Proposed New Appendix P Material, version 3 (includes final summary table)
20 Aug. 09, Harman

Following is a revised version of the new Appendix P material, that puts together the original draft, the discussion at the WG3 meeting on Wednesday, and the other written comments from me (paper WG-30-10).

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P.5 Additional Performance Analysis

Additional analysis was carried out for this publication in order to examine the performance of 1090 ES in more dense traffic environments and also to evaluate the performance of the newly-defined single-antenna A1 category of equipage. In order to be consistent with the performance criteria used in the rest of this appendix, it was decided to use the same update interval criteria that were used in Appendix P of RTCA DO-260A. These criteria were based on initial estimates of the application requirements provided by the ADS-B MASPS (RTCA DO-242A) that were published in 2002. Since the publication of RTCA DO-260A, much work has been done to refine the air-to-air applications and the accompanying requirements, so the performance criteria may change. It is possible that applications will be developed that require performance more demanding than DO-242A (longer ranges or high update rates). The opposite is also possible, that the DO-242A criteria used here are more demanding than what will be needed for the actual applications of ADS-B. For further information on more recent range and update requirements, see RTCA DO-289, RTCA DO-312, and RTCA DO-314. In addition, work is in progress to define new air-to-air applications.

P.5.1 East Coast Air Traffic Scenarios

Several new air traffic scenarios were developed for this analysis. Since ADS-B shares the 1090 MHz frequency with existing SSRs, TCAS, and other systems, understanding the interference environment is necessary to provide confidence in the predictions of future interference environments in which the system will operate. The Northeast corridor of the United States was the selected environment to base future air traffic and interference predictions since high air traffic density, TCAS equipage, and SSRs contribute to a busy 1090 MHz environment.

A flight test was conducted on January 26, 2006 in the Northeast corridor of the United States for the purpose of measuring and assessing airborne receptions of 1030/1090 MHz activity. An additional flight test was conducted on July 25, 2007 where 1030 and 1090 MHz measurements similar to the January 2006 flight test were taken. In both cases, the receiving aircraft was instrumented for recording of the flight path and both 1030 MHz and 1090 MHz receptions, for later detailed analysis.

Simultaneously with the airborne measurements in July 2007, radar recordings were also made to show the density and distribution of airborne aircraft. The distribution of the traffic was captured by taking snapshots of all aircraft seen by 33 east coast enroute and terminal radars. The composite picture was created by converting the measured radar coordinates of all the aircraft at the time of the snapshot into latitude and longitude, superimposing the pictures seen by all the radars, and eliminating duplicate reports of the

same aircraft as seen by multiple radars. The resulting measurements of aircraft density and distribution are shown in Figure P-29.

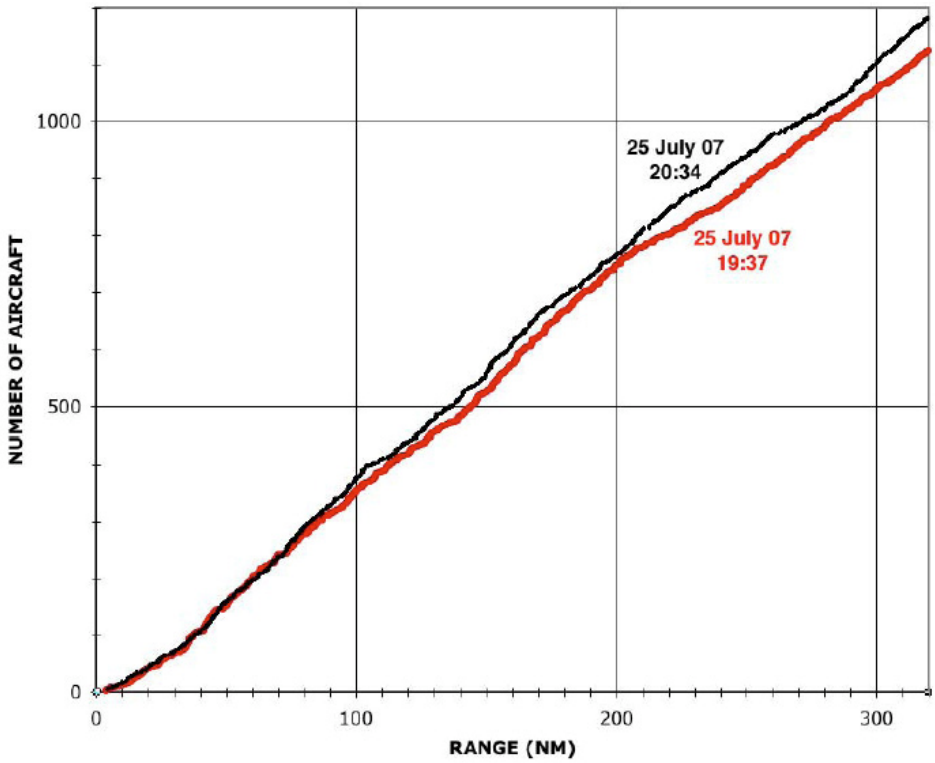

Figure P-29. Measurements of Aircraft Density at Two Times.

