



L-Band System Engineering—Concepts of Use, Systems Performance Requirements, and Architecture

Phase II: Final Report

*Stephen Henriksen and Natalie Zelkin
ITT Corporation Information Systems, Herndon, Virginia*

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

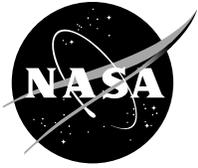
- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.

- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA STI Help Desk at 443-757-5803
- Telephone the NASA STI Help Desk at 443-757-5802
- Write to:
NASA Center for AeroSpace Information (CASI)
7115 Standard Drive
Hanover, MD 21076-1320



L-Band System Engineering—Concepts of Use, Systems Performance Requirements, and Architecture

Phase II: Final Report

*Stephen Henriksen and Natalie Zelkin
ITT Corporation Information Systems, Herndon, Virginia*

Prepared under NNC05CA85C

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

Trade names and trademarks are used in this report for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Level of Review: This material has been technically reviewed by expert reviewer(s).

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076-1320

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312

Available electronically at <http://www.sti.nasa.gov>

Preface

This National Aeronautics and Space Administration (NASA) Contractor Report summarizes and documents the work performed to develop concepts of use (ConUse), System Requirements and Architecture for the proposed L-band (960 to 1164 MHz) terrestrial en route communications system.

This work was completed under the NASA Aerospace Communication Systems Technical Support (ACSTS) contract, based on direction provided by the Federal Aviation Administration project-level agreement (PLA FY09_G1M.02-02v1) for “New ATM Requirements—Future Communications” as a follow-on to the FAA/EUROCONTROL (European Organisation for the Safety of Air Navigation) Cooperative Research Agreement (Action Plan 17 (AP-17)), commonly referred to as the Future Communications Study.

Executive Summary

ES.1 Introduction

This document is created under the project-level agreement (PLA) (PLA FY09_G1M.02-02v1) for “New ATM [air traffic management] Requirements—Future Communications” and addresses concepts of use (ConUse), system requirements, and architecture for the proposed L-band (960 to 1164 MHz) terrestrial en route communications system.

The document becomes part of a hierarchy of documents capturing concepts related to the National Airspace System (NAS). NAS-level and similar level international concept of operations (ConOps) driving this ConUse and its associated requirements include the RTCA “National Airspace System Concept of Operations and Vision for the Future of Aviation” (Ref. 1), the “Joint Planning and Development Office (JPDO) Concept of Operations (ConOps) for the Next Generation Air Transportation System (NextGen)” (Ref. 2), and the “Global ATM Operational Concept Document (International Civil Aviation Organization (ICAO) 9854)” (Ref. 3). At the next lower layer, the European Organisation for the Safety of Air Navigation (EUROCONTROL) “Operating Concept of the Mobile Aviation Communication Infrastructure Supporting ATM Beyond 2015” (Ref. 4) was used with the service-level ConOps, the Future Communications Study (FCS) Communications Operating Concept and Requirements (COCR) (Ref. 5) providing reference guidance for air/ground (A/G) and air/air (A/A) communications services operating concepts and requirements directly applicable to this ConUse. On a similar level to this ConUse, but with a different scope and intended for different services, are the operating concepts and requirements presented in the “Data Communications Safety and Performance Requirements (SPR)” (Ref. 6) and the Federal Aviation Administration (FAA) Final Program Requirements (FPR) for Data Communications (Ref. 7).

The work was performed in two phases. This report builds on Phase I results as presented in the Phase I report (Ref. 8).

ES.2 ConUse

A process recommended in the “NAS System Engineering Manual” (SEM, Ref. 9) was used as a guide in developing ConUse and requirements for the proposed L-band Digital Aeronautical Communications System (L-DACS) during the joint FAA/EUROCONTROL FCS.

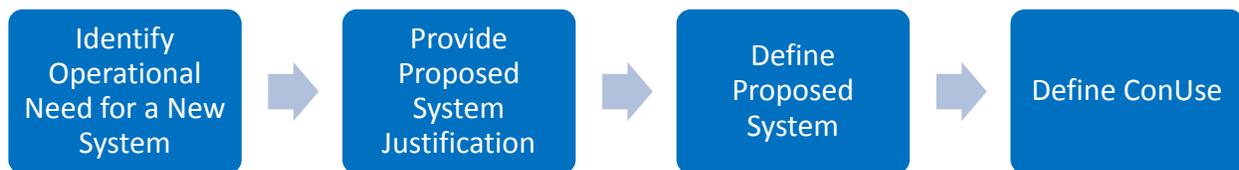


Figure ES–1.—Concepts of use (ConUse) development process.

The following subsections summarize the steps taken in developing the ConUse.

ES.2.1 Operational Needs for a New System and Proposed System Justification

Operational needs for a new system are supported by describing the current system and its associated problems and capability shortfalls. The Next Generation Air/Ground Communications (NEXCOM) system requirements document (Ref. 10) provides a good description of the FAA's current analog A/G voice communications system used for air traffic control (ATC).

The NextGen ConOps summarizes the current attributes (and associated constraints) of the voice-based A/G communications system as follows (Ref. 2):

- Limited data communications for ATM and operational control
- Limited access to real-time weather and aeronautical data
- Voice communications routine for ATM
- Analog voice
- Analog weather information display systems
- A/G and ground/ground (G/G) communications
- Loss of communications due to beyond line-of-site (BLOS) aircraft position (e.g., over the ocean)
- Individual ground systems for each information type brought to the flight deck
- Point-to-point aircraft communications based on ATC sectors

There are several principal shortcomings of the current A/G voice communications system, including lack of automation, limited or no data communications availability, aging infrastructure, technology limitations, and spectrum saturation. The resulting operational problems, if not addressed, could lead to service degradation and could limit introduction of new or expanded services. These, in turn, could potentially compromise safety of operation and increase operating costs. Saturation of the very high frequency (VHF) spectrum is the problem specifically mitigated by the introduction of a new L-band system (L-DACS), while the other operational problems will likely be mitigated to a degree dependent on the particular technology implemented with the L-DACS.

Rather than being NAS services per se, G/G, A/G, and A/A communications are enablers of NAS services. It is important to note that the FAA's Data Communications Program (Data Comm) FPR document recognizes that "the scope of the mission shortfalls identified herein [is] broader than will be addressed solely by a data communications capability" (Ref. 7). Because of the limitations and constraints of implementing data communications using VDL Mode 2 over a congested aeronautical VHF band, FAA Data Comm Program will focus on implementing the certain critical air traffic services. This provides opportunities for L-DACS systems to augment Data Comm by enabling communications of other critical and essential air traffic services to address the shortfalls listed. The Data Communications Networks Services (DCNS) A/G data communications system being developed under the Data Comm Program is expected to precede L-DACS implementation. Even though each of the shortfalls listed are meant to be addressed to some extent by the Data Comm using VDL Mode 2, there are opportunities to overcome these shortfalls to a greater extent during the later program segments of Data Comm (e.g., late Segment 2 and Segment 3) using link technologies such as L-DACS with greater bandwidth capabilities, which could augment the benefits already attained through VDL Mode 2 Data Comm program segment implementations (i.e., Segments 1 and 2) by providing a broader scope of services. Assumptions and constraints for this document include the following:

- The proposed L-DACS is assumed to provide an increase in overall A/G communications systems capacity by utilizing the new spectrum (i.e., not VHF).
- The scope of this ConUse and requirements document includes A/G communications and A/A communications.

- L-DACS will be designed specifically for data communication. When finalized, the technology may support voice communications, but this feature is not considered a system requirement at this time.
- This report assumes that the data communications system developed as part of Data Comm will precede an L-DACS implementation and deployment.
- Although some critical services are proposed, the L-DACS will also target noncritical services, such as weather advisory and aeronautical information services implemented as part of an airborne System Wide Information Management (SWIM) program. It may also target one or more unmanned aircraft system (UAS) communications services.
- Although the L-band system is proposed to be implemented with the primary objective of supporting en route and terminal communications (i.e., ENR and TMA domains), the L-band system could be used on the ground (i.e., airport domain) as well as in the air, for example, to avoid switching link types during a flight.
- Although the L-DACS ConUse and functional requirements developed for the document are largely technology-independent, services selection and overall system requirements may change if and/or when additional and/or different data is available from proposed L-DACS interference testing and as a result of a final selection of one of two L-DACS technologies under consideration at this time.
- L-DACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the L-band. Additional interference research and testing will determine if any operational constraints are to be imposed, such as limiting the number of users, time of the day, duration, etc.

ES.2.1 Proposed System Definition and ConUse

L-DACS will be introduced as part of the proposed NextGen vision and will address continental en route and terminal maneuvering area (TMA) airspace A/G and A/A communications.

In addition to potentially providing an alternative link technology suitable to support the FAA's Data Communications Segment 3 requirements, including full four-dimensional trajectory-based operations (TBO), the L-DACS is also envisioned to support other future communications applications including mobile SWIM and UAS safety-critical data communications, UAS command and control, and monitoring of UAS onboard sense-and-avoid and automation capabilities.

Table ES–1 illustrates the potential operational use of the proposed L-band system based on the COCR services previously identified as potential applications (Ref. 5).

TABLE ES–1.—POTENTIAL USE OF L–DACs IN DIFFERENT FLIGHT DOMAINS
[Acronyms are defined in Appendix A.]

Operational services	Airport domain phases						
	Predeparture airport domain ^a	Departure taxi airport domain ^a	Departure TMA domain ^a	ENR and AOA domains	Arrival TMA domain ^a	Arrival airport domain ^a	Arrival taxi airport domain ^a
Flight information services	D–OTIS ^b D–RVR ^b D–SIG D–SIGMET	D–OTIS ^b D–RVR ^b D–SIG D–SIGMET	D–ORIS D–OTIS ^b D–RVR ^b D–SIG D–SIGMET	D–ORIS D–OTIS ^b D–RVR ^b D–SIGMET	D–OTIS ^b D–RVR ^b D–SIG D–SIGMET	D–OTIS ^b D–RVR ^b D–SIG	D–RVR ^b D–SIG
Flight position, flight intent, and flight preferences services	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY SAP ^c WAKE	PPD FLIPCY SAP WAKE ^d	PPD FLIPCY SAP WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE
Advisory service				DYNAV			
Emergency information service	URCO	URCO	URCO	URCO	URCO	URCO	URCO
Delegated separation services			ITP M&S C&P	ITP M&S C&P	ITP M&S C&P PAIRAPP		
Air-to-air service				AIRSEP			
UAS services	Pilot/UA control links, including telecommand and telemetry Pilot/UA NavAids data exchanges Relaying ATC voice messages to and from UA pilots Relaying ATS data messages to and from UA pilots UA-to-pilot downlinking of nonpayload target-track data UA-to-pilot downlinking of data from UA-borne weather radars UA-to-pilot downlinking of safety-related video data from UA to pilots UA-to-pilot downlinking of safety-related sense and avoid automated decisionmaking from UA to pilots						
Airborne SWIM suitable services (generally weather advisory and aeronautical information services)	ADDS, ADAS, expanded terminal and tower data service, general information (GI) message distribution service, IDS data service, NNEW service ^e , NOTAM distribution service, TMA flight data service WARP/WINS NEXRAD Service						

^aWhile the L-band system is proposed to be implemented with the primary objective of supporting en route and terminal communications (i.e., ENR and TMA domains), the L-band system could be used on the ground (i.e., airport domain) as well as in the air, for example, to avoid switching links. As such, some ATC services are included in the table for the airport domain.

^bAt the time of this report D–OTIS and D–RVR are listed as part of the RTCA SC-214 scope (Ref. 11). As noted throughout this report, the services are considered candidates for L–DACs if not implemented by the Data Comm program.

^cSAP is primarily used en route and terminal areas but is available in all phases of flight.

^dWAKE service is not available in AOA domain.

^eIt is possible that the information provided through the NNEW service could range from the advisory for routine forecasts through safety critical for certain hazardous weather warning messages, which might limit the extent to which this might be provided over commercial links. This requires further investigation.

Table ES–2 lists the aeronautical operational control (AOC) data services noted in the COCR v.2.0. Services provided on airport surface only (e.g., Software Loading, SWLOAD) as well as those likely to be provided in the ENR and TMA domains are included in the table. Some of the services listed would be mostly provided the ground, while others may be applicable to wheels-on- and off-the-ground scenarios.

TABLE ES–2.—COCR V.2.0 AOC DATA SERVICES

Service	Acronym	Service	Acronym
AOC Data Link Logon	AOCDLL	Real Time Maintenance Information	MAINTRT
Cabin Log Book Transfer	CABINLOG	Notice to Airmen	NOTAM
Engine Performance Reports	ENGINE	Out-Off-On-In	OOOI
Flight Log Transfer	FLTLOG	Position Report	POSRPT
Flight Plan Data	FLTPLAN	Software Loading	SWLOAD
Flight Status	FLTSTAT	Technical Log Book Update	TECHLOG
Free Text	FREETXT	Update Electronic Library	UPLIB
Fuel Status	FUEL	Graphical Weather Information	WXGRAPH
Gate and Connecting Flight Status	GATES	Real-time Weather Reports for Met Office	WXRT
Load Sheet Request/Transfer	LOADSHT	Textual Weather Reports	WXTEXT
Maintenance Problem Resolution	MAINTPR		

A key NAS operational concepts source driving the L–DACS ConUse is the RTCA NAS ConOps. Appendix B presents a comprehensive listing derived from the RTCA NAS ConOps of future communications concepts to enable transfer of the following NAS information types:

- Surveillance
- Weather
- Flight planning
- Aeronautical information
- Resource management

When discussing an impact of introducing the new L-band system, it should be emphasized that the proposed L–DACS is designed to augment current operations and is not intended to replace any of the existing services. The proposed system is expected to further increase safety and efficiency of current operations. An introduction of the proposed L-band system should require no changes to the existing L-band services operating in the same band by utilizing inlay technology and/or other interference mitigation techniques.

ES.3 System Requirements

A “middle-out” approach was adopted to identify high-level requirements applicable to L–DACS. In this approach, the top-down requirements were derived from the ConUse and the associated functional capabilities. In parallel with that process, a bottom-up assessment included existing requirements provided in relevant documents such as the NAS SR–1000, the COCR, the Data Comm performance requirements, and documents associated with specific potential applications identified in Task 6.

The future communications infrastructure (FCI) aeronautical data services definition task report (Ref. 12) classifies all the COCR ATS data services as safety critical. It further identifies services that are not planned to be implemented by the Data Comm program through Segment 3, and identifies them as possible candidates for implementation via C-band and/or L-band DACS. It must be stressed that both C-band and L-band DACS are being developed for the FCI to accommodate safety and regularity of flight services and designed to operate over aviation-protected spectrum, so any COCR ATS service could be implemented via one or the other of these links (as appropriate).

L–DACS could provide a communication link to transfer surveillance and weather information, facilitate flight and resource management, enhance collaborative decision making, and enable exchange of aeronautical information in the future NAS. Table 21 through Table 25 of Appendix B document the select RTCA NAS ConOps (Ref. 1) found applicable to the proposed L–DACS.¹

Table ES–3 presents system requirements associated with the identified functionality.

TABLE ES–3.—MAPPING OF SYSTEM FUNCTIONS TO SYSTEM REQUIREMENTS

System functions	System requirements ^a
Enable ground-to-air (G/A) and air-to-ground (A/G) communication for fixed-to-mobile as well as mobile-to-mobile users	The system shall enable G/A communication for fixed-to-mobile users. The system shall enable G/A communication for mobile-to-mobile users. The system shall enable A/G communication for fixed-to-mobile users. The system shall enable A/G communication for mobile-to-mobile users.
Enable air-to-air (A/A) communication	The system shall enable A/A communication.
Support addressed communication for delivery of information to individual and multiple users	The system shall support addressed communication for delivery of information to individual users. The system shall support addressed communication for delivery of information to multiple users.
Support broadcast communication for delivery of information to multiple users	The system shall support broadcast communication for delivery of information to multiple users.
Support delivery of real-time information in a timely manner	The system shall support delivery of real-time information in a timely manner.
Enable demand, periodic, and event communication	The system shall enable demand communication. The system shall enable periodic communication. The system shall enable event communication.
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness	The system shall accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness.
Support multiple quality of service (QoS) provisions	The system shall support multiple QoS offerings, such as priority and preemption capabilities, and so on.
Support authentication of users and controlled access to National Airspace System (NAS) information (security)	The system shall support authentication of users (security). The system shall support controlled access to NAS information (security).
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground and airborne users ^b	The system shall provide support of FAA ground users. The system shall provide support of FAA airborne users. The system shall provide support of non-FAA ground users. The system shall provide support of non-FAA airborne users.
Avoid single points of failure	The system shall avoid single points of failure.
Provide a scalable solution	The system shall provide a scalable solution.
Provide standards-based solution	The system shall provide standards-based solution.

^aAll the requirements presented in the document are documented as “system shall” not “system must.” The verbiage is consistent with that used in the NAS SR–1000 as opposed to some of the newer requirements documents.

^bTo support increasing collaboration among NAS users, the proposed system shall accommodate a wide range of NAS users by accepting NAS data from NAS data sources, both internal and external to the FAA. Users may include aircraft, airline operation centers, service providers, FAA users, and other government agencies.

¹The RTCA document describes the NAS evolution in terms of three time periods—near (up to 2005), mid (2005 to 2010), and far (beyond 2010). Concepts identified in the document are found applicable for the proposed L–DACS even though it is likely to be implemented beyond 2020–2025.

Appendix B presents a hierarchical decomposition of functional requirements as diagrams and in an outline format.

The identified NAS ConOps were then traced to the desired functionality of the proposed network. Table ES-4 maps concepts of use identified in the ConUse activities and described in the preceding sections to specific functions necessary to enable those concepts. These functions are grouped into appropriate functional hierarchies, and functional requirements are derived. The table presents the mapping of NAS ConOps to L-DACS functional requirements and proposed capabilities. This encompasses a top-down approach to the development of functional requirements. Mapping the proposed services to the desired system capabilities and functional architectures presents combined functional requirements from the top-down and bottom-up approaches.

TABLE ES-4.—MAPPING L-DACS FUNCTIONALITY TO NAS CONOPS
[Acronyms are defined in Appendix A.]

Desired L-DACS capabilities	NAS ConOps references ^a	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable ground-to-air (G/A) and air-to-ground (A/G) communication for fixed to mobile as well as mobile to mobile users.	S-1; S-3; S-4; W-2; W-3; W-5; W-9; W-10; W-11; W-12; W-14; W-15; W-16; W-17; W-19; W-20; W-22; W-27; FM-3; FM-6; FM-9; FM-11; FM-13; FM-17; FM-21; FM-22; FM 24; FM-32; FM-41, FM-42; A-5; A-14; A-23; A-26; A-28; A-29; A-30; A-33; A-34	L.1.1.1.1 L.1.1.1.2 L.1.1.2.1 L.1.1.2.2	D-ORIS D-OTIS ^b D-RVR ^b DYNAV FLYPCY SAP WAKE PPD URCO
Enable air-to-air (A/A) communication	S-7; W-26	L.1.1.3.1	AIRSEP ITP M&S C&P PAIRAPP SURV
Support addressed communication for delivery of information to individual and multiple users	S-1; W-12; FM-11; FM-13	L.1.1.1.1 L.1.1.1.2 L.1.1.2.1 L.1.1.2.2 L.1.1.3.1	D-ORIS D-OTIS ^b D-RVR ^b DYNAV FLIPCY SAP PPD URCO AIRSEP
Support broadcast communication for delivery of information to multiple users	S-1; S-4; W-2; W-3; W-14; W-16; W-20; W-26; FM-13; A-23	L.1.1.1.1 L.1.1.1.2 L.1.1.2.1 L.1.1.2.2 L.1.1.3.1	D-ORIS D-OTIS ^b D-RVR ^b WAKE URCO AIRSEP
Support delivery of real-time information in a timely manner	S-1; S-3; W-10; W-18; W-22; W-24 FM-3; FM-6; FM-14; FM-17; FM-22; FM-35; A-22; A-31; FM-4; FM-15; FM-25; FM-34;		D-RVR ^b DYNAV FLYPCY SAP WAKE PPD

TABLE ES-4.—MAPPING L-DACS FUNCTIONALITY TO NAS CONOPS
 [Acronyms are defined in Appendix A.]

Desired L-DACS capabilities	NAS ConOps references ^a	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
	RM-3; RM-15; A-9; A-15		URCO AIRSEP
Enable demand, periodic, and event communication	S-1; S-8; W-14; W-19; W-20		All services
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness	S-3; W-2; W-3; A-4; A-11; A-33		All services
Support multiple quality of service (QoS), priority, etc.			All services
Support authentication of users and controlled access to NAS information (security)	W-1		All services
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground and airborne users	S-1; FM-18; FM-21; FM-26; FM-29; A-18; A-22; A-33; A-35		All services
Avoid single points of failure	RM-14		All services
Provide a scalable solution			All services
Provide standards-based solution			All services

^aAlthough only select NAS ConOps are presented for this L-DACS capability, most NAS ConOps could be traced to enabling G/A and/or A/G communication.

^bAt the time of this report D-OTIS and D-RVR are listed as part of the RTCA SC-214 scope. As noted throughout this report, the services are considered candidates for L-DACS if not implemented by the Data Comm program.

ES.4 Architectural Description

An L-DACS physical architecture can be derived from and represents a technical solution to the functional architecture and requirements. Figure ES-2 shows a high-level notional architecture of the L-DACS system supporting A/G communication. The ground infrastructure comprises a number of L-DACS ground radio stations, each providing a cell-like coverage service volume, and which are geographically situated to provide overlapping coverage (using different frequencies) to achieve seamless service volume handovers. Each ground radio station would be connected to a G/G network through a ground network interface (number 1 in Figure ES-2).

Contents

Preface	iii
Executive Summary	v
ES.1 Introduction.....	v
ES.2 ConUse	v
ES.2.1 Operational Needs for a New System and Proposed System Justification.....	vi
ES.2.1 Proposed System Definition and ConUse	vii
ES.3 System Requirements	ix
ES.4 Architectural Description.....	xii
ES.5 Conclusion	xiii
1.0 Introduction.....	1
1.1 Background	1
1.2 System Overview	2
1.3 Document Overview.....	3
2.0 ConUse and Requirements Development Processes.....	4
3.0 Concepts of Use.....	8
3.1 ConUse Development Process	8
3.2 Operational Needs	8
3.2.1 Current Air-to-Ground Voice Communication System	8
3.2.2 Current System Operational Environment	9
3.2.3 Current System Users.....	12
3.2.4 Current System Scope and Capabilities Shortfalls.....	13
3.2.5 Operational Needs for L–DACS to Provide A/A Services.....	16
3.3 New L-Band Communications Systems Justification	17
3.3.1 Potential Benefits of New L-Band Communications Systems.....	17
3.3.2 Operational Shortfalls Addressed by Data Comm	19
3.3.3 Description of Desired Changes.....	21
3.3.4 Change Priorities and Roadmaps	21
3.3.5 Assumptions and Constraints for L–DACS	23
3.4 Proposed L–DACS	23
3.4.1 Objectives and Scope	23
3.4.1.1 L–DACS as Part of the Next Generation Air Transportation System.....	24
3.4.1.2 Proposed Operational Environment	28
3.4.2 Frequency and Technology—Environment, Requirements, and Limitations	30
3.5 L–DACS Concepts of Use	31
3.5.1 User Impact	31
3.5.2 Operational Policies and Constraints	32
3.6 L–DACS Concepts of Use	33
3.6.1 RTCA NAS ConOps Guidance.....	33
3.6.2 Data Comm Operational Scenarios	33
3.6.3 L–DACS Applicable Services.....	35
3.6.3.1 Air Traffic Services.....	35
3.6.3.2 AOC Data Services	36
3.6.3.3 Unmanned Aircraft System (UAS) Suitable Services.....	37
3.6.3.4 Airborne System Wide Information Management (SWIM) Suitable Services	38

3.6.4	Communications Operational Services and Concepts Based on Flight Domain	42
3.6.5	L–DACS Operational Concepts Derived from the COCR.....	45
4.0	L–DACS System Requirements	47
4.1	L–DACS System Requirements Development Process	47
4.2	Functional Requirements for L–DACS Services—Bottom-Up Assessment.....	47
4.2.1	NAS-Level Functional Requirements for L-band System Services	47
4.2.2	NAS Functional Requirements for L-band System Infrastructure	52
4.3	L–DACS Functional System Requirements—Top-Down Approach.....	53
4.3.1	Prior Functional Analysis.....	53
4.3.2	L–DACS Concepts-of-Operations-Based Functional Analysis	54
4.4	L–DACS Performance Requirements	58
4.4.1	NAS-Level Performance Requirements Applicable to L–DACS	58
4.4.2	COCR Performance Requirements Applicable to L–DACS	60
4.5	Other L–DACS Requirements.....	60
4.5.1	L–DACS Spectrum Requirements	60
4.5.2	L–DACS User Requirements	61
4.5.3	Regulatory Requirements.....	62
4.5.4	Safety and Security Requirements Applicable to L–DACS.....	63
5.0	Physical Architecture	64
5.1	System Context.....	64
5.2	Physical Architecture Development Process.....	64
5.3	L–DACS Physical Architecture	65
6.0	Unmanned Aircraft Systems (UAS)	67
6.1	Unmanned Aircraft System Operations.....	67
6.2	Need for Change and Impact on Existing Unmanned Aircraft System Operations.....	70
6.3	Unmanned Aircraft System ConUse and Functional Analysis.....	70
6.4	Unmanned Aircraft System Applications.....	72
6.5	Operational Scenarios.....	73
6.6	Unmanned Aircraft System Requirements.....	73
6.6.1	Spectrum Requirements	73
6.6.2	Safety and Latency Requirements.....	74
6.6.3	Other Requirements.....	74
6.7	Additional Safety Considerations and Assumptions	74
6.8	Unmanned Aircraft System Architecture and Interfaces.....	75
7.0	Preliminary Inputs to L–DACS Design	76
7.1	Scope	76
7.2	L–DACS Implementation and Transition Issues.....	76
7.2.1	FAA L-Band System Development Plans.....	76
7.2.2	Technology Evaluation.....	77
7.2.3	L-Band System Implementation.....	80
7.2.4	L-Band System Transition Issues.....	81
7.2.5	Relationship between the Proposed Systems	82
7.3	Summary of the Analyses.....	83
7.3.1	Design Specifications Development Process	83
7.3.2	Spectrum Requirements and Channelization.....	84
7.3.2.1	Spectrum Allocation.....	84
7.3.2.2	Interference Studies.....	85
7.3.3	Design Specifications and Prototype Development	88
Appendix A	—Acronyms and Abbreviations.....	91

Appendix B.—National Airspace System Concept of Operations Applicable to the Proposed L-band Digital Aeronautical Communications System	99
Appendix C.—Hierarchical Diagrams of Functional Requirements	111
Appendix D.—N ² Charts	125
Appendix E.—Spectrum Requirements for Unmanned Aircraft System (UAS) Communications.....	131
E.1 Single Unmanned Aircraft Throughput Needs.....	131
E.1.1 Methodology 1	131
E.1.2 Methodology 2	131
E.2 Unmanned Aircraft System (UAS) Deployment Scenario.....	132
E.2.3 Methodology 1	132
E.2.4 Methodology 2	132
E.3 Aggregate Assessment of UAS Spectrum Needs.....	132
E.3.5 Methodology 1	132
E.3.6 Methodology 2	134
E.4 Conclusion.....	135
Appendix F.—L-Band Spectrum Applicability for Unmanned Aircraft System (UAS) Applications	137
Appendix G.—References	139

