<u>RTCA Special Committee 186, Working Group 3</u>

<u>ADS-B 1090 MOPS, Revision A</u>

<u>Meeting #15</u>

Operational Requirements for Ground Vehicles

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SUMMARY

Working Group 3 has been working to define the transmit power requirement for Non-Transponder-Based ADS-B transmitters on Class B2 Ground Vehicles. This Working Paper addresses requirements for ground vehicles only. Aircraft equipage is required to support a different subset of applications, which drive a different set of requirements. Bill Harman has prepared some simulations that characterize the performance of the data link between a vehicle based transmitter on the runway surface and an approaching aircraft. This working paper is intended to provide some of the success criteria needed to interpret the results of Bill's simulations.

Two approaches are presented for developing ground vehicle requirements: 1) analyze the adequacy of 10 Watts in light of the applications that must be supported and 2) analyze the applications that must be supported and suggest ideal values for the requirements.

This working paper addresses action item #14-02.

1 Background

Working Group 3 has been working toward defining the transmit power requirement for non-transponder based ADS-B transmitters on ground vehicles. Bill Harman has prepared some simulations that characterize the performance of the data link between a vehicle based transmitter on the runway surface and an aircraft in the terminal area. To date, the working group has not identified the success criteria for these simulations. The success criteria should be based on the operational needs of pilots. This working paper analyses the operational needs of pilots with a special focus on Final Approach and Runway Occupancy Awareness (FAROA).

Two approaches are presented for developing ground vehicle requirements: 1) analyze the adequacy of 10 Watts in light of the applications that must be supported and 2) analyze the applications that must be supported and suggest ideal values for the requirements. The first of these approaches is motivated by the fact that Sensis has developed and tested a 10-Watt ADS-B transmitter for ground vehicles. The second approach is presented to show that ideal requirements, which were developed independently of the capabilities of a 10-Watt transmitter, are similar to the 10-Watt capabilities. The working group could also use the requirements that result from the second approach in the event that general agreement can not be reached on a 10 Watt requirement.

1.1 Background information for the 10-Watt analysis

Sensis has developed and tested a 10-Watt ADS-B device for ground vehicles. The performance characteristics of the 10-Watt device have been observed, in part, in operation during airport surface testing in Syracuse, Paris, and London. Performance of a 10-Watt device transmitting to an approaching aircraft in an extremely high fruit environment has not been demonstrated, but Bill Harman has provided simulation results for the high fruit scenario. The 10-Watt analysis compares the known and simulated performance of a 10-Watt device to the needs of the applications.

1.2 Background information for the application driven requirements analysis

A Safe Flight 21 and RTCA SC-186 document called "Final Approach and Runway Occupancy Awareness Application Description v5.0" dated 10 September 2002 was used as a starting point for this research. Randall Bone of MITRE (bone@MITRE.org) edited the FAROA document.

General aviation and commercial carrier pilots were interviewed to get their opinions. Systems engineers and software engineers within Sensis who focus on safety logic and surface movement applications were also queried. During the course of this research, several different approaches were identified for establishing range and update period requirements, which are summarized in section 3 of this document.

A review of airport data was conducted on http://edj.net/cgi-bin/echoplate.pl? to determine conservative distances to be used in range derivations. Final Approach Fix and Minimum Descent Altitude data were reviewed for each of the FAA's 31 Benchmark Airports as described at http://www1.faa.gov/events/benchmarks/download.htm. Table 1 summarizes the data that were collected. The first column lists the name of the airport. The second column lists the Minimum Descent Altitude (MDA) for a non-precision approach to that airport. The MDA for non-precision approaches is analogous to the Decision Height (DH) for precision approaches.

MDA is used in this analysis because it is more conservative to use the longest MDA range from an airport, rather than the typical 200-foot DH. The third column of data in Table 1 lists the distance the aircraft would be from the runway at the MDA. The distance from the runway is calculated assuming a 3 degree approach (distance = MDA/sin(3 degrees)). This distance is actually calculated from the Touchdown Marker on the runway to the MDA, but the calculations are simplified and made more conservative by ignoring the distance between the runway threshold and the runway Touchdown Marker. The last column in Table 1 lists the distance from the runway to the Final Approach Fix (FAF).

In several of the analyses, a runway length of 13,000 feet is used. This runway length was taken from conversations with pilots, who estimated that 13,000 feet was about the longest runway that would be used. A runway length has intentionally been chosen to be much longer than the typical amount of runway used during landing so that the analyses would be conservative.

