APPENDIX

COMPARATIVE ANALYSIS OF ADS-B LINKS

References

1. Air Navigation Commission — Minutes of the Eleventh Meeting of the 160th Session.
2. AMCP/5-WP/4 "Evaluation of data links for surveillance applications".
3. RTCA, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B*)*, DO-242A, 2002.
4. FAA/Eurocontrol, "Technical Link Assessment Report", March 2001
5. Eurocontrol, "High-Density 2015 European Traffic Distributions for Simulation," 17 August 1999.
6. SCRSP/WGB WP/B/4-18, Revision 2, "Proposed SCRSP Response to AMCP on 1 090 MHz Extended Squitter Performance".
7. RTCA, Minimum Operational Performance Standards for Universal Access Transceiver (UAT) Automatic Dependent Surveillance Broadcast (ADS-B), DO-282.
8. RTCA, Minimum Operational Performance standards for 1 090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B), DO-260A.
9. Eurocontrol, "VM4 timing study"
10. AMCP/8-WP/20, "FAA ADS-B Link Decision".
11. AMCP/7 Report on Agenda Item 2, Appendix B, "Manual on Detailed Technical Specifications for the VDL Mode 4 Digital Link".
12. ICAO Annex 10, Volume IV, "Surveillance Radar and Collision Avoidance Systems".
13. ICAO Annex 10, Volume III, "Communication Systems".
14. RTCA, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B*)*, DO-242, 1998.

1. INTRODUCTION

This document contains a draft comparative analysis of potential automatic dependent surveillance — broadcast (ADS-B) data links as an input to AMCP/8 Agenda Item 3. The analysis has been developed at the request of the Air Navigation Commission [Ref. 1]. The conduct of the analysis was referred to AMCP Working Group C, which was asked to evaluate three links. Two of these links, the 1 090 MHz secondary surveillance radar (SSR) Mode S extended squitter (1 090 ES) and universal access transceiver (UAT), are wide-band links operating in the L-band. The third, VHF data link (VDL) Mode 4, is implemented using multiple narrow-band channels in the VHF band. Due to time and resource limitations, no combination of links was assessed.

The 1 090 ES has been developed as an extension of the SSR Mode S technology, which is going to be widely used for aeronautical secondary surveillance radar applications. Access to the 1 090 MHz channel is randomized, and the channel is shared with current SSR responses to interrogations from ground-based radars and airborne collision avoidance system (ACAS). The data rate used is 1 megabit per second, within a message.

UAT is a transceiver system designed specifically to support the function of ADS-B. In addition to ADS-B, UAT is intended to support uplink broadcast data from ground stations. Access to the UAT medium is time-multiplexed within a 1 second frame between ground-based broadcast services (the first 188 milliseconds of the frame) and an ADS-B segment. While the design presumes time synchronization between ground-based broadcasts to reduce/eliminate message overlap, medium access within the ADS-B segment is randomized. The UAT data rate is approximately 1 megabit/second within a message.

VDL Mode 4 provides a range of communication services including broadcast and point to point, air/ground and air/air. The services include ADS-B. VDL Mode 4 uses two separate 25 KHz global signalling channels (GSCs), with additional channels used in areas with medium to high aircraft density. Access to the VDL Mode 4 medium, within a channel, is time-multiplexed, with a data rate of 19.2 kilobits/second within a message. The self-organizing channel access scheme may reduce the need for higher bandwidth.

The following three sets of criteria have been used to assess the system design and performance:

a) the criteria considered in the assessments of data links for surveillance applications carried out by AMCP Working Group D in preparation to AMCP/5, (see AMCP/5-WP/4 [Ref. 2], also available on the AMCP web site as WGC1/WP12);

b) RTCA ADS-B minimum aviation system performance standards (MASPS) DO-242A [Ref. 3] criteria[1]; and

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[1] At this stage the RTCA MASPS have not been formally accepted by EUROCAE.

c) additional Eurocontrol criteria supplied to the joint FAA/Eurocontrol Technical Link Assessment Team (TLAT) (see Technical Link Assessment Report[2], March 2001 [Ref. 4])

Sections 2, 3, and 4 of this document deal with each of these sets of criteria, respectively. The reader should be aware that development of ADS-B requirements is still ongoing and that the criteria used in this paper were chosen to reflect a current snapshot of this development.

The criteria specified by the three sources may be divided into two categories: system design and system performance. The system design criteria relate to how well the ADS-B data links integrate into the current environment, e.g. the choice of frequency or compatibility with other avionics systems. System performance criteria are designed to describe how well the system will achieve the ADS-B objectives, in terms of the applications it is expected to support.

In order to evaluate system performance, two scenarios were chosen as representative of future environments, a high-density environment and a low-density environment. These two types of environment were chosen to permit comparison of the ADS-B data links in several different air traffic situations.

The high air traffic density scenario is modeled after the Core Europe 2015 scenario, defined in the Eurocontrol document entitled "High-Density 2015 European Traffic Distributions for Simulation," dated August 17 1999 ([Ref. 5]). The distributions and assumptions used in this comparative analysis were taken directly from [Ref. 5]. The scenario includes a total of 2 091 aircraft (both airborne and ground) and 500 ground vehicles.

The low-density scenario was developed to include a total of 360 aircraft and is described in Appendix H of the TLAT report [Ref. 4]. These aircraft are uniformly distributed in the horizontal plane within a circle of 400 nautical miles.

For both scenarios, system performance is determined by evaluating reception of transmitters at ranges up to 150 nautical miles from a victim receiver located at the center of the scenario. This receiver location is selected to provide the most challenging reception environment. The metric to characterize system performance is the "95-95 update time" for state vector and intent information, i.e. the update time selected as follows. For each 10 NM range bin (0 - 10 NM, 10 - 20 NM, etc.) the 95th percentile update time is calculated for each sample aircraft in the bin. Then the 95th percentile aircraft is chosen from among all those in the bin, and this value is plotted as a function of range. Therefore, the metric guarantees that 95% of the aircraft will have an update time at least as good as that shown 95% of the time. This metric does not reflect the disposition of the "other five percent" of aircraft, which do not meet the 95-95 update requirement. This is a limitation of the choice of metric, and variability of the value of the metric and the distribution of the remaining aircraft may be of interest. In order to understand the operational implications of this choice on safety issues, a more detailed analysis of the behaviour of the relevant distributions would be necessary. However, it is not felt that the choice of this metric favours any of the three links over the others, so the

[2] The report is available on the following websites:
www.eurocontrol.int/ads/ and
www.faa.gov/safeflight21/

relative performance of the links should be reflected by comparison to the 95-95 update time. Future assessments may use different criteria.

In an effort to capture as many real-world effects important to the assessment of the system performance of the ADS-B data links as possible, the analysis includes, representations of such effects as follows:

Simulation effects	**UAT**	**VDL Mode 4**	**1 090 MHz extended squitter**
Propagation and other losses	Y	Y	Y
Antenna gains	Y	Y	Y
Propagation delays	Y	Y	Y
Adjacent channel interference (see discussion below)	Y	Y	N[3]
Co-site interference (in and out of band)	Y	In part (for VDL mode 4)	Y
Multiple (self) interference sources	Y	Y	Y
Alternating transmissions between top and bottom antennas (where applicable)	Y	Y	Y
Performance as a function of receiver configuration (e.g. diversity, switched, bottom only) and sensitivity	Y	Y	N
Transmit power variability and configuration	Y	Y	Y
Receiver retriggering	Y	Y	Y
Receiver performance based on bench testing of equipment	Y	Y	Y
Message transmission sequence and information content by aircraft equipage	Y	Y	Y
Ground receiver antenna assumptions to assess maximum range of single ground station	Y	N[4]	N

[3] Adjacent channel interference does not pose an issue for 1090 ES as a result of the spectrum authorizations in the frequency band. However, co-site transmissions within the frequency band by other systems associated with SSR and DME will impact the available reception time for 1090 ES.

[4] For ground surveillance, the VDL Mode 4 concept is based upon a network of interconnected ground stations designed to be scaled to meet future requirements. The requirements for this system were not examined for this study, so this effect was not necessary for the VDL Mode 4 simulations. Using sectorized antennas would reduce the need for expanding the network.

In support of the transition period prior to full implementation of ADS-B, any requirements relating to the operation of Traffic Information Service-Broadcast (TIS-B) services need to be taken into account in order to evaluate the effect on ADS-B performance. These requirements are not covered in RTCA DO-242A [Ref. 3] and there are no established standards as yet for these services. For this analysis, TIS-B has been assumed to provide TIS-B reports only on non-ADS-B targets. In this context, it is expected that the capacity impact of TIS-B implementation is likely to be less than that of ADS-B equipage by all aircraft. Therefore, separate simulation of TIS-B impact on link capacity is deemed to be unnecessary, since its effect is assumed to be minimal.

The interference environment for the UAT assessment includes the simultaneous effects of multiple UAT transmissions, a challenging DME/tactical air navigation (TACAN) environment, an ongoing joint tactical information distribution systems (JTIDS) exercise, and the effects of co-site transmissions of 1 090 MHz and 1 030 MHz systems. For 1 090 ES, the high-density scenario includes a demanding projected ground interrogator environment and ACAS traffic. The VDL Mode 4 analysis includes co-channel and co-site VDL Mode 4 interference and adjacent channel interference permitted by VDL Mode 4 frequency planning criteria.

It is important to note that using the template provided below, each data link has been assessed using the identical assumptions and limitations described above. The intent was for each of the ADS-B data links to be evaluated for the two air traffic scenarios described above and compared against the system performance criteria for each of the sources in Sections 2 - 4. However, the VDL Mode 4 low-density scenario analysis was not done for this study, due to resource and time limitations.

2. AMCP/5 ADS-B CRITERIA

This section assesses the ADS-B data link performance against the criteria, which were considered in [Ref. 2]. Section 2.1 lists these criteria. Section 2.2 presents the assessment of each of the three data links against each of the criteria.

2.1 AMCP/5 WP4 ADS-B criteria

The following list is a summary of the various criteria from [Ref. 2]:

1) Interference Resistance;

2) System Availability;

3) System Integrity;

4) Acquisition Time;

5) Independent Validation of Position;

6) Functional Independence;

7) Autonomous Air-Air Operations;

8) Operational Aircraft Traffic Densities;

9) Operational Domain Radius;

10) Received Update Rates;

11) Barometric Altitude Resolution;

12) Geometric Altitude Resolution;

13) RF Frequency;

14) Antenna Requirements;

15) Spectrum Efficiency;

16) Support to All Classes of Users;

17) Support of Related Applications;

18) Minimal Complexity;

19) Non-Interference with Other Aeronautical Systems;

20) Transition Issues;

21) Fundamental Design: Frequency Band;

22) Fundamental Design: Modulation;

23) Fundamental Design: Multiple Access Technique;

24) Maturity of Technology;

25) ADS-B Related Activities and Time-Scales;

26) Interoperability;

27) Flexibility;

28) Non-Proprietary;

29) Robustness/Fallback States;

30) Future Suitability; and

31) Cost

2.2 Systems performance and compliance

This section provides discussion of the performance and design compliance of the three links with the AMCP/5 criteria specified in section 2.1.

2.2.1 Interference resistance

This section provides an overview of the potential sources of interference that UAT, VDL Mode 4 and 1 090 ES will be exposed to in their respective bands and evaluates the performance of each link in these interference environments. Details of the simulation results for each link are presented in the following sub-sections.

2.2.1.1 UAT interference resistance

In certain geographic areas, UAT may have to co-exist with transmissions from DME/TACAN and joint tactical information distribution system/multifunctional information distribution system (JTIDS/MIDS) Link 16 sources. Link 16 scenarios have been provided in cooperation with the United States Department of Defense (USDOD) and have been applied to all of the performance analysis shown in this document. Various DME/TACAN scenarios provided by Eurocontrol have also been applied to the Core Europe high-density analysis concurrently with the Link 16 interference scenario.

Although the UAT transmission protocol specifies that a transmission begin on one of a fixed number of message start opportunities, propagation delays will cause the arrivals of messages at the victim receiver to be quasi-random. There may be a number of messages overlapping one another, and these overlaps will be for variable amounts of time. This interference is accounted for in the multi-aircraft simulation. Multiple UAT interferers are treated in the receiver performance model by combining their interference levels in a way consistent with bench test measurements. The simultaneous presence of UAT interference, co-/adjacent channel interference, and co-site interference is treated in a detailed fashion by the receiver performance model.

2.2.1.1.1 High-density scenario

The high-density Core Europe scenario used for the ADS-B link comparison is defined in Section 1. This section presents the results of simulation runs which correspond to the assumptions specified for the full complement of 2 091 aircraft and 500 ground vehicles. Results are shown for the victim receiver in two different locations. One location of the victim receiver is at the center of the scenario, while the second is placed at the location EStimated to be the worst case for DME/TACAN interference. The same high-altitude receive aircraft have been used in the simulations for all three ADS-B data links reported here.

2.2.1.1.1.1 Interference sources

In addition to self-interference and co-site interference, co- and adjacent channel interference is provided by DME/TACAN transmissions and JTIDS/MIDS (Link 16) transmissions. All DME/TACANs on 978 MHz are assumed to have been moved to other frequencies, but all potential and planned DME/TACANs on 979 MHz are assumed to have been implemented and transmit at maximum allowed powers. In addition, the Baseline B Link 16 scenario (as defined by the USDOD) is also assumed to interfere with UAT receptions in this environment.

Co-site transmissions of UAT messages, DME interrogations, SSR Mode A/C replies and SSR Mode S interrogation and replies (including ACAS and 1 090 ES messages) are all treated as interference to UAT reception. All of these are labelled as co-site interference, and it is assumed that no UAT reception may occur during any of these co-site transmissions (including a "ramp-up" and "ramp-down" period added to the beginning and end of each co-site transmission).

2.2.1.1.1.2 **Results**

Results are presented in Appendix A as a series of plots of 95% update times as a function of range for state vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. The RTCA DO-242A [Ref. 3] requirements as extended by Eurocontrol are also included on the plots for reference. As pointed out by SCRSP [Ref. 6], RTCA DO-242A does not currently require 90-120 NM state vector update rate performance in high-density areas; however, this may be a future requirement as noted in footnote 10 to Table 3-4(a) of RTCA DO-242A: "It is possible that longer ranges may be necessary. Also, the minimum range required may apply even in high interference environments, such as over-flight of high traffic density terminal areas." In any event, the Eurocontrol criteria (see Section 4) mandate assessment at distances up to 150 NM in future high-density airspace.

Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types. In addition, performance of different transmit-receive pairs is shown at several different altitudes, where appropriate.

Results of the Multi-Aircraft UAT Simulation (MAUS) (see Section 2.2.1.1.1.3) for the high-density scenario are shown in Appendix A, Figure A-1 through Figure A-23, and discussed below.

The results for the high-density scenario shown in Appendix A may be summarized as follows:

- All RTCA DO-242A [Ref. 3] air-air requirements and desired criteria (see Section 3) are met for all aircraft equipage transmit-receive pairs for both state vector, TSR, and TCR0 update rates at all ranges specified by the RTCA DO-242A.

- The Eurocontrol air-air extension to 150 NM for high end air transport class (RTCA DO-242A equipage class A3 equipage (see Section 4) is not met at the 95% level. The 95% level is achieved for State Vector and one TCR to a range of around 125 NM. The 95% level for a second TCR is achieved to 70-75 NM. The current configuration of UAT does not support more than two TCRs.

- All known air-ground update rate criteria are met for all classes of aircraft out to at least 150 NM, in the absence of a co-located TACAN emitter, by using a three-sector antenna. An excursion was run, which included a 10 kW co-located TACAN. It was determined that the TACAN signal at the receiver had to be received at a level that did not exceed -50 dBm, in order for all equipage classes to meet air-ground requirements. This corresponds to an isolation of 40 dB from the receive antenna, in addition to that provided by a 50 foot separation distance and the receive antenna null.

2.2.1.1.1.3 **Discussion**

The MAUS was developed at Johns Hopkins University (JHU)/Applied Physics Laboratory (APL) for the purpose of simulating UAT performance in a scenario with multiple aircraft and interference sources. The treatment of multiple sources of interference by the receiver performance model has been validated by extensive bench testing of minimum operational performance standards (MOPS)-compliant equipment (see Sections K.3 and K.5 of Appendix K of RTCA UAT MOPS RTCA DO-282 [Ref. 7]).

For the high-density scenario, the interference environment included demanding Link 16 and DME/TACAN cases. In all cases, every attempt was made to provide conservative EStimates of the co-channel interference environment.

Several assumptions made for this analysis were different from those made by the TLAT, and these are enumerated for the purpose of clarifying any differences between these results and those in the TLAT report [Ref. 4].

- The receiver performance model used for this study is different from that used by the TLAT. In the intervening time, the UAT MOPS [Ref. 7] were developed, and these standards modified the UAT waveform to make it more resistant to pulsed interference. The receiver performance model used for this study is based on detailed bench testing of MOPS-compliant equipment, while that for the TLAT was based on testing of older equipment. Performance equivalent to that achieved with the MOPS-compliant equipment is required by RTCA DO-282 [Ref. 7] for UAT systems to be certified, so it is appropriate to use that performance standard.

- The TLAT did not consider Link 16 and DME/TACAN interference in its evaluation of UAT performance, while this analysis includes simultaneous interference from both of these in its analysis.

- This analysis also includes transmit powers as defined by RTCA DO-282 [Ref. 7], which differ from those used for the TLAT analysis.

From the results of this study, it is evident that UAT exhibits good performance in interference, even under demanding circumstances, including full equipage at the highest traffic densities, in challenging DME/TACAN environments, and during full-scale nearby military exercises utilizing JTIDS/MIDS links.

2.2.1.1.2 **Low-density scenario**

In addition to the high-density scenario described above, a scenario was also run to represent low-density traffic levels. This scenario is described in section 1. Results of the MAUS runs for the low-density scenario are shown in Figure A-24 and Figure A-25, and discussed below.

The results for the low-density scenario may be summarized as follows:

- All RTCA DO-242A [Ref. 3] air-air requirements and desired criteria are met for all aircraft for both state vector and intent update rates at all ranges specified by RTCA DO-242A (see Section 3).

- The Eurocontrol air-air extension to 150 NM for A3 equipage (see Section 4) is met at the 95% level for State Vector and two TCPs. The current configuration of UAT does not support more than two TCPs.

- All known air-ground update rate criteria are met out to at least 150 NM, in the absence of the co-located TACAN emitter, with the use of a single antenna. An excursion was run, which included a 10 kW co-located 979 MHz TACAN. It was determined that the TACAN signal at the receiver had to be received at a level that did not exceed -30 dBm, in order to meet air-ground requirements. This corresponds to an isolation of 20 dB from the receive antenna, in addition to that provided by a 1 000 foot separation distance. A three-sector antenna would also provide the possibility of successfully achieving the air-ground requirements to 150 NM.

2.2.1.2 **VDL Mode 4 interference resistance**

The VDL Mode 4 system is designed to operate in the very high frequency (VHF) aeronautical band. One VDL Mode 4 global signaling channel (GSC) is expected to be assigned in the upper part of the VHF aeronautical mobile (R) service (AM(R)S) band. A second GSC is expected to be assigned either in the upper part of the AM(R)S band or in the VHF aeronautical radionavigation service (ARNS) band if the latter becomes possible taking into account ITU considerations and the capacity of the VHF ARNS band. Other channels will also be identified on a regional or local basis. Using multiple channels provides additional capacity, and may provide resistance to intermittent interference and fading. For the performance analysis to support this study, it has been assumed that four additional VHF channels have been assigned to support the transmission of ADS-B state vector information.

VDL Mode 4 is designed to accommodate and manage self-interference from multiple VDL Mode 4 stations on a channel. This is achieved primarily with the autonomous self-organizing TDMA (STDMA) protocols, which control reservations and transmissions. In addition, an option for channel resource assignments from a ground station in the most dense airspace environments may be used to help manage self-interference.

2.2.1.2.1 **High-density scenario**

The high-density Core Europe scenario used for the ADS-B link comparison is defined in section 1. This section presents the results of simulation runs which correspond to the assumptions specified for airborne aircraft only (1 941out of the total 2 091 aircraft in the core Europe scenario). For VDL Mode 4, aircraft on the ground and ground vehicles are assumed to be transmitting on channels specifically reserved for that purpose and listened to by approaching aircraft. Therefore, they are not included in the simulations run for this performance study.

2.2.1.2.1.1 **Interference sources**

VDL Mode 4 operations may be subject to harmful radio frequency interference stemming from the keying of nearby transmitters used for air-ground communication functions on a different channel but within the same band; however, this potential interference Mode could be mitigated by the use of appropriate frequency planning criteria and the co-channel interference performance (CCI) characteristics of VDL Mode 4, as well as by the short duration of these events (i.e. the wideband noise burst due to power ramp-up, for a typical ARINC 716 radio, is on the order of microseconds).

Unintentional interference is also unlikely to occur due to human factors considerations (i.e.a pilot unintentionally tuning to a VDL Mode 4 channel will hear digital transmissions, which will indicate that the channel is not useable for voice). Unintentional interference from (and to) correctly-tuned VHF voice and data radios, including but not limited to other VDL Mode 4 radios, may be avoided with suitable receiver filter characteristics and suitable spectrum planning. The draft frequency planning criteria under development by AMCP propose that adjacent channel interference to a VDL Mode 4 channel be limited so as to degrade message success rate by no more than two percent. This effect is included in the simulation results discussed below.

In addition to self-interference (more than one aircraft transmitting in a time slot), co-site interference is provided by on-board transmissions on other VDL Mode 4 channels.

2.2.1.2.1.2 **Results**

Results are shown for a high-altitude victim receiver located at the center of the scenario. The same high-altitude receive aircraft have been used in the simulations for all three ADS-B data links.

Results are presented in Appendix B as a plot of 95% update times as a function of range for state vector updates in Figure B-1. Only a single plot is required for VDL Mode 4, because all aircraft are assumed to be similarly equipped, so there is no distinction between transmit or receive performance on different aircraft equipage classes, and no intent information is being transmitted in the VDL Mode 4 system under analysis. Therefore, only state vector update performance is shown and is valid for all aircraft equipage classes. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. The RTCA DO-242A [Ref. 3] requirements as extended by Eurocontrol are also included on the plots for reference. (See Section 2.2.1.1.1.2 for a discussion of the performance requirement in high-density airspace.)

These results may be summarized as follows:

- RTCA DO-242A [Ref. 3] air-air requirements (see Section 3) are met for all aircraft equipage transmit-receive pairs for state vector update rates between the ranges of 10 - 70 NM. Between three and ten miles range, the jitter in the VDL Mode 4 slot selection process places the 95th percentile time fractionally above the five second RTCA DO-242A requirement, since the transmissions are made every five seconds. Under three miles, the five second nominal transmission rate is insufficient to meet the three second requirement.

- The Eurocontrol air-air extension to 150 NM for high end air transport class (RTCA DO-242A equipage class A3) equipage (see Section 4) is not met at the 95% level. The 95% level is achieved for State Vector to a range of around 70 NM.

- While air-ground performance was not simulated, VDL Mode 4 experts are of the view that all known air-ground update rate criteria can be met for all classes of aircraft out to at least 150 NM, by using a sectorized antenna.

2.2.1.2.1.3 **Discussion**

The VDL Mode 4 simulation and auxiliary programmes were provided by Luftfartsverket (LFV) for use in this study, for the purpose of simulating VDL Mode 4 performance in a scenario with multiple aircraft. The treatment of multiple messages arriving simultaneously at the receiver was handled by applying the measured results of bench testing in the receiver performance model used.

A number of modifications were made to the assumptions which were made by the TLAT, and some of these are listed here, in order to provide clarity in comparing the results of this analysis with that in the TLAT report [Ref. 4].

- The channel management scheme was defined by LFV to balance transmission loads over the four channels. The differences from the TLAT scenario involved reducing the radius of the regional signalling channel (RSC) region and offsetting the line dividing RSC1 and RSC2. These changes were made to more evenly distribute the transmissions among the four channels.

- The aircraft are held stationary to avoid the difficulties inherent in changing reservations and channel switching in the simulation. Additionally, aircraft were held stationary to avoid statistical variations due to limited data available per range bin. The effect of movement is simulated only in the antenna gain calculations, which use the velocities defined in the CE 2015 scenario. This is the same as the TLAT assumed. An attempt was made to determine the effect of motion on the results, but this was not possible in the time frame of this report and will be investigated by Eurocontrol.

- Each transmitter evenly distributes its transmissions in time across all transmit channels. For example, if 12 broadcasts for a given transmitter are to be made on the two GSCs, each channel will have 6 broadcasts evenly distributed with a nominal ten-second gap between transmissions. Furthermore, each transmission between GSC1 and GSC2 will have a nominal five-second gap between them. This is accomplished in the simulation by inputting the nominal slots on each channel in which each transmitter will broadcast. These nominal slot assignments were provided by LFV. In the TLAT, the transmissions across channels were uncoordinated for the simulation and then reassembled in the post-simulation processing.

- Allowed dithering of slots is also an input to the simulation. These were supplied by LFV in the form of dither ratios for each transmitter in each channel. The overall dithering was reduced from the nominal 10% dithering on each channel used in the TLAT. This reduction in dither ratio results from the assumption that the system will control slot selection on the composite four-channel update rate rather than each channel being controlled separately.

- No intent information is being broadcast in the system being analyzed for this study. In the TLAT, one two-slot burst was sent by A3 and A2 aircraft each minute on one of the global signaling channels. The VDL Mode 4 system experts proposed that intent information would be sent on a separate channel, rather than placing the intent load on any of the four channels examined for this study. This would necessitate another channel assignment (along with any required guard channels), as well as an additional receive function for each VDL-4 antenna on the aircraft.

- Aircraft and VDL Mode 4-equipped vehicles located on the ground in the high-density scenario were excluded from the simulation. This was done in the anticipation that their transmissions would be made on a ground or local channel and not on a GSC or RSC. Although this might not require additional receivers on the aircraft, it would require additional local channel assignments.

- There are 120 reserved ground slots per minute on each GSC. These are slots in which no aircraft can transmit. This is one-half of the reserved slots assumed in the TLAT.

- Finally, this study includes a larger statistical sample than the TLAT report, which is reflected in the consistency and smoothness of the results.

The results of this study are consistent with those done by JHU/APL for the TLAT report, although the results are not identical, due to the differences in assumptions. The range for state vector updates is larger than that for the TLAT. This appears to be a result of the decreased channel loading for this study, due to the elimination of intent transmissions and optimisation of the channel management scheme to fit the air traffic scenario. The simulation results also indicate that the STDMA protocols provide for very good slot utilization efficiency for all four channels, which appears to be better than that seen by the TLAT. This may be due to the reduced dither ratios, a result of managing slot selection of the four-channel system, rather than individual channel slot management as was assumed by the TLAT.

