spec VFR from Spec VFR, TI only for VFR RE VFR	
	Class D		YES	IFR from (IFR & Special VFR). Spec VFR from Spec VFR	ATC-S, Traffic information (TI) about VFR flights
	Class E		YES	IFR from IFR	ATC-S, TI on VFR **when practiceable,**
	Class G<10000 ft	**No ADS-B Required**	**NO**	**NO**	If North of 65 deg South ---FIS otherwise: --FIS-**On Request** (OR) IFR re VFR receive TI when practiceable
	Class G>10000 ft	If registered after Feb 2014 requires ADSB-Out capable Mode S. Requires compliant ADSB-Out after Feb 2017. Exemption if incapable of powering transponder	Uncertain	**NIL. Requires CASA approval to undertake this operation**	
VFR	Class A	Not Permitted			
	Class C	Requires Mode A/C transponder. If registered after Feb 2014, require Mode S/ADSB capable.	YES	VFR from IFR	ATC-S for IFR Sep, VFR-VFR get TI and Traffic Avoidance (OR)
	Class D	**No ADS-B Required. No Transponder requirement identified?**	YES, ATC may issue abbrev clearance	**Nil separation**	ATC-S, TI on all other flights
	Class E	Currently require Mode A/C. If registered after Feb 2014, require Mode S/ADSB "capable". Exemptions for aircraft with insufficient power for new transponder.	**NO**	**NIL**	TI on VFR if in receipt of SIS If North of 65 deg South ---FIS and --- SIS Flight Follow (OR) (ATC Workload permitting) otherwise: --FIS-On Request (OR)..
	Class G>10000 ft		**NO**	**NIL. Requires CASA approval**	
	Class G<10000 ft	**NO TRANSPONDER Required**	**NO**	**NIL**	

TABLE II: ADS-B Expectations and ATC Services as a function of Airspace Class and Flight Rules, **Source**: [47][24]

example, the ATC/RPA/RP communication chain needs to incorporate provisions for the following sequences and time-frames:

- RPA ADS-B system squitters flight information which is received by ATC,
- ATC receives information, scrutinizes it for potential conflicts that may subsequently warrant timely communication with RP via either:
  - direct communication: i.e. ATC centre to the RP in the RPS,
  - relayed communication via the RPA backdown to the RPS, or alternatively ATC to RP pilot via satellite.
- RP receives traffic information or Resolution Advisory from ATC and then responds, and then commands RPA to take avoidance, within a certain time-frame,
- RPA receives command to take avoidance action, and then acts, after a delay subject to the communication pathway.

It is clear this communication cycle requires more time compared to CPA, so RPAS separation standards warrant review.

E. Scenario Testing

A key, yet unanswered question for the RPAS community is whether the full suite of equipment compliance expectation for IFR (ADS-B OUT, GNSS, barometric) will also extend to RPAS. In order to better identify and subsequently examine the array of collision risk permutations that may exist between manned and unmanned aircraft the information in Table II was used to construct Table III. For each potential conflict, 2 separate 4-bit status codes are provided, for both the manned and unmanned platform. The 4 bit status includes information about whether ADS-B OUT is installed (assuming the mandate extends to RPAS), the level of separation and service each platform is expected to receive, for the airspace class it is operating in. For instance, Row 1 (R1), Column 1 (C1) depicts the status for a CPA platform (top left of cell) and an RPA (bottom right) both operating under IFR, in Class A airspace.

Underpinning the research undertaken was the desire to substantiate whether transitioning RPAS to unsegregated operations would be better undertaken initially in controlled airspace. Of course, the suite of considerations span much more than just the airborne collision risk, it also needs to balance system reliability and the need to minimise the risk to people on the ground. Nevertheless, perusal of collision combinations in uncontrolled airspace and Class E, particularly those involving VFR CPA, reveals high levels of "*red ink*". This pictorially reinforces the degraded levels of situational awareness an RPAS will be provided by the NAS, as well as the low levels of electronically visible CPA traffic. This emphasises the ongoing importance for developing SAA solutions to address the problems posed by "uncooperative" platforms mentioned in Section III-A. In

