RTCA Free Flight Select Committee
Safe Flight 21 Steering Committee

Eurocontrol ADS Programme

ADS-B Technical Link Assessment Team (TLAT)

Technical Link Assessment Report

March 2001

Contents

1. Introduction

This report summarizes the technical assessment of candidate ADS-B/situational awareness links commissioned by both (1) the Safe Flight 21 (SF21) Steering Committee consistent with the recommendations of the RTCA Free Flight Select Committee and (2) the Eurocontrol ADS Programme Steering Group (PSG). The report builds upon the November 1999 Phase One Report [Ref. 1] developed by a precursor to the TLAT, the SF21 Technical ADS-B Link Evaluation Team.

1.1 TLAT Objectives and Membership

The SF21 Steering Committee and Eurocontrol ADS PSG requested continued technical evaluation of three ADS-B and situational awareness link candidates, 1090 MHz Extended Squitter, VHF Digital Link (VDL) Mode 4, and Universal Access Transceiver (UAT). The candidate links were to be technically characterized in a common manner and evaluated, in a reference set of traffic scenarios, to a common set of technical link assessment criteria derived from the need to support both the Free Flight Operational Enhancements [Ref. 2] specified in August 1998 by the RTCA Free Flight Select Committee and further applications as designated by the Eurocontrol ADS PSG. The Terms of Reference for the TLAT are Appendix A to this report.

The TLAT began its activities in May 2000. The roster for the Team and a list of additional contributors to TLAT activities are Appendix B to this report. Subject matter experts for each of the three ADS-B link candidates have participated, as have key technical personnel from several organizations within the FAA, Eurocontrol, and from Johns Hopkins University, the Mitre Corporation, and the industry.

1.2 Scope of this Report

This report discusses the technical assessment approach taken by the TLAT, summarizes TLAT simulation/analysis results, and presents TLAT findings. The TLAT understands that this report is intended to serve as a primary technical input to FAA and Eurocontrol selections of ADS-B link technologies for implementation. It must be emphasized that these selections of ADS-B link technologies will be based a number of considerations (e.g., cost/benefit and institutional/ transitional issues) in addition to the technical factors discussed herein.

This report does NOT contain an ADS-B link recommendation.

Section 2 of this report provides an overview of the three candidate ADS-B/situational awareness links. Section 3 discusses the Technical Link Assessment Criteria approved by the SF21 Steering Committee and the Eurocontrol ADS PSG and the traffic scenarios developed by the TLAT and approved by the SF 21 Steering Committee and the Eurocontrol ADS PSG. Section 4 discusses the technical assessment approach taken by the TLAT. Section 5 summarizes TLAT findings and areas for potential further study. Appendices to the report provide detailed system descriptions of the candidate links and significant supporting information for the Technical Link Assessment Criteria, traffic scenarios, and TLAT simulations/analyses.

2. Overview of ADS-B/Situational Awareness Link Candidates

The TLAT has been asked to evaluate three candidate links. Two of these links, 1090 MHz Extended Squitter and UAT, are wide-band links operating in the L-Band. The third, VDL Mode 4, is implemented using multiple narrow-band channels in the VHF Band. A one-page summary table of technical characteristics of the three link candidates is included as Appendix C. System descriptions of each of the three candidates, for link evaluation purposes, have been prepared by respective subject matter experts (Appendices D, E, and F). While these system descriptions have been reviewed by the TLAT and many TLAT comments have been incorporated, the development of the system descriptions has been the responsibility of the subject matter experts.

2.1 1090 MHz Extended Squitter

The 1090 MHz Extended Squitter has been developed as an extension of Mode S technology widely used for aeronautical secondary surveillance radar applications. Each extended squitter message consists of 112 bits, 24 bits of which are used for parity. The data rate used is 1 megabit per second, within a message. Access to the 1090 MHz channel is randomized, and the channel is shared with current Air Traffic Control Remote Beacon System (ATCRBS) and Mode S responses to interrogations from ground-based radars and TCAS. The squitters proposed for ADS-B are "extended" in the sense that prior Mode S squitters contained 56-bit messages.

1090 MHz Extended Squitter message formats for ADS-B and transmission rates have been defined in detail by the ICAO Secondary Surveillance Radar Improvement and Collision Avoidance System Panel (SICASP), in conjunction with RTCA Special Committee 186 and EUROCAE Working Group 51. A joint RTCA/EUROCAE ADS-B MOPS for the 1090 MHz Extended Squitter [Ref. 3] was approved by those standards bodies in September and October 2000, respectively. Augmentation to the MOPS and ICAO standards (SARPs) is in progress to describe techniques to enhance the range of the Extended Squitter system and to support TIS-B. The TLAT evaluated the Extended Squitter system as it is expected to be defined by the augmented MOPS and SARPs. Additional message formats have been proposed by 1090 MHz Extended Squitter subject matter experts to support FIS-B.

Appendix F is a description of the 1090 MHz Extended Squitter system evaluated by the TLAT.

2.2 Universal Access Transceiver (UAT)

The UAT was developed under an Independent Research and Development (IR&D) project at the Mitre Corporation. UAT is a "clean sheet" design optimized toward the support of broadcast applications, both air- and ground-based, to support surveillance and situational awareness. The UAT data rate is approximately 1 megabit/second within a message. 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. Initial UAT operations have been conducted using the experimental frequency of 966 MHz. Operational demonstrations in Alaska are using 981 MHz as the UAT frequency.

UAT MOPS development within RTCA was initiated in December 2000. FAA intends to propose UAT SARPs development in ICAO pending U.S. inter-agency coordination.

Appendix D is a description of the UAT system evaluated by the TLAT.

2.3 VHF Digital Link (VDL) Mode 4

VDL Mode 4 technology has been under development since the late 1980's, initially in Sweden but more recently in a number of States. 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. Various types of prototype single-channel VDL Mode 4 equipment have been fielded since 1991. More recently, prototype dual-GSC equipment has been demonstrated and evaluated in Italy.

While VDL Mode 4 technology has been proposed and demonstrated for a wide variety of aviation applications, including two-way aeronautical telecommunications and local area augmentation to GNSS, the TLAT, as directed by the SF21 Steering Committee and the Eurocontrol ADS PSG, has evaluated all candidate links solely with regard to their ability to support ADS-B, TIS-B, and FIS-B (see Section 3).

VDL Mode 4 Standards and Recommended Practices (SARPs) have been developed by the ICAO Aeronautical Mobile Communications Panel (AMCP) and approved by the ICAO Air Navigation Commission in December 2000. Additionally, a EUROCAE MOPS for VDL Mode 4 airborne equipment is nearing completion. Also, a European Telecommunications Standardization Institute (ETSI) standard for VDL Mode 4 ground-based radios is being circulated for public comment.

Appendix E is a description of the VDL Mode 4 system evaluated by the TLAT. The TLAT notes that two approaches to the management of multiple (greater than three) VDL Mode 4 channels have been proposed when the VDL Mode 4 system is applied to high density future air traffic scenarios. The TLAT has evaluated both approaches through analysis and /or simulation.

3. TLAT Evaluation Criteria for ADS-B/Situational Awareness Links and Traffic Scenarios

3.1 Evaluation Criteria

The TLAT link evaluation criteria provide the metrics by which the ADS-B/situational awareness link candidates have been assessed. These criteria include the criteria originally developed by the SF21 Link Evaluation Team (LET), additional criteria proposed by Eurocontrol, and other considerations specified in the TLAT Terms of Reference (TORs). This report is intended to document the performance of the candidate datalinks in relation to the different criteria (both old and new) and to provide the ability to assess technical aspects of the various options.

