A MOBILE AIRCRAFT TRACKING SYSTEM THAT SUPPORTS UNMANNED AIRCRAFT OPERATIONS

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Abstract

The integration of unmanned aircraft into the national airspace system requires new methods of ensuring collision avoidance. For unmanned aircraft a capability to 'detect-and-avoid' is required to replace the traditional 'see-and-avoid' performed by pilots. The initial results from testing a Mobile Aircraft Tracking System (MATS) show that this ground-based radar system can track a ScanEagle unmanned aircraft, a Cessna 172 general aviation aircraft, and a Boeing 777 jet airliner. A co-located ADS-B receiver has allowed the correspondence between a radar track and an ADS-B track to be demonstrated. The MATS was tested using a specially equipped aircraft that flew predetermined flight plans. The results of this testing show that the MATS is able to provide situational awareness information about local airspace users to a UAS pilot and, as such, support unmanned aircraft operations.

1 Introduction

See-and-avoid is the regulatory requirement for pilots to avoid aircraft and other objects while flying in Visual Meteorological Conditions (VMC). While see-and-avoid prevents many collisions the principle is far from reliable. Numerous limitations, including those of the human visual system, the demands of cockpit tasks and various physical and environmental conditions combine to make see-and-avoid an uncertain method of traffic separation [1] [2].

Unmanned Aircraft Systems (UAS)[1] have a long history of being used by the military in segregated airspace. As technology has matured many civilian uses of UAS are being considered. In general, military or civilian tasks that are "dull, dirty or dangerous" are thought to be well suited to the application of UAS [3].

In order to realise the benefits of the civilian applications of UAS it is necessary to achieve a greater degree of operational freedom within the National Airspace System (NAS). To gain this freedom, however, there is an over-arching requirement for UAS to have an equivalent level of safety to conventionally-piloted aircraft. Thus, until *detect-and-avoid* for UAS [4] reaches an equivalent capability to that of see-and-avoid then the operation of UAS within the NAS will continue to be restricted.

The Smart Skies Project [5] [6] is a leading edge research programme that aims to explore the research and development of technologies that support the greater utilisation of the NAS by both manned and unmanned aircraft. One aim of Smart Skies is to explore the development of enabling aviation technologies to perform the see-and-avoid function - for the detection of both dynamic and static obstacles.

Unmanned Aircraft (UA) come in a wide variety of shapes and sizes. A similarly large variety of sensors are also available for UA. A number of technological solutions to the detect-and-avoid problem are being explored, including onboard radar systems [7] [8], and passive vision-based systems [9]. However, for some smaller UA the onboard detect-and-avoid solutions may not be applicable due to

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[1] ICAO has adopted UAS instead of UAV (Unmanned Air/Aerial/Airborne Vehicle) [4].

restrictions on the space, weight and the power available onboard. One alternative solution is to use off-board sensors and systems to perform the detect-and-avoid function.

The Mobile Aircraft Tracking System (MATS) is a network enabled and portable air traffic control system. The aim of the MATS is to provide a local capability for the detection of *cooperative* and *non-cooperative* airspace users in support of the operation of UAS in unsegregated civilian airspace.

Cooperative aircraft are those aircraft that have an electronic means of identification on-board that is operating (e.g. a transponder). Thus, to be cooperative an aircraft is required to carry certain avionics and to have this equipment switched on.

Non-Cooperative aircraft do not have an electronic means of identification on-board, or the equipment is not operational due to a malfunction or deliberate action.

In Australia VHF radio carriage is not mandatory in class G airspace below 5000 ft AMSL. Some aerodromes, however, do require the carriage and use of a VHF radio.

Non-cooperative aircraft that do not carry VHF radio represent the most challenging class of airspace user – for both manned and unmanned aircraft. The traditional methods of coping with these aircraft have included the see-and-avoid function that is performed by pilots and by using primary radars, which are generally located at large airports.

The MATS, which includes a portable primary radar system, aims to provide situational awareness information to the UAS pilot. The MATS also enables a detect-and-avoid capability for UAS operations - either in a stand-alone mode or as a sensor that forms part of a larger aircraft tracking and control network.

The MATS system has been undergoing initial demonstrations and characterisation trials. A feature of these trials was the use of an aircraft that accurately logged its position and attitude the during flight trials, which provides a valuable calibration target for the MATS. The focus of this paper is to discuss the results of these experiments.

2 Materials and Methods

2.1 Introduction

Fig 1 shows the architecture of the MATS and interfaces to two external systems.

