Summary of the Functional and Technical Assessment of the ADS-B Link Architecture Alternatives

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Interim Report

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1. Introduction

This report has been prepared by a team formed by the Federal Aviation Administration, System Architecture and Investment Analysis Service. Included herein is:

- a summary of the approach used to identify the most promising ADS-B link architecture alternatives and the associated airborne configurations;
- a description of the baseline ADS-B link architecture requirements against which each link architecture alternative was assessed;
- a summary of the results from the assessment of the capability of each alternative airborne ADS-B configuration to support the baseline requirements when used within the context of a overall ADS-B system architecture (i.e. with complementary airborne and ground equipage);
- a summary of the additional technical data that has been used to supplement the findings of the joint FAA/Eurocontrol Technical Link Assessment Team
- a summary of the remaining technical and institutional issues that will require further work and/or resolution before specific ADS-B implementation details can be finalized;
- a description of seven overall ADS-B link architectures that were used as the basis for the cost benefit analysis (the CBA results are provided as a separate report);

The results reported herein reflect the assessment of the alternative ADS-B link architectures for use in support of civil aviation within the United States. The U.S. Department of Defense has conducted a separate assessment related to the costs of alternative ADS-B architectures. The results of the DOD assessment will be considered by the FAA when developing the recommended ADS-B link architecture for use in the U.S. National Airspace System (NAS).

2. Summary of Approach

The approach used by the FAA to assess the alternative ADS-B link architectures for potential use in the National Airspace System (NAS) is summarized below.

The Joint FAA/Eurocontrol sponsored Technical Link Assessment Team (TLAT) performed an assessment of the three individual candidate ADS-B link technologies. For the purpose of the TLAT assessment specific configurations of each link technologies were defined by experts directly involved in the development of each of the link technologies. The TLAT assessed the performance of the three individual links against a number of postulated future operational scenarios and for a specific set of potential ADS-B applications. The TLAT produced a report of its work in March 2001. The TLAT report is available for download via the internet at:

www.faa.gov/safeflight21/documents/tlat/index.html

It is noted in the TLAT report that their findings in some cases were inconclusive or uncertain due to conflicting data and/or lack of data. Although the TLAT as a body was disbanded after publication of their report in March 2001, the FAA and Eurocontrol have each continued efforts to evaluate various aspects of the candidate ADS-B links. The assessment reported herein builds upon the work of the TLAT by considering:

a) additional data from flight tests, laboratory tests, and simulation models of the candidate ADS-B links were used to help provide a more definitive assessment of the candidate links

b) consideration of other factors not considered by the TLAT that may impact system performance, but which have not yet been fully assessed

e) multi-link configurations that are capable of providing two-way interoperability

f) updates/revisions to the MOPS and/or SARPs that could influence system performance

g) assessment of link performance versus the near and mid-term Safe Flight 21 and Operational Evolution Plan set of ADS-B applications

The review of the economic factors that potentially differentiate the alternative ADS-B link architectures is provided in a separate report (i.e., Cost Benefit Analysis). The FAA decision on the most appropriate ADS-B link architecture considers the technical capabilities of the alternative ADS-B link architectures to support the near through long-term operational requirements, the economic factors of the alternative ADS-B link architectures by user category, transition strategies, and the flexibility to accommodate varying levels of user needs and preferences.

3. Baseline ADS-B Link Architecture Requirements

3.1 Definitions:

ADS-B Architecture: The overall set of ground and airborne functions that in combination enable air-air and air-ground ADS-B capability. The ADS-B architecture may incorporates one or multiple ADS-B link technologies to provide the desired level of ADS-B service.

Long-Term: 2011-beyond

Mid-Term: 2006-2010

Near-Term: 2001-2005

3.2 Requirements:

It is recognized that the RTCA ADS-B MASPS (DO-242) provides a more-or-less comprehensive set of performance and functional requirements for an ADS-B system and does in fact serve as the basis for assessing the capability of any candidate ADS-B link architecture to satisfy the long-term needs for ADS-B enabled services. The following requirements were used as a means of assessing the alternative ADS-B link configurations against specific known operational, technical, and transition requirements. The following 13 requirements were used as a means of identifying discriminators between the candidate ADS-B link configurations.

1: The ADS-B architecture must be able to support a baseline set of applications that include:

- a. short range situational awareness and see-and-avoid (near-term through long-term)
- b. the ADS-B enabled applications as defined in the FAA's Operational Evolution Plan (OEP) (mid-term through long-term)
  - Extend Use of 3-Mile Separation Standard into adjacent en route sectors
  - Coordinate for Efficient Surface Movement
  - Enhance Surface Situational Awareness
  - Reduce approach spacing in IMC
  - Reduce Offshore Separation
- c. applications identified by the Safe Flight 21 program (selected pockets in the near-term and national in the long-term)

2. The ADS-B architecture must support the near and mid-term ADS-B MASPS applications with reliable air-to-air reception for ranges within 20 nmi., and other long-term applications for reception ranges within 40 nmi.

3. The ADS-B architecture must support the ADS-B MASPS long-term flight path de-confliction application and possibly other strategic applications with reliable ADS-B reception at air-to-air ranges of at least 90 nmi. (in the forward direction) in oceanic and en-route airspace where "free flight" operations are authorized.

4. The ADS-B architecture must support near-term and mid-term single link equipage supporting early operational use with associated benefits

    a. air-to-ground in local pockets for terminal and/or surface applications where ADS-B ground stations and ATC ground automation upgrades have been implemented

    b. pair-wise air-to-air applications for high altitude en route/offshore airspace and terminal applications in the local pockets where the ADS-B enabled procedures are authorized.

5. The ADS-B architecture must support TIS-B delivered over the ADS-B ground-to-air link(s) in order to accommodate a mixed equipage environment of ADS-B and non-ADS-B equipped aircraft

6. The overall ADS-B requirements, especially in the long-term, may be satisfied by either by a single ADS-B link or via the combined capabilities of multiple ADS-B links as long as such a multi-link solution is integral to the ADS-B architecture.

7. The long-term ADS-B ground infrastructure and associated system architecture must, to the maximum extent practical, accommodate foreign aircraft equipped with one or multiple ICAO specified ADS-B link(s) operating on ICAO authorized frequencies.

    - support the operational benefits to the extent they can be enabled by the specific ADS-B link(s) and U.S. compatible applications for which the aircraft is equipped.

8. The ADS-B architecture must require all ADS-B equipped aircraft to provide:

    a. ADS-B transmissions of sufficient power level to support the reception range requirements for air-to-air, air-to-ground and airport surface applications as defined by the ADS-B MASPS (DO-242)

    b. ADS-B transmissions at update rates sufficient to support the reception at the rates and probabilities required by the ADS-B MASPS (DO-242)

c. ADS-B transmissions containing at least the minimum information set required by the ADS-B MASPS (DO-242) for that aircraft equipage category

9. The ADS-B architecture must include airborne reception capabilities consistent with the requirements associated with ADS-B enabled applications applicable to that aircraft equipage category.

   - supporting the requirements (range, update rate, content) as specified for all supported applications as per the applicable RTCA MASPS and/or MOPS

10. The ADS-B architecture must provide the capacity to support FIS-B services over the ADS-B ground-to-air link. Due to current FIS-B policy and existing contracts it is unlikely that FIS-B services could be offered via the ADS-B link in the near-term except in the context of limited trials.

11. The ADS-B link(s) must be functionally consistent with the near thru long term evolution of the NAS architecture.

12. Viable aircraft ADS-B configurations must be consistent with an ADS-B architecture that supports a cost effective means for the introduction of ADS-B capability into all user classes. The following criteria is used to assess alternatives against this requirement. An alternative is considered viable if the estimated installed system costs do not exceed +30% of the cost of the least expensive alternative for each aircraft category. An alternative is considered as not being viable (from a cost effective standpoint) only if the estimated installed system costs exceeded +60% of the estimated costs for the least expensive alternative for 2 or more civil aircraft categories. Otherwise the alternative is considered to be conditionally viable (i.e., might be viable for only certain aircraft categories).

13. There must be industry inputs indicating that the ADS-B link technology(ies)/configuration is technically practical with no greater than moderate technical risk.

4. Comparison of ADS-B Link Configurations

In order to assess the ability of each alternative ADS-B avionics configuration to satisfy each baseline requirement, certain assumptions were necessary as to how that avionics configuration would fit into an overall ADS-B system architecture. The following general assumptions were applied:

1. The 13 single and multi-link ADS-B avionics configurations, as reviewed at the FAA sponsored link decision workshop (June 25-26, 2001) were used as the basis for defining the alternative ADS-B link architectures.
2. Although 13 individual single and multi-link avionics configurations were considered, it is not to be assumed that any given multi-link avionics configuration is to be used fleet-wide across all user classes. The reason for considering any multi-link architecture alternative is to provide the maximum user flexibility to select from the approved configurations the one that best suits their needs in terms of capabilities, cost and compatibility with their specific aircraft configuration. Table 4-1 and Table 4-2 below indicate the compatible configurations that would provide interoperability among aircraft <u>outside</u> the coverage of a ground infrastructure. Thus the level of interoperability indicated in these tables does not rely on the availability of a ground based cross-link gateway service.
3. For multi-link configurations is was assumed that the NAS ADS-B ground stations will be capable of receiving and transmitting on all of the associated ADS-B links and will include a cross-link gateway function. However, this approach has limitations in terms of service area and potentially technical performance limitations as compared to providing direct aircraft-to-aircraft interoperability. Therefore, in the long-term it is considered necessary for at least some classes of users to be able to achieve interoperability for air-to-air ADS-B applications independent of the ground infrastructure in order to support certain ADS-B enabled operations.
4. For avionics configurations that include a transmit-only function on the 2nd link then that configuration can only take credit for providing that user with the air-to-air capabilities enabled by the link, which also includes the reception capability. That is, the transmission-only capability on the second link would support air-to-ground ATC surveillance services via both links and would allow other aircraft equipped for reception on either or both links to track this aircraft.
5. The ADS-B MASPS requirements for such factors as range, message content, and update rates are used as the criteria to judge the ability of a given link configuration to satisfy the application/operational requirements.
6. In the near and mid-term both the number of ADS-B equipped aircraft and the overall air traffic densities will be less than what must be supported in the long-term. Thus the capacity limits of the ADS-B system could become an issue over time and must be considered assessing each alternative ADS-B link architecture.
7. The TLAT results, plus additional results from simulations and tests that have been forthcoming since TLAT completed their work in March 2001, were considered in

determining the likelihood of a given avionics configuration to satisfy the application requirements.

8. For the cases of 1090 MHz Extended Squitter and VDL Mode 4, where approved MOPS and SARPs exist, then it was assumed that link characteristics and avionics configuration would be based on the MOPS/SARPs. However, in the case of 1090 ES the updated draft MOPS (DO-260a) was assumed, with enhanced reception techniques for the most capable avionics/user classes. For UAT the draft MOPS were assumed. The avionics configurations were assumed to be generally consistent with the TLAT configurations, unless this is found to lead to an inconsistency with the MOPS/SARPs.
9. For the purpose of assessing the capabilities of each airborne alternative against the above baseline link architecture requirements, it was assumed that for each of the single link configurations (i.e., avionics configurations 1, 2 and 3) all aircraft will be equipped to (at least) support that specific link with full transmit and receive capabilities.
10. For the purpose of the assessment of the multi-link configurations against the baseline link architecture requirements, it was assumed that a given multi-link avionics configuration would be used within the context of an overall ADS-B architecture that limited the allowed configurations to a set that offered two-way interoperability. Thus it was assumed that for the purpose of the assessment (i.e., as summarized in Table 4-3) that each of the other ADS-B enabled aircraft would be equipped with one of the compatible ADS-B configurations as indicated in Table 4-2.