3.1.1 LET Criteria

The LET developed a set of technical link performance criteria to evaluate the candidate ADS-B/ situational awareness links. These were based primarily upon two industry-consensus RTCA documents:

- the Joint Government/Industry Plan for Free Flight Operational Enhancements (the "Free Flight Operational Enhancements Document"), dated August 1998 [Ref. 2], and
- the ADS-B MASPS, RTCA DO-242 (the "ADS-B Minimum Aviation System Performance Standards"), dated February 1998 [Ref. 4].

Using the description of the nine operational enhancements defined in the Free Flight Operational Enhancements Document, the LET determined that all link-related requirements in the ADS-B MASPS were applicable to the evaluation of the links. Excerpts from the ADS-B MASPS that summarise these requirements are included within Appendix G of this report.

Furthermore, the consideration of the above operational enhancements made it clear that requirements relating to support of Traffic Information Service-Broadcast (TIS-B) and Flight Information Service-Broadcast (FIS-B) services need to be taken into account in order to support the identified operational enhancements. These requirements are not covered in the ADS-B MASPS and there are no established standards as yet for these services. Therefore, the LET developed additional performance criteria for TIS-B and FIS-B. The development of TIS-B and FIS-B link evaluation criteria by the LET should NOT be viewed as a statement that these services must necessarily be provided on the same radio frequency link as is ADS-B. Additionally, the TLAT recognizes that these TIS-B and FIS-B link evaluation criteria are necessarily hypothetical and may NOT reflect the systems that will be implemented.

The LET also decided that in addition to the ADS-B, TIS-B and FIS-B related criteria, there should be some "implied" criteria that need to be considered in order to evaluate comprehensively the candidate links and provide the complete picture. Two categories of such criteria were identified assessing the overall implementation feasibility and maturity and the integration/interoperation of the candidates with existing systems.

It is important to note that the LET criteria did not include considerations for the provision of Differential GNSS (DGNSS) or two-way (including air-to-air) addressed aeronautical communications services over the ADS-B/Situational Awareness link. While these services are very important in the complete picture of the aircraft equipage and they should be considered in the overall aircraft architecture, TLAT concentrated on ADS-B/situational awareness and directly linked issues.

3.1.2 Additional Criteria and Requirements

In addition to the above LET criteria, the TLAT used further criteria - approved by both the SF21 SC and the Eurocontrol ADS PSG.

3.1.2.1 Eurocontrol Criteria

The further criteria from Eurocontrol stem from European ADS requirements development that has occurred subsequent to the adoption of the ADS-B MASPS by RTCA. The ADS-B MASPS could not be endorsed by EUROCAE because European ADS requirements were not sufficiently mature. The Eurocontrol criteria are being considered for incorporation in the ADS-B MASPS by the SC-186 working group formed to update the MASPS.

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 candidate datalinks are able to provide to allow for the fulfilment of potential additional or differing ADS-B requirements. The assessment of this margin, if any, is an important element of any link decision, as it can safely be assumed that 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 in the ADS-B MASPS) to TLAT considerations. 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.

3.1.2.2 Further Criteria from the TLAT Terms of Reference

Furthermore, the TORs of the TLAT required the group to develop criteria to evaluate the candidate datalinks against some issues that are not covered by the criteria described previously. Specifically, the TORs require the TLAT:

- to evaluate the technical aspects of using multiple ADS-B datalinks potentially in different airspace or aircraft types
- to identify and evaluate any link dependent criteria originating from operational safety assessments
- to assess the expandability and excess capacity of the candidate datalinks.

3.1.3 Summary of Evaluation Criteria

3.1.3.1 Technical Performance Criteria

The ADS-B MASPS requirements for ADS-B air-to-air surveillance range, report update interval, and report accuracy are used to assess how the candidate links perform in relation to the free flight operational enhancements (including the “simultaneous approach” application referenced in the ADS-B MASPS) identified by the SF21 Steering Committee. These requirements specify the minimum range for acquisition of the state vector, the mode-status and the on condition report where applicable, as well as the maximum update period.

The Eurocontrol criteria augment those of the ADS-B MASPS with specific air/ground performance characteristics. These air/ground criteria specify ranges, use of intent information (TCP), additional ADS-B information elements (such as Controller Access Parameters) and update times. Additionally, Eurocontrol criteria extend existing ADS-B MASPS air-to-air requirements for long range deconfliction and increase the number of TCPs to be reported.

TIS-B has been considered by the TLAT in the context of encouraging ADS-B equipage by providing TIS-B reports only on non-ADS-B targets. In this context, the TLAT believes that the capacity impact of TIS-B implementation is less than that of ADS-B equipage by all aircraft. Therefore, the TLAT concluded that separate simulation of TIS-B impact on candidate link capacity is unnecessary. As the TLAT used the ability of a candidate link to support TIS-B as an evaluation criterion, specific details of TIS-B implementation are included in each candidate link system description.

For FIS-B, a datalink loading for evaluation purposes was developed by the LET based upon a prioritised listing of FIS-B information exchange requirements provided by the SF21 Steering Committee. The TLAT modelled the FIS-B impact on the channel as 200 bits per second per ground station. At the direction of the SF 21 Steering Committee and the Eurocontrol ADS PSG, the TLAT has assessed FIS-B only within the context of U.S. traffic scenarios.

3.1.3.2 Additional Implementation and Institutional Criteria Involving Technical Judgement

The additional link evaluation criteria, which address implementation and institutional issues and which involve technical judgement, are as follows:

- Time to implementation
- Time to Availability of International Standards
- Time to RF Spectrum Availability
- Status of reduction to practice: Implementation Risk/Complexity
- Ability to Integrate and Coexist with Existing Systems
- Ability to Mitigate Potentially Catastrophic Issues Raised in the ADS-B Operational Safety Assessment [Ref. 5].

Assessment of the candidate links against these criteria is made using a combination of modelling results and engineering judgement. Although universal equipage on a single agreed link is most desirable, multi-link equipage may be of interest to some states in order to encourage voluntary equipage by different user groups or to accommodate possible limitations in one alternative with complementary capability from another link. Criteria for multi-link use are not addressed in this report; however, Appendix L reviews certain multi-link alternatives with associated interoperability and incremental cost considerations.

The TLAT Evaluation Criteria of the candidate links and their derivation are discussed in detail in Appendix G.

3.2 Traffic Scenarios

The traffic scenarios are important to put into perspective the performance that the candidate links will achieve in a realistic environment. They describe the physical distribution of aircraft that must be considered in the simulations, which will complement the other investigation in lab and flight-testing.

TLAT agreed on three traffic scenarios to be used in its technical evaluation of the candidate links. Table 3-1 summarises the characteristics of these traffic scenarios.

Scenario	Total Aircraft	Scenario Area
LA Basin 2020 (LAX)	2694 (50 percent increase over estimated 1999 traffic levels) (including 225 on the ground)	400 nmi radius
Core Europe 2015 (XCE)	2091 aircraft (73 percent increase over estimated 1999 traffic levels) (including 150 on the ground)	300 nmi radius
Low Density	360 (all airborne)	400 nmi radius

Table 3-1: Selected Traffic Scenarios

In its November 1999 Report [Ref. 1], the LET had selected two additional traffic scenarios: the LA Basin 1999 and the Core Europe 2005 scenarios. The TLAT, for reasons of time, decided to evaluate only the three scenarios in Table 3-1. These scenarios are sufficient to show the performance of the candidate links in the time frame and the operational environments of interest.

The LA Basin 2020 scenario was generated using as a baseline the LA Basin 1999 scenario with the aircraft densities increased by 50 percent. The LA Basin 2020 scenario has 471 aircraft within 60 nmi of the scenario's centre (this includes aircraft on the ground). There are 1181 airborne aircraft within a radius of 225 nmi and a further 1289 airborne aircraft between 225-400 nmi. Around ten percent of the total number of aircraft is above FL 100.