The MATS currently consists of the following subsystems:

- A primary radar;
- An Automatic Dependent Surveillance – Broadcast (ADS-B) receiver;
- A VHF voice transceiver; and
- A data fusion and communications management system.

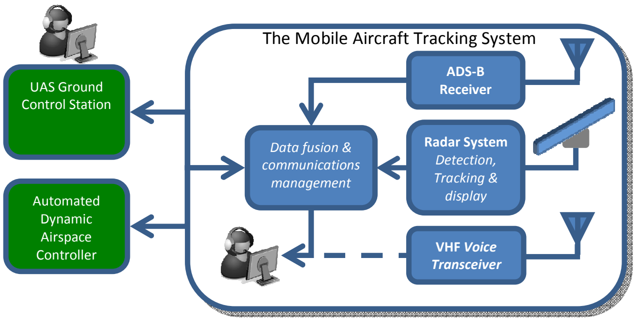


Fig 1. The MATS architecture and interfaces to two external systems.

The two external interfaces show two different methods of using the MATS. The information provided by the MATS can be used by a UAS pilot – the MATS providing the ‘detect’ function and the UAS pilot providing the ‘avoid’ capability. The information provided by the MATS can also be used by an Automated Dynamic Airspace Controller (ADAC) [12] – the MATS again providing the ‘detect’ function but where the ‘avoid’ function is automated.

The MATS forms part of the UAS Flight Demonstration System operated by Insitu Pacific Limited (IPL), which is shown in Fig 2.

The longer-term aim for the MATS is to fuse the various surveillance data sources to create a real-time Common Operating Picture (COP) of the UAS operational environment. The intent is to provide this situational awareness picture to the UAS pilot.

Fig 2. The MATS forms part of Insitu Pacific's UAS Flight Demonstration System.

2.1 The MATS radar

2.2.1 The MATS radar system

A key part of the MATS is the primary radar system. The radar consists of a commercial off-the-shelf (COTS) marine radar "front end" and a "back end" that performs the detection, tracking and display functions.

The COTS radar is a non-coherent marine radar: a Furuno FAR-2127-BB. This pulse radar has a peak output power of 25 kW. The radar uses an 8 ft slotted waveguide array antenna. This standard Furuno antenna generates a vertical fan antenna pattern and, as a result, no elevation information is available.

A summary of the key characteristics of the Furuno radar is shown in Table 1.

Table 1 - Key characteristics of the Furuno FAR-2127 radar.

Frequency	9410 MHz (X-band)
Output Power	25 kW
Pulse Length, PRF, Range resolution	0.07 µs, 3000 Hz, 10.5 m 0.3 µs, 1500 Hz, 45 m 1.2 µs, 600 Hz, 180 m
Antenna rotation rate	24 rpm
Beamwidth (Horizontal)	0.95°
Beamwidth (Vertical)	± 10°

The Accipiter® detection and tracking system forms the "back end" or "brain" of the MATS radar. The radar's performance has been enhanced by replacing the standard marine radar processing with a powerful, software-definable radar processor and tracker [10].

Accipiter's multi-target tracker is designed to manage many dynamic and manoeuvring targets. The system employs a multiple-hypothesis-testing (MHT) interacting-multiple-models (IMM) tracker that enables the system to detect and track manoeuvring targets that have a low radar cross section.

The radar operator is able to set the parameters for the detection and tracking algorithms, which allows the operator to optimise the radar's settings for specific surveillance scenarios.

A variety of display options are available. The detections from each radar scan may be displayed (these are called plots). Confirmed tracks, with estimated speeds and headings, are usually displayed. The background clutter level may also be selected for display. All of this radar information can be displayed with background maps to provide some geographic context.