4.1 ADS-B Air-to-Air Interoperability

Table 4-1 below shows in the first column the alternative ADS-B avionics configurations for the target aircraft that is transmitting ADS-B. The own aircraft is receiving ADS-B and the 13 alternative own aircraft ADS-B avionics configurations are listed horizontally across the top of the table. The table entries going down the columns under each alternative own aircraft configuration indicate which of the other ADS-B configurations will be transmitting ADS-B via at least one compatible link. The level of interoperability shown in Table 4-1 does not rely on the availability of an ADS-B ground station with a cross-link gateway function.

TABLE 4-1 Configurations Providing at Least One-Way Interoperability

Target A/C (Xmit A/C).	Own A/C ADS-B Avionics Configuration (Receiving Aircraft)												
	1 1090 ES	**2** UAT	**3** VDL-M4	**4** – ES +UAT	**5** – ES +UAT Tx	**6** – ES +UAT Rx	**7** – UAT +ES Tx	**8** – UAT +ES Rx	9 – ES +VDL4	10 – ES +VDL4 Rx	**11** – VDL4 +ES Tx	**12** – VDL4 +ES Rx	**13** –ES +UAT+VDL4
1	✓	X	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓
2	X	✓	X	✓	X	✓	✓	✓	X	X	X	X	✓
3	X	X	✓	X	X	X	X	X	✓	✓	✓	✓	✓
4	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	X	✓	✓
5	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	X	✓	✓
6	✓	X	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓
7	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	X	✓	✓
8	X	✓	X	✓	X	✓	✓	✓	X	X	X	X	✓
9	✓	X	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓
10	✓	X	X	✓	✓	✓	X	✓	✓	✓	X	✓	✓
11	✓	X	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	✓
12	X	X	✓	X	X	X	X	X	✓	✓	✓	✓	✓
13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓= Own A/C will receive ADS-B from this configuration   X=Own A/C will not receive ADS-B from this configuration

The following is presented as an example of how to use Table 4-1 (above). If own aircraft were equipped with Configuration 6 ADS-B avionics (as indicated in the top row of the table) then own aircraft would be able to directly receive ADS-B transmissions from aircraft equipped with any of the other configurations except for Configurations 3 and 12 (looking vertically down the column under Own Aircraft Configuration 6).

Table 4-2 (below) shows which combinations of ADS-B avionics configurations provide full two-way ADS-B air-to-air interoperability. Since certain applications and operations are expected to require full (i.e., two-way) air-to-air interoperability, an appropriate NAS ADS-B link architecture must support this capability. Thus, suitable ADS-B link architectures must restrict the allowed avionics configurations such as to produce an overall service that supports those applications/operations that require two-way interoperability.

Table 4-2 below shows the ADS-B avionics configurations that provide two-way interoperability between the ADS-B equipped aircraft. For example in the case of Configuration 6 avionics, full two-way interoperability is provided with other aircraft that are equipped with any of the following configurations: 1, 4, 5, 6, 8, 9, 10 or 13.

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TABLE 4-2 – ADS-B Avionics Configurations Providing Two-Way Interoperability

Target A/C Config.	Own A/C Configuration												
	1 1090 ES	**2** UAT	**3** VDL-M4	**4** – ES +UAT	**5** – ES +UAT Tx	**6** – ES +UAT Rx	**7** – UAT +ES Tx	**8** – UAT +ES Rx	9 – ES +VDL4	10 – ES +VDL4 Rx	**11** – VDL4 +ES Tx	**12** – VDL4 +ES Rx	**13** –ES +UAT+VDL4
1	✓	X	X	✓	✓	✓	X	X	✓	✓	X	X	✓
2	X	✓	X	✓	X	X	✓	✓	X	X	X	X	✓
3	X	X	✓	X	X	X	X	X	✓	X	✓	✓	✓
4	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	X	X	✓
5	✓	X	X	✓	✓	✓	✓	X	✓	✓	X	X	✓
6	✓	X	X	✓	✓	✓	X	✓	✓	✓	X	X	✓
7	X	✓	X	✓	✓	X	✓	✓	X	X	X	X	✓
8	X	✓	X	✓	X	✓	✓	✓	X	X	X	X	✓
9	✓	X	✓	✓	✓	✓	X	X	✓	✓	✓	✓	✓
10	✓	X	X	✓	✓	✓	X	X	✓	✓	X	✓	✓
11	X	X	✓	X	X	X	X	X	✓	X	✓	✓	✓
12	X	X	✓	X	X	X	X	X	✓	✓	✓	✓	✓
13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓= Both A/C will receive ADS-B with this combination of configurations X= One or both A/C will not receive ADS-B with this combination of configurations

4.2 Summary of ADS-B Link Capabilities

Table 4-3 below summarizes the results of the assessment from applying the above baseline ADS-B link architecture requirements to the 13 airborne configurations and under the assumptions stated above. This assessment has focused on the U.S. civil aviation sector. The capability reported in each box of Table 4-3 reflects the ability of the specific avionics configuration to support the listed requirement for the aircraft on which this avionics is installed. For the case of the multi-link configurations, it is assumed that the other aircraft in the fleet may be equipped with any compatible ADS-B avionics configuration that supports two-way ADS-B interoperability as per Table 4-2. However as indicated in the notes for Table 4-3, it is recognized that for scenarios where the other aircraft within the fleet are constrained to only a subset of the compatible avionics configurations more specific assessment results may be possible (e.g., a "Conditional" assessment might become a positive assessment). Also it is assumed that for multi-link configurations that TIS-B and FIS-B will be transmitted by the ground stations over all of the applicable ADS-B links.

The results of a more detailed assessment of the ability of each of the 3 individual ADS-B links (i.e., link configurations 1, 2 and 3) to satisfy link requirement 1, for supporting the baseline set of Safe Flight 21 and OEP applications, is summarized later in this document in Table 4-4. Thus, the entry for link requirement 1 in Table 4-3 is based on a roll-up of the results of the assessment reported in Table 4-4.

Note that Section 7 of this report describes seven fleet equipage scenarios including three single link scenarios and 4 multi-link equipage scenarios. Section 8 of this report then summarizes the assessment results from applying the 13 link requirements of Section 3.2 against each of the seven fleet equipage scenarios. The results of a more detailed assessment of the costs associated with the fleet equipage scenarios and the associated alternative avionics configurations are described in the separate report on the cost benefit analysis (CBA). The assessment results for Link Requirement 12 are provided in Section 8 in the context of fleet equipage scenarios rather than against the 13 individual avionics configurations listed in Table 4-3.

TABLE 4-3

Link Requirement	ADS-B Airborne Link Configurations												
	1 1090 ES	2 UAT	3 VDL4	4 – ES +UAT	5 – ES +UAT Tx	6 – ES +UAT Rx	7 – UAT +ES Tx	8 – UAT ES Rx	9 –ES +VDL4	10 – ES +VDL4 Rx	11 –VDL4 +ES Tx	12 – VDL4 +ES Rx	13 – ES +UAT+VDL4
1. …must be able to support a baseline set of applications	✓	✓	C	✓	✓	✓	✓	✓	C	C	C	C	C
2. ..must support the near and mid-term applications with reliable air-to-air reception…	C	✓	C	✓	C	C	✓	C	C	C	C	C	C
3. …must support a long-term flight path de-confliction application and possibly other strategic applications..	C	✓	C	✓	C	C	✓	C	C	C	C	C	C
4. …must support near-term and mid-term single link equipage supporting early operational use …	✓	✓	✗	✓	✓	✓	✓	✓	C	C	X	X	✓
5. …must support TIS-B delivered over the ADS-B ground-to-air link(s)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6. requirements…may be satisfied by either by a single ADS-B link or via the combined capabilities of multiple ADS-B links…	C	✓	✗	✓	C	C	✓	C	C	C	X	C	✓
7. ..long-term ADS-B… system architecture must, to the maximum extent practical, accommodate foreign aircraft….	C	?	C	C	C	C	?	C	✓	C	C	C	✓
8.. ..must require all ADS-B equipped aircraft to provide ADS-B transmissions….	✓	✓	✗	✓	✓	✓	✓	✓	✓	C	✓	X	✓
9. …must include airborne reception capabilities consistent with the requirements associated with ADS-B enabled applications …	✓	✓	C	✓	✓	✓	✓	✓	C	C	C	C	C
10. …must provide the capacity to support FIS-B services over the ADS-B ground-to-air link	C	✓	✓	✓	C	✓	✓	✓	✓	✓	✓	✓	✓
11. ..must be functionally consistent with the near thru long term evolution of the NAS architecture	✓	✓	?	✓	✓	✓	✓	✓	?	?	?	?	?
12. … Viable aircraft ADS-B configurations must … supports a cost effective means for …ADS-B capability into all user classes	**See Section 8 of this Report**												
13. There must be Industry inputs indicating that the ADS-B link technology(ies)/configuration is technically practical with no greater than moderate technical risk	✓	✓	C	✓	✓	✓	✓	✓	C	C	C	C	C

1. Are the requirements satisfied for a user equipped with this configuration ?: ✓= Satisfies Requirements ✗=does not satisfy requirements
C = conditional (requirements uncertain and/or meets requirements only in certain contexts) **?** = questions remain requiring additional data/analysis
2. Multi-link configurations assume other users may be transmitting on only one or multiple links and ground stations receive and transmit on all links

NOTES *(for Table 4-3 items marked C, ? or X)*

The following notes provide the rational for the assessment of all items in the table marked with a **?**, **C** or ×.

Configuration 1 (1090 MHz ES)

Requirement 2: The 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied with the 1090ES system. . In the longer term 1090ES system performance for the 40 nmi. air-to-air reception requirement in the highest traffic density environments (e.g., LA2020 scenario) has been shown to be unsatisfactory under the assumptions made for the TLAT. Potential mitigating assumptions (e.g., radar interrogator replacement) are being considered.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. Both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range.

Requirement 6. Same issues as described above for requirements 2 & 3 apply for the ability of 1090ES to satisfy the long term requirements for ADS-B.

Requirement 7. Since 1090 MHz ES is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting 1090 MHz ES would accommodate foreign aircraft equipped for this ADS-B link. Updates to the ICAO and RTCA 1090ES standards are in process and RTCA expects to approve/publish DO-260a in 2002. Accommodation of aircraft equipped with VDL-M4 only, the other ICAO ADS-B recognized link, would not be provided with this configuration.

Requirement 10. 1090 MHz ES will have a limited capacity to support FIS-B services. It may be able to support a basic set of FIS-B services but probably not the more real-time or high update rate services. In the highest interference environments (e.g. LA) and in the long-term, the capacity limitations may result in a reduced service volume or reduced update rates for the FIS-B services. Also the Class A0 and A1 1090ES receivers as defined by the DO-260 may not have sufficient sensitivity to provide adequate reception range to permit continuos FIS-B coverage.

Configuration 2 (UAT)

Requirement 7: RTCA MOPS for UAT will be completed in 2002. However, the role of UAT is currently under review within ICAO, and a decision on the international role of UAT is expected during 2002 at the earliest. Lacking an ICAO decision to develop standards for UAT, a UAT single link decision in the U.S. would not directly support foreign aircraft equipped with either of the ICAO already approved ADS-B solutions. Thus for the moment this requirement is not satisfied, but this could change if ICAO ultimately decides to move forward with SARPs for UAT and approves an operating frequency.

Configuration 3 (VDL-M4)

Requirement 1. VDL Mode 4 MOPS/SARPs does not provide a state vector update rate high enough to support the tactical applications of terminal approach and departure spacing in low visibility, defined by SF21 when used at air-to-air ranges of less than 3 nmi. Thus VDL-M4 could only partially support such baseline application requirements.