An approach speed of 140 knots is used in range calculations. Aircraft approach speeds are typically in the range of 120 to 140 knots. Therefore, the140 knots represents a conservative value for approach speed.

1.3 Background information on update period

DO-242A Table 3-4(a) lists update period requirements for surface situational awareness at a range less than or equal to 5 nautical miles. These range and update rate requirements do not apply directly to class B2 transmitters, but they are still useful as guidelines. The requirements call for a nominal update interval (95th percentile) of 1.5 seconds and a 99^{th} percentile received update period of 3 seconds at the 5 nautical mile range. Throughout this working paper, a 1.5 second update period (95^{th} percentile) is used as the nominal required update period.

Table 1 Distance Data for FAA Benchmark Airports

Airport	Minimum Descent Altitude (feet above ground)	MDA Distance from Runway (feet)	Final Approach Fix Distance from Runway (nautical miles)
Atlanta	385	7,356	4.7
Baltimore	594	11,350	4.1
Boston	583	11,140	5
Charlotte	511	9,764	7
Chicago	488	9,324	5.2
Cincinnati	371	7,089	4.5
Dallas	509	9,726	5.1
Denver	569	10,872	4.9
Detroit	468	8,942	5.9
Honolulu	Not Readily Available	Not Readily Available	Not Readily Available
Houston	465	8,885	5.7
Las Vegas	473	9,038	5.2
Los Angeles	459	8,770	6.3
Memphis	470	8,980	4.4
Miami	552	10,547	5.9
Minneapolis	681	13,012	6.0
Newark	602	11,503	4.4
NY- Kennedy	507	9,687	4.5
NY-LaGuardia	**787**	**15,000**	5.3
Orlando	410	7,834	4.5
Philadelphia	709	13,547	5.7
Phoenix	396	7,566	5.6
Pittsburgh	481	9,191	5.5
Salt Lake	333	6,363	5.3
San Diego	526	10,050	5.2
San Francisco	329	6,286	**8.9**
Seattle	431	8,235	4.4
St. Louis	419	8,006	5.9
Tampa	413	7,891	5.9
Washington Dulles	436	8,331	4.1
Reagan National	465	8,885	4.6
Largest Value	**787**	**15,000**	**8.9**

2 10-Watt Analysis

An ADS-B transmitter device on ground vehicles must support two varieties of applications: surveillance by ground infrastructure and surveillance by ADS-B equipped aircraft. This analysis shows that a 10-Watt transmitter on a ground vehicle is adequate to support both types of applications.

