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The Smart Skies Project

Authors:

Clothier, Reece [1]

Baumeister, Richard [2]

Brünig, Michael [3]

Duggan, Andrew [4]

Roberts, Jonathan [3]

Walker, Rodney [1]

Wilson, Michael [5]

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Abstract:

This paper describes the Smart Skies project, an ambitious and world-leading research endeavor exploring the development of key enabling technologies, which support the efficient utilization of airspace by manned and unmanned airspace users. This paper provides a programmatic description of the research and development of: an automated separation management system, a mobile aircraft tracking system, and aircraft-based sense-and-act technologies. A summary of the results from a series of real-world flight testing campaigns is also presented.

[1] Australian Research Centre for Aerospace Automation, Queensland University of Technology, 22-24 Boronia Rd, Eagle Farm, QLD 4009, Australia. r.clothier@qut.edu.au, ra.walker@qut.edu.au, P: +61 (0)7 3138 1772, F: +61 (0)7 3138 4528, W: www.arcaa.aero
[2] Boeing Research & Technology (BR&T)
[3] Australian Research Centre for Aerospace Automation, Commonwealth Scientific and Industrial Research Organisation (CSIRO) ICT Centre
[4] Insitu Pacific Limited
[5] Boeing Research & Technology Australia (BR&TA)

1 Introduction

The demand for commercial aviation, and in turn the amount of air traffic, has under gone a period of exceptional growth and this growth is expected to continue at a rate of 4.7% per annum over the next 20 years [1]. In addition, there are an increasing number of new aviation user groups, including: light sport aircraft, Very Light Jets (VLJs), routine sub-orbital aircraft, personal air vehicles and Unmanned Aircraft Systems (UAS), all of which place increasing pressure on the airspace system (*e.g.,* refer to Bonnefoy *et al*. [2], and DeGarmo [3] respectively for discussions regarding the potential impact VLJ and UAS have on the airspace system). New airspace management concepts are required to accommodate the unique requirements of these new user groups to ensure the continued sustainability of the airspace system, and to reduce the impact increased levels of aviation activity places on the environment (currently estimated as 2% of manmade global CO_2 emissions [1]).

This problem provides the motivation behind the Smart Skies project, a joint-research program between Boeing Research & Technology (BR&T)[6], and the Australian Research Centre for Aerospace Automation (ARCAA)[7]. The objective of the project is to explore the development of a number of key enabling technologies, which support the efficient utilization of Class G airspace by a mix of airspace users. These technologies are:

- A network-enabled Mobile Aircraft Tracking System (MATS) for the detection and tracking of local air traffic (Section §2);
- Sense-and-Act (SA) systems for the autonomous detection of other aircraft and ground-based obstacles (Section §3); and
- an Automated Separation Management System (ASMS) capable of providing global separation assurance between network-enabled aircraft (Section §4).

[6] Boeing Research & Technology United States and Boeing Research & Technology Australia
[7] ARCAA is a joint-research venture between Queensland University of Technology (QUT) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) ICT Centre.

One significant aspect of this project is that all of the enabling technologies under development are flight tested under real airspace conditions using a number of manned and unmanned flight test aircraft. A series of integrated flight tests are also conducted, whereby each of the enabling technologies is integrated in the ASMS concept and flight tested. The project commenced in March 2008 and will finish in February 2011. During this period eight dedicated flight trial campaigns have been scheduled. At the time of writing of this paper, four flight trial campaigns have been successfully completed and some preliminary results are presented in Section §4.4. An incremental research, develop and flight test plan was adopted to manage the complexity of the project. The objective of each successive phase was to validate the incremental capability and performance of the individual systems as well as the integrated ASMS. By the end of the three-year project, the goal is to begin fielding commercial-ready systems for use by manned and unmanned aircraft operators. These longer-term research, development and testing objectives are described in Section §5.

2 Mobile Aircraft Tracking System

Currently, 'complete' situational awareness of air traffic is limited to areas covered by Primary Surveillance Radar (PSR), which is typically only airspace within 50nmi of a major airport. Dependent surveillance systems such as Secondary Surveillance Radar (SSR) or Automatic Dependent Surveillance – Broadcast (ADS-B) provide surveillance information to the Air Navigation Service Provider (ANSP) but only from appropriately equipped airspace users. There is nearly complete SSR coverage across continental USA. In Australia, SSR coverage is primarily limited to regions surrounding major airports and the en-route areas along the eastern seaboard. Complete surveillance coverage at 30,000ft and above is provided through the combination of SSR and ADS-B. ADS-B coverage below this altitude is limited to specific regions (see Ref.[4]). Outside these areas there is limited surveillance information available on aircraft, with the primary means of establishing traffic situational awareness being provided through maintaining a "listening watch" on common traffic radio channels. Thus, there is a need for situational awareness information about the local air traffic environment to support routine UAS operations in non-segregated class G airspace.

2.1 Description of the MATS

The Mobile Aircraft Tracking System (MATS) is a network-enabled aircraft surveillance system designed to provide situational awareness of air traffic within a local (~10 nmi) area. The portable system provides position, velocity and track information on both cooperative and non-cooperative air traffic.

Within the context of the Smart Skies project, the MATS is proposed as a suitable tool to support the routine operation of UAS within Class G airspace. Class G airspace is likely to be outside of existing PSR coverage, have a high proportion of non-transponder equipped users and contain a complex mix of aircraft types and operations. Such airspace represents the most challenging operational environment for the non-segregated operation of UAS. The hypothesis is that the MATS would provide an important and cost-effective component in the safety-case supporting UAS operations in Class G airspace. The Smart Skies project endeavors to explore:

1. The performance of the MATS in detecting and tracking other airspace users (both manned and unmanned) and how this information can be used to assist in maintaining separation minima;
2. comparisons of the performance of the MATS against that of ground-based observers, or observers situated onboard a chase plane;
3. the performance of the MATS as a failure recovery aid (*i.e.,* loss of onboard navigation systems); and
4. the integration of the MATS as an additional sensor into the ASMS architecture.

