Australian Government
Australian Transport Safety Bureau

Chief Commissioner
23 December 2016

Dr Jane Thomson
Committee Secretary
Standing Committee on Rural and Regional Affairs and Transport
Australian Senate
PO Box 6100
PARLIAMENT HOUSE CANBERRA 2600

Via email: rrat.sen@aph.gov.au

Dear Dr Thomson

Inquiry into Remotely Piloted Aircraft Systems, Unmanned Aerial Systems and associated systems

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers.

The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in:

- independent investigation of transport accidents and other safety occurrences
- safety data recording, analysis and research
- fostering safety awareness, knowledge and action.

As Australia's national transport safety investigator, holding the national aviation data set of reportable incidents and accidents, the ATSB is well positioned to provide comments on the safety risks posed by remotely piloted aircraft.

The ATSB's submission addresses three of the inquiry's terms of reference:

> *(c) the international regulatory/governance environment for RPAS technology and its comparison to Australian regulation.*
>
> This submission outlines the ATSB's international and Australian safety investigation obligations in relation to remotely piloted aircraft systems (RPAS), our previous RPAS investigations, possible future investigations into RPAS occurrences and the mandatory safety reporting requirements in Australia.
>
> *(d) current and future options for improving regulatory compliance, public safety and national security through education, professional standards, training, insurance and enforcement.*
>
> The current and future safety implications posed by RPAS in Australia are presented in this submission, including:
>
> - the expected growth of RPAS ownership
> - an analysis of occurrences, including accidents involving only RPAS, and near collisions

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between RPAS and manned aircraft

- current knowledge about the potential consequences of a collision between a manned aircraft and an RPAS.

(f) the potential recreational and commercial uses of RPAS.

The ATSB's submission provides information about its use of RPAS to assist accident investigations.

ATSB investigation of RPAS accidents and incidents

The ATSB is currently resourced to investigate around 140 aviation accidents and incidents per year from about 5,500 occurrences reported.

In determining which occurrences to investigate, in accordance with section 12AE of the *Transport Safety Investigation Act 2003* (the TSI Act), the ATSB must have regard to the Government's strategic direction set out in the Minister's Statement of Expectations, including "to give priority to transport safety investigations that have the potential to deliver the best safety outcomes for the travelling public."

As Australia is a member of the Council of the International Civil Aviation Organization (ICAO), the ATSB must also take into account its international obligations. Standards and recommendations from Annex 13 to the Convention on International Civil Aviation (*Aircraft accident and incident investigation*) specify:

> 5.1 The State of Occurrence shall institute an investigation into the circumstances of the **accident** and be responsible for the conduct of the investigation.
>
> 5.1.1 *Recommendation*. The State of Occurrence should institute an investigation into the circumstances of a **serious incident**.
>
> 5.1.2 The State of Occurrence shall institute an investigation into the circumstances of a **serious incident** when the aircraft is of a maximum mass of over 2 250 kg.
>
> *Note 3: In the case of investigation of an unmanned aircraft system, only aircraft with a design and/or operational approval are to be considered.*

In Australia's context, Note 3 would require investigation of all accidents where the remotely piloted aircraft was either above 2 kg or operated under CASA approval.

Australia has lodged exceptions with ICAO for Annex 13 standards 5.1 and 5.1.2 as historically, the ATSB has not had sufficient resources to investigate all accidents and serious incidents.

The ATSB can only investigate transport safety matters as defined by Section 23 of the TSI Act. These matters include accidents and incidents, as well as "something that occurred that affected, is affecting, or might affect, transport safety".

As a result, the ATSB has published its investigation priority policy as follows:

1. Passenger transport—large aircraft
2. Passenger transport—small aircraft
3. Commercial (fare paying) recreation (for example, joy flights)
4. Aerial work with participating passengers (for example, news reporters, geological surveys)
5. Flying training
6. Other aerial work
7. High-risk personal recreation/sports aviation/experimental aircraft operations.

The ATSB will generally investigate accidents and incidents involving RPAS when there is:

- a third-party (person on the ground) injury or risk of injury, or third-party property damage; or

- damage or the potential to damage another (manned) aircraft.

The ATSB has completed three investigations involving RPAS where there was potential risk of injury or third party property damage:

- Airspace incursion involving unmanned airship, Airship 1, 2.7 NM E of Moorabbin Airport, Victoria, 28 October 2012 (Investigation number AO-2012-143).
- Loss of operator control involving a SkyJib 8 RPA, near the Melbourne Cricket Ground, Victoria, on 29 March 2015 (Investigation number AO-2015-035).
- In-flight break-up involving a DJI S900 remotely piloted aircraft, at Toowoomba, Queensland, on 19 September 2015 (Investigation number AO-2015-112).

The ATSB has completed three RPAS investigations where there was potential damage to a manned aircraft:

- Aircraft separation issues involving an Ayres S2R, VH-WBK and an unmanned aerial vehicle, 37 km SSW of Horsham aerodrome, Victoria, 12 September 2013 (Investigation number AO-2013-167).
- Near collision between an unknown object and a De Havilland DHC-8, VH-XFX, 23 km NNE Perth Airport, Western Australia, 19 March 2014 (Investigation number AO-2014-052).
- Near collision involving an unmanned aerial vehicle and a Bell 412, VH-WSR, near Newcastle Westpac Base (HLS), New South Wales, 22 March 2014 (Investigation number AO-2014-056).

Many pilot reports of encounters with remotely piloted aircraft result from very brief sightings with no known information about the aircraft or its operator, which limits the usefulness of such investigations. The ATSB does not generally investigate encounters with remotely piloted aircraft unless details of the RPAS are known.

At the time of this submission, the ATSB is investigating three accidents involving larger remotely piloted aircraft being used for aerial work (such as shark spotting, fire control, bore inspections):

- Loss of control involving remotely piloted aircraft Pulse Aerospace Vapor 55, UAV0734, 4 km NE of Ballina/Byron Gateway Airport, New South Wales, 28 September 2016 (Investigation number AO-2016-128).
- Collision with terrain involving Lockheed Martin Stalker XE UAS, Mount Disappointment, Vic. 24 October 2016 (Investigation number AO-2016-139).
- Collision with terrain involving Lockheed Martin Stalker XE UAS, Avoca Race Track, Vic. 25 October 2016 (Investigation number AO-2016-141).

Due to investigation priorities, the ATSB is highly unlikely to investigate any accident involving a very small remotely piloted aircraft (below 2 kg) or an RPAS used for recreational purposes, unless there was a risk of third party injury or damage to other aircraft.

Reporting of RPAS occurrences to the ATSB

All accidents and incidents related to flight safety in Australia, or involving Australian registered aircraft overseas, must be reported to the ATSB. While the ATSB does not investigate all of these, the data is recorded for safety research, analysis and education. The database forms part of Australia's Aviation State Safety Programme and a de-identified version is used by CASA and is available publicly on the ATSB website.

While the Transport Safety Regulations 2003 do not specifically refer to RPAS occurrences, they are treated like other aircraft and the ATSB expects occurrences to be reported. Specific reporting requirements tailored to the nature of RPAS operations are in development.

Under the current regime, notifications of accidents and incidents involving RPAS are increasing. Between 2010 and October 2016, 212 RPAS related occurrences were reported to the ATSB. Of these, 101 occurrences were reported between January and October 2016. This indicates a significant increase in 2016 compared to previous years. Statistical forecasts predict occurrence reports are likely to double by the end of 2017.

Although the number of RPAS operating in Australia is unknown, there were 754 RPAS operators registered with CASA at 31 October 2016. Available data shows registered owners and interest in ownership is increasing rapidly. Statistical forecasts suggest the number of RPAS in use in Australia will double by the end of 2017. (A detailed analysis is provided in Appendix A.)

The ATSB notes a strong correlation between occurrences recorded by the ATSB and the number of RPAS certificate holders and interest in ownership.

Near encounters

About half of the 212 occurrences recorded since January 2010 involved interference with manned aircraft. Near encounters occur when an RPAS interrupts or is sighted in the proximity of another aircraft. Occurrences only include those encounters where the aircraft had to manoeuvre (or would have manoeuvred if there was more opportunity) to avoid the remotely piloted aircraft.

Over 60 per cent of all reported instances of RPAS interference with other aircraft in the last seven years (110 occurrences), occurred between January and October 2016 (70 occurrences). Statistical modelling forecasts a doubling of the number of interference occurrences by the end of 2017.

To date, there have been no reported collisions between RPAS and manned aircraft in Australia.

About 43 per cent of all interference occurrences involved high capacity air transport aircraft and 46 per cent involved general aviation aircraft. When taking into account hours flown, helicopters were over-represented in RPAS near encounters.

Most occurrences happen in the main capital cities, with Sydney accounting for 37 per cent of all near encounters (see Appendix B for maps of near encounter locations).

The majority of near encounters took place above 1,000 ft, with about half between 1,000 and 5,000 ft. At least 13 per cent were above 5,000 ft (see Appendix B for more detail).

As RPAS are never identified for these occurrences, the ATSB does not know if they were certified RPAS, RPAS under 2 kg not requiring certification, model aircraft, or toys. Given the heights (mostly above 1,000 ft) and locations (mostly urban areas) of reported near encounters, it is unlikely the RPAS involved were being used commercially (i.e. for aerial photography). Further, 40 per cent of near encounters have occurred on weekends, suggesting non-commercial operations.

The standard operating conditions for uncertified RPAS in Civil Aviation Safety Regulation Part 101 include visual line of sight less than 400 ft, outside of controlled airspace and 5 km away from aerodrome boundaries and in non-populated areas. As most near encounters occur outside of these rules, it appears that the operators of these remotely controlled aircraft are either unaware or are unconcerned about these rules.

Terrain collisions

The next most common type of RPAS-related occurrence involves collisions with terrain, accounting for 42 occurrences in the past 7 years, 25 of which occurred between January and October 2016.

About a quarter of the remotely controlled aircraft involved in these collisions with terrain were between 2.75 and 3.65 kg, and another quarter were between 7.5 and 15 kg. None were above 25 kg. Although only about 16 per cent were below 2 kg, this may be related to a lower reporting rate by operators of these very small aircraft to the ATSB.

About 45 per cent of terrain collisions were in urban environments, including the heavier remotely piloted aircraft (average mass 9.3 kg). See Appendix B for more detail, including maps of terrain collision occurrences.

Consequence risk of a collision with a manned aircraft

While the exposure risk to manned aircraft is increasing, the consequence risk for a collision with an RPAS is unclear.

As previously mentioned, there have been no mid-air collisions in Australia involving RPAS reported to the ATSB. World-wide, there have been five known collisions and one suspected collision. Three of these resulted in no damage beyond scratches, including the suspected collision with an Airbus A320 at Heathrow Airport in April 2016. However, one collision with a sport bi-plane (Shpakow SA 750) in the US in 2010 resulted in a crushed wing. Fortunately, the aircraft landed safely. Less fortunately, a Grob G 109B motor glider had a wing broken by an RPAS collision in 1997, resulting in fatal injury to the two people on board (see Appendix C).

Due to the rarity of actual collisions, and very minimal actual testing, mathematical models have been used to predict damage expected from RPAS strikes. These are informed by abundant birdstrike data with about 2,000 birdstrikes recorded in Australia for 2015.

ATSB birdstrike analyses shows that 7.7 per cent of high capacity aircraft birdstrikes result in engine ingestions (20 per cent of which led to engine damage), with smaller aircraft having lower ingestion rates.

Aircraft damage from birdstrike analysis shows engines are most likely to be damaged in high capacity aircraft, followed by wings. For low capacity air transport aircraft, wings are most likely to be damaged, and to a much lesser extent, engines and propellers. For general aviation aircraft, again damage to wings is most likely, and to a much lesser extent, windscreens.

It should be noted that while only 6 per cent of high capacity aircraft birdstrikes result in damage, 25 per cent of birdstrikes to general aviation aircraft result in damage. This is a result of more fragile parts in general aviation aircraft including wings and windscreens.

As remotely piloted aircraft are rigid and generally heavier than most birds, the overall proportion of collisions resulting in aircraft damage is expected to be higher than for birdstrikes, and the distribution of damage across an airframe will probably also differ.

Without more information, it is difficult to thoroughly asses the risk of occurrence and the severity of the outcome for an RPAS collision. However, some observations based on the current literature and the ATSB analysis presented in Appendix C, include:

- While research has been done looking at birdstrikes, and collisions with rocket and satellite debris, it is unclear what the consequences would be for a collision between an RPAS and an air transport aircraft. Although the probability is likely to be low, RPAS components could conceivably penetrate the wing or fuselage of an air transport aircraft.
- Engine ingestion in high capacity air transport aircraft (mostly with large turbofan engines) can be expected for about eight per cent of RPAS collisions based on birdstrike data. The proportion of RPAS ingestions expected to cause engine damage and engine shutdown will be higher than for bird ingestion. However, loss of a single engine should have minimal consequence to the safety of the aircraft.
- RPAS collisions with a general aviation aircraft's windscreen poses a high risk of penetration. The risk is considerably lower for an air transport aircraft, but the possibility of windscreen penetration is uncertain.
- RPAS have the potential to damage a general aviation aircraft's flight surfaces (wings and tail), which could result in a loss of control.
- For a single engine (general aviation) aircraft, an engine ingestion could cause an engine failure, requiring a forced landing. However, the probability of ingestion is very low due to small engine intakes.

Of interest, a major RPAS collision study is currently underway in the UK. The study is a joint venture between UK Military Aviation Authority (MAA), Department of Transport (DoT), and British Airline Pilots Association (BALPA). Through testing and analysis, this research will provide a better understanding of the maximum remotely piloted aircraft mass that would result in minimal to no risk to manned aircraft. It will also assess the severity of impact of remotely piloted aircraft of masses of up to 4 kg against safety critical areas on selected civil and military aircraft. The project will include actual testing on representative windshields and modelling of tail rotor blades.