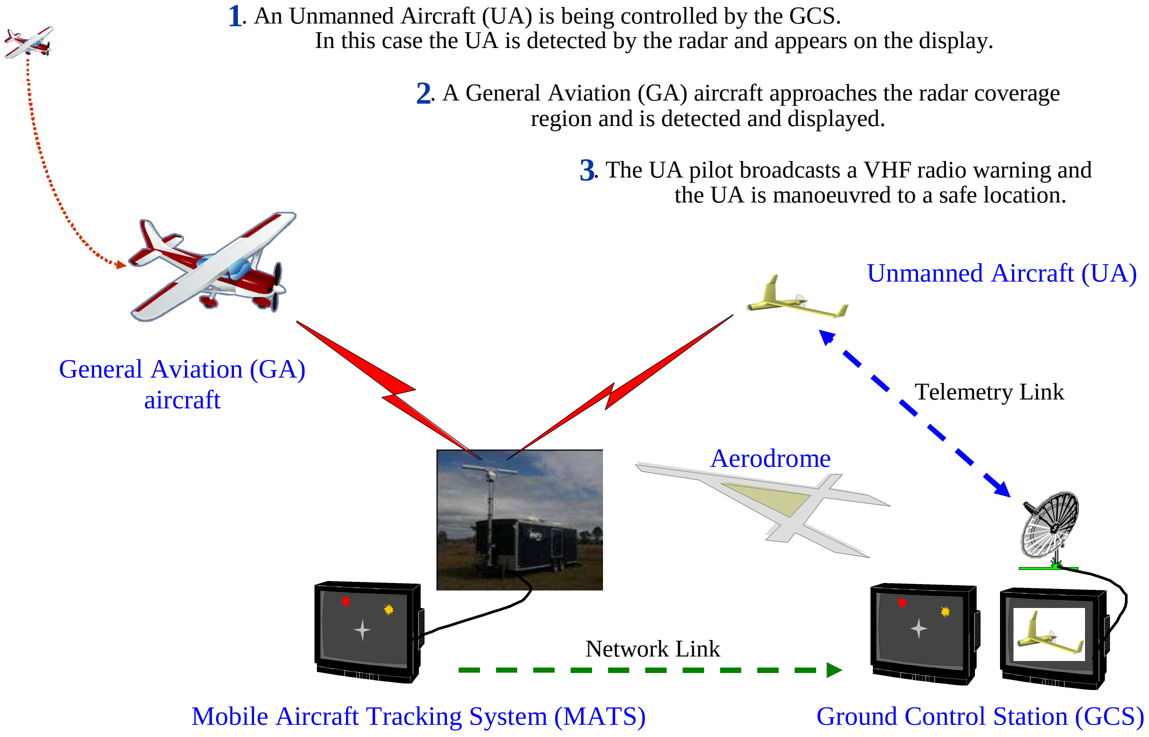
The radar's TCP/IP data networking capability allow tracks and plots to be sent to a TrackViewer Workstation (TVW) [11], which may be used by the UAS pilot located in the Ground Control Station (GCS) (as shown in Fig 1). This workstation will enable the radar and the UAS pilot to perform the detect-and-avoid function for UAS operations.

The radar also has the ability to send track information to other systems. This is particularly relevant to the ADAC [12], also shown in Fig 1, where the aim is to demonstrate the concept of an automated detect-and-avoid capability.

The radar's remote controller allows the complete off-site control of the MATS radar system. Remote operation is important, for example, when the radar is located some distance from the unmanned aircraft's GCS.

2.2.2 The MATS radar concept of operations

The high-level concept of operations of the MATS is shown in Fig 3.



1. An Unmanned Aircraft (UA) is being controlled by the GCS.
In this case the UA is detected by the radar and appears on the display.

2. A General Aviation (GA) aircraft approaches the radar coverage region and is detected and displayed.

3. The UA pilot broadcasts a VHF radio warning and the UA is manoeuvred to a safe location.

Fig 3. The concept of using the MATS to support the operation of unmanned aircraft systems in unsegregated civilian airspace. The MATS may be located separately from the GCS and provide situational awareness information via a network link. The MATS provides the 'detect' capability and the UAS pilot provides the 'avoid' capability.

The primary mission of the MATS is to detect General Aviation (GA) aircraft that may intrude into the operational area of the UAS. Detecting the operational UAS is secondary as the GCS often tracks the unmanned aircraft via a telemetry link.

The MATS may be positioned in a different location to the GCS. The MATS will then provide its situational awareness information via a network link.

Fig 3 shows that the UA is being monitored and controlled from the GCS. The UA could be performing a variety of civilian or research tasks. The MATS continuously provides situational awareness information to the UAS pilot.

In the primary scenario a GA aircraft enters the local airspace and is detected by the MATS. The UAS pilot may then broadcast a VHF radio warning about UAS operations and, if required, manoeuvre the UA to a safe location.

If a VHF radio response is heard from the GA pilot then the flight paths of the two aircraft can be coordinated. If a VHF response is not heard then the aircraft can be considered non-cooperative and the UA will need to be manoeuvred to a safe location.

Fig 1 also showed that the information provided by the MATS can be used by the ADAC [12]. In this scenario the MATS again provides the 'detect' function but the 'avoid' function is automated. A number of these scenarios will be tested in the final phase of the Smart Skies project.