The MATS comprises:

- A Primary Radar System (PRS), consisting of a commercial off-the-shelf radio frequency front end and a specialized detection and tracking system;
- an Automatic Dependent Surveillance – Broadcast (ADS-B) receiver;
- a user situational awareness display; and
- data storage, fusion, voice communications and networking.

Figure 1 shows the MATS as an integrated part of the Insitu Pacific Limited ScanEagle™ UAS ground control station.

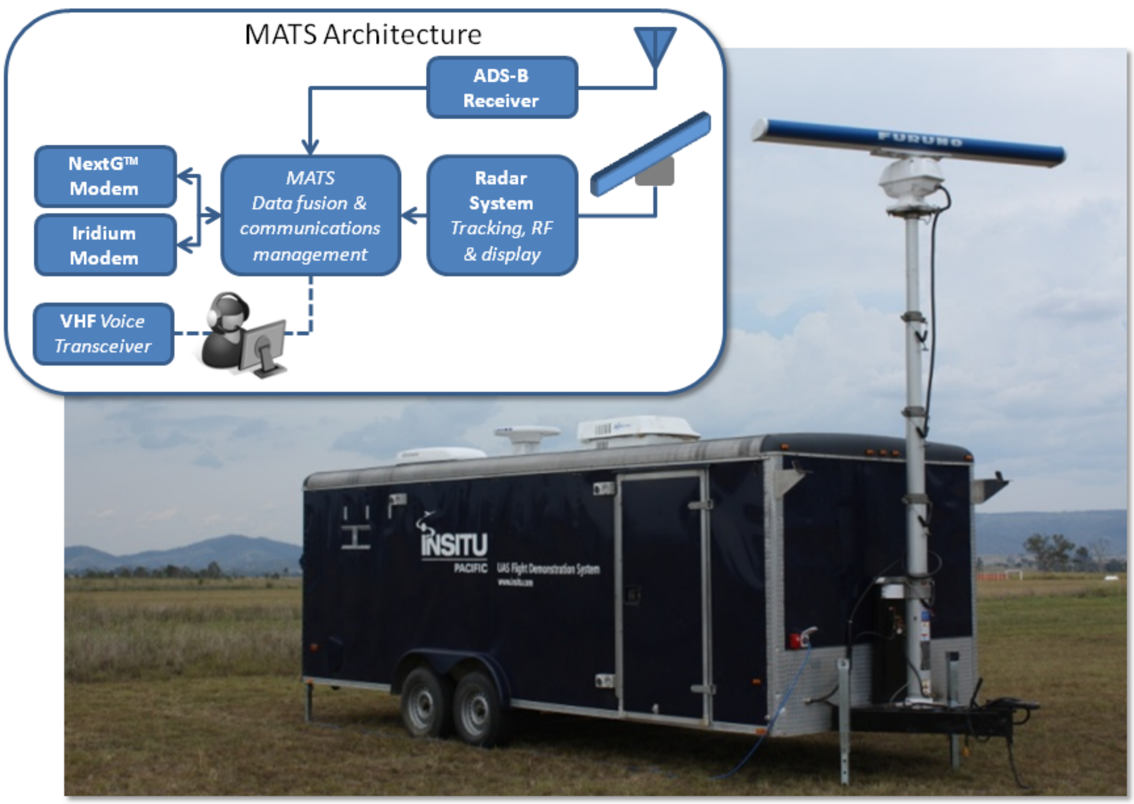

Figure 1. The Mobile Aircraft Tracking System (MATS) and system architecture (inset)

The fully operational MATS could be used as part of the safety case to support UAS operations in non-segregated airspace environments. The MATS is particularly useful in established UAS operating areas (*e.g.*, training areas) where the sighting of the MATS can be optimised for the surrounding clutter environment to provide a known coverage and detection performance. However, a significant advantage to the MATS is its mobility. This mobility allows it to be rapidly deployed in support of ad-hoc/unplanned UAS operations (*e.g.*, in support of bushfire monitoring or search and rescue missions). The MATS could prove to be a key component of the safety case needed for such time-critical deployments.

2.2 MATS Radar Characterization Flight Testing

Testing of the MATS began in March 2010. The primary objective of these tests is to characterize the detection and tracking performance of the PRS against results obtained from simulations and to compare this performance against that of a human spotter situated on the ground. The ongoing trials will investigate the detection and tracking performance of the MATS radar with varying:

- Target cross-sectional area - by using different target aircraft;
- Target aircraft range, velocity, altitude and maneuvering; and
- Clutter environments.

The MATS radar characterization testing has been developed in consultation with Australia's ANSP, Airservices Australia. Preliminary testing verified that the radar was capable of tracking a Cessna 172 in a low clutter environment out to a range of 15 NM. Consistent tracking of the aircraft typically occurred at closer ranges. The MATS also regularly tracked aircraft flying on designated air routes at ranges between 16 and 20 NM. Further details and preliminary results from the characterization testing can be found in Ref.[5]. Testing of the MATS as part of the integrated ASMS began in April 2010 and is further discussed in §4.

3 Sense-and-Act Systems

Sense-and-act refers to the capability of a system to detect, track and resolve potential collisions with other aircraft or obstacles on the ground. The Smart Skies project is exploring the development of automated aircraft-based sense-and-act systems capable of avoiding dynamic obstacles (*e.g.,* another aircraft) or static obstacles (*e.g.,* trees or power-lines).

