GROUND-BASED SENSE AND AVOID SUPPORT FOR UNMANNED AIRCRAFT SYSTEMS

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Abstract

The ability to fly an unmanned aircraft regularly and routinely for commercial or civilian applications, in non-segregated, airspace requires a sense and avoid capability.

The Mobile aircraft Tracking System (MATS) is a Ground-Based Sense And Avoid (GBSAA) system. The MATS consists of a primary radar, an ADS-B receiver and a transponder interrogator. The Smart Skies project provided an opportunity to test the performance of the MATS using a specially equipped Cessna 172R. This aircraft was also used to calibrate radar cross section (RCS) estimates.

The MATS was fielded at a non-towered aerodrome where ScanEagle operations are conducted. The system demonstrated the ability to detect and track the local airspace users and, thus, support routine and regular UAS operations

1 Introduction

Unmanned Aircraft Systems (UAS) have a long history of being used by the military in segregated airspace. As technology has matured many civilian and commercial applications of UAS are being considered. In general missions that are "dull, dirty or dangerous" are thought to be well suited to UAS.

The use of unmanned aircraft (UA) for civilian and commercial purposes requires access to the National Airspace System (NAS). One foundation of manned aviation is the ability of pilots to *see-and-avoid* other aircraft [1]. Thus, UA require a capability to Sense And Avoid (SAA) other aircraft to fly routinely in the NAS [2,3].

Many airborne solutions to the SAA problem have been considered [4,5]. An alternative is to use Ground-Based Sense And Avoid (GBSAA) systems to support UAS operations [6,7].

This paper presents the results from testing the Mobile Aircraft Tracking System (MATS), which is a GBSAA system. The MATS was tested using a specially equipped Cessna 172R during the Smart Skies project. The results from testing the MATS during ScanEagle operations are also presented.

2 Materials and Methods

2.1 The Smart Skies Project

The Smart Skies project explored technologies that support the greater utilisation of the National Airspace System (NAS) by both manned and unmanned aircraft [8].

One feature of the Smart Skies project was a series of integrated flight trials that used a specially equipped Cessna 172R aircraft. The aircraft accurately logged its position and attitude during flight trials. The aircraft could also be tasked to autonomously follow predetermined flight plans. Thus, the Cessna was a valuable asset for exploring the performance of the MATS.

2.2 Mobile Aircraft Tracking System

The MATS is shown in Fig. 1. The MATS is a cost-effective, network enabled and portable air traffic surveillance system. The aim of the

MATS is to provide a capability to detect and track the local cooperative and non-cooperative airspace users to support of the operation of UAS in non-segregated civilian airspace. Cooperative aircraft have an electronic means of identification on-board that is operating (e.g. a transponder) [9]. Non-cooperative aircraft do not have electronic means of identification on-board.

Fig. 1. The Mobile Aircraft Tracking System (MATS) is installed in a trailer that forms part of Insitu Pacific's UAS Flight Demonstration System. The MATS uses a primary surveillance radar and other sensors to monitor the local air traffic. The photo was taken at Watts Bridge airfield during ScanEagle operations.

The architecture of the MATS is shown in Fig. 2. The MATS currently consists of a primary surveillance radar (PSR) and an Automatic Dependent Surveillance – Broadcast (ADS-B) receiver. A transponder interrogator has recently been added to the system.
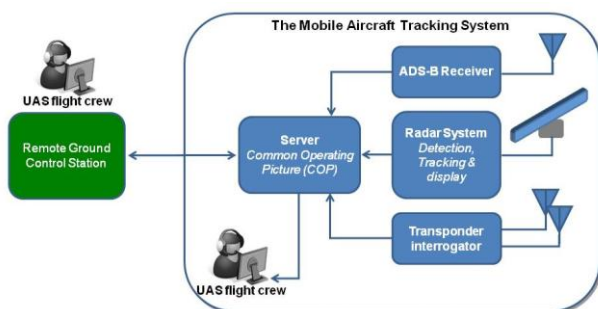

Fig. 2. The architecture of the MATS showing the major subsystems. An interface to a remote ground control station provides some flexibility in how the MATS is deployed.

The MATS PSR consists of a commercial off-the-shelf (COTS) marine radar and a system that performs the detection, tracking and display functions.