ATSB use of RPAS for investigations

Since 2013, the ATSB has been monitoring the very small remotely piloted aircraft (VSRPA) industry and regulatory environment, with the aim of establishing VSRPA operations to assist in on-site investigations. The ATSB was reluctant to pursue this goal as VSRPA were historically unequipped to meet the requirements for ATSB operations. However, advancements in modern VSRPA have addressed these issues, the industry has matured and VSRPA now provide significant advantages to traditional on-site survey techniques: The benefits of using VSRPA in ATSB investigations include:

- The initial site survey can be completed with potential safety hazards identified prior to an investigator entering the site.
- Quicker site mapping with very accurate measurements.
- The imagery will provide better information and perspectives that could previously only be obtained using a helicopter.
- Accident flight paths can be safely flown and recorded with no risk to people.
- The use of VSRPA, compared to traditional site survey equipment and software presents substantial cost savings and ease-of-use benefits.

In September 2016, CASA eased regulatory requirements for operating VSRPA. These changes allow operators to use VSRPA for commercial flights according to a set of standard operating conditions and prior notification to CASA. Importantly, users do not require a RPA operator's certificate (ReOC) or a remote pilot licence (RePL).

The ATSB has investigated the use of VSRPA across government organisations in Australia and overseas. In Australia, the Australian Federal Police and New South Wales and Queensland law enforcement agencies use VSRPA. In all cases, these agencies held an RPA operator's certificate to allow them to conduct operations. In the UK, the Air Accidents Investigation Branch (AAIB) currently operate VSRPA under an exemption to UK regulations. However, they have indicated their intention to operate under the UK equivalent RPA operator's certificate requirements due to perceived benefits.

Three significant benefits have been identified for the ATSB to operate under an RPA operator's certificate model:

- Industry and public perception of the ATSB operating under the safest possible framework.
- Improved relationships, with CASA/Airservices Australia facilitating approval of exemptions when required (i.e. operations within 5 NM of aerodromes and in suburban environments).
- Assurance that the ATSB has the appropriate framework, training, policies and procedures to safely operate a VSRPA.

The ATSB is in the process of obtaining an RPA operator's certificate and several investigators will apply for their remote pilot licence.

Thank you for the opportunity to provide input into the inquiry. The ATSB would welcome the opportunity to provide further details and clarify any information presented in its submission. If we are able to provide further assistance, please contact my office on 6274 6144.

Yours sincerely

Greg Hood

Appendices:

- Appendix A: ATSB analysis of RPAS ownership
- Appendix B: ATSB analysis of RPAS safety occurrences
- Appendix C: ATSB consequence analysis of RPAS collisions with other aircraft

Appendix A: ATSB analysis of RPAS ownership

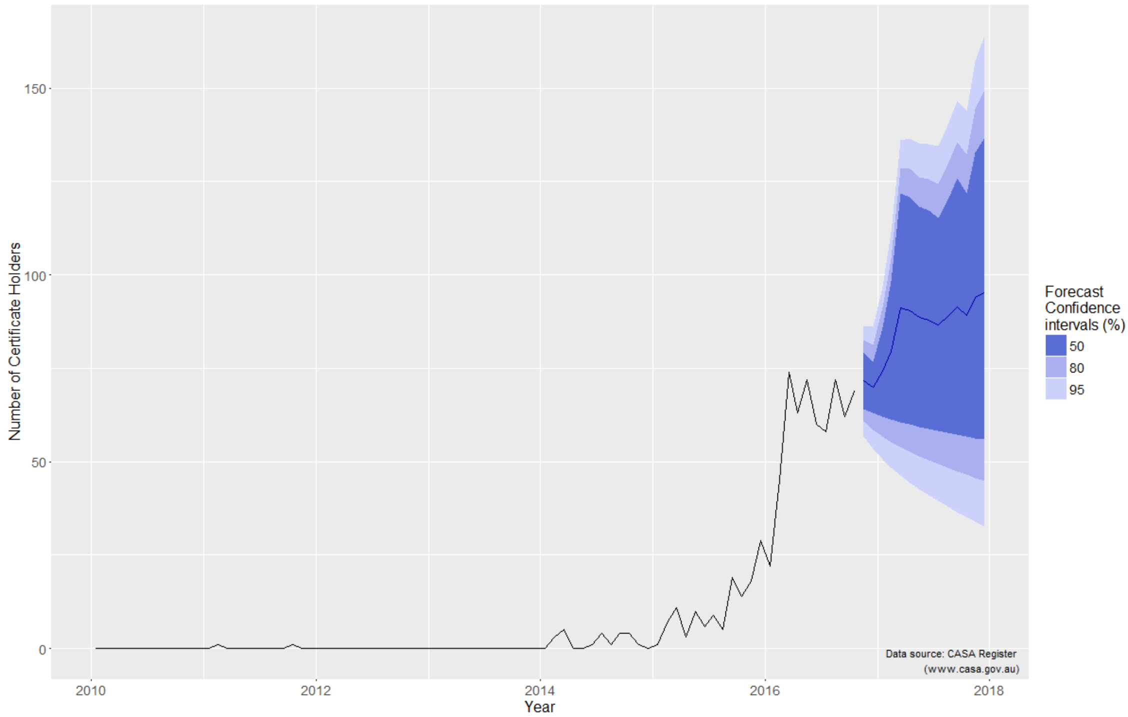
The number of remotely piloted aircraft systems (RPAS) is growing rapidly in Australia. The total number of RPAS in Australia is unknown as not all RPAS require CASA certificates. At the end of October 2016, the CASA website showed there were 754 registered RPAS certificate holders in Australia.

In addition, there are currently no records of the number of RPAS hours flown in Australia as there are for other types of aircraft (recorded by the Bureau of Infrastructure, Transport and Regional Economics).

CASA registered RPAS certificate holders

CASA registered RPAS operators likely comprise only a fraction of the total; however, the growth in their number is probably a good indicator of the general growth of RPAS (Figure 1).

Figure 1: Number of new CASA registered RPAS certificate holders per month (Jan-2010 to Oct-2016). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2]



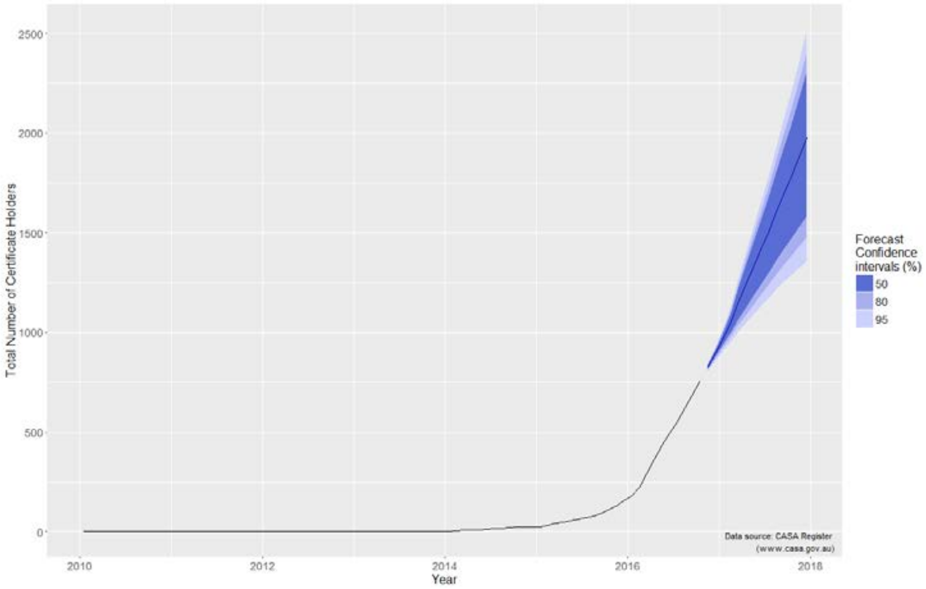
The cumulative effect of this level of growth in the number of new CASA RPAS certificate holders – assuming the operators still maintain ownership of their aircraft – leads to an exponential growth in the number of RPAS certificate holders (Figure 2).

Figure 2 Total number of CASA registered RPAS certificate holders (Jan-2010 to Oct-2016). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to

1 Forecast created using the "forecast" and "forecastHybrid" packages in R:
Hyndman RJ (2016). Forecast: Forecasting functions for time series and linear models. R package version 7.3, http://github.com/robjhyndman/forecast.
Hyndman RJ and Khandakar Y (2008). "Automatic time series forecasting: the forecast package for R." Journal of Statistical Software, 26(3), pp. 1–22. http://www.jstatsoft.org/article/view/v027i03.
David Shaub (2016). forecastHybrid: Convenient Functions for Ensemble Time Series Forecasts. R package version 0.2.0. https://CRAN.R-project.org/package=forecastHybrid.

2 Plot created using the "ggplot2" package in R:
H. Wickham. (2009) ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

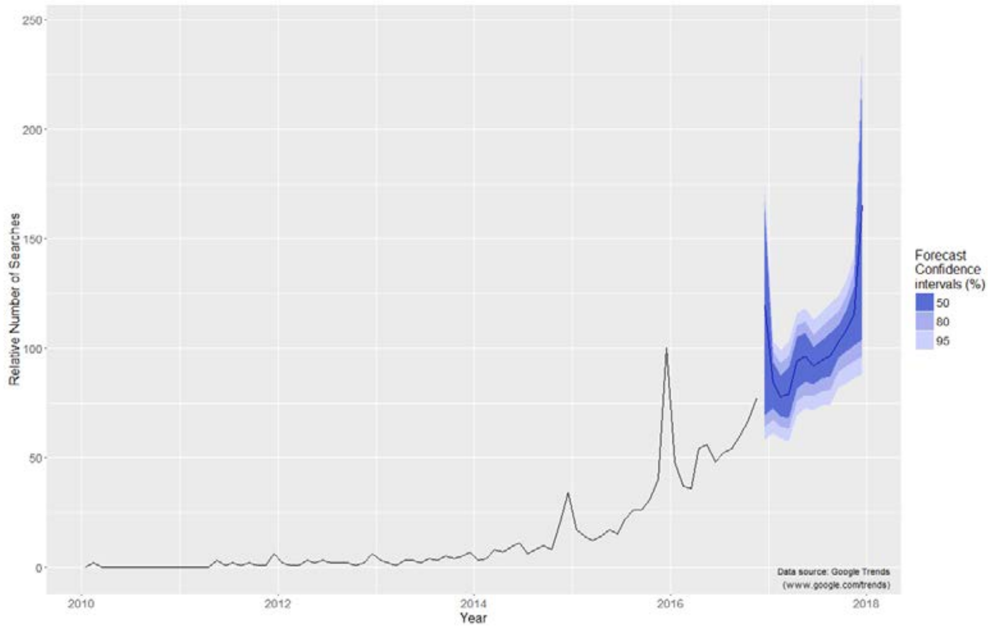
December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2]



Google trends

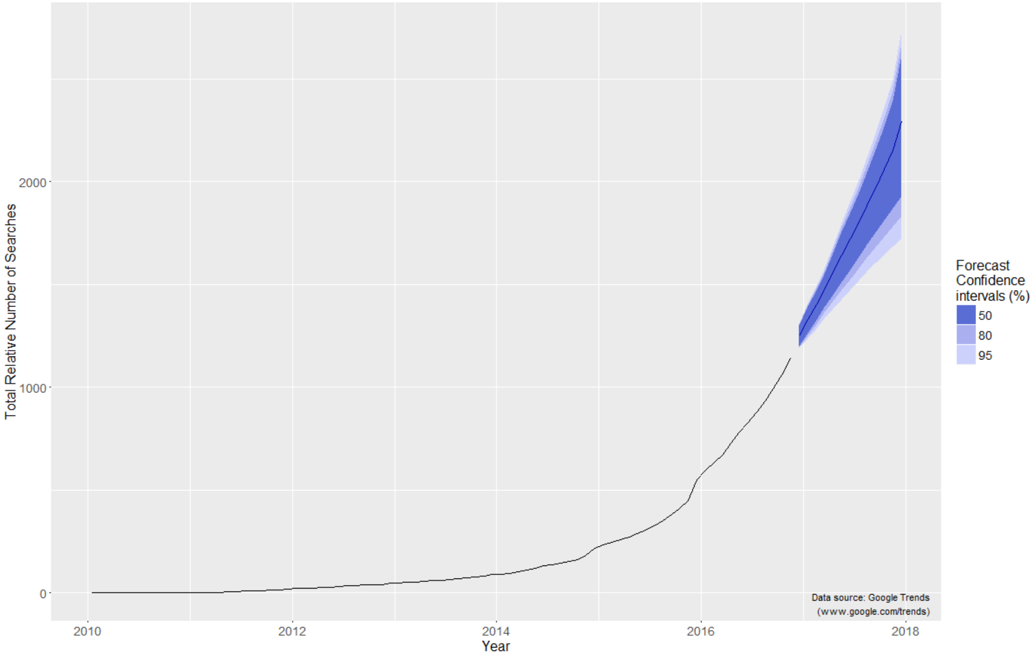
Another good resource to estimate the growth of RPAS in Australia is Google trends. This tool was used to retrieve the number of people searching for RPAS on the Google shopping site within Australia. Although this does not equate to the number of people who purchased an RPAS, it is probably a reasonable indicator of the number of people interested in purchasing an RPAS.

Figure 3 Number of Google shopping RPAS searches (Jan-2010 to Nov-2016) normalised to 100 at peak demand (Dec-2015). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2].



Peaks in the number of searches can be seen prior to Christmas each year. Similar to the number of CASA RPAS certificate holders, it can be seen that demand has increased significantly in the last year. The cumulative effect – assuming a constant fraction of people searching online purchase an RPAS and the number of losses is low – shows an exponential growth in the number of RPAS in Australia.

Figure 4: Total number of Google shopping RPAS searches in Australia (Jan 2010 to Nov 2016) normalised to 100 at peak demand (Dec 2015). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2].



Similar to the data from the CASA register, the expected number of RPAS in Australia is forecast to double by the end of 2017. Due to the level of uncertainty underlying these forecasts, they are indicative only and are not intended to be accurate predictions of the growth of RPAS in Australia.