2.2 The MATS ADS-B Receiver

The ADS-B receiver used in the current experiment is an SBS-1 from Kinetic Avionic Products Limited [13]. The SBS-1 is a portable and low-cost Mode-S/ADS-B 1090 MHz receiver. The SBS-1 provides the capability to track and log information about ADS-B equipped aircraft. The receiver also identifies and displays Mode-S equipped aircraft.

The ADS-B receiver provides the latitude, longitude, altitude, speed, heading and identity for equipped aircraft.

The aim of an ADS-B receiver for the MATS is to:

1. provide detailed information about aircraft that are also detected by the MATS radar; and
2. provide information about equipped aircraft that are beyond the radar's operational range.

One advantage of ADS-B is that the aircraft information is transmitted to the receiver. Thus, accuracy isn't imposed by the receiver – the accuracy of the information is set at transmission. This must be contrasted to radar systems where the information about the aircraft is measured and, thus, the accuracy of these measurements is range dependent. The main advantage of primary radars is that they are not dependent on aircraft avionics and, as such, are able to detect non-cooperative targets.

AirServices Australia provides an overview of ADS-B and the Australian ADS-B network [14].

2.3 The Airborne Systems Laboratory

The Australian Research Centre for Aerospace Automation (ARCAA) has developed the Airborne Systems Laboratory (ASL) as part of the Smart Skies project. Fig 4 shows the ASL - a Cessna 172R.

The ASL has been equipped with a Novatel SPAN integrated GPS-INS navigation system to provide real-time "truth" data about the aircraft's state. This data includes the aircraft's position, velocity and altitude [15].

A certified roll-steering converter was fitted to the ASL to provide a digital interface to the existing autopilot. This interface allowed the aircraft's flight management system to command the aircraft's autopilot directly. This capability allows flight plans to be followed autonomously during the cruise phases of flight.

Fig 4. The Airborne Systems Laboratory (ASL) is a Cessna 172R.

From a radar characterisation point of view the important features of the ASL are its ability to follow predetermined flight plans and its ability to provide accurate knowledge of the aircraft's position and attitude.

The ASL also represents a typical GA aircraft, which makes it ideal for radar characterisation studies as it also represents a typical 'intruder' aircraft. Thus, the ASL is ideally suited to showing how the MATS can support UAS operations in class G airspace.

2.4 The ScanEagle UAS

The ScanEagle® unmanned aircraft has a wing span of 3.11 m and a length of 1.37 m [16]. A standard ScanEagle carries a high-resolution electro-optic (EO) camera or an infrared (IR) camera and has a flight endurance that is greater than 24 hours. Launch and recovery of the ScanEagle are performed with a pneumatic catapult launcher and unique SkyHook® recovery system, respectively – an airfield is not required.

2.5 Watts Bridge

The MATS characterisation studies were carried out at Watts Bridge Memorial Airfield, Queensland, Australia (27° 05' 54.00"S, 152° 27' 36.00"E). The airfield is one and a half hours drive from the state's capital city, Brisbane.

The airfield has three grass runways: two parallel runways and one cross strip. Mt Brisbane (2244 ft) is located to the east of the airfield. Intensive skydiving can often occur at 5 NM to the north-west of the airfield.

Insitu Pacific Limited currently uses the airfield for flight training with the ScanEagle UAS. Thus, the airfield represents a realistic environment to test the MATS.

3 Results

3.1 Introduction

This section discusses the MATS characterisation testing, which aims to quantify the ability of the MATS to detect and track a variety of aircraft.

3.2 Tracking targets of opportunity

A variety of aircraft use the Watts Bridge airfield. These aircraft provide "targets of opportunity" for testing the MATS radar. An example of the radar tracks from two targets of opportunity is shown in Fig 5.