3.1 Dynamic Sense-and-Act System

The most significant technological challenge facing the seamless integration of UAS alongside other airspace users is the absence of a sense-and-act capability equivalent to the see-and-avoid capability provided by a human pilot. "See-and-avoid" refers to the requirement of a pilot, under suitable visibility conditions, to maintain a visual lookout for other aircraft and if necessary, initiate maneuvers to avoid a potential collision scenario (*e.g.,* refer to Civil Aviation Regulation 163A [6]). The responsibility for collision avoidance ultimately resides with the pilot, irrespective of any third party separation services (*e.g.,* those provided by air traffic control) or technology-based separation aids (*e.g.,* Traffic Alert and Collision Avoidance System). In the absence of a sense-and-act capability equivalent to human see-and-avoid, the risk of midair collision is managed through restrictions on where UAS operations can take place. These restrictions can include confining UAS operations to airspace: segregated from all other airspace users, with known or controlled traffic distributions, or to airspace known to have extremely low traffic movements (such as oceanic areas). Other restrictions can include the use of chase planes. There are a number of known limitations in the performance of the see-and-avoid capability provided by a human pilot (*e.g.,* refer to Refs.[7-8]), hence UAS sense-and-act systems could also be used to supplement the collision avoidance performance of conventionally-piloted aircraft operations.

3.1.1 Smart Skies Dynamic Sense-and-Act System

In addition to the MATS, which could be used to provide a localized off-board aircraft detection capability, the Smart Skies project is exploring the development of an onboard, passive and non-cooperative sense-and-act system. The system, referred to as the Dynamic Sense-and-Act (DSA) system, uses cameras onboard the aircraft in conjunction with image processing algorithms to detect aircraft on a potential collision-course. Machine vision represents a particularly attractive solution for sensing due to the relatively low cost, size, weight, and power requirements of the sensors involved. The initial focus of research is on developing a DSA system for daytime visual meteorological conditions (*i.e.,* not for operations at night or in adverse weather) – with the primary objective to demonstrate a robust collision avoidance capability at a minimum equivalent to that provided by a human pilot under the same conditions. The aim is to develop a complete and robust DSA system consisting of a detection (target observation), sensing (reasoning and decision making) and avoidance (maneuvering and control) functionality within VMC conditions.

Using specialized image filtering and processing techniques, the DSA system is optimized for the detection of dim, point-like targets under high vibration conditions. Such target characteristics are representative of collision events between fixed-wing aircraft (*e.g.,* constant relative bearing collision scenarios). Two candidate algorithms have been developed and are being tested. Both algorithms share a common 'Close-Minus-Open' morphological image pre-processing stage [9-10] with one algorithm coupled to a Hidden Markov Model (HMM) temporal filter [11-12] and another with a Viterbi-based filter [13]. The algorithms are implemented on a NVIDIA GTX 280 1024MB Graphical Processing Unit (GPU) which is attached to a mini-ITX computer. Using the parallel processing of the GPU, the algorithms are capable of processing 1024px by 768px images at a rate approaching 200Hz. The image capture is provided by a Basler FireScout industrial camera.

3.1.2 DSA Flight Testing

Initial data collection flight tests were conducted in December 2009. The objective of this flight test campaign was to capture vision data across a range of collision scenarios which would then be used to further refine the detection and reasoning algorithms under development. Multiple datasets were captured for nine different conflict scenarios between two small fixed-wing UAS. These controlled scenarios were designed to explore different conflict parameters (*e.g.,* geometry and closing speed), image/background compositions (*e.g.,* proportion of ground clutter, open skies or cloudy backgrounds) and environmental conditions (*e.g.,* wind and visibility). Data collection campaign was carried out using the ARCAA Flamingo UAS platform. Offline processing of the data demonstrated the target detection algorithm was capable of detecting the small UAS target aircraft at a range of up to 875m. Figure 2 shows the output from different stages of the target detection algorithm stages for a single image from the dataset.

Some of the key challenges that must be overcome in the use of machine vision-based DSA system are robustness in the presence of sensor noise and the noise introduced by changing and unpredictable ambient conditions.