The Core Europe 2015 scenario assumes a traffic increase of 73 percent in comparison to 1999 traffic levels and is focused around five major Terminal Maneuvering Areas (TMAs) in the busiest European area (Brussels, Amsterdam, London, Paris, and Frankfurt) with the Brussels TMA in its centre. Superimposed over the aircraft associated with each TMA, is a set of airborne en route and TMA aircraft. The 2015 scenario has 157 aircraft (25 on the ground) within a radius of 50 nmi from each TMA. There are 696 en-route aircraft within 200 nmi from the centre and an additional 585 aircraft (150 in TMAs) between 200-300 nmi. There are also 25 aircraft on the ground in the whole of the area. Approximately sixty-five percent of the total number of airborne aircraft are above FL 100.

The low-density scenario has been developed by scaling downward the LA Basin scenario. It comprises 360 aircraft uniformly distributed over a circle of 400 nmi radius. All aircraft are above FL 250.

More detailed information on the scenarios considered by TLAT may be found in Appendix H.

4. Technical Assessment Approach

The primary objective of the technical assessment of the ADS-B data link candidates is to characterize the performance of each link with respect to the technical performance criteria described in section 3.1. Link performance characterization is based on a modeling and simulation process, which uses laboratory bench and field/flight test data to validate, where possible, receiver performance and simulation models. The process and its inputs are illustrated in Figure 4-1.

The traffic scenarios and operational environment represent a series of assumptions regarding the disposition of aircraft and ground systems that must be considered in the link characterization. For example, the traffic scenarios dictate the number of aircraft in a given volume of airspace, their altitudes and their equipage. Traffic scenario assumptions are documented in Appendix H. With regard to the operational environment, interrogator databases have been provided for future high density scenarios in order to model interference on 1030 MHz and 1090 MHz pertinent to the operation of the 1090 MHz Extended Squitter and UAT. Additionally, the impact of TCAS operation and conservative estimates of DME interference have been incorporated into the modeling of the L-Band links.

The receiver/waveform model relates a signal, noise and co-channel interference types and levels at the input to a receiver to a probability of successful message receipt. The simulation model for each link invokes the receiver/waveform model to estimate the performance of the RF link between each pair of aircraft. The simulation model keeps track of aircraft, estimates ranges and timing between communicating (or interfering) pairs of aircraft, generates the received signal and interference power levels for the aircraft and determines the measures of performance. The measures of performance can then be directly compared to the evaluation criteria to complete the link characterization. Both receiver and network models are discussed in section 4.1 while the test data used to compare with results from the models are discussed in section 4.2. The TLAT believes that multipath will cause significant effects, especially on an airport surface. For practical reasons, these effects are not represented in the simulations (see Appendices M.6 and N.1).

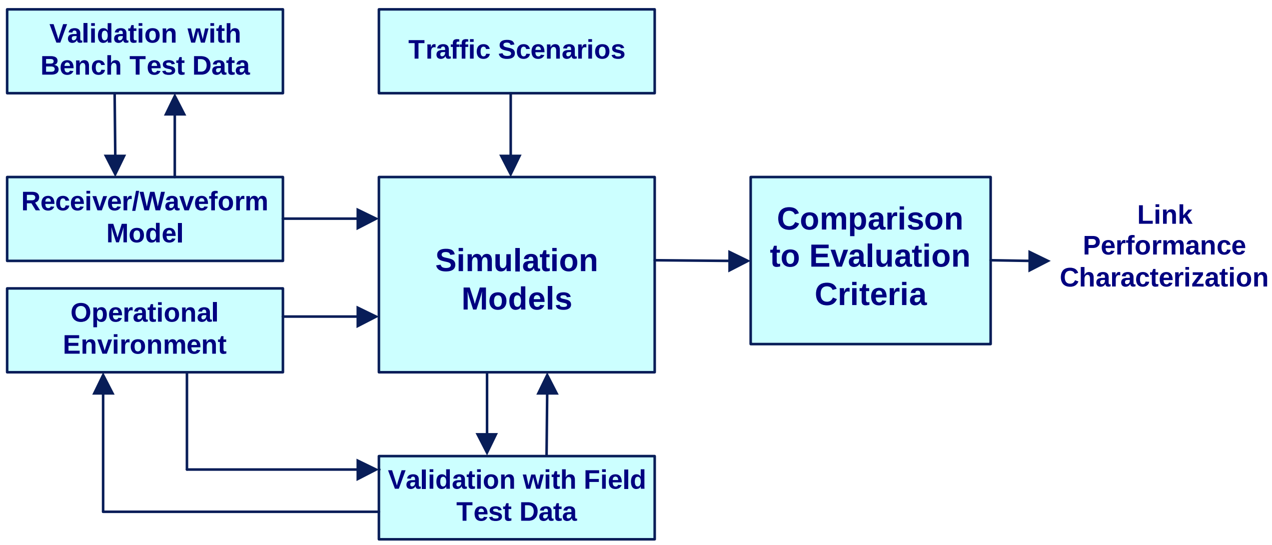

Figure 4-1: Technical Evaluation Approach Overview

4.1 Simulation Tools

There are two types of models required to complete the link characterization: receiver/waveform and full-scale simulation. There are three separate receiver/waveform models employed in the link evaluation, one for each link. All of the receiver/waveform models are based on bench test data taken by Johns Hopkins Applied Physics Laboratory (APL) on the UPS Aviation Technologies supplied radio equipment supplied for Ohio Valley SF21 Operational Evaluations. Bench test data provides the most accurate characterization of actual link equipment; however, it also introduces the effects of specific implementation choices, which may not be generally representative of the radio performance once large scale deployment has occurred. Therefore, the receiver/waveform models used in the link characterization have been designed to account for generalized implementations and thus have reduced the impact of certain implementation choices (e.g., signal acquisition process).

For each link's receiver/waveform model, there is one or more corresponding customized simulation models. The goal in the development of the simulation models was to maintain identical inputs and treatments of the three links. For example, each of the simulation models computes the signal levels at the victim receiver of all ADS-B messages transmitted by the other aircraft in the same way, including antenna gains (based on the model described in Appendix I) and propagation loss. However, because of the links' differing designs, the simulation models for each link are required to address somewhat different aspects of operation in order to focus on the issues that most critically affect performance. Table 4-1 lists the major functions collectively addressed by the simulation models and the links to which these functions are primarily applicable in order to assess performance adequately.

Functions	Links for Which Function Applicable
Traffic Distribution	All
Multiple Channel Management	VDL Mode 4
Co-site adjacent channel interference	All*
Pair-wise signal strength estimation (including LOS geometry, range, and antenna gain variations)	All
Co-channel (self) interference	All
Co-channel (other system) interference	Extended Squitter
Self-organizing slot selection logic	VDL Mode 4
Random Access	Extended Squitter, UAT

***For interference to VDL Mode 4 from voice transmissions, see also Appendix N.5.

Table 4-1: Major Functions Addressed by Simulation Models

One Extended Squitter simulation model is based on a 1090 simulation effort performed at the Volpe National Transportation System Center, which had originally been geared towards the evaluation of the effects of ADS-B on a radar interrogator. The simulation has been adapted to examine the effects of the 1090 MHz environment on ADS-B message reception. This model now produces a data stream representing a time sequence of arrival at the victim receiver of the ADS-B messages, along with both co-channel and adjacent channel (1030 MHz and 1090 MHz) interference. This data stream is then fed through a second simulation model, developed at APL, which adds other interference, including FIS-B transmissions from the ground; computes signal and interference levels as described above; and uses the receiver performance model to convert this information to a probability of successful message receipt for each ADS-B message. A second Extended Squitter simulation model has been developed at DERA in the United Kingdom, and is being used to evaluate 1090 MHz performance in the future Core Europe traffic scenario and operational environment.