Requirement 2: The VDL-M4 system could generally support the 20 nmi. air-to-air range for the state vector update requirement for the near/mid-term application and 40 nmi. for long-term applications. The rate at which intent information is transmitted is not consistent with the ADS-B MASPS requirements.

Requirement 3: Limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support state vector update requirements for the 90 nmi. air-to-air range, but the TLAT configuration would not support the intent update rate requirements.

Requirement 4: Near-term, and perhaps mid-term, use of VDL-M4 in the U.S. appears unlikely due to the lack of available VHF channels that could be assigned for exclusive use by VDL-M4.

Requirement 6. As configured by the VDL M4 TLAT Subject Matter Experts, the system does not fully support the requirements for long-term ADS-B applications requiring intent information, particularly in terms of the required update rates.

Requirement 7: Since VDL-M4 is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting VDL-M4 would accommodate foreign aircraft equipped for this ADS-B link. ICAO and EUROCAE have not yet finalized and published the detailed technical standards for VDL-M4. Publication of the ICAO VDL-M4 technical manual is planned for 2002 and EUROCAE is not expected to approve and publish a final VDL-M4 MOPS before 2002. Accommodation of aircraft equipped with 1090ES only, the other ICAO ADS-B link, would not be provided.

Requirement 8: VDL-M4 configuration defined by the TLAT, does not provide sufficient rates of transmission to satisfy the requirements of the ADS-B MASPS for the applications currently under consideration. Specifically, certain of the short-range tactical applications are not supported due to insufficient state vector update rates. Also certain of the longer-range applications require intent information that is not provided with a sufficient update rate.

Requirement 9: The VDL-M4 could satisfy the reception requirements on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the concerns noted above for requirement 8 would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications.

Requirement 11: It is currently unclear if VDL-M4 as a single link ADS-B alternative would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 13: The technical risks associated with a fully MOPS/SARPs compliant and certifiable airborne installation are considered moderate (as compared to low for the other single link ADS-B alternatives). Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also risks remain with the VDL-M4 systems management scheme.

Configuration 4 (1090 MHz ES + UAT)

Requirement 7. Since 1090 MHz ES is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting 1090 MHz ES would accommodate foreign aircraft equipped for this ADS-B link. Until, or if, an ICAO decision to develop standards for UAT is forthcoming, including a UAT capability would not contribute to support for foreign aircraft operating in the U.S. Accommodation of foreign aircraft operating in the US equipped with only VDL-M4 could only be provided with this avionics configuration on the condition that the FAA elects to implement multi-link ground stations and cross-link gateway functions this include support for VDL-M4 within the NAS.

Configuration 5 (1090 MHz ES + UAT Transmit)

Requirement 2: The 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied with the 1090ES system. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of 1090 MHz ES in the highest traffic density future U.S. environments.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. Both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. The UAT transmission capability of this configuration would have no effect on the own aircraft capability to support the de-confliction application.

Requirement 6. Same issues as described above for requirements 2 & 3 apply for the ability of 1090 MHz to satisfy the long term requirements for ADS-B.

Requirement 7. Since 1090 MHz ES is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting 1090 MHz ES would accommodate foreign aircraft equipped for this ADS-B link.

Until, or if, an ICAO decision to develop standards for UAT is forthcoming, including a UAT capability would not contribute to support for foreign aircraft operating in the U.S. Accommodation of foreign aircraft operating in the US equipped with only VDL-M4 could only be provided with this avionics configuration on the condition that the FAA elects to implement multi-link ground stations and cross-link gateway functions this include support for VDL-M4 within the NAS.

Requirement 10. 1090 MHz ES will have a limited capacity to support FIS-B services. It may be able to support a basic set of FIS-B services but probably not the more real-time or high update rate services. In the highest interference environments (e.g. LA) and in the long-term, the capacity limitations may result in a reduced service volume or reduced update rates for the FIS-B services. Also the Class A0 and A1 1090ES receivers as defined by the DO-260 may not have sufficient sensitivity to provide adequate reception range to permit continuos FIS-B coverage. The UAT transmission capability of this configuration do not contribute to support for FIS-B.

Configuration 6 (1090 MHz ES + UAT Receive)

Requirement 2: The 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied with the 1090ES system. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of 1090 MHz ES in the highest traffic density future U.S. environments. This configuration would support this requirement for target aircraft that are equipped for UAT transmission.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. For the case of the target aircraft transmitting via 1090ES, both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. For the case where the target aircraft is transmitting via UAT, the UAT reception capability of this

	configuration would allow an aircraft equipped with this configuration to perform de-confliction with targets transmitting ADS-B via UAT at the 90 nmi., even in high density airspace.
Requirement 6.	Same issues as described above for requirements 2 & 3 apply for the ability of 1090 MHz to satisfy the long term requirements for ADS-B.
Requirement 7.	Since 1090 MHz ES is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting 1090 MHz ES would accommodate foreign aircraft equipped for this ADS-B link. Until, or if, an ICAO decision to develop standards for UAT is forthcoming, including a UAT capability would not contribute to support for foreign aircraft operating in the U.S. Accommodation of foreign aircraft operating in the US equipped with only VDL-M4 could only be provided with this avionics configuration on the condition that the FAA elects to implement multi-link ground stations and cross-link gateway functions this include support for VDL-M4 within the NAS.

Configuration 7 (UAT + 1090 MHz ES Transmit)

Requirement 7.	Although this configuration supports a 1090ES transmission capability and 1090ES is one of the two ICAO recognized ADS-B links, this configuration is equipped with only an UAT reception capability and thus could not receive ADS-B from other aircraft equipped with either 1090ES or VDL-M4. Accommodation of foreign aircraft operating in the US equipped with only VDL-M4 and/or 1090ES could only be provided on the condition that FAA elects to implement multi-link ground stations and cross-link gateway functions supporting VDL-M4 within the NAS. The UAT transmission capability of this configuration would not directly contribute to the accommodation of foreign aircraft until or unless UAT SARPs are approved by ICAO.

Configuration 8 (UAT + 1090 MHz ES Receive)

Requirement 2:	For the case where the target aircraft is only transmitting via 1090ES, the 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied by 1090ES in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of

1090 MHz ES in the highest traffic density future U.S. environments. For the case where the target aircraft is equipped for UAT transmissions, it is expected that both the near and long term requirements will be satisfied.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. For the case of the target aircraft transmitting via 1090ES, both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. For the case where the target aircraft is transmitting via UAT, the UAT reception capability of this configuration would allow an aircraft equipped with this configuration to perform de-confliction with targets transmitting ADS-B via UAT at the 90 nmi., even in high density airspace.

Requirement 6. Same issues as described above for requirements 2 & 3 apply for the ability of 1090 MHz to satisfy the long term requirements for ADS-B.

Requirement 7. Since 1090 MHz ES is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting 1090 MHz ES would accommodate foreign aircraft equipped for this ADS-B link. Until, or if, an ICAO decision to develop standards for UAT is forthcoming, including a UAT capability would not contribute to support for foreign aircraft operating in the U.S. Accommodation of foreign aircraft operating in the US equipped with only VDL-M4 could only be provided with this avionics configuration on the condition that the FAA elects to implement multi-link ground stations and cross-link gateway functions this include support for VDL-M4 within the NAS.

Configuration 9 (1090 MHz ES + VDL-M4)

Requirement 1: For the case where the target aircraft is only equipped with VDL-M4 as per the TLAT configuration, this system not provide a state vector update rate high enough to support some of the tactical applications, including terminal approach and departure spacing applications in low visibility, defined by SF21 when used at air-to-air ranges of less than 3 nmi. Thus VDL-M4 could only partially support such applications.

Requirement 2: For the case where the target aircraft is transmitting via 1090ES, the 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied with 1090ES in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of 1090 MHz ES in the highest traffic density future U.S. environments. For the case where the target aircraft is transmitting via VDL-M4, that system could generally support the 20 nmi. air-to-air range state vector update requirement for the near/mid-term application and 40 nmi. for long-term applications. With the TLAT VDL-M4 configuration the rate at which intent information (is transmitted is not consistent with the ADS-B MASPS requirements.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. For the case of the target aircraft transmitting via 1090ES, both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. For the case of the target aircraft transmitting via VDL-M4, and limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support the 90 nmi. air-to-air range requirement, but the TLAT configuration would not support the update rate requirements. This is a result of the defined transmission rate of the intent information not being sufficient to satisfy the ADS-B MASPS requirements for the de-confliction application.

Requirement 4: On condition that the other aircraft are equipped with 1090ES transmit and receive capability. Near-term, and perhaps mid-term, use of VDL-M4 in the U.S. appears unlikely due to the lack of available VHF channels that could be assigned for exclusive use by VDL-M4.

Requirement 6: In general the same issues as for requirements 1 and 2 apply. Note there is a potential that an optimally configured 1090ES plus VDL-M4 combination (not constrained by the TLAT configurations) if applied fleet-wide could perhaps satisfy the long-term requirements. However, defining and assessing such a configuration is beyond the scope of the current efforts.

Requirement 9: On condition that the other aircraft are transmitting with 1090ES the requirement would be satisfied. If the other aircraft are transmitting only on VDL-M4 then the reception requirements could be satisfied on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the limitations on VDL-M4 transmission rates (see note for Configuration 3 requirement 8) would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications.

Requirement 11: The 1090ES aspects of this configuration are consistent with the planned evolution of the NAS architecture. It is currently unclear if VDL-M4 as part of a multi-link ADS-B solution would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 13: As noted for Configuration 3, the technical risk associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 airborne installation are considered moderate. Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also risks remain with the VDL-M4 systems management scheme.

Configuration 10 (1090 MHz ES + VDL-M4 Receive)

Requirement 1: For the case where the target aircraft is only equipped with VDL-M4, this system will not provide a state vector update rate high enough to support some of the tactical applications, including terminal approach and departure spacing applications in low visibility, defined by SF21 when used at air-to-air ranges of less than 3 nmi. Thus VDL-M4 could only partially support such applications.

Requirement 2: For the case where the target aircraft is transmitting via 1090ES, the 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied with 1090ES in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of

1090 MHz ES in the highest traffic density future U.S. environments. For the case where the target aircraft is transmitting via VDL-M4, that system could generally support the 20 nmi. air-to-air range state vector update requirement for the near/mid-term application and 40 nmi. for long-term applications. With the TLAT VDL-M4 configuration, the rate at which intent information is transmitted is not consistent with the ADS-B MASPS requirements.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. For the case of the target aircraft transmitting via 1090ES, both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. For the case of the target aircraft transmitting via VDL-M4, and limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support the 90 nmi. air-to-air range requirement, but the TLAT configuration would not support the update rate requirements. This is a result of the defined transmission rate of the intent information not being sufficient to satisfy the ADS-B MASPS requirements for the de-confliction application.

Requirement 4: On condition that the other aircraft are equipped with 1090ES transmit and receive capability. Near-term, and perhaps mid-term, use of VDL-M4 in the U.S. appears unlikely due to the lack of available VHF channels that could be assigned for exclusive use by VDL-M4.

Requirement 6: In general the same issues as for requirements 1 and 2 apply. Note there is a potential that for the case of a target aircraft equipped with an optimally configured 1090ES plus VDL-M4 combination (not constrained by the TLAT configurations) perhaps the long-term requirements could be satisfied. However, defining and assessing such a configuration is beyond the scope of the current efforts.