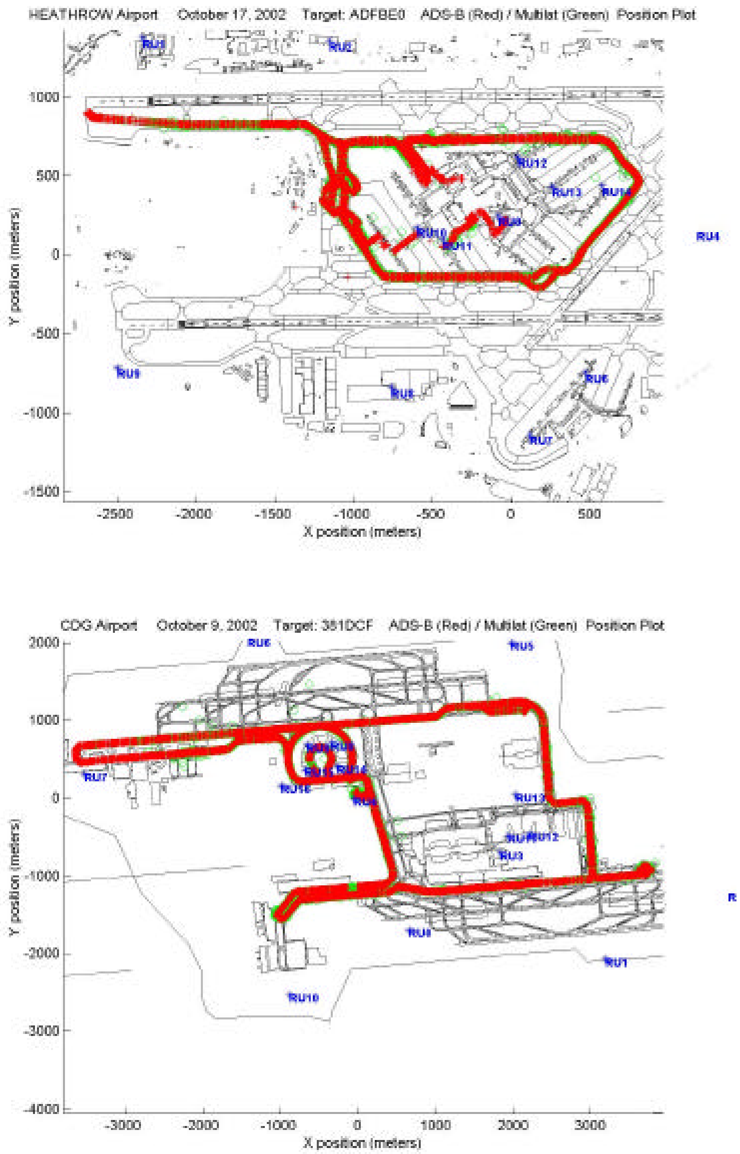

Figure 1 Surveillance of 10-Watt Ground Vehicle Transmitter by Ground Infrastructure

2.1 Surveillance of 10-Watt ground vehicle transmitter by ground infrastructure

Figure 1 shows examples of data collected at Heathrow and Paris while a 10-Watt vehicle locator squits to ADS-B receivers on the airport surface. The data demonstrate that a 10-Watt unit performs very well in this scenario. Multilateration and ADS-B reports both have very high success rates. The multilateration and ADS-B positions are consistent with each other.

2.2 10-Watt ground vehicle transmitter to ADS-B equipped aircraft

The most challenging vehicle-to-air application is the Final Approach and Runway Occupancy Awareness (FAROA) application. In the FAROA scenario, the key performance criteria include acquisition range, required update rate, and range at which the required update rate is achieved. Bill Harman's simulations show that a 10-Watt device has the characteristics shown in Table 2.

Table 2 Performance Characteristics of a 10-Watt ADS-B Transmitter on a Ground Vehicle

Characteristic	Quantitative Value
Acquisition range	7.5 nautical miles
Required update period	1.5 seconds
Range at which 1.5-second update period is achieved	2.5 nautical miles

An acquisition range of 7.5 nautical miles seems adequate. Although the required update rate is not achieved at this range, pilots could observe the presence of vehicles on the runway starting at this range. The tracks may appear "jumpy" due to slower update times at this range.

The required update period is an assumed value. A value of 1.5 seconds is called for by DO-242A for surface situational awareness. Although this requirement does not apply directly to ground vehicles (class B2), it is still a useful guideline.

The range at which the 1.5-second update period is achieved is 2.5 nautical miles. Again, this seems adequate to support the FAROA application. At 2.5 nautical miles separation, the pilot will have a track on the surface map display that is updating with a nominal period of 1.5 seconds, although most tracks would be updating with significantly smaller periods.

2.3 10-Watt Analysis Summary

A comparison of the performance characteristics (observed and simulated) of a 10-Watt ground vehicle transmitter with the needs of the surveillance applications has been performed. The performance of the 10-Watt transmitter seems adequate to support the needs of the applications.

3 Application Driven Requirements Analysis

This analysis presents four methods for developing update period and range requirements in order from least conservative to most conservative. Multiple methods are presented to demonstrate that the concerns of various stakeholders have been considered in developing operational requirements.

3.1 Safety Logic Method

The range calculated from the safety logic method is comprised of a decision range, a range attributable to decision time, and a range attributable to acquisition time. The decision range is the range at which the pilot must have made a decision and taken the appropriate action. The decision time is the time required to make the decision after information has been received on the flight deck. The acquisition time is the time it takes to acquire the target after the aircraft has entered the nominal range of the ground vehicle's transmitter. Bill Harman has stated that acquisition time is accounted for already in his simulations. Therefore, the range values calculated in this paper do not add acquisition time to the range calculations.

In this method, a landing aircraft and a ground vehicle being anywhere on the same runway at the same time constitutes an incursion. Therefore, the decision range can be up to 13,000 feet, which accommodates the case in which a ground vehicle is at the opposite end of a runway from the landing aircraft.

The safety logic method is based on the assumption that the signal must be detected at sufficient range to exceed a specified minimum warning time (decision time) of an occupied runway. A nominal value of 45 seconds warning time has been used in the AMASS surface surveillance and automation system. AMASS used 45 seconds decision time to allow for both controller and pilot recognition time, but the 45-second rule is conservatively applied to this situation in which the controller is not "in the loop." A maximum speed of 140 knots is assumed. At 140 knots, 45 seconds from the end of the runway is equivalent to 10,600 feet from the end of the runway.

The total range requirement is the sum of the decision distance (13,000 feet), the range attributable to decision time (10,600 feet).