The COTS radar is a non-coherent Furuno FAR-2127-BB X-band radar that has a peak output power of 25 kW. The radar uses an eight-foot slotted waveguide array antenna. This standard antenna provides a horizontal beamwidth of 0.95° and a vertical beamwidth of 20°. The vertical beamwidth covers ±10° from the horizontal. The antenna rotates at 24 revolutions per second, which provides an update rate of 2.5 seconds.

The radar provides a range resolution of 180 m and an instrumented range of 54 Nautical Miles (NM) when the long pulse length is selected. The radar's medium pulse provides 45 m range resolution and an instrumented range of 27 NM.

The Accipiter® detection and tracking system is the 'brain' of the MATS PSR. The Accipiter system replaces the standard marine radar processing with a powerful, software-definable radar processor and tracker [10].

An example of the MATS radar display is shown in Fig. 3. The radar display provides a real-time picture of the tracks from the local airspace users.

Fig. 3. An example of the MATS real-time radar display, centred on the Watts Bridge airfield. Two aircraft tracks are shown. The aircraft 3.5 NM to the northwest is heading away from the airfield at 89 knots. The aircraft 1.3 NM to the southeast is heading west at 63 knots. Range rings, in one nautical mile increments, are shown.

The primary radar a key subsystem of the MATS because it is one of only a few technologies that is able to detect non-cooperative aircraft.

The ADS-B receiver used by the MATS is an SBS-1 from Kinetic Avionic Products Limited. The SBS-1 is a portable and low-cost ADS-B 1090 MHz receiver. The SBS-1 provides the capability to track and log information about ADS-B equipped aircraft.

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

One aim of the ADS-B receiver is to provide detailed information about the aircraft that are also detected by the MATS radar. Another aim of the receiver is to provide information about the equipped aircraft that are beyond the radar's operational range.

An Avidyne TAS 620 transponder interrogator has recently been added to the MATS. This system is usually operated on an aircraft. For the MATS, however, the system has been configured for ground-based operation. The Avidyne system provides information about transponder-equipped aircraft in the local area. The aim of this sensor is to provide addition information to the Common Operating Picture (COP) shown in Fig. 2. Tests with the transponder interrogator system are continuing.

An interface to a remote Ground Control Station (GCS) is shown in Fig. 2. This interface allows some flexibility in how the MATS is deployed. The MATS may, for example, be positioned to optimize the radar's field of view, which could be located some distance from the GCS.

The aim of the MATS is to provide the UAS pilot with information about the local airspace users. The MATS and the UAS pilot form a SAA system: the MATS provides the 'sense' function and the UAS pilot performs the 'avoid' function by manoeuvring the UA.

2.3   Airborne Systems Laboratory

The Airborne Systems Laboratory (ASL) was developed as part of the Smart Skies project. The ASL, which is shown in Fig. 4, is a Cessna 172R.

The ASL is equipped with a Novatel SPAN integrated GPS-INS navigation system, which provides real-time 'truth' data about the aircraft's state. This data includes the aircraft's position, velocity, attitude and altitude [11]. The 'truth' data also provided an independent check of the radar's tracking measurements during post flight-trial analysis.

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

A certified roll-steering converter was fitted to the ASL to provide a digital interface to the existing autopilot. This interface allowed the ASL's flight management system to command the aircraft's autopilot directly. This capability allowed predefined flight plans to be followed autonomously during the cruise phases of flight. Thus, the ASL was able to repeatedly follow a variety of flight plans, including circular and diamond shaped flight plans, during the radar characterisation studies.

The ASL was also fitted with a 1090 MHz Extended Squitter (ES) ADS-B transmission system. The ADS-B transmissions provided an excellent means of independently monitoring the ASL during flight trials.

The ASL is a typical General Aviation (GA)[1] aircraft, which makes it ideal for radar characterization studies. The ASL also represents a typical collision threat that may be encountered in non-segregated class G airspace.

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[1] General aviation is often used to describe all civilian aviation activities other than those involved in scheduled public air transport services.

The various capabilities of the ASL make it ideally suited to demonstrating how the MATS can support UAS operations in Class G airspace.

2.4   Watts Bridge Memorial Airfield

A number of the MATS characterisation flight trials were carried out at Watts Bridge Memorial Airfield, Queensland, Australia (27° 05' 54"S, 152° 27' 36"E). The airfield has three grass runways: two parallel runways and one cross strip. Mt Brisbane (2,244 feet) is located approximately 4 NM to the east of the airfield. Intensive sky diving can often occur at 5 NM to the northwest of the airfield. Watts Bridge is approximately 38 NM north-west of Brisbane, the capital of the state of Queensland.