Requirement 7: This configuration would accommodate reception of ADS-B from foreign aircraft equipped with VDL-M4 and/or 1090ES. The only limitation would ADS-B transmissions from own aircraft could only be received by other aircraft equipped with 1090ES unless the FAA elects to implement multi-link ground stations and cross-link gateway functions.

Requirement 8: If the other aircraft is transmitting usng 1090ES this requirement is satisfied. However, if the other aircraft in only transmitting using VDL-M4 using the configuration defined by the TLAT, it does not provide sufficient rates of transmission to satisfy the requirements of the ADS-B MASPS for the applications currently under consideration. Specifically, certain of the short-range tactical applications are not supported due to insufficient state vector update rates. Also certain of the longer-range applications require intent information that is not provided with a sufficient update rate.

Requirement 9: On condition that the other aircraft are transmitting with 1090ES the requirement would be satisfied. If the other aircraft are transmitting only on VDL-M4 then the reception requirements could be satisfied on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the limitations on VDL-M4 transmission rates, as noted above for requirement 8, would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications.

Requirement 11: The 1090ES aspects of this configuration are consistent with the planned evolution of the NAS architecture. It is currently unclear if VDL-M4 as part of a multi-link ADS-B solution would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 13: The technical risk associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 receiver airborne installation are considered moderate. Concerns have been expressed on the VDL-M4 antenna installations related to some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also risks remain with the VDL-M4 systems management scheme.

Configuration 11 (VDL-M4 + 1090 MHz ES Transmit)

Requirement 1: VDL Mode 4 MOPS/SARPs does not provide a state vector update rate high enough to support the tactical applications of terminal approach and departure spacing in low visibility, defined by SF21 when used at air-to-air ranges of less than 3 nmi. Thus VDL-M4 could only partially support such baseline application requirements. Since both a transmission and reception capability is required to support the baseline set of application, the inclusion of a 1090ES transmission capability in this configuration is not sufficient to overcome these limitation associated with the VDL-M4 functions.

Requirement 2: VDL-M4 could generally support the 20 nmi. air-to-air range state vector update requirement for the near/mid-term application and 40 nmi. for long-term applications. With the TLAT VDL-M4 configuration, the rate at which intent information is transmitted is not consistent with the ADS-B MASPS requirements. The inclusion of a 1090ES transmission capability with this configuration does not directly address the reception issues associated with this configurations.

Requirement 3: Limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support the 90 nmi. air-to-air range requirement, but the TLAT configuration would not support the update rate requirements. This is a result of the defined transmission rate of the intent information not being sufficient to satisfy the ADS-B MASPS requirements for the de-confliction application. The 1090ES transmission capability included in this configuration would not contribute to own aircraft being able to support an long-range de-confliction capability.

Requirement 4: Near-term, and perhaps mid-term, use of VDL-M4 in the U.S. appears unlikely due to the lack of available VHF channels that could be assigned for exclusive use by VDL-M4. The inclusion of a 1090ES transmission capability in this configuration would not contribute toward providing a near-term solution (i.e, requiring both transmit and receive capabilities) to the issues associated with VDL-M4.

Requirement 6: As configured by the VDL M4 TLAT Subject Matter Experts, the system does not fully support the requirements for long-term ADS-B applications requiring intent information, particularly in terms of the required update rates. The inclusion of a 1090ES transmission capability in this configuration does not to address the limitations associated with the VDL-M4.

Requirement 7: This configuration would accommodate foreign aircraft equipped with VDL-M4 but own aircraft would not be able to receive ADS-B from other aircraft equipped with only 1090ES. More complete accommodation of foreign aircraft operating in the US equipped with only 1090ES could only be provided on the condition that FAA elects to implement multi-link ground stations and cross-link gateway functions supporting VDL-M4 within the NAS.

Requirement 9: The VDL-M4 could satisfy the reception requirements on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the limitations on VDL-M4 transmission rates (see note for Configuration 3 - requirement 8) would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications. The inclusion of a 1090ES transmission capability in this configuration does nothing to support this requirement.

Requirement 11: It is currently unclear if VDL-M4 as part of a multi-link ADS-B solution would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 13: The technical risk associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 receiver airborne installation are considered moderate. Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also risks remain with the VDL-M4 systems management scheme.

Configuration 12 (VDL-M4 + 1090 MHz ES Receive)

Requirement 1. VDL Mode 4 MOPS/SARPs does not provide a state vector update rate high enough to support the tactical applications of terminal approach and departure spacing in low visibility, defined by SF21 when used at air-to-air ranges of less than 3 nmi. Thus VDL-M4 could only partially support such baseline application requirements.. The inclusion of a 1090ES reception capability would allow own aircraft to receive ADS-B updates at a sufficient rate from other aircraft equipped with 1090ES but not those equipped with only VDL-M4.

Requirement 2: For the case where the target aircraft is transmitting via 1090ES, the 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied with 1090ES in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of 1090 MHz ES in the highest traffic density future U.S. environments. For the case where the target aircraft is transmitting via VDL-M4, that system could generally support the 20 nmi. air-to-air range state vector update requirement for the near/mid-term application and 40 nmi. for long-term applications. With the TLAT VDL-M4 configuration, the rate at which intent information is transmitted is not consistent with the ADS-B MASPS requirements.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. For the case of the target aircraft transmitting via 1090ES, both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. For the case of the target aircraft transmitting via VDL-M4, and limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support the 90 nmi. air-to-air range requirement, but the TLAT configuration would not support the update rate requirements. This is a result of the defined transmission rate of the intent information not being sufficient to satisfy the ADS-B MASPS requirements for the de-confliction application.

Requirement 4: Near-term, and perhaps mid-term, use of VDL-M4 in the U.S. appears unlikely due to the lack of available VHF channels that could be assigned for exclusive use by VDL-M4. The inclusion of a 1090ES reception capability in this configuration would not contribute to providing a near-term solution (i.e, such would require both transmit and receive capability).

Requirement 6: In general the same issues as for requirements 1 and 2 apply. Note there is a potential that for the case of a target aircraft equipped with an optimally configured 1090ES plus VDL-M4 combination (not constrained by the TLAT configurations) perhaps the long-term requirements could be satisfied. However, defining and assessing such a configuration is beyond the scope of the current efforts.

Requirement 7: This configuration would accommodate reception of ADS-B from foreign aircraft equipped with VDL-M4 and/or 1090ES. The only limitation would ADS-B transmissions from own aircraft could only be received by other aircraft equipped with VDL-M4 unless the FAA elects to implement multi-link ground stations and cross-link gateway functions.

Requirement 8: VDL-M4 configuration defined by the TLAT, does not provide sufficient rates of transmission to satisfy the requirements of the ADS-B MASPS for the applications currently under consideration. Specifically, certain of the short-range tactical applications are not supported due to insufficient state vector update rates. Also certain of the longer-range applications require intent information that is not provided with a sufficient update rate. The addition of a 1090ES reception capability in this multi-link configuration is not sufficient to address this requirement.

Requirement 9: On condition that the other aircraft are transmitting with 1090ES the requirement would be satisfied. If the other aircraft are transmitting only on VDL-M4 then the reception requirements could be satisfied on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the limitations on VDL-M4 transmission rates, as noted above for requirement 8, would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications.

Requirement 11: It is currently unclear if VDL-M4 as part of a multi-link ADS-B solution would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 13: The technical risk associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 airborne installation are considered moderate. Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also risks remain with the VDL-M4 systems management scheme.

Configuration 13 (1090 MHz ES + UAT + VDL-M4)

Requirement 1. For the case where the target aircraft is transmitting ADS-B using only VDL-M4 a limitation applies. VDL Mode 4 MOPS/SARPs does not provide a state vector update rate high enough to support some of the tactical applications, including terminal approach and departure spacing applications in low visibility, defined by SF21 when used at air-to-air ranges of less than 3 nmi. Thus VDL-M4 could only partially support such applications.

Requirement 2: The basis of the Conditional assessment is for the case where the other aircraft is equipped with only 1090ES capability or only a VDL-M4 capability. For the case where the target aircraft is transmitting via 1090ES, the 20 nmi. air-to-air reception requirement for near and mid-term applications is expected to be satisfied. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied with 1090ES in all but potentially the highest traffic density environments (e.g., LA or NE corridor). Enhancements to the first generation simulation model (the results of which were reviewed by the TLAT) are needed to better estimate the performance of 1090 MHz ES in the highest traffic density future U.S. environments. For the case where the target aircraft is transmitting via VDL-M4, that system could generally support the 20 nmi. air-to-air range state vector update requirement for the near/mid-term application and 40 nmi. for long-term applications. With the TLAT VDL-M4 configuration, the rate at which intent information is transmitted is not consistent with the ADS-B MASPS requirements.

Requirement 3: The basis of the Conditional assessment is for the case where the other aircraft is equipped with only 1090ES or only VDL-M4 capability. For the case of the target aircraft transmitting via 1090ES, both limited flight measurements and analysis for a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range. For the case of the target aircraft transmitting via VDL-M4, and limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support the 90 nmi. air-to-air range requirement, but the TLAT configuration would not support the update rate requirements. This is a result of the defined transmission rate of the intent information not being sufficient to satisfy the ADS-B MASPS requirements for the de-confliction application. For the case where the target aircraft is transmitting via UAT, the UAT reception capability of this configuration would allow an aircraft equipped with this configuration to perform de-confliction with targets transmitting ADS-B via UAT at the 90 nmi., even in high density airspace.

Requirement 9: On condition that the other aircraft are transmitting with 1090ES and/or UAT the requirement would be satisfied. If the other aircraft are transmitting only on VDL-M4 then the reception requirements could be satisfied on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the limitations on VDL-M4 transmission rates (see note for Configuration 3 - requirement 8) would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications.

Requirement 11: The 1090ES and UAT aspects of this configuration are well understood and are consistent with the evolution of the NAS architecture. It is currently unclear if VDL-M4 as part of a multi-like ADS-B solution would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not currently well understood.

Requirement 13: The technical risk associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 airborne installation are considered moderate (as compared to low for the other single link ADS-B alternates). This avionics configuration could have much greater size, weight and power requirements, as compared to the other alternatives, which could preclude it use on some, and perhaps many, aircraft. Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also risks remain with the VDL-M4 systems management scheme.

4.3 Support for Baseline Applications

The results of detailed assessment of the ability of each of the 3 individual ADS-B links (i.e., link configurations 1, 2 and 3) to satisfy link architecture requirement 1 (from Section 3 above), for supporting the baseline set of Safe Flight 21 and OEP applications, is summarized below in Table 4-4. This table presents in more detail the summary results that are shown in Table 4-3 for link requirement 1. The assessment reported in Table 4-4 is generally based on the work of the TLAT supplemented with additional data from tests and simulations completed subsequent to the TLAT completing its efforts. Also the applications that were the focus of the TLAT findings do not correspond one-for-one with the short and mid-term applications now being considered for implementation within the NAS. Therefore, it was necessary to apply the results of the technical assessments to the requirements associated with the near/mid-term applications as now envisioned.

