Effect of ADS-B Characteristics on Airborne Conflict Detection and Resolution

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***Abstract*—Most Free-Flight concepts rely on self-separation by means of airborne Conflict Detection and Resolution (CD&R) algorithms. A key enabling technology for airborne CD&R is the Automatic Dependent Surveillance-Broadcast (ADS-B) system, which is used for direct state information exchange between aircraft. Similar to other communication systems, ADS-B is affected by a number of limitations which can be broadly classified as system and situation related deficiencies. This research investigates the impact of these limitations on the viability of using ADS-B for airborne CD&R within the Free-Flight context. Here, 'state-based' conflict detection and the modified voltage potential conflict resolution algorithm are used as a case-study. An ADS-B model is developed, and its effect on the aforementioned CD&R method is measured using three fast-time simulation experiments. The experiments studied overall safety with ADS-B, as well as the specific effect of situation related characteristics, i.e., transmission range and interference, on safety. The results indicated that the overall safety with ADS-B was comparable to the case where perfect state information was assumed. Additionally, it was found that increasing ADS-B transmission range also increased signal interference, which in turn lowered safety. This suggests that the degrading effect of ADS-B signal interference should be considered in future airborne CD&R research, particularly for high traffic densities.**

***Index Terms*—ADS-B, Free Flight, Conflict Detection and Resolution (CD&R), Modified Voltage Potential (MVP), Air Traffic Management (ATM), Safety, Self-Separation, BlueSky ATM Simulator**

I. Introduction

The Free-Flight Air Traffic Management (ATM) concept has been proposed as a means of increasing airspace safety, efficiency and capacity by permitting user defined trajectories [1], [2]. Most Free-Flight concepts rely on self-separation using airborne Conflict Detection and Resolution (CD&R) automation. As airborne CD&R requires information sharing between aircraft, a system for inter-aircraft communication is required. In Free-Flight literature, this information sharing is often achieved using the Automatic Dependent Surveillance-Broadcast (ADS-B) system. Aircraft equipped with ADS-B transmitters periodically broadcast their own state information, such as position and velocity, using data obtained from on-board sensors. Aircraft can also receive this information from neighboring traffic, which can in turn be used for detecting and resolving conflicts [3].

Similar to other data-link systems, ADS-B has a number of limitations that affect the quality of the transmitted and received information. These limitations can be broadly classified as system and situation related deficiencies. System related limitations affect the accuracy of the transmitted state information. This is not only affected by the accuracy of on-board sensors, but also by the number of bits available for (digital) data encoding. On the other hand, situation related deficiencies reduce ADS-B message detect and decode probability due to the distance between aircraft and due to signal interference [4]. Previous researchers have modeled these situation related effects, discussed in [4], [5].

Despite these limitations, much of the previous work on airborne CD&R, particularly studies related to the development of novel conflict resolution methods [1], [6], have assumed perfect state information exchange between aircraft. Thus, it is as yet unknown whether the ADS-B system is actually capable of providing usable state information for airborne CD&R purposes. Furthermore, the extent to which the safety of CD&R methods is affected by ADS-B limitations is also unknown.

The research that is presented in this paper represents the initial work done towards understanding the effect of ADS-B on self-separation safety by focusing on one particular airborne CD&R method. Given the plethora of CD&R methods, the frequently used 'state-based' Conflict Detection (CD) method, and the Modified Voltage Potential (MVP) Conflict Resolution (CR) algorithm, have been selected as a case-study. An ADS-B model is developed, and its effect on state-based CD and the MVP CR algorithm are measured using three fast-time simulation experiments. The goal of the first experiment is to determine the overall safety with ADS-B. To this end, an ABS-B system based on Minimum Operational Performance Specifications (MOPS) [7] is compared to one that is based on measured actual performance [8], and to the case where perfect state information is used. The second and third experiments focus on the specific effect of situation related characteristics, i.e., transmission range and interference, on safety.

This paper is organized as follows. An overview of the Automatic Dependent Surveillance-Broadcast (ADS-B) system and its model derivation is described in Section II. Details of the three experiments used to study the safety impact of ADS-B, as well as a description of the Conflict Detection & Resolution (CD&R) method used are presented in Section III. The results are presented and discussed in Section IV. This paper ends with the main conclusions in Section V.

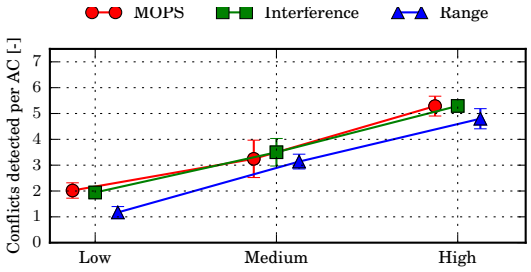

Figure 15. Number of detected conflicts per aircraft.Experiment - III.

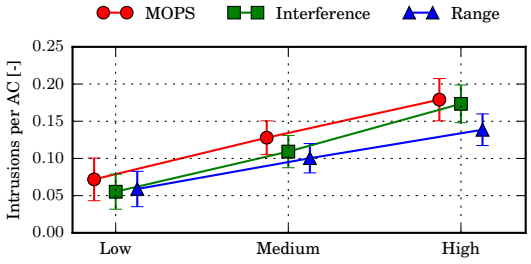

Figure 16. Number of intrusions per aircraft.Experiment - III.

to using perfect state information. This is partly due to the look-ahead time of 5 minutes, resulting in a detect and decode probability close to one. Also the position accuracy is high with respect to the dimensions of the IPZ. However, the interference effect should be taken into account. A larger transmit power increases the number of aircraft within range causing interference. Additionally, the impact of each aircraft increases, due to the higher transmitted power level. Also in the sensitivity analysis (Experiment - III) the effect of interference became larger at higher traffic densities. The detect and decode probability decreases with increasing number of aircraft according to the Poisson distribution. Additionally an increase in maximum reception range (i.e. transmit power) decreases the interference probability even further. Since significant ATM research efforts are devoted towards increasing airspace capacity, it is necessary to consider the impact of ADS-B signal interference when these higher densities are realized.

V. Conclusion

In this paper, an ADS-B model based on system and situation related characteristics was presented. The effect of these characteristics on airborne Conflict Detection and Resolution (CD&R) was studied using fast-time simulation experiments. Here, state-based conflict detection and the Modified Voltage Potential (MVP) conflict resolution algorithm was used as a case-study. For the studied conditions, the following conclusions can be drawn:

- The difference in safety between using ADS-B based state information and perfect state information was small.
- The range analysis showed that the combination of state-based conflict detection and MVP is a very robust CD&R method, even when the maximum range was artificially reduced to $\frac{1}{4}^{th}$ of the ADS-B minimum ADS-B specifications.
- An increase in maximum reception range (by increasing transmission power) decreases the total detect and decode probability. This is because increasing range also increases signal interference as additional aircraft are detected.
- The interference effect becomes more dominant than the range effect for higher traffic densities.
- The ADS-B system should not be considered as a direct limiting factor for self-separation or Free Flight. However, the interference effect at high traffic densities should be taken into account. The use of a single carrier frequency, increase in transmit power and high traffic density increase the interference effect.
- Future research will investigate the effect of ADS-B characteristics on additional CD&R methods and for higher densities.

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