In summary, the VDL Mode 4 system analysed here demonstrates interference resistance in the high-density scenario out to a range of 70 NM for state vector updates. The transmission of intent information on a separate channel was not examined for this study.

2.2.1.2.2 **Low-density scenario**

The VDL Mode 4 low-density scenario performance was not examined for this study.

2.2.1.3 **1 090 ES interference resistance**

Owing to the random nature of the 1 090 ES transmission protocol, there may be a number of messages overlapping one another from the perspective of the 1 090 ES receiver, and these overlaps will be for variable amounts of time. This interference is accounted for in the multi-aircraft 1 090 ES simulation. Multiple 1 090 ES interferers are treated in the receiver performance model by combining their interference levels in a way consistent with bench test measurements. The simultaneous presence of 1 090 ES interference, other co-channel interference, and co-site interference is treated in a detailed fashion by the receiver performance model. This treatment of interference by the receiver performance model has been derived from the results of bench testing (see Appendix P of RTCA minimum operational performance standards for 1 090 MHz automatic dependent surveillance — broadcast (ADS-B) DO-260A [Ref. 8]).

2.2.1.3.1 **High-density scenario**

The high-density Core Europe scenario used for the ADS-B link comparison is defined in Section 1. This section presents the results of simulation runs which correspond to the assumptions specified for 2 091 aircraft and 75 ground vehicles. Results are shown for a high-altitude victim receiver located at the center of the scenario. The same high-altitude receive aircraft have been used in the simulations for all three ADS-B data links.

2.2.1.3.1.1 **Interference sources**

The 1 090 MHz spectrum allocation provides dedication of the center frequency to the SSR, ACAS, and Extended Squitter ADS-B systems, and provides notches around 1 090 MHz for JTIDS/MIDS and DME/TACAN operations. Therefore, the RF co-channel interference of interest to ADS-B results from SSR replies, ACAS replies, and ADS-B itself. All of the co-channel interference environment, with the exception of ADS-B, is supplied by a simulation developed by Volpe/TASC.

Co-site transmissions of DME interrogations, SSR Mode A/C replies and SSR Mode S interrogation and replies (including ACAS and 1 090 ES messages) are all treated as interference to 1 090 ES reception. All of these are labeled as co-site interference, and it is assumed that no 1 090 ES reception may occur during any of these co-site transmissions (including a “ramp-down” period added to the end of each co-site transmission).

Prediction of the future interference environment is uncertain at best. Therefore, two Mode A/C interference levels were selected for evaluation in this analysis: 30,000/second and 45,000/second at received signal power levels greater than -84 dBm. The higher interference level of Mode A/C was felt to be a maximum consistent with continued surveillance operations. Interference levels higher than this were believed to be too much for current systems to handle, and would likely provoke responses which would limit increases above this level.

2.2.1.3.1.2 **Results**

Results are presented in Appendix C as a series of plots of 95% update times as a function of range for state vector updates and intent updates, where applicable. The 95% time means that at the range specified, 95% of aircraft will achieve a 95% update rate at least equal to that shown. The RTCA DO-242A [Ref. 3] requirements and Eurocontrol extension are also included on the plots for reference. (See Section 2.2.1.1.1.2 for a discussion of the performance requirement in high-density airspace.)

Since the transmit power and receiver configuration are defined for each aircraft equipage class, performance is shown separately for each combination of transmit-receive pair types analyzed. Results are presented for A3 equipage receivers only, and for both interference environments.

These results may be summarized as follows:

- RTCA DO-242A [Ref. 3] air-air requirements (see Section 3) are met for high-end air transport class (RTCA DO-242A equipage class A3) aircraft equipage transmit-receive pairs for both state vector and TSR update rates at ranges of 40 - 50 NM, depending on the interference environment.

- RTCA DO-242A air-air requirements (see Section 3) are met for RTCA DO-242A equipage class A1 and A2 aircraft equipage transmitters to A3 receivers for state vector update rates at ranges of around 40 NM, and for TSR update rates at ranges of 30 - 40 NM, depending on the interference environment.

- The Eurocontrol air-air extension to 150 NM for A3 equipage (see Section 4) is not met at the 95% level. The 95% level is achieved for State Vector to a range of around of 40 - 50 NM.

- While air-ground performance was not simulated, 1 090 ES experts are of the view that all known air-ground update rate criteria can be met for all classes of aircraft out to at least 150 NM, by using a six-sector antenna.

2.2.1.3.1.3 **Discussion**

The 1 090 ES multi-aircraft ADS-B simulation was developed at JHU/APL for the purpose of simulating 1 090 ES performance in a scenario with multiple aircraft and interference sources. The treatment of interference by the receiver performance model has been modeled on performance supplied by the FAA Technical Center and MIT Lincoln Laboratory for the various receiver categories and interference levels (see Appendix P of RTCA DO-260A [Ref. 8]).

A number of modifications were made to the assumptions used by the TLAT, and some of these are listed here, in order to provide clarity in comparing the results of this analysis with that in the TLAT report [Ref. 4].

- The receiver performance model used for this study is different than that used by the TLAT. In the intervening time, RTCA DO-260A was modified, improving 1 090 ES decoding techniques to make it more resistant to Mode A/C interference. The receiver performance model used for this study is based on detailed simulation of RTCA

DO-260A-compliant equipment, while that for the TLAT was based on testing of older equipment.

- The transmit power distribution for A3 transmitters, which was used for this analysis, was uniform from 53-56 dBm. A3 transmit power was specified in this way to model what is expected to be deployed. However, RTCA DO-260A allows for A3 transmitters to transmit at powers as low as 51 dBm. This corresponds more closely to the transmit power distribution assumed for A2 class aircraft in this analysis; therefore, for a class A3 aircraft with a transmit power near the lower limit of the allowed range, it would be expected that performance would be given by A2 results in this study, rather than A3.

- The Mode A/C levels assumed in this study are lower than those that were used for the TLAT report[5].

- The only intent information broadcast by the 1 090 ES system in this study is TSR. There was insufficient time to examine the transmission of TCRs.

- Seventy-five ground vehicles were assumed to transmitting in the 1 090 ES system. The 1 090 system experts on RTCA SC-186 WG-3 decided that this was more representative of the likely situation, rather than the 500 assumed for the UAT evaluation.

The assumptions causing the main differences between the results presented here and those in the TLAT report are the enhanced decoding techniques and transmit power assumptions, with the improved performance resulting from the enhanced decoding being most important.

Note that the approach used for the 1090 system and approved by SCRSP only requires receipt of a single position or velocity squitter in order to make a complete SV update.

In summary, 1 090 ES can be expected to demonstrate interference resistance to approximately 40 - 50 NM for exchange of state vector and TSR information by high-end air transport category aircraft in the high-density Core Europe 2015 scenario. If Mode A/C interference levels exceed the levels assumed here, then the resulting effect on 1 090 ES interference resistance is likely to be a deterioration of this range.

2.2.1.3.2 **Low-density scenario**

In addition to the high-density scenario described above, a scenario was also run to represent low-density traffic levels. This scenario is described in Section 1.

Results of simulation runs for the low-density scenario are shown in Appendix C.

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[5] This was a decision of SC-186 WG-3, and was based on the assumption that if levels exceeded the maximum of 45,000/sec assumed for this analysis, other systems operating at 1 090 MHz would no longer be able to perform their functions. If rates approach this level, steps would be taken to reduce interrogations from ACAS and SSR.

The results for the low-density scenario may be summarized as follows:

- Air-air requirements and desired criteria are met for all aircraft for both state vector and intent update rates at all ranges specified by the RTCA DO-242A [Ref. 3] (see Section 3).

- The Eurocontrol extension to 150 NM for A3 equipage (see Section 4) is not met at the 95% level. For State Vector the 95% requirement is achieved to a range of 130 NM, and for TSR the range supported is 120 NM. The analyzed configuration of 1 090 ES did not transmit TCRs.

2.2.2 System availability

2.2.2.1 UAT system availability

Presuming no loss of function of transmitting and receiving ADS-B equipment, system performance in the high-density scenario taking into account factors such as interference is as discussed in Appendix A. Under normal operating conditions, UAT requires an accurate source of UTC time, nominally from a GNSS receiver (which may be a GPS receiver).

RTCA DO-282 [Ref. 7] specifies that every airborne installation will maintain the capability of transmitting in the specified ADS-B segment of the frame for at least 20 minutes after loss of UTC time. In addition, all airborne receivers will be able to infer time from available ground broadcasts to ensure that the transmissions will not encroach on the ground segment of the ADS-B frame.

2.2.2.2 VDL Mode 4 system availability

The system availability for VSL Mode 4 is an issue that has to be analysed in a specific implementation context. In general, the VDL Mode 4 architectural design, which foresees a number of operating modes, achieves optimum performance when all stations are synchronized to UTC (primary timing). The system performance in the two fallback modes (secondary and tertiary timing modes) was analysed in the EUROCONTROL VDL Mode 4 timing study [Ref. 9] and was shown that operation in the fallback modes would not have a significant impact on the performance.

In low-density airspace, achieving optimum system capacity is not critical (i.e.the system will continue to operate, and be available, in the absence of accurate time information). In high-density airspace, optimum performance can be facilitated with suitable ground infrastructure which will provide the source of accurate timing. There is no inherent impact to VDL Mode 4 system availability due to its architecture. In addition, because of the low power requirement of VDL Mode 4 avionics, these radios can be placed on the emergency power bus without significantly affecting battery requirements and are, therefore, immune to onboard power failures.

2.2.2.3 1 090 ES system availability

The underlying technology of the 1 090 ES, the Mode S system, currently meets performance requirements for surveillance system availability.

2.2.3 System integrity

2.2.3.1 UAT system integrity

UAT message integrity is based on the performance of the Reed Solomon (RS) codes used by the various message types of UAT. The basic ADS-B message is a RS (30, 18) code word; the Long ADS-B Message is a RS (48,34) code word; and the Ground Up link message is six RS (92, 72) code words. These codes provide very strong error correction. Also, the error detection provided by these codes is sufficient to guarantee a maximum undetected error rate that is less than 10^{-8} for each of the message types.

The table below gives the maximum undetected message error rates (achieved when the channel bit error rate is 0.5) for each UAT message type:

Table 2.2.3-1: UAT maximum undetected RS message error rates

Message type	Maximum undetected message error rate
Basic ADS-B	2.06e-9
Long ADS-B	9.95e-10
Ground uplink	5.74e-12

2.2.3.2 VDL Mode 4 system integrity

The VDL Mode 4 system uses the 16bit cyclic redundancy check (CRC) code and independent cross-checks on transmitter ID and reported state vector changes relative to previous messages to meet integrity requirement for probability of receiving a message with an undetected error = 10^{-7}. MOPS requirements enforcing this cross-check need to be identified. Further information on VDL Mode 4 is provided in AMCP/5WP4/Appendix B [Ref. 2].

2.2.3.3 1 090 ES system integrity

The 1 090 ES system provides a 24-bit cyclic redundancy code (CRC) which provides a level of protection against undetected errors in an extended squitter message. Additional protection is provided in receiving ADS-B avionics to ensure that system integrity is at required levels. See Sections 1.2.3 and 2.1.9 in RTCA DO-260A [Ref. 8].

2.2.4 Acquisition time

Acquisition time is defined as the time required, from initial power ON or initial access to a channel (if relevant), until the first full ADS-B report is delivered to a receiving end system. This parameter may depend on the transmit and receive avionics, the assumed channel loading and ground infrastructure.

2.2.4.1 UAT acquisition time

In an interference-free or low-density environment, the UAT system would be expected to acquire another UAT transmitter within a few transmission epochs. Since UAT transmits a complete set of information in one four-second epoch, this translates to a maximum of around ten seconds. For acquisition in the high-density air traffic scenario, see Section 3 and Appendix A. In a high-density scenario, the acquisition times will generally be less than thirty seconds.

2.2.4.2 VDL Mode 4 acquisition time

For VDL Mode 4, a mobile user normally collects data on the GSCs for 60 seconds prior to transmitting. This is normally done following power ON, before the aircraft has moved or entered the movement area of an aerodrome. When a quicker entry is required, the rapid network entry (RNE) procedures may be used to provide an entry time of 3.5 seconds, resulting from the operation of protocols specified in the ICAO provisions. The stated RNE performance has been validated by simulations carried out as part of a project for Eurocontrol.

Air-to-air acquisition as aircraft converge at range, particularly at high-density scenarios needs further evaluation. While there are no specific criteria which address network entry, this is a topic of importance for VDL Mode 4 and is treated in this section. Operations on the GSCs involve a 10 second update rate and an ID burst once per minute (a ratio of 6:1). The acquisition time would thus be on the order of minutes (this would typically occur while the aircraft is still at the gate).

2.2.4.3 1 090 ES acquisition time

The 1 090 ES system transmits a complete set of information in around five seconds. In an interference-free or low-density environment, a 1 090 ES ADS-B receiver might expect to acquire another 1 090 ES participant within a few of these transmission cycles. Receipt of both an odd and even position message is required, along with the other information, so this would lead to an estimate for acquisition time in a low interference environment of around 15 seconds. For acquisition in the high-density air traffic scenario, see Section 3 and Appendix C.

2.2.5 Independent validation of position

2.2.5.1 **UAT system independent validation of position**

RTCA DO-282 [Ref. 7] contains timing requirements related to both the transmission of ADS-B Messages and reception of ADS-B and ground uplink messages. The primary objective of these requirements is to support a range measurement between ADS-B transmitting and receiving subsystems that is independent of the ADS-B reported position data. Time of message transmission is explicitly encoded in every fourth transmitted ADS-B message. Due to the pseudo-random nature of ADS-B transmissions that always occur on a limited number of message start times, the time of message transmission can be inferred for every UAT ADS-B message. Flight tests with UAT equipment purchased for the FAA Capstone programme has demonstrated that this equipment can support a time-based range measurement that is within 0.2 NM of that as determined from ADS-B.

2.2.5.2 **VDL Mode 4 system independent validation of position**

The timing accuracy requirements (400 nanoseconds to 20 microseconds) of the VDL Mode 4 transmissions support the verification of the range information reported in a transmission (passive range measurement). These timing accuracies correspond to range accuracies ranging from 0.06NM to 3.24 NM (see Eurocontrol VDL Mode 4 Timing Study [Ref. 9]). The accuracy depends on the timing mode in the sending and receiving units. Information on this time accuracy is available via the ADS-B reports and hence the expected accuracy for ranging can be determined by the receiving station.

2.2.5.3 **1 090 ES system independent validation of position**

1 090 ES ADS-B reported positions may be independently validated by ACAS-equipped aircraft within the ACAS operational range. There are several possibilities for position validation by 1 090 ES ground stations. With the use of sector antennas, as proposed for high-density terminal and long-range en route sites, it is possible to determine an estimate for the azimuth of the target aircraft, based upon the number of sectors. A second approach would make use of a possible addition of a 1 030 MHz transmit capability to the ground station that would be used to perform discrete interrogations of the associated Mode S transponder to validate a newly acquired ADS-B target. A third potential technique would be to compare the ADS-B reported position with surveillance information from an independent surveillance source, such as an SSR or from a multi-lateration system, which would require integration with the 1 090 ES ground stations. An independent validation mechanism for non-ACAS equipped aircraft outside of SSR coverage has not yet been developed.

2.2.6 **Functional independence**

Aviation systems are typically developed to support one or another of the three functional areas of communications, navigation and surveillance. From a safety standpoint, it is important that aviation systems avoid a failure Mode whereby loss of one of these three elements (i.e. communications, navigation or surveillance) leads directly to the loss of another.

2.2.6.1 **UAT functional independence**

The ADS-B concept (and hence all ADS-B data links) relies on a navigation input to an ADS-B transmitter. Additionally, UAT transmitters do rely on timing information to support precise control of ADS-B message transmission time to support independent range validation (see above). Timing with the precision to support independent range validation will require delivery of timing via GNSS. However timing information sufficient to support basic UAT media access is readily available without GNSS so that no degradation in channel throughput performance would occur.

Moreover, UAT is not proposed as a replacement for any communication or navigation element on board the aircraft. And although UAT does support uplink broadcast of FIS, it does this by preserving a permanently dedicated channel resource for ADS-B. Furthermore, UAT ADS-B installations would likely have no hardware elements in common with the ACAS system, minimizing any common-point failure scenarios between ACAS and ADS-B.

2.2.6.2 **VDL Mode 4 functional independence**

The ADS-B concept (and hence all ADS-B data links) relies on a navigation input to an ADS-B transmitter. VDL Mode 4 also requires timing information, generally derived from GNSS, although alternative timing sources may be used in the event of GNSS failure.

VDL Mode 4 has no common components with current surveillance systems (SSR transponder, ACAS). In particular, VDL Mode 4 installations would have no hardware elements in common with the ACAS system, minimizing any common-point failure scenarios between ACAS and ADS-B.

When a VDL Mode 4 airborne station is operating in high-density airspace (qualitatively similar to airspaces with radar coverage today), the service provider can ensure an independent ability to navigate and derive system time to the accuracy needed to maintain near optimal data link system performance. This also ensures continued surveillance without reliance on radar. One way ranging and 2D multi-lateration are also possible. Note that, with multiple ground stations, secondary navigation and normal ADS-B reporting is expected to be operationally superior to multi-lateration.

The VDL Mode 4 system typically relies on GNSS to optimize the use of the channel, but can operate in the complete absence of positioning and time information with a loss of efficiency. This degradation is not significant in remote airspace. When required, sync bursts from ground-based VDL Mode 4 stations (e.g. intra-system signalling) can be used to derive position and time such that no loss of efficiency is incurred and air-to-air surveillance can be maintained.

2.2.6.3 **1 090 ES functional independence**

The ADS-B concept (and hence all ADS-B data links) relies on a navigation input to an ADS-B transmitter. The 1 090 ES does not rely upon precise timing that can only be provided by GNSS. While 1 090 ES implementation can take advantage of legacy Mode S avionics, this ADS-B alternative can be implemented in a manner independent of the SSR system.

2.2.7 Autonomous air-air operations

2.2.7.1 UAT autonomous air-air operations

UAT fully supports autonomous air-air operations to the ranges shown in Section 3 in all scenarios examined (see also Appendix A).

2.2.7.2 VDL Mode 4 autonomous air-air operations

VDL Mode 4 supports both autonomous and directed operations. Autonomous operations for VDL Mode 4 are typically confined to the global signalling channels, and autonomous reporting rates remain at nominal/default values (nominally once per 10 seconds). See Section 3 and Appendix B for ranges of application.

2.2.7.3 1 090 ES autonomous air-air operations

1 090 ES supports autonomous air-air operations to the limits imposed by its effective range in the air traffic scenarios considered, due to the random nature of its transmission protocols and the ADS-B system integrity supported. See Sections 2.2.1.2 and 3 and Appendix C for ranges of application.

2.2.8 Operational air traffic densities

2.2.8.1 UAT operational air traffic densities

In Section 2.2.1.1, UAT was shown to meet all air-air update requirements for all but high-end class aircraft in the most demanding high-density operational aircraft traffic density environment expected by 2015 (2 091 total aircraft within 300 NM). For the high-end aircraft, UAT was within the required update rates to a range of 120 - 125 NM. It also met all expected air-ground update requirements for ground surveillance of all aircraft classes to past 150 NM. In high-density air traffic areas as ADS-B equipage with UAT becomes widespread, it will be necessary to tune on-channel DME/TACAN transmitters to other frequencies, in order to achieve optimum UAT system performance. However, adjacent channel DME/TACAN transmitters will not cause system performance to fall below requirements

2.2.8.2 VDL Mode 4 operational air traffic densities

VDL Mode 4 is a multiple channel system. Therefore, the performance of the VDL Mode 4 system in the considered scenarios is dependent on the number of operational channels.

The performance of VDL Mode 4 using the 2+2+2 channel scheme implemented for this study (2 global channel, 2 regional channels and 2 local channels) is provided in Section 2.2.1.2 and Appendix B. For the high-density scenario VDL Mode 4 was within the required update rates to a range of around 70 NM for state vector updates. These results apply to all aircraft equipage types, since the VDL Mode 4 system specifies that all aircraft have the same receiver capabilities, including full receiver diversity.

2.2.8.3 1 090 ES operational air traffic densities

In Section 2.2.1.3, results for 1 090 ES in the most demanding high-density operational aircraft traffic density environment expected by 2015 are presented. For the high-end air transport class aircraft, the required state vector update rates were achieved to a range of 40 - 50 NM, while for low-end transport and upper-end GA aircraft, the ranges achieved were 40 NM.

2.2.9 Operational domain radius

2.2.9.1 UAT operational domain radius

In the absence of interference, the UAT link budget calculation indicates that a minimum transmit power A0/A1L category aircraft can be received at a range of about 50 NM, an A2 at about 74 NM, and an A3 at about 186 NM (Reference RTCA DO-282, Appendix F). In Section 2.2.1.1, it was shown that, under the severe interference high-density air traffic scenario, A0 aircraft were received at greater than 10 NM, A1 at greater than 20 NM, A2 at greater than 40 NM, and A3 at around 125 NM. The ranges achieved are sufficient for these categories of aircraft to perform all applications currently envisioned for them.

2.2.9.2 VDL Mode 4 operational domain radius

In the absence of interference, the VDL Mode 4 link budget calculation indicates that a minimum transmit power aircraft can be received at a range of about 200 NM. This range is the same for all aircraft, since the system specified for this study requires that all aircraft transmit with the same power. In Section 2.2.1.2, it was shown that, under the high-density air traffic scenario, state vector information transmitted by an aircraft equipped with VDL Mode 4, using the channel management system specified, is expected to be received at a sufficient rate between the ranges of 10 - 70 NM. Although intent information is not available in the system analysed for this study, this range for state vector updates is sufficient for aircraft to perform many of the applications currently envisioned.

2.2.9.3 1 090 ES operational domain radius

In the absence of interference, the 1 090 ES link budget calculation indicates that a minimum transmit power A0 category aircraft can be received at a range of about 14 NM, an A1 at about 21 NM, an A2 at about 38 NM, and an A3 at about 67 NM (RTCA DO-260A [Ref. 8], Appendix E). In Section 2.2.1.3, it was shown that, under severe interference high-density air traffic scenario, A1and A2 category aircraft can be received at 40 NM, and A3 at around 40 - 50 NM. This range is sufficient for aircraft to perform many of the applications currently envisioned. Note that as a result of the FAA ADS-B link decision [Ref. 10], equipage class A0 1 090 ES avionics is not expected to be used in the U.S.

2.2.10 Received update rate (air-ground and air-air)

For a discussion of this criterion, see Sections 2.2.1 and 3.

2.2.11 Barometric altitude resolution

2.2.11.1 UAT barometric altitude resolution

The UAT ADS-B message structure supports reporting barometric altitude over the range of -1 000 feet to 101 325 feet to a resolution of 25 feet.

2.2.11.2 VDL Mode 4 barometric altitude resolution

The VDL Mode 4 message structure supports reporting barometric altitude with the following resolution:

Altitude in feet	**Resolution in feet**
-1 300<altitude<8 000	10
8 000<altitude<72 000	25
72 000<altitude<130 000	100

The VDL Mode 4 supports reporting of one primary altitude (either barometric or geometric) and the reporting of the offset of the other altitude to the primary altitude. The resolution of the reported offset is 50 ft when the primary altitude is below 24 000 ft and 100 ft when it is above.

2.2.11.3 1 090 ES barometric altitude resolution

The 1 090 ES ADS-B message structure supports reporting barometric altitude over the range -100 feet to 50 175 feet to a resolution of 25 feet. For altitudes above 50 175 feet, the resolution is 100 feet.

2.2.12 Geometric altitude resolution

2.2.12.1 UAT geometric altitude resolution

The UAT ADS-B message structure supports reporting geometric altitude over the range of -1 000 feet to 101 325 feet to a resolution of 25 feet. Additionally, UAT supports reporting of geometric altitude as a “Secondary” altitude simultaneously (at a lower update rate) with barometric altitude.

2.2.12.2 VDL Mode 4 geometric altitude resolution

The VDL Mode 4 message structure supports reporting of geometric altitude resolution with the same resolution as defined for the barometric altitude (see previous section).

2.2.12.3 1 090 ES geometric altitude resolution

When barometric altitude is the primary altitude being reported, geometric altitude is reported as GNSS Height Above the Ellipsoid, with a resolution dependent upon altitude, which is the same as that described in Section 2.2.11.3.

2.2.13 RF frequency

2.2.13.1 UAT RF frequency

Because of the safety aspects of surveillance operations, some national policies require that surveillance operations occur in frequency bands that are protected for aeronautical radionavigation service (ARNS). The UAT is being approved for operation in the United States at 978 MHz, part of the 960 - 1 215 MHz ARNS band. Since the UAT is proposed for international operation at 978 MHz, the UAT operating frequency is suitably protected to support critical surveillance applications. Suitability for UAT to operate in the 960 - 1 215 MHz band under existing allocations is being reviewed in certain States.

The 978 MHz frequency is currently allocated to DME and TACAN. In part, because radio regulations define use of 978 MHz for DME/TACAN for emergency use, only seven operational DME/TACAN stations have been identified worldwide as operating on 978 MHz. All seven of these stations are in the ICAO European region.

Operational impact on the use of UAT on the surface of a co-located 979 MHz (1 MHz offset) DME/TACAN ground station remains under review.

2.2.13.2 VDL Mode 4 RF frequency

VDL Mode 4 SARPs specify operation in the VHF AM(R)S band. In addition the operation in the VHF ARNS band is recommended. In order for the latter to be enabled the relevant discussions in ITU should conclude favorably.

Frequencies for VDL Mode 4 in Europe have been proposed by Eurocontrol. The plan anticipates placing the VDL Mode 4 frequencies at the top of the VHF AM(R)S band and has been approved by the ICAO EUR Frequency Management Group (FMG) in Europe.

It is uncertain at this time whether VDL Mode 4 will be permitted to use frequencies in the VHF ARNS band. The proposal to the FMG included two frequencies in the upper VHF AM(R)S band and two frequencies in the VHF ARNS band. The European planning activity is proposing four channels for VDL Mode 4 use.

For the performance analysis in the high-density air traffic scenario presented in this study, with transmission rates as set by the VDL Mode 4 experts participating in this analysis, four channels were required for air-to-air state vector transmissions alone. A realistic single-link VDL Mode 4 ADS-B system for this scenario would require 3 - 4 additional channels to support ADS-B surface operations, higher ADS-B broadcast rates for aircraft on approach, and long range air-to-air and air-to-ground deconfliction applications. This analysis assumed eight VDL Mode 4 receivers cards per aircraft (four per antenna).

2.2.13.3 1 090 ES RF frequency

The 1 090 MHz frequency has been approved for 1 090 ES operation on a global basis. Because of the safety aspects of surveillance operations, some national policies require that surveillance operations occur in frequency bands that are protected for aeronautical radionavigation service (ARNS). Operational impacts on radar systems of the transmission of extended squitters on the surface and outside of the movement areas of airports remain under review.

