Mid-Air Collision Risk and Areas of High Benefit for Traffic Alerting

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Automatic Dependent Surveillance - Broadcast (ADS-B) will be the basis of the future surveillance system in the US as well as many other countries. One way to create incentives for users to equip with the required ADS-B avionics is to create and implement ADS-B applications that are of high value to the operators. One such application is the airborne traffic alerting application named Traffic Situation Awareness with Alerting (TSAA). As a first step in the development of this application, an analysis of ten years of NTSB mid-air collision reports was conducted to identify areas of high mid-air collision risk. Similarly, ten years worth of ASRS and NMAC near mid-air collision reports were also analyzed. The airport environment is where most mid-air collisions occurred (59% of NTSB reports) and most near mid-air collisions were reported (64% of ASRS reports and 47% of NMACS reports). As such, most benefit from traffic alerting can be gained from alerts in the airport environment. Encounters between Part 121 aircraft and General Aviation were most often reported between a cruising General Aviation aircraft and a Part 121 aircraft transitioning through that same altitude. GA/Part 121 encounters make up 14% NMACS as well as ASRS reports.

Nomenclature

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADS-B</td>
<td>Automatic Dependent Surveillance - Broadcast</td>
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<tr>
<td>ASRS</td>
<td>Aviation Safety Reporting System</td>
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<td>GA</td>
<td>General Aviation</td>
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<td>MAC</td>
<td>Mid-Air Collision</td>
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<tr>
<td>NTSB</td>
<td>National Transportation Safety Board</td>
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<tr>
<td>NMAC</td>
<td>Near Mid-Air Collision</td>
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<tr>
<td>NMACS</td>
<td>Near Mid-Air Collision System</td>
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<tr>
<td>TSAA</td>
<td>Traffic Situation Awareness Application</td>
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I. Introduction

As part of the FAA’s plans for modernization of the Air Traffic Control (ATC) system, Automatic Dependent Surveillance - Broadcast (ADS-B) will be the basis of the future surveillance system in the US, supplemented by the current Radar system. Much of the benefit delivered from ADS-B is dependent on the overall equipage of all the aircraft in the airspace system. Unless a majority of aircraft transmit ADS-B, ATC will have to continue using Radar surveillance. Also, benefit from aircraft-to-aircraft ADS-B applications will be reduced. Therefore, creating incentives for aircraft operators to equip with ADS-B is crucial.

For operators to equip early and voluntarily, the benefit received from the system has to be equal to or greater than the cost of the equipment. One way of creating benefit for users is to create and implement ADS-B applications that are of high value to the operators. One ADS-B application that has been identified by the FAA1 as well as MIT researchers2,6 is Traffic Situational Awareness with Alerting (TSAA).

The initial work presented in this document was conducted to identify where the risk for a mid-air collision (MAC) is highest and thus to identify where a traffic alerting system would be most beneficial.

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II. Methodology

A. Analysis of NTSB Accident Reports of Mid-Air Collisions

NTSB mid-air collision accident reports from January 2000 until June 2010 were analyzed. Reports of accidents outside the US as well as balloon accidents that occurred during that time period were excluded. This resulted in a total of 112 accident reports. The reports did not contain any mid-air collisions involving an aircraft operating under Part 121.

The narrative of each of the 112 reports was reviewed. For each mid-air collision, the horizontal encounter geometry was reconstructed. The description of aircraft heading differed between reports (see Table 1): some reports gave exact headings, others used cardinal directions (North, Southwest, etc.) and others yet only gave descriptions of the relative location of the aircraft with respect to each other. Some reports did not have any Radar data or eyewitnesses available and thus did not have track information at all. To allow for the comparison of the horizontal encounter geometries, the accidents were grouped into bins of 45° based on flight track intersection angle. The 5 groups were centered on the 5 cardinal directions of one half of a compass rose (see Figure 2). In addition to geometry reconstruction, external factors that contributed to the collision were identified (such as the absence or malfunction of equipment).

