RTCA Special Committee 186, Working Group 3

ADS-B 1090 MOPS, Revision A

Meeting #16

Proposed Additional Text for DO-260A Appendix O: Accommodation of Trajectory Change Reporting

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SUMMARY
Previous drafts of Appendix O have omitted the text for sections O.5, O.6, and O.7 describing the “estimated performance”, “other factors and issues” and “conclusions” respectively. These sections can only be fully completed after the results of the 1090 Extended Squitter simulations are complete, as reported in Appendix P. This working paper proposes text for sections O.5, O.6 and O.7 and will need to be aligned with the final performance results presented in Appendix P.

References: 1. 1090-WP-15-05, November, 2002 (draft Appendix O)
2. December 2002 (draft Appendix P)

1. INTRODUCTION

Previous drafts of Appendix O have omitted the text for sections O.5 and O.6 describing the "estimated performance" and "other factors and issues" respectively. Also a section O.7 presenting "conclusion" needs to be added. These sections can only be completed after the results of the 1090 Extended Squitter simulations are complete, as reported in Appendix P. This working paper proposes text for sections O.5, O.6 and O.7 and will need to be aligned with the final performance results presented in Appendix P.

2. PROPOSED ADDITIONS TO APPENDIX O

O.5 Estimated Performance

O.5.1 TC+0 Performance Estimate

There are many factors that will impact the ability of the 1090 MHz ADS-B system to deliver trajectory change information. As discussed above in Section O.4 there are a number of alternatives as to the rate at which TC+0 messages are broadcast. The broadcast rate will depend on both the aircraft equipage (e.g., only able to provide basic TC information vs. more extensive TC information) and also on the ability to revise the Mode S transponder standards, both within RTCA and ICAO, to permit an increase in the peak transmission rates for extended squitters. The full set of TC+0 report information must be split into two extended squitter messages for transmission. For the case where a given aircraft is only capable of providing the information contained in the Basic TC+0 message, reception of this single message type will be sufficient to generated an TC+0 report. For the case of an aircraft equipped to provide the full TC+0 information set, then the reception of both a Basic TC+0 and a Supplemental TC+0 message would be required in order to update the TC+0 report.

Given these uncertainties and potential variations in the broadcast capabilities, estimates were developed for three alternative cases for the broadcast of TC+0 messages. Simulations runs have not been specifically conducted for these alternative cases. Rather a simplified approach was employed where the per squitter reception probability was calculated that would be required to satisfy the DO-242A, Appendix N guidance material for TC+0 report nominal update rates. The simulation results were then reviewed to estimate at what range the calculated per squitter reception probability would be supported. Since two different simulations were used to estimate the performance, both the results from the APL simulations and the results from the Lincoln Laboratory simulations are provided. These simulations are described in Appendix P. The simulation results are presented for both a low density traffic environment as well as the postulated future Los Angles traffic environment for the year 2020. The LA2020 scenario with 24K Mode A/C fruit per second interference level was used for the analysis of TC reception performance in a high density environments.

Note that the applicability of TC reporting is currently limited within DO-242A to air-to-air ranges up to 40 NM within high density airspace as represented by the LA2020 scenario and to 90 NM in low density airspace. DO-242A does note however that "..the minimum range required may apply even in high interference environments, such as over-flight of high traffic density terminal areas."

DO-242A also proposed increased reporting rates following a change in certain elements of the TC reports. The 1090 MHz ADS-B system could accommodate this by temporarily lowering the broadcast rate of lower priority messages. This is supported by the message scheduling function defined in DO-260A. However, the potential requirement for increased TC+0 reporting rates following a change in TC information is not specifically considered in the following performance analysis (i.e., only the nominal TC+0 reporting case is considered).

CASE 1 –

The first case to be considered is that in which only the Basic TC+0 message is being broadcast. In this case it is assumed that the TC+0 messages would be broadcast at the same rate as used for the Target State and Status messages (i.e., 0.8 messages per second). In order to support the MASPS guidance for TC+0 report updates at 95% probability the nominal required per message reception probability is described by the formula: $0.95 = 1 - (1-P_{message})^{N}$ or rewriting for calculating the necessary per squitter reception probability: $P_{message} = 1 - (1 - 0.95)^{1/N}$ where N is the number of transmissions within the required received update interval. The following table indicates the per message reception probability needed to satisfy the DO-242A guidance for the nominal air-to-air reporting of TC+0 information at ranges of 20, 40 and 90 NM.

<u>TABLE O-4:</u> Case 1 - TC Message Reception Probability

Air-Air Range	TC+0 Report Nominal Update Rate	"Required" Message Reception Probability
20 NM	12 Seconds	26.8%
40 NM	18 Seconds	18.8%
90 NM	41 Seconds	8.7%

In this case the effective reporting rate for TC+0, in which only a Basic TC+0 message is being broadcast, would be essentially the same as for TS Reports as described in Appendix P. The estimated TC+0 reporting rate is summarized in the Table O-5 and Figures O-1, O-2 and O-3 for the LA2020 and low traffic density scenarios. These performance estimates are for the case of Class A3 receiving systems.