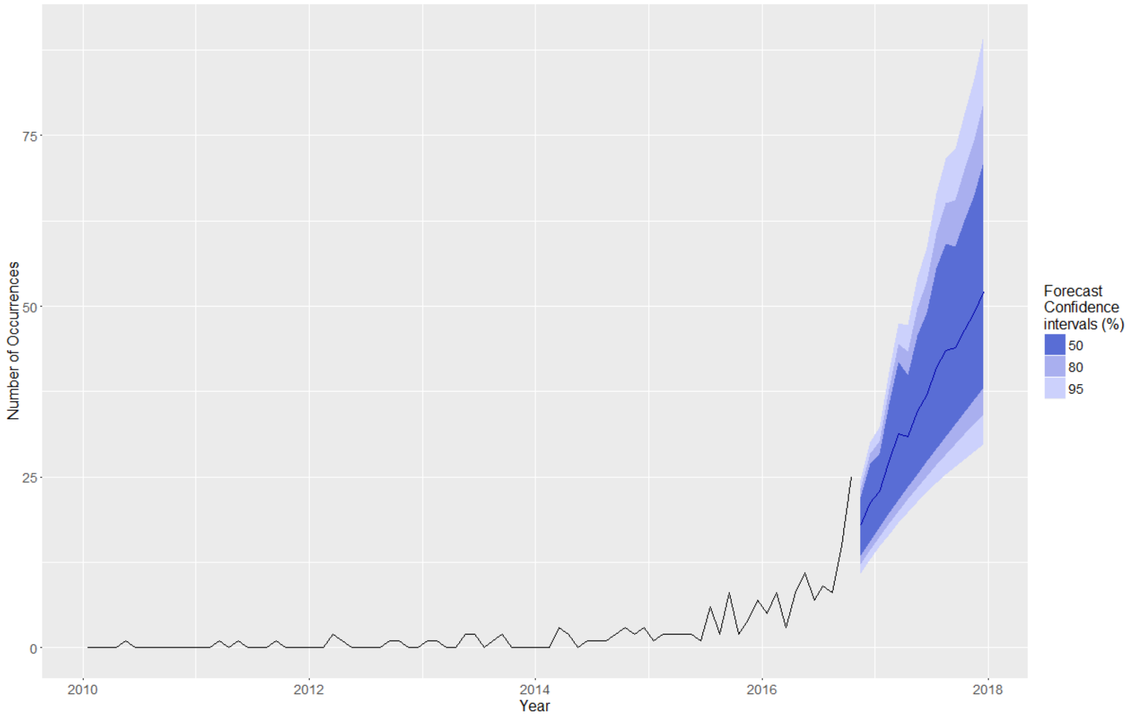
There are three main sources of uncertainty underlying the forecasts presented above:

- Uncertainty in the data: The main contributors are the inherent noise in the data and reporting issues such as under/over reporting and misclassification.
- Uncertainty in the models: This uncertainty comes from the choice of model used and how accurately it generalises the data.
- Uncertainty in external factors: Regulatory changes, changes in consumer activity and new laws or increased enforcement can all affect the accuracy of the forecast.

Appendix B: ATSB analysis of RPAS safety occurrences

The number of RPAS occurrences reported to the ATSB has significantly increased in 2016 (Figure 5). Safety occurrences are incidents and accidents either involving an RPAS, or a near encounter between an RPAS and a manned aircraft.

Figure 5: All occurrences involving an RPAS reported to the ATSB (Jan 2010 to Oct 2015). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2]



The models forecast a doubling in the number of occurrences reported to the ATSB by the end of 2017. Due to the level of uncertainty underlying these forecasts, they are indicative only and are not intended to be accurate predictions of future RPAS activity.

Table 1 displays the correlation between the number of reported RPAS occurrences, the total number of CASA registered RPAS certificate holders and the total number of Google shopping RPAS searches. It shows that the three independent data sources have a good degree of correlation.

Table 1: Correlation between the number of reported RPAS occurrences, the total number of new CASA registered RPAS certificate holders and the total number of Google shopping RPAS searches (Jan-2010 to Oct-2016).[3]

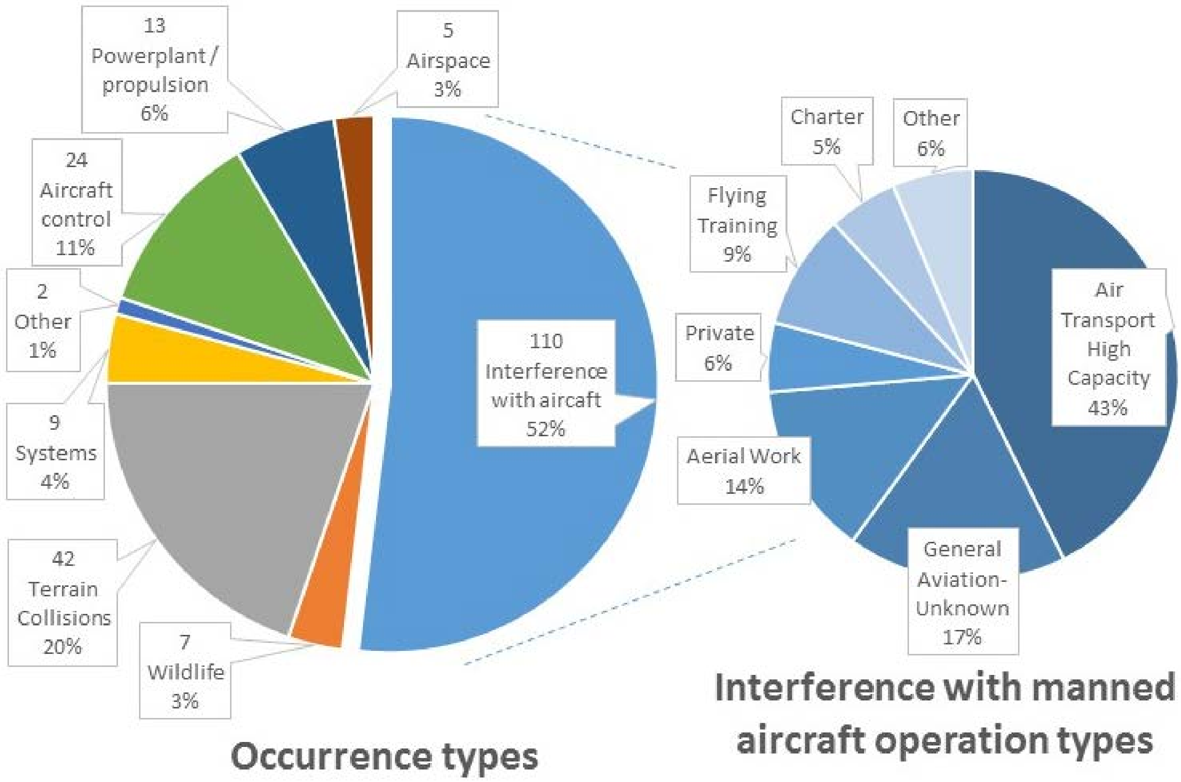
	Reported Occurrence	CASA Register	Google Trends
Reported Occurrence	1.00	0.89	0.87
CASA Register	0.89	1.00	0.94
Google Trends	0.87	0.94	1.00

Figure 6 shows the proportion of all reported RPAS occurrences per occurrence type with interference from ground broken out into the operation types involved. Interference with aircraft makes up around half of all these occurrences. In 43 per cent of these, the other aircraft was a high capacity air transport aircraft. The most common affected aircraft was the Boeing 737 (around 15 per cent of all reports) followed by the Airbus A320 (around 12 per cent).

Since January 2010, 174 RPAS-related occurrences (39 accidents, 13 serious incidents or near accidents, and 122 incidents) reported to the ATSB involved a technical, operational or separation issue.

The occurrences are shown in Figure 6 as mostly involving (in order) interference with manned aircraft, collisions with terrain, aircraft control issues, power plant/propulsion issues, or other systems.

Figure 6: Occurrence types associated with occurrences reported to the ATSB involving RPAS (Jan 2010 to Oct 2016). The break-out chart displays the operation types of the manned aircraft involved in the interference from aircraft occurrence – the most prevalent occurrence type.



[3] Values in the table are the Pearson product-moment correlation coefficient. “1” indicates positive correlation between data sets – as one data set increases the other follows to an equal degree. “0” indicates no correlation between data sets – one data set cannot be used to make predictions about the other. “-1” is negative correlation – as one data set increase the other decreases to an equal degree.

Interference with manned aircraft (near encounters)

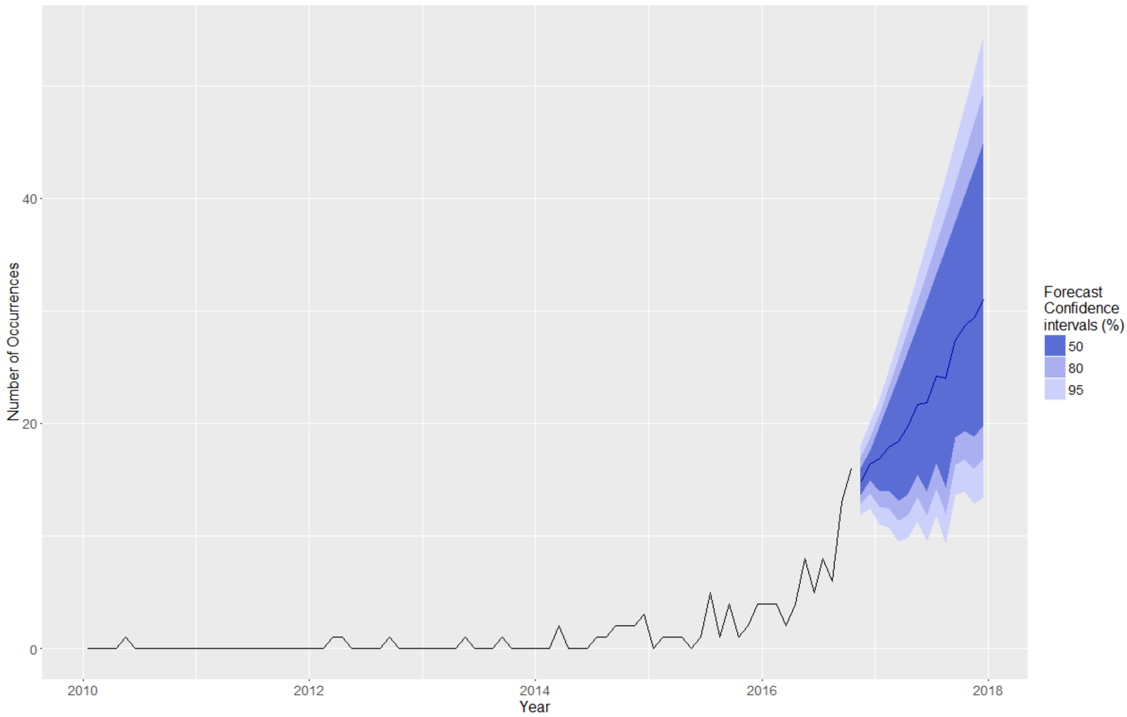
Interference with manned aircraft from an RPAS is where an RPAS interrupts or is sighted in the proximity of another aircraft. Occurrences only include those encounters where the aircraft had to manoeuvre (or would have manoeuvred if there was more opportunity) to avoid the RPA.

There were 70 interference with aircraft occurrences involving RPAS reported to the ATSB between January and October 2016. This is a significant increase considering there were 40 reported in the previous six years (Figure 7).

In addition to these 70, there were also 30 events where an RPA was either reported to air traffic control in controlled airspace, or seen by the pilot of an aircraft, but where there was no interference with any aircraft (because the RPA was too far away).

To date, there have been no collisions reported between RPAS and manned aircraft in Australia.

Figure 7 Interference with manned aircraft occurrences involving an RPAS reported to the ATSB (Jan 2010 to Oct 2015). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2].



The models forecast a doubling of the number of interference occurrences reported to the ATSB by the end of 2017. Due to the level of uncertainty underlying these forecasts, they are indicative only and not intended to be accurate predictions of future RPAS activity.

The locations of RPAS interference occurrences have been relatively evenly spread around the major population centres around Australia (Figure 8 and Figure 9).

Figure 8: Locations of reported RPAS inference from the ground occurrences (Jan 2010 to Oct 2016).

Figure 9: Proportion of interference with manned aircraft occurrences involving an RPAS at significant locations around Australia (Jan 2010 to Oct 2016). Geospatial clustering was conducted using the dbscan algorithm.

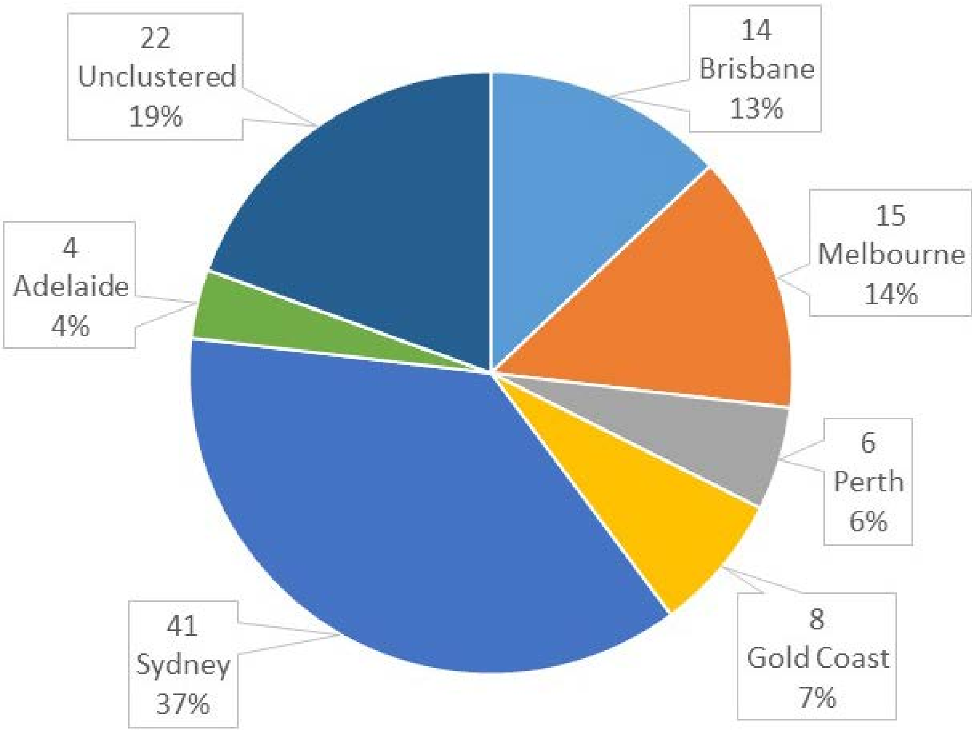


Figure 10 shows the reported altitude of RPAS involved in interference occurrences. Most occurrences are above 1,000 ft. Very few (about 6% of occurrences with a known altitude) were under 500 ft.