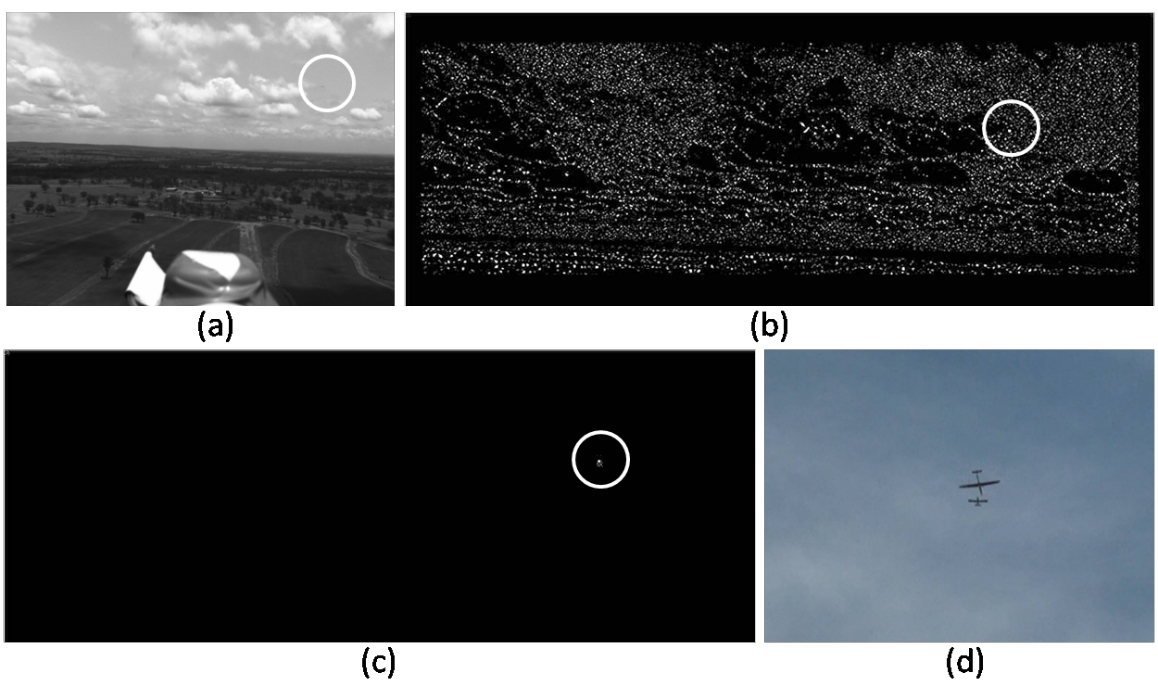

Figure 2. (a) Image captured from the UAS with target aircraft circled; (b) Output from morphology filtering stage (note the large number of false targets); (c) HMM filter output with target aircraft circled; (d) Photo captured from the ground showing a head on collision scenario between the UAS (~50ft vertical separation).

The refined algorithms are to be flight tested in May 2010. The controlled tests will involve flying the DSA payload on the ARCAA Airborne Systems Laboratory (ASL). The ASL is a custom-modified Cessna 172R flight test aircraft (further described in Section 4.4). The ASL will be flown in a number of controlled closure scenarios with another Cessna 172 target aircraft. The initial scenarios, which were developed in consultation with external aviation safety experts, only consider interactions between the two aircraft in head on closure scenarios. The DSA system is coupled to the autopilot on board the ASL, and on detection of the target aircraft, the DSA system issues a fixed heading command directly to the autopilot. The closure scenarios are designed to ensure separation minima (horizontal and vertical) are maintained irrespective of the output of the DSA payload under test. The focus of the initial tests is on the performance of the detection and tracking stages of the DSA system. Testing to be completed in late 2010 will explore different decision making and maneuver generation approaches.

3.2 Static Sense-and-Act System

A second challenge to the safe and efficient operation of manned and unmanned aircraft is the detection and avoidance of static obstacles such as tall buildings, trees and power lines. This is a particular risk for fixed-wing aircraft performing low-altitude operations (*e.g.,* crop spraying) and helicopter operations such as search and rescue, power line inspection, or lifting and winching operations. The system could also be customized to support safe aircraft ground-movements (*e.g.,* detection of animals and obstacles on taxiways, *etc.*).

3.2.1 Smart Skies Static Sense-and-Act System

One of the objectives of the Smart Skies project is to develop an autonomous Static Sense-and-Act (SSA) system which is capable of detecting and avoiding static ground-based obstacles and which can also be used to support infrastructure inspection tasks (*e.g.,* the inspection of a power pole or tall building).

ARCAA researchers are currently exploring the use of an integrated Light Detection And Ranging (LIDAR) and stereo-camera solution as the primary detection sensors for the SSA system. The LIDAR is a Hokuyo UTM-30LX laser scanner which is capable of detecting obstacles out to a maximum range of ~30m within a 270° field of view and at 40 Hz scan rate. A Videre Design stereo-camera system is used as the vision payload. This system has a 46° x 35° field of view and is capable of processing 640px by 480px images at 25Hz.

The integrated detection solution aims to exploit the advantages of both sensors. The LIDAR is an active system that can provide accurate range information on a detected obstacle. However, a disadvantage is that the detection distance and the accuracy of range information is a function of the power and consequently trade-offs exists between performance, weight and available power. The sensitive mirrors and optics found in scanning lasers are also sensitive to vibration and shock [14]. Alternatively, a stereo vision system is relatively light weight, power efficient (as it is a passive system) and can provide range information across the entire field of view of the cameras at a high update rate. However, the performance of the system is dependent on adequate texture and lighting in the scene, and the range accuracy decreases with distance squared from the camera [14]. Another disadvantage is that a stereo vision solution can require additional hardware to process the images and to extract obstacle information. Research is also being conducted to overcome some of the lighting-related issues with stereo vision. For example, techniques have been developed to increase the effective dynamic range of the stereo system [15]. The output of the integrated LIDAR-Stereo camera detection system is a 3D occupancy map. An example of such a map showing that a scaffold structure has been detected is shown in Figure 3d. Using the situational awareness provided by the detection system, the shortest collision-free path is determined using a probabilistic roadmap and D* Lite graph search algorithm [14].