Insitu Pacific Limited (IPL) currently uses Watts Bridge airfield for flight training and testing with the ScanEagle UAS[2]. Thus, the airfield represents a realistic environment for testing the MATS.

IPL operates the ScanEagle within Danger Area 651, which is shown in Fig. 5. The Danger Area is centred on Watts Bridge airfield and extends from the surface to 3000 feet (ft) Above Mean Sea Level (AMSL). A *Danger Area* is an airspace of defined dimensions within or over which activities of potential danger to aircraft flying over the area may exist (Aeronautical Information Package, Australia).
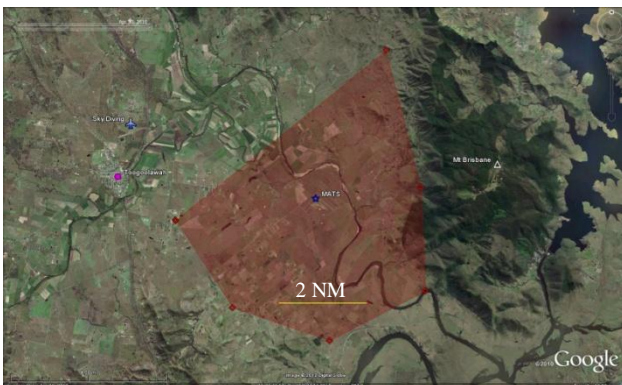

Fig. 5. The ScanEagle is operated within Danger Area 651, which is the red area centred on Watts Bridge airfield.

2.4   The ScanEagle UAS

The ScanEagle® is a small Unmanned Aircraft System (UAS) that is often used to provide imagery for a variety of applications.

The ScanEagle has a wing span of 3.11 m, a length 1.37 m, a takeoff weight of approximately 20 kg and an endurance that is greater than 24 hours. The ScanEagle uses a catapult for launch and a 'Skyhook' for capture. Thus, the aircraft does not require a runway, which provides a lot of flexibility for where the aircraft can operate.

3   Results

3.1   MATS Radar Characterisation

The performance of the MATS PSR was examined in a series of flight trials. In one series of experiments the ASL was provided with circular flight paths at a number of ranges from the Watts Bridge airfield. The circular flight paths meant that the ASL flew at a fixed range from the radar and presented a constant Radar Cross Section (RCS) to the radar.

The original aim of these experiments was to gain an appreciation of the influence that the operating environment has on the detection and tracking performance of the primary radar. The results showed that the high ground-clutter regions can prevent aircraft tracking in some areas, even at short ranges from the radar [12], [13].

The results also showed that the Cessna 172 was tracked less consistently at 14 NM. Larger aircraft, that have a larger radar cross section, were consistently tracked at longer ranges.

An RCS calibration procedure was recently implemented for the MATS radar [14]. The process requires known values of the RCS for an aircraft.

A Cessna 150 L has been noted to have median RCS of just above 5 dBsm at nose aspect and just below 5 dBsm at tail aspect[3]. The median RCS is 20 dBsm for the beam or 'side' aspect [15].

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[2] http://www.insitu.com/scaneagle

[3] dBsm - decibels relative to one square metre.

A Cessna 150L has a length of 7.34 m and a wingspan of 10.1 m. The Cessna 172R used in these experiments has an overall length of 8 m and a wingspan of 11 m. Although the Cessna 172 is larger the 20 dBsm beam RCS of the Cessna 150 was used to set the processing parameters for RCS estimation.

Once the processing parameters were set the data were reprocessed to provide RCS estimates. Reprocessing the data provides RCS estimates for each detection of each track – not just the circular flight path tracks.