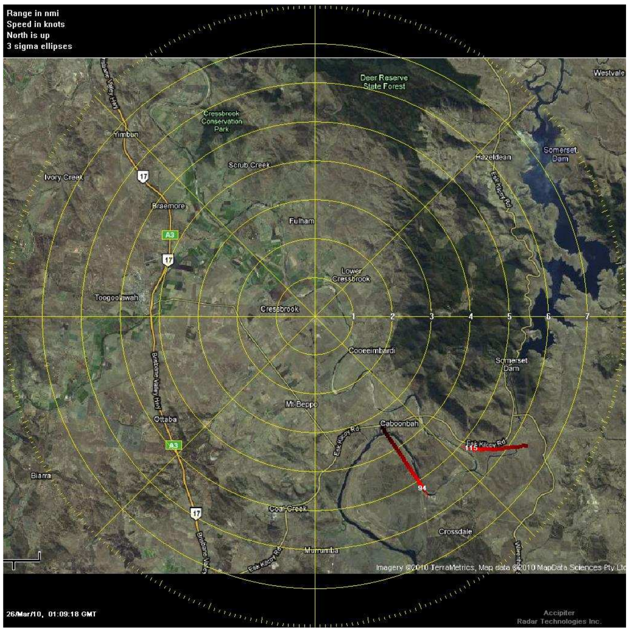


Fig 5. Two MATS radar tracks from targets of opportunity in the vicinity of the Watts Bridge aerodrome. Range rings, in one nautical mile increments, are also shown.

The figure shows an aircraft that had departed from Watts Bridge airfield and was travelling at 94 knots and an aircraft approaching Watts Bridge airfield at 115 knots.

Targets of opportunity may be used to test the ability of the MATS to track a number of different types of aircraft. Aircraft may be tracked approaching, departing and performing circuits near the airfield.

Often, though, the altitude and attitude of the targets of opportunity are unknown. The aircraft also follow their own flight plans. Thus, with the large number of unknown variables involved it is difficult to get meaningful quantitative results from targets of opportunity alone.

3.3 Smart Skies Flight Trails

The aim of a series of Smart Skies flight trials was to characterise the performance of the MATS using the ASL. For these tests the ASL was provided with a variety of flight plans to test different aspects of the radar's performance. The results in this section are from flight trials performed on 6 May 2010.

The radar's performance is influenced by the local environment. Targets are detected against the background clutter and depend on the signal-to-clutter ratio.

Fig 6 shows the background clutter environment from Watts Bridge when the radar used its long (1.2 µs) pulse. The figure shows the significant background clutter that results from Mt Brisbane at ranges of 2-4 NM from the north north-east to the south-east. The figure also shows that other geographic features provide high background clutter (e.g. 5 NM to the north of the radar).

Some of the initial flight trials were aimed at understanding the influence of the background clutter on the ability of the radar to detect aircraft.

For these experiments the ASL was provided with circular flight paths at a number of ranges from Watts Bridge. The circular flight paths meant that the ASL presented a constant Radar Cross Section (RCS) to the radar. Thus, the main variable was the background clutter environment.

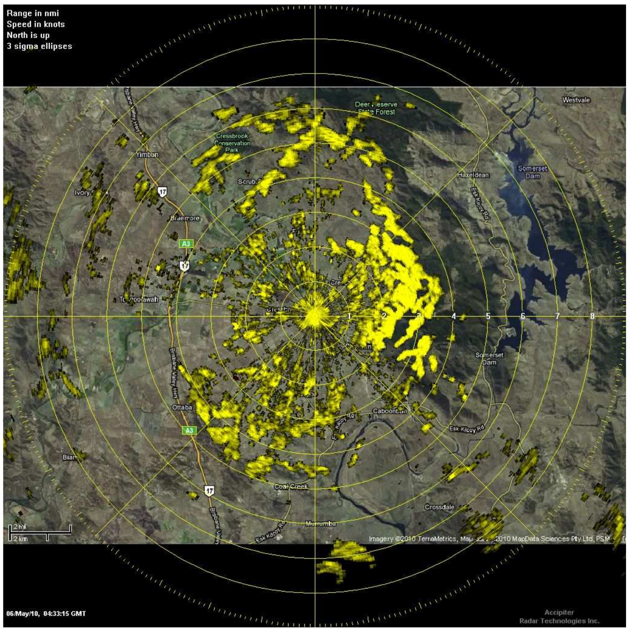


Fig 6. The clutter environment observed by the MATS radar. Range rings, in one nautical mile increments, are also shown.

Fig 7 shows the radar tracks when the radar’s long pulse was used. The figure shows the tracks from circular flight paths with a radius of 3.2 NM (6 km) and a radius of 4.3 NM (8 km).

It should be noted that the individual tracks that make up the circular paths have been extracted and plotted in Google Earth™ [17]. The gaps in the circular paths represent regions where the ASL was not tracked.

Fig 8 shows the results where the radar’s medium (0.3 µs) pulse was used. The figure shows the tracks from circular flight paths with a radius of 2.7 NM (5 km) and a radius of 4.3 NM (8 km).