Figure 10: Reported altitude of RPAS involved in interference with manned aircraft occurrences (Jan 2010 to Oct 2016). When RPAS altitude is unknown other aircraft altitude is used.

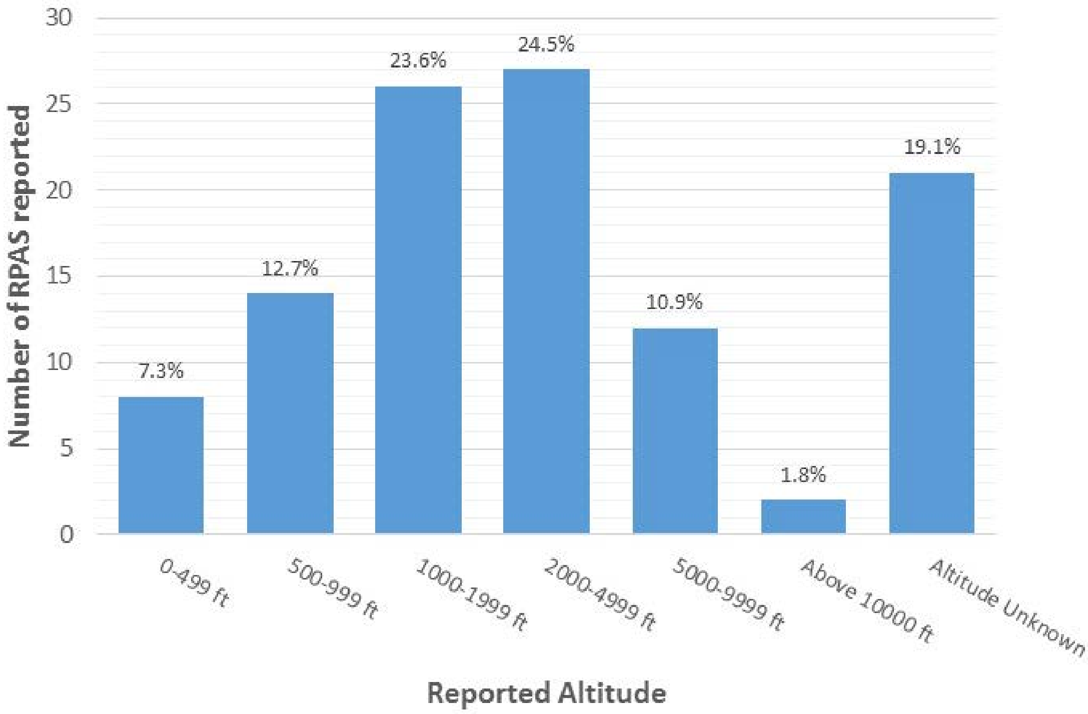


Figure **11** to Figure 13 display RPAS interference with aircraft occurrences around significant Australian locations. The estimated altitude divided into relevant categories is also displayed.

Figure 11: Locations, including relevant altitude categories, of reported RPAS interference with manned aircraft occurrences around Sydney (Jan 2010 to Oct 2016)

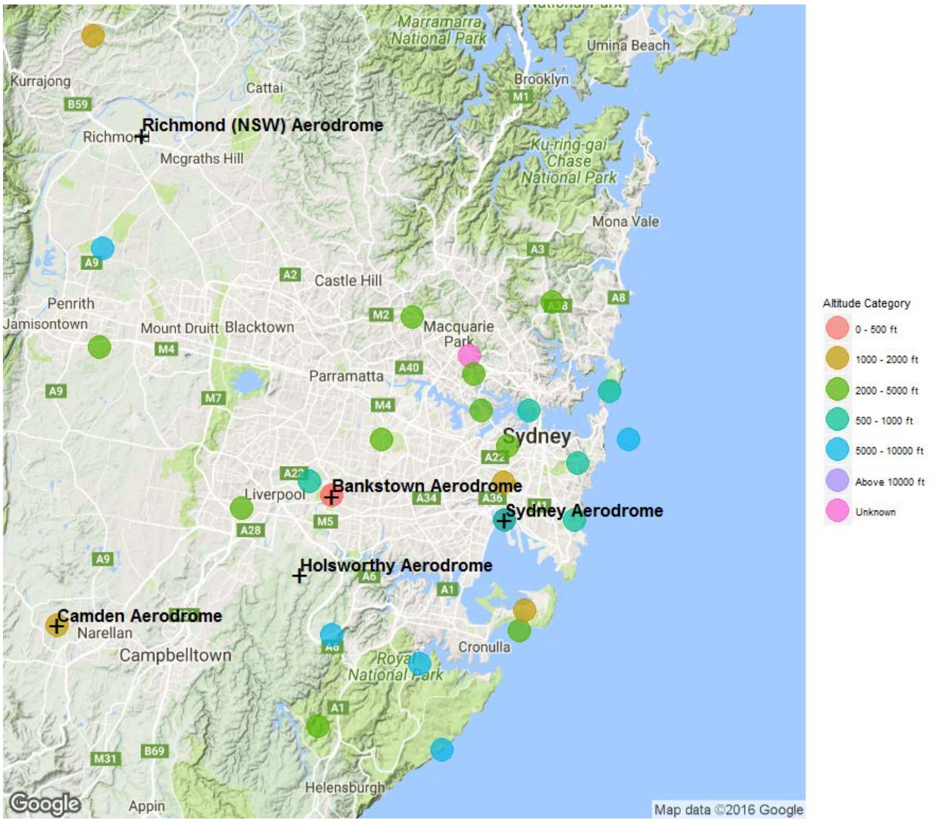


Figure 12: Locations, including relevant altitude categories, of reported RPAS interference with manned aircraft occurrences around Melbourne (Jan 2010 to Oct 2016)

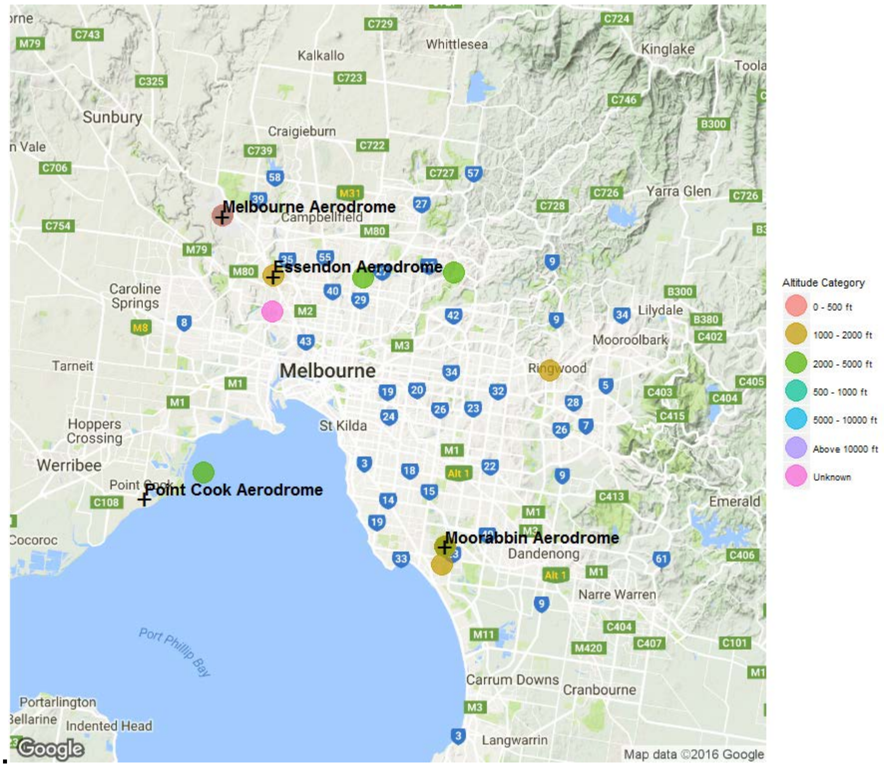
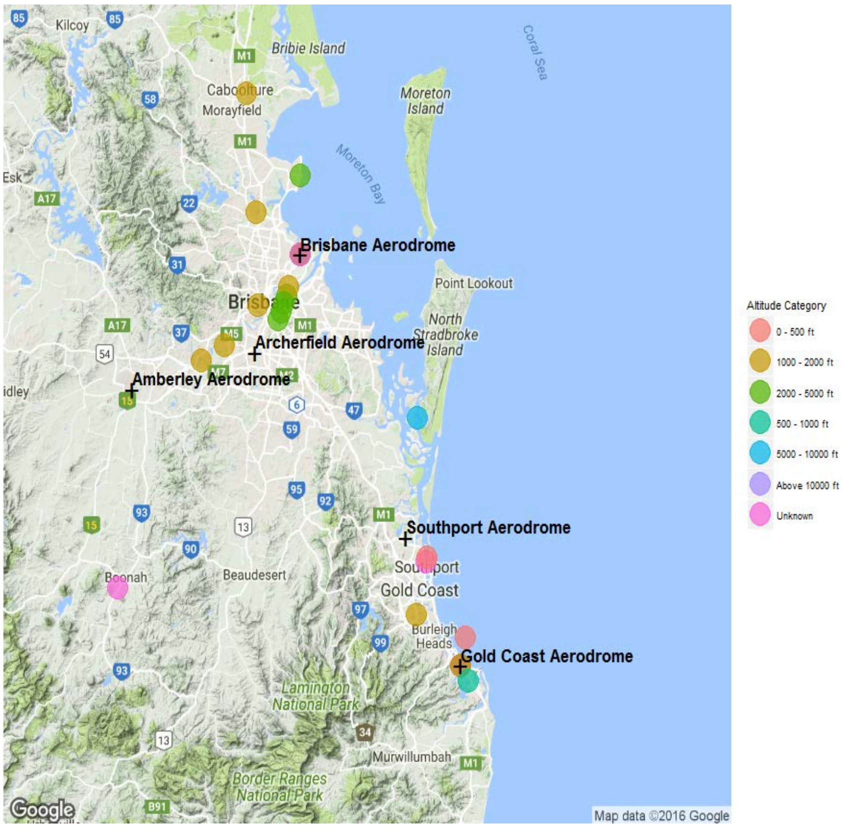
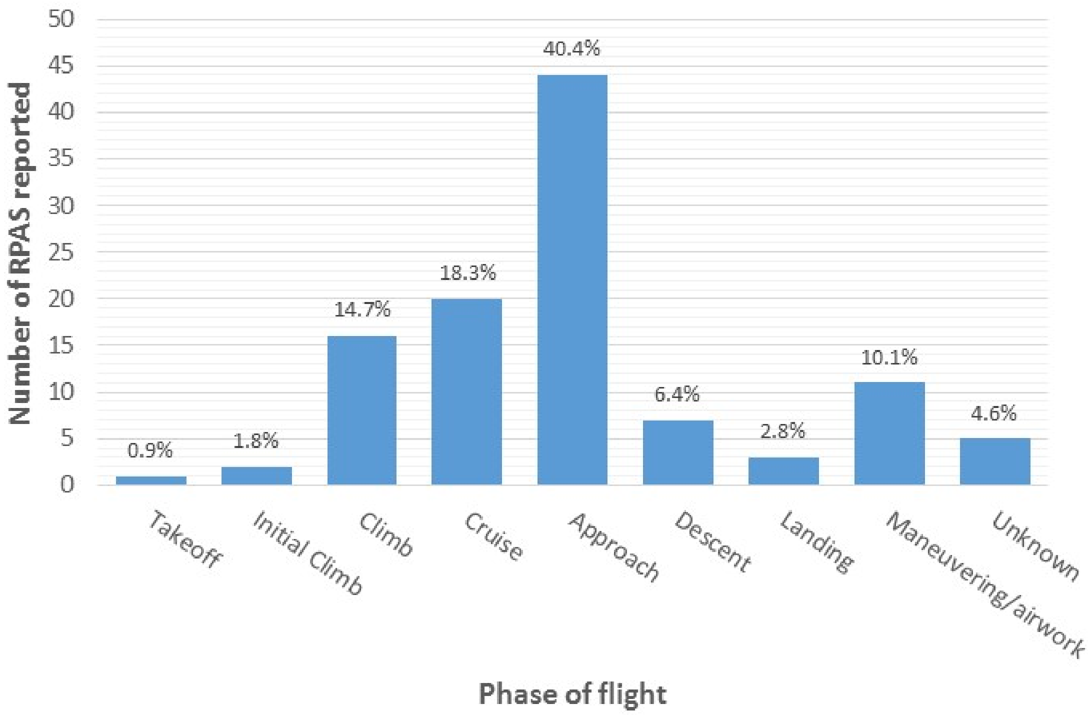


Figure 13: Locations, including relevant altitude categories, of reported RPAS interference with manned aircraft occurrences around Brisbane/Gold Coast (Jan 2010 to Oct 2016)



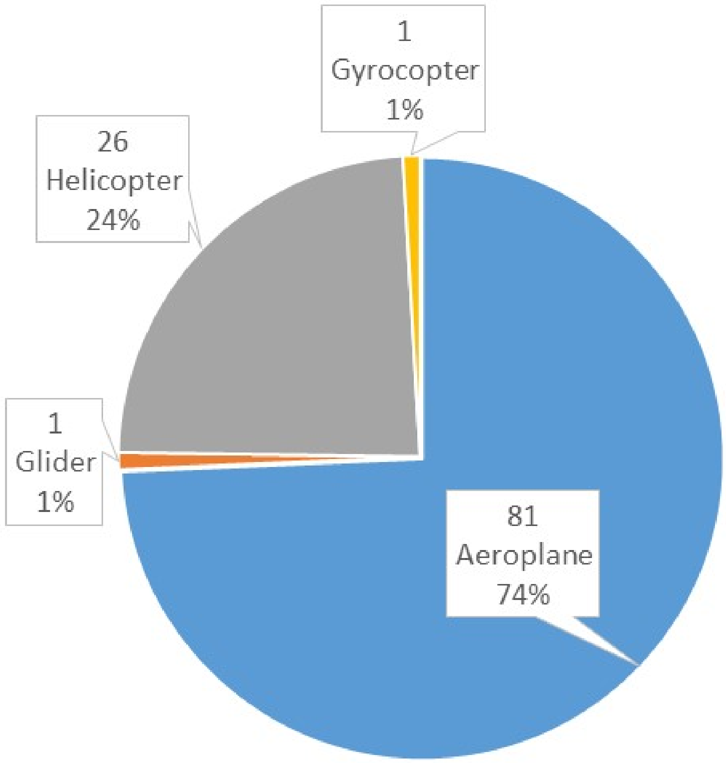
The majority of interference occurrences involving an RPAS occur when the affected aircraft is in the climb, cruise or approach phases of flight (Figure 14).