Table 4-4 ADS-B Link Support to SF 21 Application

Applications	Mode S Extended Squitter	Universal Access Transceiver	VHF Data Link Mode 4
1. Weather and Other Info to the Cockpit			
1.1.1 Initial FIS-B based on today's availability	C	✓	✓
1.1.2 Add products such as NOTAMs, lightning, icing, turbulence, real time SUA, & Volcanic ash	C	✓	✓
2. Cost Effective CFIT Avoidance	N/A (does not directly involve ADS-B)		
3. Improved Terminal Ops in Low Visibility			
3.1.1 Enhanced visual approaches (Visual acquisition with existing procedures, ADS-B only	✓	✓	C
3.1.2 Enhanced visual approaches (w/ new procedures - ADS-B only)	✓	✓	C
3.1.3 Enhanced visual approaches (w/ new procedures - ADS-B & TIS-B)	TIS-B not evaluated	TIS-B not evaluated	TIS-B not evaluated
3.2.1 Approach spacing (for visual approaches)	✓	✓	C
3.2.2 Approach spacing (for instrument approaches)	✓	✓	C
3.4 Departure spacing/clearance (VMC in radar)	✓	✓	C
4. Enhanced See and Avoid			
4.1.1 Enhanced visual acquisition of other traffic for see-and-avoid (using ADS-B only)	✓	✓	C
4.1.2 Enhanced visual acquisition of other traffic for see-and-avoid (ADS-B and TIS-B)	TIS-B not evaluated	TIS-B not evaluated	TIS-B not evaluated
4.2.1 Conflict detection	✓	✓	C
4.2.2 Conflict resolution	✓	✓	C
5. Enhanced En Route Air-to-Air Operations			
5.2.1 Pilot situational awareness beyond visual Range	✓	✓	C
6. Improved Surface Surveillance & Pilot Navigation			
6.1.1 Runway & final approach occupancy awareness (ADS-B only)	Not Assessed (lack of data)	Not Assessed (lack of data)	Not Assessed (lack of data)
6.1.2 Runway & final approach occupancy awareness (ADS-B & TIS-B)	Not Assessed (lack of data)	Not Assessed (lack of data)	Not Assessed (lack of data)
6.2 Airport surface situational awareness	Not Assessed (lack of data)	Not Assessed (lack of data)	Not Assessed (lack of data)
7. Enhanced Surface Surveillance for Controller			
7.1 Enhance existing surface surveillance with ADS-B	✓	✓	✓
7.2 Surveillance coverage at airports w/out existing surface surveillance	✓	✓	✓
8. ADS-B Surveillance in Non-Radar Airspace			
8.2 Radar-like services with ADS-B	✓	✓	✓
8.3 Tower situational awareness beyond visual range	✓	✓	✓
9. Establish ADS-B Separation Standards			
9.1.1 Radar augmentation with ADS-B to support mixed equipage in terminal airspace	✓	✓	✓
9.2.1 Radar augmentation with ADS-B to support mixed equipage in en route airspace	✓	✓	✓
OVERALL ASSESSMENT	✓	✓	C

✓ = Supports Application   **C** = Conditional (Supports application only in certain contexts – see notes)

The near and mid-term Safe Flight 21 Applications listed in Table 4-4 are all short range (<20 nautical miles) and/or evaluated in low density airspace. They do not reflect all of the considerations which went into the TLAT evaluation criteria and do not include any mid-range applications that may require coverage out to 40 nautical miles or longer-range (out to 90 miles) applications. While they may represent short to mid-term deployment goals, they do not address applications in dense airspace outside of 20 miles. Such longer-term applications requiring greater air-to-air ranges are considered in other requirements of Section 3 and Table 4-3 above.

4.3.1 Notes Associated with Table 4-4

Enhancement 1

- Enhancement 1.1.1 includes non-real time graphical weather products like NEXRAD derived graphics while enhancement 1.1.2 may include some real time products.
- The TLAT found that Mode S Extended Squitter, as configured by the Mode S system experts, would not be able to support a number of graphical FIS-B products at the maximum range in the high density LA traffic environment projected for 2020, but could support the FIS-B service in lower density airspace.

Enhancement 2

- Not applicable given that ADS-B has no direct role in CFIT. However, it could have a role if terrain is defined to include man-made obstructions (e.g., towers above 800 ft) and new obstructions are required to transmit an ADS-B message.

Enhancement 3

- Based on performance of links in support of "Aid to Visual Acquisition" defined in ADS-B MASPS, valid for ranges within 10 nautical miles.
- VDL Mode 4 meets the requirements outside 3 miles, but does not transmit frequently enough to meet the requirements for updates within 3 miles and there was uncertainty in the TLAT regarding the TCP transmission scheme

Enhancement 4

- 4.1.1 assessment is based on performance of links in support of "Aid to Visual Acquisition" in ADS-B MASPS. See Enhancement 3 for explanation of VDL Mode 4 assessment.
- 4.2.1 and 4.2.2 assessment is based on performance of links in support of "Conflict Avoidance and Collision Avoidance", valid for ranges within 20 nautical miles
- VDL Mode 4 partially meets the requirement outside of 3 miles, but does not transmit frequently enough to satisfy close range (within 3 miles) operation.

Enhancement 5

- Based on performance of links in support of "Aid to Visual Acquisition" in ADS-B MASPS. See Enhancement 3 for explanation of VDL Mode 4 assessment.

Enhancement 6

- TLAT did not consider performance of the links on the surface and no aircraft-to-aircraft data has yet been analyzed from which to draw conclusions on the expected performance.

Enhancement 7

- TLAT did not consider performance of the links on the surface. However, some data is available from measurements conducted at L-Band and VHF. Future studies and measurements are expected to confirm that with sufficient numbers of ground stations to provide path diversity sufficient coverage of the surface movement area is possible is any of the three alternative ADS-B link.

Enhancement 8

- 8.2 assessment is based on meeting the En-Route Surveillance requirement in low density airspace, as shown by analysis reported to the TLAT, as well as measurements of air-to-ground performance.
- 8.3 assessment is based on the TMA Surveillance requirement (out to 60 nmi), as shown by analysis reported to the TLAT
- This evaluation was made for A3-equipped aircraft.

Enhancement 9

- 9.1.1 assessment is based on the TMA Surveillance requirement (out to 60 nmi), as shown by analysis by reported to the TLAT, as well as measurements of air-to-ground performance.
- 9.2.1 assessment is based on meeting the En-Route Surveillance requirement, as shown by analysis reported to the TLAT, and support by air-to-ground measurements
- This evaluation was made for A3-equipped aircraft.

5. Summary of Technical Data and other Factors used to Supplement the TLAT Findings

Subsequent to the TLAT publication of their report in March 2001, the FAA and EUROCONTROL have continued to sponsor research activities that have contributed to a better understanding of the capabilities and limitations of the three ADS-B link technologies and of multi-link configurations. These activities have also identified the need for certain additional work that, when completed, can be expected to provide a more definitive characterization of the long-term link performance capabilities. The following paragraphs summarize additional data and information that has become available for the three link technologies since March 2001. This additional information is being considered in conjunction with the TLAT findings as inputs to the FAA's ADS-B link architecture decision process. The information provided below on European activities has been supplied by EUROCONTROL.

5.1 Additional 1090 MHz Extended Squitter Results/Factors

5.1.1 FAA Sponsored Activities

At the time of the TLAT report the first results had just become available from the 1090 MHz Extended Squitter (1090ES) simulation model commissioned to evaluate 1090ES performance in the TLAT scenarios. Unfortunately, there was insufficient time to complete validation of the simulation prior to issuance of the TLAT report, and several questions concerning 1090ES performance in high interference environments were left unanswered. Additional work since the TLAT report has provided more information concerning future interference environments. Work to establish confidence in the model predictions by comparing model predictions with measured field data has proceeded. Comparisons between measured field data and model predictions have been made, although further peer review is necessary prior to completing this validation. The following four modifications to assumptions made by TLAT for the LA2020 simulation are needed.

- The TLAT used radar data in a limited area of the LA Basin to generate the air traffic scenario used for LA 2020. Since the issuance of the TLAT report, flow control (ETMS) data have been examined and used to make more realistic aircraft distribution estimates beyond those areas where single radar data were available (i.e., beyond 60 nmi. of LAX). A modified aircraft distribution has been developed and is being incorporated into the simulation model, which could then be used to re-evaluate the TLAT LA2020 future scenarios. If this step is taken for 1090 ES, then it should also be done for VDL4 and UAT, in order to produce comparable results.
- Field and bench measurements of 1090ES have been based, until recently, on the performance of UPSAT receivers, which have exhibited the best sensitivity and decoding performance of any units available prior to and during the TLAT evaluation period. However, subsequent analysis suggests that improvement in 1090ES reception performance is possible for low amplitude replies in the presence of numerous ATCRBS interferers. This prediction has been confirmed by applying the improved decoding algorithms to sampled video obtained during previous field measurement activities. If the enhanced decoding

techniques are required in the updated 1090ES MOPS, then they should be included in the 1090ES simulation.

- The future interference environment (particularly the ATCRBS environment) is acutely sensitive to the types and configuration of ground and airborne beacon interrogators. Procurements by FAA and U.S. DoD to replace aging radars are expected to reduce the average interrogation rates. Sliding window beacon interrogators are being replaced by monopulse terminal radars)and selective address en route radars. These upgrades may lead to reduced 1090 MHz reply rates, and hence could reduce the future 1090 MHz ATCRBS interference levels although Mode S interference levels may show an increase. FAA and DoD radar upgrades will need to be included in the 1090ES model and updated estimates of 1090ES performance improvements made. Also the use of service area coverage maps within Mode S SSRs needs to be investigated for incorporation into the simulation model.
- Potential improvements to TCAS, including provisions for a hybrid surveillance mode allowing the use of passive listening for more distant targets, could serve to reduce TCAS interrogation rates. The effects for potential TCAS upgrades on the interference environment may also be investigated.

5.1.2 European Sponsored Activities

Validation of the model used in the TLAT has been sought on the basis of the data collected in the Frankfurt trial of May 2000. Agreement with the measured fruit rates was found to be poor, so a new 1090 MHz model is being developed to repeat the simulations. Results obtained so far are encouraging in terms of matching the measured fruit rates. ADS-B performance is being evaluated.

5.2 Additional UAT Results/Factors

5.2.1 FAA Sponsored Activities

Subsequent to the issuance of the TLAT report in March 2001, there have been a number of developments in the process of estimating the performance of the UAT system in high density air traffic environments. The three main factors, which have affected the previously reported system performance are:

- Discovery of a bug in the receiver performance model, which penalized performance in a self-interference environment; i.e., the reception of a UAT message under conditions of interference from other UAT transmitters (the vast majority of cases) was degraded by around 9 dB from the actual expected performance. Correcting this error produced significantly improved system performance.
- Modifications to the transmit powers used on the various classes of aircraft. The TLAT report used a specific set of transmit power requirements for the various classes of aircraft. The RTCA UAT MOPS working group is in the process of attempting to find a reasonable compromise between performance and cost, and the final transmit power requirements have not yet been determined. There is a nominal set of transmit powers being used for analysis.

- Inclusion of severe interference scenarios from Link 16 airborne and DME ground transmissions. The scenarios used for these sources of interference are extremely harsh and each represents a severe worst case. The addition of these sources of external interference degrades system performance. As a consequence of this, the UAT waveform has been modified to provide greater resistance to these sources of interference. Additionally, a narrower receive filter has also been implemented by the UAT MOPS WG. These modifications have been incorporated in the UAT simulation.

The cases corresponding to the TLAT scenarios have been re-analyzed, corresponding to the inclusion of the first two effects mentioned above, the corrected receiver performance model and the nominal transmit powers. Analysis shows that UAT system performance in high density air traffic under the TLAT scenarios would have significantly improved, reaching past 150 nautical miles in both the LA 2020 and Core Europe 2015 scenarios. Analysis has also been done with the inclusion of all three effects, including the unlikely simultaneous worst case Link 16 and DME scenarios in high density air traffic. This analysis shows that the effects of the three changes mentioned above tend to cancel each other out in the LA 2020 scenario; the MASPS/Eurocontrol update rate requirements are met out to around 90-95 nm. In the Core Europe 2015 scenario, the MASPS/Eurocontrol requirements are now met out to more than 100 nautical miles, while in the TLAT report, the distance was reported to be around 70 miles. Thus, the UAT system performance in the European scenario improves considerably with the addition of the three effects discussed above. This would represent a change from the TLAT finding that UAT would not support Flight Path De-confliction Planning in Europe out to 90 nm; this analysis provides evidence that the SF21 requirement would be met by UAT.