3.4 Radar and ADS-B tracks

After running the radar and ADS-B receiver together it was noticed that some ADS-B tracks corresponded to radar tracks. These tracks had a distinctive “signature” of occurring on predefined flight paths.

Fig 9 shows one example of the correspondence between an ADS-B track and a radar track recorded on 26 March 2010.

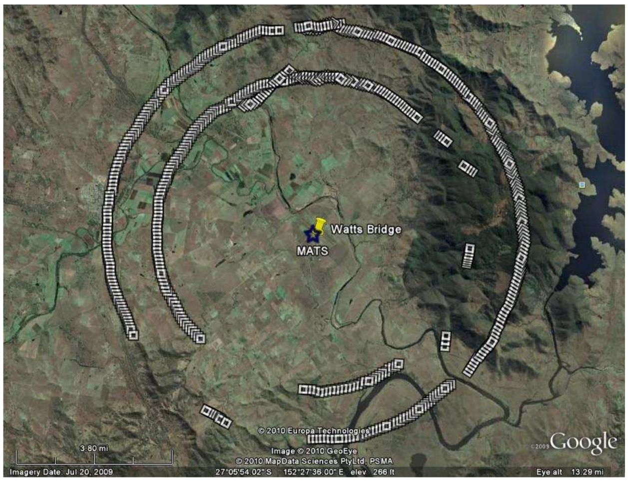


Fig 7. The MATS radar tracks of the ASL when it flew circular flight paths. The radar's long pulse was used in these tests.

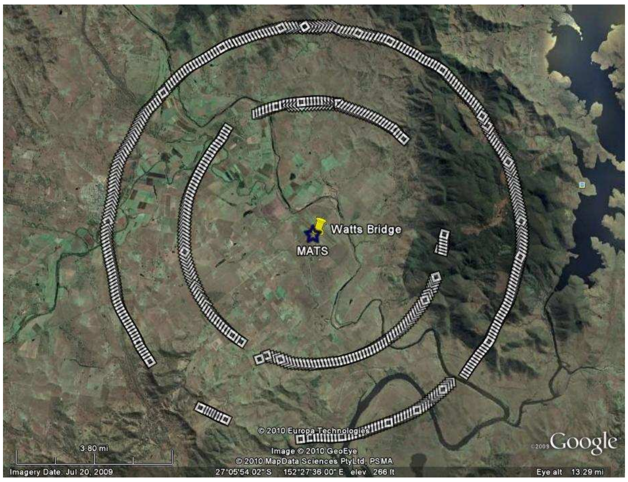


Fig 8. The MATS radar tracks of the ASL flying circular flight paths. The radar's medium pulse was used in these tests.

The received ADS-B information allowed the aircraft to be identified as a Boeing 777-2D7ER. The aircraft was on descent to Brisbane airport. The aircraft was first detected by the ADS-B receiver when it was 184 NM north-west of Watts Bridge at 11:24:22 local time.

3.5 Tracking the ScanEagle

IPL operated the ScanEagle at Watts Bridge on 26 May 2010. The ScanEagle’s GCS was located approximately 165 m to the south-west of the radar.

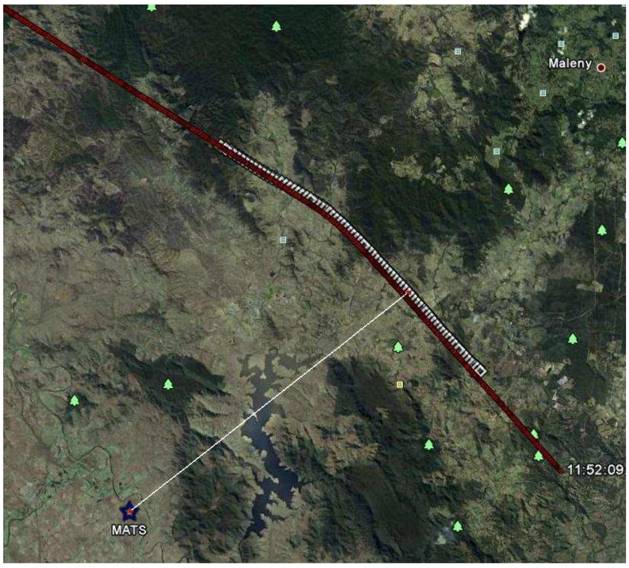


Fig 9. A plot showing the correspondence between a MATS radar track (white squares) and a MATS ADS-B track (red circles). For reference purposes a 16 NM line has been drawn from the MATS location to the tracks.