TABLE O-5: Case 1 – TC Report Performance

TC+0 Report Update Rate	Estimated Air-Air Range for Low Density Scenario (A3 Tx –to- A3 Rx)		Estimated Air-Air Range LA2020 Scenario (A2 Tx –to- A3 Rx)		Estimated Air-Air Range LA2020 Scenario (A3 Tx –to- A3 Rx)	
	APL	LL	APL	LL	APL	LL
12 Sec.	TBD	115 NM	30 NM	24 NM	40 NM	30 NM
18 Sec.	TBD	123 NM	30 NM	32 NM	40 NM	40 NM
41 Sec.	TBD	132 NM	50 NM	52 NM	60 NM	65 NM

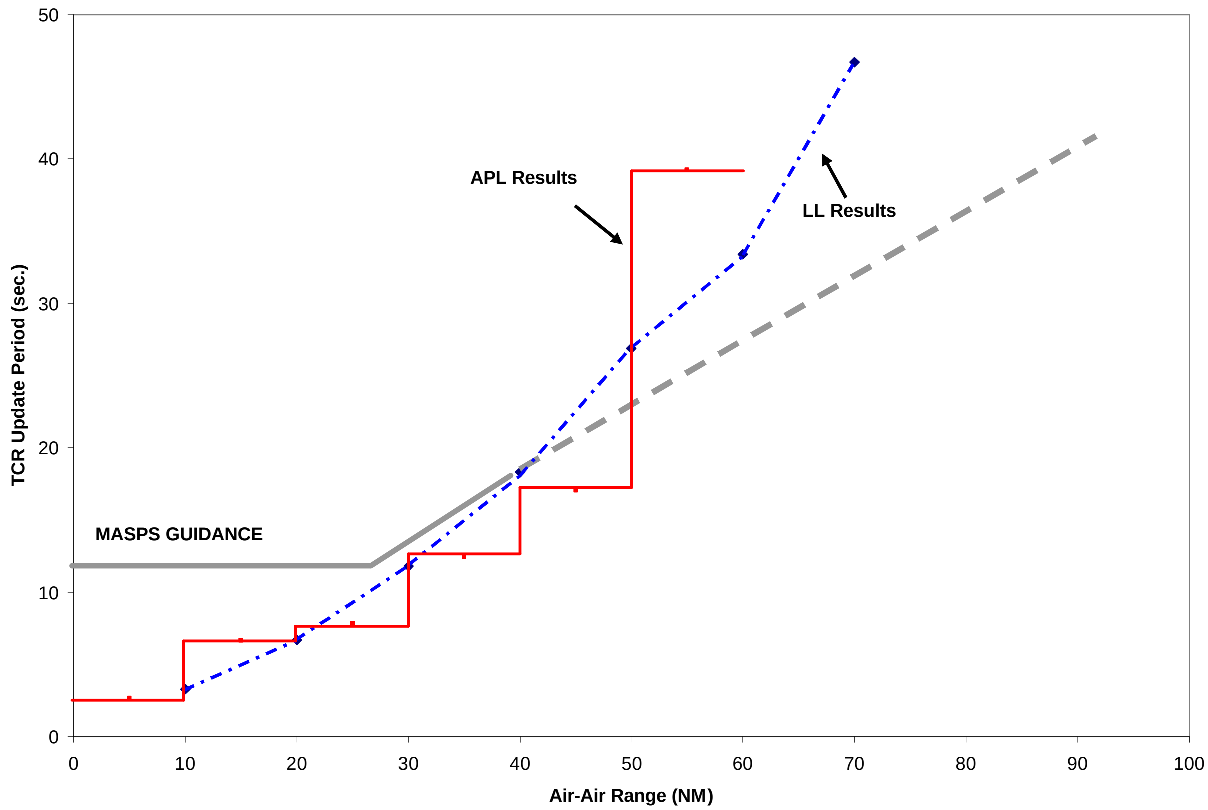

Figure O-1: Case 1 Nominal LA2020 for A3 Tx –to- A3 Rx

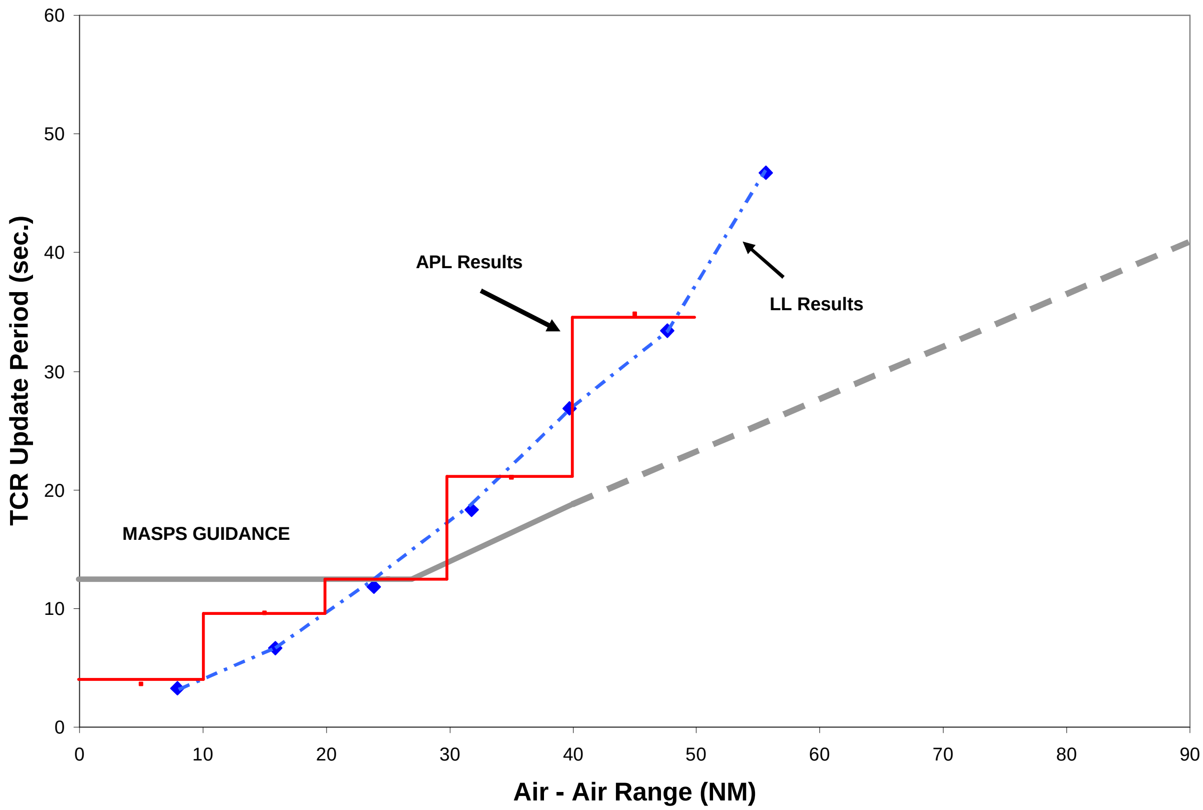

Figure O-2: Case 1 Nominal LA2020 for A2 Tx –to- A3 Rx

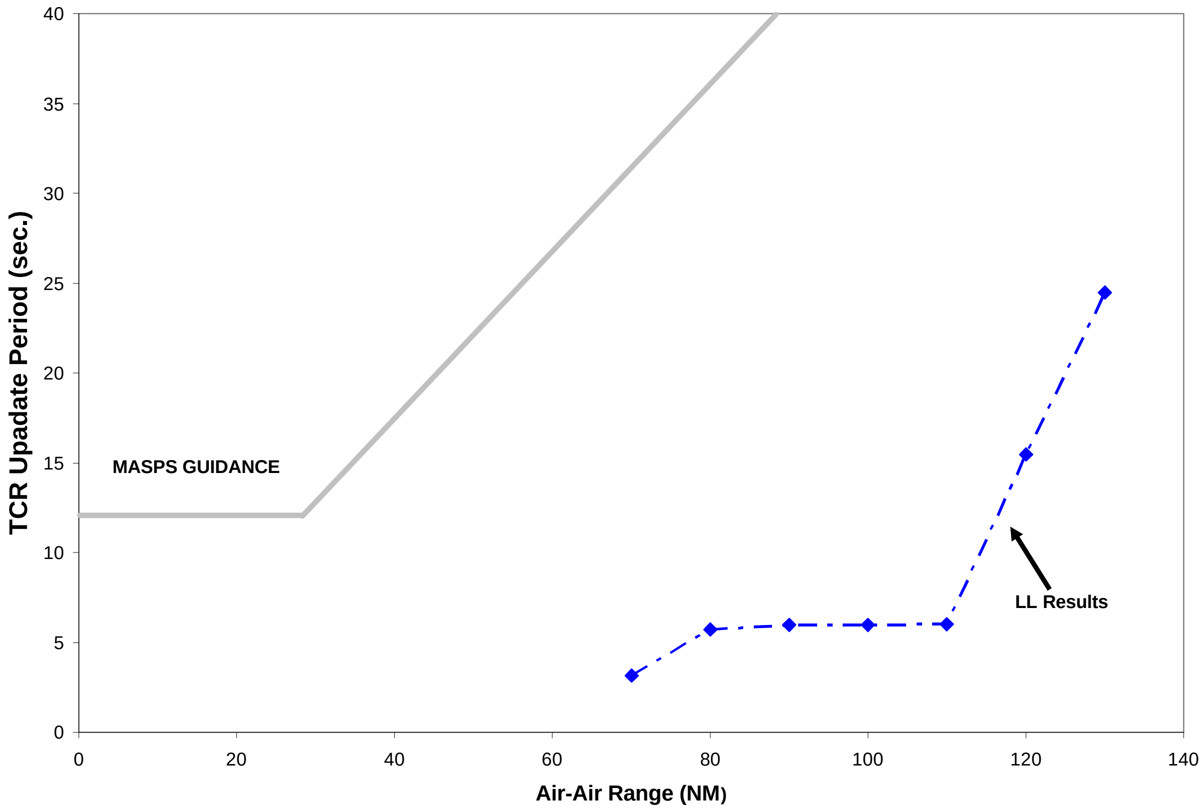

Figure O-3: Case 1 Low Density A3 Tx –to- A3 Rx

CASE 2 –

For this case, the full TC+0 information set is split between a Basic and a Supplemental TC+0 message and each message is broadcast at the rate of 0.8 messages per second. This case would only be possible if the allowed peak extended squitter broadcast rate were increased to 7 extended squitters per second or greater. In order to support the MASPS guidance for TC+0 report updates at 95% probability the nominal required per message reception probability is described by the formula: $0.95 = [1 - (1-P_{message})^N]^2$ or rewriting for calculating the necessary per squitter reception probability: $P_{message} = 1 - [1- (0.95)^{1/2}]^{1/N}$ where N is the number of transmissions within the required received update interval. Table O-6 indicates the per message reception probability needed to satisfy the DO-242A guidance for the nominal air-to-air reporting of TC+0 information at ranges of 20, 40 and 90 NM.