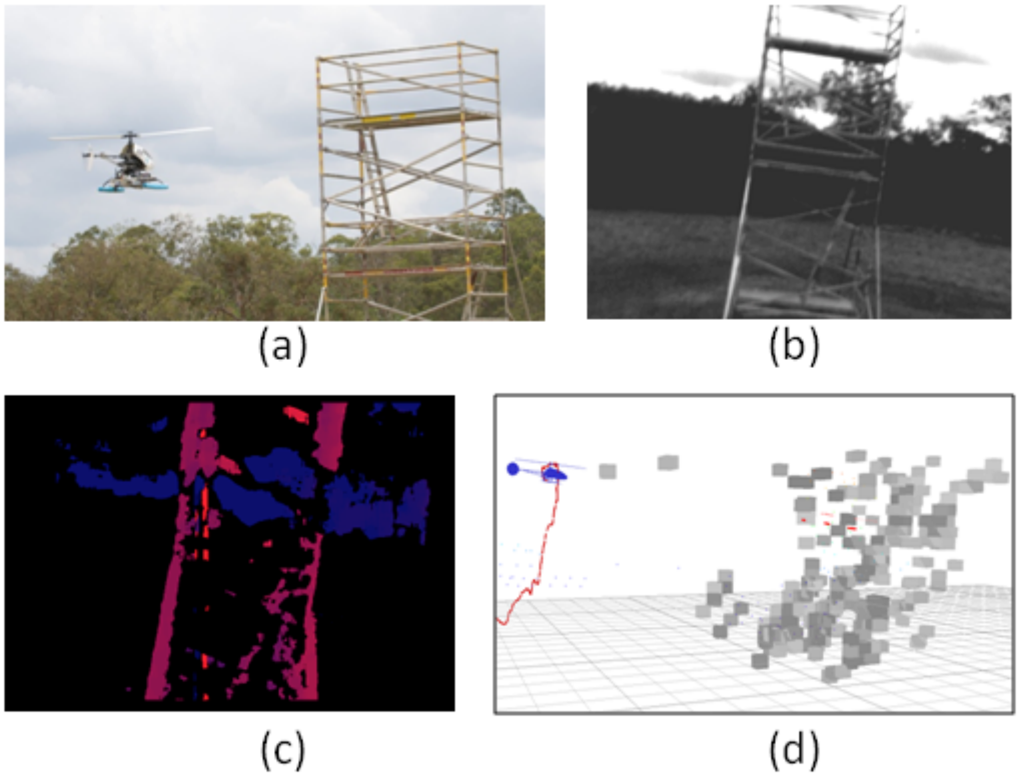

Figure 3 – a) ARCAA Heli approaching the static target; b) Image captured by onboard camera; c) Disparity image generated by stereo images; d) Output 3D occupancy map.

3.2.2 SSA Flight Testing

The primary flight test platform for the SSA payload is the ARCAA autonomous unmanned helicopter. The ARCAA Heli is based on a remote control helicopter powered by a 23cc two-stroke engine, with a 1.78m rotor diameter, a MTOW of 12.3kg, and an endurance of up to 55 minutes (shown in Figure 4 with the SSA payload fitted). The automation of the helicopter platform (*i.e.,* the design of the flight management system, autopilot, and ground control station) was completed in-house.

Initial data collection flight tests were conducted in December 2009. The objective of this flight test campaign was to capture sensor data (*i.e.,* vision-only, LIDAR-only, and fused) for a range of obstacles (*i.e.,* the number, size and texture of obstacles) and obstacle-closure scenarios (*i.e.,* the speed, altitude, and orientation of approach). Over 50 datasets were captured. Figure 3 shows some example data for one flight test scenario. Figure 3a shows the ARCAA Heli approaching an obstacle, Figure 3b shows a sample image captured by one camera, Figure 3c shows the disparity map generated using the images from both cameras, and Figure 3d shows the 3D occupancy map generated by the fused LIDAR and stereo-camera data.

Testing of the dynamic exposure control algorithms was also completed for a range of lighting conditions. Post-processing of the collected data will be used to determine the optimal sensor configuration and to further refine the detection algorithms in preparation for closed-loop testing to be completed in March 2010.

Figure 4 – The ARCAA autonomous unmanned helicopter with integrated SSA payload

4 Automated Separation Management System

Increased automation of Air Traffic Management (ATM) services aims to reduce the workload of air traffic controllers and improve airspace utilization while maintaining or exceeding current safety levels. One of the objectives of the Smart Skies project is to explore the development of an Automated Separation Management System (ASMS) that can be used to improve the efficiency and flexibility of ATM for future Class G airspace environments. It is envisaged that this airspace environment would be highly dynamic and contain a complex mix of airspace users, both manned and unmanned. In addition, the airspace is likely to contain a mix of cooperative, semi-cooperative and non-cooperative airspace users, as well as users whose position and intent are not known *a-priori* to a separation conflict scenario being encountered. Such airspace represents one of the more challenging ATM environments.

The prototype Smart Skies ASMS provides an automated separation assurance service to complex and highly dynamic airspace (illustrated in Figure 5 and further described in Ref.[16]). The three primary components of the architecture are discussed in the following sections.