5.3 Additional VDL Mode 4 Results/Factors

5.3.1 FAA Sponsored Activities

TLAT report concerns were examined, and several which were not solely issues of system configuration were addressed.

The first point, which was specifically indicated in the TLAT report as a shortcoming, was that the receiver diversity was handled in an approximate manner, instead of being calculated exactly. This limitation was due to the nature of the simulation used and the limited time available. However, subsequent to the issuance of the TLAT report, the simulation was modified, and the exact diversity calculation was incorporated, replacing the approximation. The results of this new simulation did indeed indicate a slight improvement over the results reported by the TLAT, but the amount of the change was quite small and would not have materially affected the graphical results depicted in the report. In addition, none of the TLAT findings for VDL-4 would have been changed in any way as a result of this improvement in the simulation. Thus, there is no new evidence to indicate that the VDL-4 system performance will be different than that reported by the TLAT.

The other work which was done involved the continuation of the analysis of the so-called "honeycomb" channel management scheme proposed as an alternative to the channel management plan recommended by the TLAT system experts. Some crucial information necessary for conducting the study was not made available until a few days prior to the final

TLAT meeting at which the report was completed, so the complete analysis of the honeycomb proposal was unfinished at the time of the report publication. Analysis continued, however, using the metrics described in the TLAT report. The work was completed shortly after the appearance of the report, and substantiated the indications stated in the report, namely that the honeycomb scheme did not appear to provide better results than the TLAT channel management plan, and in fact seemed to perform worse than the one the TLAT used.

5.3.2 European Sponsored Activities

Additional simulation runs have been made on the Core Europe 2015 scenario. Runs for scaled down traffic densities corresponding to 2013, 2011, 2009 and 2007 have been done. A number of changes have been incorporated on the VDL-M4 model to remove some of the limitations of the original. The following modifications have been made to the multi-channel version of the VDL-M4 simulator (SPS) since the TLAT:

- Protect the first four slots in each UTC second (these slots are used for uplink of differential GPS corrections, Directory of Service messages, and possibly TIS-B) from mobile station transmissions.
- Include the avionics antenna gain model developed by the TLAT
- Implement alternate top/bottom antenna transmissions.

The results confirm that the six VHF channel solution [two global channels, two regional channels, and two local channels) considered by the TLAT would reach saturation around 2013. Additional simulations were then done assuming a four VHF channel configuration [two global channels, two local channels] starting from the year 2005. It was found that the system might not be able to support full equipage beyond 2007, but it is not yet clear what would happen under partial equipage and use of TIS-B.

6. Opportunities for Further Work

6.1 Technical Issues

The major remaining technical issues associated with each of the individual candidate ADS-B links are addressed in Section 5 above. There are several additional technical issues that arise for the multi-link configurations.

6.1.1 Potential FAA sponsored activities

a. Simulation model enhancements

1090ES: As discussed in 5.1.1 above, there are a number of modifications being considered for the 1090 Extended Squitter simulation. The areas identified include:

(1) Modeling of the ground SSR interrogator infrastructure needs to reflect the next generation of SSRs (i.e., ASR-11 and ATCBI-6) that are now being procured by the FAA and DOD;

(2) incorporation of modified traffic models;

(3) modeling of enhanced decoding techniques (as defined in draft DO-260a); and

(4) modeling of hybrid TCAS/ACAS surveillance

It is expected that the first of these will tend to produce reductions in Mode A/C fruit rates. Work performed to date on the second of the proposed modifications has not progressed to a point to allow for an assessment on the effect it would have on 1090ES performance as compared to the traffic model used by the TLAT. For the third of the proposed modification, laboratory measurements performed using an idealized implementation of the enhanced decoding techniques indicate a potential for an improvement in 1090ES reception performance under conditions of high levels of Mode A/C fruit. The final proposed modification could be assess the level to which active TCAS interrogation rates would be reduced through a combination of passive and active surveillance.

While the combination of these modifications may yield an improvement in the overall performance of 1090ES, the magnitude of the effect can only be assessed through incorporating the changes into the simulation model.

UAT: Further efforts in the UAT modeling/simulation arena will be undertaken, in order to fully characterize UAT performance in the following areas:

- Receiver performance at different altitudes. The TLAT focused on performance at higher altitude. Operation at mid-level altitudes and on the ground will be examined in detail.
- Performance of different receiver implementations. Analysis thus far has concentrated on the performance of diversity receivers (antennas on both top and bottom of the aircraft, with separate receivers). Implementations such as switched receivers (antennas on top, with a single receiver connected to one or the other alternately) and receive on bottom antenna only will be examined.

- Use of the UAT data link to uplink FIS-B information to the cockpit and to downlink TAMDARS messages to the ground will both be investigated. The capacities of UAT for these purposes will be characterized.
- TIS-B capability will be integrated into the UAT system simulation in order to examine interim situations and to provide the means for determining the capabilities and limitations of single- and dual-link implementations.

VDL-M4: The FAA has no current plans for future enhancements to its VDL-M4 simulation model. However, the FAA will cooperate with EUROCONTROL in reviewing results from their ongoing VDL-M4 modeling/simulation activities.

b. Use of a cross-link gateway

A second area for investigation will deal with multi-link architectures that employ a ground cross-link gateway. One effect of the use of a ground cross-link gateway would be equivalent to changing the aircraft distribution. All target aircraft that are equipped to transmit only on the alternate link (a link for which own aircraft has no reception capability) would in effect be represented by ADS-B re-transmissions from the ADS-B ground station. All 3 links generally benefit from have lower received signal levels from distant targets and higher received signal levels from nearby targets (i.e., resulting in higher effective update rates for closer targets). The introduction of ground-based cross-link gateways could have a negative impact on the system capacity under high density traffic situations. However, under less dense traffic conditions it may be possible to use the ground cross-link gate to improve reception of certain long-range targets. There are also issues as to latency and service availability contributions introduced with the use of a cross-link gate. The overall consequences of the use of a cross-link gateway will need to be simulated if a multi-link architecture is selected.

c. Performance on the airport surface

Performance on the airport surface was not assessed by the TLAT. Some data have been collected and analyzed on the performance on the airport surface for the aircraft/vehicle-to-ground station path, as would be used to support ATC surveillance. 1090 ES surface data have been collected during trials in Boston, Atlanta and Dallas-Ft. Worth, and VDL-M4 data have been collected in Europe. However, additional measurements and analysis (including the use of modeling tools) are needed to better quantify the performance of the selected ADS-B link(s) for the aircraft-to-aircraft case as well as the aircraft-to-ground station case. Also the number and configuration of ground stations needed to provide reliable coverage to the surface movement area will need to be determined in order for the FAA to finalize the cost estimates in support of an investment decision for the ground infrastructure. Additional data/results for the use of 1090 ES and UAT on the airport surface is expected to be forthcoming from the planned Safe Flight 21 program operational evaluation in Memphis.

d. Security

Investigations to address the security implications from the introduction of ADS-B into the NAS would be appropriate.

6.1.2 Potential European sponsored activities

The following information was provided courtesy of EUROCONTROL.

a. New simulation tools

Previous simulations were hampered by the limitations of the available simulation tools. EUROCONTROL has contracted for the development of new VDL-4 and 1090 ES models, which should become available by Jan. 2002. Developments in the UAT MOPS group are followed closely, and if needed an updated UAT model shall be sought.

The completely new VDL-M4 simulator that is under development (built from scratch) will comply fully with the latest SARPs (the SPS has quite a few deviations). It should be available from Jan 2002 and will:

- implement rapid net entry
- incremental broadcast
- combined periodic/incremental broadcast
- change of transmission rates
- ground slot reservation
- support regional and local channels
- implement TIS-B and Directory of Service (DoS) uplinks
- implement multi-slot messages (TCPs, DoS, etc)
- support aircraft movement
- allow for larger aircraft populations and geographic areas

b. Airport Surface Movement

ADS-B performance on airport surface was not addressed by the TLAT. A number of airport surface trials have been conducted in the past by other organizations but their results were found to be inadequate to characterize the performance of the candidate technologies. It has therefore been decided to organize a new trial at Heathrow with the three ADS-B technologies and also a Sensis multi-lateration system in collaboration with NATS. The first phase of the trial is planned for October 2001.

c. Multi-link

The TLAT report and subsequent simulations done by EUROCONTROL have led to the conclusion that none of the three candidate technologies would be capable, if used alone, of meeting the requirements for ADS-B with the projected air traffic growth in Core Europe up to 2015. The objective of the Multi-link work has therefore been to establish whether a dual or triple link solution would be capable of meeting these requirements up to and beyond 2015.

There are four possible combinations of the ADS-B link technologies for a Multi-link solution. Furthermore Multi-link can be implemented in at least four different ways (re-transmissions from the ground, use of multi-mode receiver, use of multi-mode transceiver, mix of the previous three). A theoretical analysis has been carried out to establish the advantages and disadvantages of each combination, and this has been followed by a simulation program aiming to establish whether the projected combination would meet the requirements in Core Europe in the year 2015.

On-going considerations suggest that ADS-B deployment in Europe should aim for the combination 1090 ES/VDL-4 (constrained to four VHF channels: two global and two local VHF channels), and consider UAT as a possible future upgrade or replacement for 1090 ES. Work is ongoing to validate this multi-link combination, including:

- definition of intermediate Core Europe traffic scenarios between 2005 and 2015 in order to determine the epochs where the system upgrades will be needed (including introduction of second or third link)
- geographic expansion of the scenarios to cover a wider area in Core Europe in order to enable evaluation of frequency channel requirements
- comparison of baseline link options: Is there a need for a baseline link (used by all airspace users)? Which of the two should be the baseline link? The option which seems to offer the most advantages is to use 1090 ES as baseline link.
- definition of deployment over time and transition issues: There are already local implementations in Europe using VDL-4 and major airport surveillance implementations using multi-lateration and potentially 1090 ES. It is also considered that CDTI introduction shall required 3 or more years because of certification complexities. Therefore an initial "ADS-B out" (transmit only) solution is envisaged. This would serve for air-to-ground surveillance possibly replacing the previous enhanced surveillance program based on Mode S datalink capability which may be abandoned. Introduction of Air Traffic Situation Awareness applications with CDTI would follow next which will require a CDTI, and it will be followed by the introduction of spacing and separation assurance applications at which point dual link ADS-B should become mandatory (with exemptions for GA and military aircraft, and other special categories of aircraft)
- The potential role of TIS-B is being investigated providing also a limited cross-link relay service in some TMAs.
- It is also planned to consider interoperability issues with ADS-B systems in other regions, for example VDL-4 in Russia.

6.2 Institutional Issues

Within the U.S. and internationally there are spectrum availability issues associated with both UAT and VDL Mode 4.

In the case of UAT agreement must be reached between the FAA and the Dept. of Defense for the frequency to be used. In the case there are other users on the same frequency or adjacent frequencies, studies may be needed to assess the impact on the UAT performance and the impact on the other systems within that frequency band. Although the U.S. member to the ICAO Aeronautical Mobile Communications Panel (AMCP) has proposed progressing SARPs for UAT, currently there has not been a consensus reached within the ICAO AMCP to either progress SARPS for UAT or to move forward toward identifying a global frequency for use by UAT.