<u>TABLE O-6:</u> Case 2 - TC Message Reception Probability

Air-Air Range	TC+0 Report Nominal Update Rate	"Required" Message Reception Probability
20 NM	12 Seconds	31.1%
40 NM	18 Seconds	22.5%
90 NM	41 Seconds	10.6%

In this case the effective reporting rate for TC+0 information, in which both a Basic TC+0 message and a Supplemental TC+0 message is being broadcast, the estimated TC+0 reporting rate is summarized in Table O-7 and Figures O-4, O-5 and O-5 for the LA2020 and the low traffic density scenarios for the case of Class A3 receiving systems.

<u>TABLE O-7:</u> Case 2 – TC Report Performance

TC+0 Report Update Rate	Estimated Air-Air Range for Low Density Scenario (A3 Tx –to- A3 Rx)		Estimated Air-Air Range LA2020 Scenario (A2 Tx –to- A3 Rx)		Estimated Air-Air Range LA2020 Scenario (A3 Tx –to- A3 Rx)	
	APL	LL	APL	LL	APL	LL
12 Sec.	TBD	112 NM	20 NM	21 NM	30 NM	27 NM
18 Sec.	TBD	120 NM	30 NM	28 NM	40 NM	35 NM
41 Sec.	TBD	131 NM	40 NM	48 NM	50 NM	60 NM