List of Figures

Figure ES-1.—Concepts of use (ConUse) development process.....	v
Figure ES-2.—L-DACS architecture.....	xiii
Figure 1.—Communications systems covered by this ConUse document (slightly altered version of Figure 1-1 in Ref. 16).....	2
Figure 2.—National Airspace System (NAS) engineering concept document hierarchy (Ref. 9). Acronyms are defined in Appendix A.....	4
Figure 3.—Requirements management process flow (Ref. 9). Acronyms are defined in Appendix A.....	6
Figure 4.—L-DACS ConUse and system requirements development flow chart. Acronyms are defined in Appendix A.....	7
Figure 5.—ConUse development process.....	8
Figure 6.—Current en route air-to-ground (A/G) communications system (Ref. 10). Acronyms are defined in Appendix A.....	9
Figure 7.—System View 2 (SV-2) command and control detailed air-to-ground communications view for 2009 to 2010 (Ref. 19). Acronyms are defined in Appendix A.....	11
Figure 8.—Current National Airspace System air-to-ground communications operational problems.....	14
Figure 9.—Operational capabilities of Data Comm (Ref. 23). Acronyms are defined in Appendix A.....	20
Figure 10.....	20
Figure 10.—Data Link Evolution.....	20
Figure 11.—Evolution overview of aeronautical mobile communications (Ref. 22; note that this schedule is subject to change). Acronyms are defined in Appendix A.....	21
Figure 12.—Federal Aviation Administration communications roadmap (Ref. 24). Acronyms are defined in Appendix A.....	22
Figure 13.—Target plan for expedited L-DACS development and deployment in Europe (November 2007) (Ref. 22).....	22
Figure 14.—Next Generation Air Transportation System (NextGen) operational view in 2025 (Ref. 27). Acronyms are defined in Appendix A.....	24
Figure 15.—System view 2 (SV-2) 2025 communications description: command and control (Ref. 33). Acronyms are defined in Appendix A.....	29
Figure 16.—Communication system capacity demand and user base relationships.....	31
Figure 17.—Information Exchange Model (Ref. 36). Acronyms are defined in Appendix A.....	38
Figure 18.—Air-to-ground data link management and aircraft participation in System Wide Information Management (SWIM) (slightly modified from Ref. 37).....	39
Figure 19.—Full flight plan constraint evaluation and feedback OI in the context of SWIM showing interactions with other OIs mid-term operational scenario (Ref. 38).....	41
Figure 20.—System Wide Information Management (SWIM) execution by segments (Ref. 39).....	42
Figure 21.—High-level hierarchy of L-band communications system.....	53
Figure 22.—Functional flow block diagram (from Ref. 9).....	54
Figure 23.—N ² diagram (from Ref. 9).....	54
Figure 24.—National Airspace System enterprise architecture airborne elements and remote facilities (Ref. 20). Acronyms are defined in Appendix A.....	64
Figure 25.—System requirements and architecture development synthesis loop (Ref. 9).....	65
Figure 26.—L-DACS architecture. Acronyms are defined in Appendix A.....	66
Figure 27.—L-DACS ground station components.....	66
Figure 28.—High-level unmanned aircraft operational functions (Ref. 36).....	70
Figure 29.—Unmanned aircraft system applications (from proposed changes to Ref. 44).....	72
Figure 30.—Unmanned aircraft system (UAS) notional architecture (Ref. 45). Acronyms are defined in Appendix A.....	75

Figure 31.—EUROCONTROL L-band technology selection schedule (September) (Ref. 50).	78
Figure 32.—SESAR CNS systems and infrastructure roadmap (Ref. 52). Acronyms are defined in Appendix A.	79
Figure 33.—Proposed L-band communications system capabilities.	80
Figure 34.—Relationship between the L-band system and the VDL-2 and C-band systems. Acronyms are defined in Appendix A.	82
Figure 35.—Federal Aviation Administration (FAA) System Engineering Manual (SEM) requirements and architecture definition process (Ref. 9).	83
Figure 36.—Systems operating in the 960- to 1215-MHz band (Ref. 56).	85
Figure 37.—L-band communications system high level.	111
Figure 38.—Decomposition of use L-band communications system (transmit/receive messages).	111
Figure 39.—Decomposition of transceive fixed-to-mobile message.	112
Figure 40.—Decomposition of transceive mobile-to-fixed message.	113
Figure 41.—Decomposition of transceive airborne-mobile-to-airborne-mobile messages.	114
Figure 42.—Generic decomposition of transceive data message.	115
Figure 43.—Generic decomposition of initiate data message.	115
Figure 44.—Generic decomposition of process data message for sending.	115
Figure 45.—Generic decomposition of send data message.	115
Figure 46.—Generic decomposition of process received data message.	116
Figure 47.—Generic decomposition of deliver data message.	116
Figure 48.—Generic decomposition of provide failure processing.	116
Figure 49.—Decomposition of operate L-band communications system.	117
Figure 50.—Decomposition of monitor L-band communications system.	117
Figure 51.—Decomposition of maintain L-band communications system.	118
Figure 52.—Decomposition of configure L-band communications system.	119
Figure 53.—Level 2 N ² chart, L.1 L-DACS communication system.	125
Figure 54.—Level 3 N ² chart, L.1.1 provide air traffic control communications over L-band communications system.	125
Figure 55.—Level 4 N ² chart, L.1.1.1 transceive fixed-to-mobile message.	125
Figure 56.—Level 7 N ² chart, L.1.1.x.x.x.2 transceive data message.	125
Figure 57.—Level 8 N ² chart, L.1.1.x.x.x.2.1 initiate data message.	126
Figure 58.—Level 9 N ² chart, L.1.1.x.x.x.2.x.x. provide failure processing.	126
Figure 59.—Level 8 N ² chart, L.1.1.x.x.x.2.2 process data message for sending.	126
Figure 60.—Level 8 N ² chart, L.1.1.x.x.x.2.3 send data message.	127
Figure 61.—Level 8 N ² chart, L.1.1.x.x.x.2.4 process received data message.	127
Figure 62.—Level 8 N ² chart, L.1.1.x.x.x.2.5 deliver data message.	127
Figure 63.—Level 4 N ² chart, L.1.1.2 transceive mobile-to-fixed message.	128
Figure 64.—Level 3 N ² chart, L.1.2 operate L-band communication system.	128
Figure 65.—Level 4 N ² chart, L.1.2.1 monitor L-band communication system.	128
Figure 66.—Level 4 N ² chart, L.1.2.2 maintain L-band communication system.	128
Figure 67.—Level 5 N ² chart, L.1.2.2.1 perform preventative maintenance.	128
Figure 68.—Level 5 N ² chart, L.1.2.2.2 perform corrective maintenance.	129
Figure 69.—Level 4 N ² chart, L.1.2.3 configure L-band communication system.	129
Figure 70.—Level 5 N ² chart, L.1.2.3.2 configure communication path.	129
Figure 71.—Level 5 N ² chart, L.1.2.3.3 configure security.	129
Figure 72.—Links involved for line of sight (LOS). Acronyms are defined in Appendix A.	133
Figure 73.—Links involved for beyond line-of-sight (BLOS) via satellite (with onboard processing). Acronyms are defined in Appendix A.	133
Figure 74.—Links involved for beyond line-of-sight (BLOS) via satellite (without onboard processing). Acronyms are defined in Appendix A.	134

List of Tables

Table ES-1.—POTENTIAL USE OF L-DACS IN DIFFERENT FLIGHT DOMAINS.....	viii
Table ES-2.—COCR v.2.0 AOC DATA SERVICES.....	ix
Table ES-3.—MAPPING OF SYSTEM FUNCTIONS TO SYSTEM REQUIREMENTS.....	x
Table ES-4.—MAPPING L-DACS FUNCTIONALITY TO NAS ConOps	xi
TABLE 1.—MAPPING AIR-TO-GROUND VOICE COMMUNICATIONS FUNCTIONS TO NATIONAL AIRSPACE SERVICE (NAS) SERVICE CAPABILITIES (REF. 18).	12
TABLE 2.—CURRENT SHORTFALLS RELATED TO AIRPORT SURFACE AIR-TO- GROUND VOICE COMMUNICATIONS.....	15
TABLE 3.—COMMUNICATION ALLOCATION BETWEEN VOICE AND DATA LINK (D/L).....	18
TABLE 4.—L-DACS OPTIONS KEY CHARACTERISTICS (REF. 22)	31
TABLE 5.—AERONAUTICAL OPERATIONAL CONTROL (AOC) DATA SERVICES.....	36
TABLE 6.—PROPOSED NEW AOC/AAC SERVICES	37
TABLE 7.—POTENTIAL USE OF L-DACS IN DIFFERENT FLIGHT DOMAINS.....	43
TABLE 8.—EXAMPLE L-BAND DATA LINK MESSAGES	44
TABLE 9.—EXAMPLE OPERATIONAL SCENARIOS	45
TABLE 10.—MAPPING RELEVANT COMMUNICATIONS FUNCTIONS TO NATIONAL AIRSPACE SYSTEM (NAS) SERVICE CAPABILITIES (REF. 18).....	48
TABLE 11.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS	49
TABLE 12.—MAPPING OF L-DACS SYSTEM FUNCTIONS TO SYSTEM REQUIREMENTS.....	55
TABLE 13.—MAPPING L-DACS FUNCTIONALITY TO NAS ConOps	56
TABLE 14.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS	58
TABLE 15.—L-DACS DATA REQUIREMENTS.....	60
TABLE 16.—NATIONAL AIRSPACE SYSTEM (NAS) SPECTRUM REQUIREMENTS APPLICABLE TO THE PROPOSED L-DACS	61
TABLE 17.—AVIATION USER REQUIREMENTS	61
TABLE 18.—REGULATORY REQUIREMENTS.....	62
TABLE 19.—MAPPING OF ITU PRIORITY LEVELS TO COCR SERVICES (REF. 42).....	62
TABLE 20.—UAS OPERATIONAL SCENARIOS.....	73
TABLE 21.—THE ROLE OF SURVEILLANCE INFORMATION: RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED L-DACS.....	99
TABLE 22.—THE ROLE OF SURVEILLANCE INFORMATION: RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED L-DACS.....	100
TABLE 23.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps)	102
TABLE 24.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION— RTCA NATIONAL AIRSPACE (NAS) CONCEPT OF OPERATIONS (ConOps).....	105
TABLE 25.—IDENTIFICATION OF THE ROLE OF RESOURCE MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps)	108
TABLE 26.—TERRESTRIAL ESTIMATED NONPAYLOAD THROUGHPUT REQUIREMENTS OF A SINGLE UNMANNED AIRCRAFT IN BITS/S.....	131
TABLE 27.—SATELLITE ESTIMATED NONPAYLOAD THROUGHPUT REQUIREMENTS OF A SINGLE UNMANNED AIRCRAFT IN BITS/S.....	131
TABLE 28.—MAXIMUM NONPAYLOAD THROUGHPUT REQUIREMENTS.....	131

TABLE 30.—NUMBER OF UNMANNED AIRCRAFT (UA) PER FOOTPRINT OF THE SATELLITE	132
TABLE 31.—NUMBER OF UNMANNED AIRCRAFT (UA) OPERATING AT PEAK TIMES	132
TABLE 32.—AGGREGATE SPECTRUM REQUIREMENTS	132
TABLE 33.—METHODOLOGY 2, COMPARISON OF AGGREGATE BANDWIDTH REQUIREMENTS	134

1.0 Introduction

1.1 Background

During the past five years, NASA Glenn Research Center and ITT have conducted a three-phase technology assessment for the Federal Aviation Administration (FAA) under the joint FAA–EUROCONTROL cooperative research Action Plan (AP–17), also known as the Future Communications Study (FCS). NASA/ITT provided system engineering evaluation of candidate technologies for the future communications infrastructure (FCI) to be used in air traffic management (ATM). Specific recommendations for data communications technologies in very high frequency (VHF), C, L, and satellite bands, and a set of follow-on research and implementation actions have been endorsed by the FAA, EUROCONTROL, and the International Civil Aviation Organization (ICAO). In the United States, the recommendations from AP–17 are reflected in the FAA’s “Next Generation Air Transportation System Integrated Work Plan” (Ref. 13) and are represented in the “National Airspace System (NAS) Enterprise Architecture” (Ref. 14) communications and avionics roadmaps.

Action Plan 30 (AP–30), a proposed follow-on cooperative research action plan to AP–17, ensures coordinated development of FCI to help enable the advanced ATM concepts of operation (ConOps) envisioned for both the Next Generation Air Transportation System (NextGen) in the United States and for EUROCONTROL’s Single European Systems ATM Research (SESAR) program in Europe. Follow-on research and technology development recommended by ITT and NASA Glenn and endorsed by the FAA was included in the FAA’s NextGen Implementation Plan 2009. The plan was officially released at the NextGen Web site (<http://www.faa.gov/about/initiatives/nextgen/>) on January 30, 2009. The implementation plan includes an FY09 Solution Set Work Plan for C-band and L-band future communications research under the section, “New Air Traffic Management (ATM) Requirements.”

On February 27, 2009, the FAA approved a project-level agreement (PLA) (PLA FY09_G1M.02-02v1) for “New ATM Requirements—Future Communications,” to perform the FY09 portion of the FAA’s solution-set work plan; this includes development of concepts of use (ConUse), requirements, and architecture for both a new C-band airport surface wireless communications system and a new L-band terrestrial en route communications system.

In addition to potentially providing an alternative link technology suitable to support the FAA’s Data Communications Segment 3 requirements, including full four-dimensional trajectory-based operations (TBO), the L-band terrestrial en route communications system is also envisioned to support other future communications applications including mobile System Wide Information Management (SWIM) and unmanned aircraft system (UAS) safety-critical data communications, UAS command and control, and monitoring of UAS onboard sense-and-avoid and automation capabilities.

This report is being provided as part of the NASA Glenn Contract NNC05CA85C Task 7: “New ATM Requirements—Future Communications, C-band and L-band Communications Standard Development.” Task 7 is separated into two distinct subtasks, each aligned with specific work elements and deliverable items identified in the FAA’s PLA and with the FAA FY09 and FY10 spending plans for these subtasks. Subtask 7–1 addresses C-band airport surface data communications standard development tasks that define ConUse requirements and architecture, describe supporting system analyses, and test development and demonstration plans, establishing operational capability.

The purpose of the subtask 7–2, and the subject of this report, is to define the L-band terrestrial ConUse, systems performance requirements and architecture in a future L-band (960 to 1164 MHz) air/ground (A/G) communication system referred to as L-band digital aeronautical communications system (L–DACS). The proposed L–DACS will be capable of providing ATM services, including the potential applications identified in the Aerospace Communications Systems Technical Support (ACSTS) Contract task 6, in continental airspace in the 2020+ timeframe. Task 7–2 also includes an initial L-band system safety and security risk assessment (Ref. 15), supports joint FAA/EUROCONTROL L–DACS development and evaluation, and presents inputs to design specifications for L-band communications

systems. Subtasks associated with interference analysis and testing were postponed due to FAA’s European partners schedule change.

The work is being performed in two phases. This report builds on the Phase I results and is provided as a Phase II deliverable.

1.2 System Overview

Systems covered by this document provide A/G communications services in support of ATM and are shown within the dashed red box in Figure 1.

On the ground, these systems typically consist of radio ground station subsystems, including radios, antennas, cabling, power systems, environmental systems, towers, monitoring and control (M&C) functionality, and other systems to provide A/G communications services; networking subsystems to provide ground/ground (G/G) communications service connectivity to end systems and users; and usually some centralized functionality to monitor and control system operations and performance. Aircraft components include radio equipment, antennas, and associated cabling.

Additionally, while this document mainly supports the definition of FAA ground-based systems; it also discusses provision of air/air (A/A) communications services as shown in Figure 1.

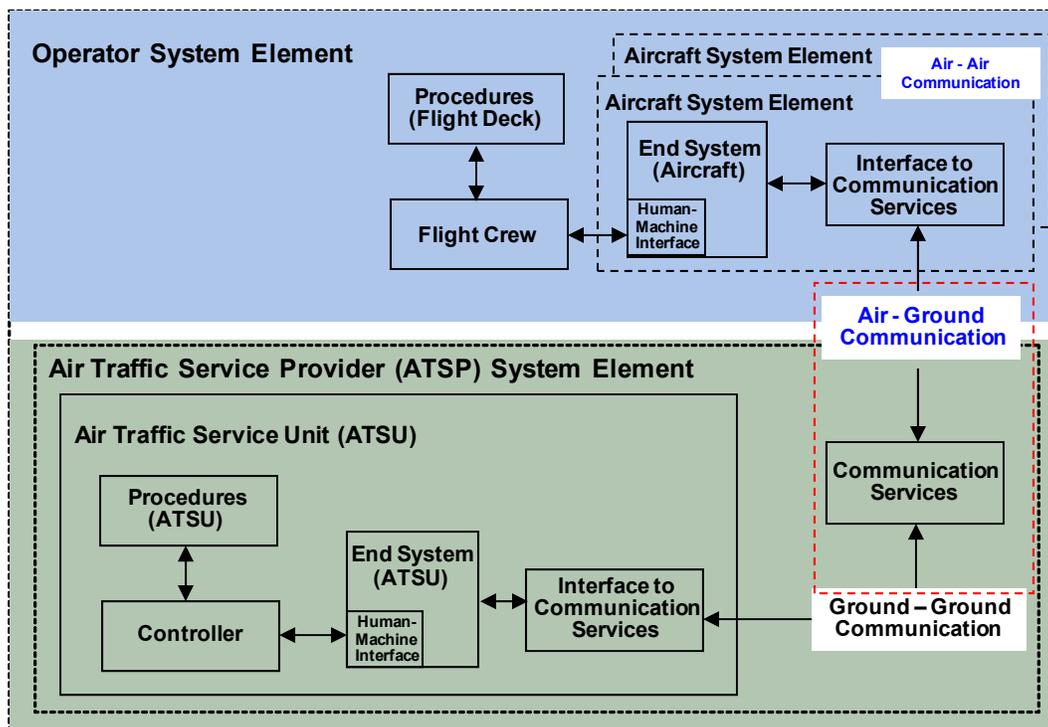


Figure 1.—Communications systems covered by this ConUse document (slightly altered version of Figure 1–1 in Ref. 16).

It should be noted that while the figure essentially illustrates A/A and A/G communications provided by the proposed L-band system, it includes air traffic service provider (ATSP) end-systems only. ATSP is part of the broader air navigation service provider (ANSP) category that, in addition to ATSP, may encompass aeronautical information services providers, communication, navigation and surveillance providers; meteorological (office) service providers; and airport/aerodrome flight information service (AFIS) providers.

1.3 Document Overview

This document is organized as follows:

- Section 1.0 provides background system information and includes document scope and organization.
- Section 2.0 presents the ConUse and requirements development processes.
- Section 3.0 is devoted to the ConUse of the proposed L-DACS. After describing the ConUse development process, it presents the operational need for the L-DACS by describing current A/G communications systems and their associated problems and capability shortfalls. New system justification shows potential benefits of new systems and describes the desired changes. A proposed system is then described.
- Section 4.0 presents L-DACS system requirements. It describes the system requirements development process and presents the results of the middle-out approach.
- Section 5.0 describes the synthesis process and introduces L-DACS physical architecture.
- Section 6.0 is devoted to unmanned aircraft systems (UAS), describing their existing operations, the need for additional communication links, and L-DACS ConUse applicable to UAS.
- Section 7.0 summarizes the preliminary inputs to L-DACS design specification. It includes an assessment of the potential L-DACS implementation and transition issues, outlines the long-term schedule for the FAA and EUROCONTROL, and notes various factors that affect the development process. An overview of the requirements definition process and the results of previous analyses provide inputs to the design specification.
- Appendix A defines acronyms and abbreviations used in this report.
- Appendix B summarizes RTCA NAS ConOps applicable to the proposed L-DACS.
- Appendix C presents hierarchical diagrams of L-DACS functional requirements.
- Appendix D contains N² diagrams illustrating L-DACS functional requirements.
- Appendix E describes spectrum requirements for UAS communications.
- Appendix F discusses spectrum applicability for UAS applications.

2.0 ConUse and Requirements Development Processes

Multiple documents related to ConUse and ConOps of the future data communication systems exist. This section provides background information related to ConUse and requirements development to offer the appropriate frame of reference and to provide traceability to better define the scope of this report and its place in the family of concepts documents.

ConUse are part of a hierarchy of concepts documents that capture concepts related to the NAS. As defined in the FAA's NAS System Engineering Manual (SEM), there are two general types of concepts documents associated with system engineering in the NAS: ConOps and ConUse. A ConOps is "a description of what is expected from the system, including its various modes of operation and time-critical parameters," whereas a ConUse is "an extension of a higher level ConOps with an emphasis on a particular NAS system and its operating environment," (Ref. 9).

Figure 2 depicts the three hierarchical levels of concept documents typically used in the NAS and defined in the SEM: two levels of ConOps and the ConUse.

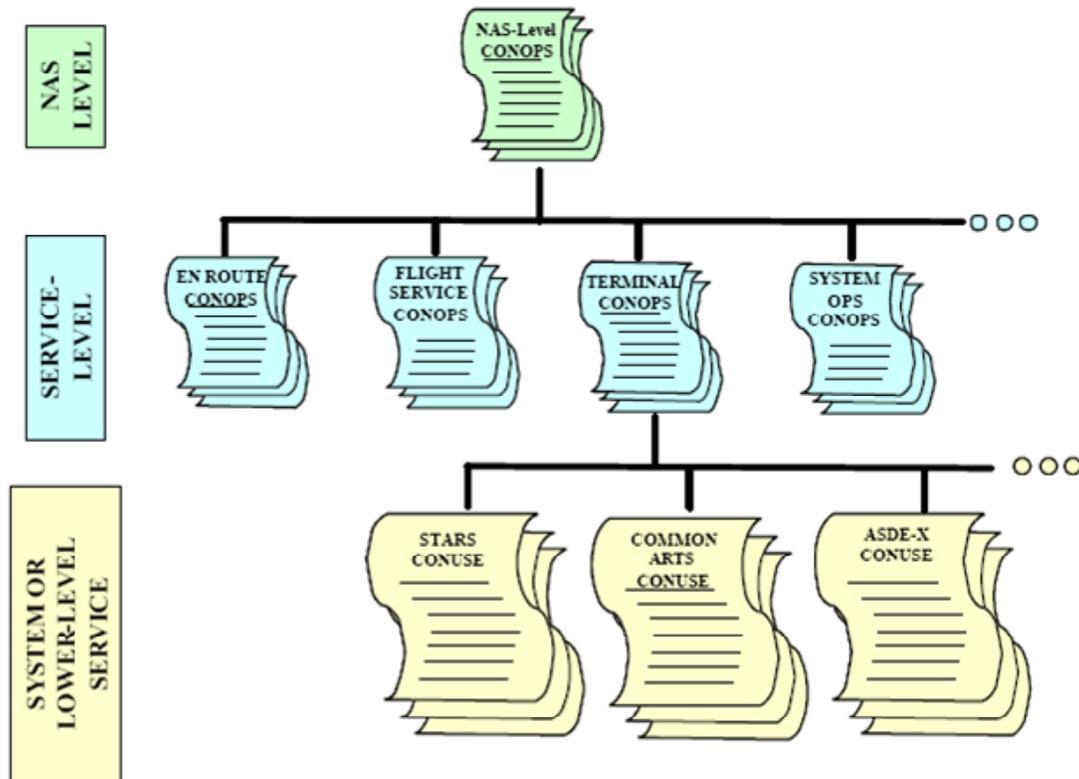


Figure 2.—National Airspace System (NAS) engineering concept document hierarchy (Ref. 9). Acronyms are defined in Appendix A.

These three levels can be summarized as follows (from Ref. 9):

- NAS-level ConOps are a high-level narrative of the user community's desired change with some performance indicators. The document indicates from the user's perspective the desired end state for respective systems in the NAS. It often uses various operational scenarios to illustrate the desired operational concept.
- Service-level ConOps provide conceptual insight into a particular service of the NAS. It gives more detail and in-depth information about the desired operations within the service.
- ConUse are extensions of the NAS-level ConOps and a particular service-level ConOps, with an emphasis on a particular NAS system and its operating environment. It is more detailed and substantial, but it still expresses the user's needs regarding a specific system within the NAS.

NAS-level and similar international ConOps driving this ConUse and its associated requirements include the RTCA's "National Airspace System: Concept of Operations and Vision for the Future of Aviation" (Ref. 1), the "Concept of Operations (ConOps) for the Next Generation Air Transportation System (NextGen)" (Ref. 2), and the ICAO's "Global ATM Operational Concept Document" (Ref. 3). At the next lower layer, EUROCONTROL's "Operating Concept of the Mobile Aviation Communication Infrastructure Supporting ATM beyond 2015" (Ref. 4) was used with the service-level ConOps—Future Communications Study (FCS) Communications Operating Concept and Requirements (COCR) (Ref. 5)—to provide reference guidance for A/G and A/A communications services operating concepts and requirements directly applicable to this ConUse. On a similar level to this ConUse, but with a different scope and intended for different services, are the operating concepts and requirements presented in "Data Communications Safety and Performance Requirements" (Ref. 6) and the FAA's "Final Program Requirements (FPR) for Data Communications" (Ref. 7).

The ConUse and performance requirements described in this document apply to a future aeronautical L-band (960 to 1164 MHz) communications system named the L-band Digital Aeronautical Communications System (L-DACS), providing services similar in scope to those described in the "FCI Aeronautical Data Services Definition Task Report" (Ref. 12). This follows from the previous FCS technology evaluation studies (Ref. 17) that identified two hybrid technologies (L-DACS1 and L-DACS2) as candidates for further development that best meet the FCS technology assessment criteria and that are designed for L-band spectrum as a recommended band for supporting new data link communications capabilities for continental airspace.

Typically, concepts documents and requirements for new systems are developed for the NAS based on the process depicted in Figure 3, which illustrates the top-down iterative process and general relationships among concepts, requirements, and architectures. Because many, if not most, NAS systems are not new, but rather, evolutionary improvements of existing NAS systems, a top-down process is not always appropriate. Instead, a "middle-out" approach is taken. This is a combination of a top-down process, which takes into account new concepts and missions needs, and a bottom-up approach, which takes into account existing requirements and concepts.

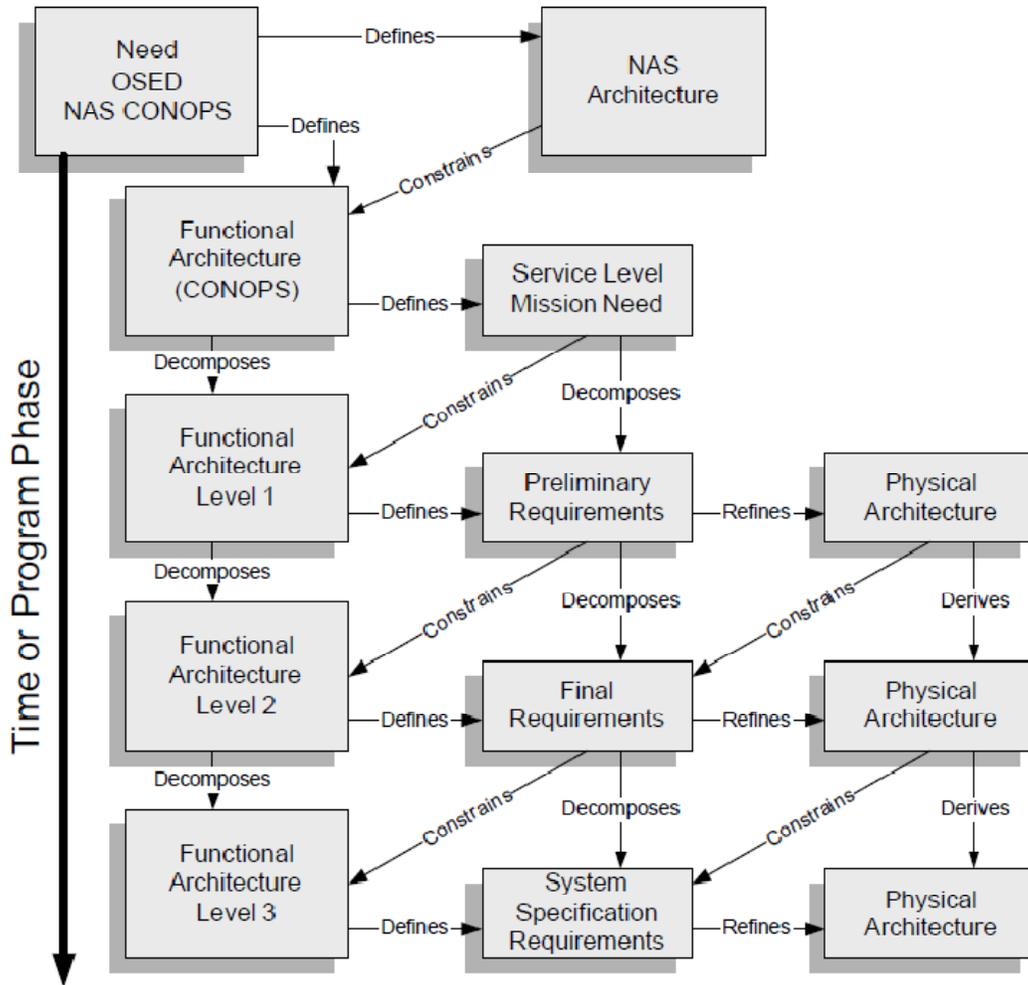


Figure 3.—Requirements management process flow (Ref. 9). Acronyms are defined in Appendix A.

Figure 4 shows a middle-out approach was adopted for the concepts and requirements developed for L-DACS. As shown in the figure, operational concepts and requirements of higher-level concepts documents flow down to this document, providing high-level guidance and direction in the form of required functions and flows for the services of interest, namely A/G and A/A communications services. In addition to this top-down process, a bottom-up process of identifying and evaluating specific concepts and requirements developed for other communications systems, such as Data Comm, Next Generation Air/Ground Communication (NEXCOM), and Link2000+, along with appropriate NAS System Requirements (SR-1000), was employed for this document.