### Table 1: Format of Heading Information

<table>
<thead>
<tr>
<th>Description of Heading</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Cardinal Directions</td>
<td>19%</td>
</tr>
<tr>
<td>Exact Radar Data</td>
<td>12%</td>
</tr>
<tr>
<td>No Radar Data</td>
<td>7%</td>
</tr>
<tr>
<td>Implied from description on report</td>
<td>62%</td>
</tr>
</tbody>
</table>

The description of vertical motion of the aircraft was much less consistent. Many reports never mention vertical movement while others simply state that the aircraft was climbing or descending. In many cases, however, it was possible to extract at least the relative vertical motion of the two aircraft based on the narratives.

B. Analysis of ASRS and NMACS database Near Mid-Air Collision Reports

In an effort to widen the scope and validate the findings of the NTSB report analysis, Aviation Safety Information Analysis And Sharing (ASIAS) reports categorized as near mid-air collisions were also analyzed. The ASIAS Aviation Safety Reporting System (ASRS) and ASIAS Near Mid-Air Collision System (NMACS) databases were searched for every event classified as a near mid-air collision (NMAC) during the same time period used for the NTSB report analysis. The ASRS database yielded 2,059 reports and the NMACs database yielded 1,527 reports. The reports in the ASRS database contain a set of fields that the individual creating the report fills in as well as a narrative of the event. The reports in the NMACS database contain a similar set of data fields but do not have a publically available narrative.

The data fields were analyzed for the frequency by which a given characteristic appeared. For example, the reported flight phases of the own-ship were plotted versus the reported flight phases of the intruder aircraft.

One interaction that was not observed in the NTSB database was encounters between commercial aircraft and general aviation aircraft. A secondary analysis of GA/Part 121 encounters in the ASRS and NMACS databases was conducted in order to understand the nature of this interaction. Aircraft operating under Parts 91, 135, 137 and 141 were all considered general aviation.

Since the aforementioned databases are voluntary reporting systems, care needs to be taken when interpreting the results. Filing an ASRS report gives the reporter certain protections against possible charges and as such creates a reporting bias toward events where the pilot violated a regulation\(^\dagger\). Also, because of the subjectivity of the reports, the reports “…represent what the reporter believes he/she saw or experienced.”\(^\ddagger\) Lastly, a cross analysis showed that IFR report rates are higher than the percentage of IFR hours flown which indicates some over reporting or higher sensitivity by the IFR population.

\(^\dagger\) The ASRS database website notes: “The existence in the ASRS database of records concerning a specific topic cannot, therefore, be used to infer the prevalence of that problem within the National Airspace System.”\(^\ddagger\)
III. Results

A. Results from NTSB Report Analysis

1. Location Analysis of NTSB accident reports
   All accidents reported in the NTSB database were separated into three categories based on their proximity to the airport (Figure 1). The category defined as “Pattern” only includes accidents with aircraft that were flying the airport pattern with intention to land or having recently departed that same airport. As can be seen, the area surrounding an airport is where mid-air collisions most often occurred (59%). As a single category, the airport pattern was the location with the most accidents (45%). This implies that the Traffic Situational Awareness Application needs to be operational in the area surrounding an airport.

![Figure 1: Percentage of Mid-Air Collisions by Location](image)

2. Geometry Analysis of NTSB accident reports
   The intersect angle between the tracks of the two aircraft for all accident reports is summarized in Figure 2. The own-ship is the aircraft in the center and the intruder aircraft for a given mid-air collision is one of the aircraft along the perimeter of the compass rose. The colors and percentages indicate the frequency at which a given intersect angle was reported. As can be seen, over half (54%) of mid-air collisions occur between aircraft flying in the same direction. No collisions were observed where both aircraft were operating under IFR.

![Figure 2: Track intersect angle summarized for all NTSB mid-air collision reports](image)

To gain a better understanding of the characteristics of encounters based on their location, each of the three environments identified in Figure 1 was analyzed individually. The results are discussed in the following sections.
3. *Detailed Analysis of Mid-Air Collisions Reported in the Airport Pattern*

Out of the 112 reported cases, 50 occurred in the airport pattern. This section analyzes those 50 accidents in more detail. As can be seen in Figure 3, over 80% of the mid-air collisions in the airport pattern happened on final, short final or on the runway. As a result, the track intersection angle most often observed is that of two aircraft going in the same direction. The narratives of these reports paint a similar picture for most of these accidents: two aircraft on approach to the same runway settling into each other as they get closer to the runway. This type of encounter is characterized by a rather small relative velocity which often results in the two aircraft only “bumping” each other. As a result, 31 of the 50 accidents in the airport pattern were non-fatal.