Figure 14: Affected aircraft's phase of flight at time of an RPAS interference with manned aircraft occurrence (Jan 2010 to Oct 2016).



The majority of aircraft affected are aeroplanes (Figure 15). Helicopters make up around 13 per cent of the flying hours of all aircraft types[4] (2010-2014[5]), but 24 per cent of near encounters. This implies helicopters are more likely to be involved in a reported RPAS interference, per flight hour, than aeroplanes. However, there is a high level of uncertainty surrounding the calculation of aircraft type – due to the low count and reporting issues.

Figure 15: Proportion of aircraft type effect by an RPAS interference with manned aircraft occurrences (Jan 2010 to Oct 2016).



The majority of occurrences have no detail concerning the RPAS – model, operation type or operator.

The day of the week (Figure 16) and time of day (Figure 17) when an RPAS interference occurrence happened may be an indicator of the type of operator flying the RPAS. An occurrence was more likely to happen on a weekend day between 10 AM and 4 PM. The probability that the occurrence was on a weekend day (around 20 per cent) was almost double that of a weekday (approximately 11 per cent).

[4] The Bureau of Infrastructure, Transport and Regional Economics (BITRE) collect and compile this activity data from reports submitted by airlines, and from other aircraft operators through the General Aviation Activity Survey.

[5] 2014 was the last year that aircraft type activity data was available from BITRE for all operation type.

Figure 16: Day of week when an RPAS interference with manned aircraft occurrence happened (Jan 2010 to Oct 2016).

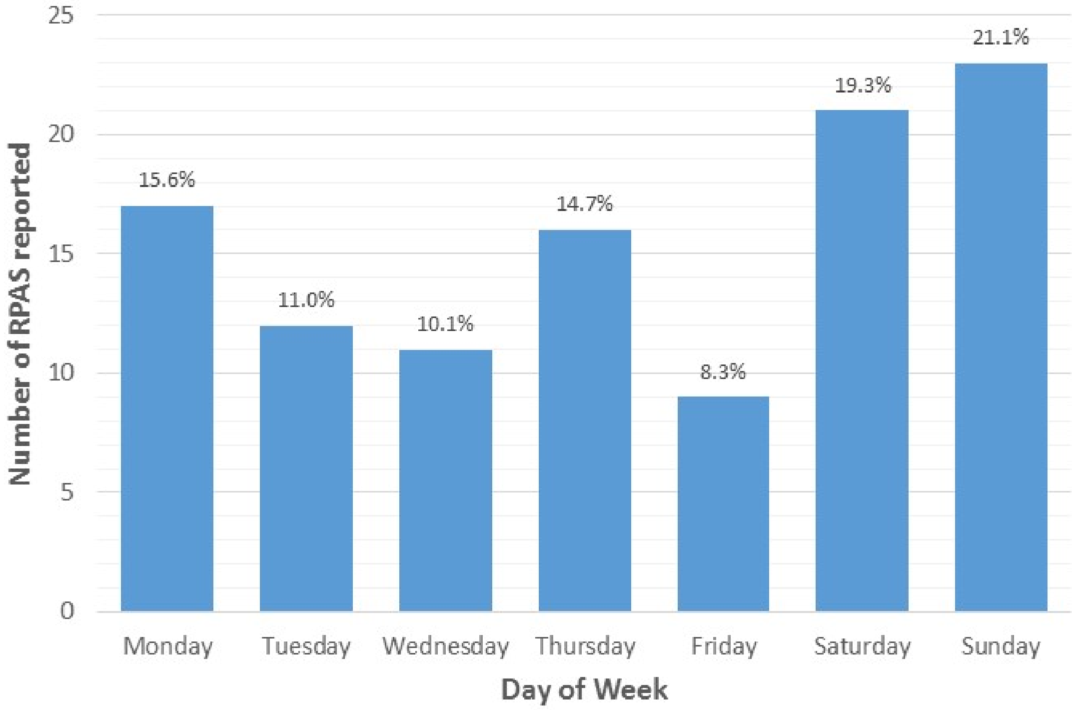
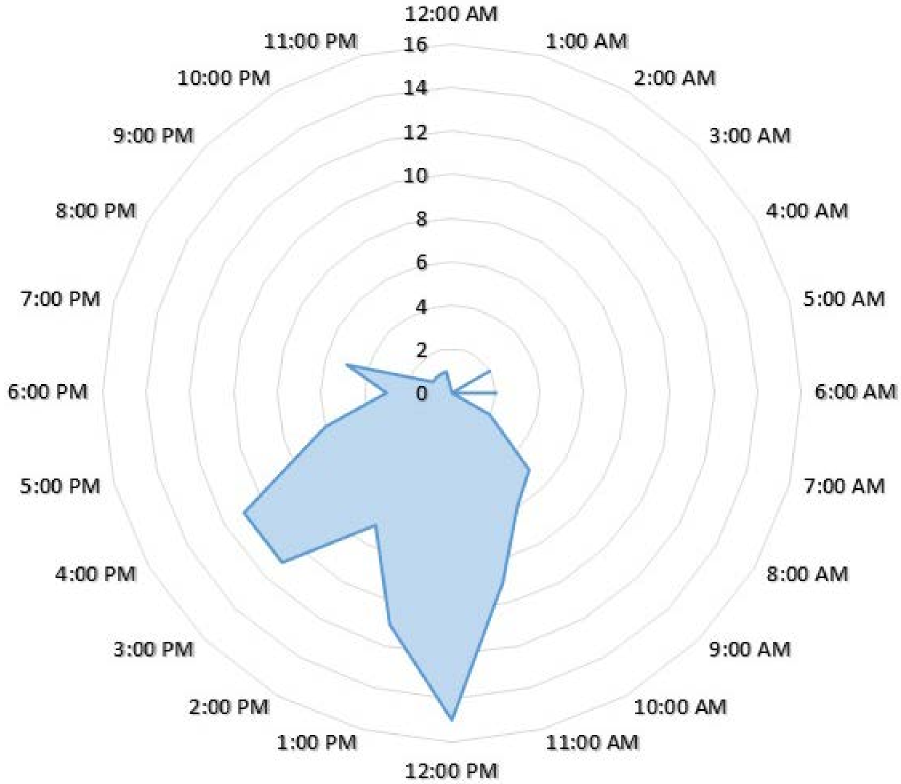


Figure 17: Twenty-hour clock displaying the number of reported RPAS interference with manned aircraft occurrences for each hour of the day (Jan 2010 to Oct 2016).

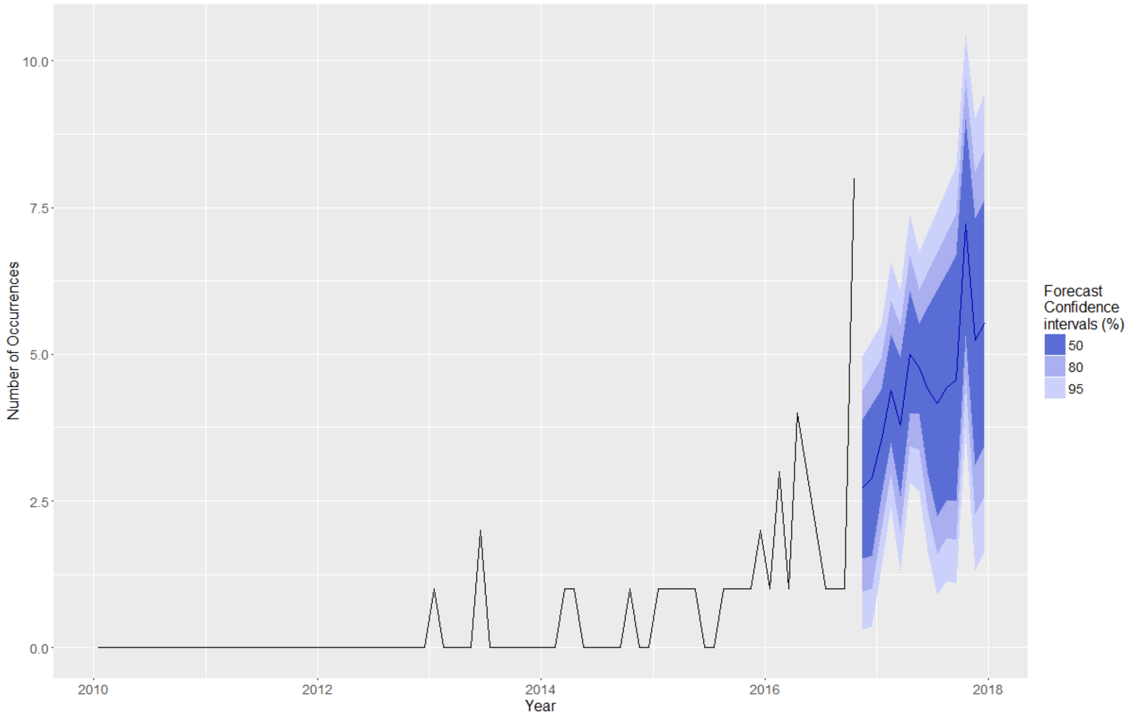


Terrain collisions

Twenty-five terrain collisions involving an RPAS were reported to the ATSB between January and October 2016, while only 27 were reported in the previous six years.

Figure 18 shows how the number of terrain collisions involving an RPAS reported to the ATSB is steadily increasing.

Figure 18: Terrain collisions involving an RPAS reported to the ATSB (Jan 2010 to Oct 2015). The blue regions are the 50th, 80th and 95th per cent confidence intervals for the forecasts – up to December 2017 – calculated using the weighted average of ARIMA and Exponential smoothing state space models[1,2].



The models forecast a steady increase in the number of terrain collisions involving an RPAS reported to the ATSB by the end of 2017. Due to the level of uncertainty underlying these forecasts, they are indicative only and are not intended to be accurate predictions of future RPAS occurrences.

Case Study: Collision with terrain near Geraldton Aerodrome on 7 April 2014

In 2014, a race participant received minor injuries while competing in a triathlon in Geraldton, WA, from collision with an RPAS that was filming the race, after the operator lost control of the aircraft (ATSB occurrence 201402113).

The location of RPAS terrain collisions has been relatively evenly spread around Australia's major population centres (Figure 19 to Figure 20).

Figure 19: Locations of reported RPAS terrain collisions (Jan 2010 to Oct 2016).