The Swedish CAA has developed a simulation tool called STDMA/VDL Mode 4 Performance Simulator (SPS), and Eurocontrol has modified it to produce a version they call enhanced SPS. The purpose of this simulation tool is to model the VDL Mode 4 data link network management approach in order to evaluate its performance under a variety of conditions. This model has been modified further by APL to include a signal level calculation (described above), the VDL Mode 4 receiver performance model, and the necessary outputs for this evaluation.

APL has developed a UAT simulation model for use in the TLAT evaluation which is appropriate to provide a simulation of UAT that is analogous to the simulations provided for the other two link candidates.

Further information on the receiver/waveform models and simulation tools may be found in Appendices I and J, respectively.

4.2 Trials and Simulations (including Validation)

During the course of this link assessment, there were a number of flight trials of test equipment for all three candidate data links. These trials provided data used by the TLAT to support model development and validation. The trials were conducted at a number of locations, including (1) Operational and Technical Evaluations of ADS-B in the Ohio River Valley (1090 MHz Extended Squitter and UAT); (2) VDL Mode 4 testing at the FAATC; (3) LAX and Frankfurt Extended Squitter interference tests; and (4) UAT and VDL Mode 4 trials conducted in Europe. These trials were conducted under the auspices of the SF21 effort, the FAA, Eurocontrol, DFS, and other organizations. Additional data for all three link candidates has also come from laboratory bench testing conducted by APL to characterize radio equipment performance and calibrate the equipment for field testing.

These data have served a number of purposes: as reasonableness checks on the expected nominal performance of the links; as indicators of the magnitude of operational effects, such as antenna gains; as a calibration of the simulated 1090 MHz interference environment; and as information which characterizes receiver performance in the presence of noise and interference.

Since validation of simulation results in future environments is not possible, other means of verification of the reasonableness of the results are required. System characteristics represented in these simulations should agree with actual measurements on components of the proposed design, e.g., bench measurements on prototype equipment and calibrated flight test data should be compared with the modeled link budget and receiver/decoder capabilities. Similarly, flights monitoring interference levels associated with current SSR and TCAS, coupled with a suitable interference model, support estimates of how these conditions may change in future scenarios. Credibility of any simulation results for future scenarios also requires that they be able to model current conditions and provide results that appropriately agree with measurements made under these conditions. Appendix K provides further information on simulation validation performed by the TLAT.

In addition to the large-scale simulation models used to assess link performance in a future environment, there are a number of simulation tools, results from which have been made available to the TLAT. These existing tools have also been used as cross-checks for the final detailed simulations and models.

Mitre has used one or more modeling tools for each link candidate for looking at issues concerning link performance, top/bottom antenna, multipath, receiver/decoder, and signal variations. Mitre has also used an analysis tool which draws upon an external traffic distribution definition and receiver model developed from the Mitre RF model to estimate the probability of reception in face of co-channel interference, as another cross check on the large-scale simulation models. MIT Lincoln Laboratory used an internally-developed simulation for comparisons with TLAT 1090 MHz bench test results for ADS-B receivers employing enhanced decoding. Lincoln also used another analysis tool to make predictions of track acquisition in a two-aircraft encounter scenario. The Mitre and Lincoln tools have served to support a number of the analyses presented in Appendices K and M.

4.3 Analytical Assessments

The TLAT identified a number of issues that were not amenable to evaluation through the use of the large-scale simulations. This was generally due to the complexity of a data link candidate and the limitations of the corresponding large-scale simulation. Therefore, these issues were dealt with through analytical assessments, in which it was attempted to evaluate, quantitatively if possible, the particular issue or problem in question, and its effect on link performance. Each of these issues will be enumerated and discussed in turn.

TIS-B: The TLAT views TIS-B as an incremental system, i.e., it is assumed that only information on detected aircraft which are not ADS-B equipped will be broadcast by the TIS-B system on the ADS-B data link. An evaluation of the total ADS-B system load which would result from partial ADS-B equipage plus the remaining aircraft information transmitted as TIS-B information (also on the ADS-B link) was done. It was decided that the worst case load on the ADS-B data link would occur with 100% ADS-B equipage. Therefore, the future scenarios have been evaluated with 100% ADS-B equipage, and, since TIS-B is being treated as a system which supports the transition to ADS-B, TIS-B traffic has not been modeled in the full scale simulations of the high density future traffic scenarios. Support of TIS-B uplinks from a ground infrastructure perspective is addressed in the candidate link descriptions.

FIS-B: FIS-B is viewed as additional message traffic on the ADS-B data link. Furthermore, it was only applied to the future LA Basin scenario, since Eurocontrol has not yet decided whether FIS-B functionality will be provided in Core Europe through an ADS-B link.

For this assessment, FIS-B is being treated somewhat differently for each of the link candidates. For UAT, the system expert has specified that FIS-B information will be transmitted by the ground stations during the part of each UAT epoch reserved for ground station transmissions. Therefore, FIS-B messages will not interfere with UAT airborne ADS-B broadcasts. For the 1090 MHz Extended Squitter, for evaluation purposes a network of ground stations has been established, a hexagonal grid of side 60 nmi. Each of these ground stations transmits ten Extended Squitter messages per second, to simulate a representative load for FIS-B. These messages serve as interference for the ADS-B messages. For VDL Mode 4, the treatment is similar to that for UAT. A portion of the VDL Mode 4 frame is allocated as being reserved for ground station transmissions of FIS-B on one of the GSCs. Several studies were done to determine that the appropriate number of slots to reserve for ground station transmissions of FIS-B is four per second. Thus, four out of each second’s 75 slots on one VDL Mode 4 GSC are unavailable for transmission by the aircraft. In addition, for both LA and Core Europe, four slots per second have been reserved in the system design on the other GSC for ground station transmissions of Directory of Services and, e.g., transmissions of GNSS augmentations.

Channel Management of VDL Mode 4: An alternative channel management proposal to that initially specified by the TLAT VDL Mode 4 system experts has also been assessed. This proposal makes use of four channels, with only two required for transmission in any single region of airspace. Two of these channels are managed in a shared manner that depends on the location of the aircraft. The key channel management feature is to create a set of disjoint regions ("tiles") which allow for channel reuse. The tiles are organized in a hexagonal “beehive” pattern. This technique is used, for example, in cellular communications systems. Users who are far enough away from each other in different tiles can use the same frequency band for communications. In this ADS-B channel management approach, this approach is used for the sharing of slots within frequency channels. The ground directs the use of slots on these two channels, so that there is no autonomy of slot selection by individuals. Results of the analysis of this channel management scheme are presented in Appendix M.1.

VDL Mode 4 Two-Slot Messages: The transmission sequence for aircraft with Classes A2 and A3 VDL Mode 4 ADS-B equipment calls for a single two-slot message to be transmitted on one of the GSCs, in order to accommodate the requirements for TCP transmissions. The simulation model does not include a two-slot message, however, so the simulations employed indirect techniques to evaluate the impact of two-slot messages. Appendix M.2 summarizes an analysis of the effect on slot selection of two-slot messages.

Transitions Involving VDL Mode 4 Regional Signaling Channels: Since the simulation model for VDL Mode 4 cannot handle a change in broadcast rate on a channel when moving from one region of airspace to another, as is required by the VDL Mode 4 channel management plan, an analysis of this effect was undertaken. The results appear in Appendix M.3.