2.2.14 Antenna requirements

2.2.14.1 UAT antenna requirements

Depending on the UAT equipment class of the installation, UAT will require either one or two antennas. The type of antennas currently in use on civil aircraft for either DME or transponder operation will perform well for UAT. Furthermore, testing of two separate commercially available diplexer devices is underway at FAA Technical Center. It is expected that these diplexer devices will allow sharing of the existing transponder antenna(s) with UAT. This could be especially applicable for air-carrier installations where the transponder antenna network includes top and bottom antennas and manages access to redundant transponders (ADS-B systems).

Additionally, one major equipment manufacturer has investigated an antenna sharing implementation for a new transponder/UAT integrated implementation and has indicated that such an implementation is feasible.

2.2.14.2 VDL Mode 4 antenna requirements

The VDL Mode 4 system is expected to be implemented using one or two antennas. A single antenna installation is typical for a ground vehicles, gliders, small general aviation etc. A two-antenna installation is typical for general aviation and air transport. A two-antenna configuration could use both antennas for receiving and one or both for transmitting. It may be possible to share antennas with other VHF systems, but this needs to be analysed in specifying an overall airborne architecture.

For the performance analysis in the high-density air traffic scenario presented in this study, it was assumed that all aircraft were equipped with two antennas, one on top and one on the bottom, and that both were used for receiving and that transmissions alternated between the two.

2.2.14.3 1 090 ES antenna requirements

Antenna requirements for 1 090 ES on air transport class aircraft will generally be met by existing transponder/TCAS antennas. Antenna guidance for general aviation aircraft is provided in RTCA MOPS. The 1 090 ES antenna requirements are provided in Section 2.2.13 of RTCA DO-260A [Ref. 8], and the antenna characteristics are defined in Appendix C of RTCA DO-260A.

2.2.15 Spectrum efficiency

2.2.15.1 UAT spectrum efficiency

The ICAO 960 - 1 215 MHz channel plan divides the band into distinct 1 MHz paired channels (i.e. 1 MHz for the uplink signal and 1 MHz for the downlink signal). Due to its use of spectrally efficient frequency shift keying (FSK) modulation, the UAT requires a single 1 MHz channel to meet combined uplink/downlink ADS-B and TIS-B requirements even in the most stringent and challenging ATC environments. In addition, that single channel will also provide 32 assignable “sub-channels” for uplink of broadcast messages such as FIS-B. Because of the format of the ICAO channel plan, utilization of the 978 MHz frequency (uplink for channel 17X) for UAT does not preclude the use of the paired 1 041 MHz (downlink for channel 17X) frequency, as that frequency is also used as part of the 17Y (1 041/1 104 MHz) pair.

2.2.15.2 VDL Mode 4 spectrum efficiency

The STDMA technique and multi-channel concept provide flexible alternatives for implementing VDL Mode 4 with spectrum efficiency in mind. When an entire 25 kHz channel is used to its maximum capacity, a new channel can be allocated to cope with a more demanding air traffic scenario.

The VDL Mode 4 system spectrum efficiency in terms of bits per second per Hz of channel bandwidth also depends on the number of guard bands that may need to be used. The number of guard channels required will be specified by compliance with VDL Mode 4 frequency planning criteria currently being developed by AMCP. Draft frequency planning criteria propose that adjacent channel interference to a VDL Mode 4 channel be limited so as to degrade message success rate by no more than two percent. (This metric would imply that the maximum message success rate for VDL Mode 4, independent of range, would need to be less than 98%.)

Note that studies should be performed to determine if it is possible for additional uplink broadcast services, such as FIS-B and TIS-B to be accommodated in the guard bands located between the channels allocated for air/air and air-ground services. This would have the potential to enable efficient spectrum utilization.

2.2.15.3 1 090 ES spectrum efficiency

The 1 090 ES system shares already allocated aeronautical spectrum and in fact improves the utilization of that spectrum by providing additional services therein. The additional interference caused by ADS-B transmissions on 1 090 MHz is not projected to produce a material impact on the operation of the SSR or ACAS systems.

2.2.16 Support to all classes of users

2.2.16.1 **UAT support to all classes of users**

UAT is expected to support the full range of users with no special installation constraints that would limit its adoption. RTCA DO-282 [Ref. 7] addresses a range of equipment classes to tailor UAT equipment to the appropriate cost/performance combination for each class of potential user. In addition, as described in Sections 1 and 15, UAT has been shown to be resistant to the numerous co-site transmissions on 1 030 and 1 090 MHz, and tests are ongoing into the possibility of shared L-band antennas.

2.2.16.2 **VDL Mode 4 support to all classes of users**

VDL Mode 4 is expected to be available to all classes of users. The low power requirements support the low-end category of users (ground vehicles, gliders, etc). For example, recent airport surface testing at London Heathrow has confirmed advantages of using the VHF band referred to in section 2.2.30.2.

2.2.16.3 **1 090 ES support to all classes of users**

The 1 090 ES system has been designed to support the full spectrum of aviation users (see Section 2.1.11 of RTCA DO-260A [Ref. 8]). Cost implications of the system for general aviation were a factor in the July, 2002 FAA ADS-B link decision [Ref. 10], which discusses the choice of UAT as the general aviation ADS-B link within the U.S. National Airspace System.

2.2.17 **Support of related applications**

2.2.17.1 **UAT support of related applications**

UAT has specifically been designed to attempt to support, in both today's and future high-density airspaces, the air-to-air and air-ground ADS-B applications in industry ADS-B system-level documents including the Minimum Aviation System Performance Standards for ADS-B developed by RTCA Special Committee 186, the Free Flight Operational Enhancements proposed by the RTCA Free Flight Select Committee, and air-ground applications articulated by Eurocontrol during the Technical Link Assessment Team effort. UAT complies with 225 of 228 RTCA DO-242A [Ref. 3] requirements and offers near-compliance with the remaining three. UAT further fully meets one of three Eurocontrol additional criteria and partially meets another. Assessment of the UAT against the technical requirements mentioned above is provided in Sections 3 and 4 of this paper as well as in Appendix A. UAT is intended to support other applications, such as those discussed in Appendix E of RTCA DO-242A.

Additionally, the Ground Uplink Segment of UAT was designed expressly to support surveillance- and situational awareness-related broadcast services such as Traffic Information Service-Broadcast (TIS-B) and Flight Information Service-Broadcast (FIS-B). UAT has been assessed as supporting all mandatory requirements of the Minimum Aviation System Performance Standards for FIS-B published by RTCA in 2001.

2.2.17.2 **VDL Mode 4 support of related applications**

VDL Mode 4 offers the potential and flexibility to support multiple applications since it is a channelized system (different applications can be separated onto different channels), and is designed to support communications, navigation and surveillance applications. For example the system supports both air-ground and air-air point to point communications services.

Even though VDL Mode 4 supports reception/transmission on different channels for different services this is not a necessity. In both high- and low-density airspace a well-planned, interconnected ground infrastructure can optimize the channel usage.

2.2.17.3 **1 090 ES support of related applications**

The 1 090 ES system can directly support hybrid surveillance, a technique which uses the receipt of ADS-B information to improve the spectrum efficiency of ACAS. Furthermore, 1 090 ES uses the overall Mode S message frame structure, the most similar message format being Comm B; therefore, there is a synergy between Extended Squitter and Mode S Data Link equipage.

2.2.18 **Minimal complexity**

2.2.18.1 **UAT minimal complexity**

The TLAT agreed that the UAT has the simplest technical concept among the three links (TLAT report [Ref. 4] Section 5.1.2). The following attributes of UAT allow it to be implemented with a minimal amount of complexity:

- No tracking or message assembly required to generate ADS-B reports;
- No latitude/longitude decompression or ambiguity resolution is required;
- No channel sensing required for performing media access; and
- No channel management or tuning required

2.2.18.2 **VDL Mode 4 minimal complexity**

VDL4 has a simple control architecture for low density airspace regions. For high density regions VDL4 has a moderate complexity control arch using ground protocols to manage the assignment of channels for bdcst services. This is handled by broadcasting Directory of Service messages in the Global Signaling Channels (GSCs).

2.2.18.3 **1 090 ES minimal complexity**

The 1 090 ES system has moderate to high complexity, because of properties of the legacy systems with which it must interoperate. On the other hand, this complexity is in most cases well understood, because of extensive operational experience with these legacy systems. The addition of a 1 090 ES capability to a Mode S transponder introduces modest additional complexity.

2.2.19 **Non-interference with other aeronautical systems**

2.2.19.1 **UAT non-interference with other aeronautical systems**

The UAT has been designed to operate at 978 MHz, in the lower portion of the 960 - 1 215 MHz ARNS band. This band is extensively used throughout the world for DME and TACAN. The band is also utilized in some States on a non-interference basis by the military JTIDS/MIDS. Recognizing this heavy use, UAT has been specifically tailored - through matched hardware filters, and extensive digital error-correction coding - to be compatible with high-density pulsed environments. Coupled with the selection of a UAT center frequency (978 MHz) that is unused for DME/TACAN in much of the world due to difficulties protecting its paired VHF omni-directional range (VOR) frequency from FM broadcast stations[6], testing/analysis has confirmed that the UAT can be introduced to the band with no change required to either DME/TACAN "ramp tester" utilization or JTIDS/MIDS operations. Furthermore, DME/TACAN testing has shown that acceptable operational DME/TACAN performance will be maintained for co-channel (978 MHz) DME/TACAN assignments even in the presence of high-density UAT environments, and that UAT performance is achieved in the presence of high-density co-channel DME/TACAN in low-density UAT self-interference environments. Note that while future UAT performance will ultimately require vacating some number of the 7 European 978 MHz operational DME/TACAN assignments, the robust nature of the UAT signal, together with its non-interference to DME/TACAN applications, will greatly ease system transition in those limited geographic areas where 978 MHz is used for DME/TACAN.

Whilst a suitable frequency seems likely to be available in the USA, the European situation is more complex. The ECAC navigation strategy foresees the long-term use of DMEs to support GNSS in providing a harmonised area navigation environment. This will require significant deployment of new DMEs in Europe, in particular within terminal areas. The current estimate is that 180 - 200 new DMEs will be required by 2010. Assignment of UAT to 978 MHz in Europe will need to be coordinated with execution of this ECAC navigation strategy which itself will need to be reconciled with current radio regulations for the use of 978 MHz by DME/TACAN. The performance analysis for this study accounted for all currently planned DME/TACAN allocations.

Additionally, the single-aircraft UAT duty cycle is .0004, which provides a low level of co-site interference to other systems.

[6] In particular ICAO Annex 10 notes, "108.0 MHz is not scheduled for assignment to ILS service. The associated DME operating channel No. 17X may be assigned for emergency use."

2.2.19.2 **VDL Mode 4 non-interference with other aeronautical systems**

VDL Mode 4 will operate in the VHF aeronautical band on dedicated channels. The frequency planning criteria should address the interference issue to systems (VDL Mode 4 and others) operating in adjacent channels. Section 2.2.1.2.1.3 states that the analysis done for this report allows for the accepted level of adjacent channel interference. The analysis also assumes no other interference of any sort.

2.2.19.3 **1 090 ES non-interference with other aeronautical systems**

The "notching" of the 1 090 MHz frequency with regard to frequency allocation of services other than SSR and ACAS substantially mitigates any interference by 1 090 ES with the operation of such other systems. The operation of 1 090 ES is not projected to materially affect the performance of the SSR and ACAS systems. With regard to co-site interference by 1 090 ES on other L-band aircraft systems, responses to interrogations by SSR and TCAS take precedence over the transmission of 1 090 ES. The duty cycle of 1 090 ES is at worst on the order of .001. This low duty cycle, in conjunction with standard mutual suppression techniques, implies that co-site interference of 1 090 ES should have no material operational impact.

2.2.20 **Transition issues**

All ADS-B link will require new aircraft equipment and ground infrastructure. The transition process must take into account timescales for the introduction of ADS-B applications by air navigation service providers and aircraft equipage. TIS-B is an important application to support the transition process.

2.2.20.1 **UAT transition issues**

The design of the UAT Ground Uplink Segment furnishes an alternative implementation of transition services such as TIS-B that provides no interference to UAT transmissions from equipped aircraft, should such an alternative implementation become necessary in high-density airspace. The proposed UAT frequency of 978 MHz is, on a worldwide basis, populated by only 7 DME/TACAN assignments. Investigation of the use of a diplexer to permit the sharing of existing transponder antennas by UAT avionics is being undertaken.

2.2.20.2 **VDL Mode 4 transition issues**

The protocol stack of VDL Mode 4 enables Ground-to-Air services (e.g. TIS-B) to be transmitted in either the pre-protected slots of the VDL Mode 4 timeframe or in protected slots assigned dynamically. It is also possible to transmit on dedicated channels.

2.2.20.3 1 090 ES transition issues

The 1 090 ES system has specific attributes that support transition to ADS-B in several important ways. First, early operational implementation of ADS-B on a worldwide basis can be supported at present, because of the worldwide frequency allocation and SARPS for the 1 090 ES system. In large part because of this attribute, as well as the synergy between 1 090 ES and existing SSR/ACAS avionics, the 1 090 ES system has been selected by the FAA and is under consideration by Eurocontrol as the near-term ADS-B link for ADS-B implementation that is interoperable between the United States and Europe. The 1 090 ES system also supports TIS-B.

Both Boeing and Airbus are expected to deliver their new commercial air transport aircraft with 1 090 ES installed beginning in 2003, using the initial 1 090 ES MOPS (DO-260 [Ref. 8]) as a baseline (see 2.2.25.3 below). TCAS/ACAS manufacturers are either currently shipping or have plans to offer by 2003 avionics that also incorporate 1 090 ES capability.

2.2.21 Impact of fundamental design: frequency band

2.2.21.1 UAT impact of fundamental design: frequency band

The ICAO 960 - 1 215 MHz channel plan divides the band into distinct 1 MHz paired channels (i.e. 1 MHz for the uplink signal and 1 MHz for the downlink signal). This supports designs like the UAT that utilize high burst rate, unscheduled transmissions on a single channel. The choice of frequency band for UAT has beneficial cost impacts as discussed in Section 2.2.31.1. The UAT has been designed to operate compatibly with existing users of the band, and from a regulatory standpoint, at least one Administration's responsible agency has made a preliminary ruling that UAT is an acceptable use of the band under the existing provisions for "electronic aids to airborne navigation" as contained in S5.328 of the International Telecommunications Union (ITU) Radio Regulations.

2.2.21.2 VDL Mode 4 impact of fundamental design: frequency band

VDL Mode 4 operates in the VHF aeronautical band. As a result, it is a 25 KHz system and the choice of this band provides long-range performance using low power transmissions, while necessitating multi-channel operation in high-density airspace.

The radio wave propagation characteristics in the VHF band make VDL Mode 4 well suited to operation in all phases of flight, including operations on the ground. The recent trials at Heathrow have indicated that good results are obtained with VDL Mode 4 for surface operations.

2.2.21.3 1 090 ES impact of fundamental design: frequency band

The frequency band in which 1 090 ES system operates provides wide channelization (8 MHz band allocation), which is well-suited to broadcast services.

2.2.22 **Impact of fundamental design: modulation**

2.2.22.1 **UAT impact of fundamental design: modulation**

The UAT uses continuous phase frequency shift keying modulation. The continuous phase aspect limits the bandwidth of the transmitted signal, while frequency shift keying supports simple, cost-effective receiver and transmitter equipment, as no knowledge of the phase of the carrier (i.e. carrier coherence) is needed.

2.2.22.2 **VDL Mode 4 impact of fundamental design: modulation**

VDL Mode 4 uses a GFSK modulation scheme, which provides a 19.2 kbps data rate within a message, while providing a relatively low 12 dB D/U ratio for a system involving airborne transmitters (Manual on Detailed Technical Specifications for the VDL Mode 4 Digital Link [Ref. 11]). A required D/U of 10 dB is specified in MOPS as a result of tests on equipment.

2.2.22.3 **1 090 ES impact of fundamental design: modulation**

The 1 090 ES system uses the well-understood and validated modulation scheme of the Mode S data link (ICAO Annex 10, Volume IV [Ref. 12]).

2.2.23 **Impact of fundamental design: multiple access technique**

2.2.23.1 **UAT impact of fundamental design: multiple access technique**

UAT operates in a single channel using the same frequency for transmit and receive. The UAT frame is divided into two segments. One segment uses a random access protocol and is used for mobile station transmissions. The other segment is used for ground station transmissions and is divided into timeslots.

The impacts of the above multiple access techniques are:

- Ground uplink transmissions do not interfere with aircraft transmissions, and vice versa, improving the robustness of ADS-B and ground uplink services.

- UAT spectrum efficiency is improved and equipment design is simplified.

2.2.23.2 **VDL Mode 4 impact of fundamental design: multiple access technique**

VDL Mode 4 system utilises a self-organising TDMA access scheme, which provides for autonomous and ground controlled modes.

2.2.23.3 1 090 ES impact of fundamental design: multiple access technique

1 090 ES uses a randomized media access protocol, with dithering of successive transmissions from a single ADS-B system participant.

2.2.24 Maturity of technology

2.2.24.1 UAT maturity of technology

UAT technology has been used operationally for 170 aircraft to supply radar-like ATC services and improved situational awareness in the FAA Alaska region. This operational experience has served as the basis for the recent completion of MOPS, U.S. spectrum approval for use of the system at 978 MHz, and development of a Technical Standard Order (TSO) C-154, which is the first certification order for operational ADS-B equipment. Two hundred additional aircraft will be equipped with MOPS-compliant, certified UAT equipment by 2004, and existing operational UAT equipment will be upgraded to the certification baseline provided by the MOPS and TSO. UAT is sufficiently mature that SARPS development has started on an at-risk basis.

2.2.24.2 VDL Mode 4 maturity of technology

VDL Mode 4 has ICAO provisions approved. In addition interim MOPS (ED-108) have been developed and are being updated. A European Norm (EN) for ground stations has been developed (EN 301842 parts 1 and 2, December 2002).

A local implementation of STDMA/VDL Mode 4 for surface movement applications has been in operation since 1988 at Arlanda Airport tracking ground vehicles for snow clearance operations.

An ADS-B ground station has been installed at Kiruna, in northern Sweden which does not have radar. The VDL Mode 4 ground station is intended to support ATC surveillance through the presentation of equipped aircraft on a situation display in the control tower. At Arlanda Airport, VDL Mode 4 will serve as a common platform for distribution of operational data. When fully implemented the system will provide ADS-B reporting for a large number of airport surface vehicles and a number of SAS and other operators' aircraft.

Trials and flights have taken place in various projects in Europe and details are provided in Section 2.2.25.2.

2.2.24.3 1 090 ES maturity of technology

The 1 090 ES system builds upon mature SSR technology. Joint RTCA-EUROCAE MOPS and ICAO SARPS and guidance material are available and are being updated to reflect the improved 1 090 ES design under assessment in this document.

2.2.25 **2.2.25 ADS-B related activities and time-scales**

2.2.25.1 **UAT ADS-B related activities and time-scales**

UAT (in a pre MOPS form) has been used in the FAA's Alaska Capstone programme beginning in February 2000. UAT is currently installed on over 170 air taxi aircraft in Western Alaska. Beginning in January 2001, the UAT/ADS-B has been supporting the first operational use of ADS-B for aircraft in flight, providing ATC radar-like services in the Bethel Alaska area. The Capstone programme plans to replace the pre-MOPS UATs with MOPS compliant equipment and add approximately 200 aircraft in Southeast Alaska beginning in 2003.

2.2.25.2 **VDL Mode 4 related activities and time-scales**

A number of trials involving VDL Mode 4 have been completed or are underway. Demonstrations of VDL Mode 4 support for air-air, air-ground and surface surveillance have been conducted in Europe including North-European ADS-B Network (NEAN), NEAN Update Programmeme (NUP), Mediterranean Free Flight (MFF) and Mediterranean Update Programmeme (MEDUP). NEAN provided early evidence that ADS-B is feasible and can be used in ATM from gate-to-gate. Based on the experiences from NEAN and associated projects, the NUP was formed to move the work closer to operational use by investigating the necessary steps in terms of certification, aircraft integration and application development. NUP is entering its second phase with the objective of establishing a European ADS-B network based on global standards supporting certified applications and equipment in synergy with the European ATM concepts providing benefits to ATM stakeholders.

Within Sweden, the network implemented as part of the NEAN programmeme is being updated to become fully compliant with the ICAO VDL Mode 4 provisions within the framework of NUP. The network of ground stations will be made denser by a national programmeme called ADS2005.

The MEDUP and MFF programmes are evaluating the feasibility of applying ADS-B services in the Mediterranean area. MEDUP is focused on establishing an extensive VDL Mode 4 infrastructure, while MFF is focused on operational aspects while taking advantage of ADS-B based services. Live flight trials are planned.

2.2.25.3 **1 090 ES related activities and time-scales**

Existing RTCA and ICAO standards for 1 090 ES are being updated. The updated RTCA MOPS are expected to be published in the second quarter of 2003 and the FAA will then publish a TSO some months later. This TSO will be used as the basis for the certification of 1 090 ES for operational use in the United States. Corresponding revisions to the ICAO standards are expected to be approved at SCRSP/1 in 2004. The revisions to the 1 090 ES standards maintain backward compatibility with the existing RTCA, EUROCAE and ICAO standards. Version 0 (DO-260 conformant) is currently being installed in some aircraft. 1 090 ES (version 0) systems have been installed on aircraft to support broadcast-only (i.e. air-to-ground applications) trials in Australia.

2.2.26 Interoperability

Note that all ADS-B links evaluated support TIS-B, thereby assisting interoperability with non-equipped aircraft.

2.2.26.1 UAT interoperability

The UAT MOPS, updated as needed to ensure conformance with anticipated UAT SARPS, will continue to ensure interoperability across different vendor implementations of UAT.

As articulated in the 2002 FAA ADS-B Link Decision Document [Ref. 10], interoperability between UAT and the 1 090 ES in the United States will be supplied through ADS-B gateways. Moreover, multi-link implementations within a single aircraft are being explored (e.g. see the discussion in Paragraph 2.2.14.1 above).

2.2.26.2 VDL Mode 4 interoperability

The VDL Mode 4 SARPS, MOPS (when approved), and EN will ensure interoperability between systems developed by different manufacturers.

2.2.26.3 1 090 ES interoperability

The 1 090 ES SARPS and MOPS will ensure interoperability across different vendor implementations of 1 090 ES.

As articulated in the 2002 FAA ADS-B Link Decision Document [Ref. 10], interoperability between UAT and 1 090 ES in the United States will be supplied through ADS-B gateways. Moreover, multi-link implementations within a single aircraft are being explored.

2.2.27 Flexibility

2.2.27.1 UAT flexibility

UAT offers flexibility in the following areas:

- Future changes to the ADS-B message structure could be accommodated through over 20 spare payload type codes that are unused in the current MOPS definition of the system.
- The 5 UAT equipment classes defined in RTCA DO-282 [Ref. 7] allow users the flexibility to install a system with only the cost and performance that meets their needs.
- Due to the frequency relationship between UAT and the 1 030/1 090 MHz SSR system, use of a diplexer device to share antennas with the transponder will offer some flexibility for installation on aircraft.

2.2.27.2 **VDL Mode 4 flexibility**

The VDL Mode 4 provides the flexibility to define new messages following the evolution of the application requirements. The high degree of configurability of VDL Mode 4 permits it to be highly adaptable to changes in airspace needs and composition.

VDL Mode 4 has the flexibility to support other services such as ground broadcast and point-to-point communications, either air-to-ground or air-to-air. Air-to-air communications may be a requirement for advanced airborne separation assistance system (ASAS) applications.

It is possible to take advantage of the position data provided by VDL Mode 4 to enhance the safety and security of data communication and to manage the communication system for maximum channel utilization. The use of position data is an inherent advantage of a system supporting combined CNS services.

2.2.27.3 **1 090 ES flexibility**

1 090 ES has necessarily been designed with a number of constraints owing to its relationship with SSR/ACAS. These same relationships support cost-effective flexibility in partitioning surveillance implementation between SSR, ACAS, and ADS-B as a function of time. Multiple equipage classes of 1 090 ES avionics have been defined to provide users with a choice of functionality and cost.

2.2.28 **Non-proprietary**

ICAO policy is that if there is any need to use a patent then the patent must be offered for license to aviation in a fair, reasonable and non-discriminatory way.

2.2.28.1 **UAT non-proprietary**

The UAT system does not have any known proprietary aspects.

2.2.28.2 **VDL Mode 4 non-proprietary**

AMCP/7 noted that no patents applicable to the VDL Mode 4 SARPs were identified at the meeting. It therefore concluded that the material proposed in the SARPs would be freely accessible to everybody, subject to no particular conditions.

2.2.28.3 **1 090 ES non-proprietary**

The holder of a key patent for 1 090 ES technology has made that technology available to the aviation community without any financial obligation. Therefore, there are no known proprietary issues associated with 1 090 ES.

2.2.29 Robustness/fallback states

2.2.29.1 UAT robustness/fallback states

Under normal conditions UAT relies on timing information derived from GNSS. Timing information from GNSS is needed primarily to support a range to target measurement independent of ADS-B. Upon a failure of GNSS, the navigation input to UAT could come from any appropriate navigation source (e.g. inertial, FMS). For timing the UAT can fall back to timing derived from receipt of uplink messages from ground stations in order to prevent ADS-B transmissions from conflicting with ground uplink transmissions. In this fallback condition, the independent range measurement would not be available, but basic UAT ADS-B transmission performance should not be affected.

2.2.29.2 VDL Mode 4 robustness/fallback states

VDL Mode 4 provides 3 timing modes. The primary timing Mode relies on GNSS to provide the required accuracy. The two fallback modes support continuing operations. If a station is unable to maintain primary time, a station reverts to secondary timing. Under secondary timing, the station uses its internal oscillator to limit the drift away from UTC. Under tertiary timing, no sources synchronized to UTC are available and stations transmit a time calculated as the mean slot start time of the surrounding transmitters. This circumstance, while degrading VDL Mode 4 communications, will not result in a loss in communication capability, the drift away from UTC will result in errors when the stations are resynchronized to UTC.

2.2.29.3 1 090 ES robustness/fallback states

The randomized nature of 1 090 ES media access mitigates the impact of avionics failure of any given ADS-B system participant. Additionally, operation of the 1 090 ES system does not substantively degrade when precise timing (e.g. from GNSS) is lost. The enhanced Extended Squitter decoder provides for improved probability of successful receipt of an ADS-B Extended Squitter in the presence of multiple SSR overlaps.