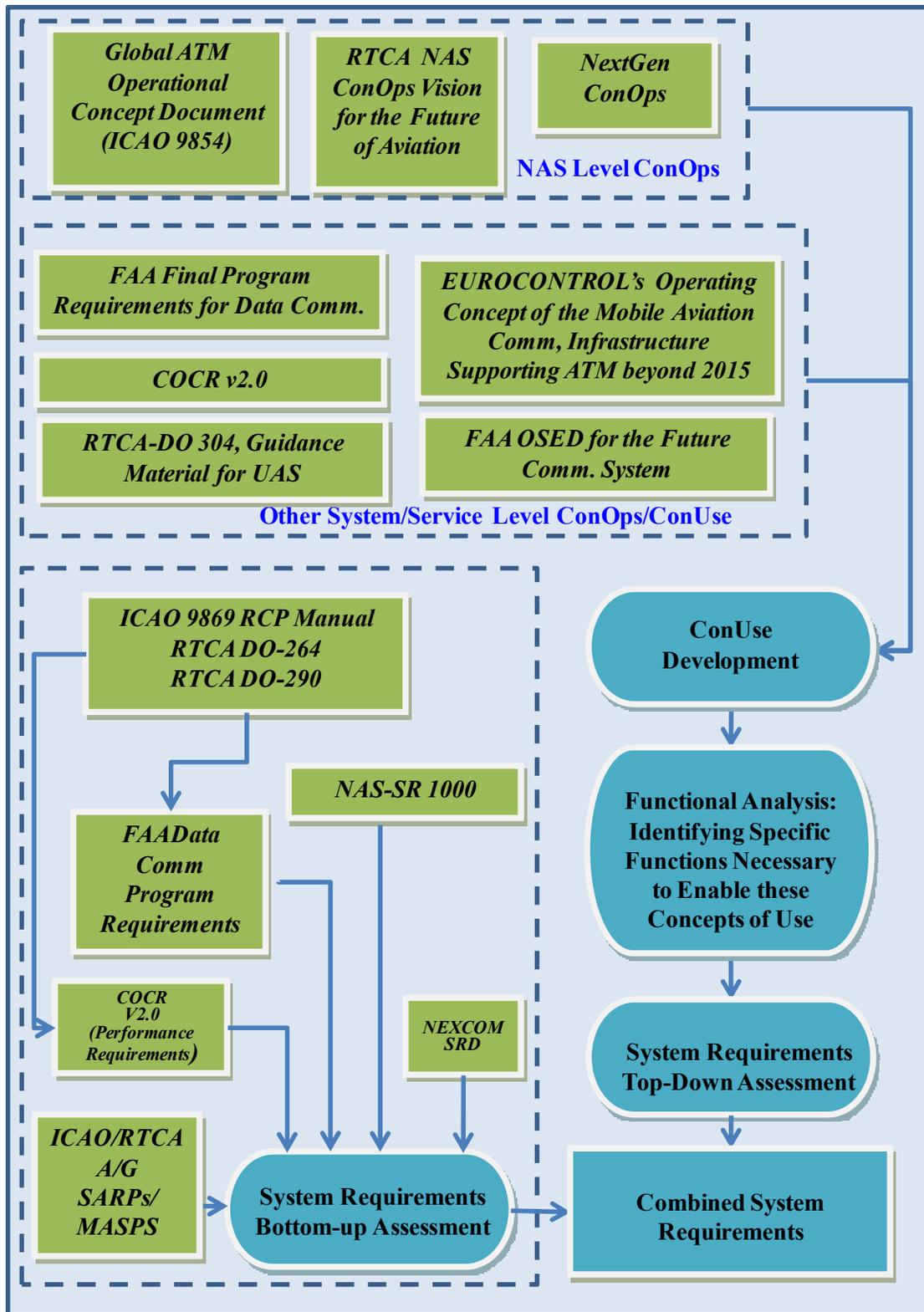


Figure 4.—L-DACS ConUse and system requirements development flow chart. Acronyms are defined in Appendix A.

3.0 Concepts of Use

3.1 ConUse Development Process

A process recommended in the NAS system engineering manual (SEM, Ref. 9) was used as a guide in developing ConUse for the proposed L–DACS. Figure 5 summarizes the steps. The following sections describe the findings for each of the steps shown in the figure.

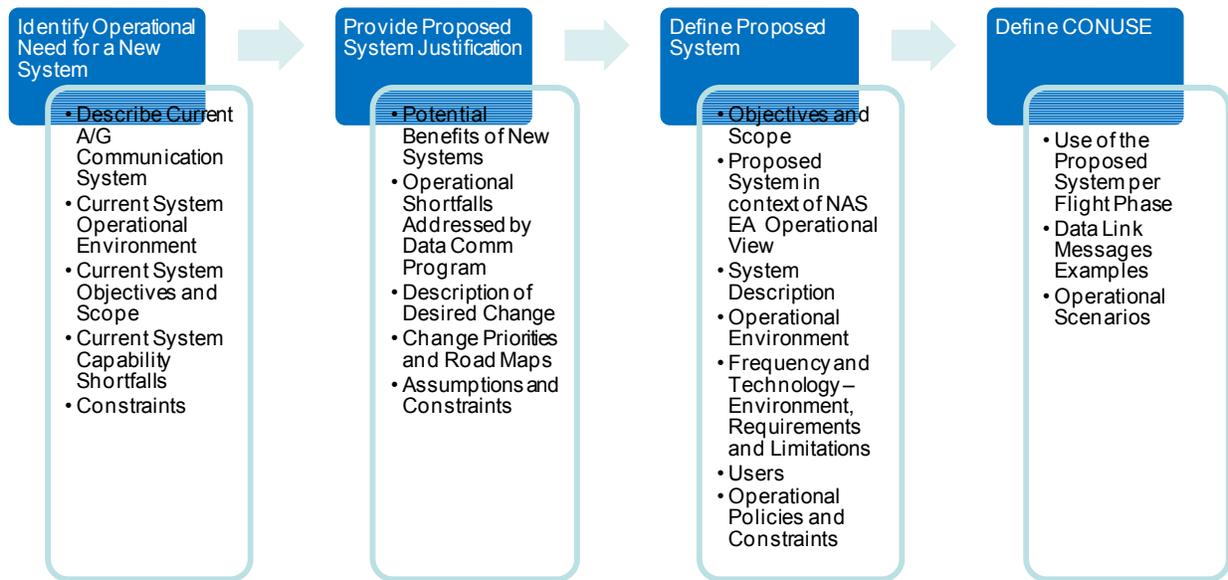


Figure 5.—ConUse development process.

3.2 Operational Needs

This section defines the operational needs for the L–DACS by describing current and planned A/G communications systems and their associated problems and capability shortfalls. Though not a current system at this time, the planned data communications networks services (DCNS) A/G data communications system being developed under the FAA’s Data Comm Program is discussed here because its initial implementation is expected to precede L–DACS. Data Comm should mitigate many of the current A/G operational problems and shortcomings, while still leaving room for L–DACS to provide additional gains over current shortcomings.

This section also describes the operational needs for L–DACS to provide A/A services not currently available.

3.2.1 Current Air-to-Ground Voice Communication System

The NEXCOM system requirement document (Ref. 9) provides a good description of the FAA’s current analog A/G voice communications system used for air traffic control (ATC).

The current A/G Communications System for ATC consists of voice-based networks that use DSB–AM radios and operate in the 117.975 to 137 Megahertz (MHz) VHF band for civil aircraft and the 225 to 400 MHz UHF band for military aircraft. The radios operate with the same frequency used for controller-to-pilot (uplink) and pilot-to-controller (downlink) transmissions in a simplex “push-to-talk” mode. There is a dedicated, non-interconnected radio network for each operational environment (En Route, Terminal, airport surface, and

flight service). In the event of a control facility power loss, engine generators provide back-up power. In the event of equipment failure, A/G communications are provided by Backup Emergency Communications (BUEC) in the Enroute, Emergency Communications System (ECS) in the large TRACONS and portable transceivers in the smaller TRACONS and Air Traffic Control Towers (ATCT).

The current A/G communications system architecture is roughly the same for all operational environments. The specific equipment used in the A/G communications string can differ among the various facilities. Different control facility types have different voice switches, with each type of switch having a unique interface.

Figure 6 shows this system for en route A/G communications. Similar architectures are in place for terminal area and airport surface area A/G communications. Appendix A of the NEXCOM system requirements document (Ref. 10) provides a detailed description of the current A/G voice communications architecture and facilities.

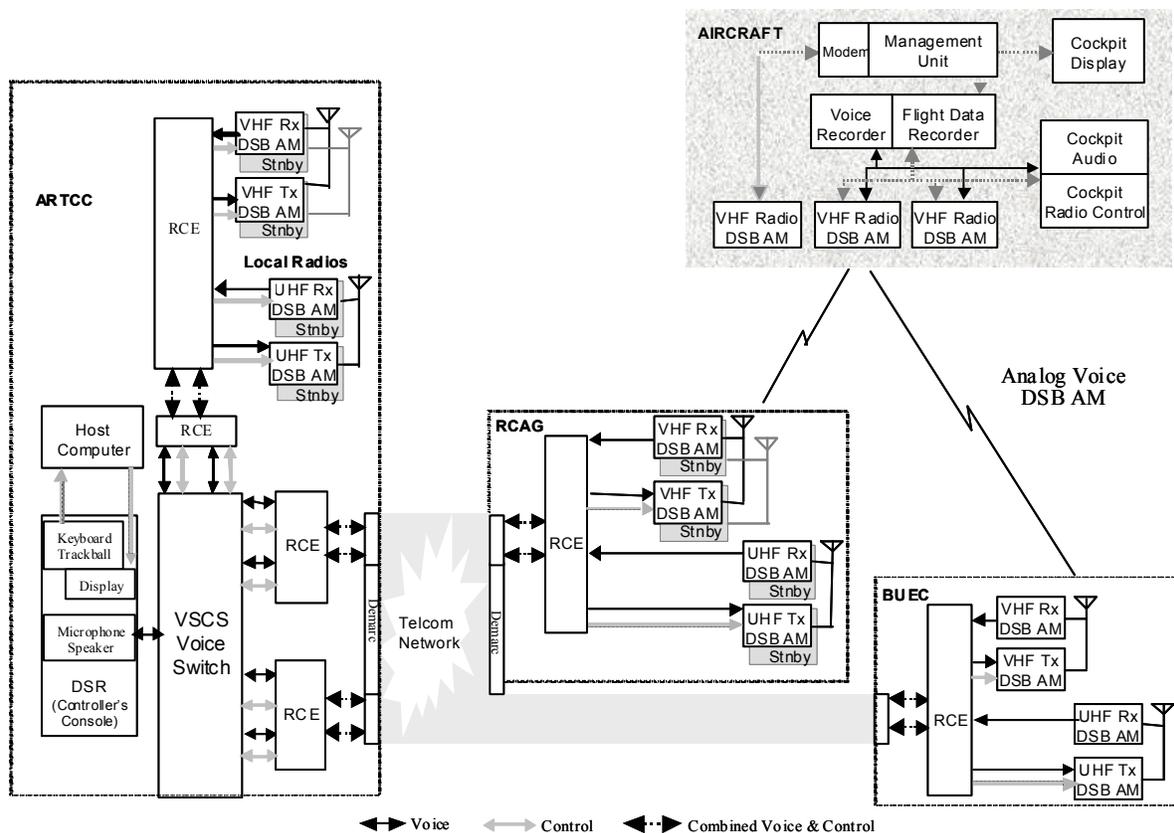


Figure 6.—Current en route air-to-ground (A/G) communications system (Ref. 10). Acronyms are defined in Appendix A.

3.2.2 Current System Operational Environment

Rather than being NAS services per se, G/G and A/G communications are enablers of NAS services and provide the following functionality (Ref. 18):

Communications enables the NAS to exchange information with users, specialists, ATC facilities, and other Government agencies. Communications enables air traffic control operations within the NAS by employing appropriate technologies to exchange voice and

data. This information is transported over land lines and wireless connectivity utilizing government and commercial assets. Communications defines how data is moved across the NAS to accomplish flight planning, control functions and navigation services for ground and space based systems. This enabler provides end-to-end service to pilots to include disseminating and coordinating the flight plan and defines how controllers provide service throughout the flight while coordinating with other facilities and government agencies. The communications enabler supports collaboration between users and specialists for traffic synchronization and flow services. Communications support the exchange of navigation and surveillance information across the NAS. Information includes electronic signals emanating from ILS, VOR and space based systems and aircraft transmitted beacon code data.

Reference 19, which gives an as-is System View 2 (SV-2) of the NAS, describes how NAS interfaces, as identified in the NAS System View 1 (SV-1) (Ref. 20), are supported by physical media.

Pertinent information about communications systems, communications links, and communications networks is presented as a pictorial view of system interactions and telecommunications service characteristics along with implementation technologies. Six as-is SV-2 views were developed depicting an overall telecommunications infrastructure and providing separate views for the following five information flow areas:

- Surveillance
- Weather
- Command and control
- Flight data
- Aeronautical information

Figure 7 presents an overview chart depicting an SV-2 telecommunications view and associated data for the command and control functional flow area.

Specifically, A/G communications is mainly used for communications between air traffic controllers or specialists on the ground and manned aircraft pilots to enable the following required NAS functions (Ref. 18)²:

- Manage flight plans (plan flights)
- Monitor aircraft status (monitor flights)
- Control aircraft (control traffic)
- Manage weather information (support flight operations)
- Maintain NAS infrastructure (monitor NAS operations)
- Plan traffic flow (plan NAS usage)
- Assess traffic flow performance (plan NAS usage)

²In the listing the subfunction is shown, followed by the parent function in parentheses.

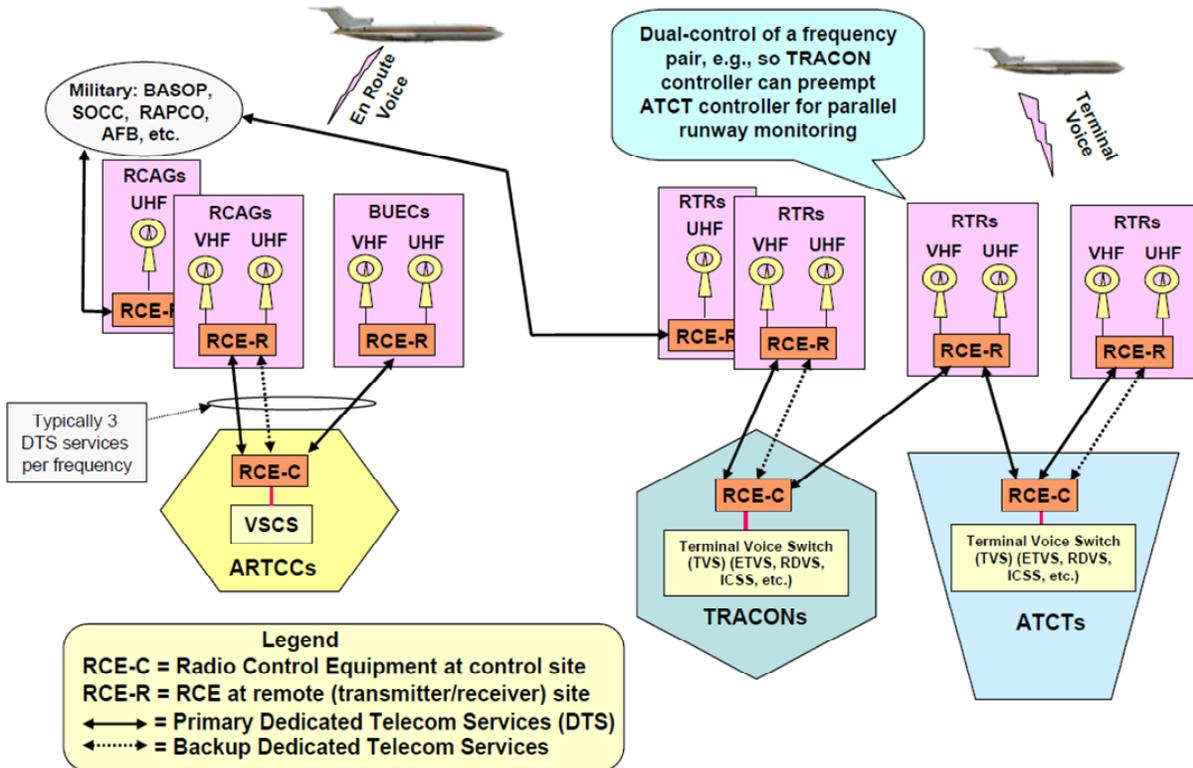


Figure 7.—System View 2 (SV-2) command and control detailed air-to-ground communications view for 2009 to 2010 (Ref. 19). Acronyms are defined in Appendix A.

For the most part, these functions are currently implemented in the NAS via voice communications, although NAS-SR-1000 (Ref. 18) includes requirements for some functions that explicitly designate data communications as the means of A/G communications and other requirements that do not specify the A/G communications type.

The NAS functions listed earlier are needed to provide several of the NAS service capabilities defined in NAS-SR-1000 (Ref. 18). Table 1 provides a mapping of NAS level functions to NAS service capabilities enabled by those functions. An “x” at a row-column intersection in the table indicates that the particular function in that row is needed to provide the NAS service capability in that column. Of particular interest for this report are the functions that can be enabled by A/G communications to provide specific NAS service capabilities. For example, A/G communications is used to implement some of the functionality needed to manage flight plans in support of the flight planning service capability. This A/G communications-specific mapping is indicated by the blue boxes in the table. Thus, as shown in the table, A/G communications is needed to support the following NAS service capabilities (denoted with blue boxes in the “Capability” heading row of the table):

- Flight planning
- Separation assurance
- Advisory services
- Traffic flow management
- Emergency services
- Infrastructure and information management

TABLE 1.—MAPPING AIR-TO-GROUND VOICE COMMUNICATIONS FUNCTIONS TO NATIONAL AIRSPACE SERVICE (NAS) SERVICE CAPABILITIES (REF. 18).

Function \ Capability	Flight Planning	Separation Assurance	Advisory Services	Traffic Synchronization	Traffic Flow Management	Emergency Services	Navigation Services	Airspace Management Services	Infrastructure and Information Management
Evaluate Flight Conditions			X						
Manage Flight Plans	X								
Collect Surveillance Information	X	X	X	X		X	X		
Determine Aircraft Trajectory		X		X					
Monitor Aircraft Status	X					X	X		
Disseminate Aircraft Status	X	X				X			
Manage Separation Information		X							
Synchronize Traffic		X	X	X	X				
Control Aircraft		X							
Coordinate Traffic Control Distribution		X							X
Manage Weather Information			X						
Operate NAVAIDS							X		
Monitor NAS Flight Operations			X		X				
Maintain NAS Infrastructure		X	X			X			X
Plan Traffic Flow					X				X
Assess Traffic Flow Performance					X				
Manage Airspace Configuration	X	X				X	X	X	X

Some of the NAS service capabilities listed above, such as separation assurance and (A/G communications-enabled) flight planning, are considered to be safety critical for the NAS. Based on the need to support the NAS critical services, A/G voice communications latency and availability performance requirements are fairly stringent. Typically, this has resulted in requirements for 0.99999 availability and an end-to-end latency of 250 msec³ for the most critical voice communications services.

For continental airspace, A/G voice communications is provided in the en route, terminal maneuvering area (TMA), and airport surface domains, with the current architecture as described in Section 3.2.1. Voice communications is used for all phases of flight, that is, from gate to gate.

3.2.3 Current System Users

The users of the current VHF A/G communications system include the following (Ref. 21):

- (1) Scheduled air transport carriers (including international, trunk, regional, commuter, and air freight carriers)

³This performance value for end-to-end A/G voice communications latency was provided in earlier versions of NAS-SR-1000, but is not in current versions.

- (2) Nonscheduled air carriers
- (3) General aviation (GA) (including operators of turbine-powered and reciprocating-engine aircraft)
- (4) Operators of unpowered aircraft (including gliders and lighter-than-air aircraft)
- (5) Operators of various military aircraft
- (6) Operators of certain ground and maritime vehicles (e.g., airport service vehicles, those vehicles coordinating in a search-and-rescue mission)
- (7) ATS providers
- (8) Aeronautical operational control (AOC) service providers

3.2.4 Current System Scope and Capabilities Shortfalls

The objectives of the current A/G communications system are consistent with the provisions of the NAS service capabilities and performance requirements listed in Section 3.2.2. Currently, they are characterized by “high availability, low end-to-end latencies, the ability to convey human feelings, flexibility of dialogue, provision of a party-line, and use for non-routine, time critical, or emergency situations” (Ref. 5).

Some of these characteristics actually offer an advantage to voice communications as compared to data communications; however, there are several disadvantages of voice communications that motivate the need for data communications for many applications.

The NextGen ConOps has summarized the current attributes (and associated constraints) of the voice based A/G communications system as follows (Ref. 2):

- Limited data communications for ATM and operational control
- Limited access to real-time weather and aeronautical data
- Voice communications routine for ATM
- Analog voice
- Analog weather information display systems
- A/G and G/G communications
- Loss of communications due to beyond line-of-site (BLOS) aircraft position (e.g., over the ocean)
- Individual ground systems for each information type brought to the flight deck
- Point-to-point aircraft communications based on ATC sectors

Currently continental A/G voice communications systems operate over the VHF and UHF aeronautical mobile (route) service (AM(R)S) frequency bands; the scope of operation is constrained to be radio line of sight, which dictates the need for networks of ground radio stations to provide radiofrequency (RF) coverage for the entire airspace volume for which the NAS service is to be provided. This is usually not a problem for A/G communications in continental airspace with manned aircraft. However, this imposes a constraint to the routine operation of UAS in the NAS. Even though the UAS operate under a Certificate of Authorization to allow flight in the NAS, UAS often currently operate in beyond line of sight conditions using non protected frequency bands (i.e., not AM(R)S or aeronautical mobile satellite (route) service (AMS(R)S) frequency bands). Other operational constraints for UAS are described in Section 6.0.

Figure 8 summarizes several principal shortcomings of the current A/G voice communications system, including lack of automation, limited or no data communications availability, aging infrastructure, technology limitations, and spectrum saturation. The resulting operational problems, if not addressed, could lead to service degradation and limit introduction of new or expanded services. These, in turn, could potentially compromise safety of operation and increase operating costs.

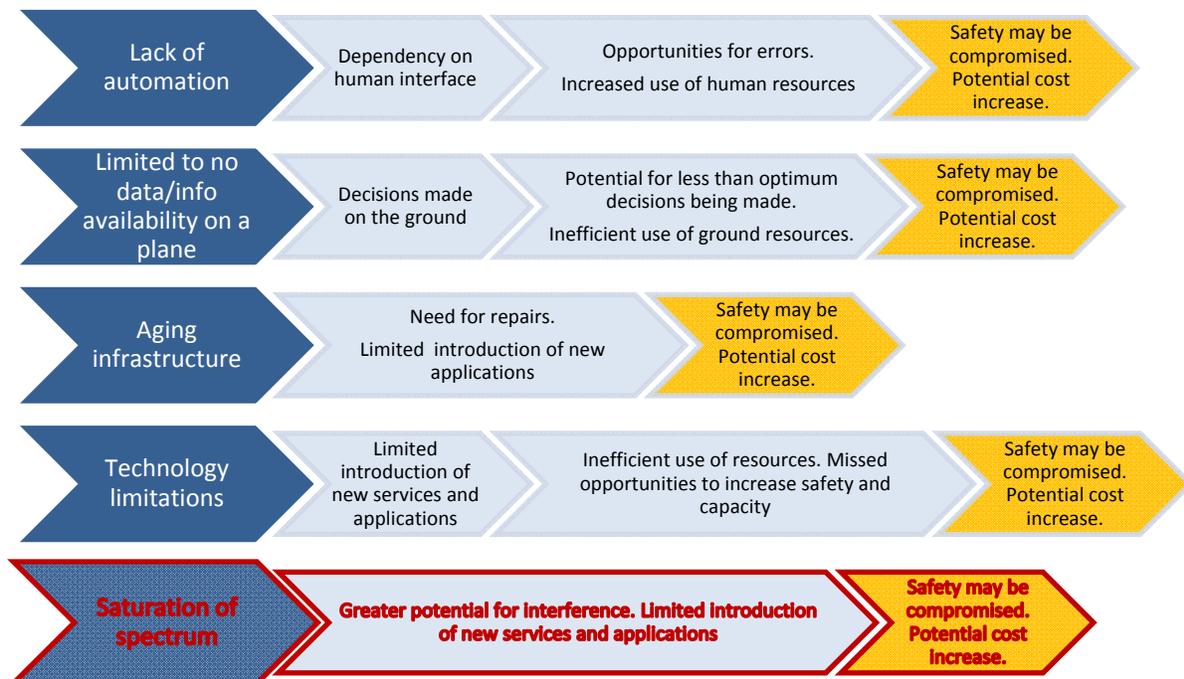


Figure 8.—Current National Airspace System air-to-ground communications operational problems.

Though the FAA Data Comm Program employing very high frequency digital link (VDL) Mode 2 technology is expected to mitigate these shortcomings to a considerable degree (as described below), saturation of spectrum is highlighted in red as the problem specifically mitigated by the introduction of a new L-band system (L-DACS). In addition it is likely that L-DACS will provide additional relief to the technology limitations of voice communications by providing broadband service capabilities not possible with VDL Mode 2.

As the NAS evolves to achieve the JPDO and FAA’s NextGen vision and ConUse, many of the transformational services and planned operational improvements will be enabled via data communications. Unfortunately, as shown in Figure 8, the current A/G communications system lacks data communications capability for ATS. In moving towards NextGen, this shortcoming will become more acute and could lead to several significant shortfalls in safety, capacity, efficiency, and productivity. As part of the investment analysis process for Data Comm, a fairly comprehensive list of these shortfalls was developed. These are repeated in Table 2 to specifically identify the shortfalls that the Data Comm intends to address.

It is important to note that the Data Comm FPR document recognizes that “the scope of the mission shortfalls identified herein are broader than will be addressed solely by a data communications capability” (Ref. 7). Because of the limitations and constraints of implementing data communications using VDL Mode 2 over a congested aeronautical VHF band, Data Comm will focus on implementing the most critical ATS services not requiring extensive amounts of bandwidth. This provides opportunities for L-DACS systems to augment Data Comm by enabling communications of other critical and essential ATS services, including those requiring greater bandwidth, to address the shortfalls listed in Table 2.

TABLE 2.—CURRENT SHORTFALLS RELATED TO AIRPORT SURFACE AIR-TO-GROUND VOICE COMMUNICATIONS

[From a subset of shortfalls described in Ref. 7]

Safety shortfalls
<p>Peak communication workload demands on the radar controller take a larger portion of the controller’s available cognitive resources.</p> <p>Situations conducive to producing errors, confusion, and read-back and hear-back errors arising from voice congestion and voice communication quality.</p> <p>Inability to implement a coherent “sector resource management” concept for the sector team where air/ground communication workload can be shared.</p> <p>Alternate means to enable air/ground communication support for contingency plans when the primary voice communication capability is not available. For example, when a catastrophic event results in the loss of air/ground voice communication at an air route traffic control center (ARTCC) or during transient events such as a “stuck microphone” in the cockpit.</p>
Capacity shortfalls
<p>The capability to rapidly and accurately communicate complex clearances containing multiple latitude/longitude-defined route elements, such as those associated with high-altitude airspace design; arrival and approach procedure names; and, speed, altitude, and heading instructions and preferences.</p> <p>The ability to more effectively manage inter- and intra-facility sector air/ground voice communication transfer.</p> <p>The ability to efficiently communicate air traffic instructions such as altimeter settings and aircraft beacon codes.</p> <p>The ability to disseminate efficiently, airspace congestion and weather advisories; and NAS infrastructure status information.</p> <p>The ability to efficiently communicate complete departure clearances and revisions necessitated by traffic management initiatives.</p> <p>The ability to provide for the maximum efficient use of the airspace and strategic plans by adjusting individual flights to reduce contention for resources and assure no resource is allowed to remain idle in the face of demand.</p> <p>Limited ability to use four-dimensional trajectories associated with flight objects and the airspace plan to identify areas of congestion, and the potential need for flow control initiatives to mitigate severe congestion.</p>
Efficiency and productivity shortfalls
<p>Lack of the ability to support airspace user operational requirements, utility, performance, and other flight operations preferences. Avionics and airframe manufacturers need consistent global communication capabilities requirements.</p> <p>Lack of the ability to exchange user preferred trajectories in real time. There are limited decision support tools to communicate and ensure user preferred routing, integrated sequencing, and spacing of arrivals and departures in Terminal Radar Approach Control (TRACON) airspace.</p> <p>Absence of synchronization between onboard avionics, such as Flight Management Systems, with ground Flight Data Processing Systems. Lack of synchronization between airborne and ground-based ATC increases controller and flight crew workload, imposes additional communications requirements, and introduces risks of operational errors and incidents. Providing for synchronization between aircraft flight management systems and ground-based ATC data processing systems provides increased predictability for flights and will allow aircraft operators to reduce costs, optimize flight routes, improve utility, and reduce dependency on voice communications.</p> <p>Misaligned communications infrastructure and service delivery to meet anticipated growth in the number of sectors and areas of specialization that must be supported for a given airspace combined with the high cost for hiring additional/maintaining current controller staff, leads to smaller and smaller sectors thus increasing flight crew/controller workloads and increased cost.</p> <p>Currently, air/ground communication capabilities are not integrated with other aspects of the automation environment. Instructions to and requests from airspace users must be independently exchanged via voice air/ground communications and then manually updated in automation systems such as the flight data processor leading to system errors and less efficient movement of aircraft through the airspace.</p> <p>Inability to handle multiple, simultaneous traffic management initiated trajectory changes is limited to single voice transmissions that are prone to miscommunications and may lead to system errors.</p> <p>Inability to automate many repetitive and time-consuming tasks precludes labor resources from focusing on more productive tasks.</p> <p>The current communication system lacks the capabilities inherent in modern, network-based communications and therefore limits more efficient dynamic resource management.</p>

In addition to the shortfalls described in Table 3, there are significant operational and technical shortfalls in the ability of the current A/G communications system to meet the needs of UAS operating in the NAS. Further discussion of shortfalls related to UAS operations in the NAS is provided in Section 6.