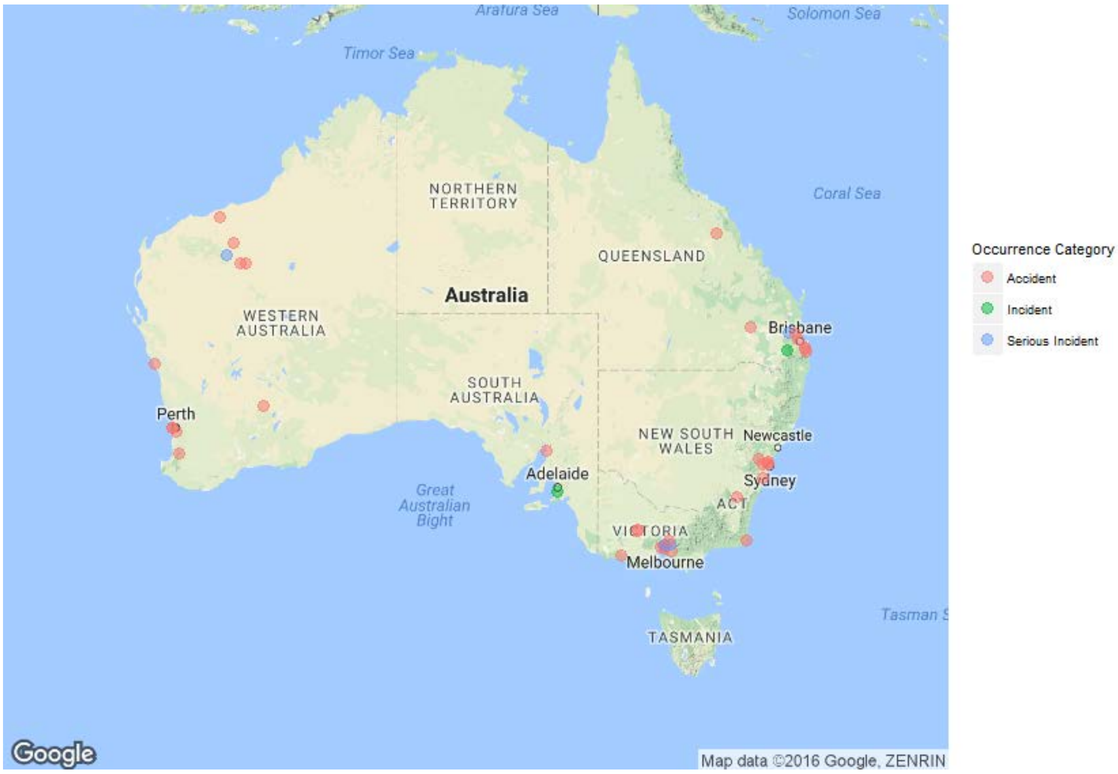
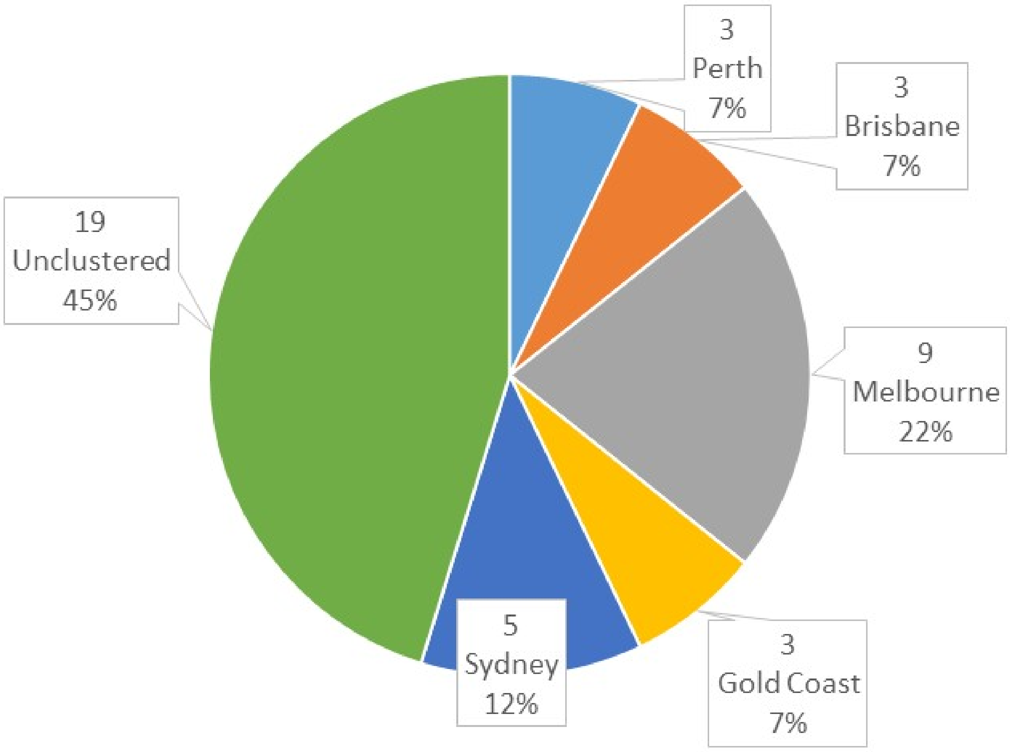
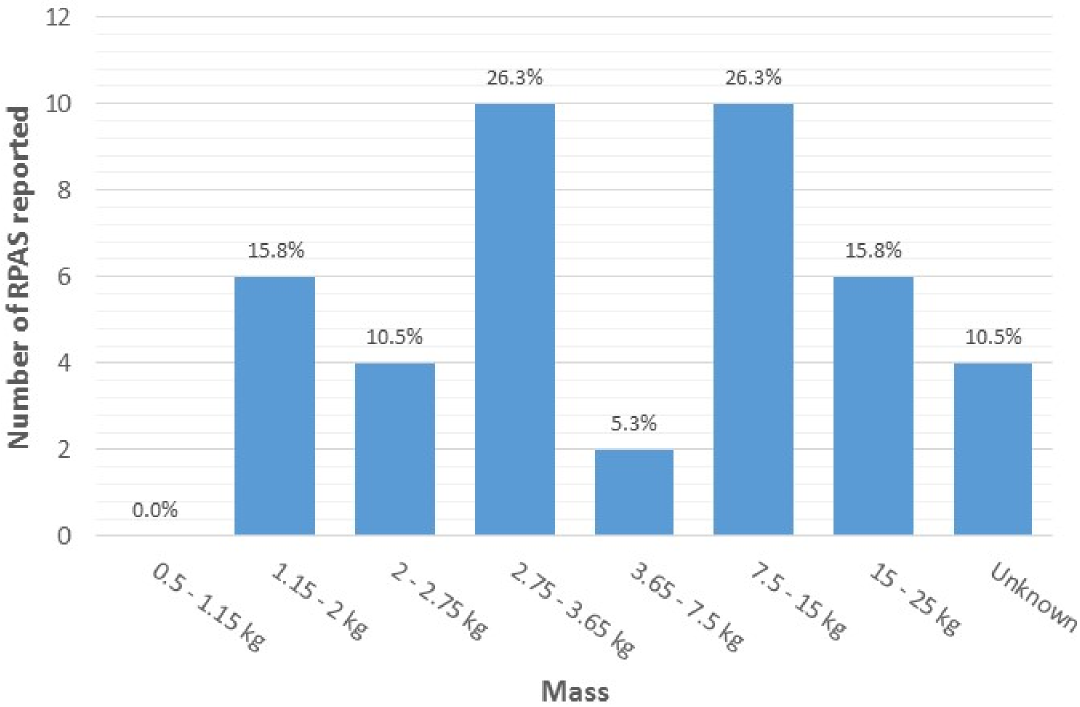


Figure 20: Proportion of collisions with terrain involving an RPAS at significant locations around Australia (Jan 2010 to Oct 2016). Geospatial clustering was conducted using the dbscan algorithm



The majority of terrain collisions reported to the ATSB have detail concerning the RPAS involved. Figure 21 displays the mass of the RPA where information regarding the model is reported. The average mass was 7.4 (± 1.9) kg with a mode of 2.9 kg (around 21 per cent of occurrences).

Figure 21: Mass of RPA involved in terrain collisions reported to the ATSB (Jan 2010 to Oct 2016).



Around 45 per cent of the reported RPAS terrain collisions were in relatively built-up areas.[6] Further, the average mass from an RPAS involved in a terrain collision in a built-up location (9.3 kg) was greater than that for remote locations (5.7 kg).

Figure 22 to Figure 24 show RPAS terrain collisions around significant locations including the mass categories.

[6] This was calculated by viewing each of the reported RPAS terrain collision locations on Google Earth and determining whether there were a significant number of houses within 1 km.

Case Study: Loss of operator control involving an Aeronavics SkyJib 8 remotely piloted aircraft near the Melbourne Cricket Ground, Melbourne, Vic. on 29 March 2015

In 2015, an AERONAVICS SKYJIB 8 collided with terrain near Rod Laver Arena, Vic. The RPAS was operating as part of the media coverage of the International Cricket Council World Cup Final, at the Melbourne Cricket Ground. Radio frequency interference was the most likely cause of the accident. The volume of radio frequency traffic at the time of the accident was probably substantial, and perhaps sufficient to override RPA control signals under the prevailing conditions (ATSB investigation AO-2015-035).

Aeronavics SkyJib 8 remotely piloted aircraft from AO-2015-035. Source: RPA operator

Figure 22: Locations, including relevant mass categories, of reported RPAS interference from ground occurrences around Sydney (Jan 2010 to Oct 2016)

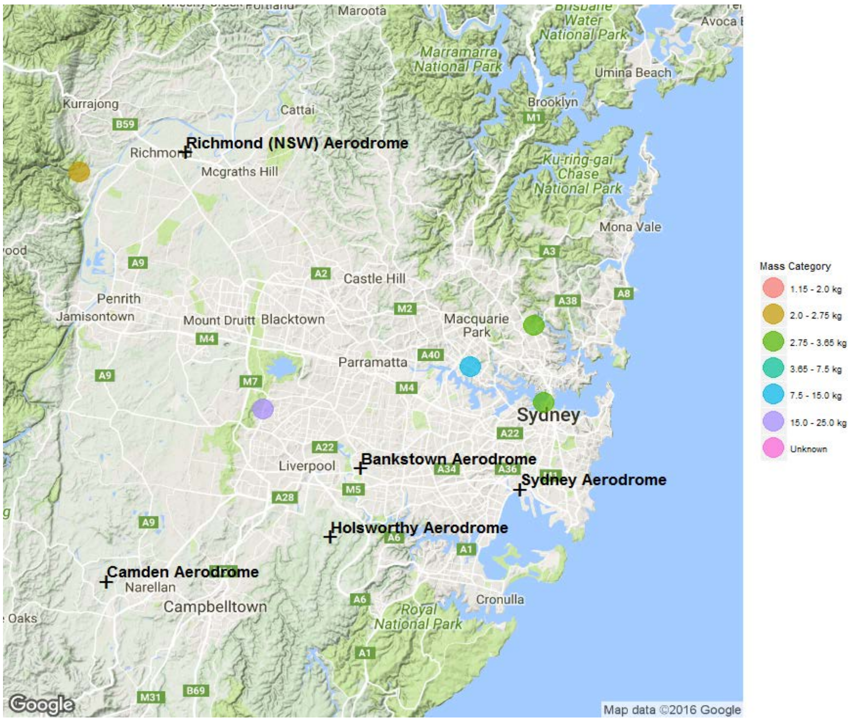


Figure 23: Locations, including relevant mass categories, of reported RPAS interference from ground occurrences around Melbourne (Jan 2010 to Oct 2016)

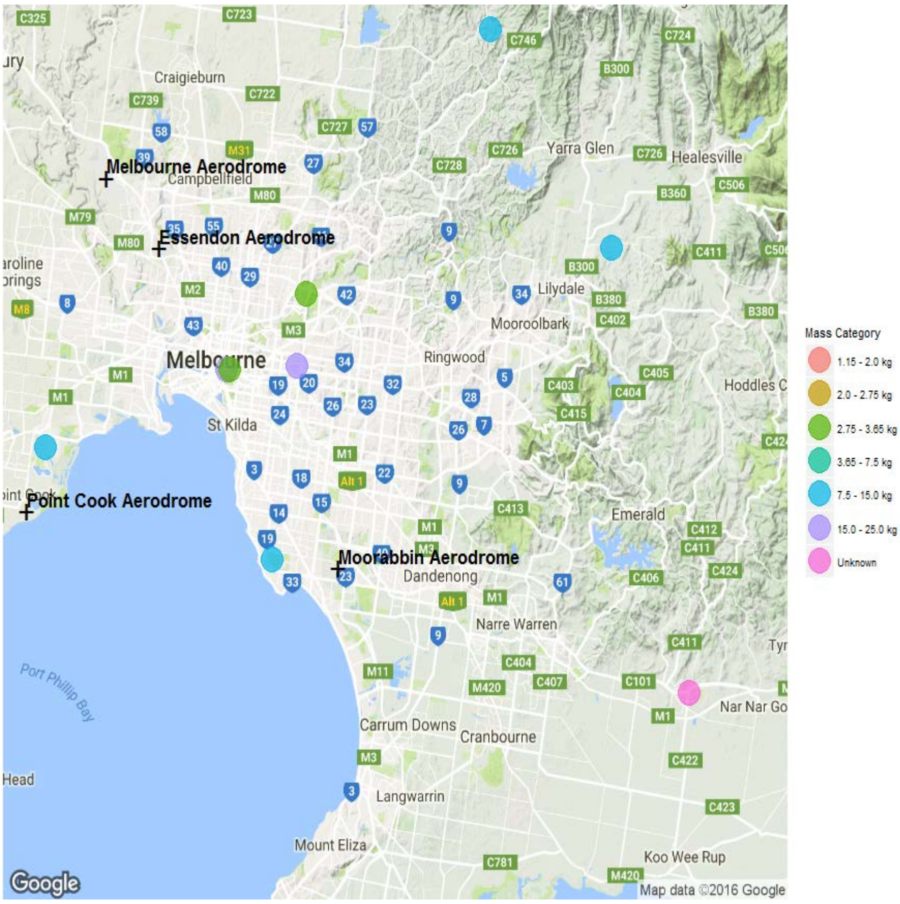
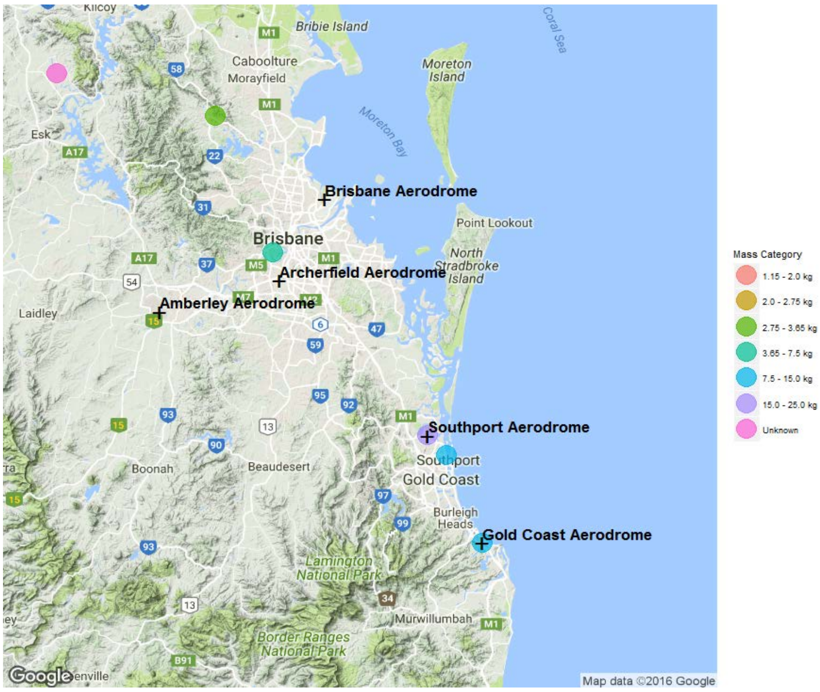


Figure 24: Locations, including relevant mass categories, of reported RPAS interference from ground occurrences around Brisbane/Gold Coast (Jan 2010 to Oct 2016).