Fig. 6 shows the results of the MATS PSR tracking the ASL as it flew circular flight paths. The flight paths have radii of 2.7 (5 km), 6, 10 and 14 NM. The radar's long pulse was tested during this series of flight tests, which provided a range resolution of 180 m.
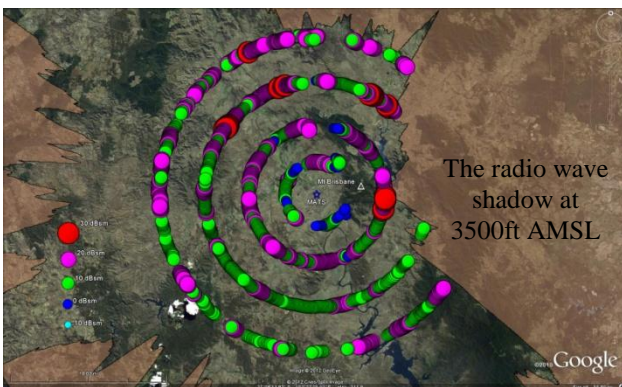

Fig. 6. The MATS radar tracks of the ASL when it flew circular flight paths around Watts Bridge airfield on 13 July 2010. The circular flight paths have radii of 2.7, 6, 10 and 14 NM. The colour and size of each symbol indicate the estimated radar cross section (RCS). The key shows the minimum RCS for each symbol. The red shaded areas show the radio wave shadow regions at 3500 ft AMSL.

The red shaded areas of the figure show the radio wave shadows regions at 3500 ft AMSL. As expected the ASL was not detected and tracked in these regions.

Aircraft detection also depends on the signal to clutter ratio. The gaps in the tracking observed at short ranges were from areas where the ground clutter prevented detection of the ASL. Thus, the results show that the clutter environment has an influence on the detection performance of the radar.

Fig. 6 shows that the RCS estimates greater than or equal to 30 dBsm are indicated by the red symbol, which is also the largest symbol.

Magenta, green, blue, cyan and white symbols are used to indicate RCS 'bins', in 10 dB increments, below 30 dBsm. The symbol size is also progressively decreased for these RCS 'bins'.

The RCS estimates at 10 NM, for three altitudes, are shown in Fig. 7, Fig. 8 and Fig. 9. Fig. 7 shows the detail of the RCS estimates at 10 NM that were also shown in Fig. 6.

Radar performance testing can involve a large number of variables. In these experiments the aircraft and the aspect angle that the aircraft 'presents' to the radar were kept constant. Despite this the RCS was observed to vary with azimuth, range and altitude. The observed ground clutter also varies with range and azimuth and influences the ability of the radar detect aircraft [12,13]. Thus, some of the variation in the RCS estimates is also likely to be due to ground clutter.

3.2 MATS ADS-B Characterisation

The ASL was fitted with a 1090 MHz ADS-B transmission system during the Smart Skies project. Fig. 10 shows the ADS-B track of the ASL from 8:24am to 2:10pm on 13 July 2010. The circular flight paths with radii of 6, 10 and 14 NM are easily distinguished. The 10 NM circular flight path was flown for three altitudes, as shown in Fig. 7, Fig. 8 and Fig. 9.

Not surprisingly the ADS-B signal was lost whenever the ASL flew into a radio wave shadow region. The largest gap in reception may be seen in the outer 14 NM circular flight path. The ADS-B signal was also lost for the low-altitude 10 NM flight path.

Fig. 11 shows the ADS-B track of the ASL from 2:10pm to 4:51pm on 13 July 2010. The performance of the radar's medium pulse was being tested during this series of flight tests.

The figure shows that the circular flight paths with radii of 6 and 10 NM are easily distinguished. The 10 NM circular flight path was flown for two altitudes.

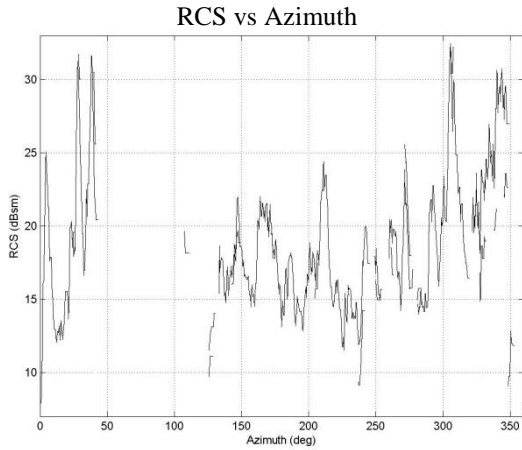The ADS-B signal was again lost whenever the ASL flew into a radio wave shadow region.