2.2.30 Future suitability

2.2.30.1 UAT future suitability

UAT has been demonstrated, through simulation and analysis, to be suitable to support most air-to-air ranges and ADS-B Report update requirements, required and desired, of RTCA DO-242A in “worst-case” future (2015) high-density airspaces. Line-of-sight reception for air-ground applications has been ensured as well, using a single ground station (although multiple sector ground antennas may be required in areas of significant off-channel DME activity).

2.2.30.2 VDL Mode 4 future suitability

VDL Mode 4 offers a flexible solution in that it provides variable reporting rates and is able to provide other services such as ATN communications. It can also provide air-to-air point-to-point communications. It is expected to offer good airport surface performance as VHF has good ground propagation characteristics.

2.2.30.3 1 090 ES future suitability

The 1 090 ES system is projected to be suitable for high update rate, short range air-air and air-ground ADS-B applications (e.g. hybrid surveillance, support of parallel runway approaches, enhanced see-and-avoid, conflict detection, air-ground applications within a TMA) for the foreseeable future.

2.2.31 Cost

Only two known attempts to comprehensively assess costs of the three ADS-B link have been undertaken. The FAA undertook a comprehensive cost analysis in 2001 - 2002 as part of its ADS-B link decision process. (see http://adsb.tc.faa.gov/ADS-B.htm) which showed UAT to have relatively lower cost profiles across all classes of installations. Note that this was a snapshot of the market and it is expected that costs for all links may change in the future. Similar considerations have been taken by Eurocontrol and the European Commission [www.datalinkroadmap.com], concluding that costs were scenario dependent and that the cost of link avionics was not a discriminator among the links. Equipment cost considerations can indeed be complex, and proponents of individual ADS-B links have objected, for one reason or another, to assumptions made in the cost analyses referred to above.

2.2.31.1 UAT cost

The following factors of the UAT design serve to minimize its installed system cost:

- The frequency of UAT operation and its very low duty cycle, may make it practical to share antenna with transponder systems. This could be an important consideration on air transport category aircraft where the transponder antenna network supports both diversity and access from redundant transponder units.

- The single channel operation of UAT eliminates the need for multiple channels or logic to support channel tuning.

- A random-based media access allows for minimal transmit-only installations and requires only simple logic

As an example of costs for small single engine aircraft, the FAA’s Alaska Capstone programme has purchased approximately 180 shipsets of avionics equipment at a cost of around $20 000 per shipset installed. This cost includes UAT avionics, a GPS navigator, a multifunction cockpit display, and installation (average of $5 000). The breakdown of cost between UAT avionics, GPS navigator, and the multifunction cockpit display is not publicly available. Installed equipment cost for large air transport aircraft will be higher.

2.2.31.2 VDL Mode 4 cost

VDL Mode 4 is designed to be applicable to all classes of users (including for example ground vehicles). For low-end users it should be possible to provide low-cost installations based around a simple architecture of a single box containing VHF data link and GPS receiver equipment.

2.2.31.3 1 090 ES cost

In the FAA Safe Flight 21 Pre-Investment Analysis (July, 2002), costs of installing 1 090 ES ADS-B equipment on a number of different categories of aircraft were calculated. In developing the avionics costs, the team worked with avionics manufacturers to come up with estimates for equipage costs. From the perspective of the unit point estimates of equipment cost, it was concluded that for air transport category aircraft, 1 090 ES offered attractive cost profiles over a range of aircraft types. The costs for low- and mid-end general aviation equipage were estimated to be in the moderately high range.

3. RTCA ADS-B MASPS (DO-242A) COMPLIANCE

This section discusses ADS-B data link system performance as compared to the subset of requirements of RTCA DO-242A [Ref. 3] analogous to the earlier RTCA DO-242 requirements expressly considered by the TLAT [Ref. 4]. Section 3.1 is a summary of the requirements and references to the sections of RTCA DO-282 [Ref. 7], VDL SARPS in Annex 10, Volume III [Ref. 13] and the Manual on Detailed Technical Specifications for the VDL Mode 4 Digital Link [Ref. 11], and RTCA DO-260A [Ref. 8], which discuss the results of analysis of the system performance and compliance with the criteria set forth in RTCA DO-242A. Section 3.2 - 3.4 present summary discussions of compliance of the UAT, VDL Mode 4, and 1 090 ES systems with the requirements of RTCA DO-242A selected for assessment.

When assessing the needs of Free Flight Operational Enhancements as articulated by the RTCA Free Flight Select Committee and developed by the Safe Flight 21 Programme in the United States, the TLAT concluded that a DO-242 compliant ADS-B System would support those Operational Enhancements.

The VDL Mode 4 system configuration used in making this assessment is that used by the TLAT for the Core Europe 2015 scenario. The UAT and 1 090 MHz Extended Squitter configurations have been updated to be specifically aligned to the requirements of DO-242A (i.e. in terms of ADS-B information fields broadcast), and therefore are including the broadcast of a small number of data fields not broadcast in the VDL Mode 4 configuration. The total payload impact on UAT, for example, of these additional fields is the addition of 6 percent to the payload used in the TLAT analysis.

3.1 DO-242A ADS-B requirements and references

Table B-1: ADS-B MASPS compliance matrix

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R2.3 (§2.1.2)	The ADS-B system **shall** be capable of transmitting messages containing the information specified in the following subsections [of §2.1.2].	N/A (see following)	N/A (see following)	N/A (see following)
R2.5 (§2.1.2.2)	The basic identification information to be conveyed by ADS-B **shall** include the following elements: 1. Call Sign (§2.1.2.2.1) 2. Participant Address (§2.1.2.2.2.1) and Address Qualifier (§2.1.2.2.2.2) 3. ADS-B Emitter Category (§2.1.2.2.3)	Complies Table 2-39 §2.2.4.5.4.2 §2.2.4.5.1 §2.2.4.5.1.3.1 §2.2.4.5.1.2 §2.2.4.5.4.1	Compliant (see Note 1) Call sign: Table 3-2 Table 3-9 Table 3-8a Table 3-11 Participant address and Address Qualifier: §1.3.2 Table 1-5 §1.3.2.2 §1.4.2.2 Table 1-55 ADS-B Emitter Category: §3.3 Table 3-15 'small' aircraft and 'large' aircraft are grouped together as 'medium aircraft' in VDL4 Not covered are: 'High vortex large' 'Cluster obstacle' 'Line obstacle'	Complies §2.2.8.2.6 §2.2.5.1.11 §2.2.5.1.1 §2.2.5.1.1.3 §2.2.8.2.3 §2.2.3.2.5.2 §2.2.8.2.7

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R2.14 (§2.1.2.4)	Position Information **shall** be transmitted in a form that can be translated, without loss of accuracy and integrity, to latitude, longitude, geometric height and barometric pressure altitude.	Complies §2.2.4.5.2 Table 2-11 §2.2.4.5.2.1 §2.2.4.5.2.2 §2.2.4.5.2.3	Compliant §1.5.2.2 §3.3	Complies §2.2.3.2.3 §2.2.3.2.3.4.3 §2.2.3.2.3.7 §2.2.3.2.3.8 §2.2.3.2.4 §2.2.3.2.4.7 §2.2.3.2.4.8
R2.19 (§2.1.2.6)	Both barometric pressure altitude and geometric height **shall** be reported, if available to the transmitting ADS-B subsystem.	Complies §2.2.4.5.2.2 Table 2-13	Compliant §1.5.2.2 Table 1 - 68 §3.3 Table 3-12 Table 3-21	The Altitude Subfield only allows for a single altitude to be reported as indicated by the Airborne Position Message "Type" code. §2.2.3.2.4.3
R2.30 (§2.1.2.12)	Table 2-2 defines the navigation integrity categories [NIC] that transmitting ADS-B participants **shall** use to describe the integrity containment radius.	Complies Table 2-15	compliant (note 1) VDL4 TM does not support the NIC parameter(s). It defines NUCP, Table 1-67	Complies §2.2.3.2.7.2.6 Table 2.2.3.2.7.2.6
R2.31 (§2.1.2.13)	Table 2-3 defines the navigation accuracy categories that **shall** be used to describe the accuracy of positional information in ADS-B messages from transmitting ADS-B participants.	Complies §2.2.4.5.4.9 Table 2-45	compliant (note 1) VDL4 TM does not support the NAC parameter(s). It defines NUCP, Table 1-67	Complies §2.2.3.2.7.2.7 Table 2.2.3.2.7.2.7

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R2.32 (§2.1.2.13)	The NAC_P value broadcast from an ADS-B participant **shall** include any inaccuracies in the reported position due to the transmitting participant's not correcting the position from the navigation sensor to that of the ADS-B position reference point (see §2.1.2.5).	Complies §2.2.4.5.4.9 Table 2-45	compliant (note 1) VDL4 TM does not support the NAC parameter(s). It defines NUCP, Table 1-67	Responsibility for NAC_P adjustment lies outside the 1 090 MHz ES equipment. Compliance must be assessed as part of installation certification. §2.2.3.2.7.2.7 Table 2.2.3.2.7.2.7
R2.33 (§2.1.2.14)	[In determining NAC_V, the] velocity accuracy category of the least accurate velocity component being supplied by the reporting A/V's source of velocity data **shall** be as indicated in Table 2-4.	Complies §2.2.4.5.4.10	compliant (note 1) VDL4 TM does not support the NAC parameter(s). It defines NUCP, Table 1-67	Complies Table 2-20 Table 2-21 Table 2-22
R2.34 (§2.1.2.15)	The Surveillance Integrity Limit encoding **shall** be as indicated in Table 2-5	Complies §2.2.4.5.4.6 Table 2-44	compliant (note 1) VDL4 TM does not support the SIL parameter	Complies §2.2.3.2.7.1.3.13 Table 2.2.3.2.7.1.3.13 §2.2.3.2.7.2.9
R2.35 (§2.1.2.16)	The Barometric Altitude Quality Code (BAQ), is a 2-bit field which **shall** be zero for equipment that conforms to version DO-242A of the ADS-B MASPS	Complies §2.2.4.5.4.8	compliant (note 1) VDL4 TM does not support the BAQ parameter.	Complies §2.2.3.2.7.2.8
R2.37 (§2.1.2.19.1)	For equipage classes A2 and A3, the ADS-B system **shall** provide the capability to transmit and receive messages in support of the TS report. [TS report capability is optional for equipage class A1.]	Complies §2.2.4.5.6 §2.2.4.5.7	compliant (note 1) VDL4 TM defines Single-slot TCP and two-slot TCP in §3.3, Tables 3-8a, 3-9	Complies Table 2-3 Table 2-5

DO-242A ADS-B MASPS Requirements		**Compliance**		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R2.38 (§2.1.2.19.2)	For equipage class A2, the ADS-B system **shall** provide the capability to transmit and receive messages in support of one TC (TC+0) report.	Complies §2.2.4.5.8 Appendix L	compliant VDL4 TM defines Single-slot TCP and two-slot TCP in §3.3, Tables 3-8a, 3-9 It was assumed in the assessment that TC information was sent on a separate channel(s).	Complies Table 2-3 Table 2-5 §2.2.3.2.7.1
R2.39 (§2.1.2.19.2)	For equipage class A3, the ADS-B system **shall** provide the capability to transmit and receive messages in support of multiple TC reports.	Complies §2.2.4.5.8 Appendix L	compliant VDL4 TM defines Single-slot TCP and two-slot TCP in §3.3, Tables 3-8a, 3-9 It was assumed in the assessment that TC information was sent on a separate channel(s).	Complies Table 2-3 Table 2-5 §2.2.3.2.7.7 Appendix O
R3.1 (§3.3.1)	ADS-B equipage classes summarized in Table 3-1 **shall** provide air-to-air coverage specified in Table 3-2(a). The stated ranges are the basis for the indicated relative effective radiated power (ERP) and the receiver sensitivity requirement for each transmit unit. **Table 3-2 (a)** **Class Range TX ERP RXsensitivity** A0 10 NM $-2.5 dB +3.5 dB A1 20 NM 0 dB 0 dB A2 40 NM +3 dB -3 dB A3 90 NM #+6 dB -7 dB A3+ 120 NM #+6 dB -9.5 dB *Note — Required range requirements for A3 and A3+ are forward direction coverage. Port and starboard coverage may be one half of this value; aft coverage may be one third of this value.*	Complies §2.1.11 Appendix F Complies §2.1.12 Appendix F Complies §2.1.13 Appendix F Complies §3.1.1.2 Appendix F	compliant (note 2)	Complies Appendix E Table E-1 Appendix P

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.2 (§3.3.1)	The effective radiated power (ERP) and minimum signal detection capabilities **shall** support the associated pair-wise minimum operational ranges listed in Table 3-2(b). **Table 3-2(b), Interoperability Ranges** RX A0 RX A1 RX A2 RX A3 RX A3+ TX A0: 10 NM 15 NM 21 NM 34 NM 45 NM TX A1: 13 NM 20 NM 28 NM 45 NM 60 NM TX A2: 18 NM 28 NM 40 NM 64 NM 85 NM TX A3: 26 NM 40 NM 56 NM 90 NM 120 NM	Complies §2.1.12 Table 2-2 §2.1.13 Appendix F	compliant (note 2)	Complies For performance in high-density airspace, see Appendix P. Future possible improvements for extended range reception techniques are discussed in Appendix M. §2.2.2.1.1 §2.2.4.1 §2.2.4.2 §2.2.4.3 Appendix E Appendix I Appendix P
R3.4 (§3.3.1)	Ground vehicles operating on the airport surface (class B2) **shall** provide a 5 NM coverage range for Class A receivers.	In a surface-to-surface multi-path environment, coverage range for ground vehicle transmissions is approximately 3 miles. §2.1.11 Table 2-1	This was not evaluated for this report. See also 2.2.21.2	This was not evaluated for this report. §2.2.2.2.10.2 Appendix E

DO-242A ADS-B MASPS Requirements		**Compliance**		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.7 (§3.3.2)	Each equipage class **shall** meet the required information broadcast and receiving capability at the indicated range to support the applications indicated in Table 3-3(a) and Table 3-3(b).	Complies. §2.1.11 Table 2-1	Compliant (note 1, 2)	Complies. For performance in high-density airspace, see Section 2.2.1.3.1 of this report. Future possible improvements for extended range reception techniques are discussed in Appendix M .§2.2.2.1 §2.2.2.2 §2.2.3 §2.2.4.2 §2.2.4.3 Appendix E Appendix P
R3.8 (§3.3.3.1)	… report acquisition **shall** be considered accomplished when all report elements required for an operational scenario have been received by an ADS-B participant.	Complies §2.2.9 §2.2.9.1	Compliant.	Complies §2.2.10.3
R3.9 (§3.3.1.1)	Report accuracy, update period and acquisition range requirements are derived from the sample scenarios of Chapter 2, and are specified in Table 3-3(a). The state vector report **shall** meet the update period and 99 percentile update period requirements for each application listed.	Compliant for all SV update applications at required and desired ranges with one exception: the surface-to-surface 1.5 second (95%) update requirement. §2.2.8.2.2 §2.2.8.2.4(a)	Compliant for applications with desired ranges >10nm and < 70nm under loaded conditions. See Section 2.2.1.2.1 of this report.	Complies at ranges under 40-50 NM under loaded conditions. For performance in high-density airspace, see Section 2.2.1.3.1 of this report. Appendix E Table E-1 Appendix P

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.10 (§3.3.1.1)	For each of the scenarios included in Table 3-4(a), the state vector from at least 95% of the observable user population (radio line-of-sight) supporting that application **shall** be acquired and achieve the time and probability requirements specified for the operational ranges.	Complies at all required and desired ranges, with exception noted in R3.9. §2.2.10.3 Table 2-67	Compliant for applications with desired ranges >10nm and < 70nm under loaded conditions. See Section 2.2.1.2.1 of this report.	Complies at ranges under 40 - 50 NM under loaded conditions. For performance in high-density airspace, see Appendix P. Future possible improvements for extended range reception techniques are discussed in Appendix M. Appendix E Appendix L Appendix P
R3.11 (§3.3.3.1.1)	Required ranges for acquisition **shall** be as specified in Table 3-4(a): (10 NM for A0, 20 NM for A1, 40 NM for A2, and 90 NM for A3).	Complies §2.2.10.3 Table 2-67	This was not evaluated for this report.	This was not evaluated for this report. For performance in high-density airspace, see Appendix P. Future possible improvements for extended range reception techniques are discussed in Appendix M. Appendix E Appendix L Appendix P

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.14A R3.14B (§3.3.3.1.2)	For each of the equipage classes included in Table 3-4(a), the Mode status reports from at least 95% of the observable (radio line-of-sight) population **shall** be acquired at the range specified in the "Required 95th Percentile Acquisition Range" row of Table 3-4(b). (10 NM for A0, 20 NM for A1, 40 NM for A2, and 90 NM for A3). Likewise, for each of the equipage classes included in Table 3-4(b), the Mode status reports from at least 99% of the observable (radio line of sight) population **shall** be acquired at the reduced range specified in the "Required 99th Percentile Acquisition Range" row of Table 3-4(b)	Complies §2.2.10.3 Table 2-67	This was not evaluated for this report.	This was not evaluated for this report.
R3.21 (§3.3.3.1.4)	When there has been no change in intent information, the nominal update period for A2 equipage at ranges within 40 NM and for A3 equipage at ranges in the forward direction within 90 NM **shall** be T_U such that T_U =max[12s, 0.45 s/NM * R] where R is the range to the broadcasting aircraft and T_U is rounded to the nearest whole number of seconds. If implemented, these requirements are applicable to TS Report update rates for A1 equipment for ranges of 20 NM or less.	Complies §3.2.1.6 Appendix K	This was not evaluated in the assessment.	Complies to ranges shown in Appendix C of this report. Table 2-3 Appendix E Appendix P
R3.22 (§3.3.3.1.4	If the TS report is implemented in ADS-B systems of equipage class A1, such systems **shall** have a 20NM acquisition range for TS Report.	Complies §3.2.1.6 Appendix K	Note 1 and Note 2 TS reports not specified in VDL4 TM	Not evaluated Table 2-3 Appendix E Appendix P
R3.23 (§3.3.3.1.4)	For equipage class A2, the acquisition range for TS reports and TC reports **shall** be 40 NM, with 50 NM desired.	Complies §3.2.1.6 Appendix K	Note 1 and Note 2 TS reports not specified in VDL4 TM It was assumed in the assessment that TC information was sent on a separate channel(s).	Complies to ranges of 30 - 40 NM for TSR. Table 2-3 Appendix E Appendix P

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.24 (§3.3.3.1.4)	For equipage class A3, the acquisition range for TC reports in the forward direction **shall** be 90 NM, with 120 NM desired.	Complies §3.2.1.6 Appendix K	Note 1 and Note 2 It was assumed in the assessment that TC information was sent on a separate channel(s).	Not evaluated Table 2-3 Appendix E Appendix P
R3.32 (§3.3.4)	Requirements specified for en route, Low-density air space **shall** be met in the traffic density shown by the Low-density curve in Figure 3-8.	Complies Appendix K	The system was not evaluated in this environment.	Complies Appendix E Appendix P
R3.34 (§3.3.5)	Radio frequencies used for ADS-B Message transmission **shall** operate in an internationally allocated aeronautical radio navigation band(s).	Complies §2.2.2.1	Compliant. SARPS 6.1.4 SARPS 6.9.2.1	Complies §2.2.2.2.1

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.39 (§3.3.6.5)	The integrity of the ADS-B system **shall** be 10-6 or better on a per report basis.	Complies §2.2.3.1.3.1 Appendix C Appendix M	VDL Mode 4 experts claim compliance, no reference cited. Further analysis required.	1 090 MHz link established to be 10^{-7} without acknowledgement, based on message length and error correction. (ref. DO-181; 24 parity check bits used for error detection, supports undetected error rate owing to data link (per ADS-B message) of better than 1in 10^{-7}). This integrity requirement is not likely to be met with single-string equipage. Avionics integrity is treated at the aircraft level in certification activities. §1.2.3 §2.1.9
R3.88 (§3.4.3.18)	The NIC field in the SV report is a 4-bit field that **shall** report the Navigation Integrity Category described in Table 2-2 in §2.1.2.12.	Complies §2.2.4.5.2.4 Table 2-15	compliant (note 1). VDL4 TM does not support the NIC parameter(s). It defines NUCP, Table 1-67	Complies §2.2.8.1.16 Table 2.2.8.1.16
R3.92 (§3.4.4.3)	The ADS-B Version Number **shall** be defined as specified in Table 3-9.	Complies Table 2-43	compliant (note 1)	Complies §2.2.8.2.5 Table 2.2.3.2.7.2.5
R3.104 (§3.4.4.9.3)	At least four bits (sixteen possible encodings) **shall** be reserved in the capability class codes for the “Service Level” of the transmitting ADS-B participant.	Complies Table 2-39	compliant (note 1)	Complies §2.2.8.2.10 §2.2.3.2.7.2.3 §2.2.3.2.7.2.3.1

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.110A R3.110B R3.110C (§3.4.4.10.1)	The CC code for "TCAS/ACAS Resolution Advisory Active" **shall** be set to ONE if the transmitting aircraft has a TCAS II or ACAS computer that is currently issuing a Resolution Advisory (RA). Likewise, this CC code **shall** be set to ONE if the transmitting ADS-B equipment cannot ascertain whether the TCAS II or ACAS computer is currently issuing an RA. This CC code **shall** be ZERO only if it is explicitly known that a TCAS II or ACAS computer is not currently issuing a Resolution Advisory (RA).	Complies Table 2-49	compliant (note 1)	Complies §2.2.8.2.11 §2.2.3.2.7.2.4 §2.2.3.2.7.2.4.2 §2.2.3.2.7.1.3.14
R3.111A R3.111B R3.111C (§3.4.4.10.2)	Initially, the IDENT Switch Active" OM code **shall** be ZERO. Upon activation of the IDENT switch, this flag **shall** be set to ONE for a period of 20 +/-3 seconds: thereafter, it **shall** be set to ZERO.	Complies §2.2.4.5.4.13.2	Compliant (note1)	Complies §2.2.8.2.11 §2.2.3.2.7.2.4 §2.2.3.2.7.2.4.3
R3.112 (§3.4.4.10.3)	The "Receiving ATC Services" flag is a one-bit OM code. When set to ONE, this code **shall** indicate that the transmitting ADS-B participant is receiving ATC services; otherwise this flag should be set to ZERO.	Complies §2.2.4.5.4.13.3	Compliant (note1)	Complies §2.2.8.2.11 §2.2.3.2.7.2.4 §2.2.3.2.7.2.4.4
R3.113 (§3.4.4.11)	The NAC_P field in the MS report is a 4-bit field that **shall** be encoded as described in Table 2-3 in §2.1.2.13.	Complies §2.2.4.5.4.9 Table 2-45	Compliant (note1) VDL4 TM defines NUCP, Table 1-67	Complies §2.2.8.2.12 Table 2.2.3.2.7.2.7 §2.2.3.2.7.1.3.11 §2.2.3.2.7.2.7
R3.114 (§3.4.4.12)	The NAC_V field in the MS report is a 3-bit field that **shall** be encoded as described in Table 2-4 in §2.1.2.14.	Complies §2.2.4.5.4.10 Table 2-46	Compliant (note1) VDL4 TM defines NUCP, Table 1-67	Complies §2.2.8.2.13 Table 2-20 Table 2-21 Table 2-22 §2.2.3.2.6.1.5 ..§2.2.3.2.6.41.5

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.115 (§3.4.4.13)	The SIL field in the MS report is a 2-bit field that **shall** be encoded as described in Table 2-5 in §2.1.2.15.	Complies §2.2.4.5.4.6 Table 2-44	Compliant (note1)	Complies §2.2.8.2.14 Table 2.2.3.2.7.2.9 §2.2.3.2.7.1.3.13 §2.2.3.2.7.2.9
R3.130 (§3.4.7.1)	An airborne ADS-B participant of equipage class A2 or A3 **shall** transmit messages to support the TS report when either of the following conditions are met. a. The flight director or autopilot is engaged in a vertical Mode and a target altitude or an acceptable substitute for target altitude (§3.4.7.11) is available from the automation system; or b. The flight director or autopilot is engaged in a horizontal Mode and a target heading or target track (§3.4.7.6) is available from the automation system.	Complies §2.2.4.5.6	Compliant (note1)	Complies §2.2.3.3.1.4.1
R3.131 (§3.4.7.2)	The higher "state change" update interval requirements specified for TS Report information in §3.3.3.1.4 and Table 3-4 (d) **shall** be met whenever there is a change in the value of any of the following TS report fields: Horizontal Data Available and Horizontal Source Ind. §3.4.7.4 Target Heading or Track Angle §3.4.7.5 Target Heading /Track Indicator §3.4.7.6 Vertical Data available (§3.4.7.10) Target Altitude (§3.4.7.11).	Complies Appendix K	Compliant (note1)	Higher rates for when a state change occurs to specified TS report elements is only listed as desired in DO-242A §3.3.3.1.4 and Table 3-4(d). §2.2.3.3.1.4.1
R3.135 (§3.4.7.5)	Target heading or track angle **shall** be reported over the full range of all possible directions, 0 to almost 360, expressed as an angle measured clockwise from a reference direction.	Complies §2.2.4.5.6.1.5 Table 2-55	Compliant (note1)	Complies Table 2.2.8.3.1 §2.2.8.3.1.5 §2.2.3.2.7.1.3.8
R3.136 (§3.4.7.5)	Target heading or track angle **shall** be communicated and reported with a resolution at least as fine as one degree of arc.	Complies §2.2.4.5.6.1.5 Table 2-55	Compliant (note1)	Complies Table 2.2.8.3.1 Table 2.2.3.2.7.1.3.8

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.143 (§3.4.7.11)	Target altitude **shall** be represented as the operational altitude recognized by the transmitting aircraft's guidance system.	Complies §2.2.4.5.6.2.5	Compliant (note1)	Complies §2.2.8.3.1.12 §2.2.3.2.7.1.3.6
R3.144 (§3.4.7.11)	If a substitute value is provided, that value **shall** be consistent with the aircraft's target altitude capability as listed in Table 3-22.	Complies Table 2-60	Compliant VDL4 TM defines target altitude in two-slot TCP and single-slot TCP. The target altitude complies with the requirement specified here. §3.3 Tables 1-66, 1-68, 3-8a, 3-8b, 3-11	Complies §2.2.8.3.1.14 §2.2.3.2.7.1.3.4 §2.2.8.3.1.11 §2.2.3.2.7.1.3.6
R3.145 (§3.4.7.11)	Target Altitude field **shall** be provided with a range from -1 000 ft to +100,000 feet	Complies Table 2-61	Compliant (note1)	Complies Table 2.2.8.3.1 Table 2.2.3.2.7.1.3.6
R3.146 (§3.4.7.11)	Target Altitude field **shall** be communicated and reported with a resolution of 100 feet or finer.	Complies Table 2-61	Compliant (note1)	Complies Table 2.2.8.3.1 Table 2.2.3.2.7.1.3.6
R3.147 (§3.4.7.12)	The Target Altitude Type **shall** be encoded as specified in Table 3-21.	Complies Table 2-57	Compliant (note1)	Complies §2.2.8.3.1.13 Table 2.2.3.2.7.1.3.2
R3.148 (§3.4.7.13)	The Target Altitude capability field **shall** be encoded as specified in Table 3-22.	Complies Table 2-60	Compliant (note1)	Complies §2.2.8.3.1.14 Table 2.2.3.2.7.1.3.4

DO-242A ADS-B MASPS Requirements		Compliance		
RTCA DO-242A [Ref. 3] Ref. # (Section #)	**Requirement Text**	**UAT (RTCA DO-282 [Ref. 7] Section #)**	**VDL Mode 4**	**1 090 ES (RTCA DO-260A [Ref. 8] Section #)**
R3.151 (§3.4.8.1)	Given that the above conditions are satisfied, and any TC+0 report previously generated is not currently valid, an A2 level system **shall** initiate broadcast of a TC+0 report when the aircraft is within 4 minutes TTG to the trajectory change described in that TC+0 report, or as otherwise needed to meet the acquisition range requirements for A2 equipage as specified in Table 3-4(e).	Complies Appendix K	Compliant It was assumed in the assessment that TC information was sent on a separate channel(s).	This MOPS has reserved a message type for support of broadcasting data for supporting TC+0 and TC+1 reports. This message, its scheduling, and how the data might be sent within these messages is defined in Appendix O. There are not, however, any requirements in this MOPS for the transmission or reception of these messages or support of the TC reports. This was done at the direction of the SC-186 plenary. Table 2-3 Table 2-11 Appendix E Appendix P Appendix O
R3.152 (§3.4.8.1)	Similarly, [i.e. given that the prerequisite conditions listed in R3.151 are met] an A3 level system **shall** initiate broadcast of a TC+0 report when the aircraft is within 8 minutes TTG to the trajectory change described in that report, or as otherwise needed to meet the acquisition range requirements for A3 equipage as specified in Table 3-4(e).	The UAT System has been designed to support all preliminary requirements of DO-242A concerning the TC+0 Report, including meeting all report update rate requirements at all ranges specified as "desired.	Compliant It was assumed in the assessment that TC information was sent on a separate channel(s).	See entry for R3.151 Table 2-3 Appendix E Appendix P Appendix O

Note.— MG = Message Generation; ME = Message Exchange; ME(T) = Message Exchange (transmit); ME(R) = Message Exchange (receive); RG = Report Generation

The following notes accompany the table entries for VDL Mode 4:

Notes.—

1. VDL Mode 4 was developed to meet the information requirements of an earlier version of the ADS-B MASPS. Hence, in many cases, particular information fields are not available in the current VDL Mode 4 message set. One example is that NIC, NAC, and SIL have replaced NUCp.