Appendix C: ATSB consequence analysis of RPAS collisions with other aircraft

In the past few years, Australians have embraced remotely piloted aircraft systems (RPAS) at an increasingly rapid rate. Similarly, there has been an increase in the number of reported sightings around controlled aerodromes and near encounters with manned aircraft. This is cause for concern. Although there have been no reported instances of a mid-air collision between an RPAS and an aircraft in Australia, the outcome of such an occurrence is not well understood.

A recently published (October 2016) European Aviation Safety Authority (EASA) report from their ‘Drone Collision’ Task Force[7] effectively summarised all known RPAS strikes in Europe and USA to date, summarised in Table 2. As the table shows, only five confirmed strikes have occurred, and only two of these strikes caused serious damage to the aircraft. In the fatal accident, the aircraft in question was a motor glider, which was struck on the wing by a radio-controlled aeroplane, causing an in-flight break-up.

In addition to those five occurrences, a high profile suspected RPAS collision occurred on 17 April 2016 when an A320 reportedly struck a ‘drone’ during landing at Heathrow Airport.[8] While it is encouraging that the aircraft was undamaged, this incident is one of very few collisions between a high capacity aircraft and an RPAS. Therefore, in order to best assess the risk posed by RPAS to the aviation industry, methods other than direct observation must be used.

Table 2: List of known mid-air collisions with RPAS in Europe and USA

Date	Airspace type	Altitude in ft	A/C type	Aircraft Registration	Drone type	Aircraft Damage	Comments
30/08/2015	Unknown	2500	Grumman AA-1	N3LY	Unknown	None	RPAS struck undercarriage
30/04/2015	Controlled airspace	700	Robin DR 400-180	F-GSBM	SAS Wildthing	Scraping on wing	Type of airspace unknown - final approach - exact altitude not available
05/04/2015	G	630	Pioneer 300	G-OPFA	Valenta Ray X, S037996	Scuffing and scraping (GBP 1 400)	Uncontrolled airspace
14/08/2010	Controlled airspace	50	Shpakow SA 750	N28KT	AJ Slick model airplane	Lower left wing crushed aft to the main spar	Video
03/08/1997			Grob G 109B		Dingo	Destroyed	2 fatalities

Birdstrikes are currently the most appropriate comparison to RPAS collisions, and a rich dataset exists in Australian aviation. They are not completely analogous, and it is important to understand the limitations in the comparison. Firstly, birds will often flock, whereas RPAS are a generally a single unit controlled by a single pilot. Birds are also less predictable and prone to startling. According to the most recent damage models, the physical behaviour of a bird upon impact with an aircraft is best described as an incompressible fluid.[9] An RPAS, on the other hand, would be better simulated by several connected, solid parts, depending on its construction. These differences must be kept in mind when using birdstrike data to assess the potential outcomes of RPAS strikes.

[7] ‘‘Drone Collision’ Task Force, Final Report’. *EASA*, October 2016

[8] ‘‘Drone’ hits British Airways plane approaching Heathrow Airport’, in *BBC News*. 17 April 2016, viewed on 1 December 2016, http://www.bbc.com/news/uk-36067591

[9] R. Vignjevic, M. Orłowski, T. De Vuyst, J.C. Campbell, ‘A parametric study of bird strike on engine blades’. *International Journal of Impact Engineering*, vol 60, 2003, pp. 44-57.

Studies sanctioned by the US Federal Aviation Administration (FAA) investigated the likelihood and outcomes of airframe penetration by solid debris, assumed non-deformable. The FAA has developed a penetration equation (known as the FAA V_{50} equation, or ballistic limit equation) shown below:[10]

$$V_{50} = \sqrt{\frac{2 \cdot L \cdot G_d \cdot t^2}{m \cdot \cos^2 \theta}}$$

This equation describes the velocity, V_{50} (in m/s) at which an item of debris has a 50 per cent probability of penetrating a target, where:

L = Presented area perimeter of the debris (small L for a smaller impact area) [m]
G_d = Dynamic shear modulus (empirically determined constant based on target material) [Pa]
t = Target thickness [m]
m = Mass of debris [kg]
θ = Obliquity of impact (0° is an impact orthogonal to the surface)

The FAA penetration equation has been used by other agencies to assess the potential risks posed to aircraft by debris. The Range Commanders Council released a study examining the risks of falling satellite debris utilising the FAA penetration equation.[11] This is a valuable resource for assessing the similar risks posed by RPAS, but dissimilarities must be kept in mind when analysing their findings, such as the difference in trajectory between satellite debris and an RPAS, as well as the difference in size and velocity.

Probable strike locations

Birdstrike occurrences can be used to help predict the areas of aircraft that are most likely to be involved in a collision with RPAS. While birdstrike records in Australia are kept for commercial passenger transport and general aviation, the details of strike location are only provided if damage to the aircraft is detected. The exception is engine ingestion events, where all occurrences are recorded. Table 3 provides the number of bird ingestion events, per operation type, over the last 10 years.

Table 3: Number of bird ingestions by operation type, 2006 - 2015

Operation Type	Engine Ingestion	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total	As a % of Total Birdtrikes
High capacity air transport	1 engine	63	74	76	71	82	82	81	55	67	62	**713**	**7.7%**
	2 engines	3	0	1	2	0	0	0	0	0	1	**7**	
Low capacity air transport	1 engine	8	14	20	6	6	10	6	11	5	11	**97**	**3.9%**
	2 engines	0	0	1	0	0	1	0	0	0	0	**2**	
General Aviation	1 engine	0	3	5	1	2	2	1	3	2	5	**24**	**1.5%**

The majority of birdstrike occurrences are during high capacity transport operations. This is due in part to the large number of commercial flights, but it is also a function of the size and type of the engines in question. The turbofan engines commonly used in high capacity air transport have a large intake relative to the aircraft's frontal area, and their effective area is increased by additional suction. Conversely, a conventional single-piston engine aircraft has a small intake relative to the aircraft size, and no additional suction. The variability in engine size is the reason the percentage of strikes resulting in ingestion is

[10] S.J. Lundin, 'Engine Debris Fuselage Penetration Testing Phase II'. *FAA*, September 2002, viewed on 1 December 2016, http://www.tc.faa.gov/its/worldpac/techrpt/AR01-27-2.pdf
[11] 'Common Risk Criteria Standards for National Test Ranges: Supplement'. *Range Commanders Council*, 2007.

greater for high capacity air transport compared with general aviation (Table 3, right column). If the difference in behaviour between birds and RPAS can be neglected, then these percentages should be a reasonable approximation of the proportion of RPAS collisions that will result in engine ingestion.

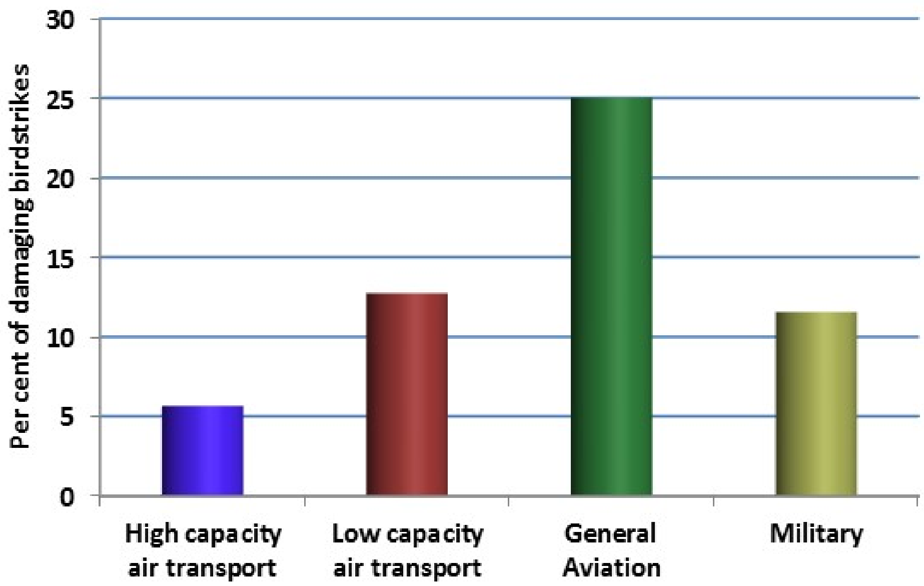
Table 4 shows the number of birdstrikes that resulted in damage, as well as the part damaged and the associated operation type. In high capacity air transport, the engine is the most frequently damaged component. This is probably due to the size of the engines relative to the aircraft's frontal cross sectional area. Additionally, the relatively strong parts like the wings, fuselage, and windscreen on jet aircraft are less susceptible to damage. In low capacity transport and general aviation, the wings (and helicopter rotors) are the most common region damaged.

Table 4: Number of birdstrikes by part damaged and operation type over the 2006 -2015 period

Part damaged	High capacity air transport	Low capacity air transport	General Aviation
Wing/Rotor	106	112	190
Engine	145	44	10
Nose	49	23	15
Propeller	28	35	24
Other	23	30	30
Landing Gear	25	11	12
Windscreen	10	9	30
Lights	24	12	7
Tail	15	9	18
Fuselage	17	8	9

This data represents a strong starting point to predict damage from RPAS collisions. However, given the different physical composition of RPAS, the distribution of damage across an airframe will change for RPAS, which are more rigid, and generally heavier than most birds. For example, there are more incidents involving damaged wings in general aviation than there are in high capacity air transport, despite there being more than five times the number of birdstrikes in the latter category. This is the result of a more fragile wing in general aviation. RPAS may be more likely to damage the stronger wings in high capacity air transport aircraft, which would result in wings becoming more represented in the total number RPAS strikes resulting in damage. Out of 720 engine bird ingestions in high capacity air transport (Table 3), 145 resulted in damage to the engine (Table 4). Once again, due to the added weight and rigidity, this proportion will likely increase for RPAS strikes.

Figure 25: Proportion of birdstrikes resulting in damage in each operation type over the 2006-2015 period



More generally, the overall proportion of strikes resulting in aircraft damage is expected to increase from the recorded birdstrike values shown in Figure 25. The following section discusses this in more detail.

Possible damage

The physical composition and resulting behaviour on impact of RPAS is significantly different to that of a bird. However, even between different remotely piloted systems, there is substantial variation. Table 5 displays the smallest and largest commercially available RPAS, by weight, that have been involved in Australian aviation occurrences. For comparison, the widely popular DJI Phantom 4 is listed as well.

Table 5: Specifications for RPAS involved in Australian aviation occurrences

Name:	Sensefly eBee	DJI Phantom 4	Pulse Aerospace Vapor 55
Weight:	0.69 kg	1.38 kg	25.0 kg (MTOW)
Type:	Fixed wing	Quadcopter	Helicopter
			

As is evident from the table above, the size and composition varies significantly. However, generally speaking, most RPAS can be described as a collection of common components built into a comparatively light airframe. The airframe is generally made of expanded polystyrene or a rigid polymer, which is often fibre-reinforced. The elements common to many RPAS are: motors, batteries, cameras, and propeller blades. Upon impact with an aircraft, the RPAS airframe will provide relatively low resistance, as will most propeller blades. As such, the behaviour of an RPAS colliding with an aircraft can be simply modelled as multiple solid objects striking in close proximity to one another. These objects will of course vary in size and weight. For reference, the battery (generally the heaviest component) on the Vapor 55 weighs up to 10 kg, while the Phantom 4 battery weighs 0.46 kg.

Possible Airframe Damage

EASA's 'Drone Collision' Task Force report utilised the knowledge of various stakeholders from within the aviation industry (e.g. aircraft manufacturers, RPAS manufacturers, regulators, and safety agencies) in an effort to assess the threat posed by RPAS collisions. As stated in the report, there are obvious limitations for a study such as this. Stakeholders with a wide range of technical expertise each used their own judgment when assessing threats. In addition, each stakeholder might have a different idea on the appropriate damage classifications and what is considered 'likely'. The limited number of stakeholder responses also limits the value of this data. When discussing the possible severity impact, this paper frequently refers to the kinetic energy involved (based solely on the mass and speed of the colliding bodies). However, the reality is much more complex. The rigidity, angle of incidence, and orientation of components can all have substantial effects on the outcome of an impact. This is discussed in more detail below.

With respect to large aeroplanes, the report identified impact to the following areas as posing the most risk:

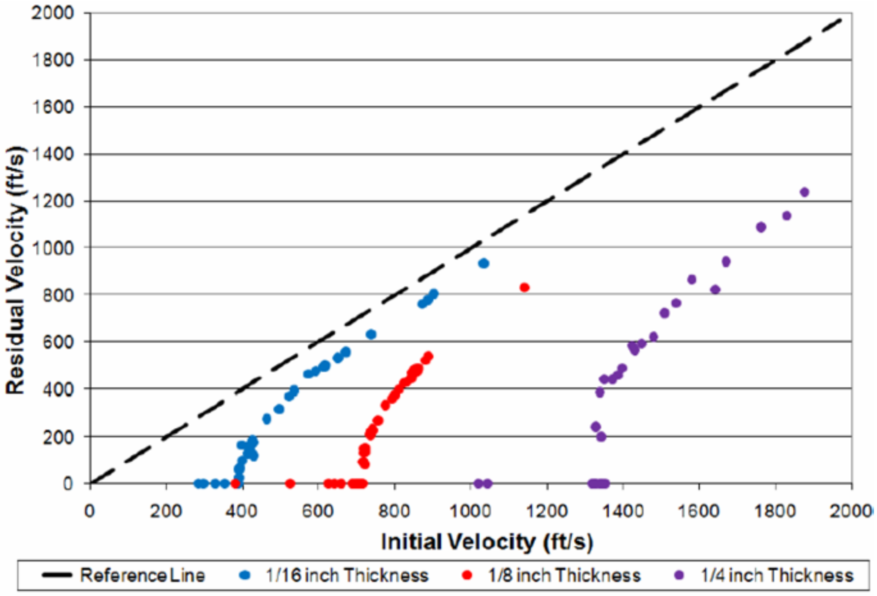
- fuselage areas above and below windshields
- engines
- tailplane/wing leading edges and flaps
- nose/radomes/antennas
- windshields
- propellers.