	C1	C2	C3	C4	C5
		CPA	RPAS	RPAS Flight Status	
				IFR	VFR
R1	Class of Operation & RPAS Flight Status	Class A	IFR	☑☑☑☑ ☑☑☑☑	No Conflict
			VFR	NOT PERMITTED	
R2		Class C	IFR	☑☑☑☑ ☑☑☑☑	☑☑☑☑ ?☑☑☑
R3			VFR	?☑☑☑ ☑☑☑☑	?☒☑☑ ?☒☑☑
R4		Class D	IFR	☑☑☑? ☑☑☑?	☑☒☑☑ ☒☒☑☑
R5			VFR	☒☒☑☑ ☑☒☑☑	☒☒☑☑ ☒☒☑☑
R6		Class E	IFR	☑☑☑? ☑☑☑?	☑☒☑? ☒☒☒?
R7			VFR	☒☒☒? ☑☒☑☑	☒☒☒☑ ☒☒☒?
R8		Class G < 10000 ft	IFR	☒☒☒? ☒☒☒?	☒☒☒? ☒☒☒?
R9			VFR	☒☒☒☑ ☒☒☒☑	☒☒☒? ☒☒☒?

TABLE LEGEND

Entry Descriptions

Entry 1	ADS-B Status
Entry 2	Separation Service Provided
Entry 3	ATC Clearance Required
Entry 4	ATC Service providing traffic related information

Options for Each Entry

Yes ☑
No: ☒
Caveats? See Table II for caveats regarding service

NOTE

For each IFR/VFR permutation, the CPA is shown in top left of cell and RPAS in bottom right

TABLE III: Hazard Analysis Table for RPAS/Manned Aircraft assuming Completion ADS-B Mandates (2017)

the interim, initial BVLOS operations are best constrained to controlled airspace, where collision hazards are more efficiently minimised by NAS layering.

VII. CONCLUSION

The information presented in this paper was motivated by our desire to understand the critical factors necessary for safe, efficient integration of RPAS into all classes of airspace. The intent was to employ this knowledge to improve hazard identification granularity, more specifically, those scenarios which elevate RPAS/CPA collision risk. Particular attention was paid to the support available in the NAS that serve to reduce the possibility that aircraft will breach the separation and collision volume, in addition to identification of NAS system weaknesses that may need further attention. Details of equipment mandates that will impact on the distribution of "*cooperative*" platforms was provided, as well as the variation in surveillance and ATC service across each of the airspace classes.

The review of Australian surveillance coverage identified some limitations (ADS-B, SSR and in some instances PSR). Whilst these have negligible impact on safety for CPA operations, they may need further investigation for RPAS operations, particularly at lower levels and around Class D airspace. Restrictions for Operator Certificate applications where coverage limitations for ADS-B, PSR and SSR are known to exist, may be necessary. It was highlighted that compliance with the ADS-B fitment mandate is accompanied with additional equipment expectations, including a GNSS system and barometric source. Both have higher compliance standards than have typically been observed. The impact this mandate will have on RPAS SWaP and cost considerations may require further examination.

Preliminary attempts at refining collision risk scenarios were presented, across all classes of airspace, incorporating regulatory equipment requirements (as expected for CPA) and ATC separation support. This information was used to assess the ramifications of operating RPAS under IFR or VFR, and the comparative safety in controlled or uncontrolled airspace.

The equipment levels that VFR aircraft (manned or unmanned) require to operate in controlled or uncontrolled airspace, do not support an "electronically" cooperative environment because there is no regulatory requirement for ADS-B fitment. Furthermore, Tables II & III highlight the compounding risk to Situational Awareness (SA), because VFR platforms also receive significantly less support from ATC, particularly in uncontrolled airspace. The loss of SA, for the RPAS, CPA and ATC exacerbates the collision risks for RPAS and CPA operating in close proximity. In contrast, the enhanced surveillance and ATC oversight, and greater degrees of electronic visibility because of increased equipment requirements, acts to significantly enhance SA and lower the chances of collision. Finally, it was highlighted that the ATC/RPAS communication chain is significantly different to CPA operations, with many more permutations and variability in communication latency. Accordingly, review of CPA/RPAS separations standards is required.

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