ADS-B Availability in Areas of Non-Radar Coverage: An analysis of the potential requirements for the use of ADS-B for separation assurance in areas of non-radar coverage is presented in Appendix M.4, with a particular configuration of avionics for the 1090 MHz Extended Squitter used as an exemplary point of evaluation.

Projections of 1090 MHz Extended Squitter Performance under Current Conditions in the LA Basin: An analysis prepared by MIT Lincoln Laboratory is presented in Appendix M.5.

Multipath Effects: Several potential effects of multipath are examined in Appendix M.6.

5 Technical Assessment

5.1 Findings

The TLAT developed findings based on the terms of reference (Appendix A) and agreed link evaluation criteria (Section 3). Section 5.1.1 presents findings related to state vector and intent information update periods at specified ranges for applications selected by RTCA's Free Flight Select Committee and Eurocontrol's ADS Programme Steering Group. Section 5.1.2 presents other findings.

All findings in this section have been unanimously agreed upon by the members of the TLAT**.**

5.1.1 Application Performance Results

The TLAT used both simulation results and analysis (presented in Appendices K and M) to determine the ability of the candidate links to meet the performance requirements associated with each application as specified in Section 3. The following tables depict the results for each of the three traffic scenarios discussed in Section 4.

The results are presented using the following terms:

- Supported means that the performance requirements for the application were met.
- Inconclusive means that the uncertainties associated with the simulation results were too great to permit assessment.
- Not supported means that the candidate link does not meet one or more performance requirement for the application for the specified range.
- Not addressed means that the TLAT did not have time to address this issue. Not addressed does not infer that the requirement cannot be met.
- Not applicable means that the scenario does not include the application.

Results obtained exclusively through analysis are designated as such. The following acronyms are used in the tables:

SV: State Vector

TCP: Trajectory Change Point

RSC: Regional Signalling Channel

CAP: Controller Access Parameters

A-SMGCS: Advanced-Surface Movement Guidance and Control System

ATS: Air Traffic Services

a/g: air-to-ground

TMA: Terminal Maneuvering Area

Core Europe 2015 Scenario

	1090 Extended Squitter	UAT	VDL Mode 4
SF21 Performance Criteria[1]			
Aid to Visual Acquisition (SV Update Rates to 10 nm)	Supported (by analysis)	Supported (by analysis)	Not supported except in Approach and Climb-out areas[2] (by analysis)
Conflict and Collision Avoidance (SV Update Rates to 20 nm)	Supported	Supported	For ranges above 3nm, supported within RSC and supported outside RSC when below 10000ft
Separation Assurance and Sequencing (SV and 1 TCP Update Rates to 40 nm)	Inconclusive	Supported	SV Updates are supported; Proposed TCP scheme not evaluated
Flight path deconfliction planning (SV and 2 TCP Update Rates to 90 nm)	Not supported	Requirement is met only up to 70 nm	Inconclusive
Airport Surface	Not addressed	Not addressed	Not addressed
Simultaneous approaches (SV Update Rates based upon physical runway separation)	Supported (by analysis)	Supported (by analysis)	3sec SV update req. met (by analysis)

[1] Performance Requirements are defined in Table 3.4 of the RTCA ADS-B MASPS DO-242 (Ref. 3).
[2] Requires an LSC (Local Signalling Channel) in the area.

Core Europe 2015 Scenario--continued

	1090 Extended Squitter	**UAT**	**VDL Mode 4**
Additional Eurocontrol Criteria[3]			
ATS Surveillance a/g			
TMA (SV and 4 TCP Update Rates to 60 nm)	Met with a 6-sector antenna	Likely to be met (by analysis)	Not supported with one Ground Station[4]
En-Route (SV and 4 TCP Update Rates to 150 nm)	Met up to 100 nm with 6-sector antenna[5]	Not addressed	SV Update Requirement met up to 70 nm with one omnidirectional antenna inside the RSC[6]. TCP update method provided in Appendix E but not evaluated
ATS Enhanced Surveillance a/g	Not addressed for the transmission of CAP information[7]	All parameters were addressed	Not addressed for the transmission of CAP and TCP information[8]
TMA (SV and 4 TCP Update Rates to 60 nm)	Met with a 6-sector antenna	Likely to be met (by analysis)	Not supported with one Ground Station[6]
En-Route (SV and 4 TCP Update Rates to 150 nm)	Met up to 100 nm[5]	Not addressed	SV Update Requirement met up to 70 nm with one omnidirectional antenna inside the RSC[6].
A-SMGCS			
Taxi (0-5 nm)	Not addressed	Not addressed	Not addressed
Approach (5-10 nm)	Not addressed	Not addressed	Not addressed
Autonomous air to air operations – long range (SV and 4 TCP to 150 nm)	Not supported	Not supported	Not supported

[3] Requirements proposed in the Eurocontrol document [Ref. 6].
[4] May be supported with appropriate ground infrastructure (not evaluated by the TLAT). See Appendix E.
[5] The full 150 nm requirement is expected to be met with a more complex ground antenna.
[6] May be supported with appropriate ground infrastructure (not evaluated by the TLAT). See Appendix E.
[7] Appendix F proposes the use of the Mode S datalink for the transmission of CAP information in high density airspace.
[8] Appendix E proposes the use of the VDL-4 datalink for the transmission of CAP and TCP information in high density airspace.

Los Angeles Basin 2020 Scenario

	1090 Extended Squitter	**UAT**	**VDL Mode 4**
SF21 Performance Criteria[9]			
Aid to visual Acquisition (SV Update Rates to 10 nm)	Supported (by analysis)	Supported (by analysis)	Not supported except in Approach and Climbout areas[10] (by analysis)
Conflict and Collision Avoidance (SV Update Rates to 20 nm)	Supported	Supported	Supported beyond 3nm
Separation Assurance and Sequencing (SV and 1 TCP Update Rates to 40 nm)	Unlikely to be met[11]	Supported	SV Updates are supported; Proposed TCP scheme not evaluated
Flight path de-confliction planning (SV and 2 TCP Update Rates to 90 nm)	Not supported	Supported	Inconclusive
Airport Surface	Not addressed	Not addressed	Not addressed
Simultaneous approaches (SV Update Rates based upon physical runway separation)	Supported (by analysis)	Supported (by analysis)	3 sec SV update requirement met (by analysis)

[9] Performance Requirements are defined in Table 3.4 of the RTCA ADS-B MASPS, DO-242.
[10] Requires an LSC (Local Signalling Channel) in the area.
[11] Simulations produced differing fruit environments. The requirements of the application were not met in the most likely of these fruit environments.

Los Angeles Basin 2020 Scenario - continued

	1090 Extended Squitter	UAT	VDL Mode 4
Additional Eurocontrol Criteria[12]			
ATS Surveillance a/g			
TMA (SV and 4 TCP Update Rates to 60 nm)	Not addressed	Likely to be met (by analysis)	Not supported with one Ground Station[13] (by analysis)
En-Route (SV and 4 TCP Update Rates to 150 nm)	Not addressed	Not addressed	At least as good as Core Europe 2015 because of the higher transmission rates used (by analysis)
ATS Enhanced Surveillance a/g			
TMA (SV and 4 TCP Update Rates to 60 nm)	Not addressed	Likely to be met (by analysis)	Not supported with one Ground Station[13] (by analysis)
En-Route (SV and 4 TCP Update Rates to 150 nm)	Not addressed	Not addressed	At least as good as Core Europe 2015 because of the higher transmission rates used (by analysis)
A-SMGCS			
Taxi (0-5 nm)	Not Addressed	Not addressed	Not Addressed
Approach (5-10 nm)	Not Addressed	Not addressed	Not Addressed
Autonomous air to air operations – long range (SV and 4 TCP Update Rates to 150 nm)	Not supported	Not supported	Not supported

[12] Requirements proposed in the Eurocontrol document [Ref. 6].
[13] May be supported with appropriate ground infrastructure (not evaluated by the TLAT). See Appendix E.