3.2.5 Operational Needs for L-DACS to Provide A/A Services

The COCR has defined several A/A services that could be used enable at least two of the solution sets of the FAA's NextGen portfolio: *Increase Flexibility in the Terminal Environment* and *Increase Arrivals/Departures at High Density Airports*. (Specific Operational Improvements addressing these solution sets are discussed in Section 3.4.1.1.) Referring to Table 1, these A/A could be provided in the NAS environment to address the NAS-SR-1000-defined separation assurance capability, most specifically by way of the Control Aircraft function.

The applicable A/A services defined in the COCR include the following (Ref. 5):

- Wake Service (WAKE): The WAKE service provides information enabling encounter-specific separation based on wake vortex characteristics. Ground automation uses the WAKE parameters (e.g., aircraft type, weight, and flap and speed settings) and other environmental data to determine the required minimum separation between a pair of aircraft to avoid a wake vortex encounter. The WAKE service uses A/A and G/A broadcast communications.
- Air Traffic Control Surveillance (SURV): The SURV service uses Automatic Dependent Surveillance (ADS) positional information provided by equipped aircraft for separation or monitoring purposes. The information can be provided via broadcast, (i.e., ADS-Broadcast (ADS-B)), or via addressed contracts, (i.e., ADS-Contract (ADS-C)). ADS-B can be A/A and/or G/A, while ADS-C is A/G only.
- Delegated Separation Services (employs SURV service)
 - In-trail procedure (ITP): The ITP service requires both the ACL and SURV services. The ITP service is initiated by issuing an air traffic control clearance (ACL) instruction to one aircraft to perform a climb, descent, or station-keep relative to a target aircraft. The aircraft performing the ITP instruction receives the SURV data from the target aircraft and displays the position information on the cockpit display of traffic information (CDTI). The flight crew receiving the ITP instruction identifies the target aircraft using the CDTI and assumes separation responsibility with the target aircraft during the procedure. The ITP service uses both A/G addressed (ACL) communications and A/G and A/A broadcast (SURV) communications.
 - Merging and spacing (M&S): The M&S service requires both the ACL and SURV services. The M&S service is initiated by a controller issuing an ACL instruction to one aircraft to perform a merging and spacing maneuver relative to a target aircraft. The aircraft performing the M&S instruction receives the SURV data from the target aircraft and displays position information on the CDTI. The flight crew receiving the M&S instruction assumes separation responsibility with the target aircraft during the procedure. The M&S service uses both A/G addressed (ACL) communications and A/G and A/A broadcast (SURV) communications.
 - Crossing and passing (C&P): The C&P service requires both the ACL and SURV services. The C&P service is initiated by a controller issuing an ACL instruction to one aircraft to perform a crossing and passing maneuver relative to a target aircraft. The aircraft performing the C&P instruction then receives the SURV data from the target aircraft and displays the position information on the CDTI. The flight crew receiving the C&P instruction assumes separation responsibility with the target aircraft during the procedure. The C&P service uses both A/G addressed (ACL) communications and A/G and A/A broadcast (SURV) communications.
 - Paired approach (PAIRAPP): The PAIRAPP service requires both the ACL and SURV services. The PAIRAPP service is initiated by an ACL instruction to a pair of aircraft to perform a simultaneous approach. Both aircraft performing the simultaneous approach

exchange SURV data and display position data on the CDTI. The flight crews assume separation responsibility with the partner aircraft during the procedure. The PAIRAPP service uses both A/G addressed (ACL) communications and A/G and A/A broadcast (SURV) communications.

- Air-to-air self separation (AIRSEP): The AIRSEP service exchanges data between aircraft to ensure separation in the autonomous operations area (AOA) domain, without the aid of ground ATC support. AIRSEP requires automated airborne algorithms that detect or estimate the probability of conflicts with other flight trajectories, airspace, or weather restrictions along the intended route of flight. The AIRSEP service uses addressed and/or broadcast communications.

Currently, lack of suitable data communications technologies has been a major contributing factor in keeping these services from being implemented.

A/A communications is also currently used in the oceanic domain to provide voice communications in a relay fashion when aircraft are beyond line of sight (BLOS) of VHF ground stations providing ATS services. This need and/or shortcomings and the associated mitigations are outside the scope of the L-band communications system, which is intended for operation in continental airspace.

3.3 New L-Band Communications Systems Justification

3.3.1 Potential Benefits of New L-Band Communications Systems

The NextGen ConOps states that “[t]ransformation of the ATM system in NextGen is necessary because of the inherent limitations of today’s system, including limits driven by human cognitive processes and verbal communications” (Ref. 2). Likewise, the joint EUROCONTROL/FAA Facility Review Committee conducted for AP-17 concluded that “in the longer term, a paradigm shift will occur in the operating concept and the prime mode of communication exchanges will be based in data exchanges rather than voice communications as it is today” (Ref. 22).

The following excerpts (Ref. 2) from JDPO’s NextGen ConOps comprehensively describe the NextGen A/G network services. They are repeated here because they effectively communicate the full envisioned scope, benefits, and advantages of these services and the importance of data communications in enabling them:

With the transformed role of the flight crew and flight deck in NextGen, data communications are critical to ensuring that data is available for flight deck automation (i.e., avionics to support flight crew decision making). ... Data communications are also needed to provide real-time data to the ANSP on the operational aspects of flights. In certain defined airspace, data communications are the primary means of communicating clearances, routine communications, and 4DT agreements between the ANSP and flight deck. ... Voice communications are used to supplement data communications for tactical situations and for emergencies to augment procedural responses or risk mitigations. Voice communications are used to communicate with lesser-equipped aircraft in appropriate airspace. ...

One of the key transformations is that air-ground voice communications are no longer limited by the assigned frequency-to-airspace sector mapping. This allows greater flexibility for developing and using airspace/traffic assignments in all airspace. Communications paths, including both voice and data, are controlled by an intelligent network. Communications between the ANSP and the flight deck are established when the flight is activated and are maintained continuously and seamlessly. This capability is linked to the flight data management function so that the system automatically manages who has authority to interact with the flight deck based on the type of agreement being negotiated or information being exchanged. Labor-intensive transfers of control and communication are automated. Data and

voice communications are automatically transferred in the flight deck as the aircraft moves between ANSPs.

Data communications are central to TBO [(trajectory based operations)], including the use of 4DTs (pushback and taxi inclusive) for planning and execution on the surface, automated trajectory analysis and separation assurance, and aircraft separation assurance applications that require flight crew situational awareness of the 4DTs and short-term intent of surrounding aircraft.

In addition, as indicated above, there is increased sharing of improved common data between the flight deck, operator, and ANSP. In classic airspace where data communications will be available but not required, information exchange can take place with data communications for participating aircraft to provide an operational advantage. Common data includes ATC clearances, current and forecast weather, hazardous weather warnings, notices to airmen (NOTAMs), updated charts, current charting, special aircraft data, and other required data. Data communications also include weather observations made by the aircraft that are automatically provided to ANSPs, weather service providers, and flight operators for inclusion in weather analysis and forecasts. Each of these data communications functions are managed by required communications performance (RCP) standards.

The trend toward 2015 and beyond features a decreasing use of voice, with data becoming the primary communication link. This is shown in Table 3, which illustrates a projected allocation between voice and data communications during this period. As suggested by the table, for the en route domain, data link would become the primary means for most of the exchanges, with voice communication used for emergency messages and tactical clearances. In the TMA domain and on the airport surface, voice would remain the primary mode of communications for low delay and high availability pilot-ATC exchanges, with a data link used as a primary service for other messages and data-intensive services such as graphical weather. In all domains, voice communication would remain a backup for any data service.

TABLE 3.—COMMUNICATION ALLOCATION BETWEEN VOICE AND DATA LINK (D/L)
[Information from Ref. 4.]

	Pilot-controller dialog				Pilot-pilot dialog	Flight information exchange	ATM exchange	Information broadcast	Air-air surveillance
	Emergency messages	Tactical clearances	Strategic clearances	Information messages					
En route	Voice D/L	Voice D/L ^a	Voice D/L	Voice D/L	Voice ^b D/L	Voice D/L	Voice D/L	Voice D/L	D/L
TMA	Voice D/L	Voice D/L	Voice D/L	Voice D/L	Voice ^b D/L	Voice D/L	Voice D/L	Voice D/L	D/L
Airport surface	Voice D/L	Voice Some D/L Voice &D/L	Voice D/L	Voice D/L	Voice ^b D/L	Voice D/L	Voice D/L	Voice D/L	D/L

Legend:

- Red—Primary
- Blue—Backup

^aIn 2015, en route operational data communications is purely strategic. In that timeframe tactical data exchanges are to be used as backup either to voice or to the strategic data clearance service.

^bNo specific requirements identified except current traffic information broadcast by aircraft (TBA) procedure.

Although a gradual introduction of data communications to the existing VHF systems should accommodate capacity requirements in the near- to mid-term, additional spectrum is required to provide enough capacity to satisfy a growing demand for data communications in the far term. An L-DACS built to augment VHF voice and data communications systems already in place, including those implemented

as part of the Data Comm, would increase overall communications system capacity, thus relieving congestion and allowing for introduction of additional services. Because of spectrum constraints in the aeronautical L-band, L-DACS should be built as a broadband system, potentially accommodating a wide array of applications and services that would otherwise be difficult, inefficient, or even impossible to implement.

The congestion in a heavily utilized VHF band is more prevalent in Europe, where the 8.33-kHz channelization has already been introduced. Thus, an L-DACS rollout is expected in Europe prior to the United States. In the United States, frequency management options, such as the use of 8.33-kHz voice channel spacing in the VHF aeronautical band, may be considered prior to the introduction of an L-band system.

3.3.2 Operational Shortfalls Addressed by Data Comm

The FAA intends for Data Comm to significantly mitigate the safety, capacity, efficiency, and productivity shortfalls described in Table 2. It is anticipated that Data Comm will support the following improvements in airspace use and capacity (Ref. 7):

- Improved airspace use and capacity
- A more efficient A/G information and clearances exchange mechanism
- An additional means of communication between flight crews and controllers
- Reduced congestion on the voice channels
- Reduced operational errors and flight crew deviations resulting from misunderstood clearances and read-back errors
- Trajectory-based operations
- Reduced controller and flight crew workload

Data Comm is planned to be implemented in three segments (Ref. 7, see Figure 9):

- The first segment will facilitate data communications deployment and introduce initial four dimensional (4-D); (latitude, longitude, altitude, and time) routes.
- The second segment will introduce conformance management and initial 4-D agreements.
- The third segment will expand 4-D agreements and provide an operational environment that allows the transfer of some separation assurance tasks from the ground to the air.

An L-DACS implementation in the United States might follow or overlap Segment 2 (VDL Mode 2 implementation) and enable additional services and operational capabilities not covered by VDL Mode 2 for Data Comm.⁴ Figure 9 depicts the planned capabilities for Data Comm, and for comparison also includes the European planned deployment of data communications capabilities. Those operational capabilities and the associated services shown in the figure for Segment 3, for example, the services needed to provide widespread 4-D agreements and widespread delegated separation, might benefit from a higher performance technology implementation like L-DACS. In addition to potentially augmenting the critical data communications services provided by VDL Mode 2 for Data Comm, L-DACS also could enable new noncritical services and UAS communications services.

⁴An L-DACS could be a candidate communications technology for Segment 3 of Data Comm if capacity limits in the VHF band are exceeded earlier than currently anticipated in that program.

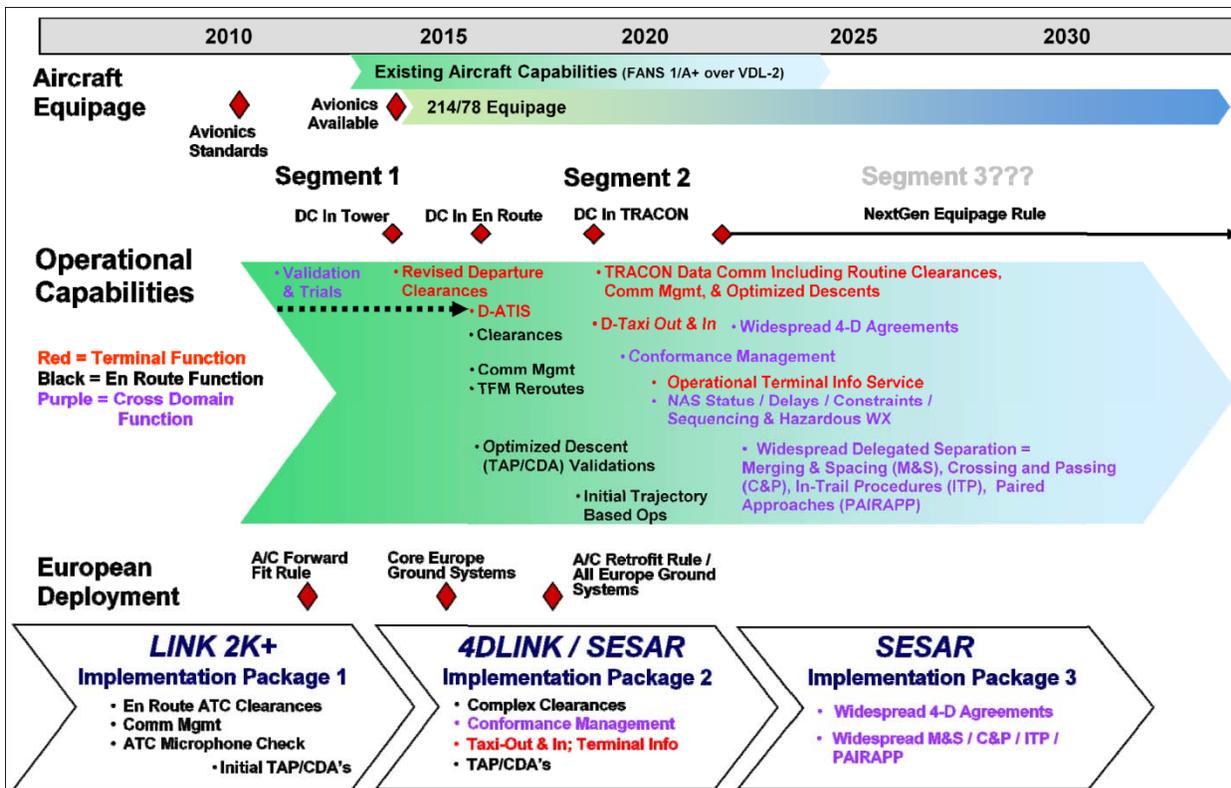


Figure 9.—Operational capabilities of Data Comm (Ref. 23). Acronyms are defined in Appendix A.

Figure 10 provides additional detail about the data link evolution in Europe. The VDL Mode 2 transition to the FCI shown in the figure demonstrates the potential difference between the U.S. and European approach to the data link development. Contrary to the European plan to transition many safety critical services to the FCI (e.g., AeroMACS⁵), the U.S. is currently looking at FCI to augment, not to replace, the VDL Mode 2 data link enabling the FAA Data Comm services.

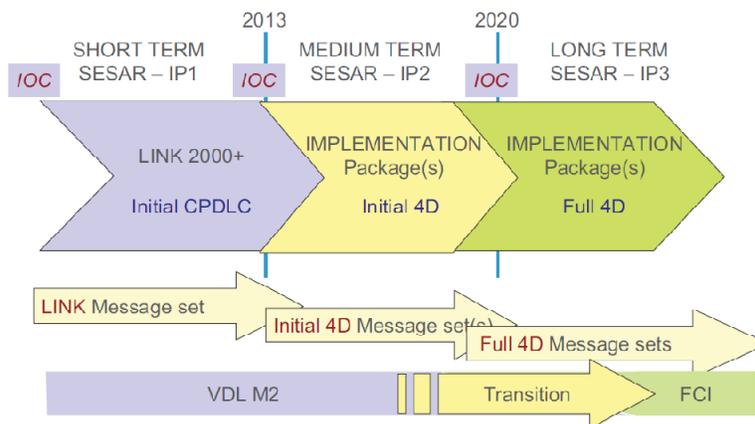


Figure 10.—Data Link Evolution (LINK 2000+ Update. AEEC DataLink Users Forum, 13-14 July 2010, Brussels. (Used with permission.)

⁵AeroMACS is a term for the C-band airport surface communication technology based on the IEEE 802.16e standard.

It should be noted that augmenting Data Comm services provided by VDL Mode 2 with L-DACS to provide ATS services would not be operationally trivial to implement. Specific ConOps for both the ground users (e.g., ATC controllers) and airborne users (e.g. pilots) would have to be developed to appropriately segment the two systems to operate cooperatively and in parallel and without adding to existing workloads. (See Section 7.2.5 for further discussion of this issue).

3.3.3 Description of Desired Changes

Data Comm will provide data communications as an enhancement to and potential replacement of A/G voice communications as the primary A/G link in an ATC operational environment. This additional mode of communications will contribute to improvements in airspace use and capacity. An L-DACS could further reduce congestion on VHF voice channels and increase A/G communications capacity by offering spectrum for additional services not offered by Data Comm. In addition, L-DACS offers a viable alternative for the implementation of one or more of the communications links for UAS ATS communications, command/control, and/or sense-and-avoid systems. With Data Comm and L-DACS, the overall A/G information exchange could become more dynamic and efficient, potentially reducing operational errors and improving safety.

The L-DACS is not proposed to replace any current systems or services; rather, it is proposed to augment them. Furthermore, it is assumed that the critical services proposed for implementation by the Data Comm program as an addition and/or replacement of voice communication will be in place by the time an L-DACS is implemented.

The proposed L-DACS is being designed to limit interference to the existing services and operations in the L-band. No operational changes are expected for the L-band incumbent systems.

3.3.4 Change Priorities and Roadmaps

Figure 11 demonstrates how the L-band system development fits into the FCS proposed communications evolutionary roadmap for European and U.S. ATM (as envisioned in 2007).

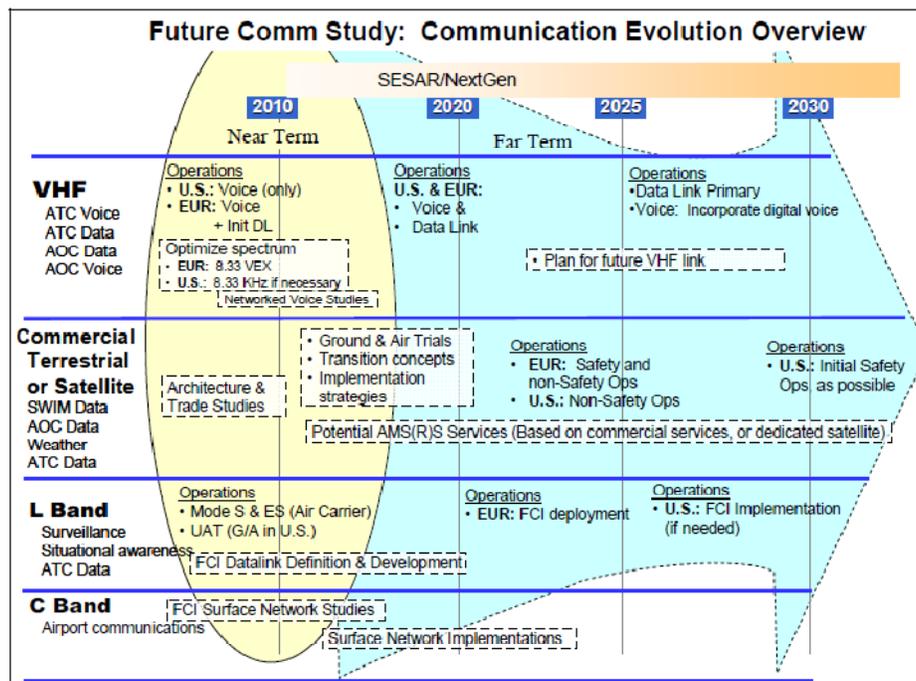


Figure 11.—Evolution overview of aeronautical mobile communications (Ref. 22; note that this schedule is subject to change). Acronyms are defined in Appendix A.

Figure 12 depicts the proposed L-band (and C-band) communications systems far-term strategy as part of the NAS Enterprise Architecture Communication Infrastructure Roadmap.

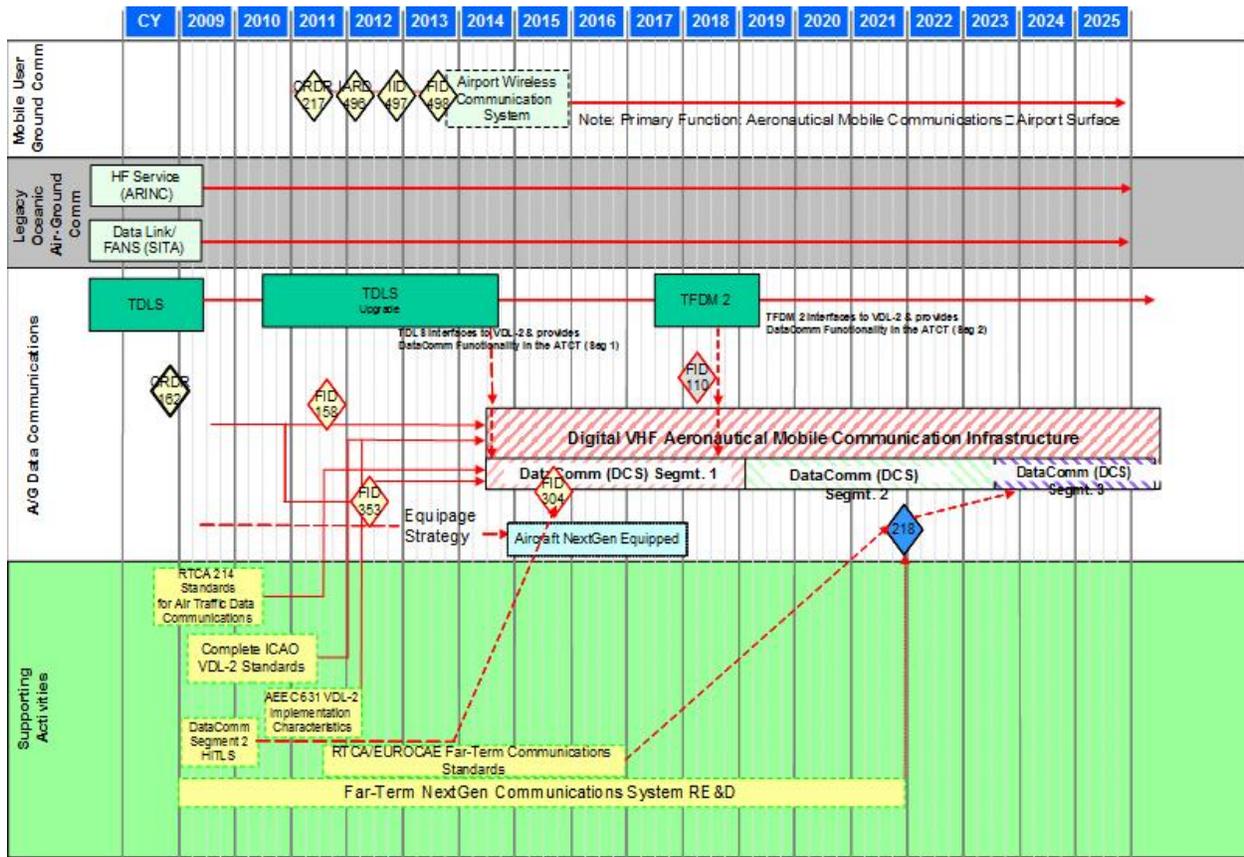


Figure 12.—Federal Aviation Administration communications roadmap (Ref. 24). Acronyms are defined in Appendix A.

Figure 13 shows the proposed timeline for the expedited development and deployment of an L-DACS in Europe (in the 2007 timeframe).

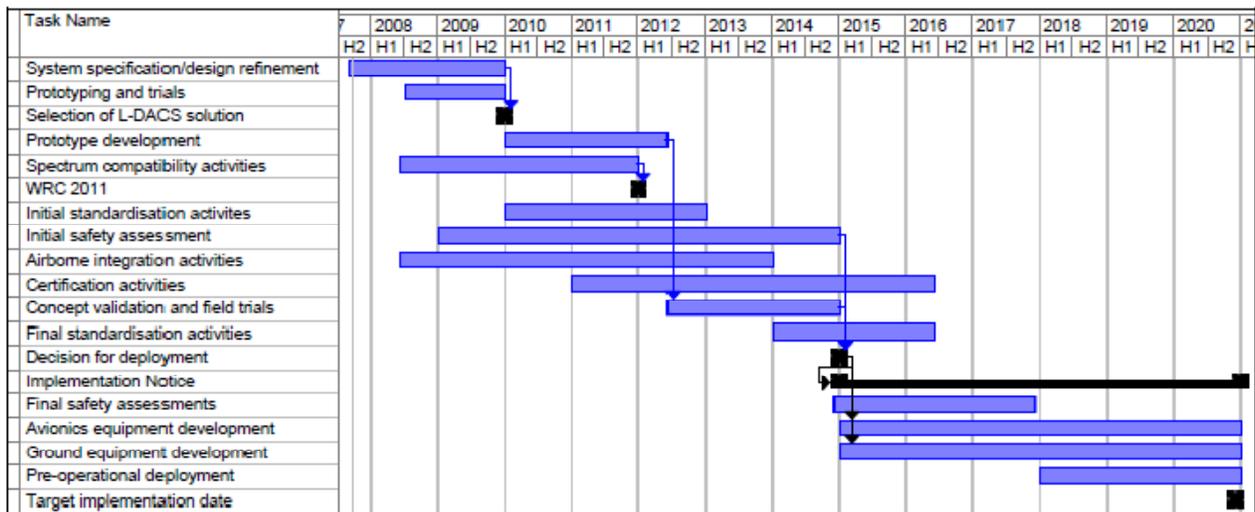


Figure 13.—Target plan for expedited L-DACS development and deployment in Europe (November 2007) (Ref. 22).

3.3.5 Assumptions and Constraints for L-DACS

Assumptions and constraints for this document follow:

- The proposed L-DACS is assumed to provide an increase in overall A/G communications systems capacity by utilizing new spectrum (i.e., not VHF).
- As noted earlier, the scope of this ConUse and requirements document includes A/G and A/A communications.
- L-DACS will be designed specifically for data communication. When finalized, the technology may support voice communications, but this feature is not considered a system requirement at this time.
- As noted earlier, this document assumes that the data communications system developed as part of Data Comm will precede an L-DACS implementation and deployment.
- Although some critical services are proposed, the L-DACS will also target noncritical services, such as weather advisory and aeronautical information services implemented as part of an airborne SWIM program. It will also target one or more UAS communications services.
- While the L-band system is proposed to be implemented with the primary objective of supporting en route and terminal communications (i.e., ENR and TMA domains), the L-band system could be used on the ground (i.e., airport surface domain) as well as in the air, for example, to avoid switching between link technologies during flight.
- Although the L-DACS ConUse and functional requirements developed for this document are largely technology independent, services selection and overall system requirements may change if and when additional or different data is available from proposed L-DACS interference testing and as a result of a final selection of one of the two L-DACS technologies under consideration as of the time of this report.
- L-DACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the L-band. Additional interference research and testing will determine if any operational constraints are to be imposed, such as limiting the number of users, the time of the day, duration, and other parameters.

The economic feasibility of an L-DACS, from the perspective of an ground infrastructure provider, was evaluated at a top level during the FCS Phase II project (Ref. 25) based on the results of the earlier technology prescreening (FCS Phase I) (Ref. 26). The initial economic analysis showed that a positive business case for an L-band system implementation could be achieved with a payback period of approximately four years (Ref. 4). However, although the first order of magnitude cost estimate yielded positive results, the assumptions made during the analysis should be revisited at a later stage, when more details of a planned implementation are known. The analysis assumptions included consideration of coverage, system requirements, research and development, and operations and maintenance costs.