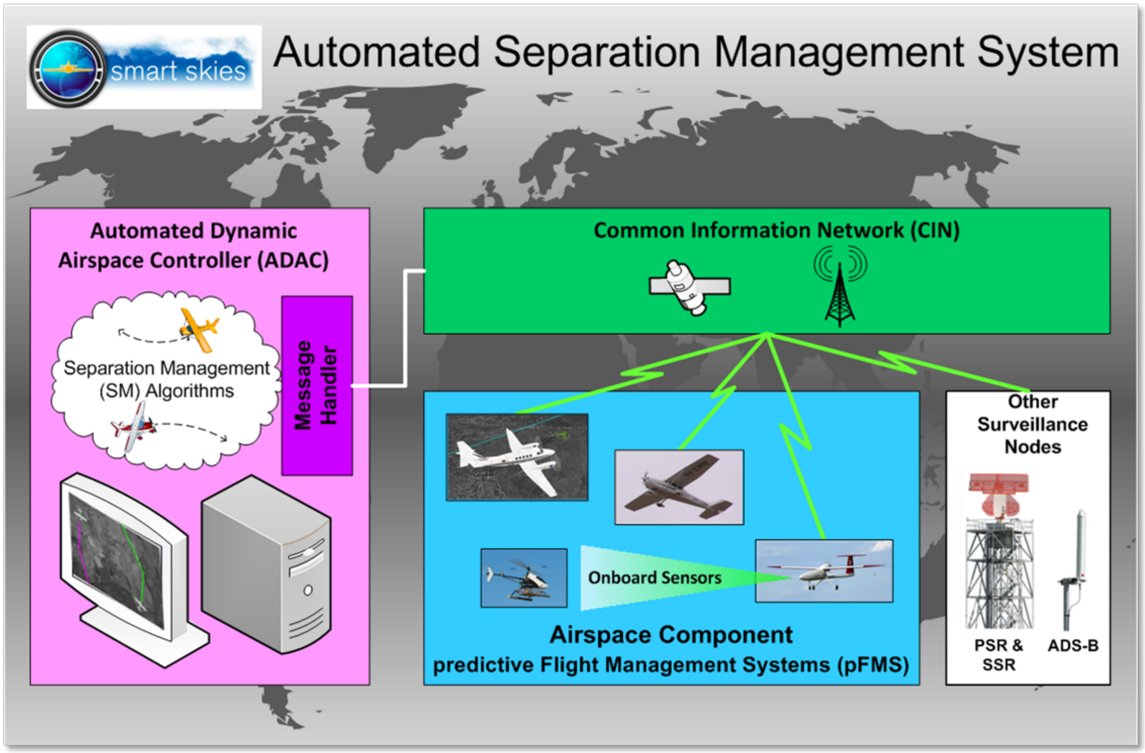

Figure 5 – The Smart Skies Automated Separation Management System Concept

4.1 The Automatic Dynamic Airspace Controller (ADAC)

Central to the ASMS architecture is the Automatic Dynamic Airspace Controller (ADAC) developed by researchers at BR&T. The primary functionality of the ADAC is: a) To continually maintain situational awareness of the state of the airspace system by receiving aircraft tracking information and changes within the airspace environment (*e.g.,* weather, dynamic/temporary airspace activations *etc.*); b) Monitor the airspace system state, and if necessary, transmit recommended control information to cooperative airspace users where there is the potential for a Loss of Separation (LOS).

The Message Handler (MH) provides the lower-level ADAC interface functionality (*i.e.,* manages communications links and message encoding/decoding *etc.*). The Separation Management (SM) software component monitors current and future aircraft separation distances, determines and issues recommended modifications to aircraft trajectories to ensure adequate separation between aircraft. The term *Dynamic* in ADAC implies that aircraft are not necessarily constrained to fly pre-approved flight plans, or to fly in designated airspace corridors, or that the airspace system/environment itself is static (*e.g.,* activation of special use airspace, weather or the loss of a particular communications network). The SM determines safe separation distances based on latency-compensated information on the airspace environment, the performance of the air traffic management system (*e.g.,* availability, bandwidth, and latency of communications), the type and performance of aircraft and on the quality of the aircraft trajectory data. The ADAC also comprises a visualization tool.

As illustrated in Figure 5, the ADAC can receive and process other sources of situational awareness such as that provided by ground-based PSR, SSR, ADS-B, or other sensors onboard cooperative aircraft.

4.2 The Common Information Network (CIN)

The backbone of the ASMS architecture is the Common Information Network (CIN). The CIN provides the communications infrastructure to network aircraft and other sensors (*e.g.,* surveillance and weather) to the ADAC. The CIN functionally enables multiple communication channels between cooperative aircraft (suitably equipped) and the ADAC. The CIN supports a global ASMS architecture where the ADAC does not need to be geographically co-located with the managed airspace. Further, the architecture can support multiple redundant and geographically distributed ADAC systems.

4.3 The predictive Flight Management System (pFMS)

To enable communication with the ADAC, all participating aircraft require a flight management system modified with a predictive capability; referred to as a predictive Flight Management System (pFMS). The pFMS functionality includes: Estimation of current and future aircraft states (position, attitude, time and uncertainties); Management of the multiple communications links comprising the CIN; Receiving, loading and execution of ADAC generated commands; the intelligent management of onboard sensors and sensor information (such as the DSA systems); and the display of information. Aircraft-based sensor information can also be sent to the ADAC. The pFMS facilitates a mixed centralized/decentralized ASMS architecture. In a centralized mode of operation, the ADAC provides separation assurance to aircraft, however should this service fail (*e.g.,* due to system failures or due to the detection of a non-cooperative airspace user, *etc.*) the pFMS onboard the aircraft can operate in a decentralized mode, providing separation assurance using the localized situational awareness obtained from onboard sensors and other available surveillance nodes (*i.e.,* the MATS).

4.4 ASMS Flight Testing

A prototype ASMS architecture has been developed and fielded to explore the different functional and performance aspects under real world operating conditions. This prototype architecture is illustrated in Figure 6.

Two existing communications systems are currently being explored as part of the CIN: the Iridium™ Satellite System and the Telstra™ Next Generation (3G) cellular system, referred to as NextG™. The two communications systems are markedly different in performance in terms of their coverage, latency, drop outs, and bandwidth. One of the broader objectives is to better understand the overall performance of the ASMS with variations in the performance of the underlying communications networks comprising the CIN.