Consensus from the report determined that a 'large' RPAS (3.5 kg) generally poses a threat to commercial aircraft at any altitude. However, 'medium' RPAS (1.5 kg) were considered less likely to pose a threat at lower altitudes (under 10,000 ft) due to slower aircraft speeds. The risk was assessed to be lower because aircraft are certified to withstand a bird of equivalent mass. However, this is not a valid comparison, because the impact behaviour of RPAS (and RPAS components) will be significantly different to a bird.

Figure 26 illustrates impact test results from an FAA-sponsored study investigating aircraft vulnerability to falling rocket/satellite debris.[12] A good approximation for the ballistic limit, (V_{50} as described in the FAA equation) is the point at which the impact velocity is high enough for some residual velocity to result. That is, when the projectile has penetrated the target.

[12] P.D. Wilde, 'Impact Testing and Improvements in Aircraft Vulnerability Modeling for Range Safety.' 20 October, 2014.

Figure 26: Impact testing involving a ½" steel sphere striking aluminium plates of different thicknesses.



A collaborative report between Monash University and the Civil Aviation Safety Authority (CASA) uses this methodology for a theoretical study on the possibility of aircraft penetration by RPAS components.[13] Table 6 lists the components that were used in the study, which were based off actual RPAS parts.

Table 6: Dimensions and weights of UAV components

	Item	Model	Geometry	Dimensions [mm]	Weight [g]
Quad-copter (small)	Motor A	NX-4006-530kv	Cylinder	D=45, L=12	67
	Battery A	--	Block	25x50x65	160
	Camera A	GoPro Hero 2	Block	42x60x30	190
Quad-copter (big)	Motor B	Turnigy Multistar 4830-480Kv	Cylinder	D=47, L=33	154
	Battery B	--	Block	45x45x138	583
	Camera B	Canon EOS 7D	Block	148x110x74	820
Single-engine	Motor C	Turnigy CA120-70 (100cc eq)	Cylinder	D=118, L=120	2730

The Monash/CASA study calculated the ballistic limit for these components, based on the FAA equation:

$$V_{50} = \sqrt{\frac{2 \cdot L \cdot G_d \cdot t^2}{m \cdot \cos^2 \theta}}$$

The study assumed the fuselage and wings to be modelled as 1/8" and 1/16" aluminium plates, and treated the impact as perpendicular (θ = 0°). The shear modulus, G_d, was assumed to be 276 MPa in accordance with the FAA-sponsored study. Boxplots in Figures 27 and 28 illustrate the ballistic limit for the different components as well as the maximum flap speeds of a Boeing 737-400 and 747-400 (162 kt and 180 kt, respectively). Uncertainty in the values is the result of changes in the projected area of the perimeter of the debris (L in the equation).

[13] 'Potential damage assessment of a mid-air collision with a small UAV'. *Monash University/CASA*, 12 June 2013.

Figure 27: Ballistic limits of drone components impacting 1/8" thick aluminium

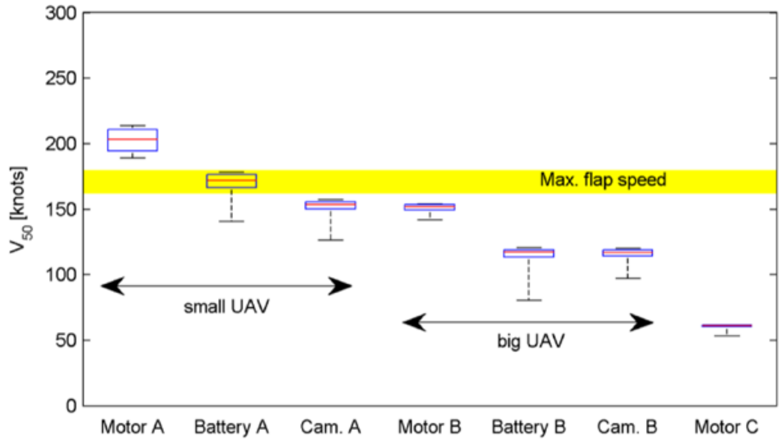
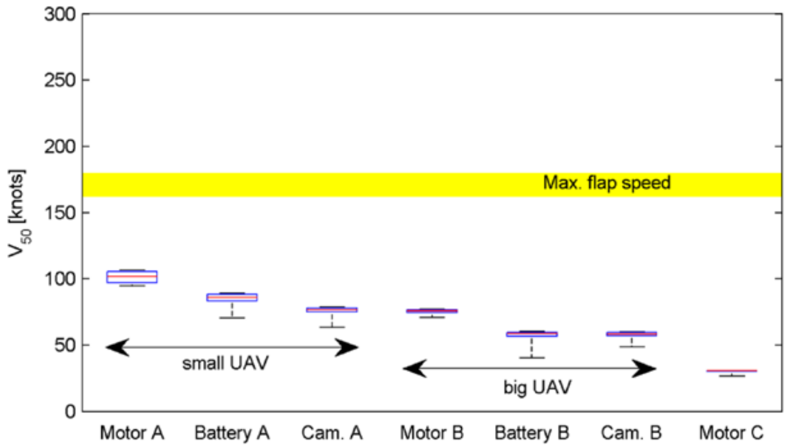


Figure 28: Ballistic limits of drone components impacting 1/16" thick aluminium



As the figures show, all components are expected to penetrate 1/16" thick aluminium at an impact speed lower than speeds reasonably expected by a commercial airliner on take-off or landing. All components except for the small quadcopter motor are predicted to penetrate 1/8" thick aluminium under the same conditions.

Before any conclusions are drawn based on the findings of the Monash/CASA study, it is important to note the limitations created by several critical assumptions:

1. **An obliquity of 0° is not a realistic assumption for most RPAS strikes**. Given the relatively low velocity of an RPAS with respect to an aeroplane, particularly a Boeing 737 or 747, it can be reasonably assumed that the impact will occur on one of the front-facing surfaces of the aeroplane, such as the nose, or wing leading edge. As an aerodynamic requirement, all of these surfaces are swept, so almost any head-on collision will be a glancing blow. In the worst-case scenario, such as an RPAS striking the exact point of the wing's leading edge, the obliquity may be 0°, but the thickness of the skin will be higher in this area for the sake of wing strength. The curve of the leading edge also adds geometric strength, which will assist in resisting debris penetration, whereas the FAA ballistic limit equation assumes a flat surface.
2. **The equation assumes a perfectly rigid projectile**. In the FAA-sanctioned study, the impact test results shown in Figure 26 served to validate the ballistic limit equation. The results fitted well with the equation because the elastic modulus of the steel projectile is substantially higher than that of the aluminium target, so the rigid assumption is valid. In the case of RPAS components, the rigidity of the projectile is questionable (although it will be far more rigid than a bird). A lithium-ion battery for example, will generally consist of several materials including aluminium, lithium, copper, graphite, and an electrolyte paste. Relative to an aluminium skin, the

rigidity of a battery will depend heavily on its construction, geometry, and its orientation at impact. A motor is more likely act as a rigid body due to its components, but it could still fragment on impact.

3. **Assumptions of an aluminium skin are oversimplified/outdated.** The materials used in the skin of a modern commercial airliner are diverse. Even general aviation airframes are including more composite materials in their design. Unfortunately, composite materials, particularly fibre metal laminates such as Glare, are too complex to be modelled by something as simplistic as the ballistic limit equation. The non-linearity of composite material properties means the dynamic shear modulus term, G_d, would likely need to be expressed as a function of both strain and strain rate at the very least. Finite element modelling of impact for a particular material configuration would probably be more practical than developing a universal equation.

These assumptions will tend to over-predict the probability of penetration. On the other hand, the calculated V_{50} values were much lower than the expected impact velocities. Therefore, the probability of penetration into the wing and fuselage of a commercial airliner cannot be ruled out. However, it is unlikely to occur as often as implied by the Monash/CASA study.

Figure 29: Analysis of penetration consequences

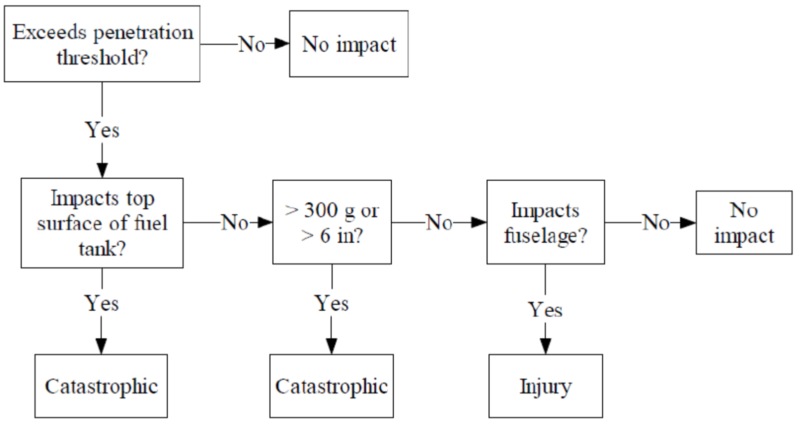


Figure 29 is a flow chart from an ICAO working paper discussing the hazards of launch/re-entry operations.[14] The chart is based off the FAA Aircraft Vulnerability Model. It is clearly conservative with regard to the possible consequences of an item penetrating the aircraft. A fuel tank rupture, or even penetration of an object in excess of 300 grams will not necessarily result in a catastrophic outcome. This chart was made with regard to debris falling at terminal velocity. Such debris will have more energy (relative to mass) and strike with less obliquity than an RPAS. Therefore, outcomes from penetration of RPAS components will generally (but not necessarily) result in less adverse consequences.

Aside from penetration events, RPAS strikes could cause loss of control due to damaged flight surfaces. In 2008, a Cessna Citation collided with terrain in the United States following a birdstrike.[15] The subsequent investigation found the accident was due to a damage to the wing structure caused by one more of the birds. The strike altered the aerofoil's aerodynamic profile enough to cause a loss of control, even though no penetration of the airframe was observed. This is one such example of a catastrophic outcome from a strike on the airframe without penetration. An RPAS collision is more likely to damage flight surfaces due to the higher potential mass and comparatively rigid components.

With regard to general aviation operations, the study produced by the Range Commanders Council identified penetration of the windscreen and subsequent pilot incapacitation as a high risk in the event of falling satellite/rocket debris. There are numerous examples of birds penetrating the windscreen of general aviation aircraft and incapacitating the pilot. It is therefore obvious that RPAS collisions could

[14] G. Smiley, 'Launch/Reentry Operation Aircraft Hazard Areas'. *Presented at the 26th Separation and Airspace Safety Panel Meeting.* May 2015.
[15] 'Crash of Cessna 500, N113SH, Following an In-Flight Collision with Large Birds, Oklahoma City, Oklahoma, March 4, 2008'. *National Transportation Safety Board*, 2009.

result in similarly adverse outcomes. For high capacity transport operations, there are no examples of birds penetrating the windscreen in the event of a strike. The likelihood of an RPAS doing so is unknown, but it is certainly plausible, particularly for the heavier models.

In the EASA 'Drone Collision' Task Force report, stakeholders expressed significant concern for the outcome of an RPAS strike on general aviation category aircraft. Commuter-type general aviation aircraft in Europe are only certified to withstand a birdstrike of less than 0.91 kg, and only on the windscreen. Most RPAS weigh more than this and are of significantly higher density, so the chance of penetration through the fuselage or windscreen is high. The empennage was also considered by stakeholders to be a high-risk strike location.

Possible engine damage

For single engine aircraft, ingestion of an RPAS could have catastrophic consequences. With regard to reported birdstrikes in Australia over the last 10 years, 41 per cent of general aviation engine ingestions resulted in damage. This value is expected to increase with regard to RPAS strikes. As mentioned in the previous section, the proportion of birdstrikes resulting in ingestion for general aviation operations is quite low (1.5%). While the consequence of an RPAS ingestion could be an engine failure, given that no RPAS strikes have yet been reported in Australia, the probability of a RPAS ingestion during general aviation operations is extremely low at present.

The proportion of birdstrikes resulting in engine ingestion increases for larger aircraft, while the likelihood of damage is reduced. A similar proportion of RPAS are expected to be ingested (approximately 7.7% of collisions for high capacity, based on Table 3), but the outcome of ingestion is still uncertain. For single bird ingestions, FAA regulations require turbine engines with a throat area in excess of 3.90 m^2 to be able to ingest a bird of up to 3.65 kg without any adverse effects[16] (such as more than 50% power loss immediately after the strike). Any bird weighing more than 3.65 kg is beyond the certification standards of any current turbofan engine. Ignoring the fact that even lighter RPAS could cause more damage due to their rigid components, there are already many RPAS in operation that weigh far in excess of 3.65 kg.

For twin-engine aircraft, the consequence of an engine shutdown due to RPAS ingestion is expected to be relatively minor. Certified commercial aircraft are required to be able to continue safe flight in the event of a single engine shutdown. Only a tiny percentage of birdstrikes have resulted in 2-engine ingestion, and this percentage is expected to be smaller still for RPAS, given that they are less likely to operate in groups.

Given that twin-engine aircraft are not likely to experience a 2-engine RPAS ingestion, the largest risk posed by RPAS ingestion during commercial passenger transport activities is the possibility of an uncontained engine failure. While turbofan engines are certified to contain a thrown blade or ingested bird (under 3.65 kg), an uncontained engine failure cannot be ruled out in the event of ingestion of a large RPAS. Further research is required in order to assess the risks of such an occurrence, and it is worth remembering that an uncontained engine failure rarely results in a catastrophic outcome.

[16] 'Electronic Code of Federal Regulations – 33.76: Bird Ingestion', in *US Government Publishing Office.* December 2016, viewed on 1 December 2016, http://www.ecfr.gov/cgi-bin/text-idx?SID=e41faf7af7c74e01eb8769152998fd6f&mc=true&node=se14.1.33_176&rgn=div8