3.4 Proposed L-DACS

3.4.1 Objectives and Scope

Consistent with the need to overcome the specific current communications systems problems and shortfalls discussed earlier, two additional primary drivers for a future radio system (FRS) are: (1) to provide an appropriate communications infrastructure to support future air traffic growth and (2) to provide a consistent global solution to support the goal of seamless air traffic management (Ref. 5).

Accordingly, the proposed L-DACS component of the FRS aims to expand data communications capacity while being developed as a collaborative effort of the U.S. and European partners.

3.4.1.1 L-DACS as Part of the Next Generation Air Transportation System

Figure 14 illustrates the proposed NextGen operational view 1 (OV-1) in 2025 listing six of the seven solution sets of the FAA’s NextGen portfolio.⁶ L-DACS could fulfill part of the proposed NextGen vision by supporting implementation of the following solution sets:

- Increase flexibility in the terminal environment
- Support trajectory-based operations (TBO)
- Increase arrivals and departures at high-density airports
- Improve collaborative ATM
- Reduce weather impact



Figure 14.—Next Generation Air Transportation System (NextGen) operational view in 2025 (Ref. 27). Acronyms are defined in Appendix A.

The following three subsections briefly describe the specific operational improvements (OIs) that could be enabled by L-DACS for these five solution sets.⁷ Except as noted, these OIs are applicable to the provision of A/G communications services.

⁶The seventh solution set, not shown in the figure, is “safety, security, and environment.”

⁷These descriptions are extracted from the NAS Enterprise Architecture web portal (<https://nasea.faa.gov>) (Ref. 28).

Increase flexibility in the terminal environment (excerpts from Ref. 28)

OI 102152—Dynamic, Pairwise Wake Turbulence Separation: Wake turbulence separation applications for departure, arrival, and en route operations are integrated into air traffic automation to provide dynamic, pairwise, lateral, longitudinal, and vertical separation requirements for trajectory management based on aircraft and weather conditions, in real time.

OI 102406—Provide Full Surface Situation Information: Automated broadcast of aircraft and vehicle position to ground and aircraft sensors/receivers provides a digital display of the airport environment. Aircraft and vehicles are identified and tracked to provide a full comprehensive picture of the surface environment to ANSP, equipped aircraft, and flight operations centers (FOCs).

OI 102409—Provide Surface Situation to Pilots, Service Providers and Vehicle Operators for Near-Zero-Visibility Surface Operation : Aircraft and surface vehicle positions are displayed to aircraft, vehicle operators, and air navigation service providers (ANSP) to provide situational awareness in restricted visibility conditions, increasing efficiency of surface movement

OI 103206—Expanded Traffic Advisory Services Using Digital Traffic Data: Surrounding traffic information is available to the flight deck, including automatic dependent surveillance (ADS) information and the rebroadcast of non-transmitting targets to equipped aircraft. Surveillance and traffic broadcast services improve situational awareness in the cockpit with more accurate and timely digital traffic data provided directly to aircraft avionics for display to the pilot.

O I 104207—Enhanced Surface Traffic Operations: Data communication between aircraft and ANSP is used to exchange clearances, amendments, and requests. At specified airports, data communications is the principle means of communication between ANSP and equipped aircraft

Initiate trajectory-based operations (excerpts from Ref. 29)

OI 101103—Provide Interactive Flight Planning From Anywhere: Flight planning activities are accomplished from the flight deck as readily as any location. Airborne and ground automation provide the capability to exchange flight planning information and negotiate flight trajectory contract amendments in near real-time.

OI 104121—Automated Negotiation/Separation Management: Trajectory management is enhanced by separation management automation that negotiates with properly equipped aircraft and adjusts individual aircraft Four-Dimensional Trajectories (4DTs) to provide efficient trajectories, manage complexity, and ensure separation assurance.

OI 104126—Trajectory-Based Management—Gate-To-Gate: All aircraft operating in high density airspace are managed by Four Dimensional Trajectory (4DT) in En Route climb, cruise, descent, and airport surface phases of flight to dramatically reduce the uncertainty of an aircraft's future flight path in terms of predicted spatial position (latitude, longitude, and altitude) and times along points in its path.

Integrating separation assurance and traffic management time constraints (e.g., runway times of arrival, gate times of arrival), this end state of 4DT-based capability calculates and negotiates 4DTs, allows tactical adjustment of individual aircraft trajectories within a flow, resolves conflicts, and performs conformance monitoring by Air Navigation Service Providers (ANSPs) to more efficiently manage complexity, ensure separation assurance, and enhance capacity and throughput of high-density airspace to accommodate increased levels of demand. This will be enabled by the trajectory exchange through data communications, as well as many new surface automation and 3D (x, y, and time) trajectory operations.

Increase arrivals and departures at high-density airports (excerpts from Ref. 30)

OI 102142—Efficient Metroplex Merging and Spacing: Air navigation service provider (ANSP) automation and decision support tools incorporate aircraft wake characteristics and forecast wake transport conditions. Spacing buffers between streams approaching and departing multiple metroplex runways are reduced to allow efficient airborne merging and spacing, increasing greater traffic

throughput and reduced ANSP workload in terminal areas. Arrival and departure flows are planned and executed based on a comprehensive view of real time airport operations. Automation provides optimal departure staging and arrival sequencing based on aircraft wake, wake conditions and airborne performance characteristics. Data communications provides required navigation performance routes to the flight deck.

OI 102143—Delegated Responsibility for Horizontal Separation (Lateral and Longitudinal): Enhanced surveillance and new procedures enable the ANSP to delegate some responsibility for maintaining aircraft-to-aircraft separation to flight crews. Improved display avionics and broadcast positional data provide detailed traffic situational awareness to the flight deck. Broadcast surveillance sources and improved avionics capabilities provide ANSP and the flight deck with accurate position and trajectory data and therefore increased situational awareness. Aircraft that are equipped to receive the broadcasts and have the associated displays, avionics, and crew training will perform delegated separation when authorized by the controller.

OI 102149—Delegated Separation - Complex Procedures: In Air Navigation Service Provider (ANSP)-managed airspace, the ANSP delegates separation responsibilities to capable aircraft to improve operator routing, enhance operational efficiency, or increase ANSP productivity. This Operational Improvement involves more complex delegated separation responsibilities than those performed using a cockpit display to cross, merge, or pass another aircraft. Using advanced airborne technologies with conflict detection and alerting, aircraft in ANSP-managed En Route and transition airspace are delegated separation responsibilities to perform more complex operations, possibly maintaining separation from more than one other aircraft.

OI 102153—Limited Simultaneous Runway Occupancy: Runway capacity is increased through the allowance of more than one aircraft on the runway, at a given time, for specific situations.

OI 104117—Improved Management of Arrival/Surface/Departure Flow Operations: This Operational Improvement (OI) integrates advanced Arrival/Departure flow management with advanced Surface operation functions to improve overall airport capacity and efficiency. Air Navigation Service Provider (ANSP) automation uses arrival and departure-scheduling tools and four dimensional trajectory (4DT) agreements to flow traffic at high-density airports. Automation incorporates Traffic Management Initiatives (TMIs), current conditions (e.g., weather), airport configuration, user provided gate assignments, requested runway, aircraft wake characteristics, and flight performance profiles. ANSP, flight planners, and airport operators monitor airport operational efficiency and make collaborative real-time adjustments to schedules and sequencing of aircraft to optimize throughput.

OI 104125—Integrated Arrival/Departure and Surface Traffic Management for Metroplex: Metroplex traffic flow is more efficiently managed through arrival/departure and surface scheduling automation, integrated with all available constraint information, including weather impacts, optimizing traffic throughput by eliminating potential gaps in unused capacity, thereby increasing regional/metroplex capacity.

Data communications is a key element of super-density operations, allowing the Air Navigation Service Provider (ANSP) to maximize access for all traffic, while adhering to the principle of giving advantage to those aircraft with advanced capabilities.

OI 104128—Time-Based Metering in the Terminal Environment: Aircraft are time-based metered inside the terminal environment, enhancing efficiency through the optimal use of terminal airspace and surface capacity. ANSP automation develops trajectories and allocates time-based slots for various points (as needed) within the terminal environment, applying RNAV route data and leveraging enhanced surveillance, data communications, and closely spaced parallel, converging, and intersecting runway capabilities (where applicable)

OI 104206—Full Surface Traffic Management with Conformance Monitoring: Efficiency and safety of surface traffic management is increased, with corresponding reduction in environmental impacts, through the use of improved surveillance, automation, onboard displays, and data link of taxi instructions.

Equipped aircraft and ground vehicles provide surface traffic information in real-time to all parties of interest.

OI 104208—Enhanced Departure Flow Operations: Enhancements to surface traffic management incorporate taxi instructions, surface movement information, and aircraft wake category to enhance departure flow operations. Clearances are developed, delivered, monitored and provided in graphical or textual format that is used by the flight deck display to support taxi, takeoff and departure flows in all conditions. At high-density airports clearances and amendments, requests, NAS status, airport flows, weather information, and surface movement instructions are issued via data communications.

Surface decision support and management systems use ground and airborne surveillance and a scheduling and sequencing system to develop and maintain schedules of departing aircraft within a defined time horizon. Information is sent to participating aircraft and the air navigation service provider via data communications or voice and adjustments are made to push back times, taxi instructions, etc. to maintain schedules.

OI 104209—Initial Surface Traffic Management: Departures are sequenced and staged to maintain throughput. ANSP automation uses departure-scheduling tools to flow surface traffic at high-density airports. Automation provides surface sequencing and staging lists for departures and average departure delay (current and predicted).

ANSP automated decision support tools integrate surveillance data. This includes weather data, departure queues, aircraft flight plan information, runway configuration, expected departure times, and gate assignments.

Improve collaborative air traffic management (excerpts from Ref. 31)

OI 101102—Provide Full Flight Plan Constraint Evaluation with Feedback: Timely and accurate national airspace system (NAS) information enables users to plan and fly routings that meet their objectives. Constraint information that impacts the proposed route of flight is incorporated into air navigation service provider (ANSP) automation, and is available to users. Examples of constraint information include special use airspace status, SIGMETS [data link significant meteorological information], infrastructure outages, and significant congestion events.

OI 103305—On-Demand NAS Information: National Airspace System (NAS) and aeronautical information will be available to users on demand. NAS and aeronautical information is consistent across applications and locations, and available to authorized subscribers and equipped aircraft. Proprietary and security sensitive information is not shared with unauthorized agencies/individuals.

OI 105207—Full Collaborative Decision Making: Timely, effective, and informed decision-making based on shared situational awareness is achieved through advanced communication and information sharing systems.

Stakeholder decisions are supported through access to an information exchange environment and a transformed collaborative decision making process that allows wide access to information by all parties (whether airborne or on the ground), while recognizing privacy and security constraints. Decision-makers request information when needed, publish information as appropriate, and use subscription services to automatically receive desired information through the net-centric infrastructure service.

Reduce weather impact (excerpts from Ref. 32)

OI 103119—Initial Integration of Weather Information into NAS Automation and Decision Making: Advances in weather information content and dissemination provide users and/or their decision support with the ability to identify specific weather impacts on operations (e.g., trajectory management and impacts on specific airframes, arrival/departure planning) to ensure continued safe and efficient flight. Users will be able to retrieve (and subscribe to automatic updates of) weather information to support assessment of flight-specific thresholds that indicate re-planning actions are

needed. In particular, the 4-D Weather Data Cube (and later The 4-D Weather Single Authoritative Source (4-D Wx SAS)) will support enhanced volumetric extractions, by time frame of interest, of weather information by NAS users to quickly filter the enhanced weather content to the region of interest for impact analysis. This will streamline the process by which the user—with or without decision support ATM tools—conducts system-wide risk management in planning for both individual flight trajectories and flows.

OI 103121—Full Improved Weather Information and Dissemination: This improvement provides the full capability that supports the NextGen concept of operations to assimilate digital weather information into decision-making for all areas of operations.

OI 103123—Full Integration of Weather Information into NAS Automation and Decision Making: Further advances in weather information content/dissemination and a NAS-wide increase in the direct integration of weather into decision support tools will enable users and service providers to more precisely identify specific weather impacts on operations (e.g., trajectory management and impacts on specific airframes, arrival/departure planning) to ensure continued safe and efficient flight.

L–DACS could be introduced as part of the proposed NextGen vision and would likely address continental en route and TMA airspace A/G communications needs. While communication on the airport surface is more likely to be conducted over AeroMACS in the mid- to long-term, it could also be enabled by L–DACS. As such, OIs related to surface communications are included in the list above.

The proposed L–DACS could provide supplemental means to the provision of ATC communications required by the operating rules (e.g., VHF voice communications) in continental airspace and would adhere to the data link characteristics noted in “Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace (Continental SPR Standard)” (Ref. 16).

3.4.1.2 Proposed Operational Environment

Along with the “as-is” SV–2 views of the NAS developed by the FAA Air Traffic Organization (ATO) planning organization, were a series of different “to be” views providing separate views for the five information flow areas for the 2025 timeframe. Figure 15 presents a 2025 service view for the command-and-control function for the proposed NAS.

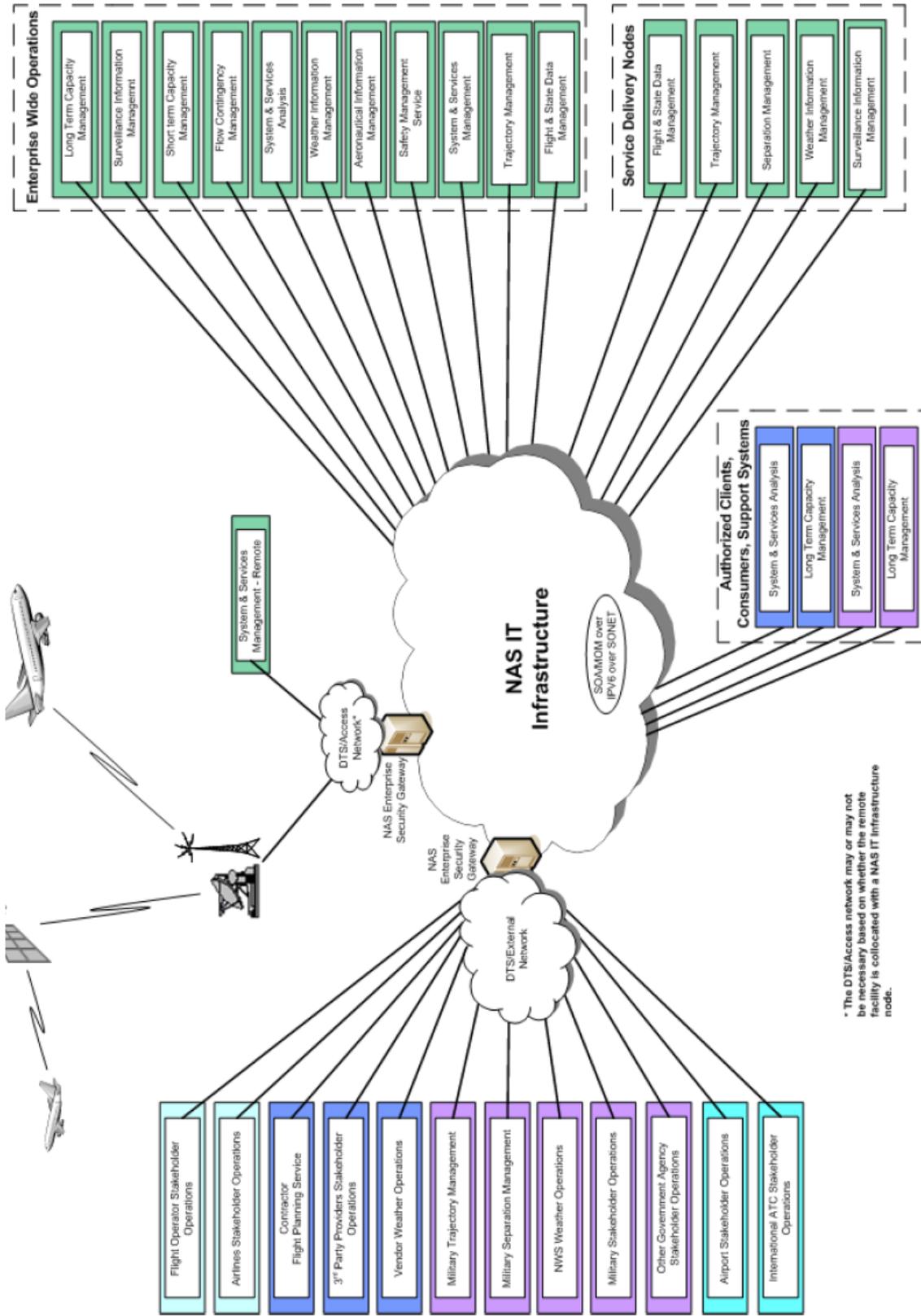


Figure 15.—System view 2 (SV-2) 2025 communications description: command and control (Ref. 33). Acronyms are defined in Appendix A.

The NextGen ConOps (Ref. 2) notes the increased demand for air transportation and the associated services. Changes will occur in both volume and demand characteristics with improved aircraft capabilities to support airborne self-separation and spacing, and manage tasks to precisely navigate and execute 4DTs. Aircraft operations are also expected to change to support sophisticated flight planning and operations management.

3.4.2 Frequency and Technology—Environment, Requirements, and Limitations

While the aeronautical L-band spectrum (960 to 1164 MHz) is identified as appropriate for supporting a new data link communication capability, limitations associated with the use of this spectrum band should be recognized and accounted for.

One of the big advantages of the L-band is a potentially large spectral region to support future broadband aeronautical communication services. At the same time, “it is a challenging environment for aeronautical communications due to the aeronautical channel characteristics and the current usage of the band” (Ref. 19). These challenges include the following noted in the AP–17 Future Communications Study (FCS): “Estimated RMS delay spreads for this channel, on the order of 1.4 μ s, can lead to frequency selective fading performance for some technologies. Interference to and from existing aeronautical L-band systems for a proposed communication technology requires detailed examination, including validation measurements and testing” (Ref. 22).

The AP–17 FCS further concluded (Ref. 22)

The aeronautical L-band spectrum provides an opportunity to support the objectives for a future global communication system; however no technology evaluated for the Future Communication System (as defined) for supporting data communication in this band fully addresses all requirements and limitations of the operating environment.

- Initial co-channel interference testing indicates potential interference of evaluated candidate technology waveforms to existing navigation systems. Further evaluation, including consideration of duty cycle effects on interference, is required to determine collocation feasibility (with on-tune channels, off-tune channels or cleared spectrum).
- Each technology was identified as having some technical, cost or risk concerns that require modification of the technology specification for applicability and/or willingness to assume moderate levels of cost/risk.
- Due to unique requirements, a technology adapted from existing standards wherever possible is recommended for this band.

Desirable features for an aeronautical L-band technology include

- Existing standard for safety application with some validation work performed (reducing time for standardization, increasing TRL, and reducing risk of certification)
- Multi-carrier modulation (power efficient modulation for the aeronautical L-band fading environment)
- Low duty cycle waveform with narrow-to-broadband channels (more likely to achieve successful compatibility with legacy L-band systems without clearing spectrum)
- Adaptable/scalable features (improving flexibility in deployment and implementation, and adaptability to accommodate future demands)
- Native mobility management and native IP interface (increasing flexibility and providing critical upper layer compatibility with worldwide data networking standards)

These conclusions help to drive the L–DACS ConUse and system requirements presented in this report, and have also served as guiding principles for the development of the L–DACS1 and L–DACS2 technologies.

In depth studies conducted to support the technology evaluation process resulted in the recommendation of two alternative L-DACS technologies that provide all the desirable features listed above and could support a standardization effort, potentially reducing cost and risk. Table 4 shows the proposed technology options for the L-DACS.

TABLE 4.—L-DACS OPTIONS KEY CHARACTERISTICS (REF. 22)
[Acronyms are defined in Appendix A.]

L-DACS option	Access scheme	Modulation type	Proposed technologies
L-DACS1	Frequency division duplex	Orthogonal frequency division multiplexing	B-AMC and TIA-902 (P34)
L-DACS2	Time division duplex	Continuous phase frequency shift keying/ GMSK type	LDL and AMACS

3.5 L-DACS Concepts of Use

Follow-on FCS activities will further characterize and evaluate the proposed technology solutions, validate performance, and lead to a single L-DACS technology recommendation.

3.5.1 User Impact

Users of the proposed L-DACS system will include service providers and airspace users of A/G communications for the following:

- Safety and regularity of flight component
 - Air traffic controllers on the ground and flight crews in the air
 - UAS operations in the NAS
- L-DACS may provide commercial data transfer related to airline operations and provisions of services to passengers, both on the ground and in flight.

Both civil and military users could utilize the system. Growing requirements to use UAS in civilian airspace using AM(R)S and AMS(R)S frequency allocations adds a new layer of requirements and adds different type of users to an aeronautical system.

The introduction of an L-band system is expected to increase communications system capacity, thus allowing the addition of new services and expanding the user base. Figure 16 illustrates the effect of new system addition on the user base.

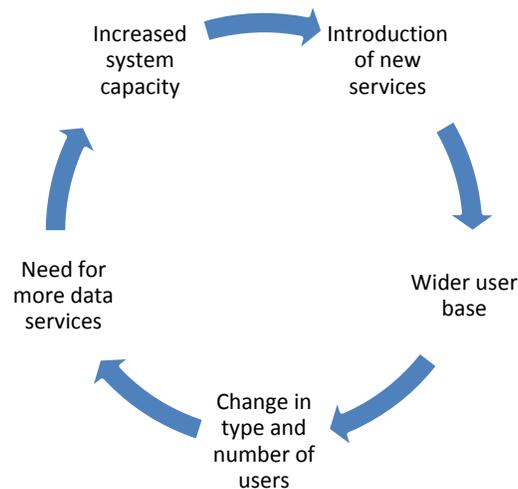


Figure 16.—Communication system capacity demand and user base relationships.

It should be noted that the relationship between the capacity demand and changes in the user base are viewed as a cycle of events. The proposed introduction of an L-band system will increase the overall capacity of the system and open up opportunities for addition of data services not provided under the Data Comm. Many of those, for example, services associated with the Airborne SWIM program, will provide for the wider system use. Not only would more users be expected to take advantage of the new data communications capabilities, the types of users allowed to participate would change as well.

As more data services are introduced and become part of day-to-day operations, the demand for additional services, and therefore capacity, is expected to grow. An introduction of a new frequency band, such as an L-band, in addition to the VHF frequencies supporting the existing voice and data communications services, will alleviate long-term capacity problems.

The expanded use of advanced technologies in general and L-DACS in particular, along with increased capacity, is expected to improve aviation safety and enhance operational efficiency for NAS users. The continued migration from a NAS based on a ground infrastructure and voice communication to a system that encompasses both ground and airborne components and utilizes the exchange of digital data as the primary type of communication, will “support the human in doing what they do best—choosing alternatives and making decisions, while the technology accomplishes what it can do best—the acquisition, compilation, evaluation and exchange of information” (Ref. 2).

NextGen communications systems will enable users to play a more active role in each of the NAS service areas:

- NAS management (strategic flow and resource management): SWIM capability will enable stakeholders’ access to relevant information. Users will become key participants in the planning of traffic flow management and will utilize a comprehensive information exchange process to improve flight operations planning according to capacity and traffic conditions to minimize congestion and delays.
- Flight planning and emergency alerting services: Users will have interactive flight planning capabilities with an immediate access to real-time data. User-preferred routing will become available to properly equipped aircraft for both domestic and international flights.
- Surface operations: Increased data-exchange capabilities will provide more users at more airports with flight clearances, airport information, positions of other aircraft, taxi routes, and weather conditions (current, forecast, or hazardous). Users will have improved real-time planning with continuous update of the flight profile.
- Arrival/departure and en route: A/G data exchange will enable more active flight deck participation in the decision making process. Users will utilize data, such as ATC clearances, current and forecast weather, NOTAMs and hazardous weather warnings, updated charts, current weather, special use airspace status, and other required data.
- Oceanic: A/G communication via L-DACS will not be provided in oceanic airspace.

3.5.2 Operational Policies and Constraints

Operational aspects of aeronautical communications are changing with an increased emphasis on safety and cost reduction achieved via increased automation, efficiency, delays reduction, and other improvements.

General issues such as cost, spectrum availability, technology choice, and standards development, as well as logistics of system rollout will all influence operational policies and constraints.

The NextGen ConOps document details operational policy issues that would affect the NextGen system. To support the proposed L-DACS development and implementation, policies need to be developed in the following areas:

- International and domestic regulations
- Safety management standards
- Processes to streamline certification and reduce costs for aircraft and ground equipment

- Privacy and liability legal concerns related to information sharing
- Communications priority and congestion relief (e.g., market-driven vs. aircraft type)
- Government role versus private sector role
- Financing and maintenance responsibilities

3.6 L–DACS Concepts of Use

3.6.1 RTCA NAS ConOps Guidance

As noted in Section 2, the L–DACS ConUse were defined based on guidance and information provided by several higher order ConOps. A key NAS ConOps source driving the L–DACS ConUse is the RTCA NAS ConOps (Ref. 1). Appendix A presents a comprehensive listing derived from the RTCA NAS ConOps of future communications concepts to enable transfer of the following NAS information types:

- Surveillance
- Weather
- Flight planning
- Aeronautical information
- Resource management

3.6.2 Data Comm Operational Scenarios

Operational scenarios can illustrate how proposed system capabilities could be used in an operational environment. The scenarios can demonstrate how the services offered by the new communications system could help to

- Minimize operational errors, including those resulting from misunderstood instructions and read-back errors
- Improve efficiency
- Provide further automation of traffic control
- Enable more decisions made off the ground

The Data Comm FPR (Ref. 7) lists operational scenarios envisioned to be enabled by a future data communications system. These scenarios also would be generally applicable to an L–DACS, implementation. As noted throughout this report, although L–DACS could be used on the ground, it will likely be more applicable to the en route and TMA domains, while another data link, such as IEEE 802.16e based AeroMACS, provides more promise for airport surface.

During late Segment 2 and beyond, Data Comm VDL Mode 2 operational capabilities could be augmented by L–DACS. The following are examples of the operational scenarios from Segment 3 of Data Comm that are potentially applicable to L–DACS (Ref. 7).

- Departure TRACON airspace scenarios

“Depending on the time criticality of a given clearance, and the altitude of the aircraft, communication services in the departure TRACON airspace are conducted via a mixture of voice and data. Typical exchanges via data communications for basic equipped departing aircraft include altitude and direct routing assignments.

“The aircraft follows the previously negotiated 4-D trajectory. Trajectory negotiations conducted pre-departure typically leave some conflicts unresolved such that maximum use of the airspace resource can be utilized. Therefore, the controller takes necessary

action via data communications to alleviate potential conflicts through the revision of the 4-D agreement or assignment of delegated separation services e.g., Crossing and Passing.

The voice frequency and data communications eligibility transfers are conducted automatically without the need for flight crew interaction.

- En route airspace scenarios

The voice frequency and data communications eligibility transfers are conducted automatically without the need for flight crew interaction.

Communications with the first en route controller is conducted through data communications. Routine clearances with aircraft are communicated via data communications while time critical clearances continue to be communicated by voice. Some of the aircraft operating in this normal (not High Performance (HP)) airspace are equipped with full 4-D trajectory-capable integrated data communications, while other aircraft have less capable data communications or lack ATC data capabilities and thus rely exclusively on voice. Only aircraft capable of communicating and conducting 4-D trajectory operations via data communications may enter the High Performance Airspace (HPA), which may initially be established at higher en route altitudes. Aircraft not properly equipped continue to operate in normal (non-HPA) airspace.

The HPA entry, 4-D trajectory, and exit previously loaded into the flight management system during the pre-departure phase are updated to reflect any changes made by ATC, and to reflect the current timing and actual position of the aircraft. The aircraft downlinks the revised requested profile, which is probed for conflicts by automation, then presented to the controller, who will typically approve and send the HPA clearance to the aircraft. If the automation determines a conflict will exist within the probed window of time, the automation will suggest revised constraints for controller approval and uplink to the aircraft. If the controller determines the conflict-free routing is sub-optimal, the controller may revise the constraints and uplink them.

Since the controller remains responsible for separation, the output of decision support tools are reviewed by the controller when a conflict is predicted. A proposed resolution will be sent to the aircraft via data communications upon the controllers review and acceptance.

The controller assesses any proposed trajectory changes generated by traffic management initiatives. If the proposed trajectory is predicted to cause a conflict, the controller takes the necessary action to alleviate the conflict. Upon determination of a conflict-free trajectory the controller sends the new trajectory to the flight crew via data communications. The flight crew checks whether the aircraft is capable of complying with the proposal through the flight management system. In this scenario the flight crew responds with an alternative trajectory. The ground automation confirms the proposal is conflict free and provides a new trajectory agreement to the controller for transmission to the aircraft. To prevent mistakes on re-entry of the trajectory clearance information, the data communications airborne system and the flight management system navigation function are interfaced, allowing direct transfer of clearance data upon flight crew approval.