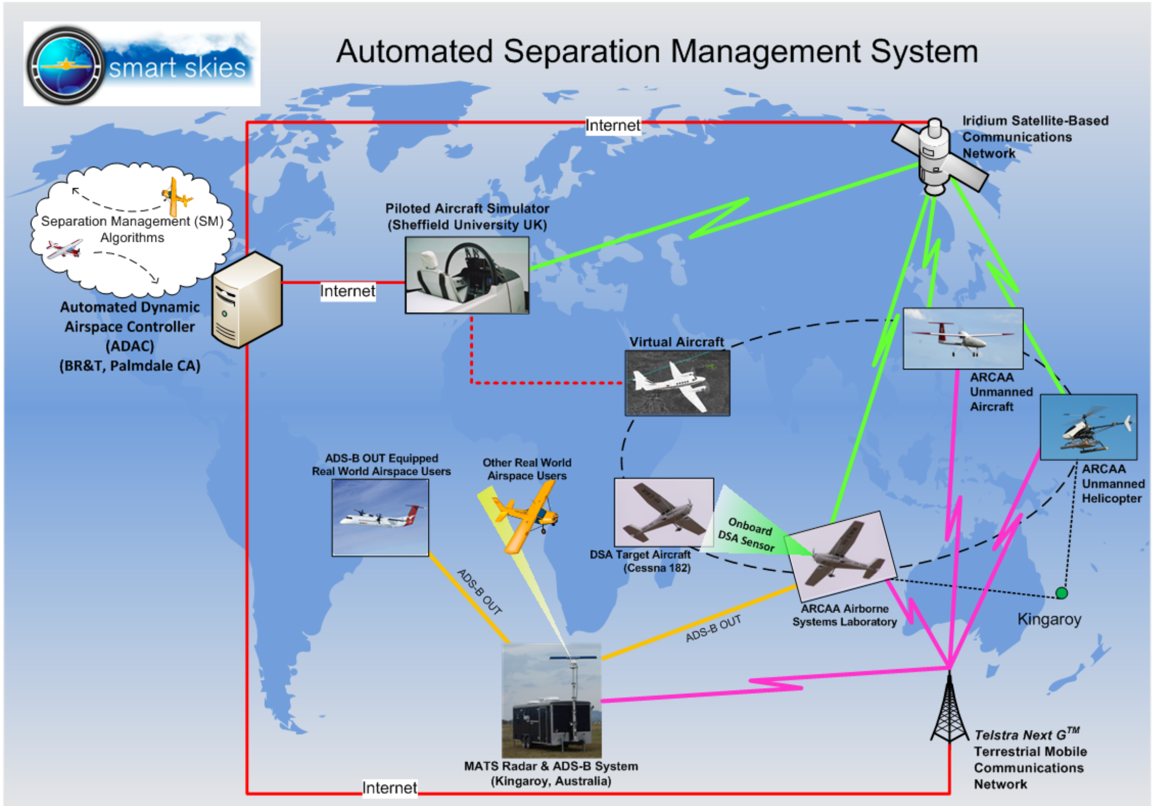

Figure 6 – The ASMS Architecture

Three flight test aircraft are used as part of the test architecture. The primary test aircraft is the ARCAA Airborne Systems Laboratory (ASL). The ASL is a custom modified Cessna 172R, with integrated pFMS, custom cockpit display and onboard aircraft state-data logging system. The ASL can be manually flown by a pilot or lateral trajectory commands can be autonomously fed directly into the autopilot from the pFMS. The ARCAA fixed wing UAS and ARCAA Helicopter UAS are also fitted with a pFMS and are flown under full autonomous mode of operation with the ADAC trajectory commands being fed directly into the autopilots. The unique flight dynamics of the helicopter also provide another dimension of complexity to the conflict scenarios. All flight testing is conducted near the township of Kingaroy, Queensland, Australia.

In addition to the flight test aircraft, up to 50 simulated aircraft are also used to support the safe execution of a range of conflict scenarios. These simulated aircraft are provided by the BR&T flight simulation capability situated in Sheffield University UK, described in Ref. [17].

The Smart Skies project has adopted a phased flight testing approach which aims to progressively develop and explore the performance of the ASMS illustrated in Figure 7. For Phase Three Flight Trials (P3FT) the ADAC was situated in Palmdale California and a range of collision scenarios were flown with each scenario exploring different conflict parameters (*e.g.,* communications, data quality and rate, conflict geometry, conflict closure rate, and the number, type and degree of cooperation of aircraft, *etc.*). Some results from earlier flight testing campaigns are described in Refs. [16, 18]. A screen capture of the ADAC display showing the results for an actual flight test scenario between the ASL and a simulated Cessna is shown in Figure 7. The ADAC display depicts the two aircraft, their conflicting flight plan trajectories (indicated in pink) and the 'resolution' trajectories issued by the ADAC (indicated in blue). Note that the aircraft with ID (AID) six is the ASL, which is being flown in Australia (closer in screen). More recent flight trials have demonstrated the successful integration of MATS aircraft track data into the ASMS.

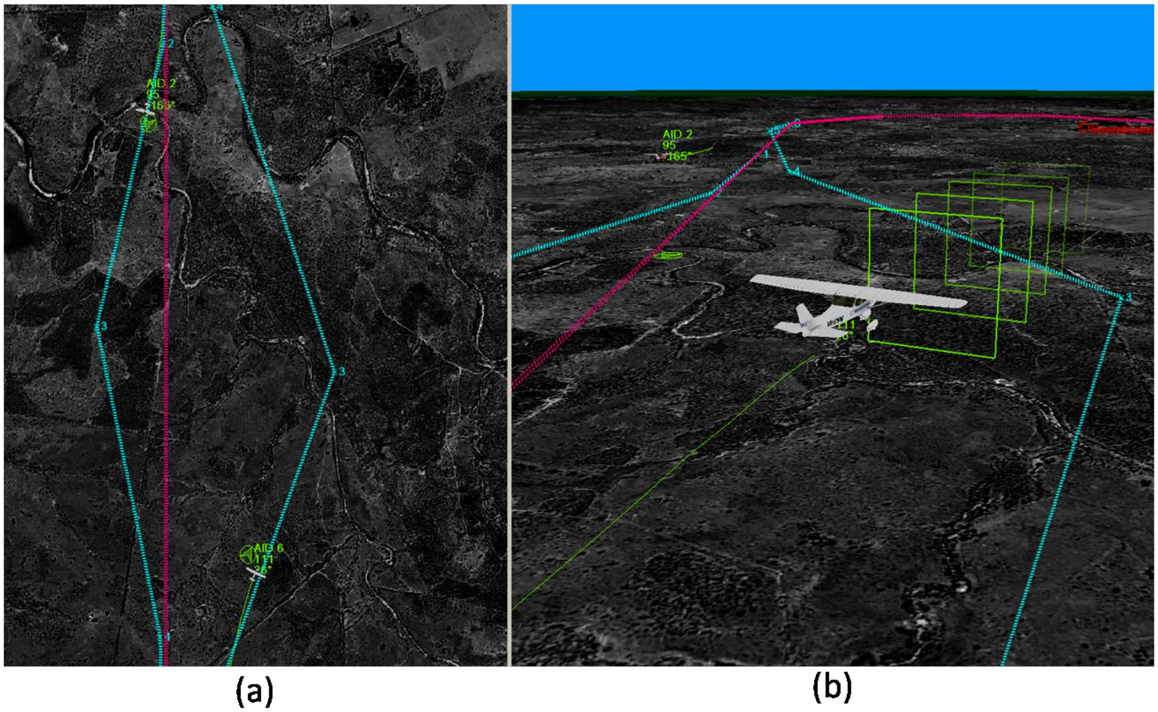

Figure 7 – Plan view (a) and side view (b) of a head on collision flight test scenario between the ASL and a simulated aircraft