   VDL Mode 4 experts see no fundamental difficulties in supplying the required information but have not done so yet. Currently, EUROCAE WG-51 SG2 are developing MOPS for VDL Mode 4. It will be the task of that group to propose amendments to the message set.

   Note that Mode 4 possesses a flexible message addressing structure to which the addition of new message types is straightforward.

   Where compliance is simply a matter of changing the message set, this is marked as "compliant (note 1)" in the table. This is based upon the assumption that the newly defined message set has enough unused capacity to accommodate the additional information required by RTCA DO-242A [Ref. 3].

2. VDL Mode 4 was developed before the requirement for specific classes of transmitter. Simulation work with VDL Mode 4 has introduced such classes, but this division has not yet been introduced in MOPS or indeed in the ICAO standards material. WG-51 SG2 will address this issue.

   Within the current standards material, a variation in allowed transmit power is provided for and hence it is expected that the different classes could be accommodated. Link budget calculations performed in support of the development of VDL Mode 4 indicate that the system can support ranges in excess of the A3+ requirement. Meeting the requirements of Table 3-2a) and Table 3-2b) is then an issue of specifying appropriate transmit ERP and receive sensitivity levels for the other classes.

3.2 UAT system performance and compliance

This section provides discussion of some of the aspects of the UAT system performance and design compliance with the corresponding RTCA DO-242A [Ref. 3] criteria specified in Section 3.1. The table in Section 3.1 contains references to sections of RTCA DO-282 [Ref. 7], where discussions and analysis of compliance with the RTCA DO-242A requirements appear. However, Appendix A of this report contains much of the relevant system performance analysis which appears in much more detail in Appendix K of DO-282.

In brief, UAT system performance may be summarized as follows:

- All RTCA ADS-B MASPS air-air update rate requirements and desired criteria are met for all aircraft equipage transmit-receive pairs for both state vector and intent update rates for all aircraft equipage types and at all ranges specified by RTCA DO-242A. (The graphs in Appendix A show that TCR+1, which is not required to be broadcast in DO-242A, can be supported at around one-half the received update rate of TCR+0.)

- All known air-ground update rate requirements are met out to at least 150 NM, in the absence of a co-located TACAN emitter. Under some circumstances, a sectorized antenna may be required. In the presence of a co-located TACAN emitter, additional antenna isolation may be required.

- UAT is compliant for all SV update applications at required and desired ranges with one exception: the surface-to-surface 1.5 second (95%) update requirement is met for A3 transmitters for 2 to 3 NM (not 5 NM) in a multi-path environment, and A0, A1 and A2 transmissions are received at 2 to 3 NM at 2 to 3 seconds (95%) in the same environment. Additionally, the UAT System has been designed to support line-of-sight air-ground performance in future high-density terminal air spaces at update rates specified by ATC authorities.

- In the high-density scenario, track acquisition (defined as receipt of all state vector, intent, and Mode status information broadcast by an ADS-B participant) is achieved for each class of aircraft equipage at ranges beyond what is necessary to perform flight applications currently envisioned for them.

For additional information about the entries in the table in Section 3.1, please see the sections of RTCA DO-282 [Ref. 7] cited in the table.

3.3 VDL Mode 4 system performance and compliance

This section provides discussion of some of the aspects of the VDL Mode 4 system performance and design compliance with the corresponding RTCA DO-242A [Ref. 3] criteria specified in Section 3.1. The table in Section 3.1 contains references to sections of the VDL SARPS [Ref. 13] and the Manual on Detailed Technical Specifications for the VDL Mode 4 Digital Link [Ref. 11], where discussions and analysis of compliance with the RTCA DO-242A requirements appear. However, Section 2.2.1.2 and Appendix B of this report contain much of the relevant system performance analysis for the high-density air traffic environment. Time constraints did not permit analysis of the low-density scenario for this report.

In brief, VDL Mode 4 system performance may be summarized as follows:

- For the system evaluated, RTCA DO-242A air-air requirements are met for all types of aircraft equipage transmit-receive pairs in the high-density air traffic environment for state vector update rates to ranges of 70 NM. Intent information was not transmitted, so no evaluation of intent update rates was possible.

- A number of the requirements in the table in section 3.1 have to do with the transmission of data elements which are not currently part of the VDL Mode 4 message set. These requirements are listed as “compliant” under the assumption that it is possible to redefine the message set to include all of these data elements, while leaving transmission of other required data unchanged.

For additional information about the entries in the table in Section 3.1, please see the sections of VDL SARPs [Ref. 13] and the Manual on Detailed Technical Specifications for the VDL Mode 4 Digital Link [Ref. 11] cited in the table.

3.4 1 090 ES system performance and compliance

This section provides discussion of some of the aspects of the 1 090 ES system performance and design compliance with the corresponding RTCA DO-242A criteria specified in Section 3.1. The table in Section 3.1 contains references to sections of RTCA DO-260A [Ref. 8] , where discussions and analysis of compliance with the RTCA DO-242A [Ref. 3] requirements appear. However, Appendix C of this report contains much of the relevant system performance analysis. Appendix P of RTCA DO-260A [Ref. 8] contains information on the low-density scenario, but the high-density analysis in that reference does not include the 2015 Core Europe scenario, which is the scenario of interest in this report.

In brief, 1 090 ES system performance may be summarized as follows:

- RTCA DO-242A [Ref. 3] air-air requirements are met for high-end air transport class (DO-242A equipage class A3) aircraft equipage transmit-receive pairs in the high-density air traffic environment for both state vector and TSR update rates to ranges of 40-50 NM, depending on the interference environment.

- RTCA DO-242A air-air requirements are met for DO-242A equipage class A1 and A2 aircraft equipage transmitters to A3 receivers for state vector update rates at ranges of around 40 NM, and for TSR update rates at ranges of 30 - 40 NM, depending on the interference environment. The required ranges, as specified in the table in Section 4.1, for these categories are 20 NM for A1 and 40 NM for A2.

For additional information about the entries in the table in Section 3.1, please see the sections of RTCA DO-260A [Ref. 8] cited in the table.

4. EUROCONTROL TLAT CRITERIA ADDITIONAL TO THOSE IN DO-242A

The additional criteria from Eurocontrol stem from European ADS requirements development that occurred subsequent to the adoption of the original ADS-B MASPS by RTCA (DO-242 [Ref. 14]). DO-242 could not be endorsed by EUROCAE because European ADS requirements were not sufficiently mature.

Since the European ADS-B requirements are not yet finalised, the Eurocontrol criteria represent a snapshot of the ongoing discussions in Europe in relation to ADS-B requirements. These criteria aim to assess the margin that the data links are able to provide to allow for the fulfilment of potential additional or differing ADS-B requirements, since the ADS-B system as currently envisaged may differ from the implemented system.

The Eurocontrol criteria cover two air-ground surveillance scenarios expected to be implemented in Europe. The first scenario is the overlay of monopulse Secondary Surveillance Radar with ADS-B, where the latter serves as gap filler and also supplies trajectory intent information. This first scenario is applicable to airspace of medium and low-density traffic. The second scenario is the overlay of Mode S Enhanced Surveillance services with ADS-B, where ADS-B provides state vector and trajectory intent information as well as serves as a gap filler for enhanced surveillance. This second scenario is applicable to airspace of high-density traffic (e.g. Core Europe).

In addition, the Eurocontrol criteria extend the requirements for long-range deconfliction applications. These extended requirements are applicable to all European free flight airspaces (including Core Europe).

These additional Eurocontrol criteria provide air-ground scenarios (not included in RTCA DO-242A) for consideration. In addition, these criteria dictate an extended range requirement for the air-air case and the provision of two additional (four in total) Trajectory Change Points (TCP) for both the air-ground case and the air-air case. Detailed information on the criteria is provided in Appendix G of the TLAT report [Ref. 4].

Section 4.1 contains a summary of the requirements and references to the sections of this report which discuss the results of analysis of the system performance and compliance with the criteria set forth by Eurocontrol. Section 4.2-4.4 present summary discussions of compliance of the UAT, VDL Mode 4, and 1 090 ES systems with the additional Eurocontrol requirements.

4.1 Additional Eurocontrol ADS-B requirements and references

	UAT	**VDL Mode 4**	**1 090 Extended Squitter**
Air-Air Extension to 150 NM	Meets 120 - 125 NM See Section 4.2.1	Meets 70 NM for State Vector See Section 4.3.1	Meets 40 - 50 NM for State Vector and TSR See Section 4.4.1
Air-Ground to 150 NM	Complies See Section 4.2.2	Not evaluated See Section 4.3.2	Not evaluated See Section 4.4.2
Transmission of Four TCPs	Supports 2 TCPs See Section 4.2.3	Not evaluated See Section 4.3.3	Not evaluated See Section 4.4.3

4.2 UAT system performance and compliance

This section provides discussion of the UAT system performance and design compliance with the additional Eurocontrol criteria specified in section 4.1. Each of the criteria and UAT performance are discussed in a separate sub-section.

4.2.1 Air-air extension to 150 NM

As previously discussed in Section 2.2.1.1.1.2, based on the analysis of the performance of UAT in the high-density scenario, and as shown in Appendix A, the air-air extension to 150 NM is not achieved. In the worst-case interference environment analyzed, maximum air-air range for high-altitude aircraft is around 125 NM.

4.2.2 Air-ground to 150 NM

As previously discussed in Section 2.2.1.1.1.2, based on the analysis of the performance of UAT in the high-density scenario, and as shown in Appendix A, the air-ground update rate requirement to 150 NM is achieved. In the worst-case interference environment analyzed, air-ground ranges for all aircraft categories are beyond 150 NM.

4.2.3 Transmission of our TCPs

RTCA DO-282 [Ref. 7] do not provide for the transmission of more than two TCPs. However, there are more than 20 spare payload type codes that are unused in the current MOPS definition of the system. These message types could be defined to provide increased intent information; however, the UAT epoch, as defined in RTCA DO-282, would need to be revised to accommodate transmission of these message types.

4.3 VDL Mode 4 system performance and compliance

This section provides discussion of the VDL Mode 4 system performance and design compliance with the additional Eurocontrol criteria specified in section 4.1. Each of the criteria and VDL Mode 4 performance are discussed in a separate sub-section.

4.3.1 Air-air extension to 150 NM

As previously discussed in Section 2.2.1.2.1.2, based on the analysis of the performance of VDL Mode 4 in the high-density scenario, and as shown in Appendix B, the air-air extension to 150 NM is not achieved. In the worst-case interference environment analyzed, maximum air-air range for high-altitude aircraft is around 70 NM.

4.3.2 Air-ground to 150 NM

As previously discussed in Section 2.2.1.2.1.2, although air-ground performance was not simulated, VDL Mode 4 experts are of the view that all known air-ground update rate criteria can be met for all classes of aircraft out to at least 150 NM, by using a sectorized antenna. This should be verified by appropriate simulations.

4.3.3 Transmission of four TCPs

As stated in Section 2.2.1.2.1.3, no intent information is being broadcast in the system being analyzed for this study. The VDL Mode 4 system experts proposed that intent information would be sent on a separate channel, rather than placing the intent load on any of the four channels examined for this study. This would necessitate another channel assignment (along with any required guard channels), as well as two additional receivers on the aircraft.

4.4 1 090 ES system performance and compliance

This section provides discussion of the 1 090 ES system performance and design compliance with the additional Eurocontrol criteria specified in Section 4.1. Each of the criteria and 1 090 ES performance are discussed in a separate sub-section.

4.4.1 Air-air extension to 150 NM

As previously discussed in Section 2.2.1.3.1.2, based on the analysis of the performance of 1 090 ES in the high-density scenario, and as shown in Appendix C, the air-air extension to 150 NM is not achieved. In the worst-case interference environment analyzed, maximum air-air range for high-altitude aircraft is around 40-50 NM, depending on the interference environment.

4.4.2 Air-ground to 150 NM

As previously discussed in Section 2.2.1.3.1.2, although air-ground performance was not simulated, 1 090 ES experts are of the view that all known air-ground update rate criteria can be met for all classes of aircraft out to at least 150 NM, by using a sectorized antenna. This should be verified by appropriate simulations.

4.4.3 Transmission of four TCPs

As stated in Section 2.2.1.3.1.3, the only intent information broadcast in the system being analyzed for this study is TSR. Analysis of transmission of TCRs has not yet been completed.

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ATTACHMENT A

UAT SYSTEM PERFORMANCE RESULTS

The figures in this Appendix illustrate the system performance of the UAT in both the high-density and low-density scenarios. Figures A-1 through A-33 show performance in the heavy interference high-density scenario. RTCA DO-242A specifies the maximum ranges for air-air update rates required for A0 to 10 NM, A1 to 20 NM, A2 to 40 NM, and A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. The RTCA ADS-B MASPS requirements for state vector, TSR, and TCR+0 updates are shown as black dotted lines on the plots. The Eurocontrol extension to 150 NM is applied to the state vector, and Eurocontrol TCR requirements are shown as black dashed lines. Although results for TCR+1 transmissions are shown, there are currently no ADS-B MASPS requirements that have been set for TCR+1 reception. Performance in compliance with requirements is indicated by results that are below the dotted and dashed lines.

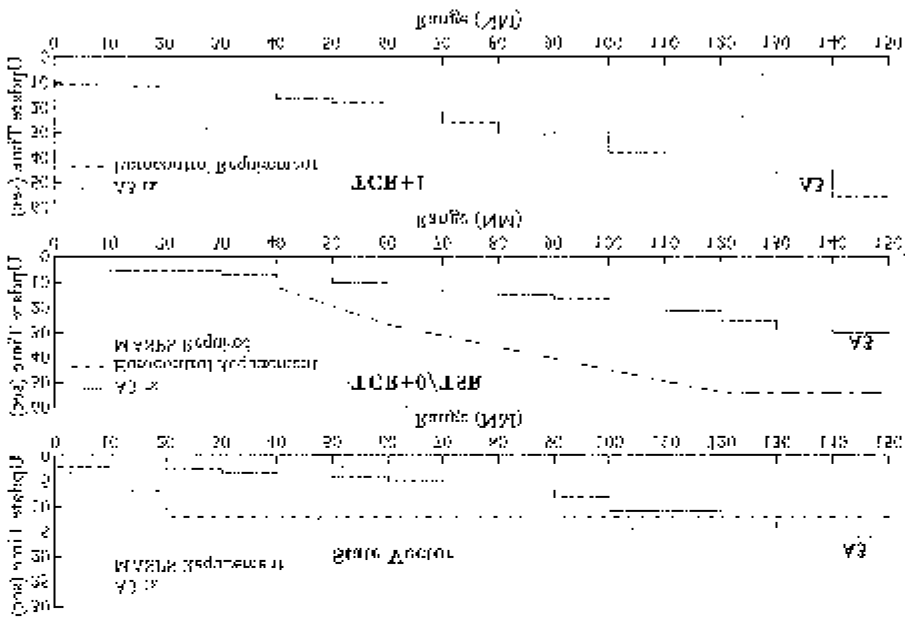

Figure A-1. A3 receiver in high density at high altitude receiving A3 transmitters

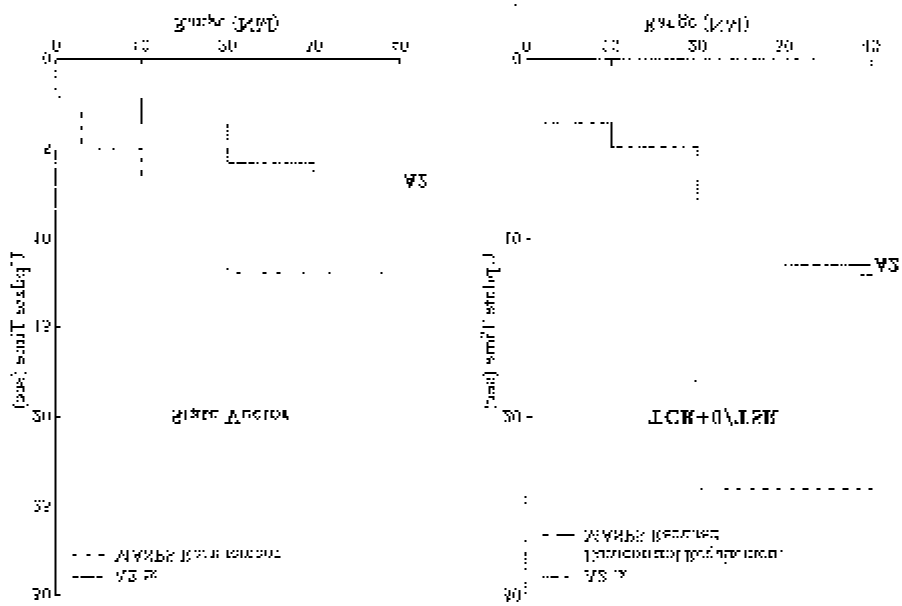

Figure A-2. A3 receiver in high density at high altitude receiving A2 transmitters

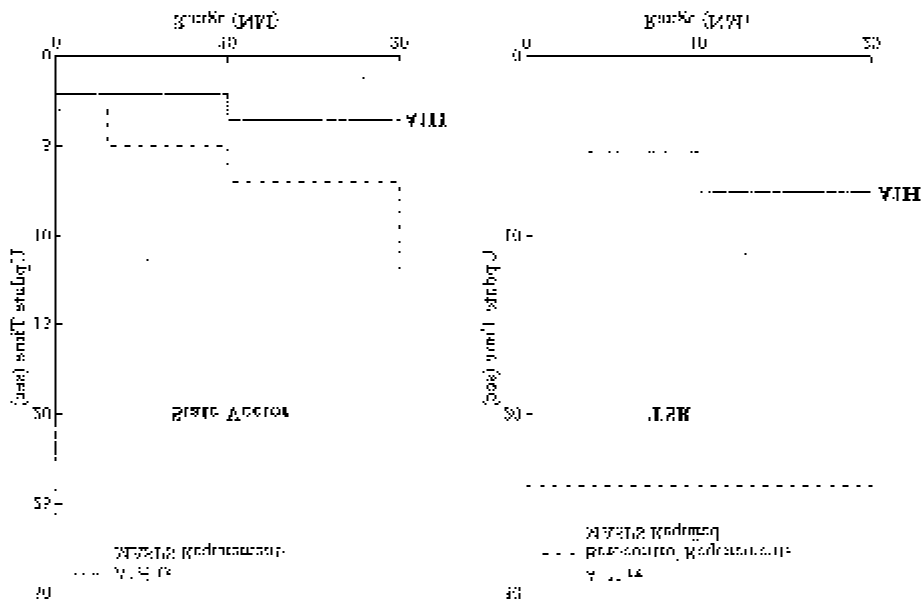

Figure A-3. receiver in high density at high altitude receiving A1H transmitters

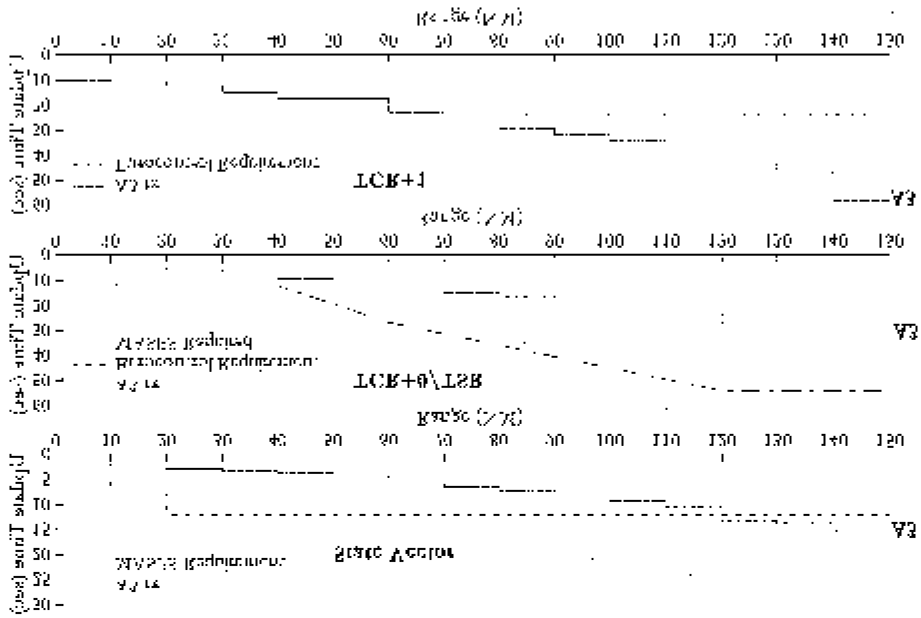

Figure A-4. A3 receiver in high density at FL 150 receiving A3 transmitters

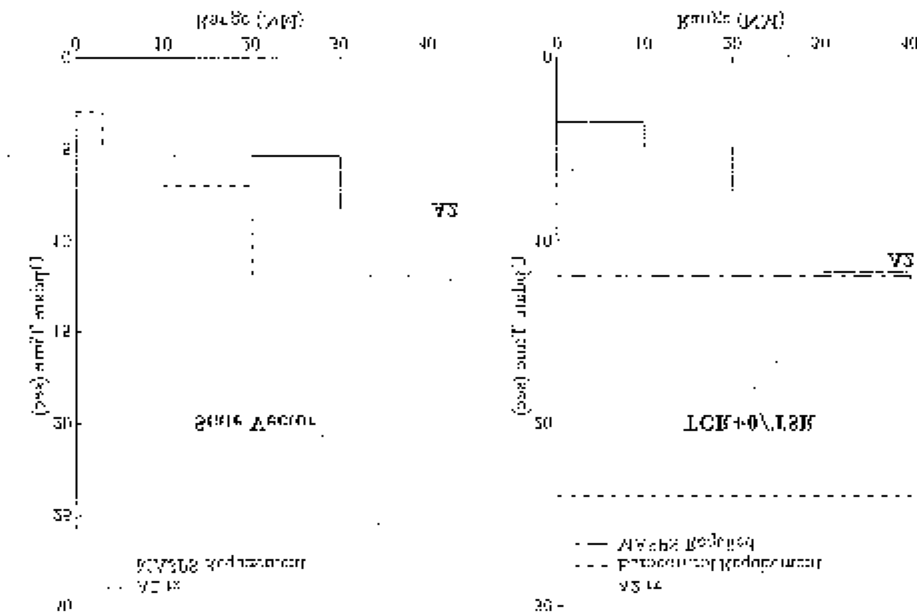

Figure A-5. A3 receiver in high density at FL 150 receiving A2 transmitters

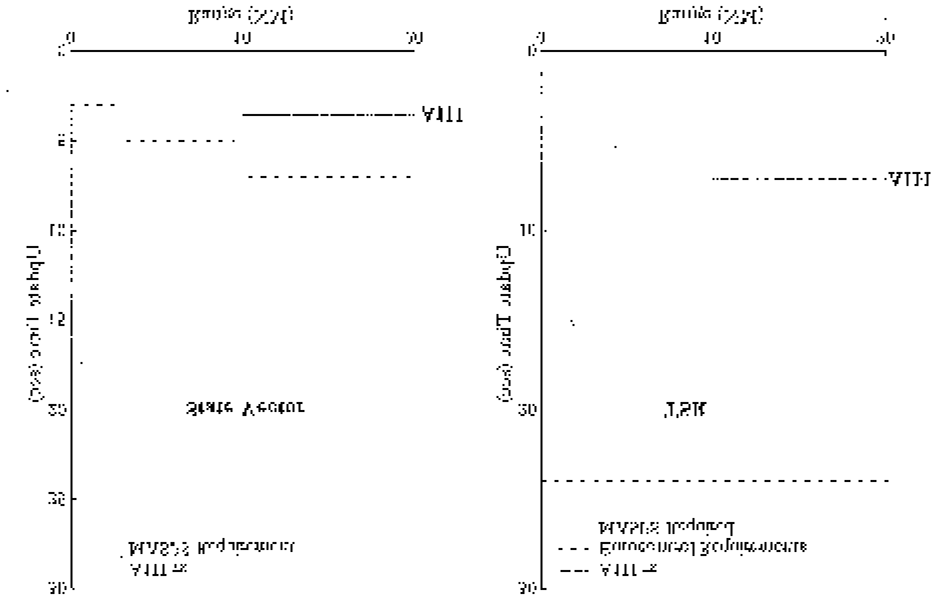

Figure A-6. A3 receiver in high density at FL 150 receiving A1H transmitters

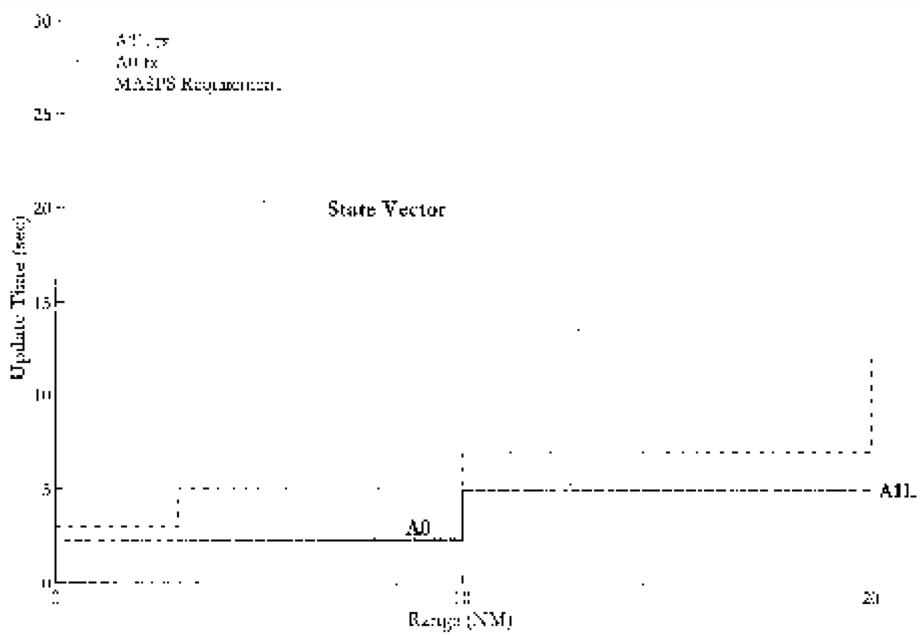

Figure A-7. A3 receiver in high-density at FL 150 receiving A1Land A0 transmitters