The MATS radar's short (0.07 μs) pulse was selected in order to provide high-resolution (10 m) tracking. Fig 10 shows a section of the MATS radar track recorded for the ScanEagles's flight.

Fig 10. The MATS radar track of the ScanEagle. The location of the MATS on the Watts Bridge aerodrome is also shown.

The ScanEagle was operated at short ranges from the GCS. At short ranges the ScanEagle – radar geometry is important. If the altitude of the ScanEagle is too high, for example, then it may not be in the radar's field of view. A comparison of the radar's tracks with the ScanEagle's on-board position and attitude log is ongoing.

4 Discussion

The MATS characterisation testing has provided results for targets of opportunity, a typical general aviation aircraft, a Boeing jet and for the ScanEagle UAS.

The large numbers of unknowns make targets of opportunity unsuitable for obtaining quantitative radar performance results. These unknowns include aircraft type and altitude. Targets of opportunity usually only provide tracking opportunities over a limited spatial area, which make any radar performance information difficult to generalise.

Targets of opportunity do, however, provide opportunities to demonstrate the ability of the MATS to provide situational awareness information to the UAS operator i.e. they provide realistic examples of unknown aircraft approaching and departing an aerodrome at unpredictable times and directions. Other studies have also show the ability of radars to improve the situational awareness of UAS pilots [18].

Targets of opportunity also provide an opportunity to demonstrate the detect-and-avoid capability that uses the MATS radar and the UAS pilot. In the future this detect-and-avoid function may be automated.

In terms of UAS operations targets of opportunity can provide an important indication of how the local airspace is used. Fig 5, for example, shows aircraft approaching and departing the airfield from a particular direction. As such, this direction could be identified as being high risk from a UAS operations point of view. By using the MATS to monitor the air traffic over a period of time a "risk map" could be developed as a guide for UAS operations. This is a similar concept to the statistical traffic map that was generated from the surveillance of traffic on a lake [11].

The ASL and its truth system provide a means of quantifying the performance of the

MATS as all aircraft parameters can be independently measured. The initial Smart Skies flight trials were aimed at understanding the influence of the background clutter on aircraft detection results. The ASL was directed to follow circular flight paths at a number of ranges from Watts Bridge. The circular flight paths meant that the ASL presented a constant RCS to the radar.

The results show that the background clutter environment can influence the detection results. The tracks were dropped at predictable high-clutter locations. The tracks were then reacquired when the aircraft moved away from these locations.

The influence of high-clutter areas on target detection has led to the consideration of alternative antenna configurations. Elevating the main beam of the antenna will simultaneously reduce the ground clutter and increase the elevation coverage of the radar. Increasing the elevation coverage also has operational benefits as it increases the surveillance area near the radar – a 10° beam reaches 5000 ft at 4.67 NM while a 20° beam reaches the same altitude at 2.26 NM.

Detection results for two radar pulse lengths were provided. The long radar pulse provides a range resolution of 180 m while the medium pulse provides a range resolution of 45 m. One outcome from the testing will be to decide which pulse length to use operationally.

Ideally, the inner circular flight paths for the two pulse lengths would be the same, which would allow a direct comparison of the results. The results do, however, show the influence of the strong clutter environment to the east of the radar.

The outer circular flight paths for the two pulse lengths do allow a direct comparison of the results. The high-clutter regions in the south-west quadrant cause the tracks to be dropped for both pulse lengths. The similarity of the results for the two pulse lengths mean that it may be another metric, such as manoeuvre tracking performance, that determines which pulse is selected for UAS operations.

Work is in progress to determine the useful operational range of the radar for general aviation size aircraft. This range is likely to be different for each location because of the differences in the clutter environment at each site. An operational range of 10 to 14 NM is expected. There are opportunities to optimise the detection and tracking parameters. Because the consequences of a missed detection are greater than those of false detections there may be an easy system performance gain by setting lower detection thresholds.

The correspondence between an ADS-B track and a MATS radar track was demonstrated. ADS-B's ability to identify the type of aircraft, along with position, altitude, heading and speed, is valuable for radar studies because it provides a general guide to the RCS of the detected aircraft.

The radar and ADS-B data are not currently fused in real-time. The eventual aim is to provide a fused common operating picture for the UAS pilot. The operator will be provided with more information when ADS-B equipped aircraft are observed, which should make it easier for non-cooperative aircraft to be identified.

Tracking a ScanEagle UAS was also demonstrated. Tracking the ScanEagle is not currently the primary mission of the MATS. Tracking a ScanEagle does, however, demonstrate a capability to track targets with a low RCS.