5 Future Direction

The Smart Skies project aims to explore the development of future technologies, which can potentially improve the efficiency, utilization and safety of airspace operations for both manned and unmanned aircraft. This paper has provided but a brief snapshot of the ongoing research being conducted. The phased development and testing program continues to build on system capabilities with a further four flight trial campaigns scheduled for 2010. These trials will explore the progressive integration of the MATS and DSA systems into the ASMS architecture (as illustrated in Figure 6). In addition, BR&T and ARCAA researchers are also exploring the performance of a range of different separation management algorithms [19] and the impact of communication failures on separation performance [20], respectively.

The focus of this paper has been on the enabling technologies; however an important objective of the Smart Skies project is to relate the lessons learnt to airspace users, ANSPs, industry and aviation regulators. In realizing this objective, Smart Skies personnel have maintained an active role in regulatory development initiatives such as the Australian Aerospace Industry Forum Certification and Regulation Working Group UAS Sub-committee and industry education and broader advocacy groups such as Association for Unmanned Vehicle Systems International. Such activities are an essential component to the progression, acceptance and adoption of increased levels of automation in the aerospace industry.

6 Acknowledgement

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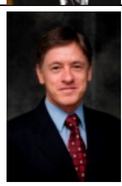
7 Biographies

	Reece A. Clothier is the Smart Skies project manager at ARCAA. He has a B.E. (AeroAv) and is a Ph.D. candidate at QUT. His primary research interests are in the area of aviation risk management, regulation and complex aviation systems.
	Richard Baumeister has a B.S., M.S. and Ph.D. in Mathematics and Physics from the University of Arizona. After a brief stint as Assistant Professor of Mathematics at Arizona State University, Rich joined the Boeing Company in 1979 and has since worked on several Boeing successful Aircraft, Missile and Spacecraft programs. Current research interests include Automated Control of Aerial Platforms and Quantification of Airspace Complexity.
	Dr Michael Brünig is the Research Director of CSIRO's strategic research program in Sensors and Sensor networks. Dr Brünig obtained his Ph.D from RWTH Aachen University, Germany and he holds an Adjunct Professor appointment with the University of Queensland. Dr Brünig has worked in high tech areas in Europe, the USA and Australia. Before working for CSIRO, he was with Robert Bosch Corp., USA, where he lead a research program that connected technology scouting with the company's strategic interests.

	Andrew Duggan is the Managing Director of Insitu Pacific Pty Ltd. Insitu Pacific are the primary industry partner for Smart Skies and provide the hardware components for the MATS System. Future experimental phases will see Insitu Pacific support trials with the ScanEagle UAS. Andrew has a B.Ec from UT and has been working in the UAS industry in a variety of roles for 6 years. Prior to that he spent 7 years serving as an Australian Army officer in Intelligence and Electronic Warfare
	Jonathan Roberts has a B.E. in Aerospace Systems and a Ph.D. from the University of Southampton. Jonathan has extensive research experience in the field of robotics, particularly in mining automation, machine vision and autonomous aerial systems. Jonathan is the Research Director of the CSIRO Autonomous Systems Lab where he continues to further his research interests in the development of highly autonomous robotic systems.
	Rod Walker is the CEO of ARCAA and a Professor at Queensland University of Technology. He has a B.Eng, B.AppSci and Ph.D. from QUT. He is a private pilot with aerobatic endorsement. Rod has previously worked on spacecraft systems but in the last decade his research interests have turned towards aerial robotics and automation in the aviation industry.
	Michael Wilson holds a Ph.D. in physics from The University of Queensland, Australia. He is currently a Senior Researcher at Boeing Research and Technology Australia, specializing in advanced applications of unmanned aircraft systems.

8 Glossary

ADAC	Automated Dynamic Airspace Controller
ADS-B	Automatic Dependent Surveillance – Broadcast
ARCAA	Australian Research Centre for Aerospace Automation
ANSP	Air Navigation Service Provider
ASL	Airborne Systems Laboratory
ASMS	Automated Separation Management System
ATM	Air Traffic Management
BR&T	Boeing Research & Technology
CASA	Civil Aviation Safety Authority
CIN	Common Information Network
CO_2	Carbon Dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUAS	CSIRO Unmanned Aircraft System
DSA	Dynamic Sense and Act
HMM	Hidden Markov Model
IPL	Insitu Pacific Limited
LIDAR	Light Detection And Ranging
LOS	Loss Of Separation
MATS	Mobile Aircraft Tracking System
MH	Message Handler
P3FT	Phase Three Flight Trials
pFMS	Predictive Flight Management System

PSR	Primary Surveillance Radar
QUAS	QUT Unmanned Aircraft System
QUT	Queensland University of Technology
RF	Radio Frequency
SSA	Static Sense and Act
SM	Separation Manager
SSR	Secondary Surveillance Radar
UAS	Unmanned Aircraft System
VLJ	Very Light Jet
VMC	Visual Meteorological Conditions

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