Fig. 7. The RCS estimates for the 10 NM radius flight path flown at 3500 ft AMSL. The missing data corresponds to the radio wave shadow shown in Fig. 6.
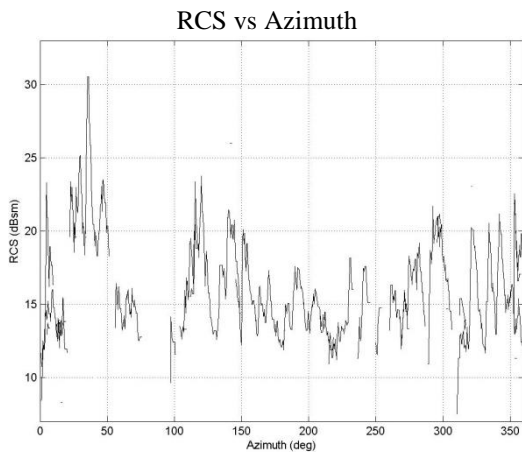

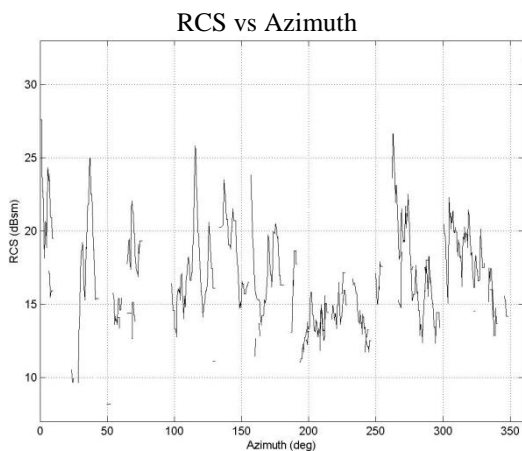Fig. 8. The RCS estimates for the 10 NM radius flight path flown at 4500 ft AMSL.

Fig. 9. The RCS estimates for the 10 NM radius flight path flown at 4500 ft AMSL (30° to 100°) and then 2400 ft AMSL (170° to 360° to 30°). There was no value in flying lower than 4500ft behind Mt Brisbane (see Fig. 8).

Fig. 10. The ADS-B track of the ASL from 8:24am to 2:10pm on 13 July 2010. The view is to the west towards the MATS. The circular flight paths with radii of 6, 10 and 14 NM from Watts Bridge are easily distinguished. The ADS-B signal was lost whenever the ASL flew into a radio wave shadow region.
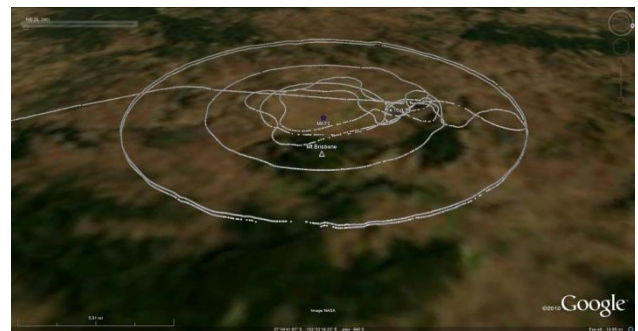

Fig. 11. The ADS-B track of the ASL from 2:10pm to 4:51pm on 13 July 2010. The view is to the west towards the MATS. The circular flight paths with radii of 6 and 10 NM are easily distinguished. The ADS-B signal was lost whenever the ASL flew into a radio wave shadow region.

Fig. 12. The ADS-B tracks of the equipped aircraft in the region around Watts Bridge airfield, from 13 July 2010. The ADS-B track of the ASL is also shown.

The ADS-B receiver provides information about the equipped aircraft in the local area. Fig. 12 shows some of the ADS-B aircraft tracks observed during this day.

Eighty three different aircraft were observed between 8:21am and 5:00pm. The

ADS-B receiver was able to provide information about equipped aircraft out to 200 NM, well beyond the detection range of most air traffic control primary radars.

3.3 Supporting ScanEagle Operations

Insitu Pacific currently conducts ScanEagle operations from the Watts Bridge airfield. Operations are currently restricted to within Danger Area 651. One aim is to expand the area where the ScanEagle may be operated. To expand the area it is worth understanding the traffic patterns and traffic levels around the airfield, especially away from where aircraft can be visually monitored.

Fig. 13 shows the aircraft detected by the MATS during almost two hours of operation. A symbol was used to mark the end of each track and the associated 'tail' shows the track's history.

The radar's medium pulse was used to capture the aircraft tracks in this section, which provided a range resolution of 45 m.

The figure shows a variety of aircraft tracks. The tracks 16 NM to the north-east of the radar, which are heading towards the south-east, occur on a flight path for aircraft on decent to Brisbane International airport.