This was a major measurement and data-analysis program, which included a detailed simulation of the 1030 MHz and 1090 MHz reception that would be expected given the number of airborne aircraft and the known ground based radars [ref. P-2]. The end result was an improved understanding of the signal environment and the behavior of 1030/1090 MHz avionics in a dense environment.

P.5.2 Future Interference Environments

Building upon the measured values of aircraft density and airborne signal receptions, four models were developed to represent future higher density conditions. Figure P-30 shows the aircraft density conditions in these four models as compared with the measurements.

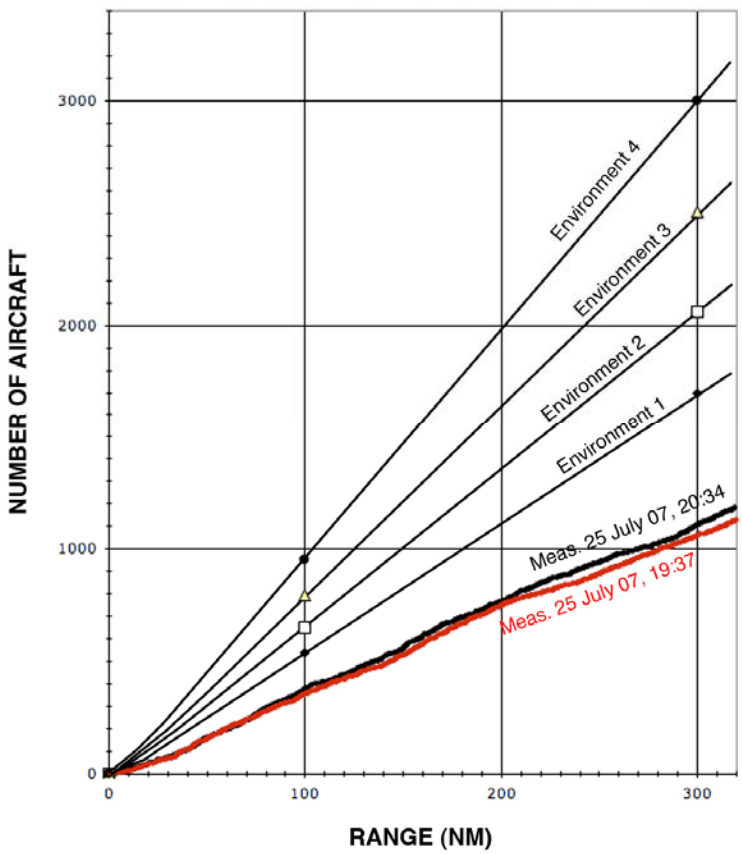

Figure P-30. Range Distribution of Aircraft, Measured and Modeled.

Each of the four new environments can be characterized by a growth factor relative to the measurements of aircraft density. Table P-8 shows the four growth factors, and also lists the Mode S and ATCRBS fruit rates, received airborne for comparison. These values of fruit rate apply to receptions stronger than -84 dBm referred to the antenna. Whereas the measured number of aircraft within a range of 100 NM varied by time-of-day and also according to the centerpoint of the calculation, for this purpose the maximum value was used to characterize the measured density and to calculate the growth factors of the four new environments.

Table P-8: Four Interference Environments for Evaluating A1S Air-to-Air ADS-B Performance

	Number of Aircraft Within 100 NM	Relative No. of Aircraft Within 100 NM	Number of Aircraft Within 300 NM	Mode S Fruit Rate	ATCRBS Fruit Rate
	number	factor	number	per sec.	per sec.
Measured, July 07	384	1	1000	3,010	25,900
Environment 1	539	1.4	1,700	8,311	32,996
Environment 2	653	1.7	2,060	10,218	40,074
Environment 3	794	2.1	2,502	13,268	48,848
Environment 4	952	2.5	3,000	16,009	58,811

In considering future higher aircraft densities, it is necessary to consider possible changes in the frequency management by the FAA of 1030/1090 MHz. For example, the FAA recognizes that the rate of All-Call interrogations by SSRs is higher than needed by about 2:1 and the FAA is implementing a plan to make a 2:1 reduction.

All-Call 2:1 Reduction. Looking many years into the future, it is reasonable to assume that the 2:1 reduction in All-Call rate has been made, and that assumption was used in this study. Other similar assumptions can be summarized as follows.