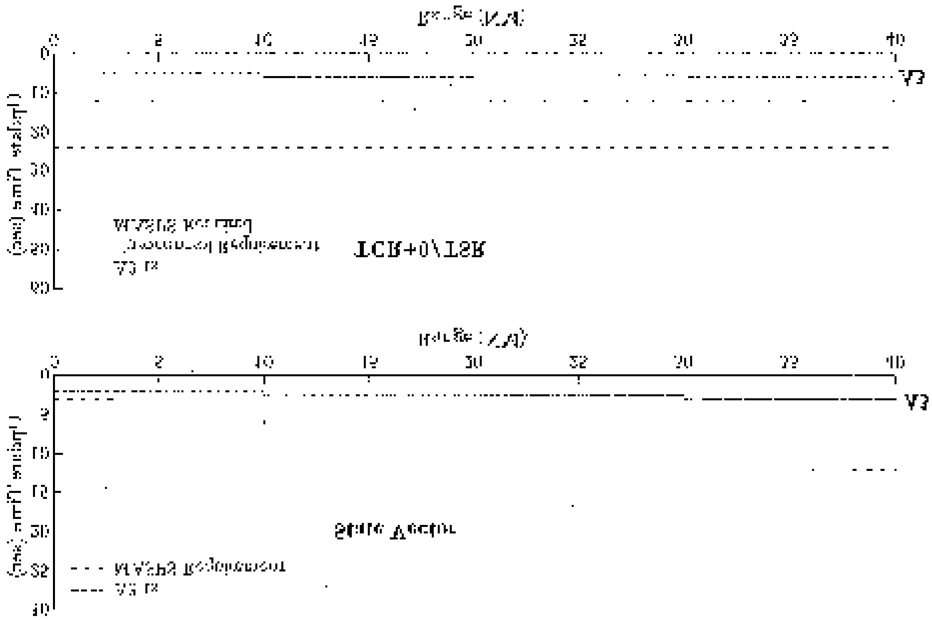

Figure A-8. A2 receiver in high density at high altitude receiving A3 transmitters

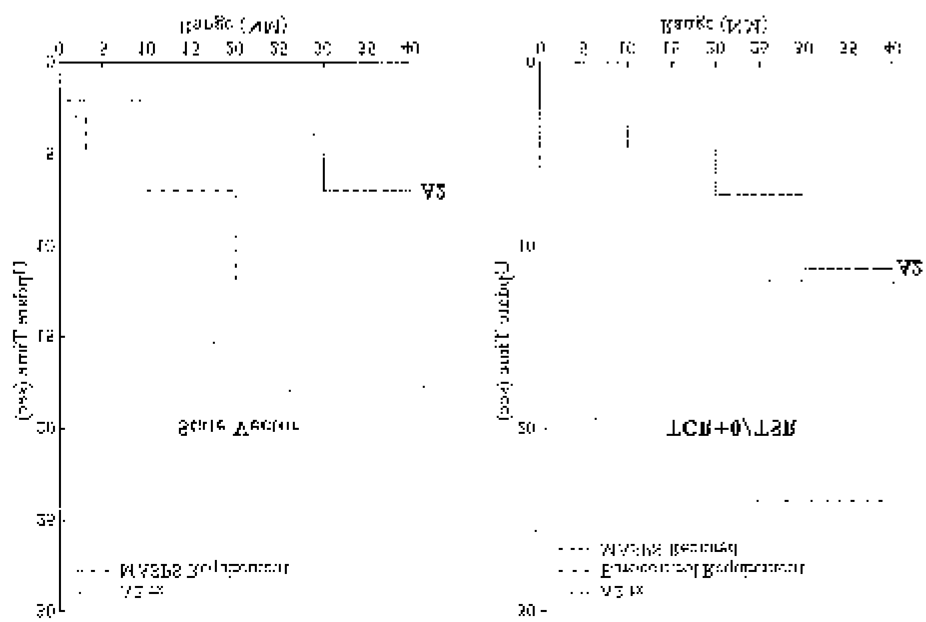

Figure A-9. A2 receiver in high density at high altitude receiving A2 transmitters

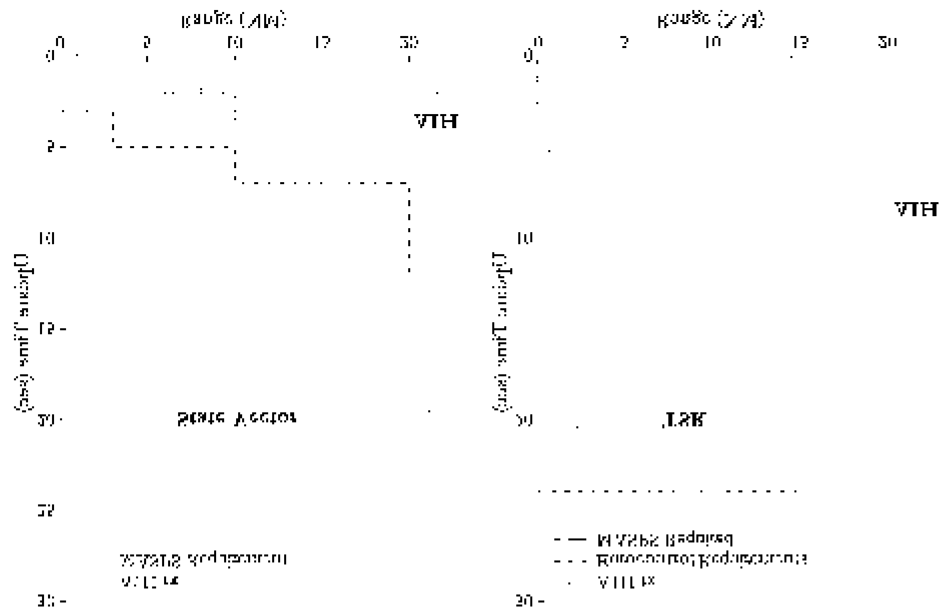

Figure A-10. A2 receiver in high density at high altitude receiving A1H transmitters

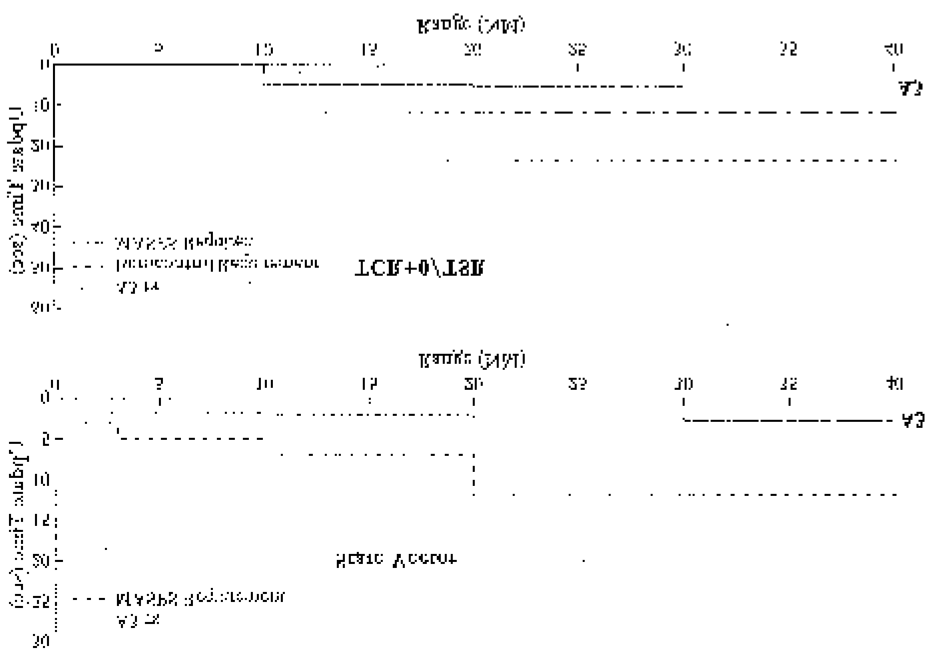

Figure A-11. A2 receiver in high density at FL 150 receiving A3 transmissions

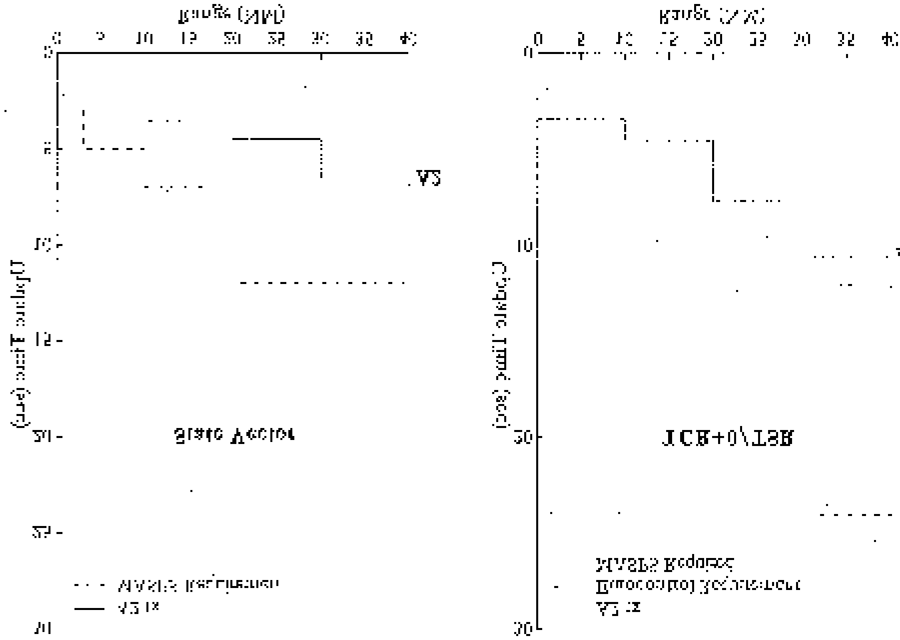

Figure A-12. A2 receiver in high density at FL 150 receiving A2 transmissions

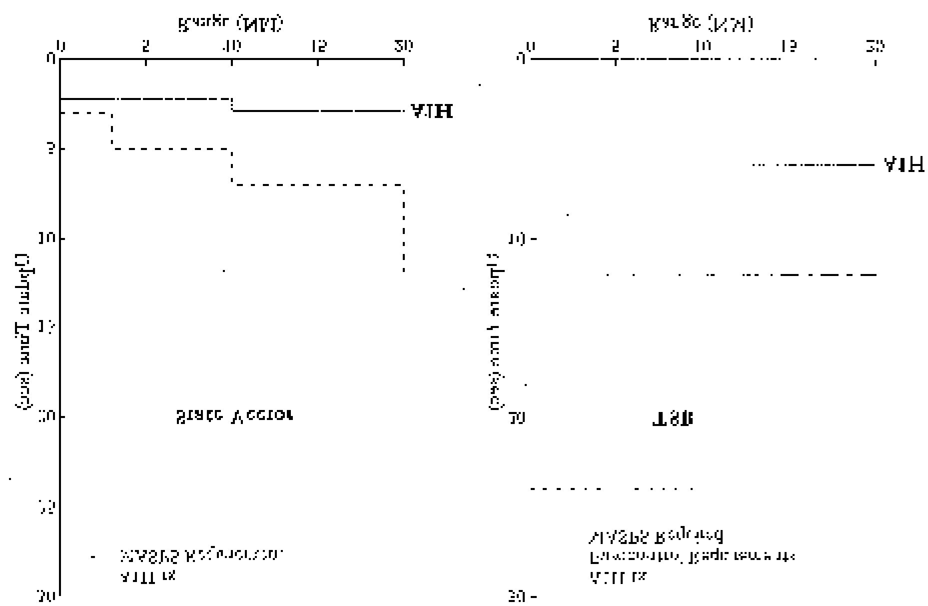

Figure A-13. A2 receiver in high density at FL 150 receiving A1H transmissions

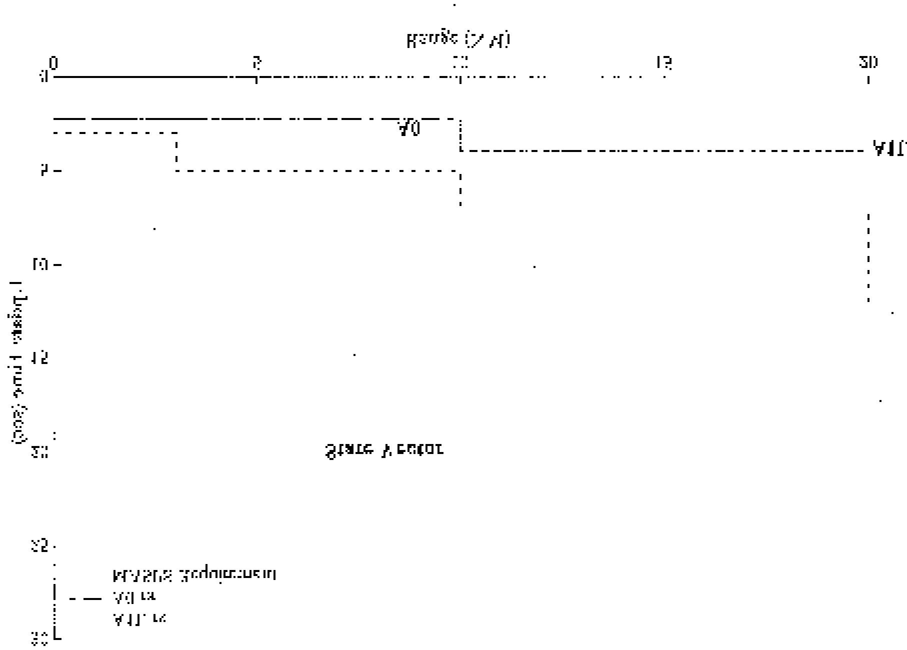

Figure A-14. A2 receiver in high density at FL 150 receiving A1L and A0 transmissions

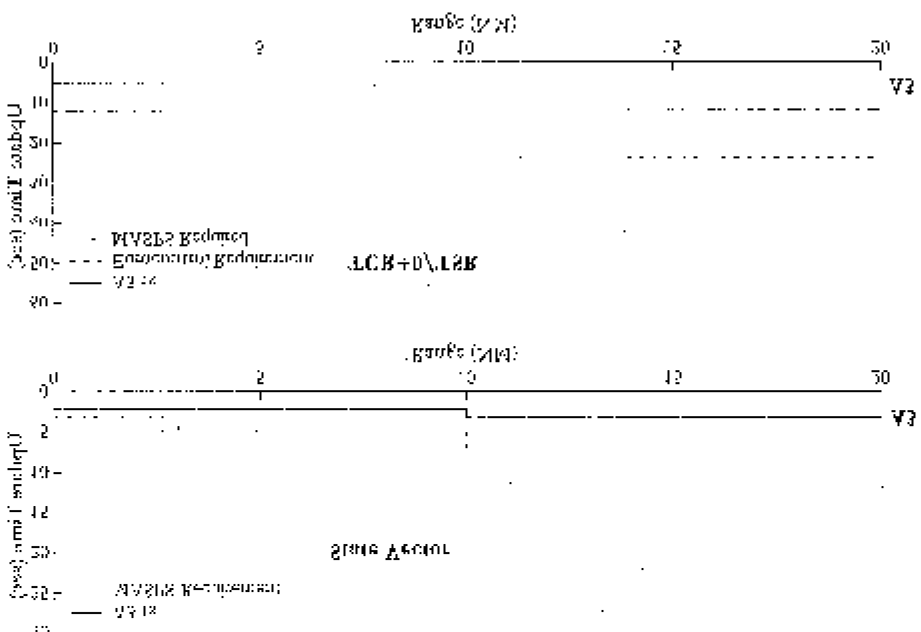

Figure A-15. A1H receiver in high density at high altitude receiving A3 transmissions

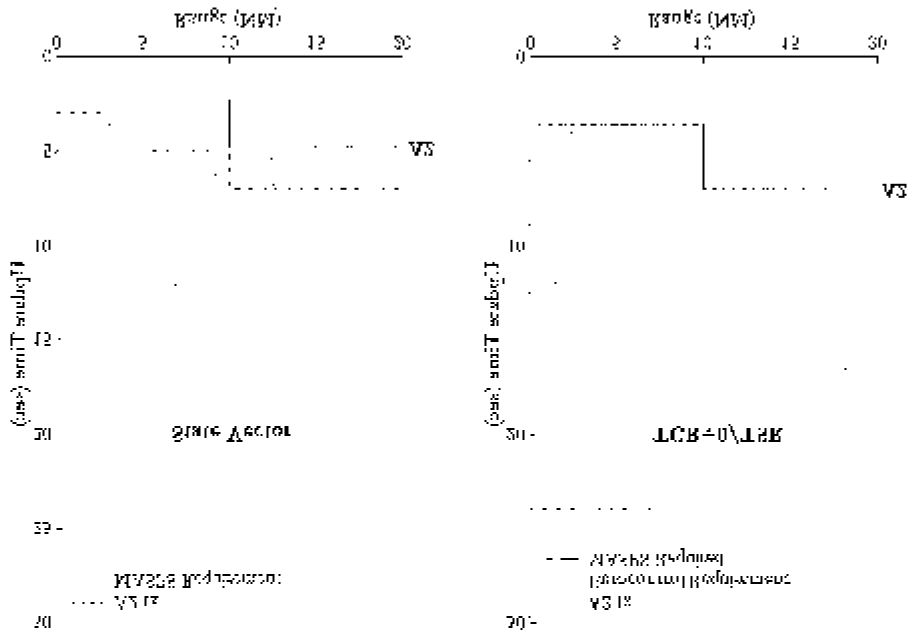

Figure A-16. A1H receiver in high density at high altitude receiving A2 transmissions

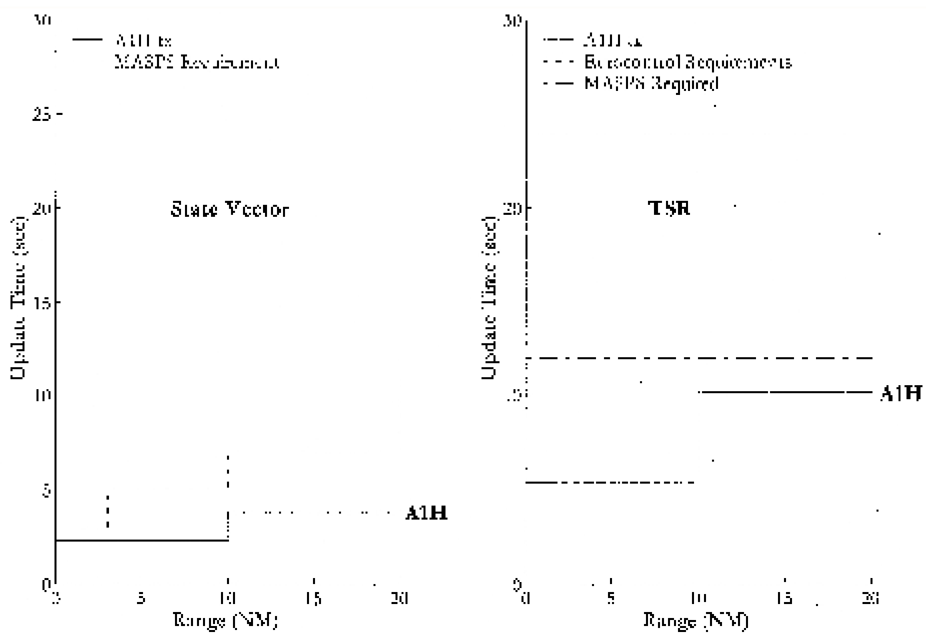

Figure A-17. A1H receiver in high density at high altitude receiving A1H tansmissions

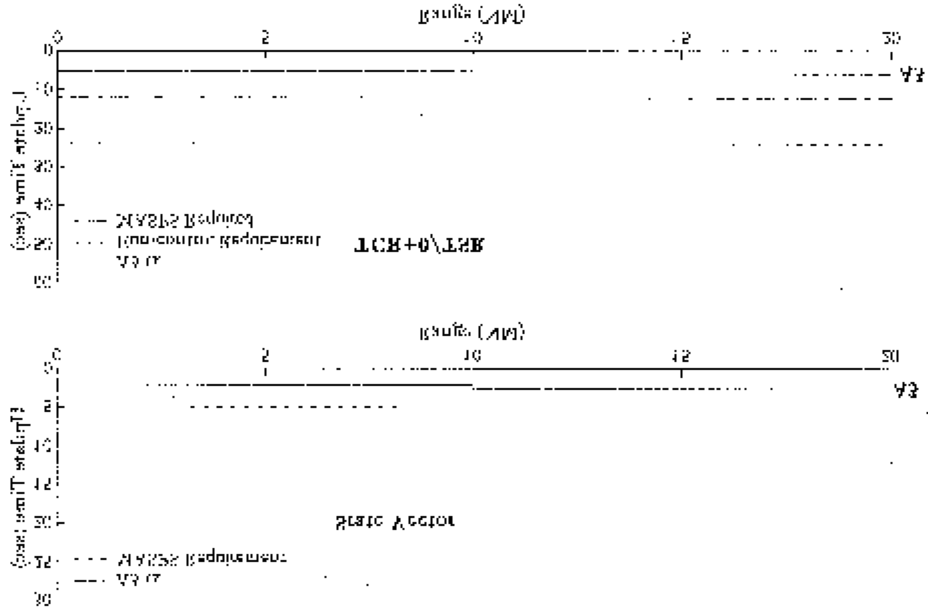

Figure A-18. A1 receiver in high density at FL 150 receiving A3 transmissions

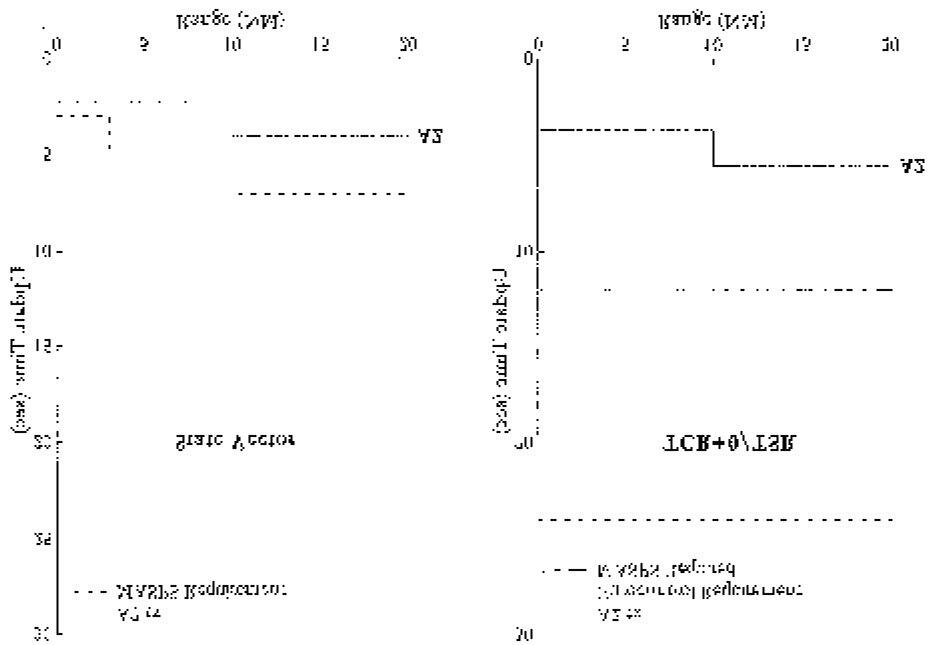

Figure A-19. A1 receiver in high density at FL 150 receiving A2 transmissions

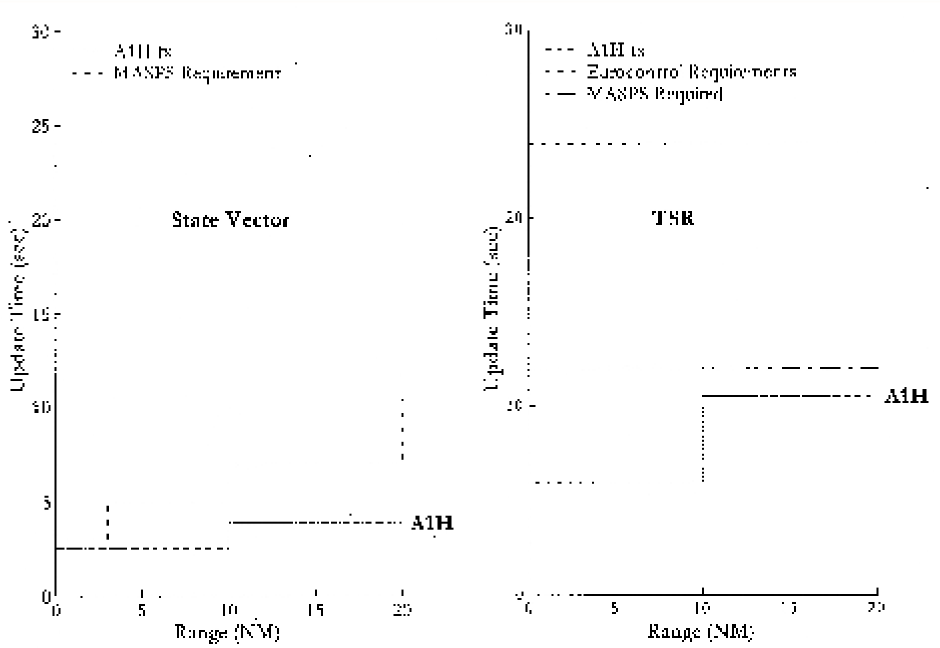

Figure A-20. A1 receiver in high density at FL 150 receiving A1H transmissions

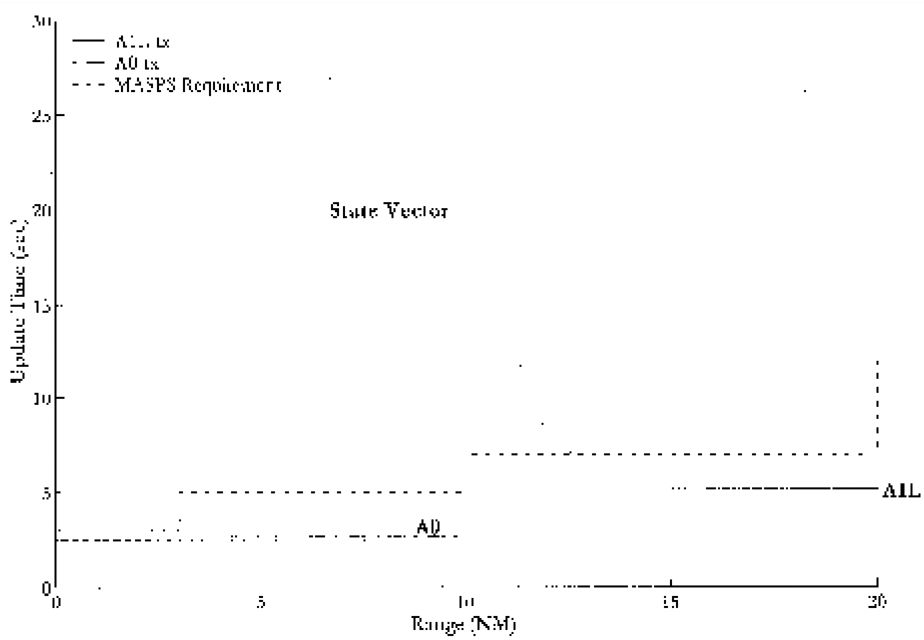

Figure A-21. A1 receiver in high density at FL 150 receiving A1L and A0 transmissions