Fig. 14 shows the aircraft detected by the MATS during the next two hours of operation. Aircraft following the flight path to Brisbane airport may again be seen, along with a variety of other aircraft tracks.

Fig. 15 shows a zoomed-in view of Fig. 14. The figure shows the details of the aircraft tracks near the airfield. Tracks from aircraft flying in the circuit area may clearly been seen. Aircraft may also be seen approaching, departing and flying in the vicinity of the airfield.

The above figures provide examples of the information available from the MATS PSR. The MATS was able to provide information about the aircraft traffic patterns and traffic levels around what is currently a non-towered aerodrome.

The MATS typically provides real-time information about the location, speed and heading of the local airspace users on a single display: the COP shown in Fig. 2. This capability is especially valuable for UAS operations if there are a number of aircraft to monitor.

Fig. 13. The primary radar aircraft tracks observed from Watts Bridge airfield from 10:57am to 12:45pm, 6 July 2010. A symbol was used to mark the end of each track and the associated 'tail' shows the track's history.

Fig. 14. The primary radar aircraft tracks observed from Watts Bridge airfield from 12:45pm to 2:56pm, 6 July 2010. A symbol was used to mark the end of each track and the associated 'tail' shows the track's history.

Fig. 15. The short-range radar tracks from Fig. 14 showing aircraft tracks in the circuit (pattern) area.

3.4 Distinguishing birds from aircraft

Apart from aircraft the MATS PSR is also able to detect and track birds [16,17]. The relatively small RCS of birds means that, in general, their detection range is more limited than aircraft.

Fig. 16 shows the radar tracks from a one hour and nineteen minute period. The figure shows that some of the longer tracks were from aircraft flying in the circuit area.

The tracks with orange tails had mean speeds of less than 30 knots. Some of these tracks are likely to be from birds. The figure shows that the tracks just to the west of the airfield are aligned with the nearby river – another potential indicator of tracking birds.

Fig. 16. The primary radar tracks observed from Watts Bridge airfield from 2:12pm to 3:31pm, 13 July 2010. A symbol was used to mark the end of each track and the associated 'tail' shows the track's history. The tracks with orange tails had mean speeds of less than 30 knots.

Fig. 15 also shows that some of the tracks just to the west of the airfield are located near the river and are also likely to be bird tracks.

A number of track features may be used to distinguish birds from aircraft. These features include the speed, location, RCS and the temporal and spatial behavior of the track.

The ability to distinguish between aircraft and birds is an important feature of any SAA system.

3.5 Tracking the ScanEagle

The standard Furuno radar antenna has a 20° vertical beam width that covers ±10° about the horizontal. An antenna tilt system was added to the standard antenna that allowed the vertical coverage of the radar system to be adjusted.

Fig. 17 shows the results of tracking the ScanEagle when the antenna tilt system was set to provide vertical coverage from 18° to 38°. During this time the ScanEagle flew clockwise from the north-east to the north-west. The figure shows that the ScanEagle performed a number of circular 'orbits' while it was located to the west of the radar.

Fig. 17. The MATS radar tracks of the ScanEagle unmanned aircraft during operations at Watts Bridge airfield from 8:45am to 9:02am, 30 May 2012.

The radar's medium pulse was used to track the ScanEagle, which provided a range resolution of 45 m.

Fig. 18 shows the estimated RCS and other tracking information for the radar tracks shown in Fig. 17. The data for this figure was reprocessed off-line to extract the RCS estimates.
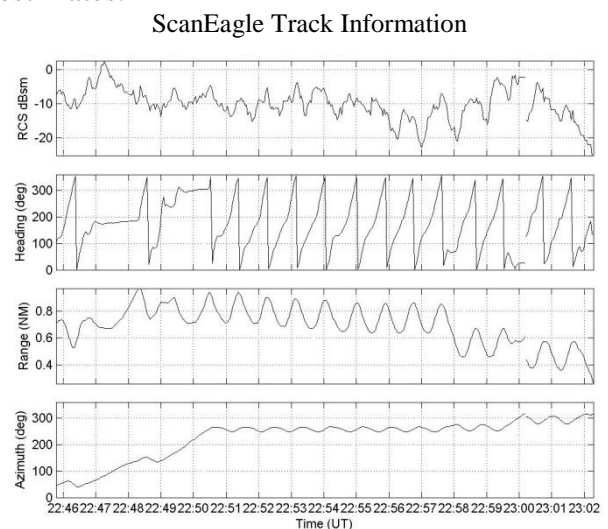

Fig. 18. The primary radar track information from the ScanEagle unmanned aircraft flight at Watts Bridge airfield from 8:45am to 9:02am, 30 May 2012.