Terra Fix. The FAA is planning to phase-out the Terra Fix, and it was assumed that is will be phased-out for environments 1, 2, 3, and 4.

Extended All-Call Lockout. Although the FAA is considering extending All-Call Lockout beyond 60 NM, that change was not assumed in this study.

Fewer SSRs. With increasing ADS-B, the FAA is planning to reduce the number of SSRs by 50 percent. For this study, an SSR reduction by 8 percent was assumed for all four interference environments.

Unwanted Mode A Replies. Airborne measurements have revealed a mechanism in which unwanted Mode A replies are triggered by low-level Mode S interrogations. This problem is limited to certain transponder models, and transponder standards have been changed to eliminate the problem in the future. But it was assumed in this study that this problem will not be controlled in the future.

TCAS Interference Limiting. Some limitations in the effectiveness of TCAS interference limiting have been observed. It was assumed for this analysis that no steps will be taken in the future to keep Interference Limiting working effectively.

TCAS Hybrid Surveillance. It is generally expected that Hybrid Surveillance will improve the efficiency of TCAS and reduce the effects of TCAS on the frequency band use. This study assumed that Hybrid Surveillance will reduce TCAS interrogation effects by 60 percent in the four future environments.

P.5.3 Air-to-Air Performance Results

This section presents the air-to-air performance results in the four interference environments described in the previous section.

P.5.3.1 Performance for Class A1-S

The single-antenna A1 category of ADS-B equipage (A1-S) was evaluated for air-to-air performance using the four new interference environments. The analysis applies when both transmitter and receiver are equipped with class A1S. The air-to-air ranges considered and the corresponding requirements for Nominal Update Interval are the requirements given in RTCA DO-242A. The results are given in Table P-9.

Table P-9: A1-S Air-to-Air ADS-B Performance in Four Interference Environments

	T_{95}(3 NM)	T_{95}(10 NM)	T_{95}(20 NM)	T_{95}(40 NM)
Update Interval Reqt. (95%)	**3 s**	**5 s**	**7 s**	**12 s**
Environment 1	**1 s**	**8 s**	**25 s**	**X**
Environment 2	**2 s**	**10 s**	**X**	**X**
Environment 3	**2 s**	**15 s**	**X**	**X**
Environment 4	**3 s**	**20 s**	**X**	**X**

Note. An "X" in a box indicates that the value was very large.

These results indicate that this avionics class would be quite limited in range in areas having densities as high as the four new models.

P.5.3.2 Performance for Class A3

Class A3 avionics were evaluated in the same manner. The results are given in Table P-10, which apply when both the transmitting aircraft and the receiving aircraft are equipped with Class A3 avionics.

Table P-10: A3 Air-to-Air ADS-B Performance in Four Interference Environments

	T_{95} (3 NM)	T_{95} (10 NM)	T_{95} (20 NM)	T_{95} (40 NM)	T_{95} (60 NM)
Update Interval Reqts (95%)	**3 s**	**5 s**	**7 s**	**12 s**	**TBD**
Environment 1	**1 s**	**1 s**	**2 s**	**8 s**	**23 s**
Environment 2	**1 s**	**1 s**	**3 s**	**12 s**	**36 s**
Environment 3	**1 s**	**2 s**	**4 s**	**33 s**	**X**
Environment 4	**1 s**	**2 s**	**7 s**	**X**	**X**

Note. An "X" in a box indicates that the value was very large.

These results clearly show that increasing aircraft density and increasing interference would have an effect limiting air-to-air range. The DO-242A requirements would be satisfied out to 20 NM in all four new environments, but for the longer-range column (40 NM) the Update Interval requirement would not be satisfied if the actual environment grew more dense than Environment 2 (growth by more than a factor of 1.7).

Following is a comparison of these new results for A3-to-A3 ranges together with other results in Appendix P and the power-limited range given in Appendix E. These results exhibit a monotonically decreasing air-to-air range as the density of aircraft and interference increases.

Table P-11. Air-to-Air Range Comparison For Eight Cases of Increasing Interference

Environment	A3-A3 Range
Power Limited	140 NM
"Low Density" Model	135 NM
LA[24k]	70-80 NM
LA[30k]	60-70 NM
NY[x1.4]	> 40 NM
NY[x1.7]	> 40 NM
NY[x2.1]	35 NM
NY[x2.5]	30 NM

REFERENCES:

P-1. "Technical Link Assessment Report," Safe Flight 21 Steering Committee, ADS-B Technical Link Assessment Team (TLAT), March 2001.

P-2. A. G. Cameron, et al, "The 1030/1090 MHz Interference Simulation Technical Description and Initial Results," TR-9454-02-01, TASC Inc., April 2001.

P-3. "Measurement of 1090 MHz Extended Squitter Performance In the Los Angeles Basin," DOT/FAA/ND-00/7, May 2000.