For VDL Mode 4, the ICAO SARPs allow for two global signaling channels plus local channels. However, no agreement has been forthcoming to allocate international VHF channels for use by VDL Mode 4 and currently VDL Mode 4 could only be used based on locally assigned channels. The FAA's office of spectrum engineering has concluded that if it were to be decided to authorized VDL Mode 4 for use in the NAS, it would be required to operate within the VHF radio navigation frequency band. Further, the efforts that would be necessary to create clear channels, and the associated guard channels, to permit VDL Mode 4 operations in the NAS would require perhaps a decade to put into place.

7. ADS-B Civil Fleet Equipage Scenarios

The ADS-B civil fleet equipage scenarios, presented below in Table 7-1, are used as the basis for developing the estimates of costs and benefits across a wide range of possible architectures and implementations. A technical assessment of the capabilities of each of these scenarios has already been performed. A summary of the results of these assessments is provided in Section 8 of this report.

Specific civil fleet equipage scenarios were developed to enable an effective and timely update to the SF21 'preliminary' cost/benefit analysis. They were chosen to reflect the widest cross-section of possible ADS-B architectures while at the same time limiting the number of analyses required to allow for efficient processing of data and development of meaningful results. The number of scenarios chosen could only be as large as the time for analysis allowed; in this case, this limited the number of scenarios to 7. However, the definition of the scenarios is not intended to limit the scope of the equipage alternatives considered for the final link recommendation. The final ADS-B link architecture recommendation may incorporate all or parts of any of these scenarios (or other options) as deemed fit at the time of the decision. Also the FAA will also consider the inputs of the U.S. Dept. of Defense as related to military fleet equipage. The scenarios and the accompanying cost benefit analysis serve only as a partial basis for more informed link decision-making.

Over-riding assumptions used in developing the ADS-B civil fleet equipage scenarios:

- Scenarios are end-state and do not address the possible transition steps
- Full interoperability between each equipped aircraft is supported independent of ground infrastructure
- Avionics equipage must be kept to a minimum while maintaining full interoperability
- Low-end GA equipage rates are the most cost sensitive and some/many low-end GA will not equip if the minimum ADS-B avionics configuration requires more than one full transmit/receive-capable link system
- All transport aircraft are equipped with TCAS (with TCAS II for > 30 seats and with TCAS I for > 20 seats)
- Each scenario must support (to the maximum extent possible for the link(s) used) all SF21 applications

Specific assumptions:

- The set of scenarios must include at least each of the single-link cases, i.e., 1090 ES only, UAT only, and VDL Mode 4 only, across all user segments
- Full dual-link scenarios need to be considered in light of the potential exclusive use of a single link technology in certain areas of the world
- Each dual-link scenario contains 1090 ES as one of the links, as this is the only link that has current international acceptance/standards/spectrum, and appears to have interest by a significant number of users and vendors
- In keeping with the expressed cost sensitivity on the part of the GA community, consideration of full dual-link equipage was limited to transport and high-end GA aircraft

- Limited dual-link scenarios need to be considered to allow for users to equip fully with the link of their choice, and only the minimum required for the other link technology to support full interoperability (e.g., dual link reception and single link transmission per aircraft – or – dual link transmission and single link reception per aircraft)
- Since VDL Mode 4 cannot operate in a transmit-only mode, the possible dual-link scenarios considered that involved VDL Mode 4 were more limited than those with 1090 ES and UAT
- Based on recent statements of various constituency groups, UAT was assumed to be the ADS-B link generally preferred by GA owners (low-end & perhaps to a somewhat less extent by high-end GA), and 1090 ES was assumed as the link generally preferred by transport aircraft owners/operators.

Table 7-1 Civil Fleet ADS-B Equipage Scenarios Purposes

Equipage Scenario*	Low/Mid GA**	High GA	Transport (non-PFD)	Transport (Integrated PFD)
A (config 1)	Mode S Xponder 1090 ES (1)	Mode S Xponder 1090 ES (1)	Mode S Xponder TCAS 1090 ES (1)	Mode S Xponder TCAS 1090 ES (1)
B (config 2)	Mode A/C Xponder UAT (2)	Mode A/C Xponder UAT (2)	Mode S Xponder TCAS UAT (2)	Mode S Xponder TCAS UAT (2)
C (config 3)	Mode A/C Xponder VDLM4 (3)	Mode A/C Xponder VDLM4 (3)	Mode S Xponder TCAS VDLM4 (3)	Mode S Xponder TCAS VDLM4 (3)
D (config 4 & 2)	Mode A/C Xponder UAT (2)	Mode S Xponder 1090 ES UAT (4)	Mode S Xponder TCAS 1090 ES UAT (4)	Mode S Xponder TCAS 1090 ES UAT (4)
E (config 1 & 9)	Mode S Xponder 1090 ES (1)	Mode S Xponder 1090 ES VDLM4 (9)	Mode S Xponder TCAS 1090 ES VDLM4 (9)	Mode S Xponder TCAS 1090 ES VDLM4 (9)
F (config 5 & 7)	Mode A/C Xponder UAT 1090ES TX (7)	Mode A/C Xponder UAT 1090ES TX (7)	Mode S Xponder TCAS 1090 ES UAT TX (5)	Mode S Xponder TCAS 1090 ES UAT TX (5)
G (config 6 & 8)	Mode A/C Xponder UAT 1090ES RX (8)	Mode A/C Xponder UAT 1090ES RX (8)	Mode S Xponder TCAS 1090 ES UAT RX (6)	Mode S Xponder TCAS 1090 ES UAT RX (6)

* ADS-B avionics configurations listed in ( ) are as shown in Tables 4-1 through 4-3

** ADS-B MASPS configuration A1 avionics assumed for Low/Mid GA aircraft class

8. Summary of Assessment Results

This section provides a summary of the results of the assessment of the costs and technical capabilities associated with the seven civil aircraft fleet equipage scenarios described above in Section 7 of this report. The ability of each fleet equipage scenario was assessed against the link requirements described in Section 3.2. More details of the costing aspects of this assessment will be found in the separate report on the Safe Flight 21 Cost-Benefit Analysis (addendum to original report).

Table 8-1 below shows the aircraft equipage, by ADS-B links supported, for three general categories of users. Scenarios A, B and C are single link scenarios while Scenarios D through G would include multi-link equipage for some or all of the users classes.

TABLE 8-1 Equipage Scenarios for Assessment of ADS-B Airborne Link Configurations

Scenario	Low/Mid GA	High GA	Air Carrier
A	**1090 ES**		
B	**UAT**		
C	**VDL4**		
D	**UAT**	**1090ES & UAT**	
E	**1090 ES**	**1090ES & VDL4**	
F	**UAT & 1090 ES Tx**		**1090 ES & UAT Tx**
G	**UAT & 1090 ES Rx**		**1090 ES & UAT Rx**

Note: Shaded cells indicated single-link configuration for indicated user class

8.1 Assessment Results for Civil Fleet Equipage Scenarios

Table 8-2 below presents the results from applying the 13 link requirements of Section 3.2 against the technical capabilities and costs associated with each of the seven civil fleet equipage scenarios described above. Additional details for the assessment of link requirement 12 on the cost effectiveness of each fleet equipage scenario is provided in Section 8.2 below. Notes are provided following Table 8-2 in Section 8.1.1 summarizing the reason(s) for any assessment other than the requirement is satisfied

TABLE 8-2 Assessment of ADS-B Fleet Equipage Scenarios A Through G

Link Reqt	User	ADS-B Airborne Link Equipage Scenarios						
		A	B	C	D	E	F	G
	Air Carrier	1090ES	UAT	VDL4	1090ES UAT	1090ES VDL4	1090ES UAT Tx	1090ES UAT Rx
	High GA						UAT 1090ES Tx	UAT 1090ES Rx
	Low/Mid GA				UAT	1090		
1. Support for Baseline Applications...		Ö	Ö	**C**	Ö	Ö	Ö	Ö
2. Support Air-to-Air Reception...		**C**	Ö	**C**	Ö	**C**	**C**	**C**
3. Support Flight Path De-confliction...		**C**	Ö	**C**	Ö	**C**	**C**	**C**
4. Support Near/ Mid-term Equipage...		Ö	Ö	**X**	Ö	Ö	Ö	Ö
5. Support TIS-B...		Ö	Ö	Ö	Ö	Ö	Ö	Ö
6. Long-term satisfied by single or multi-link...		**C**	Ö	**X**	Ö	**C**	**C**	**C**
7. Accommodate foreign aircraft...		**C**	**?**	**C**	**C**	**C**	**C**	**C**
8. Support ADS-B Transmissions...		Ö	Ö	**X**	Ö	Ö	Ö	Ö
9. Support Airborne Reception...		Ö	Ö	**C**	Ö	Ö	Ö	Ö
10. Support FIS-B...		**C**	Ö	Ö	Ö	Ö	**C**	Ö
11. Consistent With NAS Architecture...		Ö	Ö	**?**	Ö	**?**	Ö	Ö
12. Supports Cost-Effective Implementation...		Ö	Ö	**C**	**C**	**X**	**C**	**C**
13. Configuration is Technically Practical...		Ö	Ö	**C**	Ö	**C**	Ö	Ö

1. Are the requirements satisfied for a user equipped with this configuration ?: ✓ = Satisfies Requirements
X =does not satisfy requirements **C** = conditional (requirements uncertain and/or meets requirements only in certain contexts) **?** = questions remain requiring additional data/analysis

8.1.1 Notes for Table 8-2

The following notes are provided to summarize the reason(s) for any assessment other than the requirement is satisfied, as reported in Table 8-2 above.

Notes for Scenario A

Requirement 2: The 20 nmi. air-to-air reception requirement for near and mid-term applications are expected to be satisfied with the 1090ES system. In the longer term, 1090ES system performance for the 40 nmi. air-to-air reception requirement in the highest traffic density environments (e.g., LA2020) has been shown to be unsatisfactory under the assumptions made for the TLAT. Potential mitigating assumptions (e.g., radar interrogator replacement) are being considered.

Requirement 3: The flight path de-confliction application, as defined by the ADS-B MASPS (DO-242) applies in low density en route and oceanic airspace. The findings of the TLAT also considered this application in the context of a LA2020 high density environment. Limited flight measurements in a low traffic density environment indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in high density environments, such as the LA 2020 environment, at the full 90 nmi. range.

Requirement 6: Same concerns as previously described above for requirements 2 & 3 apply. These relate to the ability of 1090ES to satisfy the long term requirements for ADS-B at the required air-to-air ranges especially if applied in high density airspace.

Requirement 7: Since 1090 MHz ES is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting 1090 MHz ES would accommodate foreign aircraft equipped for this ADS-B link. Accommodation of aircraft equipped with VDL-M4 only, the other currently approved ICAO ADS-B link, would not be provided.

Requirement 10: 1090 MHz ES will have a limited capacity to support FIS-B services. It may be able to support a basic set of FIS-B services but probably not the more real-time or high update rate services. In high density environments (e.g. LA) and in the long-term, the capacity limitations may result in a reduced service volume or reduced update rates for the FIS-B services.

Notes for Scenario B

Requirement 7: RTCA MOPS for UAT will be completed in 2002. However, the role of UAT is currently under review within ICAO, and a decision on the international role of UAT is expected during 2002 at the earliest. Lacking an ICAO decision to develop standards for UAT, a UAT single link decision in the U.S. would not directly support foreign aircraft equipped with either of the ICAO already approved ADS-B solutions. Thus for the moment this requirement is not satisfied, but this could change if ICAO ultimately decides to move forward with SARPs for UAT and approves an operating frequency.