The figure shows that the ScanEagle has a median RCS of approximately -10 dBsm. The figure also shows that the RCS of the ScanEagle changes as the aircraft orbits.

The RCS estimate decreases towards the end of the track as the range to the ScanEagle decreases – probably because the aircraft approaches the far-field boundary. The far field of a radar target exists outside a range R_f, which is given by:

$$R_f = 2\,D^2/\lambda \qquad (1)$$

where D is the maximum target dimension that is transverse to the line of sight and λ is the wavelength of the illuminating radio wave [18].

For 9.41 GHz and a ScanEagle wingspan of 3.11 m the far-field distance is 0.33 NM. By contrast the far-field is 2.18 NM for an 8 m Cessna 172.

One application of tracking unmanned aircraft is that they can provide a calibration source for ground based sensors. Often the aircraft will log position, speed and other information that can be use for detailed off-line analysis and tuning of the sensor systems.

4 Discussion

The performance of the MATS was examined using a specially equipped Cessna 172R. In one series of experiments the ASL flew circular flight paths at a number of ranges from the Watts Bridge airfield. We don't expect aircraft to always fly in circles, however, the circular flight paths provided a method of controlling a number of variables and provided calibration information for the RCS estimation procedure.

The estimated speed provides important information about the capabilities of an object that is being tracked by the radar. The cruise speeds of GA aircraft and large passenger jets, for example, are distinctly different. RCS estimates provide additional target size information, which may be used to help distinguish between birds, vehicles, aircraft and ships.

The ASL allowed the advantages of ADS-B to be demonstrated. The MATS was able to independently monitor the ASL throughout the flight trials. The ADS-B receiver also provided insight into the movement of equipped aircraft observed from the airfield.

Approximately 75% of the international airline flights are by ADS-B approved aircraft. Approximately 35% of the domestic airline flights are by ADS-B approved aircraft. The percentage of ADS-B approved domestic flights is expected to rise rapidly as a number of Australian ADS-B mandates come into effect. This first of these occurs on 13 December 2013 when all aircraft operating at or above FL290 will require ADS-B. The implications for the UAS community are clear: ADS-B equipage, and compliance with other regulations, could lead to greater access to airspace.

The radar and ADS-B tracks provide examples of the information that the MATS provides to the UAS pilot. Without this information the UAS pilot may not be aware of all of the local airspace users.

Typically, Very High Frequency (VHF) radio communication on the local Common Traffic Advisory Frequency (CTAF) is used to coordinate UA operations with the other airspace users in the area. Radio carriage, however, is not currently mandatory in Class G airspace below 5000 ft. Thus, it can be difficult to keep aircraft 'well clear' of each other using radio communication alone.

Visual line-of-sight observers have been proposed to provide a collision avoidance capability [9]. Operating with observers is quite restrictive as they are to be positioned no greater than one nautical mile laterally and 3,000 feet vertically from the UA.

The MATS provides the capability to simultaneously monitor a number of aircraft well beyond the range provided by visual observers. The MATS also provides a means of monitoring the traffic patterns and traffic levels at what are traditionally non-towered aerodromes. This information could, for example, be used to help justify the expansion of some UAS operating areas. In the future such information could also be used to assess the risk associated with the operation of a UAS in a new area.

Tracking UA with the MATS has been reported elsewhere [12,19,13]. Tracking UA is

not the primary mission of the MATS. The GCS usually provides real-time information about the location of the UA. Tracking the ScanEagle, however, did provide an opportunity to test some of the new capabilities added to the MATS.

Tracking the ScanEagle provided the opportunity to test the additional vertical coverage provided by the antenna-tilting system. Tracking the ScanEagle also provided the opportunity to gain an estimate of the aircraft's RCS.

5 Conclusions

The MATS is a GBSAA system that uses a primary radar, an ADS-B receiver and a transponder interrogator to provide information about the location and intent of the local airspace users. This information may be used by a UAS pilot to keep the unmanned aircraft well clear of other aircraft. The ability to keep an unmanned aircraft well clear of other aircraft is an important step towards routine and regular UAS operations in the national airspace system.

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