AIR TRAFFIC SURVEILLANCE IN REMOTE AND OCEANIC AIRSPACE USING ORBITAL DETECTION OF AUTOMATIC DEPENDENT SURVEILLANCE — BROADCAST (ADS-B) SIGNALS

R. Francis, Royal Military College of Canada. (*Now at*: Centre for Planetary Science and Exploration, University of Western Ontario, Department of Electrical and Computer Engineering, London, Ontario, Canada, N6A 5B7, rfranci8@uwo.ca)

Introduction: The continuing increase in commercial aviation traffic has prompted airspace authorities to take measures to increase the capacity and ensure the safety of flight in increasingly crowded airspace such as the North Atlantic region. Current radar surveillance cannot track aircraft beyond sight of land, requiring traffic over the ocean to use inefficient and imprecise procedural techniques to provide separation. Provision of continuous surveillance in this airspace would increase safety and security of air traffic, as well as allowing aircraft to follow more direct routes, saving time and fuel and reducing engine emissions. Such a system could also be used over land, for example in Canada's high arctic, where large areas without air traffic surveillance currently exist.

As a potential source of continuous surveillance, the possibility of using the Automatic Dependent Surveillance – Broadcast (ADS-B) system for monitoring air traffic from orbit is examined. Experimental work is described which successfully demonstrated reception using a stratospheric balloon of ADS-B signals sent over the 1090 MHz Extended Squitter system. A model is developed of the signal propagation from aircraft to satellites in various orbits, including atmospheric effects. The resulting power level at the orbital altitude is used to determine the net receiver gain needed to reliably detect the signals from orbit. The effect of signal collisions is modeled and resulting design parameters determined. ADS-B signals are concluded to be detectable with reasonable receiver gain at both LEO and GEO altitudes. The potential for a satellite system to implement ADS-B based surveillance is discussed [1].

Background on Air Traffic Management: An essential function of Air Traffic Services (ATS), including Air Traffic Control and other entities, is the management of air traffic in such a way as to prevent collisions between aircraft. This is termed the provision of 'separation' [2]. In order to provide this service, ATS relies on position information for aircraft in a given parcel of airspace. Historically, ATS has relied on radar surveillance to provide this position information. However, due to the cost and complexity of radar installations, large areas of land exist without radar coverage, for example in remote northern Canada [3]. As well, radar coverage is not available over the open ocean. In these areas, control of air traffic has either not been possible, or has relied on 'procedural separation', wherein aircraft are assigned designated positions, altitudes, and timings, and required to routinely report their positions by radio [4]. This technique requires the use of standardized waypoints for ocean-crossing aircraft, lengthening their flights compared to great-circle routes with resulting increases in flight time, fuel consumption, and engine emissions. These issues, as well as the navigational uncertainties associated with procedural separation [5] and the increasing crowdedness of some oceanic airspace have prompted an interest in new ways of providing surveillance and separation in remote and oceanic airspace.

Automatic Dependent Surveillance – Broadcast (ADS-B): An alternate method of providing aircraft position data is by ADS-B, in which aircraft continually transmit their identity and navigational information. Such signals are received by ground stations and relayed to ATS where they are used to supplement radar data. They can also be received by other aircraft to allow aircrews knowledge of nearby traffic.

ADS-B has the advantage that the ground stations are less complex and have lower power requirements than radar installations, and so a network of such surveillance can be installed in remote areas for lower cost [6]. Such networks have already begun implementation in Canada and elsewhere [7]. However, ground stations cannot be installed in mid-ocean, leaving a coverage gap for oceanic airspace.

Orbital surveillance: A possible solution for surveillance in oceanic airspace, or indeed over land, is the monitoring of aircraft-transmitted ADS-B signals using satellite-borne receivers. To investigate this possibility, work was undertaken to determine the detectability of such signals from orbit.

Stratospheric balloon experiments. The implementation of ADS-B selected for use in Canada, Europe, Australia, and the United States, called the 1090 MHz Extended Squitter (1090 MHz ES), defines an antenna pattern with a null directly above the aircraft. To demonstrate and characterize the detectability of the signals from above, two stratospheric balloons carrying 1090 MHz ES receivers were flown. These trials, called the *Flying Laboratory for Detection of ADS-B Transmissions* (FLOAT), successfully detected ADS-B signals from altitudes of over 28 km, including from aircraft very near the nadir position, as well as at ranges over 500 km [1][8].