Notes for Scenario C

Requirement 1: VDL Mode 4 MOPS/SARPs does not provide a state vector update rate high enough to support the tactical applications of terminal approach and departure spacing in low visibility, defined by SF21 when used at air-to-air ranges of less then 3 nmi. Thus VDL-M4 could partially support such baseline application requirements.

Requirement 2: The VDL-M4 system could generally support the 20 nmi. air-to-air range requirement for the near/mid-term application and 40 nmi. for long-term applications. With the TLAT configuration the rate at which certain information (e.g., intent) is transmitted is not consistent with the ADS-B MASPS requirements.

Requirement 3: Limiting consideration to just the use in low density airspace, the nominal characteristics/performance for the VDL-M4 system as defined in the MOPS/SARPs (and the TLAT configuration) would support the 90 nmi. air-to-air range requirement, but the TLAT configuration would not support the update rate requirements. This is a result of the defined transmission rate of the intent information not being sufficient to satisfy the ADS-B MASPS requirements for the de-confliction application.

Requirement 4: Near-term, and perhaps mid-term, use of VDL-M4 in the U.S. appears unlikely due to the lack of available VHF channels that could be assigned for exclusive use by VDL-M4.

Requirement 6: As configured by the VDL M4 TLAT Subject Matter Experts, the system does not fully support the requirements for long-term ADS-B applications requiring intent information, particularly in terms of the required update rates.

Requirement 7: Since VDL-M4 is one of the two ICAO recognized ADS-B links, any NAS ground infrastructure supporting VDL-M4 would accommodate foreign aircraft equipped for this ADS-B link. Accommodation of aircraft equipped with 1090ES only, the other ICAO approved ADS-B link, would not be provided.

Requirement 8: VDL-M4 configuration defined by the TLAT, does not provide sufficient rates of transmission to satisfy the requirements of the ADS-B MASPS for the applications currently under consideration. Specifically, certain of the short-range tactical applications are not supported due to insufficient state vector update rates. Also certain of the longer-range applications require intent information that is not provided with a sufficient update rate.

Requirement 9: The VDL-M4 could satisfy the reception requirements on the condition that the VHF channel loading be kept to a moderate level and the airborne installation includes the capability to simultaneously receive on all channels serving the airspace. However, the concerns noted for requirement 8, scenario C would prevent the reception at an adequate update rate to satisfy the ADS-B MASPS requirements for certain applications (i.e., using the TLAT configuration).

Requirement 11: It is currently unclear if VDL-M4 would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 12: See Section 8.2 below for details

Requirement 13: The technical risks associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 airborne installation are considered moderate (as compared to low for the other ADS-B link alternatives). Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also some risks remain with the VDL-M4 systems management scheme.

Notes for Scenario D

Requirement 7: Although foreign aircraft equipped with the ICAO approved 1090ES would be accommodated, aircraft equipped with VDL-M4 only, the other ICAO recognized ADS-B link, would not be provided.

Requirement 12: See Section 8.2 below for more details. It should be noted that the cost effectiveness results for this scenario came very cost being assessed as acceptable. The only case where the criteria for being considered cost effective was for the high GA/Corp. user class where the associated avionics costs were 31% greater than the lowest cost alternative. The criteria of this requirement has the cut-off point at 30% for being considered cost effective resulting in the conditional assessment shown in the table.

Notes for Scenario E

Requirement 2: The concerns for Requirement 2, Scenarios A and C also apply to this case. These relate to concerns of the effective reception range of 1090ES in high density airspace and the update rates provided by VDL-M4.

Requirement 3: The concerns for Requirement 3, Scenarios A and C also apply to this case. These relate to concerns of the effective reception range of 1090ES in high density airspace and the update rates provided by VDL-M4.

Requirement 6: In general the same issues as for Requirement 2 for Scenario A and Requirements 1 and 2 for Scenario C apply. Note there is a potential that an optimally configured 1090ES plus VDL-M4 combination (not constrained by the TLAT single-link configurations) could perhaps satisfy the long-term requirements for those users so equipped. However, defining and assessing such a configuration was beyond the scope of the efforts to date.

Requirement 7: Although both of the currently recognized ICAO ADS-B links are accommodated, ICAO is currently considering UAT and if ICAO decides to move forward with UAT standards then this scenario would not accommodate aircraft equipped with only UAT.

Requirement 11: It is currently unclear if VDL-M4 would fit into the evolution of the NAS surveillance architecture. The requirements for the VDL-M4 systems management including the associated ground network and management requirements are not clear.

Requirement 12: See Section 8.2 below for details

Requirement 13: The technical risks associated with a fully MOPS/SARPs compliant and certifiable VDL-M4 airborne installation are considered moderate (as compared to low for the other ADS-B link alternatives). Concerns have been expressed related to the VDL-M4 antenna installations on some smaller airframes where achieving the desired isolation from other VHF antennas may be difficult. Also some risks remain with the VDL-M4 systems management scheme.

Notes for Scenario F

Requirement 2: For the case where only a 1090ES air-to-air path exists the 20 nmi. air-to-air reception requirement for near and mid-term applications are expected to be satisfied with the 1090ES system. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied in all but potentially the highest traffic density environments (e.g., LA or NE corridor). For the case where a UAT path exists the requirement is satisfied.

Requirement 3: For the case where only a 1090ES air-to-air path exists both limited flight measurements and analysis for a low traffic density environment, as required by the ADS-B MASPS, indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range (if this were to become a requirement). For the case where a UAT path exists the requirement is satisfied including use in high density environments.

Requirement 6: In general the same issues as for Requirement 2 and 3 above. These relate to configurations where only a 1090ES air-to-air path is provided. In this case the ability of 1090ES to satisfy the long term requirements for ADS-B at the maximum required air-to-air ranges especially if applied in high density airspace (including those that have been suggested that go beyond that required by the current ADS-B MASPS). For the case where a UAT path exists the requirement is satisfied including use in high density environments.

Requirement 7: This scenario would accommodate foreign aircraft equipped with only VDL-M4. Also Low/Mid GA equipage would not support full 2-way 1090ES capability.

Requirement 10: For the air carrier case where the aircraft has only 1090ES reception capability, 1090 MHz ES will have a limited capacity to support FIS-B services. It may be able to support a basic set of FIS-B services but probably not the more real-time or high update rate services. In the highest interference environments (e.g. LA) and in the long-term, the capacity limitations may result in a reduced service volume or reduced update rates for the FIS-B services. Also the Class A0 and A1 1090ES receivers as defined by the DO-260 may not have sufficient sensitivity to provide adequate reception range to permit continuos FIS-B coverage. For the GA aircraft equipped with UAT reception capability the requirement would be satisfied.

Requirement 12: See Section 8.2 below for details

Notes for Scenario G

Requirement 2: For the case where only a 1090ES air-to-air path exists the 20 nmi. air-to-air reception requirement for near and mid-term applications are expected to be satisfied with the 1090ES system. In the longer term the 40 nmi. air-to-air reception requirement is expected to be satisfied in all but potentially the highest traffic density environments (e.g., LA or NE corridor). For the case where a UAT path exists the requirement is satisfied.

Requirement 3: For the case where only a 1090ES air-to-air path exists both limited flight measurements and analysis for a low traffic density environment, as required by the ADS-B MASPS, indicate that 1090 MHz ES may be able to satisfy the 90 mile range ADS-B MASPs requirement. The current simulations indicate that 1090 MHz ES would be unable to support this application in the highest interference environments, such as LA, at the full 90 nmi. range (if this were to become a requirement). For the case where a UAT path exists the requirement is satisfied including use in high density environments.

Requirement 6: In general the same issues as for Requirement 2 and 3 above. These relate to configurations where only a 1090ES air-to-air path is provided. In this case the ability of 1090ES to satisfy the long term requirements for ADS-B at the maximum required air-to-air ranges especially if applied in high density airspace (including those that have been suggested that go beyond that required by the current ADS-B MASPS). For the case where a UAT path exists the requirement is satisfied including use in high density environments.

Requirement 7: This scenario would accommodate foreign aircraft equipped with only VDL-M4. Also Low/Mid GA equipage would not support full 2-way 1090ES capability.

Requirement 12: See Section 8.2 below for details

8.2 Assessment of the Cost Effectiveness of each Civil Fleet Equipage Scenario

The assessment reported below relates only to the U.S. civil aircraft fleet. Separate studies are being conducted by the U.S. Department of Defense for the military aircraft fleet. The detailed results from the cost analysis reported below and the DoD results (not reported in this document) will be considered by the FAA when developing the recommendation on the preferred ADS-B equipage configuration.

Link requirement 12 from Section 3.2 of this report states:

> *Viable aircraft ADS-B configurations must be consistent with an ADS-B architecture that supports a cost effective means for the introduction of ADS-B capability into all user classes. The following criteria are used to assess alternatives against this requirement. An alternative is considered viable if the estimated installed system costs do not exceed +30% of the cost of the least expensive alternative for each aircraft category. An alternative is considered as not being viable (from a cost effective standpoint) only if the estimated installed system costs exceeded +60% of the estimated costs for the least expensive alternative for 2 or more civil aircraft categories. Otherwise the alternative is considered to be conditionally viable (i.e., might be viable for only certain aircraft categories).*

As detailed in the separate report on the Safe Flight 21 Cost-Benefit Analysis (addendum to the original report), an economic assessment was performed for each of the seven ADS-B fleet equipage scenarios described above. Table 8-3 below presents details concerning the relative costs for aircraft equipage, by user class, from the cost assessments for the seven fleet equipage scenarios previously discussed. In Table 8-3 the relative total costs for ADS-B equipage for each user class is reported as the percentage of increase above the least expensive alternative for that user class. Table 8-3 also includes the results of applying the Requirement 12 criteria stated above against the avionics cost results reported by the Cost-Benefit Analysis. The FAA formulation of a recommendation on the ADS-B link architecture for the NAS will be based on the details of the Cost Benefit Analysis and not specifically on the results reported in Table 8-3 associated with Requirement 12. Rather, results from applying Requirement 12 criteria are intended to offer a snapshot at possible cost discriminators among the link equipage scenarios that were considered. It is recognized that individual aircraft operators/owners may have different views on what is the acceptable range of costs.

TABLE 8-3 Assessment of ADS-B Airborne Link Scenarios:
Cost Versus Lowest Cost Link Configuration in User's Group

		ADS-B Airborne Fleet Link Equipage Scenarios (Change from Lowest Cost Configuration)						
		A	B	C	D	E	F	G
Equip-age	Air Carrier	1090ES	UAT	VDL4	1090ES UAT	1090ES VDL4	1090ES UAT Tx	1090ES UAT Rx
	High GA						UAT 1090ES Tx	UAT 1090ES Rx
	Low GA				UAT	1090ES		
User	**Group**	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Air Carrier	Forward Fit	Lowest Cost	+ 1 %	+22 %	+8 %	+41 %	+5 %	+5 %
	Modern/ Integ	+1 %	Lowest Cost	+25 %	+7 %	+60 %	+5 %	+5 %
	Neo-Classic	+1 %	Lowest Cost	+11 %	+4 %	+33 %	+3 %	+3 %
	Classic	+2 %	Lowest Cost	+62 %	+12 %	+138 %	+9 %	+9 %
General Aviation	High/ Advanced Avionics	+6 %	Lowest Cost	+25 %	+31 %	+82 %	+24 %	+22 %
	Low-Mid/ Basic Avionics	+21 %	Lowest Cost	+59 %	Lowest Cost	+21 %	+46 %	+42 %
Assessment of Cost Effectiveness (Requirement 12)		Ö	Ö	C	C	X	C	C

Notes:
Assessment against Link Requirement 12: ✓= Cost Effective ✗=Not Cost Effective as a U.S. fleet-wide alternative C = Conditionally Cost Effective