Tracking UAS with a radar may also be of interest for navigation when GPS has failed or for applications where independently tracking a number of UAS is important.

The FAA has provided some interim operational approval guidance for UAS flight operations [19], which notes:

> *If special types of radar or other sensors are utilized to mitigate risk, the applicant must provide supporting data which demonstrates that:*
>
> - *both cooperative and non-cooperative aircraft, including targets with low radar reflectivity, such as gliders and balloons, can be consistently identified at all operational altitudes and ranges, and,*
> - *the proposed system can effectively deconflict a potential collision.*

The results shown in this paper provide examples of the supporting data that may be included in applications for greater access to airspace for UAS.

5 Conclusion

Unmanned aircraft require a capability to 'detect-and-avoid' to replace the traditional 'see-and-avoid' performed by pilots.

The aim of the MATS is to provide a local capability for the detection of cooperative and non-cooperative airspace users in support of the operation of UAS in unsegregated civilian airspace.

The MATS was tested using targets of opportunity and a specially equipped aircraft that flew predetermined flight plans. The results of flight testing show that the MATS was able to track a variety of aircraft. A co-located ADS-B receiver provided additional information about equipped aircraft in the local area.

The flight trial results show that a ground-based detect-and-avoid system is able to provide a viable means of supporting UAS operations in unsegregated airspace within the NAS.

The MATS continues to be tested – both with targets of opportunity and with the ASL. The current plan also includes testing the system at other locations.

References

[1] Limitations of the see-and-avoid principle. *Australian Transport Safety Bureau (ATSB)*, ISBN 0 642 16089 9, 1991.

[2] Morris C. Midair Collisions: Limitations of the See-and-Avoid Concept in Civil Aviation. *Aviation, Space, and Environmental Medicine*, Vol. 76, No. 4, April 2005.

[3] Department of Defense. Unmanned Aerial Vehicles Roadmap: 2000-2025. *Office of the Secretary of Defense*, April 2001.

[4] ICAO. Unmanned Aircraft Systems (UAS). *ICAO draft Circular 328*, 2010.

[5] Clothier R, Baumeister R, Brünig M, Duggan A, Roberts J, Walker R, Wilson M. The Smart Skies project. submitted for review to *IEEE AESS Magazine*, 2010.

[6] http://www.smartskies.com.au

[7] Kwag Y, Chung C. UAV based collision avoidance radar sensor. *International Geoscience and Remote Sensing Symposium, IGARSS*, pp. 639 – 642, 2007.

[8] Korn B, Edinger C. UAS in civil airspace: Demonstrating "sense and avoid" capabilities in flight trials. *Digital Avionics Systems Conference, DASC*, pp 4.D.1-1 - 4.D.1-7, 2008.

[9] Carnie R, Walker R and Corke P. Image Processing Algorithms for UAV "Sense and Avoid". *IEEE Conference on Robotics and Automation*, Orlando, Florida, 15-19 May 2006.

[10] Weber P, Premji A, Nohara T and Krasnor C. Low-Cost Radar Surveillance of Inland Waterways for Homeland Security Applications. *IEEE Radar Conference*, Philadelphia, PA, April 26-29, 2004.

[11] Nohara T, Weber P, Jones G, Ukrainec A, Premji A. Affordable high-performance radar networks for homeland security applications. *IEEE Radar Conference*, Rome, pp 1-6, 2008.

[12] Baumeister R, Estkowski R and Spence G. Automated aircraft tracking and control in Class G Airspace. *International Council of the Aeronautical Sciences*, Nice, 2010.

[13] http://www.kinetic-avionics.co.uk/index.php

[14] http://www.airservices.gov.au/projectsservices/projects/adsb/default.asp

[15] D Greer, R Mudford, D Dusha , R Walker, Airborne Systems Laboratory for Automation Research. *International Council of the Aeronautical Sciences*, Nice, 2010

[16] http://www.insitu.com/insitu-pacific

[17] Google Inc. (2010). Google Earth. Available from http://earth.google.com/

[18] Denford J, Steele J, Roy R, Kalantzis E. Measurement of air traffic control situational awareness enhancement through radar support toward operating envelope expansion of an unmanned aerial vehicle. *Proceedings of the 2004 Winter Simulation Conference*, pp 1017 - 1025, 2004.

[19] Interim Operational Approval Guidance 08-01, Unmanned Aircraft Systems Operations in the U. S. National Airspace System. *Federal Aviation Administration*, 2008.

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