Orbital detection analysis. A signal propagation model of the 1090 MHz ES transmission from an aircraft to a satellite has been developed, which accounts for the aircraft-to-satellite geometry as well as atmospheric effects on the signal. These latter include attenuation in the neutral atmosphere and in clouds and precipitation, refraction, ionospheric effects, and scintillation. As well, the Doppler effect is calculated for all cases. Finally, the possibility of signal collisions – obscuration due to simultaneous reception of signals from multiple aircraft – is investigated.

Results. The signal propagation model gives, as an output, the normalized signal-to-noise ratio of the signal at the position of the satellite, expressed as bit energy per noise (Eb/No). This allows direct reading of the gain margin in the aircraft-to-satellite link, excluding gains or losses in the receiver. From this the net receiver gain required to reliably detect the signal can be determined. For Low Earth Orbiting (LEO) satellites, net receiver gains of 0-5 dB were found necessary; at geostationary orbit (GEO), 30 dB are required. LEO receivers would have a circular coverage region several hundreds of kilometers in radius (dependent on altitude), with a central null of a few tens of kilometers in which aircraft cannot reliably be detected. At GEO, a receiver would have very large coverage areas, and a central null of thousands of kilometers radius. With a 30 dB gain, a single satellite at 100° W longitude could cover all of Canada (with the exception of the northern tip of Ellesmere Island), along with the oceanic airspace for which Canada has responsibility, virtually the entire United States, the bulk of Brazil, and many other areas. A second receiver spaced in longitude could cover Europe and provide continuous surveillance across the North Atlantic airspace.

The Doppler effect for both LEO and GEO cases is found to be several orders of magnitude lower than the frequency variance allowed within the 1090 MHz ES standard [9].

A statistical model of the signal collisions is developed, and suggestions are made for techniques to address the high rate of collisions which can occur for satellites with wide fields of view containing large aircraft populations.

Mission implications: Numerous features of the ADS-B system lend it to an orbital implementation. ADS-B receiver equipment is comparatively low in mass and power requirements, having been carried routinely on aircraft for many years, and experimentally on balloon payloads. As well, the technology already exists, and needs only be adapted for spaceborne use, not developed. A key advantage is that it allows a new surveillance capability without requiring new equipment aboard aircraft, easing the cost of adoption and of integration with existing ATS systems.

The nature of the satellite coverage – moving and near-global at LEO, covering broad swathes of the globe at GEO – implies both that the system implementation can be staged for validation and cost reasons, and that international co-ordination, as already exists in aviation standards and intercontinental traffic management, is a likely avenue for deploying an eventual operational system.

Conclusion: ADS-B from orbit provides a potential technique for expanding surveillance of remote areas of Canada, including arctic regions seeing an increase in commercial aviation traffic, as well as in increasingly crowded airspace. Provision of surveillance in these regions has the potential to increase the safety, security, and efficiency of air traffic, with additional benefits in cost and environmental effects of aviation. Experimental work has demonstrated the detectability of ADS-B signals from stratospheric platforms, and theoretical analysis shows they can be detectable from orbit with receiver gains obtainable from realistic systems. An orbital ADS-B system has additional advantages in ease of implementation, low payload demands, and high technical maturity.

Acknowledgements: Significant assistance and supporting data was provided by Chris Burridge at Nav Canada, for which the author is particularly thankful. Funding was provided primarily by Defence Research and Development Canada. Thanks are also due to Transport Canada, and to several airlines including Air Canada, WestJet, and Continental Airlines, for providing details of their ADS-B equipage. Several staff and students at the Royal Military College of Canada provided assistance with the experimental work and review of the theoretical results.

References: [1] This work is discussed in detail in Francis R. (2010), *Detection of Automatic Dependent Surveillance – Broadcast signals using stratospheric and orbital platforms*. Master's thesis, Royal Military College of Canada. [2] Transport Canada (2009). *Aeronautical Information Manual*. 2009-2 edition. TP 14371E. [3] Nav Canada (2010). *Designated Airspace Handbook*. Issue No, 215, TP 1820E. [4] International Civil Aviation Organization (ICAO) (2009) *NAT ASM*: *Application of Separation Minima - North Atlantic Region* V-3.0(2009) [5] ICAO North Atlantic Systems Planning Group (NAT SPG) (1999). *North Atlantic Region Air Traffic Management Concept of Operations. Version 0.34*. [6] ICAO (2003). *Operational use of ADS-B in Non Radar Airspace: Generic design safety case.* [7] Wright G. (2009), in *9th ICNS*. [8] Francis R. et al. (2009) in *CSS 2009* [9] RTCA Inc. (2009) DO-260B *MOPS for 1090 MHz ADS-B / TIS-B*.