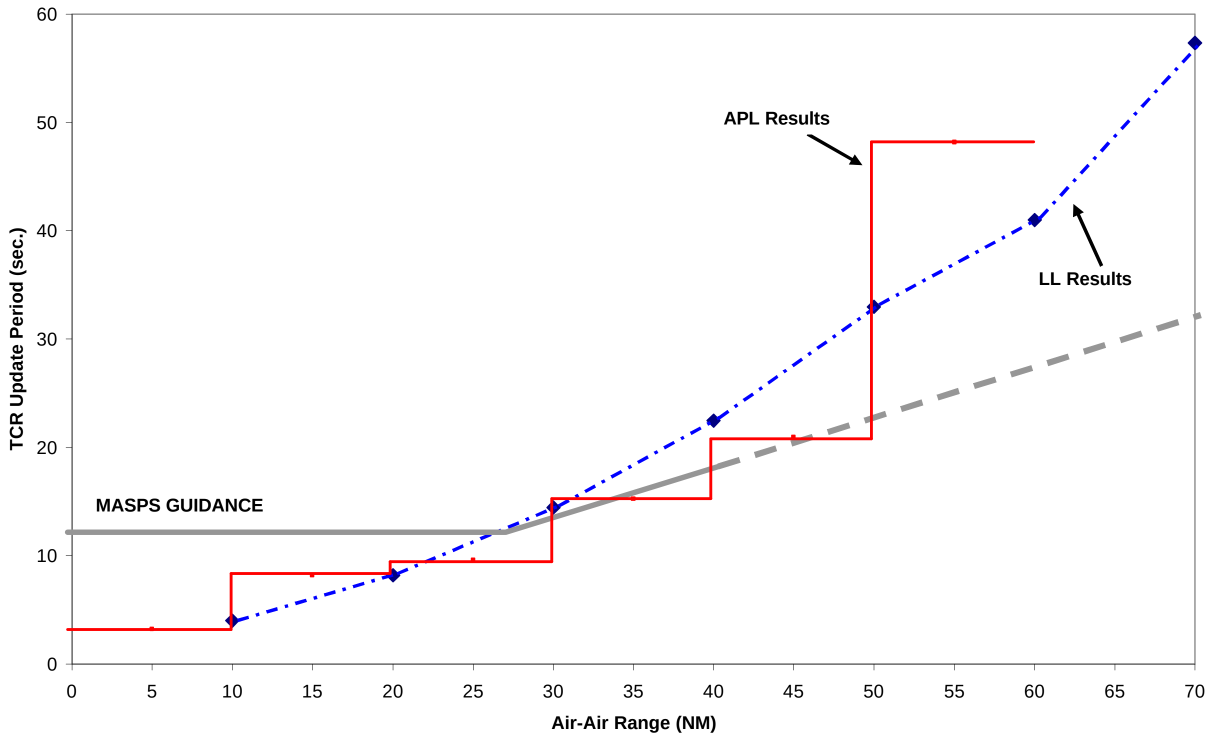

Figure O-4: Case 2 Nominal LA2020 for A3 Tx –to- A3 Rx

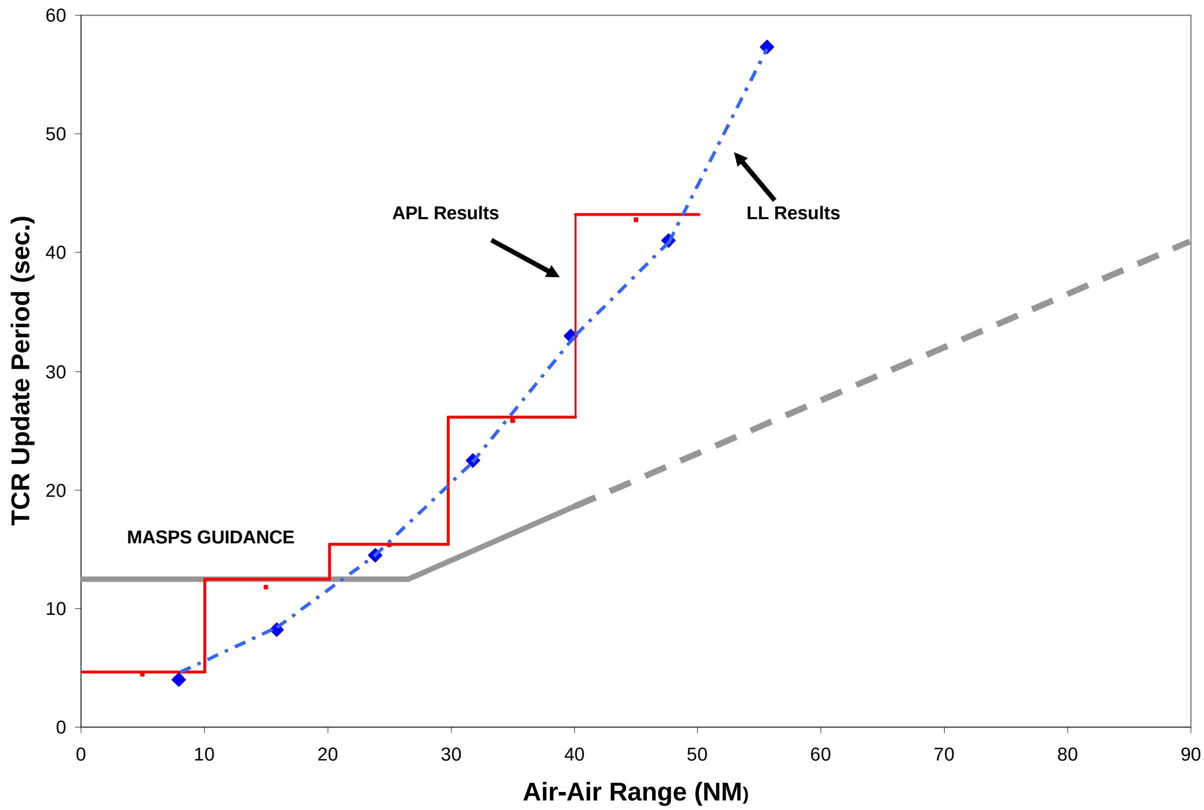

Figure O-5: Case 2 Nominal LA2020 for A2 Tx –to- A3 Rx

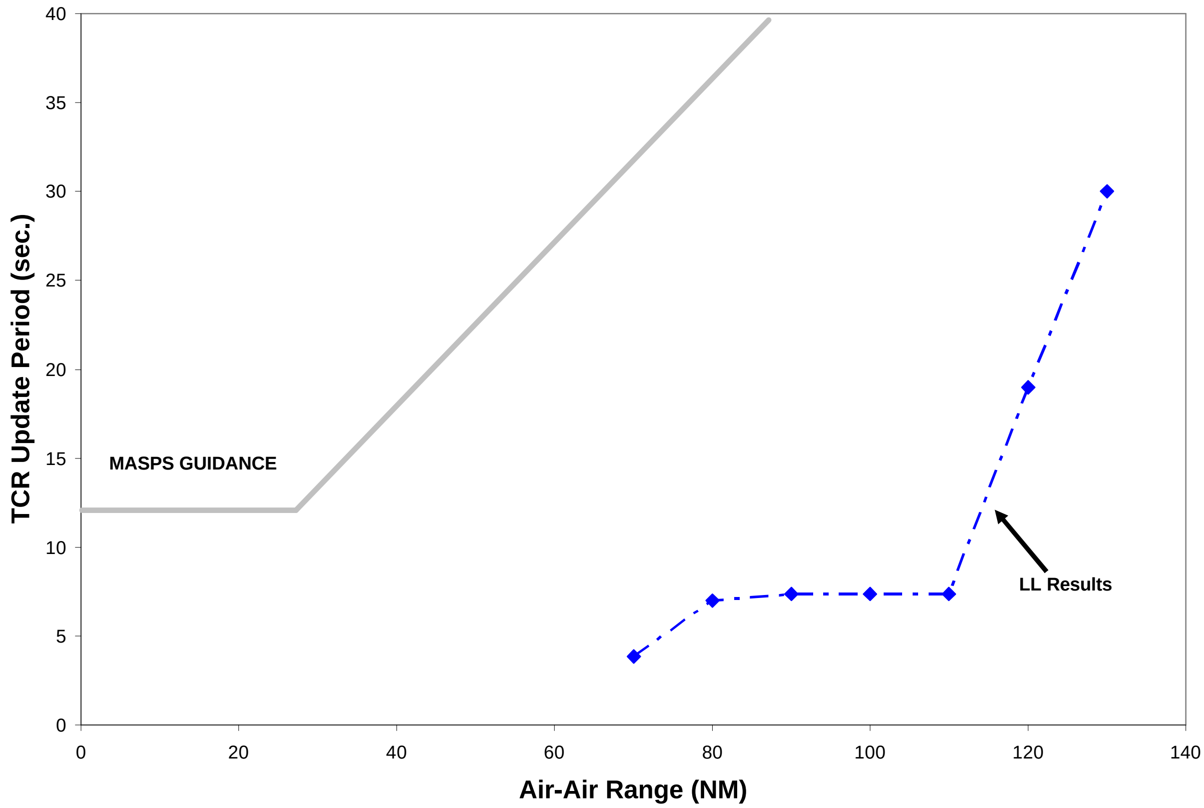

Figure O-6: Case 2 Low Density A3 Tx –to- A3 Rx

CASE 3 –

For this case, it is assumed that both a TC+0 basic and a TC+0 supplemental messages would be broadcast at 0.4 messages per second. This would be the worst case situation, in which the peak extended squitter transmission rate is limited to 6.2 squitters per second, where the aircraft is sending the full TC+0 information set and where the supplemental information could not be updated at a lower rate than the basic information. In order to support the MASPS guidance for TC+0 report updates at 95% probability the nominal required per message reception probability is described by the formula: $0.95 = [1 - (1-P_{message})^N]^2$ or rewriting for calculating the necessary per squitter reception probability: $P_{message} = 1 - [1- (0.95)^{1/2}]^{1/N}$ where N is the number of transmissions within the required received update interval. The following table indicates the per message reception probability needed to satisfy the DO-242A guidance for the nominal air-to-air reporting of TC+0 information at ranges of 20, 40 and 90 NM.