Out of the 50 accidents, 9 (18%) involved at least one aircraft that didn’t have a radio. According to the 2007 FAA Avionics Survey\(^2\), only 2% of the GA fleet did not have a radio installed. 6 accidents (12%) involved at least one agricultural aircraft. According to the FAA Avionics Survey, 5% of GA hours flown are flown by agricultural aircraft.

![Distribution of Mid-Air Collisions in the Airport Pattern](image)

**Figure 3: Location Distribution and Geometry of Mid-Air Collisions in the Airport Pattern**

4. *Detailed Analysis of Mid-Air Collisions Reported in the Airport Vicinity*

A total of 16 accidents happened in the airport vicinity. 9 of those were between aircraft that had identical flight phases, i.e. both aircraft were departing or arriving at the airport. 3 accidents occurred inside the bounds of the airport pattern but the aircraft were not actually flying the pattern. Specifically, one collision was during a race, one during parachute operations and one during practice for an airshow above the airport. The last 4 accidents involved one aircraft that was arriving to or departing from an airport and another aircraft in cruise or performing maneuvers around that same airport. Figure 4 shows the geometry distribution for the accidents reported in the airport vicinity.

![Geometry of Mid-Air Collisions in the Airport Vicinity](image)

**Figure 4: Geometry of Mid-Air Collisions in the Airport Vicinity**
5. Detailed Analysis of Mid-Air Collisions Reported Away from the Airport

A total of 46 accidents occurred away from the airport. The accidents included aircraft that were in cruise as well as aircraft engaging in flight training, surveying, firefighting, EMS transport, aerial application or news reporting (all referred to as “Maneuvering” in Figure 5). As Figure 5 shows, out of the 46 accidents, 24 (52%) happened between two aircraft that were both in straight and level cruise. One fifth (9 accidents) of the accidents away from the airport were between aircraft that were deliberately engaging in close flight such as pilots practicing formation flight or friends going to a similar destination. Those accidents are labeled as “Formation Flight” in Figure 5 and Figure 6.

![Figure 5: Frequency of Flight Phase for Mid-Air Collisions away from the Airport](image)

Of the 46 accidents, 13 (28%) involved at least one aircraft conducting maneuvers such as surveying, firefighting or flight instruction. The intersect angle most often observed is that of two aircraft with perpendicular tracks (29%). This may be due to blind spots resulting from wings and/or window frames out the side of the aircraft. A recurring theme in the narratives (6 cases) was that witnesses or survivors mention sun glare as a contributing factor.

![Figure 6: Track intersection angle for mid-air collisions away from the airport with and without formation flights](image)
B. Results from the ASRS and NMACS Database Analysis

The ASRS and NMACS databases were first evaluated based on the flight phases of the reporting and target aircraft. Reports that included a field left as “unknown” are not shown. Figure 7 and Figure 8 show the near mid-air collision reports for both databases with flight phases on the X and Y axes. The Z axis is the percentage of a given interaction. The flight phases on both axes are aligned such that the diagonal represents the encounters between two aircraft on the same flight phase. In the ASRS as well as the NMACS data, the flight phase interactions most often observed are those of two aircraft on “Initial Approach” (24% and 14% respectively). Note that in the NMACS data “Approach” has one category where in the ASRS data an approach is split into three sub-categories. The second most common interaction was between two aircraft in “Cruise” (11% and 13%, respectively). A review of the ASRS narratives showed that reports with flight phases categorized as “Initial Approach” were most often in the pattern.

![ASRS Database: Flight Phase](image)

**Figure 7:** Near mid-air collisions reported in the ASRS database by respective flight phase. Encounters along the diagonal are between aircraft in the same flight phase.

![NMACs Database: Flight Phase](image)

**Figure 8:** Near mid-air collisions reported in the NMACs database by respective flight phase. Encounters along the diagonal are between aircraft in the same flight phase.