Data communications supports aircraft clearances to use the appropriate services to self-separate e.g., Crossing and Passing, Sequencing and Merging or In-Trail Procedures. Separation responsibility is delegated to the flight crew for these functions.

The flight crew requests relevant information for the weather, airport field conditions and local notices to airmen for the destination airport through data communications. Selected aircraft parameters are monitored by data communications-enabled conformance management capability which decreases controller and flight crew workload and improves surveillance performance.

As the aircraft approaches the Top of Descent position, the appropriate controller provides scheduled time of arrival information to the flight crew via data communications. The flight crew then downlinks a route request to the en route controller, through data communications, which is composed of a tailored 4-D trajectory based on the aircraft's performance. The controller coordinates the request with the arrival TRACON airspace controller via automation. The en route controller responds to the flight crew via data communications with a message containing the confirmed clearance.

In conjunction with the ground automation handoff, which is done automatically unless the controller takes an extra action to reject it, data communications provides the next frequency to the flight crew, and transfers the data communications eligibility to the next sector or Center. The data communications system automatically validates the aircraft's Mode-C reported altitude and confirms the assigned altitude for the receiving controller.

- **Arrival TRACON airspace scenarios**

The flight crew contacts the TRACON controller via data communications. The data communications system automatically validates the aircraft's Mode-C and confirms the assigned altitude and ATIS code for the receiving controller. The TRACON controller replies with the initial information on approach expectations, potential airport information changes, and initial clearances. Aircraft continue to employ continuous descent profiles from the en route Top of Descent constraint. Arrival at the final constraint, which is typically the final approach fix, terminates trajectory based operations.

When necessary due to the traffic density, aircraft use the appropriate data communications services (e.g., Merging and Spacing (M&S) or Paired Approach) to perform delegated separation in the final approach phase from traffic landing on the same or closely spaced parallel runways.

A data communications clearance to execute the approach is issued. An instruction to monitor the tower voice communication frequency is subsequently issued via data communications. Data communications manages the data communications eligibility transfer.

3.6.3 L-DACS Applicable Services

3.6.3.1 Air Traffic Services

Reference 12 classifies all of the COCR ATS data services as safety critical. Furthermore, it identifies services that are not expected to be implemented by Data Comm through Segment 3, and identifies them as possible candidates for implementation via C-band and/or L-DACS. It must be stressed that both C-band and L-DACS are being developed for the FCI to accommodate safety and regularity of flight services. These are designed to operate over aviation-protected spectrum, so any COCR ATS service could be allowed to be implemented via one or the other of these links (as appropriate).

As described earlier, this document focuses on the COCR ATS data services that are not expected to be provided by Data Comm through Segment 3 and are proposed as candidates for L-DACS. These include the following, and except as noted, are applicable for A/G communications services:

- Flight information services
 - Data link operational route information service (D-ORIS)
 - Data link operational terminal information service (D-OTIS)
 - Data link surface information and guidance (D-SIG)
 - Data link runway visual range (D-RVR) while airborne
 - Wake vortex (WAKE)
 - Surveillance (SURV), as a potential A/A service
 - Flight plan consistency (FLIPCY)
 - System access parameter (SAP)
 - Pilot preferences downlink (PPD)
- Weather advisory service
 - Data link significant meteorological information (D-SIGMET)
- Advisory service
 - Dynamic route availability (DYNAV)
- Emergency information service
 - Urgent contact (URCO), if in conjunction with other more routine services
- A/A service
 - Air-to-air self separation (AIRSEP)

COCR (Ref. 5) contains descriptions of the above services. Additional data services that may be provided via FCI may be identified as NextGen and Single European Sky ATM Research (SESAR) progress.

3.6.3.2 AOC Data Services

Table 5 lists the AOC data services noted in the COCR v.2.0. Services provided on airport surface only (e.g., Software Loading, SWLOAD) as well as those likely to be provided in the ENR and TMA domains are included in the table. Some of the services listed would be mostly provided the ground, while others may be applicable to wheels on- and off-the-ground scenarios.

TABLE 5.—AERONAUTICAL OPERATIONAL CONTROL (AOC) DATA SERVICES

Service	Acronym	Service	Acronym
AOC Data Link Logon	AOCDLL	Real Time Maintenance Information	MAINTRT
Cabin Log Book Transfer	CABINLOG	Notice to Airmen	NOTAM
Engine Performance Reports	ENGINE	Out-Of-On-In	OOOI
Flight Log Transfer	FLTLOG	Position Report	POSRPT
Flight Plan Data	FLTPLAN	Software Loading	SWLOAD
Flight Status	FLTSTAT	Technical Log Book Update	TECHLOG
Free Text	FREETXT	Update Electronic Library	UPLIB
Fuel Status	FUEL	Graphical Weather Information	WXGRAPH
Gate and Connecting Flight Status	GATES	Real-time Weather Reports for Met Office	WXRT
Load Sheet Request/Transfer	LOADSHT	Textual Weather Reports	WXTEXT
Maintenance Problem Resolution	MAINTPR		

Table 6 lists the additional AOC and airline administration communications (AAC) services documented by the European SANDRA Program (Ref. 34). These services were not mentioned by the COCR but recommended based on industry feedback during data link standardization activities. Although the services are already implemented in new aircraft, they are highly customizable. As noted in the document, the following list does not claim to be exhaustive and is awaiting feedback from Airbus and major airlines. The document is a work in progress.

TABLE 6.—PROPOSED NEW AOC/AAC SERVICES
[Acronyms are defined in Appendix A.]

Service	Acronym	Allowed on SANDRA
Electronic flight folder exchange with ground of flight data for cockpit crew collected on ground. Format defined by ARINC 633	EFFuplink EFFdownlink	x
Exchange with ground of aircraft configuration data	CONF	x
Exchanges of performance data with ground (computation on ground) ^a	PERF	x
Flight data records transmitted on ground	VQAR	WiMAX only: proposal is to allow it. This system has the ability, if transmission was not complete when aircraft departs, to resume transmission at the following airport.
Air-to-ground cabin video streaming for security/surveillance (potential future use case, to be discussed)	CVM	x This service is TBC.
Real time of summary transmission of failures/monitored CABIN/IFE parameters	CabMAINTTRT	x
Transmission of telemedicine data to ground (sick passenger)	TELEMED	x
Ordering and provisioning of fuel from cockpit when on ground	REFUEL	x
De-icing service ordering and management from cockpit when on ground	DEICING	x

^aThis service may be specific to some airline operators only, as the technical trend is rather to integrate these functions in avionics, as for business jets for example, instead of using data links.

CVM and VQAR involve transmission of large amounts of data (up to several tens of Mbytes). The remaining services listed above are similar to the AOC services defined in COCR v.2.0 in terms of the required message sizes, data rates, and phase of flight usage.

The AOC services in Table 5 may be mapped to the flight regularity category (Ref. 10) and may be transported over the AM(R)S link. Services with large bandwidth requirements may be more suitable to provide via FCI (e.g., L-DACS and AeroMACS), and services involving smaller traffic volumes may be more appropriate for a VDL-2 based system.

3.6.3.3 Unmanned Aircraft System (UAS) Suitable Services

Services specific to the operation of UAS in the NAS and potentially suitable for implementation via an L-DACS would include the following:

- Pilot/UA control links, including telecommand and telemetry
- Pilot/UA NavAids data exchanges
- Relaying ATC voice messages to and from UA pilots
- Relaying ATS data messages to and from UA pilots⁸
- UA-to-pilot downlinking of nonpayload target-track data
- UA-to-pilot downlinking of data from UA-borne weather radars
- UA-to-pilot downlinking of safety-related video data from UA to pilots
- UA-to-pilot downlinking of safety-related sense and avoid automated decisionmaking from UA to pilots

⁸Such as the services presented in the COCR, including those listed above in Section 4.2.

Section 6.0 contains more detail on UAS-related services.

3.6.3.4 Airborne System Wide Information Management (SWIM) Suitable Services

Introduction of L-DACS would support transitioning from Aeronautical Information Services (AIS) to Aeronautical Information Management (AIM) (Ref. 35) notes the data-centric nature of AIM as opposed to the product-centric nature of AIS and emphasizes the need for a robust communication network to enable digital communication services and support the increasing bandwidth demands.

SWIM, an FAA technology program designed to facilitate sharing of ATM system information (airport operational status, weather information, flight data, status of special-use airspace, and NAS restrictions), can be implemented via G/G, A/G, and A/A communications infrastructure components. Each of these components would enable efficient data exchange between authorized users in the respective domain. An L-DACS could provide means for A/A and A/G data transfers.

An implementation of the proposed L-band system would facilitate meeting the primary objective of the SWIM program, that is, to improve the FAA's ability to manage the efficient flow of information through the NAS. When used to enable Airborne SWIM capabilities, an L-band system could be designed to assure that its use provides the following desired SWIM features:

- Reduced costs for NAS users to acquire NAS data and exchange information
- Increased shared situational awareness among the NAS user community
- FAA-compliant secure data exchange among the NAS user community

Figure 17 shows how Airborne SWIM (with the communication links potentially provided over the L-band) fits in the overall FAA Information Exchange Model.

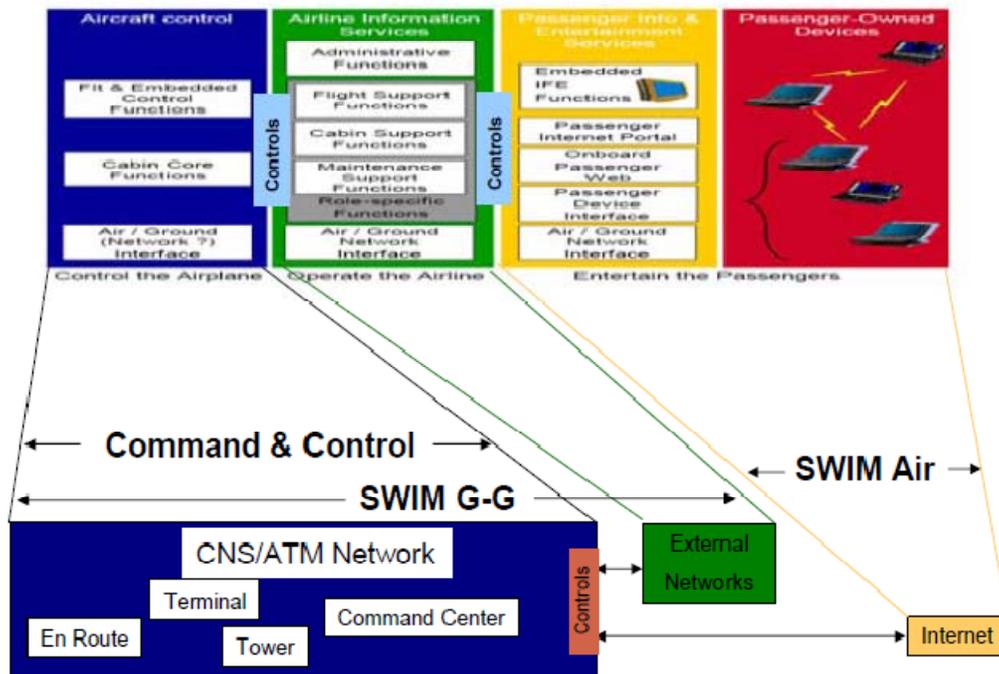


Figure 17.—Information Exchange Model (Ref. 36). Acronyms are defined in Appendix A.

Although it is anticipated that some Airborne SWIM services could be provided over commercial (i.e., unprotected (non-AM(R)S)) spectrum, as shown in the figure, it is likely that other Airborne SWIM services could make use of protected spectrum to support “regularity of flight”.⁹ These later services would be suitable targets for an L–DACS implementation.

As part of SWIM, L–DACS would enable exchange of information between diverse users adopting a service-oriented architecture (SOA). Services would be offered from individual providers as well as centralized providers.

Figure 18 shows A/G (airborne) and G/G SWIM elements. The figure depicts Airborne SWIM (potentially provided over L–DACS) as a facilitator of NAS data exchange, such as surveillance, flight, aeronautical, meteorological, air traffic flow and capacity management (ATFCM) scenario, and demand and capacity data.

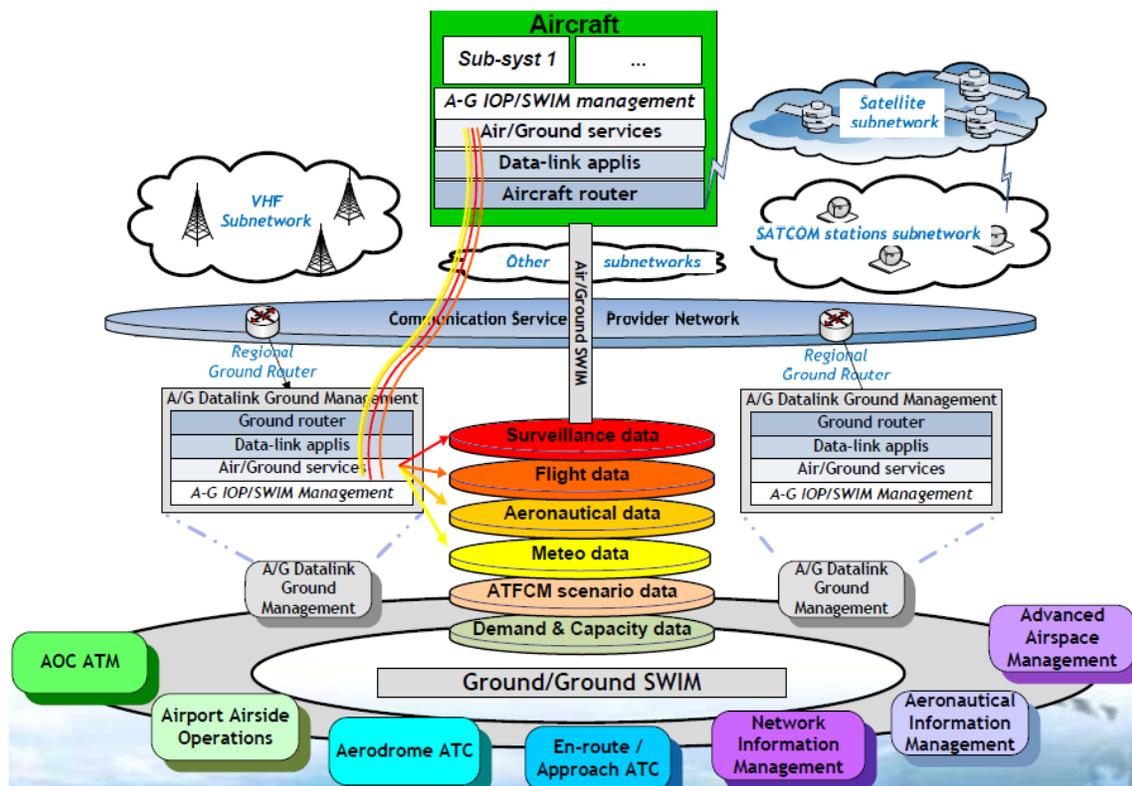


Figure 18.—Air-to-ground data link management and aircraft participation in System Wide Information Management (SWIM) (slightly modified from Ref. 37). Copyright Thales Air Systems; used with permission. Acronyms are defined in Appendix A.

These weather advisory and aeronautical information services include:

- Aviation digital data service (ADDS)
- AWOS data acquisition service (ADAS)
- Expanded terminal and tower data service
- General information (GI) message distribution service
- Information display system (IDS) data service

⁹For example, current AOC communications is conducted over AM(R)S spectrum to support regularity of flight operations rather than “safety of flight” operations.

- NextGen Network Enabled Weather (NNEW) service¹⁰
- Notices to airmen (NOTAM) distribution service
- TMA flight data service
- WARP/WINS NEXRAD service

Joint Planning and Development Office (JPDO) Next Generation Air Transportation System (NextGen) ATM-Weather Integration Plan (Ref. 65) provides ATM-weather integration plan and emphasizes the need for an efficient flow of weather information and its translation into constraints to enhance decisions.

Several OIs identified in Section 3.4.1.1 as those potentially enabled by L-DACS are noted as part of the NextGen solution-set-oriented weather integration analysis. OIs 104117, 102406, 104207, 104208, 104209 as well as 101102 and 103305 would require Mid-Term weather-related capability with the OI 104117—Improved Management of Arrival/Surface/Departure Flow Operations—leveraging “advanced communications and automation technologies as the primary means of accomplishing its goals” (Ref. 38). The proposed L-DACS offers communications links to fulfill the demand for such communication technology.

Under the OI 101102—Provide Full Flight Plan Constraint Evaluation with Feedback—a user would be able to adjust the flight plan based on available information and refile as additional information is received. Updated information would be provided to filers if conditions along trajectory change with a user being able to submit alternative flight plans if needed. After filing a flight plan and up until departure, weather and nonweather constraints that impact the plan as well as FAA mitigation strategies would be provided to the user.

[The] evaluation capability will provide the user with feedback that is based on consistent information to that of the ANSP, thereby increasing common situational awareness. The feedback will include current and predicted information for a flight along its complete flight path (i.e., full route) throughout the flight’s life cycle. The feedback will include weather information, probabilistic information, TMIs (including delay information), airspace information (e.g., High Performance Airspace [HPA]/Mixed Performance Airspace [MPA], RNAV routes), required aircraft performance characteristics (e.g., RNP, RNAV requirements), active routes, restrictions (e.g., Letters of Agreement (LOAs), SOPs, SAA, terminal status information (e.g., airport conditions, runway closures, wind, arrival rates, RVR, airport (current and planned) configurations, surface information, and other NAS status information and changes along the path of the evaluated route or filed route. In addition, the nature (e.g., fully restricted or conditional access), the time, and the impact (e.g., distance, delay) associated with any restriction or constraint will be provided. It is expected that the evaluation feedback will evolve as changes in airspace, and new information systems become integrated and available (Ref. 38).

Users with different level of flight planning capabilities would have access to varying levels of information. L-DACS could provide communications links to enable these services.

¹⁰ It is possible that the information provided through the NNEW service could range from the advisory for routine forecasts through safety-critical information for certain hazardous weather warning messages, which might limit the extent to which this might be provided over commercial links. This requires further investigation.

Figure 19 illustrates Provide Full Flight Plan Constraint Evaluation and Feedback OI in the context of SWIM showing interactions with other OIs.

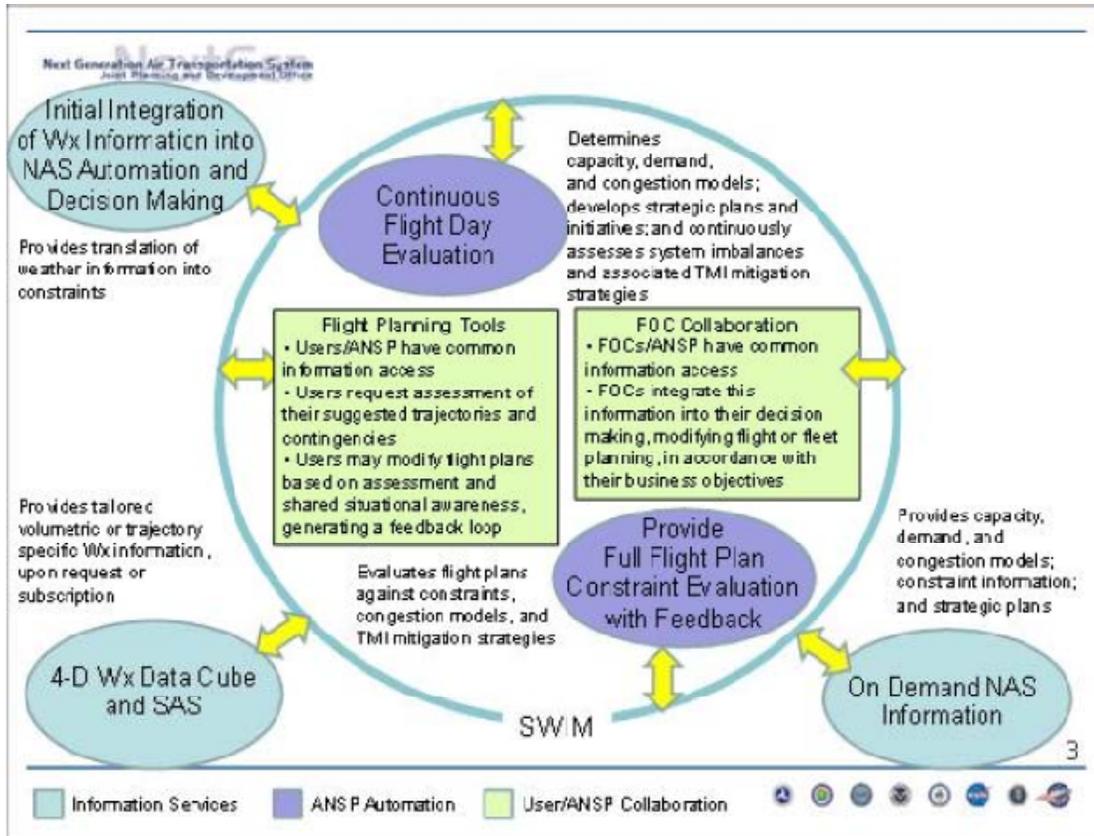


Figure 19.—Full flight plan constraint evaluation and feedback OI in the context of SWIM showing interactions with other OIs mid-term operational scenario (Ref. 38).

Figure 20 illustrates the introduction of SWIM services over time. Implementation of the proposed L-DACS is likely to overlap with SWIM Segments 3 and 4 when air/airborne SWIM is introduced.

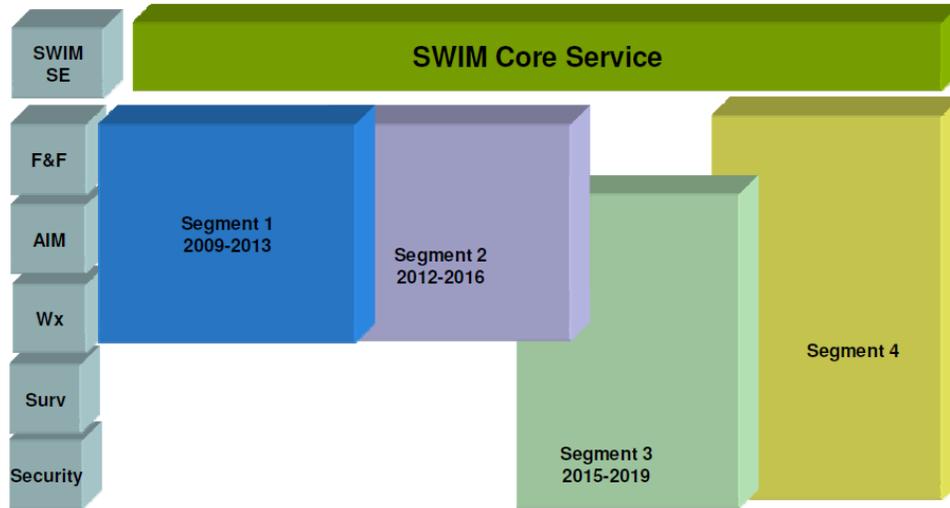


Figure 20.—System Wide Information Management (SWIM) execution by segments (Ref. 39).

3.6.4 Communications Operational Services and Concepts Based on Flight Domain

Operational concepts can be defined according to the different geographic flight domains, defined as follows (from Ref. 40):

- Airport (APT): airport surface/immediate vicinity of the airport.
- Terminal maneuvering area (TMA): airspace surrounding an airport to about 50 nautical miles from the center of an airport.
- En route (ENR): airspace that surrounds the TMA domain. This is the continental or domestic airspace used by ATC for the cruise portion of a flight.
- Oceanic, remote, polar (ORP): same as the ENR domain, but in geographical areas generally outside of domestic airspace.
- Autonomous operations area (AOA): airspace associated with autonomous operations where aircraft self-separate.

Table 7 illustrates the potential operational use of the proposed L-band system based on the COCR services previously identified as potential applications (Ref. 12).

TABLE 7.—POTENTIAL USE OF L-DACS IN DIFFERENT FLIGHT DOMAINS
[Acronyms are defined in Appendix A.]

Operational services	Airport domain phases						
	Predeparture airport domain ^a	Departure taxi airport domain ^a	Departure TMA domain ^a	ENR and AOA domains	Arrival TMA domain ^a	Arrival airport domain ^a	Arrival taxi airport domain ^a
Flight information services	D-OTIS ^b D-RVR ^b D-SIG D-SIGMET	D-OTIS ^b D-RVR ^b D-SIG D-SIGMET	D-ORIS D-OTIS ^b D-RVR ^b D-SIG D-SIGMET	D-ORIS D-OTIS ^b D-RVR ^b D-SIGMET	D-OTIS ^b D-RVR ^b D-SIG D-SIGMET	D-OTIS ^b D-RVR ^b D-SIG	D-RVR ^b D-SIG
Flight position, flight intent, and flight preferences services	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY SAP ^c WAKE	PPD FLIPCY SAP WAKE ^d	PPD FLIPCY SAP WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE
Advisory service				DYNAV			
Emergency information service	URCO	URCO	URCO	URCO	URCO	URCO	URCO
Delegated separation services			ITP M&S C&P	ITP M&S C&P	ITP M&S C&P PAIRAPP		
Air-to-air service				AIRSEP			
UAS services	Pilot/UA control links, including telecommand and telemetry Pilot/UA NavAids data exchanges Relaying ATC voice messages to and from UA pilots Relaying ATS data messages to and from UA pilots UA-to-pilot downlinking of nonpayload target-track data UA-to-pilot downlinking of data from UA-borne weather radars UA-to-pilot downlinking of safety-related video data from UA to pilots UA-to-pilot downlinking of safety-related sense and avoid automated decisionmaking from UA to pilots						
Airborne SWIM suitable services (generally weather advisory and aeronautical information services)	ADDS, ADAS, expanded terminal and tower data service, general information (GI) message distribution service, IDS data service, NNEW service ^e , NOTAM distribution service, TMA flight data service WARP/WINS NEXRAD Service						

^aWhile the L-band system is proposed to be implemented with the primary objective of supporting en route and terminal communications (i.e., ENR and TMA domains), the L-band system could be used on the ground (i.e., airport domain) as well as in the air, for example, to avoid switching links. As such, some ATC services are included in the table for the airport domain.

^bAt the time of this report D-OTIS and D-RVR are listed as part of the RTCA SC-214 scope (Ref. 11). As noted throughout this report, the services are considered candidates for L-DACS if not implemented by the Data Comm program.

^cSAP is primarily used en route and terminal areas but is available in all phases of flight.

^dWAKE service is not available in AOA domain.

^eIt is possible that the information provided through the NNEW service could range from the advisory for routine forecasts through safety critical for certain hazardous weather warning messages, which might limit the extent to which this might be provided over commercial links. This requires further investigation.

Examples of operational messages that could be transmitted over the proposed L-band data link in support of the services in each flight domain are presented in Table 8. The messages are grouped according to the information type, as defined by the function identifications (IDs) provided in Section 7.0.

TABLE 8.—EXAMPLE L-BAND DATA LINK MESSAGES

Information type (including corresponding function ID)	Message examples
Transceive air traffic services (ATS) to airborne aircraft message L.1.1.1.1	Contract requesting data Contract acknowledgements Operational terminal information service (OTIS) reports, addressed or broadcast communications Operational en route information service (ORIS) reports, addressed or broadcast communications Significant meteorological information (SIGMET) reports, addressed or broadcast communications, event basis only Airport data to be displayed on board (data link surface information and guidance, D-SIG) Runway visual range (RVR) information, addressed or broadcast communications Available alternative routes (dynamic route availability, DYNAM), addressed communication Urgent contact message (URCO), addressed and/or broadcast communications
Transceive airborne aircraft to ATS message L.1.1.2.1	Requests (i.e., demand, periodic, or event contract) for reports Contract acknowledgements Current and periodic position (flight plan consistency, FLIPCY), addressed communications Meteorological data (FLIPCY), addressed communications Ground speed (FLIPCY), addressed communications Indicated heading, indicated air speed or mach, vertical rate, selected level, and wind vector (system access parameters, SAP), addressed communications Broadcast of aircraft wake turbulence (WAKE) characteristics (e.g., aircraft type, weight, and flap and speed settings) Flight limitations (e.g., maximum acceptable flight level) (pilot preferences downlink, PPD), addressed communications Pilot flight preferences (PPD), addressed communications Flight plan modification requests (e.g., desired route or speed limitations) (PPD), addressed communications URCO, addressed and/or broadcast communications
Transceive ATS to on-ground aircraft message L.1.1.1.2	Contract requesting data Contract acknowledgements OTIS reports, addressed or broadcast communications ORIS reports, addressed or broadcast communications SIGMET reports, addressed or broadcast communications, event basis only Airport data to be displayed on board (D-SIG) RVR information, addressed or broadcast communications Available alternative routes (DYNAM), addressed communication URCO, addressed and/or broadcast communications

TABLE 8.—EXAMPLE L-BAND DATA LINK MESSAGES

Information type (including corresponding function ID)	Message examples
Transceive on-ground aircraft to ATS message L.1.1.2.2	Requests (i.e., demand, periodic, or event contract) for reports Contract acknowledgements Current and periodic position (FLIPCY), addressed communications Meteorological data (FLIPCY), addressed communications Ground speed (FLIPCY), addressed communications Indicated heading, indicated air speed or match, vertical rate, selected level, and wind vector (SAP), addressed communications Broadcast of WAKE characteristics (e.g., aircraft type, weight, and flap and speed settings) Flight limitations (e.g., maximum acceptable flight level) (PPD), addressed communications Pilot flight preferences (PPD), addressed communications Flight plan modification requests (e.g., desired route or speed limitations) (PPD), addressed communications URCO, addressed and/or broadcast communications
Transceive airborne aircraft to airborne aircraft message L.1.1.3.1	Trajectory intent exchange (air-to-air self-separation, AIRSEP), addressed and/or broadcast communications. Conflict negotiation (AIRSEP), addressed and/or broadcast communications. Resolution accept/confirmation

3.6.5 L-DACS Operational Concepts Derived from the COCR

Table 9 shows examples of operational scenarios for the proposed L-band system according to specific services identified earlier (Ref. 12) as proposed L-DACS applications (services that are not planned to be implemented by Data Comm through Segment 3). The scenarios are a subset of those provided in COCR Version 2.0 (Ref. 5).