Low Density Scenario

	1090 Extended Squitter	UAT	VDL Mode 4
SF21 Performance Criteria[14]			
Aid to visual Acquisition (SV Update Rates to 10 nm)	Supported (by analysis)	Supported (by analysis)	Not supported (by analysis)
Conflict and Collision Avoidance (SV Update Rates to 20 nm)	Supported (by analysis)	Supported	Not supported (all a/c in scenario are en route and above 10000ft)[15]
Separation Assurance and Sequencing (SV and 1 TCP Update Rates to 40 nm)	Likely to be supported (by analysis)	Supported	SV updates supported in 20 to 40 nm and TMAs; TCP change is likely to be met (by analysis); Acquisition was not evaluated;
Flight path de-confliction planning (SV and 2 TCP Update Rates to 90 nm)	Likely to be supported (by analysis)	Supported	SV updates supported TCP change is likely to be met (by analysis); Acquisition was not evaluated;
Airport Surface	Not applicable	Not applicable	Not applicable
Simultaneous approaches (SV Update Rates based upon physical runway separation)	Not applicable	Not applicable	Not applicable
Additional Eurocontrol Criteria[16]			
ATS Surveillance a/g			
TMA (SV and 4 TCP Update Rates to 60 nm)	Not applicable	Not applicable	Not applicable
En-Route (SV and 4 TCP Update Rates to 150 nm)	Not addressed	Not addressed	Not addressed
ATS Enhanced Surveillance a/g	Not applicable	Not applicable	Not applicable
TMA (SV and 4 TCP Update Rates to 60 nm)			
En-Route (SV and 4 TCP Update Rates to 150 nm)			
A-SMGCS	Not applicable	Not applicable	Not applicable
Taxi (0-5 nm)			
Approach (5-10 nm)			
Autonomous air to air operations – long range (SV and 4 TCP to 150 nm)	Unlikely to be met to 150 nm; may be possible to <120 (by analysis)	Supported	SV updates supported TCP change is likely to be met (by analysis); Acquisition was not addressed

[14] Performance Requirements are defined in Table 3.4 of the RTCA ADS-B MASPS DO-242.
[15] VDL-4 could support the requirement in TMAs with ground stations (see Appendix E).
[16] Requirements proposed in the Eurocontrol document [Ref. 6].

The TLAT agreed to the following observations concerning the sensitivity of the values noted in the tables above to particular simulation and analytical assumptions.

a) The VDL Mode 4 system is highly configurable and may be optimised in a number of ways in a particular air traffic environment.

b) VDL Mode 4 performance improvements may be achieved through the use of sectorised ground antennas.

c) The VDL Mode 4 MOPS requires (protocol level) co-channel interference (CCI) performance (10 dB) at least 2 dB better than the value stated in Appendix E. VDL Mode 4 simulations assumed a 10 dB CCI threshold.

d) Trajectory change point transmission rates for UAT and VDL Mode 4 are subject to further optimisation.

e) The 1090 MHz Extended Squitter simulations suggest that a breakpoint in 20 to 40 nm performance occurs within the range of fruit environments examined.

f) A 1090 MHz Extended Squitter ADS-B receiver as specified in Draft DO-260 will exhibit significantly lower performance than that summarised above for the scenarios considered by the TLAT. Receivers conforming to DO-260A (which is the case assumed in Appendix F) are expected to perform as indicated in the tables.

The TLAT agreed to the following observations concerning the capacity (relating to the number of ADS-B system participants) of the candidate links:

a) In the high density traffic scenarios considered by the TLAT, there is no excess ADS-B capacity for any of the links as defined in their System Descriptions.

b) None of the three links meets all performance requirements in all three traffic scenarios. However, UAT was assessed as meeting all evaluated TLAT range and update rate requirements in the case of the low density scenario.

c) All three links exhibit a graceful degradation of performance with regard to the parameters listed in the tables above in the presence of interference.

5.1.2 Further Findings

For **TIS-B**, the TLAT has considered the capability of the candidate links to support the service, but in terms of simulations it was not taken into account as the 100% ADS-B equipage scenario is considered more loaded than a mixed ADS-B TIS-B scenario. All link candidates have the capability to uplink TIS-B information.

FIS-B was evaluated by simulation using the future LA Basin scenario (2020). The following apply to FIS-B capacity for each link relative to the TLAT evaluation rate:

a) UAT was the only link shown to have FIS uplink capacity substantially greater than the TLAT evaluation rate. The total capacity of the protected uplink slots had over 80 times the TLAT evaluation rate.

b) VDL Mode 4 met the TLAT evaluation rate.

c) 1090 MHz Extended Squitter was shown to deliver about one third of the TLAT evaluation rate at the maximum range.

There are several items to consider when assessing the **time until implementation**—availability of standards, availability of spectrum, and complexity. Regarding <u>standards</u>:

a) **1090 MHz Extended Squitter**: The system described in Appendix F contains features not standardised in the current MOPS (RTCA DO-260/ED-102). RTCA DO-260A currently in progress is expected to include these features. SARPs for Extended Squitter are in place; SARPs harmonised to DO-260A await completion of DO-260A. Complementary AEEC characteristics are expected to be completed by the end of 2001. The TLAT is unaware of any standards activity for 1090 MHz ES ground stations.

b) **UAT**: RTCA MOPS activity has been initiated and is scheduled to be completed by February 2002. SARPs and AEEC characteristics have not been initiated. The FAA intends to request initiation of SARPs development. The TLAT is unaware of any standards activity for UAT ground stations.

c) **VDL Mode 4**: SARPs have been approved and will be published by November 2001. EUROCAE MOPS are scheduled to be approved and published by mid 2001. European Telecommunications Standardisation Institute (ETSI) standards for radio station approval for ground stations are expected mid 2001. Additional ETSI work is ongoing. AEEC activity has not been initiated as yet.

Regarding <u>availability of spectrum</u>:

a) **1090 MHz Extended Squitter**: International spectrum allocation of the required 3 MHz channel exists. No further action is required.

b) **UAT**: Operating frequencies (supporting the required 3 MHz channel) must be identified. This will be done during the SARPs development process. International coordination of the UAT frequency is expected to take until 2006. After identification of a UAT frequency, DME channel(s) will need to be cleared.

c) Resolution of interference issues concerning **UAT** and **JTIDS/MIDS**, an important military tactical datalink, is critical to the deployment of UAT. The TLAT's evaluation of UAT has not taken into account the effects of JTIDS/MIDS systems. The UAT MOPS activity is considering this issue.

d) **VDL Mode 4**: VDL Mode 4 requires seven 25 KHz channels to operate in the high density scenarios evaluated by TLAT. The seven channels include: two Global Signalling Channels, two Regional Signalling Channels, two Local Signalling Channels, and one ground channel.

e) ICAO working groups are tasked to identify Global Signalling Channels. **VDL Mode** 4 operation in the VHF navigation band may require International Telecommunications Union coordination. The international co-ordination of the VDL Mode 4 Global Signalling Channels is expected to take until 2003.