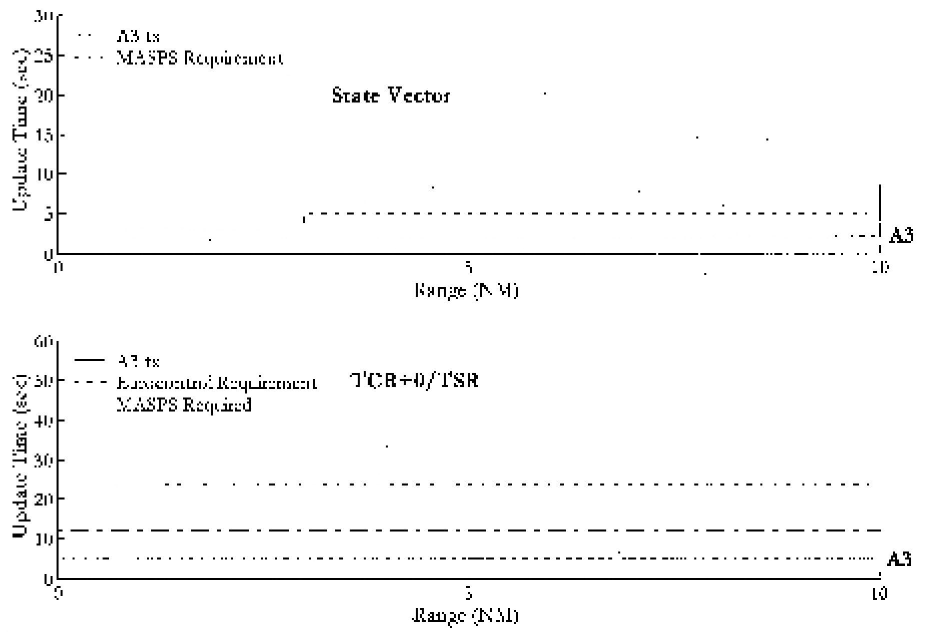

Figure A-22. A0 receiver in high density at FL 150 receiving A3 transmissions

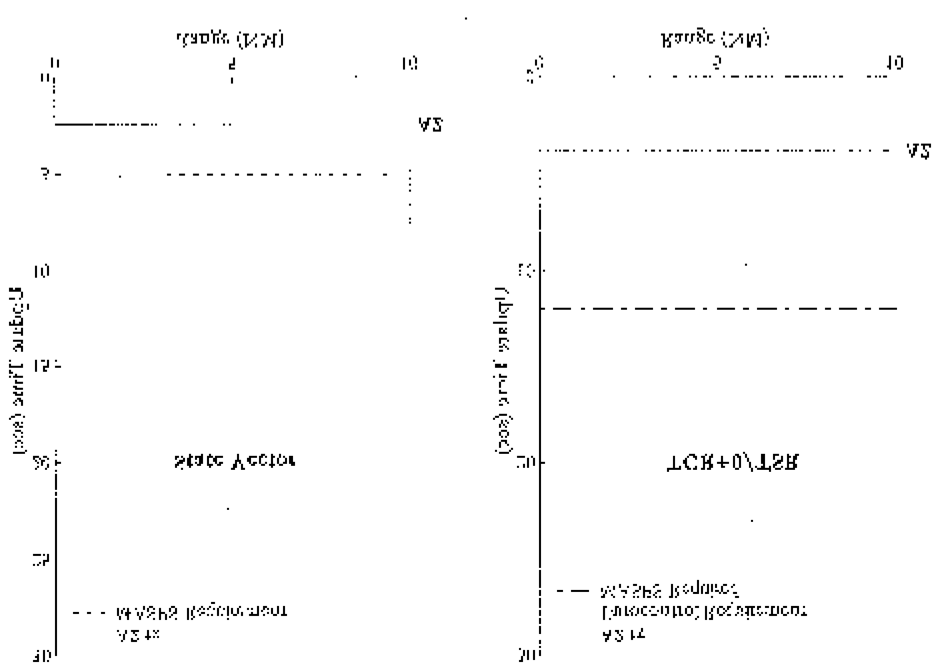

Figure A-23. A0 receiver in high density at FL 150 receiving A2 transmissions

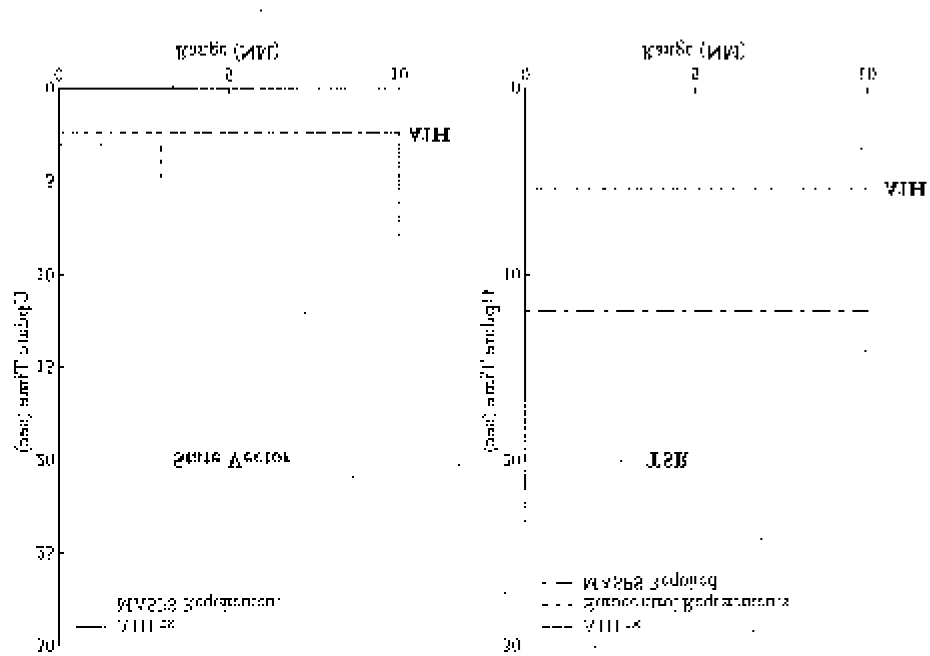

Figure A-24. A0 receiver in high density at FL 150 receiving A1H transmissions

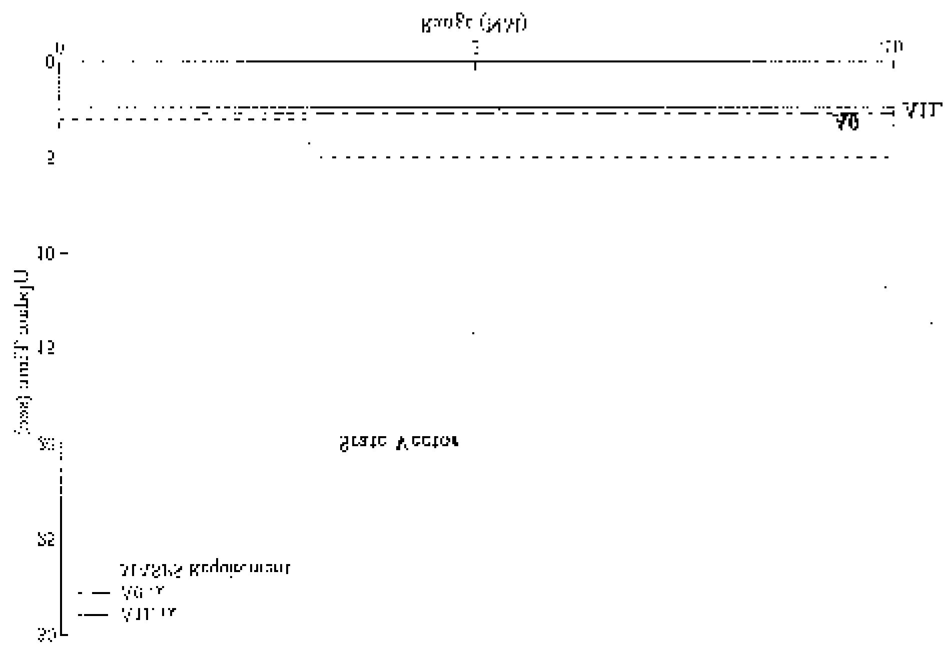

Figure A-25. A0 receiver in high density at FL 150 receiving A1L and A0 transmissions

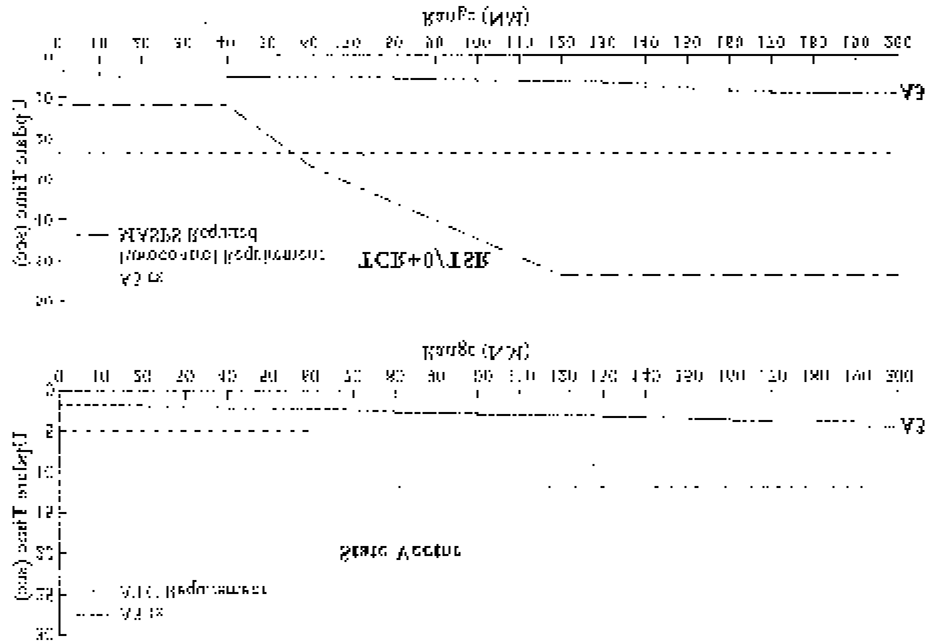

Figure A-26. Ground receiver in high density with 3-Sector antenna in Brussels receiving A3 transmissions

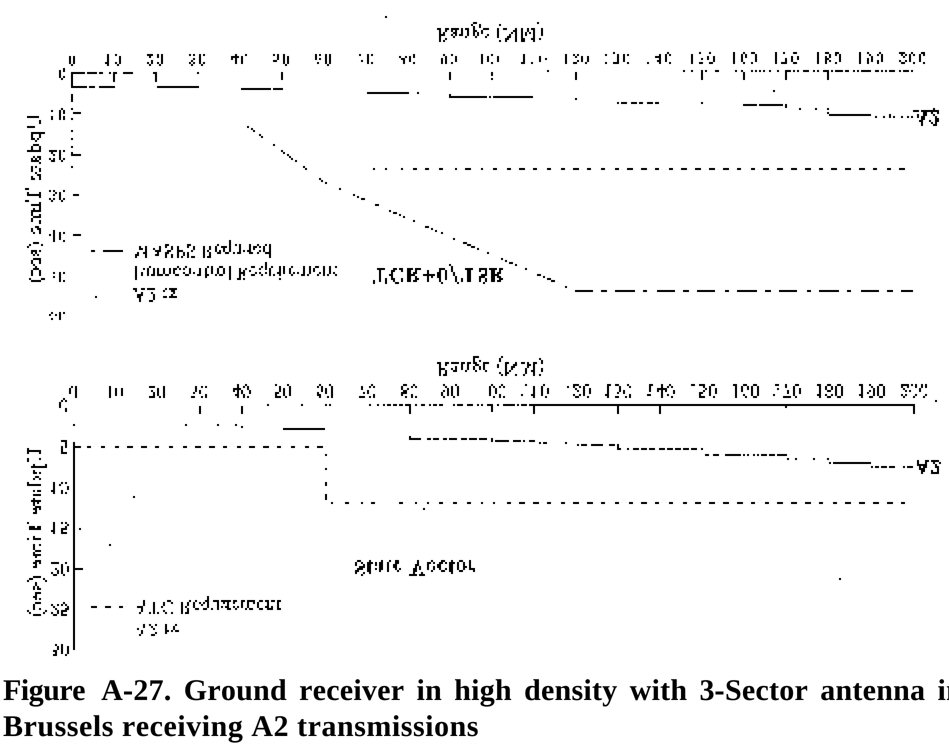

Figure A-27. Ground receiver in high density with 3-Sector antenna in Brussels receiving A2 transmissions

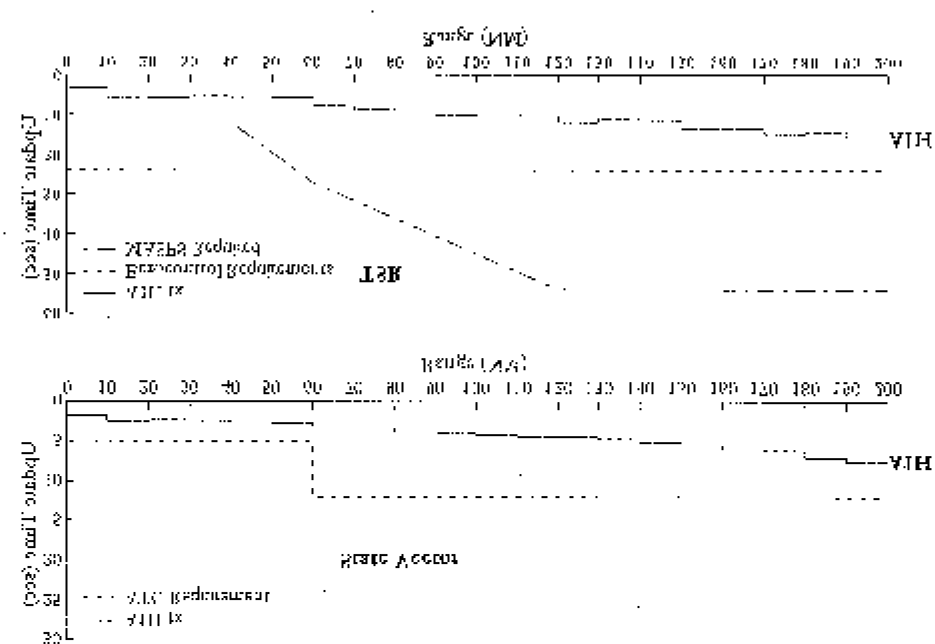

Figure A-28. Ground receiver in high density with 3-Sector antenna in Brussels receiving A1H transmissions

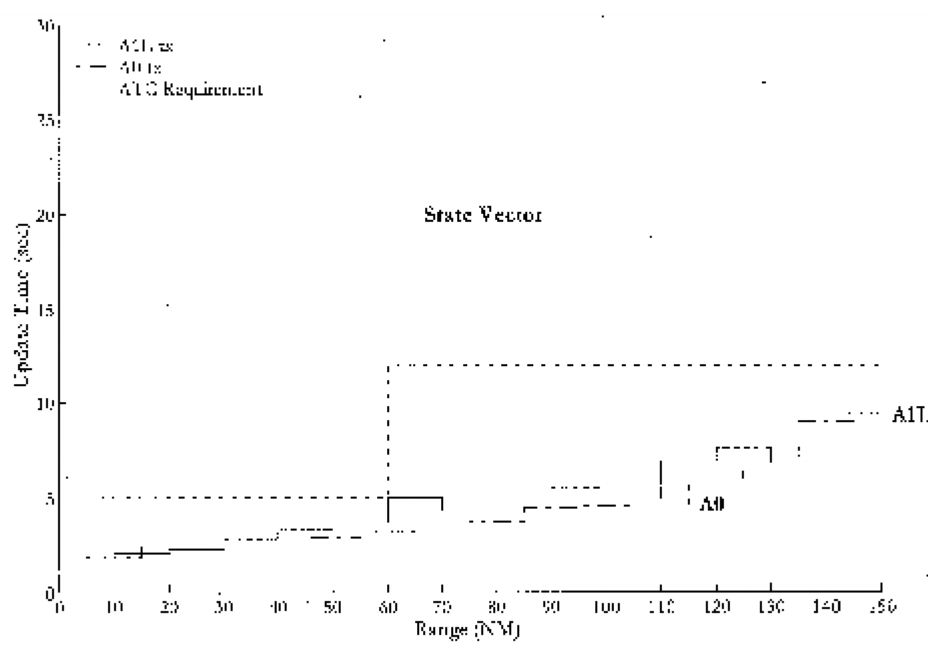

Figure A-29. Ground receiver in high density with 3-Sector antenna in Brussels receiving A1L and A0 transmissions

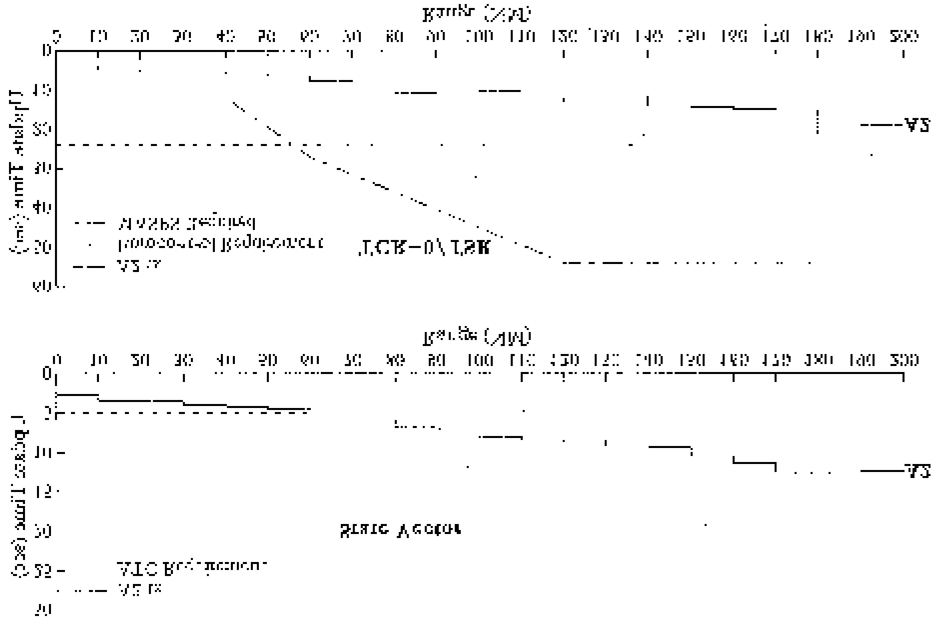

Figure A-31. Ground receiver in CE2015 with 3-Sector antenna at center of scenario, co-located with a 979 MHz TACAN delivering -50 dBm power to antenna, receiving A2 transmissions

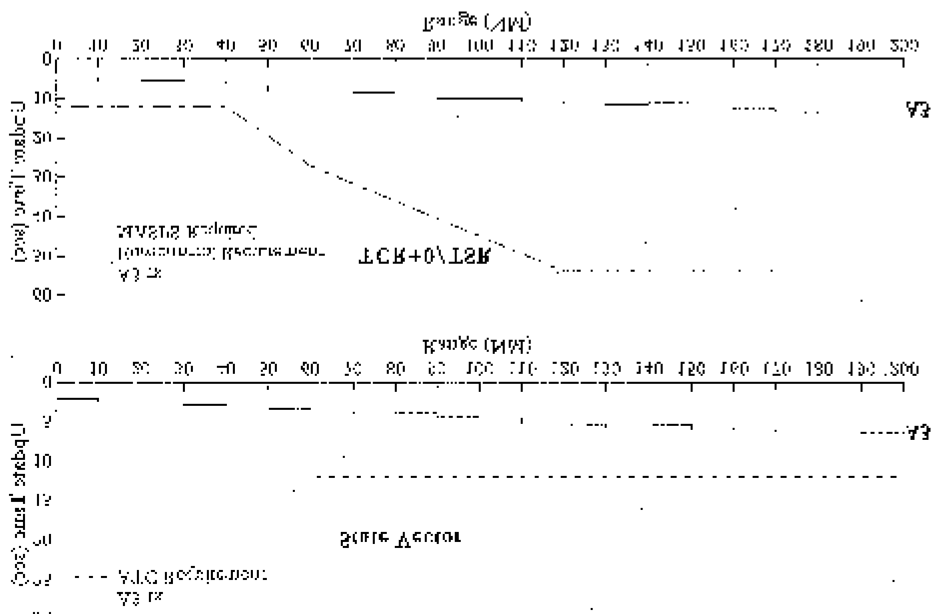

Figure A-30. Ground receiver in CE2015 with 3-Sector antenna at center of scenario, co-located with a 979 MHz TACAN
delivering -50 dBm power to antenna, receiving A3 transmissions

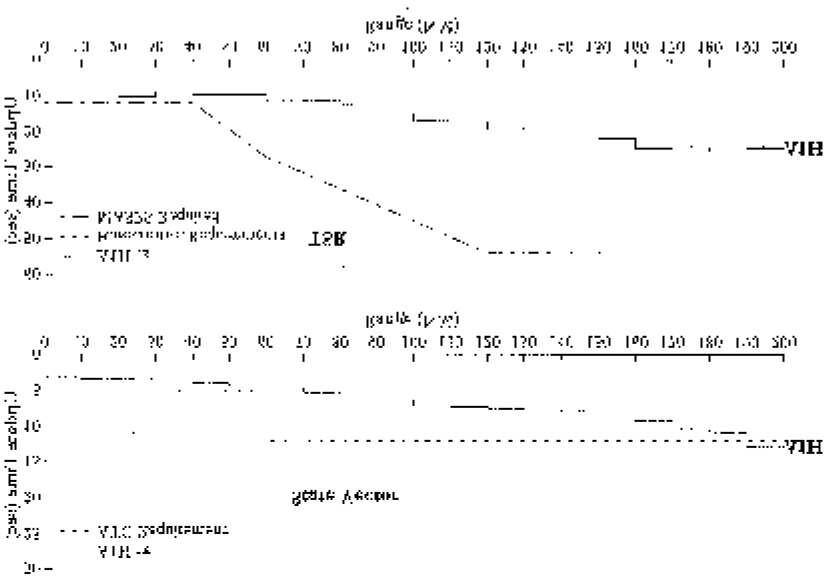

Figure A-32. Ground receiver in CE2015 with 3-Sector antenna at center of scenario, co-located with a 979 MHz TACAN delivering -50 dBm power to antenna, receiving A1H transmissions

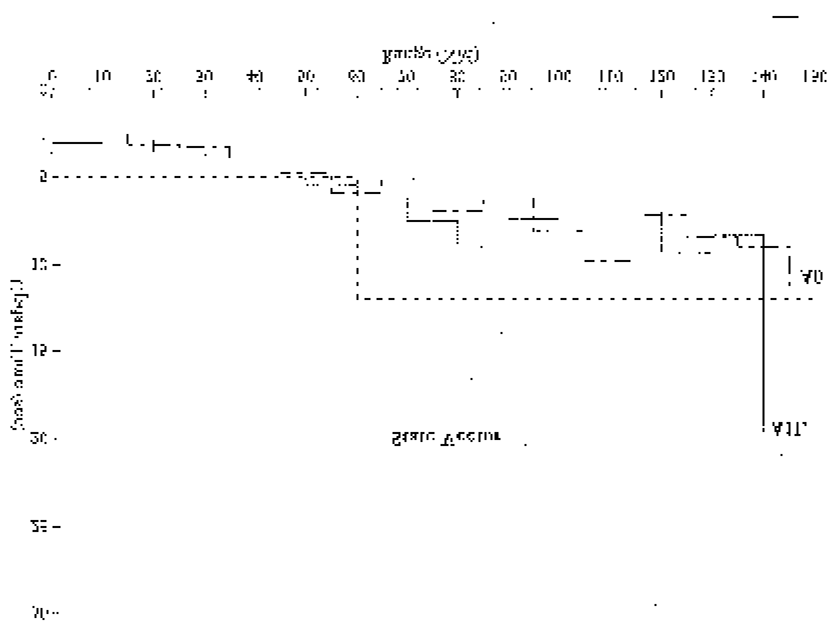

Figure A-33. Ground receiver in CE2015 with 3-Sector antenna at center of scenario, co-located with a 979 MHz TACAN delivering -50 dBm power to antenna, receiving A1L and A0 transmissions

Aircraft track acquisition was examined in terms of the distance at which aircraft were acquired in a head-on high-speed scenario. For this analysis, many instances of two approaching aircraft were placed in the midst of the high-density air traffic scenario, and the acquisition range was calculated for each encounter. The 99th percentiles are presented below for transmit-receive pairs. This represents the range where 99% of the aircraft are expected to perform at least as well 99% of the time.