TABLE O-8: Case 1 - TC Message Reception Probability

Air-Air Range	TC+0 Report Nominal Update Rate	"Required" Message Reception Probability
20 NM	12 Seconds	53.5%
40 NM	18 Seconds	40.0%
90 NM	41 Seconds	20.1%

In this case the effective reporting rate for TC+0, in which both a Basic TC+0 message and a Supplemental TC+0 message is being broadcast and the broadcast rate for each is 0.4 messages per second, the estimated TC+0 reporting rate is summarized in Table O-9 and Figure O-7, O-8 and O-9 for the LA2020 and the low traffic density scenarios for the case of Class A3 receiving systems.

TABLE O-9: Case 3 – TC Report Performance

TC+0 Report Update Rate	Estimated Air-Air Range for Low Density Scenario (A3 Tx –to- A3 Rx)		Estimated Air-Air Range LA2020 Scenario (A2 Tx –to- A3 Rx)		Estimated Air-Air Range LA2020 Scenario (A3 Tx –to- A3 Rx)	
	APL	LL	APL	LL	APL	LL
12 Sec.	TBD	75 NM	10 NM	12 NM	10 NM	15 NM
18 Sec.	TBD	110 NM	10 NM	17 NM	20 NM	22 NM
41 Sec.	TBD	121 NM	30 NM	30 NM	40 NM	37 NM