The last aspect for time to implement relates to <u>risk and complexity</u>.

a) Implementation of ADS-B on any of the links—for performance consistent with the System Descriptions—will require new equipment installations.

b) A limited 1090 Mhz Extended Squitter capability (supporting Aid to Visual Acquisition and Conflict Detection and Collision Avoidance applications) is available as an option now with new TCAS and transponder installations (installations since 1999), and could offer some near-term benefits.

c) Long-range, SARPs- and MOPS-compliant receivers are expected to be available within one year from the completion of DO-260A (receiver availability is estimated by 2003). These estimates apply to applications that require a maximum of 2 Trajectory Change Points (TCPs). The development and certification of avionics to support more than two TCPs applications may take longer.

d) Standards-compliant VDL Mode 4 avionics are expected to be available in the near future. The current standards address equipment of two receivers (while Appendix E proposes a four-receiver configuration).

e) UAT, as currently defined, has the simplest technical concept of the candidates. This simplicity suggests that the necessary validation testing and standards development may be accomplished relatively expeditiously. Presuming that JTIDS/MIDS interference issue is resolved, UAT avionics complying with Appendix D are expected to be available in 2003.

f) The TLAT is aware that Russia has published an order that determines October 1, 2005, as the date to start using ADS-B for air traffic monitoring in Russian airspace. Russia has indicated to ICAO that it plans to implement VDL Mode 4-based ADS-B.

The TLAT agreed to the following additional observation concerning the ability of the candidate links to be integrated with and/or coexist with existing systems:

- Any operational frequency chosen for UAT will require coexistence with the JTIDS/MIDS military tactical data link. The TLAT's UAT results presume resolution of this important issue in a manner that does not add adverse interference to that used in the TLAT simulations.

The TLAT agreed to the following observation concerning the abilities of the candidate links to mitigate potentially catastrophic issues raised in the FAA's ADS-B Operational Safety Assessment [Ref. 5]:

- It is important for the ADS-B system to have a means for independent air-to-air range validation to reduce the risk of spoofing. Both UAT and VDL Mode 4 offer this capability by passive range monitoring. The 1090 MHz Extended Squitter ADS-B system as currently defined in DO-260 or Appendix F has no provision for air-to-air passive range monitoring (proposals to add this function to the system are under consideration for Draft DO-260A). Active air-to-air range monitoring can be employed by TCAS-equipped aircraft; however, the range of this active range monitoring is limited.

The TLAT agreed to the following observations concerning the expandability of the candidate links:

a) Future applications may require air-to-air two way data link. The combination of long range operation and the ability to provide two-way data link may make VDL Mode 4 attractive to support these future applications. UAT as currently defined does not support two way data link. TCAS-based installations could be modified to provide a two-way air-to-air data link capability for short- to medium-range applications.

b) All three links can be upgraded to support the broadcast of additional (to what is specified in RTCA DO-242) information, although VDL Mode 4 and UAT have more flexibility in this respect than does the 1090 MHz Extended Squitter.

c) In the high density scenarios considered, none of the three links appear to have excess air-to-air and air/ground capacity. The UAT System Description in Appendix D provides a uplink mechanism that is independent of the number of aircraft using the channel. In the case of VDL Mode 4, there is also a protected uplink mechanism; however, the capacity is less than that of UAT.

d) VDL Mode 4 has the capability to provide Global Navigation Satellite System (GNSS) augmentation services, and the channel loading from this application has been considered in the TLAT high density simulations. Although the ICAO GNSS panel is not currently considering VDL Mode 4 as a means to uplink GNSS augmentation, regional implementation of this capability is planned.

The TLAT considered general multi-link issues; this work is summarised in Appendix L. Multi-link discussions are ongoing within the FAA and Eurocontrol.

5.2 Areas for Potential Further Study

5.2.1 Multipath

Appendix M.6 provides an analysis of multipath effects for air to air, air to ground, and airport surface operations using L-Band and VHF datalinks. This analysis shows that the potential of multipath for degrading L-Band long range air to air decoder performance. The TLAT simulations did not include multipath effects. Measurements are available from several sources, see Appendix N.1. The complexity of the RF environment particularly for airport surface operations suggests that further investigations are necessary.

5.2.2 Propagation in VDL Mode 4

The modelling of overlapping interfering signals (due to propagation delays) used in the TLAT VDL Mode 4 simulations was based on theoretical analysis. This model should be further refined and validated. Appendix N.2 indicates that the effect of overlaps due to propagation delay in the TLAT VDL Mode 4 simulation results was far smaller than other uncertainties.

5.2.3 Range Limit of Core Europe Scenario

The Core Europe 2015 scenario used by the TLAT was specifically designed to measure performance in the scenario center (Brussels) and had a range of 300 nm. Appendix N.3 indicates that this scenario would have to be extended in order to measure performance in areas lying in the periphery and/or adjacent areas.

5.2.4 Multi-link

The TLAT considered general multi-link issues, this work is summarized in Appendix L. Multi-link discussions are ongoing within the FAA and Eurocontrol.

5.2.5 Co-site interference

Co-site interference is highly implementation dependent and will vary with each aircraft depending on its type, antenna location, and installation quality. The TLAT has not been able to assess the potential co-site issues relating to VDL Mode 4. Appendix N.5 indicates that VDL Mode 4 frequency planning criteria are being considered by the ICAO AMCP Working B. Co-site interference should therefore be further investigated when these criteria are in place.

5.2.6 Terrain Effects

The TLAT 1090 simulations of the Los Angeles Basin 2020 scenario considered terrain effects. The results suggest that inclusion of the terrain had a significant effect on ADS-B performance depending on the aircraft altitude distribution. Appendix N.6 indicates that terrain effects need to be considered also for VDL Mode 4 evaluations.

5.2.7 "Honeycomb" Channel Management Scheme for VDL Mode 4

Appendix E, Attachment 3 describes an alternative scheme for VDL Mode 4 channel management based on centralised ground control of channel access. Appendix N.7 provides an initial analysis of this scheme, suggesting that further investigations will be needed to establish its feasibility and benefits.

6. References

(1) RTCA, Phase One Link Evaluation Report: Status and Initial Findings, RTCA Free Flight Select Committee, Safe Flight 21 Steering Committee, Safe Flight 21 Technical/Certification Subgroup, ADS-B Link Evaluation Team, November 1999.

(2) RTCA, Joint Government/Industry Roadmap for Free Flight Operational Enhancements, August 1998, RTCA Select Committee.

(3) RTCA, Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance—Broadcast (ADS-B), RTCA DO-260, September 13, 2000.

(4) RTCA, Minimum Aviation System Performance Standards for Automatic Dependent Surveillance—Broadcast (ADS-B), RTCA DO-242, January 7, 1998.

(5) Federal Aviation Administration, Automatic Dependent Surveillance Broadcast Operational Safety Assessment Report, August 13, 2000.

(6) Eurocontrol, Eurocontrol ADS Programme Proposed Criteria for ADS-B Datalink Technical Assessment, October 13, 2000

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Appendix A

Technical Link Assessment Team
Terms of Reference

As Approved by the SF21 Steering Committee, June 2000, and
EUROCONTROL ADS PSG, September 2000, and
Amended in January 2001

1. Produce an updated Technical Link Assessment Report evaluating the suitability of three candidate ADS-B/situational awareness[17] radio-frequency links used alone or in combination: 1090 Extended Squitter, UAT, and VDL Mode 4. This Report, to the SF21 Steering Committee (SC) and Eurocontrol ADS PSG, should be produced by the end of November, 2000.

2. Review the previously defined Eurocontrol and SF/21 DLET methodologies for the technical link evaluation process leading to a set of technology evaluation criteria and, if required, propose changes to the SF21 SC and Eurocontrol ADS PSG.