Refer to Section 6 for ConUse and operational scenarios applicable to UAS.

TABLE 9.—EXAMPLE OPERATIONAL SCENARIOS

Flight domain	Communication scenarios
Pre-departure airport domain	<ul style="list-style-type: none"> • The flight crew initiates a request for a data link operational terminal information service (D-OTIS) contract for the departure airfield. The flight information service (FIS) system response provides all relevant information for the weather, Automatic Terminal Information Service (ATIS), and field conditions, plus the local Notices to Airmen (NOTAMs). • In low-visibility conditions, the flight crew may also use the data link runway visual range (D-RVR) service to request RVR information for the departure and the destination airports. For data-link-equipped aircraft preparing to taxi, the current graphical picture of the ground operational environment is uplinked and loaded using the data link surface information guidance (D-SIG) service. • The flight crew specifies preferences that should be considered by the controllers using the pilot preferences downlink (PPD) service.
Departure terminal maneuvering area (TMA) domain	<ul style="list-style-type: none"> • The system access parameters (SAP) service is initiated by the air traffic service unit (ATSU) automation system, and the downlinked information is provided to the various ground components (e.g., for smoothing of trackers) or on request for display of parameters to controllers. The ATSU automation system monitors the aircraft behavior in accordance with the given clearances. The tracking system issues warnings to the executive controller in case of noncompliance. The executive controller intervenes if the situation requires action. The tracking system uses the automatic dependent surveillance (ADS) and radar data to monitor whether the aircraft performance is in accordance with the ground-predicted trajectory and updates the trajectory where necessary.

TABLE 9.—EXAMPLE OPERATIONAL SCENARIOS

Flight domain	Communication scenarios
En route, and autonomous operations area (AOA) domains	<ul style="list-style-type: none"> • The ATSU automation system confirms/sets the exit/entry conditions with the sectors in the en route phase. At each entry into a subsequent ATSU, FLIPCY is performed to verify the flight management system route against what is held in the ATSU flight data processing system. • Planning controller indicating that moderate to severe turbulence may be expected over this portion of the flight. This information is sent to the aircraft via the data link significant meteorological information (D–SIGMET) service. A new network connection is established between the aircraft and the remote domain ground system before the connection with the en route domain ground system is released. • The planning controller analyses interactions with other aircraft that are reported to him/her by the conflict probe system. The planning controller probes “what-if” solutions for interactions. The conflict probe system may offer alternatives to the existing route, the planning controller assesses these alternatives, and the alternatives are provided via the dynamic route availability (DYNAV) service for flight crew assessment. The planning controller enters the flight-crew-selected alternative and updates the flight trajectory in the ATSU automation system. The flight crew flies the aircraft according to the instructions given. The ATSU automation system recognizes the aircraft’s position relative to exiting the ATSU, compiles a data link operational en route information service (D–ORIS) report specific to the remaining portion of the area to be over-flown, and sends it to the aircraft.
Arrival TMA domain	<ul style="list-style-type: none"> • The system updates arrival manager (AMAN) with changes to the arrival sequence. AMAN calculates constraints by taking into account the actual traffic situation and makes the information (time to lose, gain, or hold) available to the concerned planning controller and executive controllers in upstream sectors/ATSUs. If required, the conflict probe system calculates a conflict-free alternative trajectory for the flight to comply with the AMAN constraints. The planning controller of the receiving sector checks the PPD service information to see if the conflict probe system-provided trajectory could be improved with these preferences. The planning controller accepts the proposal and coordinates the sending of the ACL instruction with the Executive Controller. Based on the equipment and flight crew qualification information contained in the flight plan and data obtained via SAP and PPD, the Executive Controller determines which aircraft may execute a spacing application and issues merging and spacing clearances to those aircraft via ACL (ACL is expected to be supported by Data Comm). • The ATSU automation generates a D–SIG of the arrival airport surface. The D–SIG surface map is communicated in advance of the landing clearance so that the Flight Crew can determine any impacts to its configuration.

4.0 L–DACS System Requirements

4.1 L–DACS System Requirements Development Process

Section 2.0 presented an overview of the ConUse and system requirements development process used for this task. A middle-out approach was adopted to identify the high-level requirements applicable to L–DACS. In this approach, the top-down functional requirements were derived from the ConUse and the associated functional capabilities. In parallel with that process, a bottom-up assessment of existing requirements in relevant documents such as the NAS SR–1000 (Ref. 18), the COCR (Ref. 5), and Data Comm performance requirements and their applicability to the current needs for L–DACS was performed. Thus, the top-down approach employs the classic “clean-sheet” system engineering process, and the bottom-up approach addresses how L–DACS fits into the existing environment.

4.2 Functional Requirements for L–DACS Services—Bottom-Up Assessment

4.2.1 NAS-Level Functional Requirements for L-band System Services

Functions identified in the NAS SR–1000 document (Ref. 18)—plan flights, monitor flights, control traffic, support flight operations, monitor NAS operations, and plan NAS usage—cut across all L–DACS capabilities shown in Table 9.

Table 2 mapped A/G communication functions to NAS service capabilities highlighting services potentially enabled by A/G voice communication.

Similarly, Table 10 highlights capabilities of the proposed system enabling NAS functionality as specified in NAS SR–1000. The boxes denote services potentially enabled by A/G communication with the blue boxes representing voice and/or data communication and green boxes representing data communication only.

It is possible that some services not identified in NAS SR–1000, for example UAS-related services, could be enabled by A/G communication, and thus could potentially be conveyed by FCI systems.

TABLE 10.—MAPPING RELEVANT COMMUNICATIONS FUNCTIONS TO NATIONAL AIRSPACE SYSTEM (NAS) SERVICE CAPABILITIES (REF. 18)

Function \ Capability	Flight Planning	Separation Assurance	Advisory Services	Traffic Synchronization	Traffic Flow Management	Emergency Services	Navigation Services	Airspace Management Services	Infrastructure and Information Management
Evaluate Flight Conditions			X						
Manage Flight Plans	X								
Collect Surveillance Information	X	X	X	X		X	X		
Determine Aircraft Trajectory		X		X					
Monitor Aircraft Status	X					X	X		
Disseminate Aircraft Status	X	X				X			
Manage Separation Information		X							
Synchronize Traffic		X	X	X	X				
Control Aircraft		X							
Coordinate Traffic Control Distribution		X							X
Manage Weather Information			X						
Operate NAVAIDS							X		
Monitor NAS Flight Operations			X		X				
Maintain NAS Infrastructure		X	X			X			X
Plan Traffic Flow					X				X
Assess Traffic Flow Performance					X				
Manage Airspace Configuration	X	X				X	X	X	X

In Table 11 functional requirements applicable to an L-DACS were extracted from the superset of NAS requirements specified in the NAS SR-1000 document (Ref. 18).

TABLE 11.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
 [Numbers in the table correspond to communication requirements in the NAS SR-1000 (Ref. 18)]

NAS functions		Communication requirements
Plan flights	Evaluate flight conditions	The NAS shall disseminate the status of special use airspace to users. (08760) The NAS shall disseminate weather information to users to support flight planning. (27150) The NAS shall disseminate aeronautical information to users to support flight planning. (27160)
	Manage flight plans	The NAS shall disseminate flight information to users. (00010) The NAS shall disseminate flight plan information to users via external data interfaces. (00410) The NAS shall disseminate flight plan information to users via air-ground data communications. (00970) The NAS shall disseminate flight data summaries to users. (00070) The NAS shall disseminate flight plans to users. (02160) The NAS shall disseminate flight plan clearances to users. (02900) The NAS shall disseminate recommended collision avoidance maneuvers to users. (03690)
Monitor flights	Collect surveillance information	The NAS shall disseminate the location of an aircraft equipped with a functioning VHF transceiver in designated areas greater than or equal to 2000 feet above ground level independent of surveillance capabilities. (12960)
	Monitor aircraft status	The NAS shall respond to requests for assistance from in-flight users. (12560) The NAS shall respond to emergency transmission received via radio communications. (12600) The NAS shall respond to emergency transmissions received via data link. (12620) The NAS shall continuously monitor air-to-ground communications utilizing designated frequencies for detection of emergency transmissions. (12650) The NAS shall transmit aerodrome recommendations to expedite resolution of emergency situations. (12830) The NAS shall accept airspace reservations from search and rescue aircraft. (13150) The NAS shall exchange essential information and emergency alert information with aircraft in the area via external data interfaces. (22310) The NAS shall disseminate essential information on missing aircraft. (13130)
	Report aircraft status	The NAS shall disseminate current flight activity information in restricted areas. (08780) The NAS shall disseminate current flight activity information in warning areas. (08790) The NAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations. (12820)
Control traffic	Address active aircraft conflicts	The NAS shall disseminate recommended collision avoidance maneuvers to users. (03690)
	Control aircraft	The NAS shall disseminate aeronautical information to users via air-ground data communications. (07440)
	Coordinate traffic control distribution	The NAS shall acquire pilot reports (PIREP). (05530) The NAS shall acquire PIREP from airborne pilots. (05570) The NAS shall disseminate weather advisories via direct specialist to pilot communications. (09290)

TABLE 11.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
 [Numbers in the table correspond to communication requirements in the NAS SR-1000 (Ref. 18)]

NAS functions		Communication requirements
Support flight operations	Manage weather information	<p>The NAS shall disseminate graphical weather information to airborne users. (06310)</p> <p>The NAS shall maintain communication links adequate to avoid user delay in gaining access. (07090)</p> <p>The NAS shall disseminate weather information to users continuously. (07110)</p> <p>The NAS shall disseminate current weather effect along the users proposed flight path. (07470)</p> <p>The NAS shall disseminate forecast weather in effect along the users proposed flight path. (07480)</p> <p>The NAS shall disseminate intensity levels of weather by route of flight to users. (08260)</p> <p>The NAS shall disseminate intensity levels of weather by geographic area to users. (08300)</p> <p>The NAS shall disseminate weather advisories to users in response to a request. (09300)</p> <p>The NAS shall broadcast the latest approved aerodrome conditions on communications media accessible by aircraft in flight. (09330)</p> <p>The NAS shall broadcast the latest approved aerodrome conditions on communications media accessible by aircraft on the ground. (09340)</p> <p>The NAS shall broadcast the latest approved terminal area conditions on communications media accessible by aircraft in flight. (09350)</p> <p>The NAS shall broadcast the latest approved terminal area conditions on communications media accessible by aircraft on the ground. (09360)</p> <p>The NAS shall respond to user requests for weather information from NAS facilities through common carrier communications networks. (09370)</p> <p>The NAS shall disseminate selected weather information directly to appropriately equipped aircraft. (09420)</p> <p>The NAS shall display intensity levels of weather by geographic area to users. (08310)</p> <p>The NAS shall display intensity levels of weather by route of flight to users. (08280)</p> <p>The NAS shall accept requests for weather information from airborne aircraft via data link communications. (09550)</p> <p>The NAS shall provide flexible and convenient access to required weather information to users. (19380)</p> <p>The NAS shall provide weather advisories to aircraft in flight. (19790)</p> <p>The NAS shall disseminate weather information to airborne users for pictorial display. (06290)</p>
	Operate NAVAIDS ^a	<p>The NAS shall coordinate navigation guidance information reception requirements between en route and terminal area navigation systems to minimize equipment costs to users. (14770)</p> <p>The NAS shall disseminate nonprecision-approach and missed-approach position guidance information to users. (14330)</p> <p>The NAS shall disseminate navigational accuracy correction values for supplemental navigation systems to users. (17040)</p> <p>The NAS shall disseminate correction values for navigational aids to users. (16790)</p> <p>The NAS shall disseminate available supplemental terminal navigation guidance information error correction values to users. (14820)</p>

TABLE 11.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
 [Numbers in the table correspond to communication requirements in the NAS SR-1000 (Ref. 18)]

NAS functions		Communication requirements
Monitor NAS operations	Monitor NAS flight operations	<p>The NAS shall disseminate future delay advisories in effect along the users proposed flight path. (07500)</p> <p>The NAS shall disseminate traffic advisories upon user request. (09120)</p> <p>The NAS shall disseminate advisories to aircraft approaching special use airspace. (09210)</p> <p>The NAS shall disseminate traffic advisories to pilots when applying VFR separation services. (19780)</p> <p>The NAS shall provide traffic alerts to participating aircraft within 5 NMI, 500 feet below and 500 above special use airspace. (04350)</p> <p>The NAS shall provide traffic advisories to aircraft on the surface. (30270)</p>
	Maintain NAS infrastructure	<p>The NAS shall disseminate airway usage information to users. (00030)</p> <p>The NAS shall disseminate route usage information to users. (00050)</p> <p>The NAS shall disseminate aeronautical information to users via external data interfaces. (07430)</p> <p>The NAS shall disseminate aeronautical information per user request. (07130)</p> <p>The NAS shall disseminate aeronautical information upon user request continuously. (07340)</p> <p>The NAS shall disseminate aeronautical data for a maximum of 8 specified locations per request. (07400)</p> <p>The NAS shall disseminate the status of supplemental navigation systems to users. (17010)</p> <p>The NAS shall disseminate status of supplemental navigation systems to users. (16770)</p> <p>The NAS shall disseminate flow control information to users via external data interfaces. (07920)</p> <p>The NAS shall disseminate derived restrictions to the user. (11700)</p> <p>The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)</p> <p>The NAS shall disseminate terrain information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03900)</p> <p>The NAS shall disseminate manmade obstacle information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03940)</p> <p>The NAS shall disseminate ground information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (25520)</p> <p>The NAS shall disseminate filtered terrain information to users. (25560)</p> <p>The NAS shall disseminate filtered ground information to users. (25570)</p> <p>The NAS shall disseminate filtered manmade obstacle information to users. (25580)</p>

TABLE 11.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
 [Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 18)]

NAS functions		Communication requirements
Plan NAS usage	Plan traffic flow	The NAS shall disseminate preferred route information at least 24 hours prior to it becoming effective. (07280)
		The NAS shall disseminate military air traffic control plans related to national emergencies. (16140)
		The NAS shall disseminate flow control information to users via external data interfaces. (07920)
		The NAS shall disseminate interfacility traffic flow plans. (11970)
		The NAS shall disseminate derived restrictions to the user. (11700)
		The NAS shall disseminate derived alternative courses of action to the user. (11720)
		The NAS shall determine flight restrictions for specific aircraft. (11760)
		The NAS shall disseminate flight restrictions to users. (11770)
		The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)
		The NAS shall process derived alternatives to the user. (11680)
Assess Traffic Flow Performance		The NAS shall disseminate reports on equipment performance. (18870)
		The NAS shall disseminate reports on maintenance activities. (18880)
		The NAS shall disseminate reports on equipment repair activities. (18890)

^aThese services are typically provided via satellite communication but could be provided via a ground-based system.

4.2.2 NAS Functional Requirements for L-band System Infrastructure

The following is a summary of NAS infrastructure (communications) requirements found applicable to the proposed L–DACS as documented in the NAS SR–1000 (Ref. 18). The list supports the high-level functional requirements presented in the document.

- The NAS shall provide A/G voice and data communications within the en route and terminal airspace of the conterminous United States, Alaska, Hawaii, and Puerto Rico. (19920)
- The NAS shall provide data channels in the frequency band appropriate for A/G data communications equipment for data communications coverage for both civil and military users. (19940)
- The NAS shall automate communications capabilities to reduce specialist and user workload. (20210)
- The NAS shall provide A/G communications continuously. (part of 20330)
- The NAS shall provide reconfiguration of communications capabilities without degradation of A/G voice or data communications. (20380)
- The NAS shall support peak busy hour exchange of data including short-term peaks that may occur within the peak hour, with minimal change in the data transmission response times and no loss of data. (20760)
- The NAS shall reconfigure communication capabilities to support changes in operating responsibilities. (20800)
- The NAS shall design emergency communications networks to operate for a 30-day period without commercial power at selected critical facilities. (20990)
- The NAS shall provide processing and communications capacities to support the required backup capabilities and to meet the response time requirements specified above, while maintaining safe separation of all aircraft receiving ATC services (i.e., both normal and backup sectors) from the backup facilities. (21670)
- The NAS shall provide configurable communications. (32120)

4.3 L-DACS Functional System Requirements—Top-Down Approach

This section presents a top-down determination of functional requirements through: (1) a functional analysis based on prior work, and (2) a functional analysis based on the ConUse defined in Section 3.0, and an analysis of appropriate NAS-SR-1000 requirements.

4.3.1 Prior Functional Analysis

A functional architecture can be interpreted as a hierarchical arrangement of functions and interfaces that represents the complete system from a performance and behavioral perspective (Ref. 9). For its top-down functional analysis, this report leverages prior functional analysis work to characterize aeronautical A/G and A/G communication. Figure 21 depicts the hierarchy at the highest level. Appendix C presents a hierarchical decomposition of functions as diagrams and in an outline format derived from Reference 8.

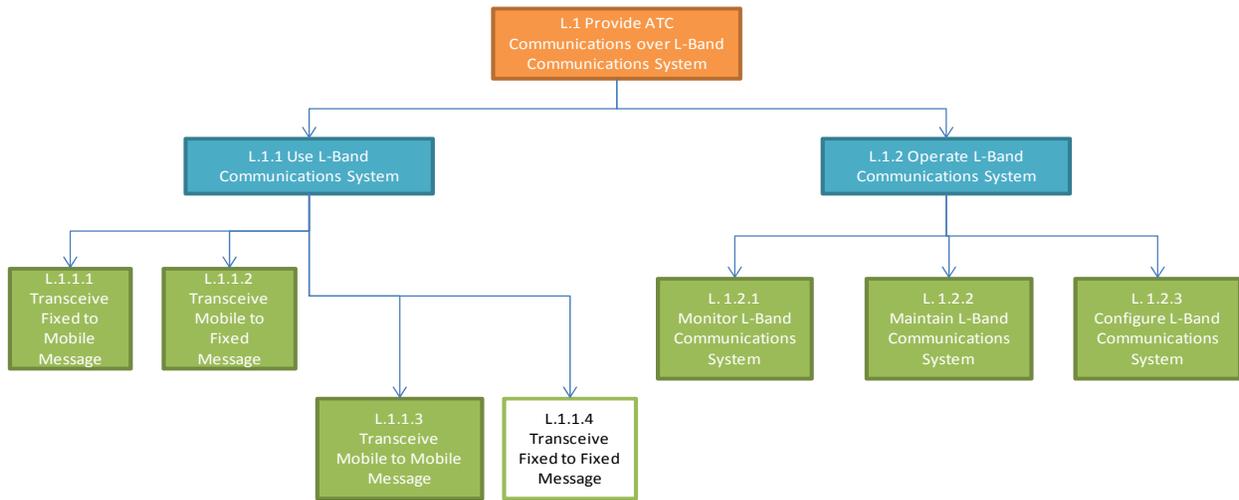


Figure 21.—High-level hierarchy of L-band communications system.

Functional architectures can be presented in several different ways. As indicated in the SEM (Ref. 9), the FAA “prefers using the complementary FFBD (functional flow block diagram) and N² diagramming techniques for modeling the functional behavior of a system.... The simple FFBD technique captures the control (or the logical) environment of a system, while the N² diagramming captures the data environment of a system.” These two techniques are illustrated in Figure 22 and Figure 23, respectively. N² charts were selected to document the L-band functional architecture defined in Appendix C for this high-level architecture and requirements document. These charts are presented in Appendix D.

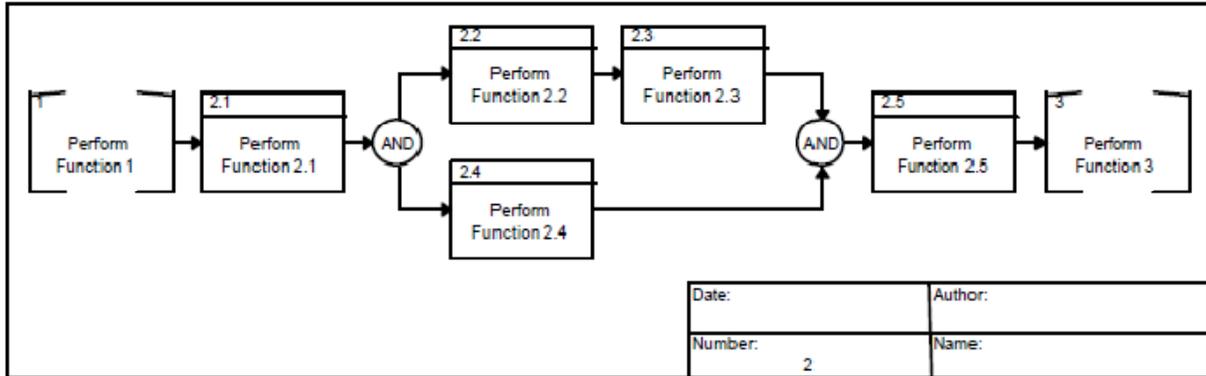


Figure 22.—Functional flow block diagram (from Ref. 9).

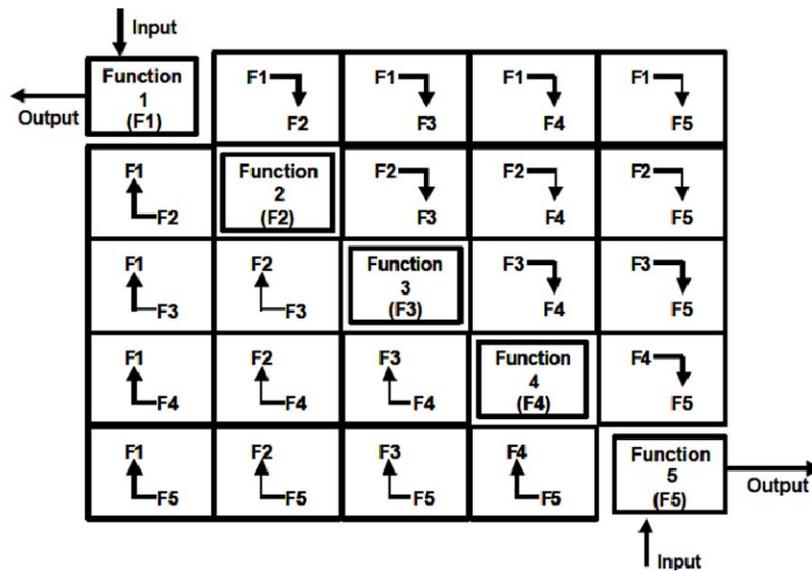


Figure 23.—N² diagram (from Ref. 9).

4.3.2 L-DACS Concepts-of-Operations-Based Functional Analysis

L-DACS could provide a communication link to transfer surveillance and weather information, facilitate flight and resource management, enhance collaborative decision making, and enable exchange of aeronautical information in the future NAS. Tables in Appendix B document the select RTCA NAS ConOps (Ref. 1) found applicable to the proposed L-DACS.¹¹

¹¹Although the RTCA document (Ref. 1) describes the NAS evolution in terms of three time periods—near (up to 2005), mid (2005 through 2010), and far (beyond 2010)—concepts identified in the document are found applicable for the proposed L-DACS, even though it is likely to be implemented beyond 2020 to 2025.

L–DACS should enable a reliable and consistent data exchange by providing the following functionality and associated requirements provided in Table 12.

TABLE 12.—MAPPING OF L–DACS SYSTEM FUNCTIONS TO SYSTEM REQUIREMENTS

System functions	System requirements ^a
Enable ground-to-air (G/A) and air-to-ground (A/G) communication for fixed-to- mobile as well as mobile- to-mobile users	The system shall enable G/A communication for fixed-to-mobile users. The system shall enable G/A communication for mobile-to-mobile users. The system shall enable A/G communication for fixed-to-mobile users. The system shall enable A/G communication for mobile-to-mobile users.
Enable air-to-air (A/A) communication	The system shall enable A/A communication
Support addressed communication for delivery of information to individual and multiple users	The system shall support addressed communication for delivery of information to individual users The system shall support addressed communication for delivery of information to multiple users
Support broadcast communication for delivery of information to multiple users	The system shall support broadcast communication for delivery of information to multiple users
Support delivery of real-time information in a timely manner	The system shall support delivery of real-time information in a timely manner
Enable demand, periodic, and event communication	The system shall enable demand communication The system shall enable periodic communication The system shall enable event communication
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness	The system shall accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness
Support multiple quality of service (QoS) provisions	The system shall support multiple QoS offerings, such as priority and preemption capabilities, and so on
Support authentication of users and controlled access to National Airspace System (NAS) information (security)	The system shall support authentication of users (security) The system shall support controlled access to NAS information (security)
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground and airborne users ^b	The system shall provide support of FAA ground users The system shall provide support of FAA airborne users The system shall provide support of non-FAA ground users The system shall provide support of non-FAA airborne users
Avoid single points of failure	The system shall avoid single points of failure
Provide a scalable solution	The system shall provide a scalable solution
Provide standards-based solution	The system shall provide standards-based solution

^aAll the requirements presented in the document are documented as “system shall” not “system must.” The verbiage is consistent with that used in the NAS SR–1000 as opposed to some of the newer requirements documents.

^bTo support increasing collaboration among NAS users, the proposed system shall accommodate a wide range of NAS users by accepting NAS data from NAS data sources, both internal and external to the FAA. Users may include aircraft, airline operation centers, service providers, FAA users, and other government agencies.

L-DACS applicable NAS ConOps can be traced to the desired functionality of the proposed network. Table 13 maps capabilities identified in the ConUse activities and described in the preceding sections to specific functions necessary to enable those concepts. These functions are grouped into appropriate functional hierarchies and functional requirements are derived. This encompasses a top-down approach to the development of functional requirements. Mapping the proposed services to the desired system capabilities and functional architectures presents combined functional requirements from the top-down and bottom-up approaches.

TABLE 13.—MAPPING L-DACS FUNCTIONALITY TO NAS ConOps
[Acronyms are defined in Appendix A.]

Desired L-DACS capabilities	NAS ConOps references ^a	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable ground-to-air (G/A) and air-to-ground (A/G) communication for fixed to mobile as well as mobile to mobile users.	S-1; S-3; S-4; W-2; W-3; W-5; W-9; W-10; W-11; W-12; W-14; W-15; W-16; W-17; W-19; W-20; W-22; W-27; FM-3; FM-6; FM-9; FM-11; FM-13; FM-17; FM-21; FM-22; FM 24; FM-32; FM-41, FM-42; A-5; A-14; A-23; A-26; A-28; A-29; A-30; A-33; A-34	L.1.1.1.1 L.1.1.1.2 L.1.1.2.1 L.1.1.2.2	D-ORIS D-OTIS ^b D-RVR ^b DYNAV FLYPCY SAP WAKE PPD URCO
Enable air-to-air (A/A) communication	S-7; W-26	L.1.1.3.1	AIRSEP ITP M&S C&P PAIRAPP SURV
Support addressed communication for delivery of information to individual and multiple users	S-1; W-12; FM-11; FM-13	L.1.1.1.1 L.1.1.1.2 L.1.1.2.1 L.1.1.2.2 L.1.1.3.1	D-ORIS D-OTIS ^b D-RVR ^b DYNAV FLIPCY SAP PPD URCO AIRSEP
Support broadcast communication for delivery of information to multiple users	S-1; S-4; W-2; W-3; W-14; W-16; W-20; W-26; FM-13; A-23	L.1.1.1.1 L.1.1.1.2 L.1.1.2.1 L.1.1.2.2 L.1.1.3.1	D-ORIS D-OTIS ^b D-RVR ^b WAKE URCO AIRSEP
Support delivery of real-time information in a timely manner	S-1; S-3; W-10; W-18; W-22; W-24 FM-3; FM-6; FM-14; FM-17; FM-22; FM-35; A-22; A-31; FM-4; FM-15; FM-25; FM-34; RM-3; RM-15; A-9; A-15		D-RVR ^b DYNAV FLYPCY SAP WAKE PPD URCO AIRSEP

TABLE 13.—MAPPING L-DACS FUNCTIONALITY TO NAS ConOps
 [Acronyms are defined in Appendix A.]