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Both figures underscore the observation made from the NTSB reports that the airport environment is the location where most encounters are reported. Table 2 shows the percentages of encounters reported in the airport environment in the ASRS and NMACS databases. For comparison, 59% of the NTSB reported accidents occurred in the airport environment.

Table 2: Near Mid-Air Collisions Reported in the Airport Environment

<table>
<thead>
<tr>
<th>Database</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>ASRS</td>
<td>64%</td>
</tr>
<tr>
<td>NMAC</td>
<td>47%</td>
</tr>
</tbody>
</table>

Table 3 shows the percentages of encounters by FAR (Federal Aviation Regulation) under which the aircraft were operating. Both databases indicate that encounters between GA aircraft are most common which is consistent with the NTSB mid-air collision data. However, unlike the NTSB data, interactions between GA and Part 121 aircraft were also observed in the near-miss data.

Table 3: NMAC encounters by FAR, ranked by percentage

<table>
<thead>
<tr>
<th>ASRS Database</th>
<th>NMACS Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interaction</td>
<td>Percentage</td>
</tr>
<tr>
<td>GA/GA</td>
<td>44%</td>
</tr>
<tr>
<td>GA/Part 121</td>
<td>14%</td>
</tr>
<tr>
<td>Part 121/Part 121</td>
<td>5%</td>
</tr>
<tr>
<td>At least one aircraft unknown</td>
<td>36%</td>
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The flight phases of the GA/Part 121 encounters were analyzed in more detail and are shown in Figure 9. The largest interaction observed in the ASRS database was between a Part 121 aircraft on “Initial Approach” and a GA aircraft on “Cruise” (20%). The data indicates that the encounters are most likely when the GA aircraft is in cruise and the Part 121 aircraft is in any other flight phase, specifically climbing or descending. This is likely due to Part 121 aircraft often transitioning through altitude layers where GA aircraft would be cruising. Also shown in Figure 9 is the altitude distribution where the GA/Part 121 encounters took place. Again, encounters were most often reported at altitudes that are typical for GA cruising altitudes.

Figure 9: Flight Phase and Altitude Distribution of GA/Part 121 Encounters in the ASRS Database

Figure 10 shows the same GA/Part 121 analysis using NMACS data. Here, the largest interaction was between two aircraft on “Approach” to an airport (12.5%). The encounter between cruising/transitioning aircraft observed in the ASRS data is not as pronounced but can still be observed. The altitude distribution of the NMACS reports shows a distinct second peak around 10,000ft MSL. Upon reviewing the narratives, the low level peak is mostly from VFR
traffic while the mid-altitude peak is from cruising IFR traffic as well as sailplanes. Additionally, the second peak may be a result of increased aircraft velocities due to the airspeed restriction of 250kts below 10,000ft.

![NMACS Database: GA/Part 121 Encounters](image1)

**Figure 10: Flight Phase and Altitude Distribution of GA/Part 121 Encounters in the NMACS Database**

### IV. Discussion and Conclusions

In summary, the airport environment is the location where most mid-air collisions occurred (59%) and where the most near mid-air collisions were reported (ASRS, 67%). Encounters between Part 121 and GA aircraft were most often reported to occur between GA aircraft cruising at a constant altitude and Part 121 aircraft that were transitioning through that same altitude. These interactions are most often observed in two distinct altitude layers: low altitude (1,000 feet to 4,000 feet MSL) and mid-level (9,000 feet to 13,000 feet MSL).

A system that is to provide ADS-B based Traffic Situation Awareness would therefore have to be operational in the airport environment. One major challenge in designing such systems is that the airport environment is a high-density environment with aircraft performing frequent and abrupt maneuvers. Most currently available systems such as TAS or TCAS (transponder based) are of limited usefulness in the airport vicinity because of their high false alarm rate in high-density environments.

ADS-B’s position information is much more accurate than that based on transponders – as a result, it is expected that ADS-B will enable reliable traffic alerting in the terminal area of an airport and even in the airport pattern. This ability has the potential to provide a substantial benefit to General Aviation. ADS-B based traffic alerting would therefore provide significant benefit and an incentive for GA to equip with ADS-B avionics.

### References