3. Expand and refine as appropriate, for SF21 Steering Committee and Eurocontrol ADS PSG approval, the set of technical link evaluation criteria to support the ADS-B link decision process, including specifically consideration of the following:
   i) applications to be supported (as indicated by either SF21 SC or Eurocontrol) but were not considered in the Phase 1 Link Evaluation Report;
   ii) technical requirements derived from additional applications (to be supplied by Eurocontrol);
   iii) technical aspects of the use of multiple ADS-B/situational awareness[17] links for different aircraft types and in different airspace types, identifying any technical advantages/disadvantages and outstanding issues;
   iv) technical implications of spectrum availability;
   v) Interference /compatibility issues of each datalink with other systems or applications;
   vi) any link-dependent criteria uncovered by ADS-B operational safety assessments;
   vii) potential criteria for expandability and excess capacity.

4. Continue and complete the analysis of link performance data and link simulations (including additional bench testing and modeling as required) with respect to the link evaluation criteria, as approved by the SF21 Steering Committee and Eurocontrol ADS PSG, and the agreed air traffic and ground infrastructure scenarios. Use the link data gathered during evaluations and trials to further validate the link simulations.

5. Assess expected compliance to ADS-B MASPS, to European requirements, and to requirements for TIS-B and FIS-B, for each candidate link or combination of links using the defined scenarios. Assessment will proceed using simulation, modeling results, and field data in comparison to normalized criteria and by examination of detailed simulation outputs of each received message.

[17] Situational awareness as facilitated by the availability of ADS-B, TIS-B, FIS-B, and CFIT data

6. Recommend, for SF21 Steering Committee and Eurocontrol ADS PSG approval, any additional sources of actual link performance data to be used in developing the updated Technical Link Assessment Report.
   i) Define the necessity and scope of multipath testing for the candidate links;
   ii) Develop procedures and define test configurations to measure received signal level and noise power in dBm during field measurements.

7. Participate in relevant FAA and Eurocontrol link activities by providing guidance on data gathering and by performing analysis of collected data (Examples of these activities include the 1090 ADS-B Trial being conducted by Eurocontrol, FAA and DFS in Frankfurt, and the ADS-B link simulations being conducted by Johns Hopkins University, Eurocontrol and SCAA).

8. Provide technical expertise, if requested, in support of the datalink safety assessment activities ongoing within Eurocontrol and the FAA.

9. Develop the updated Technical Link Assessment Report based upon the expanded link evaluation criteria, ADS-B operational evaluation data, link performance and simulation data, and compliance to ADS-B MASPS and European requirements.

10. **Leadership**

The Joint SF21 SC/ADS PSG Technical Link Assessment Team will report to both the Safe Flight 21 Steering Committee and the Eurocontrol ADS Program Steering Group.

11. Membership

Ann Tedford,	FAA/ASD-100, Co-chair
Constantine Tamvaclis,	Eurocontrol Experimental Centre, Co-chair
George Ligler,	PMEI, Team Facilitator
Vince Nguyen,	FAA/AND-500
Don Willis,	FAA/ASR-100
Tom Pagano,	FAA/ACT-300
Stan Jones,	MITRE
Larry Bachman,	JHU/APL
Ray Yuan,	JHU/APL
Nikos Fistas,	Eurocontrol
John Gonda,	DoD/USAF
Rich Weathers,	DoD/JCS

Subject Matter Experts (SME):

Bill Harman,	Lincoln Labs
Jonathan Bernays,	Lincoln Labs
Chris Moody,	MITRE
Johnny Nilsson,	Swedish CAA
Christian Axelsson,	Swedish CAA
Armin Schlereth,	DFS

Additional members:
Additional members may be co-opted at any time at the discretion of either Co-chair.

Related Activities
Contact with Industry

The SMEs of each radio-link technology will maintain regular contact with all relevant avionics manufacturers active in the relevant technology field and airframe manufacturers.

Appendix B
Technical Link Assessment Team (TLAT) and Key Contributors

TLAT

Ann Tedford, Co-Chair	Federal Aviation Adimnistration (FAA), Architecture and Systems Engineering
Constantine Tamvaclis, Co-Chair	Eurocontrol Experimental Centre
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Ex Officio

Pieter van der Kraan	Eurocontrol ADS Programme Manager
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Appendix C

Summary Table of Selected Technical Characteristics of Link Candidates

Characteristic	1090 MHz Extended Squitter Proposed Operational System	1090 MHz Extended Squitter 1999 Tests	VDL Mode 4 Proposed Operational System	VDL Mode 4 1999 Tests	UAT Proposed Operational System	UAT 1999 Tests
Frequency Band	1090 MHz	Same	118-137 MHz (in addition Rec. for 108-117.975 MHz)	112-118 MHz	Not Assigned	966 MHz
Bit Rate	1 Megabit/sec	Same	19200 bits/sec/channel	Same	1.041667 Megabits/sec	Same
Modulation	PPM	Same	Binary GFSK/FM	Same	Binary GFSK ±312 KHz	Same
Synchroni-zation	4 pulse preamble (9 pulse processing)	Same	First 24 bits Plus burst flag	Same	First 36 bits	Same
Message Length	112 bits	Same	192 bits after synchronization	Same	246 bits, short 372 bits, long	Same
Parity	24 bits	Same	16 bits	Same	48 bits FEC and 24 bits CRC	Same
Address	24 bits	Same	3+24 bits	Same	25 bits	Same
Airborne Longitude	CPR 17 bits, even 17 bits, odd LSB ~5 meters	Same	Compressed 18-22 bits even 16-20 bits odd LSB ~1-18 meters	Same	Uncompressed 24 bits LSB = 2.3 meters	Same
PVT Segmentation?	Yes: Velocity in separate message	Same	No: PVT in one message	Same	No: PVT in one message	Same
Transmitter Power (at Antenna)	51-57 dBm, high-end 48.5-57 dBm, low-end	Same	43-44.5 dBm, high-end (ground station) 39-40.5 dBm, medium 36-37.5 dBm, low-end	44, 39.8, and 37.8 dBm	50-54 dBm, high-end 44-48 dBm, low-end	44 dBm +/- 3 dB
Receiver MTL (90%) (at Antenna)	≤ -84 dBm, high end ≤ -72 dBm, low-end	~-79 to ~-87 dBm	≤ -103 dBm at 10^{-4} BER	-80 and –90 dBm at 1% MER	≤ -93 dBm	-93 dBm
Polarization	Vertical	Same	Vertical	Same	Vertical	Same
Transmission Rate for PVT	Position at 2 Hz Velocity at 2 Hz	Same	1, 2, 5, or 10 seconds (can be varied between 1-60; event-driven or by command)	PVT every 1 second	PVT every 1 second	Same
Transmission Rate for Intent/Flight Ident.	3.4 per second	0.75 per second	Each TCP once every minute. Flight Ident. Once every 5 minutes	Not transmitted	Within same Message as PVT	Flight Ident. Transmitted
Multiple Access Technique	Random messages	Same	Self-organizing TDMA (75 slots/second per channel)	Same	Slots to separate ground/air. Aircraft use random messages	Same
RF Channels	One channel	Same	2 (25KHz) Global Signaling Channels, plus up to 2 Regional and 3 Local Channels in High Density Airspace	2 Channels (Used as if Global)	One Channel	Same

Acronyms:

BER	Bit Error Rate
CPR	Compact Position Reporting (Compression)
CRC	Cyclic Redundancy Code
FEC	Forward Error Correction
GFSK	Gaussian Frequency Shift Keying
LSB	Least Significant Bit
MER	Message Error Rate
MTL	Minimum Trigger Level
PPM	Pulse Position Modulation
PVT	Position, Velocity and Time (Information for ADS-B State Vector)
RF	Radio Frequency
TCP	Trajectory Change Point
TDMA	Time Division Multiple Access