13,000 feet + 10,600 feet = 23,600 feet

3.2 Minimum Descent Altitude (MDA) Method

A Radio Frequency Design Engineer on staff at Sensis recommended the Minimum Descent Altitude (MDA) method. This engineer has years of work experience with an avionics manufacturer. He states that this is a logical argument that has been used multiple times when making similar decisions at an avionics manufacturer.

The MDA method asserts that a pilot needs to know about runway occupancy conflicts at least 5 seconds before the missed approach point. Five seconds is conservatively the minimum time required for a pilot to hear or see an alert, internalize the information, and respond by going around.

Based on a three degree geometry of the approach and a 787 foot minimum descent altitude (missed approach point for non-precision approach at New York, LaGuardia), aircraft would be 15,000 feet from the runway at their MDA. Using 13,000 feet as the runway length, the total decision range needs to be 28,000 feet. To account for the 5-second decision time at maximum speed of 140 knots (236 ft/sec), 1,200 feet must be added to that distance. The total range requirement is the sum of the decision distance (28,000 feet), the range attributable to decision time (1,200 feet).

28,000 feet + 1,200 feet = 29,200 feet

Note that the MDA is not the latest point at which an aircraft can go around. The MDA is the earliest that an aircraft would go around due to runway visibility or runway occupancy concerns.

3.3 MASPS Method

DO-242A states that transmitters on ground vehicles shall have a range of 5 nautical miles. The definition of range is not provided within that requirement. DO-242A also states range requirements in Table 3-4(a) on page 90. The Airport Surface operational domain requires a range of 5 nautical miles. The MASPS developed surface requirements based on equivalence with other surveillance systems, analysis of a blind taxi scenario, and analysis of a runway incursion scenario. The MASPS explicitly names classes A0-A3, B0, B1, and B3, but does not address class B2 in table 3-4(a). Therefore, it is not clear whether the update rate requirements associated with the 5 nautical mile range specified for the other classes is required by the MASPS for class B2. However, the 5 nautical mile range and the associated update rate requirements are probably a useful guideline for class B2 as well.

3.4 Final Approach Fix (FAF) Method

The final approach fix method asserts that runway occupancy data would be of interest to pilots if the following two conditions were met:

1. the aircraft has been cleared to land, and
2. the aircraft has passed the final approach fix.

These two conditions summarize conversations conducted with commercial and general aviation pilots. If both of these conditions are met, then the aircraft is in landing configuration, which includes having landing gear and flaps in their landing positions. At this point in the flight, a pilot is in a position to observe information concerning runway occupancy. The pilot has an unambiguous intent to land the aircraft and he does not expect to get “vectored” by air traffic control.

Appendix A of FAROA version 5.0 also implies that pilots will view the surface map some time after they have passed the Final Approach Fix. The FAROA document states that pilots will display the surface map after they have reduced speed to the final approach speed, configured other systems for landing, and completed the LANDING CHECKLIST.

The longest distance to a Final Approach Fix at any of the FAA Benchmark Airports is 8.9 nautical miles at San Francisco Airport. Adding 13,000 feet for the runway yields a required range of 67,000 feet (11 nautical miles).

Pilots that were interviewed stated that they might find information on runway occupancy of interest at this point in the flight. However, no interviewed pilot could think of any actionable decision that would be made based on the presence of vehicle traffic on the runway when the approaching aircraft is still 11 nautical miles away from the ground vehicle. The summaries and conclusions of this paper ignore this range determination method due lack of clear requirements, utility, and benefit of data at this range.

3.5 Application driven requirements summary

Table 3 summarizes the results of the application driven requirements analyses.

Table 3 Summary of Analyses

Analysis	Suggested Value
Safety logic method	Range of 23,600 feet (~3.9 nautical miles)
Minimum Descent Altitude method	Range of 29,200 feet (~4.8 nautical miles)
MASPS method	Range of 30,400 feet (~5 nautical miles)
Final Approach Fix method	Range of 67,000 feet (~11 nautical miles)

4 Conclusions

Based on test data and simulation data, a 10-Watt transmitter for ground vehicles seems adequate to address the needs of the anticipated ADS-B applications. Ten Watts supports a sufficient acquisition range and update period to provide a margin of safety for surveillance by ground infrastructure and surveillance by approaching ADS-B equipped aircraft. A 10-Watt power requirement for ground vehicles is recommended for DO-260A.

Other methods of deriving range and power requirements have also been presented. The other methods have been presented for comparison to the 10-Watt analysis. In the event that the 10-Watt proposal is not accepted by the working group, the results of these other methods could be used in conjunction with Bill Harman's simulations to derive a power requirement for ground vehicles.