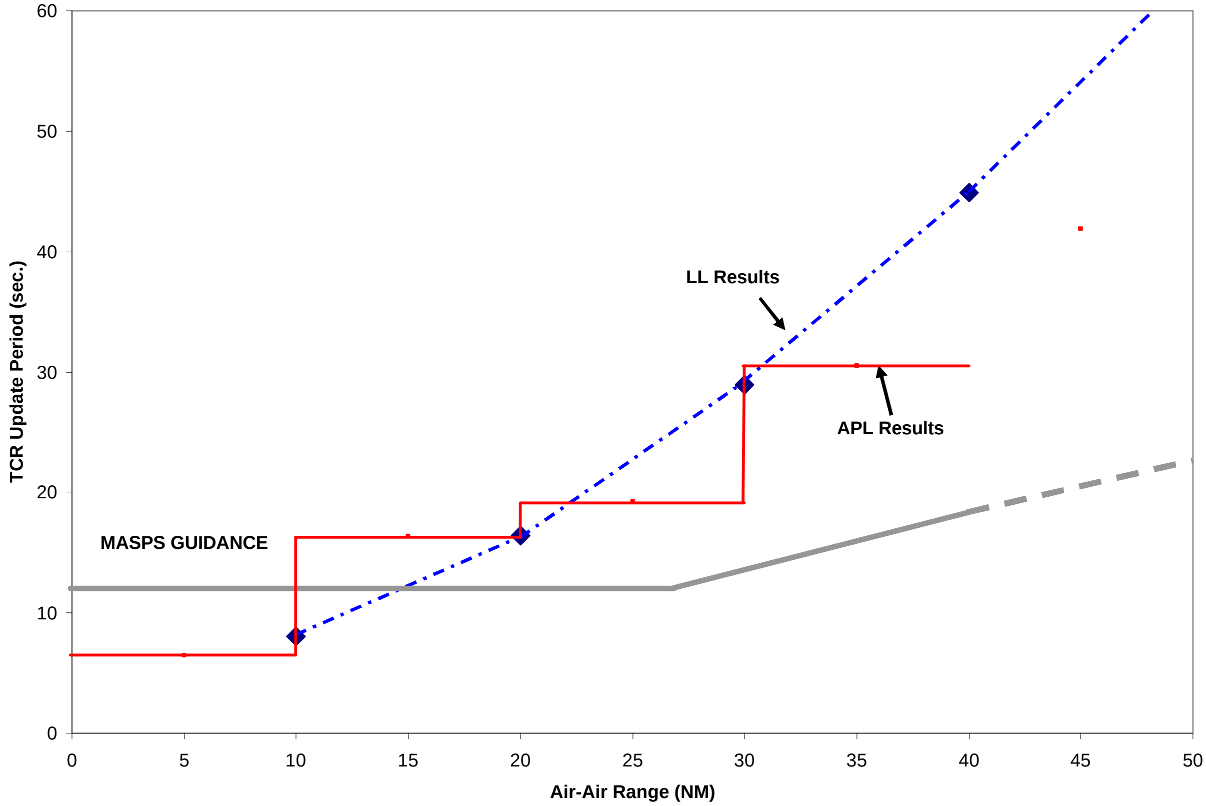

Figure O-7: Case 3 Nominal LA2020 for A3 Tx –to- A3 Rx

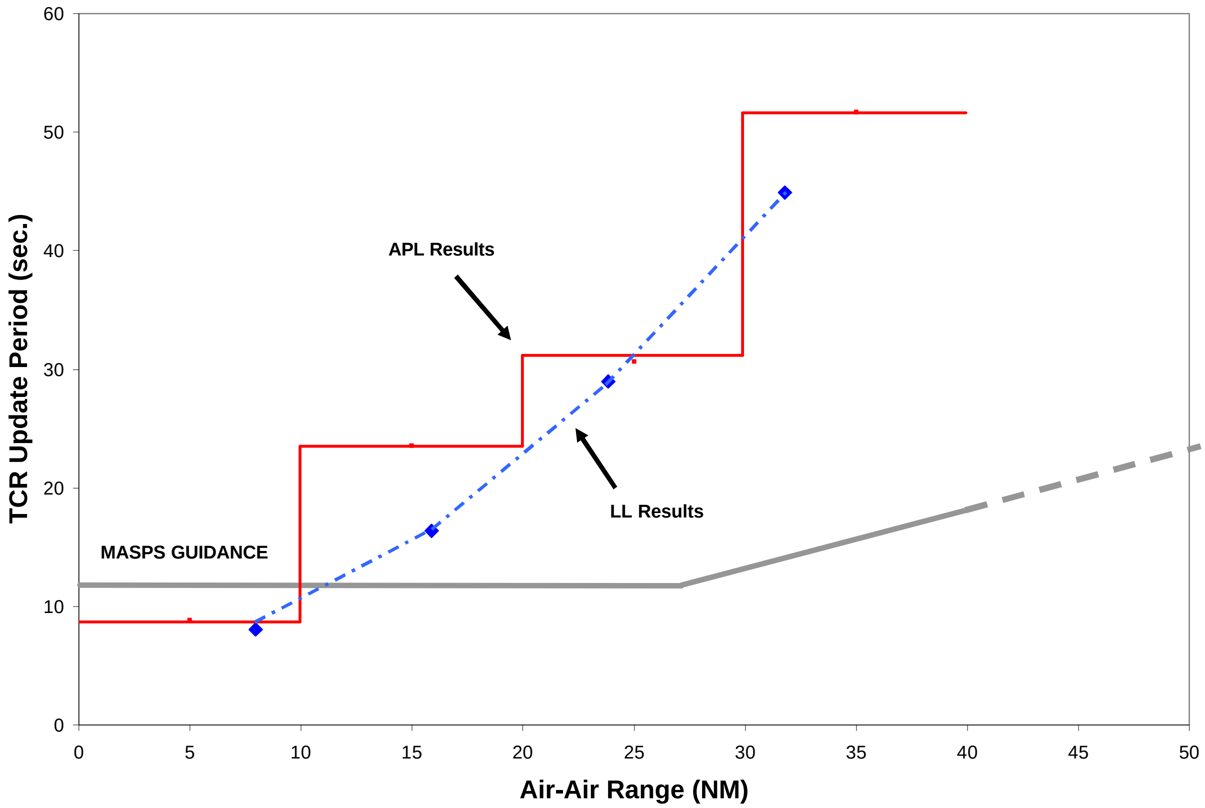

Figure O-8: Case 3 Nominal LA2020 for A2 Tx –to- A3 Rx

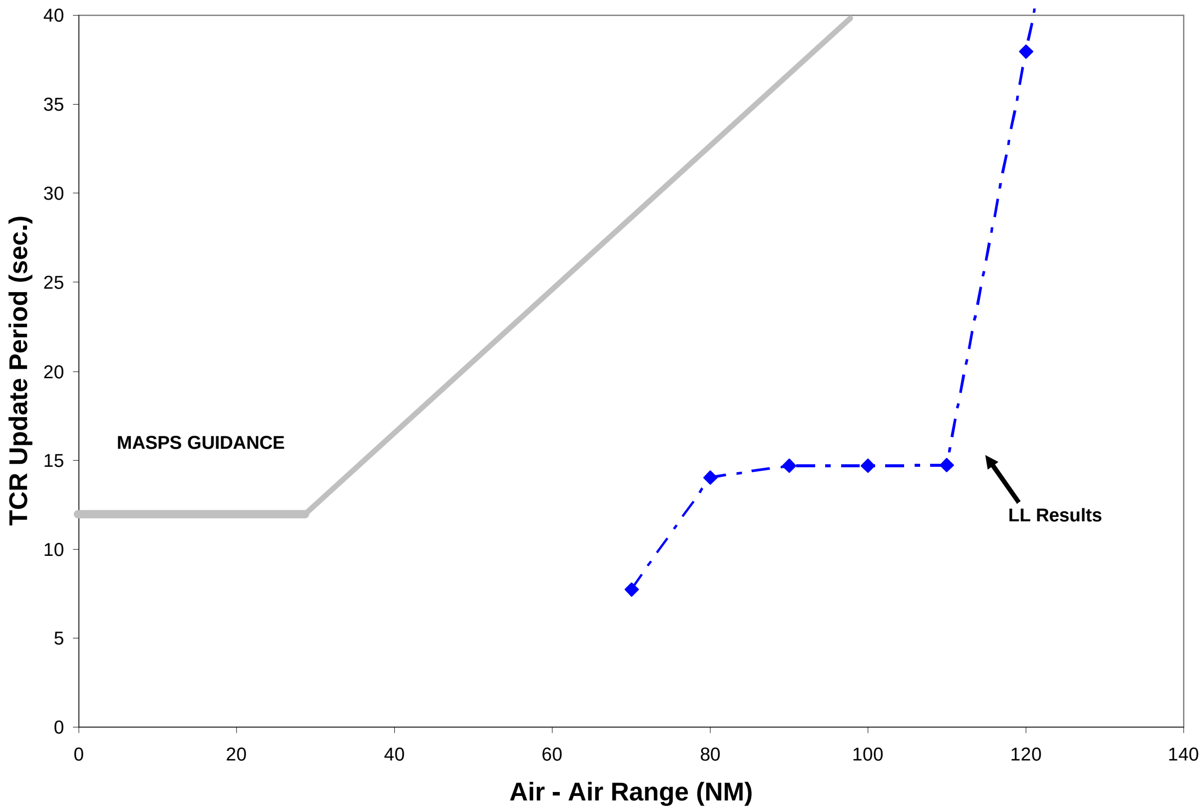

Figure O-9: Case 3 Low Density A3 Tx –to- A3 Rx

O.5.2 TC+1 Performance Estimate

The broadcast of TC+1 information in support of an air-to-air applications should only be considered on 1090 MHz if the allowed peak extended squitter rate is increased above the current RTCA MOPS and ICAO SARPs limit of 6.2 squitters per second. If the limit were increased to on the order of 8 to 8.6 squitters per second then the performance for TC+1 reporting would be similar to that described above in section O.5.1 for Case 1 and Case 2. However, in order to limit channel loading and in order to gain ICAO acceptance for an increase in the peak allowed squitter rate, the transmission of TC+1 messages might need to be limited to operations above a fixed altitude threshold, such as only in high altitude en route airspace where airborne flight path deconfliction might be operationally authorized.

O.6 Other Factors and Issues

The performance estimates presented above in section O.5 address only the air-to-air reception of TC information. It is possible that the primary needs for TC information are not best served by the exclusive use ADS-B as the delivery mechanism and/or are not best offered as an air-to-air service. For example, this could be the case with high density terminal environments where the responsibility for aircraft separation will remain the responsibility of the ATC controller and supported by the ground automation tools. For this case addressed Mode S services may be a technically superior method for the ground ATC automation system to obtain the aircraft's intent information. Once the intent information is obtained by the ground ATC automation and used by the ground decision support tools, it may be appropriate to employ an addressed (or broadcast) ground-to-air communications service to provide airborne applications with the information they to achieve conflict free flight paths.

The air-to-ground performance for 1090 MHz extended squitter is substantially better than for the air-to-air case. This is a consequence of the use of substantially higher gain antennas at the ground stations and the ground station receivers are subjected to substantially lower levels of co-channel interference (i.e., fruit) as a result of Earth curvature and other line-of-sight obstructions. Also ground stations equipped with sector antennas are expected to achieve further improvements improved signal strength and reduced interference levels. Furthermore, the networking of multiple ground stations can provide a more robust service with higher effective update rates. The rate at which TC information is broadcast may need to be tailored to satisfy the most important of the operational needs. This could imply that the broadcast rate, and perhaps the information contents of TC messages, be varied depending on the operational environment in which the aircraft is operating. A simple example would be to include an altitude dependency on the types of intent information being broadcast (e.g., TCP+1 only broadcast above a fixed altitude).