Table A-1: 99th percentile acquisition ranges (in NM) for UAT transmit/receive Pairs

	A3 xmtr	**A2 xmtr**	**A1H xmtr**	**A1L xmtr**	**A0 xmtr**
A3 rcvr	137	53	53	49	18
A2 rcvr	145	54	53	52	17
A1 rcvr	122	50	38	37	11

Aircraft acquisition was defined differently for each equipage class. For A0/A1L transmitters, acquisition was defined to be simply the reception of a state vector update. For A1H category aircraft, it was defined to require the reception of not only a state vector (SV), but also a Target Status Report (TSR) and a Mode Status (MS) message as well. A2 acquisition required a SV, TSR, MS, and a Trajectory Change Report (TCR0). Finally, acquiring an A3 meant getting SV, TSR, MS, TCR0, and TCR1. The MAUS was used with probe aircraft in order to get a large enough statistical sample to determine the 99th percentile. The results in Table A-1 show that acquisition is achieved for each class of aircraft equipage at ranges beyond what is necessary to perform flight applications currently envisioned for them.

Figures A-34 and A-35 show UAT system performance in the low-density scenario. RTCA DO-242A [Ref. 3] specifies the maximum ranges for air-air update rates required for A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM. The RTCA DO-242A requirements for state vector, TSR, and TCR+0 updates are shown as black dotted lines on the plots. The Eurocontrol extension to 150 NM is applied to the state vector, and Eurocontrol TCR requirements are shown as black dashed lines. Although results for TCR+1 transmissions are shown, there are currently no ADS-B MASPS requirements that have been set for TCR+1 reception. Performance in compliance with requirements is indicated by results that are below the dotted and dashed lines.

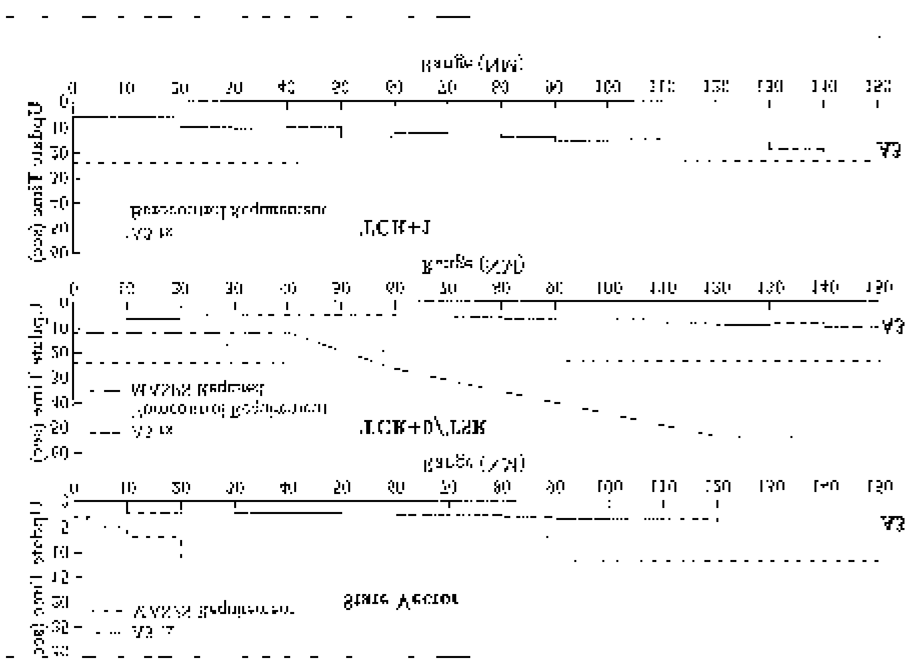

Figure A-34. A3 receiver at high altitude in center of low-density scenario receiving A3 transmissions

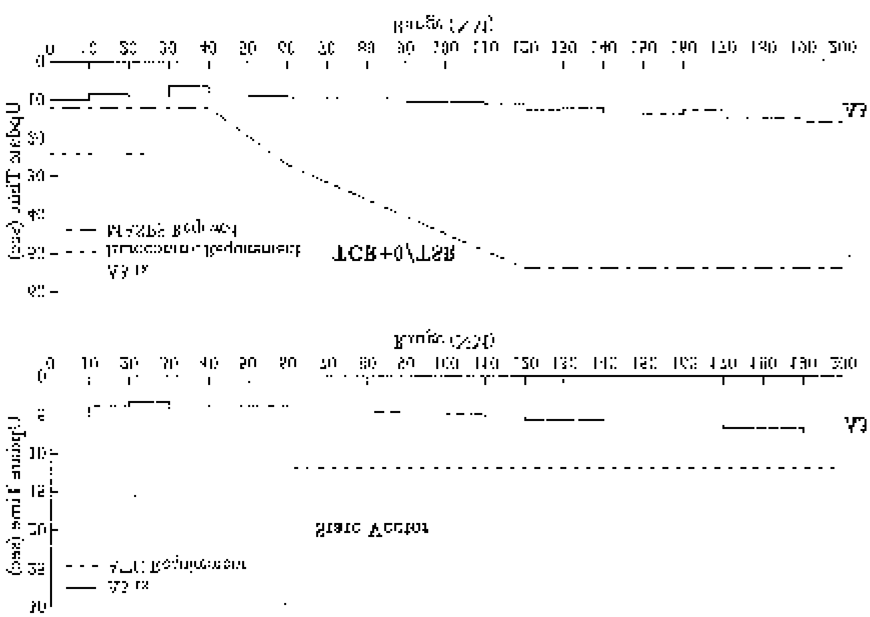

Figure A-35: Receptions of A3 transmissions by a standard ground receiver at the center of low-density scenario co-located with a TACAN at 979 MHz with -30 dBm Power at the UAT antenna

ATTACHMENT B

VDL MODE 4 SYSTEM PERFORMANCE RESULTS

Figure B-1 in this Appendix illustrates the system performance of VDL Mode 4 in the high-density 2015 European scenario. RTCA DO-242A [Ref. 3] specifies the maximum ranges for air-air update rates required for A0 to 10 NM, A1 to 20 NM, A2 to 40 NM, and A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. The RTCA DO-242A requirements for state vector are shown as black dotted lines on the plot, with the Eurocontrol extension to 150 NM applied. Performance in compliance with requirements is indicated by results that are below the dotted and dashed lines. Note that in the VDL Mode 4 assumptions, all equipages had the same characteristics for transmit and receive, and therefore are not shown by equipage type, since all transmitters and receivers are considered to be the same.

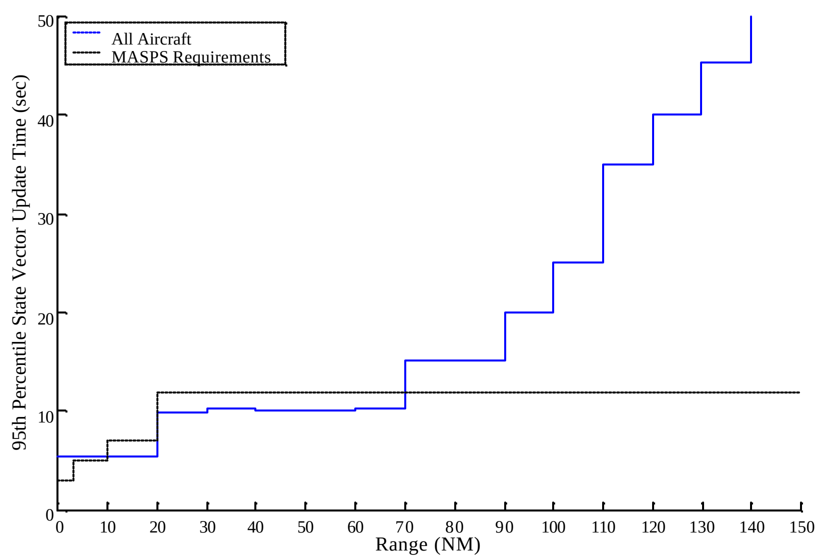

Figure B-1. VDL Mode 4 receiver in high density at high altitude receiving all VDL Mode 4 transmitters

ATTACHMENT C

1 090 EXTENDED SQUITTER
SYSTEM PERFORMANCE RESULTS

The figures in this Appendix illustrate the system performance of 1 090 ES in both the high-density and low-density scenarios. Figures C-1 through C-8 show performance in the heavy interference high-density scenario. Two cases are shown: 30,000 Mode A/C replies greater than -84 dBm per second, and 45 000 Mode A/C replies per second. RTCA DO-242A [Ref. 3] specifies the maximum ranges for air-air update rates required for A0 to 10 NM, A1 to 20 NM, A2 to 40 NM, and A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM for A3. The RTCA DO-242A requirements for state vector and TSR updates are shown as black dotted lines on the plots. The Eurocontrol extension to 150 NM is applied to the state vector. Performance in compliance with requirements is indicated by results that are below the dotted and dashed lines.

The transmit power distribution for A3 transmitters, which was used for this analysis, was uniform from 53-56 dBm. A3 transmit power was specified in this way to model what is expected to be deployed. However, RTCA DO-260A allows for A3 transmitters to transmit at powers as low as 51 dBm. This corresponds more closely to the transmit power distribution assumed for A2 class aircraft in this analysis; therefore, for a class A3 aircraft with a transmit power near the lower limit of the allowed range, it would be expected that performance would be given by A2 results in this study, rather than A3.

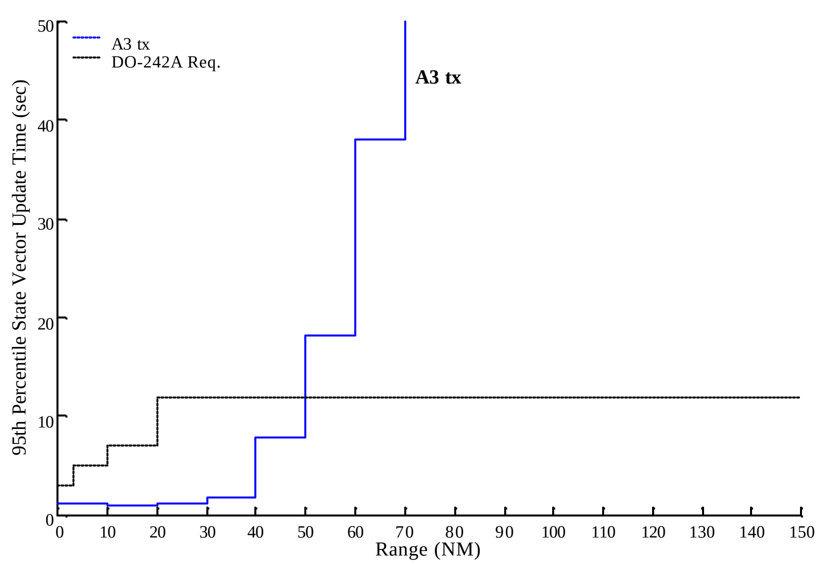

Figure C-1. State vector update times for an A3 receiver at high altitude in high density receiving A3 transmissions (30 00 Mode A/C replies per second)

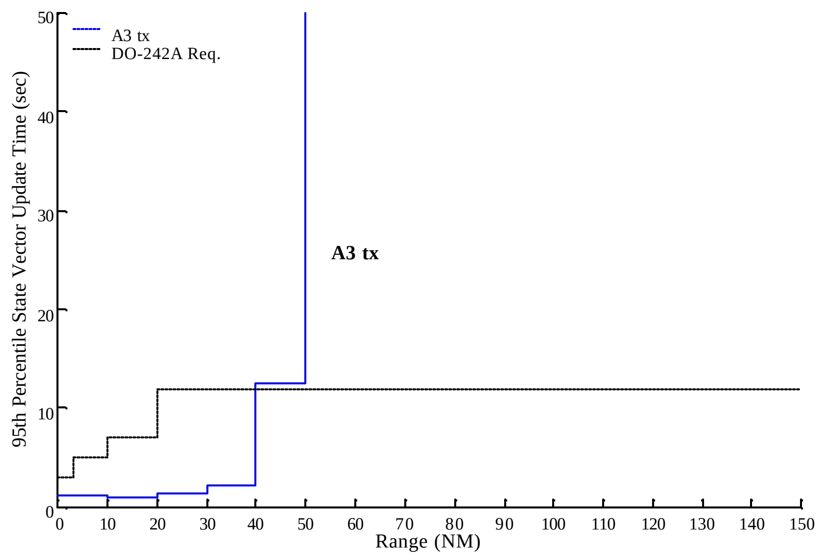

Figure C-2. State vector report update times for an A3 receiver at high altitude in high density receiving A3 transmissions (45 000 Mode A/C replies per second)

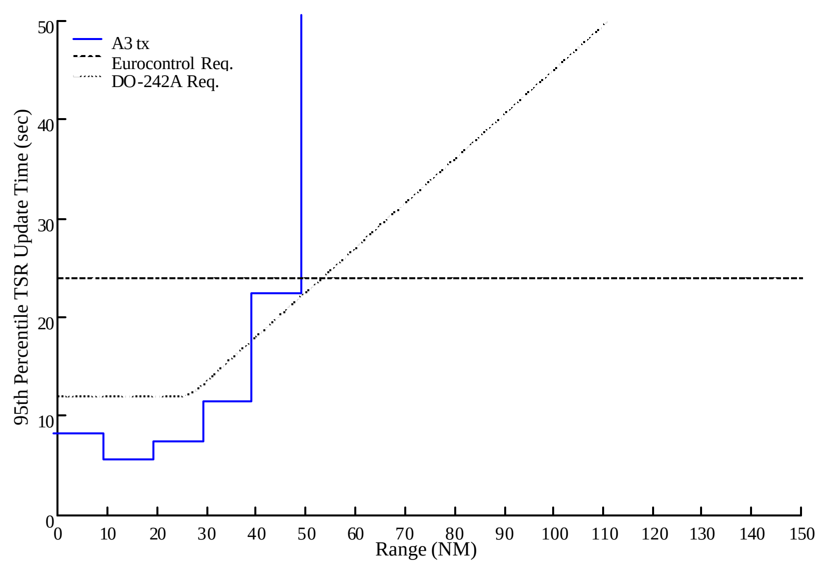

Figure C-3. Target State report update times for an A3 receiver in high density receiving A3 transmissions (30 000 Mode A/C replies per second)

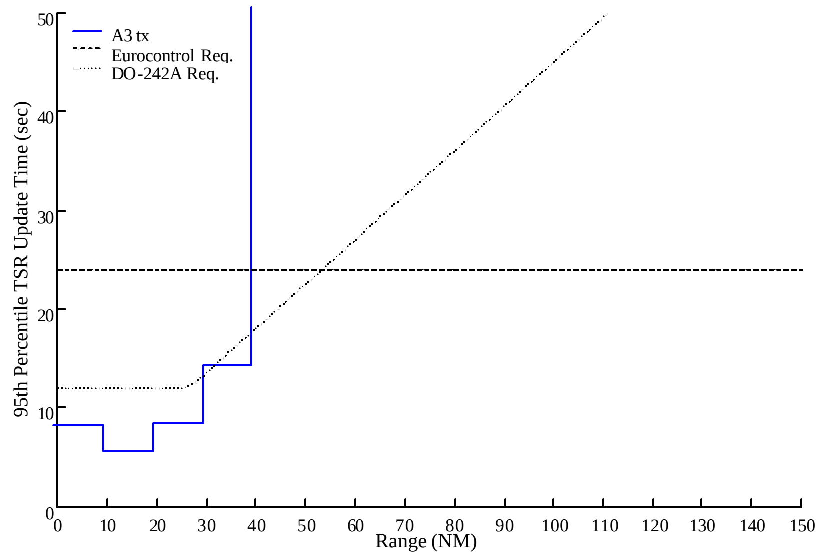

Figure C-4. Target State report update times for an A3 receiver in high density receiving A3 transmissions (45 000 Mode A/C replies per second)

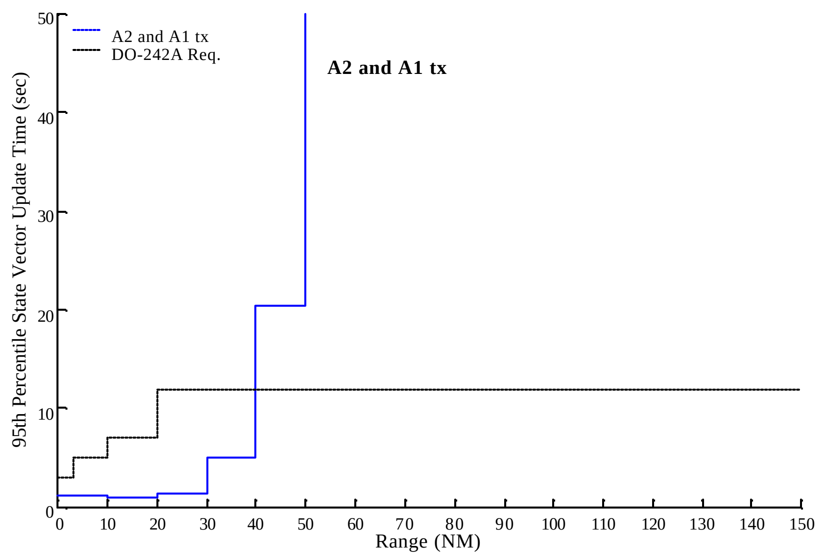

Figure C-5. State vector update times for an A3 receiver in high density receiving A2 and A1 transmissions (30 000 Mode A/C replies per second)

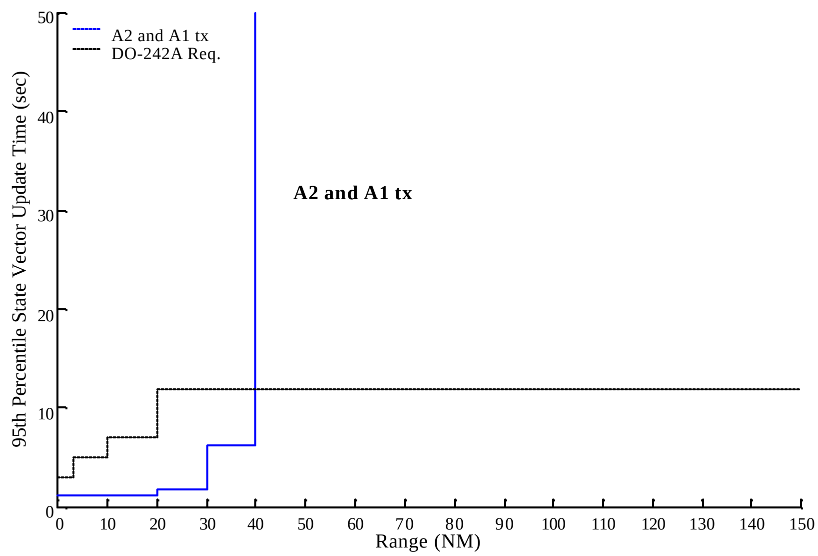

Figure C-6. State vector update times for an A3 receiver at high altitude in high density receiving A2 and A1 transmissions (45 000 Mode A/C replies per second)

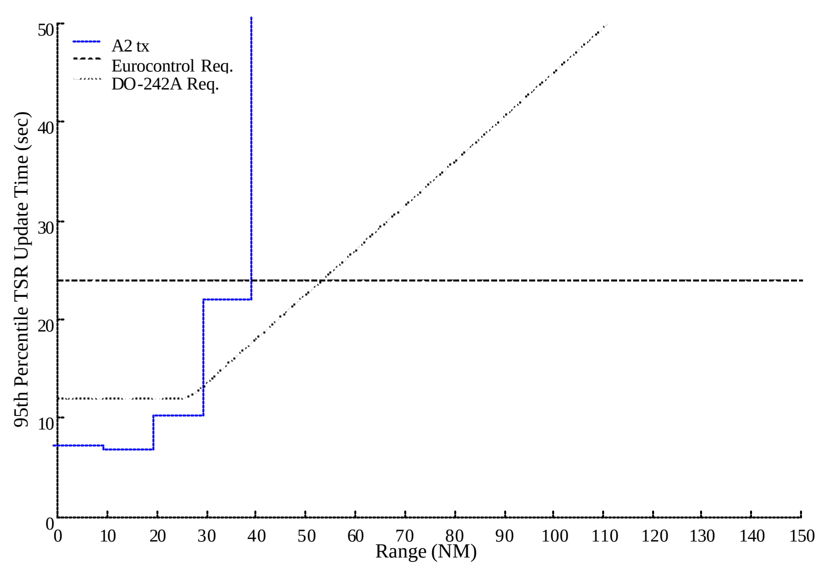

Figure C-7. Target State report update times for an A3 receiver in high density receiving A2 transmissions (30 000 Mode A/C replies per second)

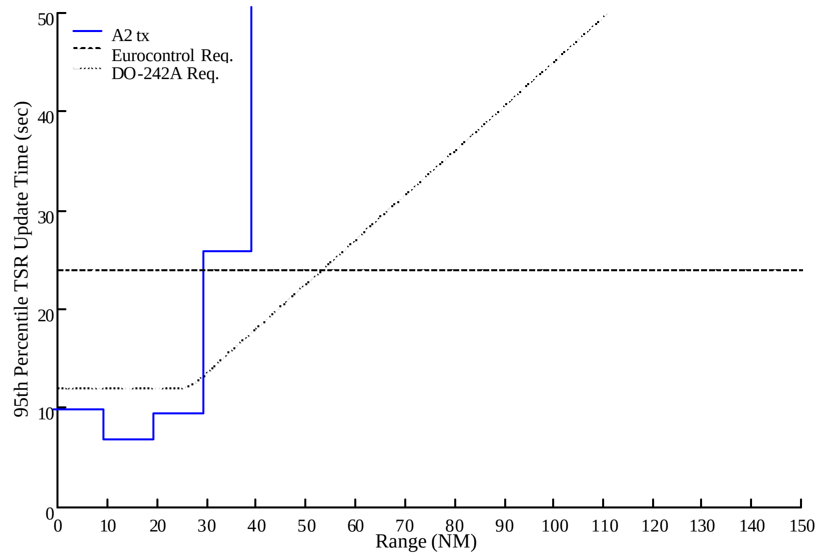

Figure C-8. Target State report update times for an A3 receiver in high density receiving A2 transmissions (45 000 Mode A/C replies per second)

Figures C-9 and C-10 show 1 090 ES system performance in the low-density scenario. RTCA DO-242A [Ref. 3] specifies the maximum ranges for air-air update rates required for A3 to 90 NM (120 NM desired), while the Eurocontrol criteria continue to 150 NM. The RTCA DO-242A requirements for state vector and TSR updates are shown as black dotted lines on the plots. The Eurocontrol extension to 150 NM is applied to the state vector and TSR. Performance in compliance with requirements is indicated by results that are below the dotted and dashed lines.

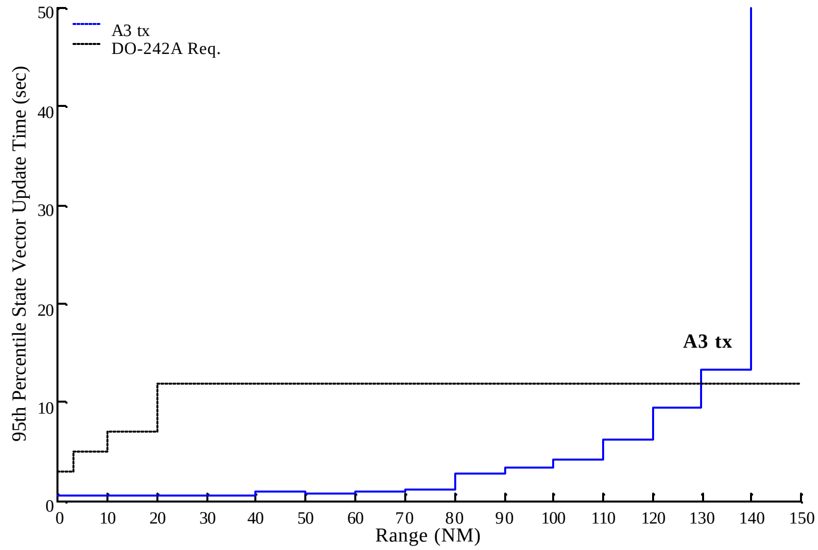

Figure C-9. Target State report update times for an A3 receiver in a low-density scenario receiving A3 transmissions (5 000 Mode A/C replies per second)

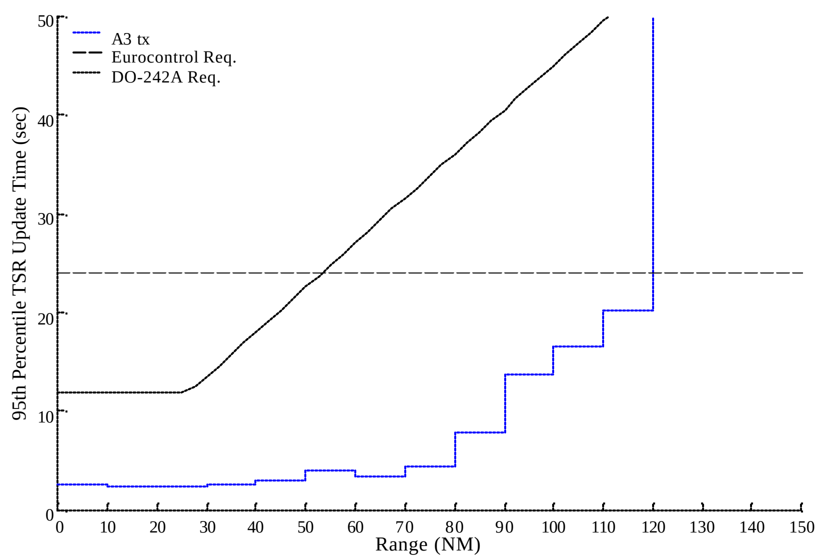

Figure C-10. Target State report update times for an A3 receiver in a low-density scenario receiving A3 transmissions (5 000 Mode A/C replies per second)

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