O.7 Conclusions

The predicted performance for the reception of Trajectory Change information on 1090 MHz ADS-B is expected to well exceed the DO-242A, Appendix N, guidance on TC+0 Report update rates in low density environments where air-to-air ranges in excess of 100 NM are possible.

For the future nominal LA2020 high density scenario the two simulation models employed for this assessment have produce similar results. Both sets of simulation results indicate that for Class A3 receivers receiving broadcasts from Class A3 transmitters it may be possible satisfy the MASPS guidance for TC+0 reporting at air-to-air ranges of approximately 40 to 50 NM. At longer air-to-air ranges the effective update rate for TC+0 reports would fall below the MASPS guidance, but may prove usable for certain applications to ranges up to 60 NM where TC+0 updates rates of less than 40 seconds may be practical.

The performance for the reception of TC broadcasts from Class A2 systems being received by Class A3 systems is predicted to fall short of the MASPS guidance in the case of the nominal LA2020 scenario. For the case the MASPS guidance on TC report rates is predicted to satisfied at air-to-air ranges to on the order of 20 to 30 NM. However, beyond 30 NM the TC reporting rates may prove to be useful to certain applications at ranges of perhaps up to 40 NM where an TC Report update rate of less than 30 seconds may be possible.

However, in order to support such air-to-air ranges in the nominal LA2020 scenario, and also to support the TC Report complete set of parameters defined in DO-242A, the peak transmission rate for extended squitters would need to be increased above the currently allowed maximum of 6.2 squitters per second. Support for TC+1 would also require an increase in the maximum allow rate for extended squitter transmission.

For the case of an enroute aircraft directly over-flying LAX, the duration of time in which the air-to-air performance would be limited to the above ranges is perhaps 5 minutes or less. This is a consequence of the simulation models only considering the case in which the receiving aircraft in the worst case interference environment (i.e. near LAX). Experience from the 1090 MHz data collection conducted by the FAA in 1999 suggests that the 1090 MHz interference levels peak in the immediate vicinity of LAX and decrease away from this area.

It must be noted that the above analysis and conclusions are based on the air-to-air delivery of TC information in support of airborne based applications. In certain operational environments it may be more appropriate for focus on the air-to-ground delivery of TC information in support of ground-based ATC automation tools, rather than in support of airborne based applications. It is expected that for the air-to-ground delivery of TC messages the desired update rates could be achieved using the 1090 MHz ADS-B system within a future high density environment, such as represented by the LA2020 scenario.