Desired L-DACS capabilities	NAS ConOps references ^a	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable demand, periodic, and event communication	S-1; S-8; W-14; W-19; W-20		All services
Accommodate a wide range of data types (e.g., surveillance reports, weather raw data and products, flight profiles, etc.) to support common situational awareness	S-3; W-2; W-3; A-4; A-11; A-33		All services
Support multiple quality of service (QoS), priority, etc.			All services
Support authentication of users and controlled access to NAS information (security)	W-1		All services
Provide support of both Federal Aviation Administration (FAA) and non-FAA ground and airborne users	S-1; FM-18; FM-21; FM-26; FM-29; A-18; A-22; A-33; A-35		All services
Avoid single points of failure	RM-14		All services
Provide a scalable solution			All services
Provide standards-based solution			All services

^aAlthough only select NAS ConOps are presented for this L-DACS capability, most NAS ConOps could be traced to enabling G/A and/or A/G communication.

^bAt the time of this report D-OTIS and D-RVR are listed as part of the RTCA SC-214 scope. As noted throughout this report, the services are considered candidates for L-DACS if not implemented by the Data Comm program.

4.4 L-DACS Performance Requirements

4.4.1 NAS-Level Performance Requirements Applicable to L-DACS

Performance requirements were derived to define system capabilities based on the functional requirements developed in preceding sections and considering propagation characteristic of the L-band. Table 14 summarizes NAS performance requirements found relevant to the proposed L-DACS as documented in the NAS SR-1000 (Ref. 18). Note that these are high-level NAS requirements that do not specify how they should be implemented.

TABLE 14.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 18.]

NAS function	Performance requirement
Control traffic	<p>The NAS shall disseminate hazardous weather avoidance recommendations to users within 1 minute of request. (08440)</p> <p>The NAS shall communicate aircraft actions to users within 1 minute of implementing a weather avoidance plan. (08460)</p> <p>The NAS shall alert participating aircraft to predicted conflicts with obstructions within 10 seconds of prediction. (09170)</p> <p>The NAS shall alert participating aircraft to predicted conflicts with special use airspace within 10 seconds of prediction. (09180)</p> <p>The NAS shall notify users of non-adherence to ATC clearance within 10 seconds of the detection of the deviation. (02010)</p> <p>The NAS shall alert appropriately equipped users to the collision danger within 10 seconds after the prediction is made. (03660)</p> <p>The NAS shall alert users of predicted aircraft-obstacle separation standards violations in en route airspace at least 65 seconds in advance of the actual violation of separation standards. (26110)</p> <p>The NAS shall alert users of predicted aircraft-terrain separation standards violations in en route airspace at least 65 seconds in advance of the actual violation of separation standards. (26100)</p> <p>The NAS shall alert users of predicted aircraft-ground separation standards violations in terminal airspace at least 30 seconds in advance of the actual violation of separation standards. (26060)</p> <p>The NAS shall alert users of predicted aircraft- terrain separation standards violations in terminal airspace at least 30 seconds in advance of the actual violation of separation standards. (26070)</p> <p>The NAS shall alert users of predicted aircraft-obstacle separation standards violations in terminal airspace at least 30 seconds in advance of the actual violation of separation standards. (26080)</p> <p>The NAS shall alert users of predicted aircraft-ground separation standards violations in en route airspace at least 30 seconds in advance of the actual violation of separation standards. (26090)</p>
Support flight operations	<p>The NAS shall disseminate a requested summary of hazardous weather for any airspace in the continental United States within a mean response time 3.0 seconds of the request. (08060)</p> <p>The NAS shall notify users affected by the presence of hazardous weather within 2 minutes of acquisition. (08170)</p> <p>The NAS shall update hazardous weather broadcasts at least once every 30 minutes. (09400)</p> <p>The NAS shall disseminate automated weather observations once per minute to designated interfaces. (05270)</p> <p>The NAS shall disseminate terminal area hazardous weather information to users within one minute of detection. (06990)</p> <p>The NAS shall display requested routine weather information to the user within a mean response time of 3.0 seconds of the request. (23380)</p> <p>The NAS shall display requested routine weather information to the user within a 99th percentile response time of 5.0 seconds of the request. (23390)</p> <p>The NAS shall display requested routine weather information to the user within a maximum response time of 10.0 seconds of the request. (23400)</p> <p>The NAS shall disseminate a requested summary of hazardous weather for any airspace in the continental United States within a 99th percentile response time of 5.0 seconds of the request. (23510)</p> <p>The NAS shall disseminate a requested summary of hazardous weather for any airspace in the continental United States within a maximum response time of 10.0 seconds of the request. (23520)</p>

TABLE 14.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
 [Numbers in the table correspond to performance requirements in Ref. 18.]

NAS function	Performance requirement
Monitor NAS operations	<p>The NAS shall alert users to a full navigation system failure affecting NAS operations within 10 seconds of the failures detection. (17110)</p> <p>The NAS shall alert users to a partial navigation system failure affecting NAS operations within 10 seconds of the failures detection. (17130)</p> <p>The NAS shall disseminate the results of Traffic Management Coordinator capacity projection requests within 99th percentile response time of 5.0 seconds of the request. (10820)</p> <p>The NAS shall disseminate the results of Traffic Management Coordinator capacity projection requests within a maximum response time of 10.0 seconds of the request. (10820)</p> <p>The NAS shall disseminate the results of Traffic Management Coordinator demand projection requests within the 99th percentile response time of 5.0 seconds of the request. (10850)</p> <p>The NAS shall disseminate the results of Traffic Management Coordinator demand projection requests within a maximum response time of 10.0 seconds of the request. (10850)</p>
Plan NAS usage	<p>The NAS shall disseminate current flight activity information in military special use airspace within 1 minute of request. (08890)</p> <p>The NAS shall disseminate requested flow control advisory information to users within a mean response time of 3.0 seconds of the request. (07890)</p> <p>The NAS shall disseminate scheduled flight activity information in military special use airspace within 1 minute of request. (08900)</p> <p>The NAS shall disseminate requested delay advisory information to users within a mean response time of 3.0 seconds of the request. (07900)</p> <p>The NAS shall alert users not more than 10 seconds after any failures of navigation guidance affecting operations within the NAS. (16810)</p> <p>The NAS shall alert users not more than 10 seconds after any failures of portions of navigation guidance affecting operations within the NAS. (16820)</p> <p>The NAS shall alert users within 10 seconds, of failures to navigation guidance that affect operations. (17150)</p> <p>The NAS shall alert users within 10 seconds, of failures to portions of navigation guidance that affect operations. (09590)</p> <p>The NAS shall assure ground-air transmission time for data messages not exceed 6 seconds. (20090)</p> <p>The NAS shall provide retrievable air-ground data messages within 30 minutes and from “off-line” storage within 60 minutes. (20270)</p> <p>Individual air-ground data messages shall be retrievable from “off-line” storage within 5 minutes of a request by authorized NAS personnel. (20280)</p> <p>The NAS shall strive to restore critical system service to users/specialists within 6 seconds of failure. (22900)</p> <p>The NAS shall strive to restore essential system service to users/specialists within 10 minutes of failure. (22910)</p> <p>The NAS shall disseminate requested aeronautical information to users within a mean response time of 3.0 seconds of the request. (23580)</p> <p>The NAS shall disseminate requested aeronautical information to users within a 99th percentile response time of 5.0 second of the request. (23590)</p> <p>The NAS shall disseminate requested aeronautical information to users within a maximum response time of 10.0 seconds of the request. (23600)</p> <p>The NAS shall disseminate requested flow control advisory information to users within a 99th percentile response time of 5.0 seconds of the request. (23950)</p> <p>The NAS shall disseminate requested flow control advisory information to users within a maximum response time of 10.0 seconds of the request. (23960)</p> <p>The NAS shall disseminate requested delay advisory information to users within a 99th percentile response time of 5.0 seconds of the request. (23970)</p> <p>The NAS shall disseminate requested delay advisory information to users within a maximum response time of 10.0 seconds of the request. (23980)</p>

4.4.2 COCR Performance Requirements Applicable to L-DACS

Table 13 demonstrates how the identified concepts of use map to the functional requirements. They, in turn, lead to the performance requirements for addressed and broadcast data services.

Performance assessments start with an end-to-end context and allocate performance requirements to humans, systems, and or subsystems. An operational performance assessment (OPA) begins with required communication performance (RCP) and allocates these requirements to humans and technical components (e.g., equipment). The term required communication technical performance (RCTP) refers to the allocation to the technical components. The performance requirements resulted from the OPA conducted as part of the COCR. That OPA determined the performance a system or service must achieve and led to determination of the availability, integrity, and transaction time requirements. Performance requirements were driven by operational needs and safety requirements as well as other assessments (e.g., information security) to determine overall communication performance requirements.

The more stringent of the safety objectives and operational requirements for each parameter were used to determine the communication performance requirements. The operational requirements were driven by the type of exchange (e.g., trajectory change and general information) and the domain in which the service was offered.

Values in Table 15 are based on COCR ATS FRS performance requirements (Ref. 5) for the select services with the most stringent requirements presented. For example, the WAKE service is a driving service for defining the latency requirements in the airport, TMA, and en route domains.

Performance requirements should be revisited at a later stage in system development process to reflect most current ConUse and services selection.

TABLE 15.—L-DACS DATA REQUIREMENTS
[Acronyms are defined in Appendix A.]

Service type	Confidentiality	Latency (sec)				Integrity	Availability of provision
		APT	TMA	ENR	AOA		
Addressed	Medium	0.4	1.2	1.2	2.4	5.0×10^{-8}	0.999995
Broadcast	Medium	1.4	1.4	2.4	2.4	5.0×10^{-8}	0.999995

4.5 Other L-DACS Requirements

4.5.1 L-DACS Spectrum Requirements

One of the main objectives of the proposed L-DACS system is to increase communications system capacity. A channel plan will be developed driven by frequency availability to support broadband services. Interference studies proposed to be performed in the near future and the subsequent final technology selection will allow defining the channel plan.

The proposed system should provide seamless operations around the globe. To achieve full interoperability, international standards are being developed.

Table 16 summarizes NAS spectrum requirements applicable to the proposed L-DACS as documented in the NAS SR-1000 (Ref. 18).

TABLE 16.—NATIONAL AIRSPACE SYSTEM (NAS) SPECTRUM REQUIREMENTS APPLICABLE TO THE PROPOSED L-DACS

[Numbers in the table are the requirements as they appear in Ref. 18]

Category	NAS Requirements
Secure Spectrum with the Federal Aviation Administration (FAA)	The NAS shall secure and protect national radio spectrum for the FAA and the U.S. aviation community. (32470) The NAS shall coordinate national spectrum allocation programs. (19190) The NAS shall establish new systems spectrum development activities compatible with projected national use. (19290)
Secure frequency for the FAA	The NAS shall establish national frequency allocation programs. (19170) The NAS shall establish new systems frequency development activities compatible with current national use. (19230) The NAS shall establish new systems frequency development activities compatible with projected national use. (19270)
Secure international spectrum	The NAS shall establish new systems spectrum development activities compatible with current national use. (19250) The NAS shall comply with national standards to avoid the interference of new systems with existing systems. (19310) The NAS shall coordinate national spectrum management assistance programs. (19210) The NAS shall disseminate en route navigational guidance such that ambiguities in guidance information have a minimal impact on NAS operations. (13960)
Manage international spectrum	The NAS shall comply with international standards to avoid the interference of new systems with existing systems. (32090)

4.5.2 L-DACS User Requirements

Table 17 summarizes aviation user requirements based on those documented in the RTCA DO-224B (Ref. 41) and found potentially applicable to the proposed system.

TABLE 17.—AVIATION USER REQUIREMENTS

<p>The system shall be capable of supporting all categories of users including the following:</p> <ul style="list-style-type: none"> • Scheduled air transport carriers (including international, trunk, regional, commuter and air freight carriers) • Nonscheduled air carriers • General aviation (GA) (including operators of turbine-powered and reciprocating-engine aircraft); scheduled air transport carriers (including international, trunk, regional, commuter and air freight carriers) • Nonscheduled air carriers • General aviation (GA) (including operators of turbine-powered and reciprocating -engine aircraft) • Rotorwing aircraft (including helicopters and gyrocraft) • Unpowered aircraft (including gliders and lighter-than-air) • Military aircraft • Certain ground and maritime vehicles (e.g., airport service vehicles, those vehicles coordinating in a search-and-rescue mission)
<p>The system shall be capable of operation with appropriately equipped aircraft of all types and all flight regimes including at rest. There shall be no limitation imposed by the intrinsic characteristics of the ground system or the signal-in-space that limit suitable equipage of any type of aircraft or flight conditions,^{a,b}</p>
<p>Relative aircraft velocities $\pm 1,200$ knots (two aircraft converging or diverging each at 600 knots) Relative ground speed 0 to 850 knots (600 knots aircraft plus 250 knots wind) Altitude ground level to 70,000 feet above mean sea level</p>
<p>The new system shall satisfy any data communications requirements for use in any authorized category of communications service including air traffic services, ATS, aeronautical (airline) operational control, and aeronautical administrative communication.</p>
<p>The avionics equipment shall communicate with any compatible ground system. The new system shall be capable of implementation and operation anywhere in the world.</p>

^aRelative aircraft velocity is important for air-to-air communications.

^bDoes not include requirements for extremely high-speed aircraft (e.g., hypersonic transport).

4.5.3 Regulatory Requirements

Table 18 summarizes regulatory requirements based on those documented in the RTCA DO-225 (Ref. 21) and found potentially applicable to the proposed system.

TABLE 18.—REGULATORY REQUIREMENTS

<p>The system shall comply with AM(R)S spectrum allocation requirements. The system shall comply with the U.S. ATS and AOC service rules and regulations. The system shall comply with the U.S. Federal aviation regulations. The system shall support the requirements for message priority capability.</p>

Article 44 of ITU Radio Regulations defines the order of priority for communications in the aeronautical mobile service and the aeronautical mobile-satellite service. Table 19 shows the ITU priority levels (from 1 to 10 respectively from the highest priority to the lowest priority) and maps them to the ATS and AOC services defined by the COCR. Only services identified by Ref. 12 as potential applications for L-DACS are included in the table.

TABLE 19.—MAPPING OF ITU PRIORITY LEVELS TO COCR SERVICES (REF. 42)

ITU Priority Level		COCR Services	
		ATS	AOC ^a
1	Distress calls, distress message and distress traffic	URCO	
2	Communications preceded by the urgency signal		
3	Communications related to radio direction-finding		
4	Flight safety messages	D-RVR	Notice to Airmen (NOTAM)
		D-OTIS	Flight Plan Data (FLTPLAN)
		D-ORIS	Load Sheet Request/Transfer (LOADSHT)
		D-SIG	Update Electronic Library (UPLIB)
		D-SIGMET	
		DYNAV	
		FLIPCY	
		PPD	
		SAP	
		WAKE	
		AIRSEP	
		SURV	
		ITP	
		M&S	
S&P			
5	Meteorological messages	PAIRAPP	
			Textual Weather Reports (WXTEXT)
			Real-time Weather Reports for Met Offices (WXRT)
		Graphical Weather Information (WXGRAPH)	

TABLE 19.—MAPPING OF ITU PRIORITY LEVELS TO COCR SERVICES (REF. 42)

ITU Priority Level		COCR Services	
		ATS	AOC ^a
6	Flight regularity messages		Flight Status (FLTSTAT)
			Maintenance Problem Resolution (MAINTPR)
			Real-Time Maintenance Information (MAINTRT)
			AOC Data Link Logon (AOCDLL)
			Out-Off-On-In (OOOI)
			Cabin Log Book Transfer (CABINLOG)
			Technical Log Book Update (TECHLOG)
			Fuel Status (FUEL)
			Gate and Connecting Flight Status (GATES)
			Engine Performance Reports (ENGINE)
			Flight Log Transfer (FLTLOG)
			Position Report (POSRPT)
			EFFuplink ^b
			EFFdownlink ^b
			CONF ^b
			PERF ^b
VQAR ^b			
CVM ^b			
CabMAINTTRT ^b			
TELEMED ^b			
REFUEL ^b			
DEICING ^b			
7	Messages related to the application of the United Nations Charter		
8	Government messages for which priority has been expressly requested		
9	Service communications related to the working of the telecommunication service or to communications previously exchanged		
10	Other aeronautical communications		Free Text (FREETEXT)
			Software Loading (SWLOAD) ^c

^aMost of the AOC services listed in the COCR are included here as they are either airport-surface-only applications or applicable to both, surface and in-the-air, scenarios.

^bThese are additional AOC services not specified in the COCR and therefore not addressed in the ITU Informational Paper ACP-WGF 19/IP01 as all other services.

^cAlthough listed in the COCR, this service may not be applicable application for a wireless communications system.

4.5.4 Safety and Security Requirements Applicable to L-DACS

A fundamental safety requirement is that a new system shall not cause a degradation in safety when compared with the existing A/G (or A/A, as applicable) communications system. The overall objective is to improve safety. Preliminary safety and security analysis and the associated requirements are covered in a separate document (Ref. 15).

5.0 Physical Architecture

5.1 System Context

The L-DACS architecture can be characterized at many levels. In accordance with U.S. Government policy, all Government agencies, including the FAA, have developed an enterprise architecture (EA). Of most relevance to this report is the NAS EA, which relates to activities that support operational air traffic services. The NAS EA contains architecture products and views that describe the current NAS “portfolio” of infrastructure and services, the 2025 far-term and 2018 mid-term target architectures, and roadmaps to reach the target architectures. Some examples of the NAS EA views have been depicted in Section 3.0 of this report.

Figure 24 shows the NextGen 2025 System Interface Description SV-1p depicting airborne and ground components in the context of the NAS EA. System elements are presented depicting their functionality. A/G communications is shown as an enabler of various NAS services facilitating surveillance, weather, flight management, and other data exchange.

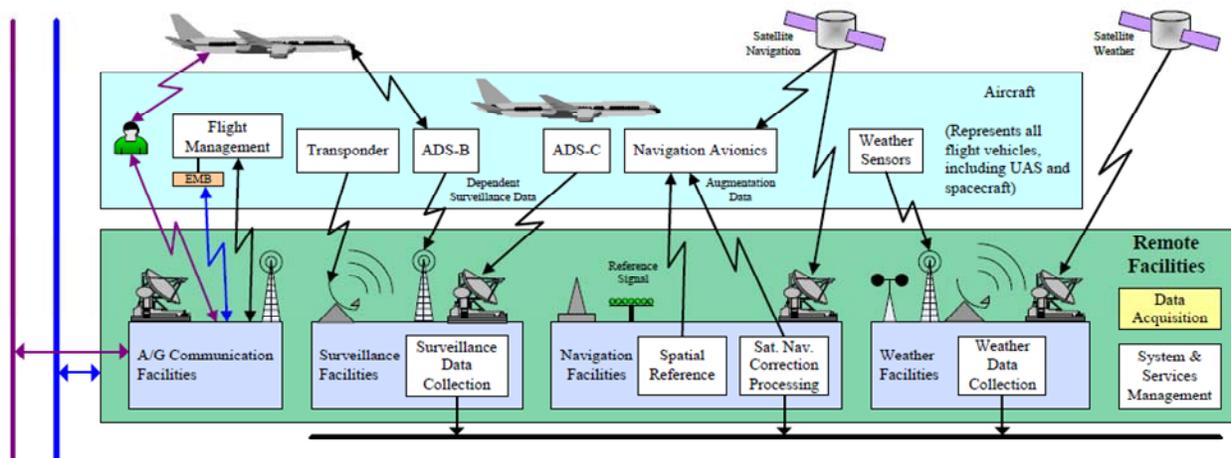


Figure 24.—National Airspace System enterprise architecture airborne elements and remote facilities (Ref. 20). Acronyms are defined in Appendix A.

The L-DACS functionality presented in this document nominally corresponds to the A/G and A/A communications links shown on the left of Figure 24; however, it might serve as a link for other services shown on the figure. The L-DACS architecture, as it matures, may be incorporated into the NAS EA. The high-level L-DACS architecture presented in this document might serve as a high-level entry point for EA incorporation.

5.2 Physical Architecture Development Process

Figure 25 depicts recommended steps for requirements and architecture development as described in the SEM. It should be noted, however, that the FCS technology assessments leading to candidate technologies recommendations were conducted before formal system requirements, ConUse, and architecture were developed. As such, the development of L-DACS candidate technologies: L-DACS1 and L-DACS2, to a certain extent, might dictate a reverse-engineering approach to be taken for developing the proposed system architecture to assure traceability in the technology selection process. It is recommended that this approach be considered as part of future U.S. and European coordination activities in the L-DACS technology downselection process.

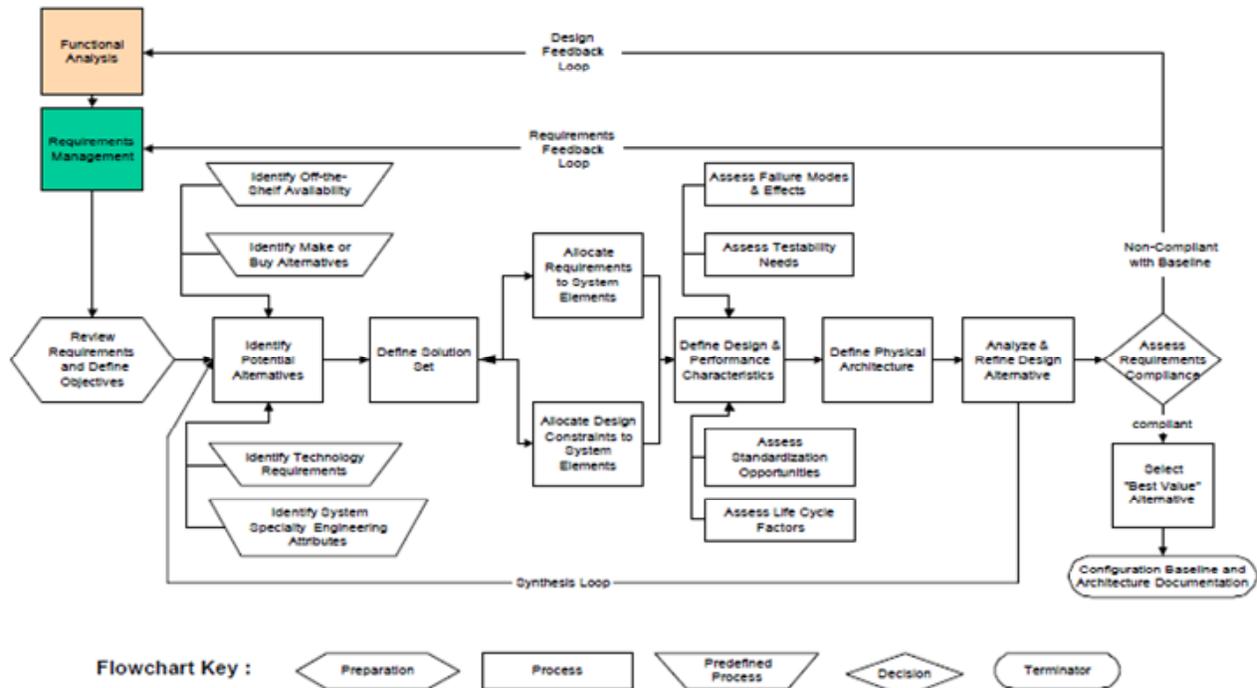


Figure 25.—System requirements and architecture development synthesis loop (Ref. 9).

The physical architecture synthesis element typically defines design solutions and systems that satisfy program requirements. At least one iteration of that process has been completed and is reflected in the FCS technology assessment reports. Another aspect of synthesis—“translating the requirements, as set in context by the functional architecture, into the design architecture, consisting of the physical architecture with its associated technical requirements” (Ref. 9)—is covered in this report.

5.3 L–DACS Physical Architecture

An L–DACS physical architecture can be derived from and represents a technical solution to the functional architecture and requirements. It represents “a hierarchical arrangement of hardware and/or software components along with associated interfaces depicting the physical definition of the system. Lower level Functional Analysis work is constrained by a higher level physical architecture” (Ref. 9).

Figure 26 shows a high-level architecture of the L–DACS system supporting A/G communication. The ground infrastructure comprises a number of L–DACS ground radio stations, each providing a cell-like coverage service volume, and which are geographically situated to provide overlapping coverage (using different frequencies) to achieve seamless service volume handovers. Each ground radio station would be connected to some G/G network through some ground network interface (GNI) (no. 1 in the figure).

6.0 Unmanned Aircraft Systems (UAS)

6.1 Unmanned Aircraft System Operations

The RTCA Issue Paper SC203–CC011 (Ref. 43) describes the characteristics of the current UAS control and communications (CC) data links. The main attributes of the current UAS would apply to the proposed system as well when services are provided over the L–DACS and as such are detailed below.

- Most current UAS are equipped with line-of-site (LOS) control data links. UA with more autonomy (e.g., automatic takeoff and landing) rely less on the LOS system for takeoff and landing, since the pilot is not “in-the-loop” (actively flying the aircraft) but “on-the-loop” (monitoring the flight of the aircraft with the capability to override preprogrammed maneuvers if needed). However, such systems will still require LOS control data links. The level of reliance on the LOS system is reflected in the level of control data link redundancy and low latency adopted by different UAS. Most pilot in-the-loop takeoff and landing UAS use dual redundant data links and have low pilot-control-input-to-pilot-observable-response latencies since the pilot is actively maneuvering the aircraft in real time. Conversely, pilot on-the-loop systems often only have single-thread LOS data links and higher latencies because the pilot is not in real-time control of the takeoff or landing maneuvers. Dual redundant LOS control data links offer the advantage of having two sets of data link equipment significantly improving the overall mean time between failures (MTBF) of the data link. The two links can also offer improved data link availability. For example, if one of the links is temporarily suffering degradation, because of interference or propagation-related effects, then the other link in a different frequency band could take over the delivery of telecommands and telemetry, because interference and propagation effects are not correlated for the two links.

Both links could be provided over the L–DACS.

- Some current UAS are equipped with BLOS UA control systems. Most are satellite-based, offering wide geographical coverage and allowing the aircraft to be controlled thousands of miles away from its takeoff and landing location. While most takeoff and landing activity is controlled using the LOS systems, at a manufacturer-specific altitude or range, the UAS is switched from LOS to BLOS control and is usually flown this way for the bulk of the distant flight activity. The pilot using the LOS system to control the aircraft does not necessarily have to be the same pilot controlling the aircraft using the BLOS system. A LOS system will again be used for landing but not necessarily the same one that was used for takeoff. This allows the UA to make landings at distant locations and also allows for pilot relief. To enhance link availability when using satellite communications, current UAS that fly BLOS missions often utilize two or three different satellite communications systems, all operating in parallel. Typically, the flight computer on the aircraft and the computer in the control station simultaneously monitor all links and choose, on a real-time basis, the best link as appropriate. This link choice can also be manually controlled by the pilot.

The proposed L–DACS will not offer BLOS communication; these links will remain satellite-based.

- Not all current UA carry voice communication equipment. However, all UAS have the ability for their pilot to have voice communication with air traffic controllers and pilots of other aircraft. Current UA that are equipped only for LOS flights often have their VHF voice transceivers located in their control stations. This is adequate when the control-station based VHF transceiver can maintain voice communication with the controlling ATC entity; however, for BLOS operation this is unacceptable. For present-day BLOS missions, the VHF voice communication

equipment must be carried on the aircraft so the pilot can communicate with various ATC centers or pilots as the aircraft transits different regions. In current BLOS UAS, the voice traffic is carried (along with the telecommands and telemetry) as part of the overall data link between the control station and the aircraft. Most of the VHF voice equipment currently used for both LOS and BLOS systems is standard equipment covered by current technical standard orders (TSOs). However, the method for monitoring the voice traffic between the pilot and the VHF equipment, when it is carried by the aircraft flying a BLOS mission, is not specifically covered by current regulations.

It should be noted that while the proposed L-DACS could support voice communication only data communication was planned over the L-band for manned aircraft.

- As all mobile radio communication systems, those used on UA are designed to achieve a specific level of performance and under certain conditions could become temporarily unavailable. Typically, given the statistical nature of the situation, the data links will return to full functionality. The amount of time a particular UA can operate without its data links is dependent on its design and level of autonomy, but after a certain amount of time without a data link all systems must declare that the link is lost. The vast majority of UA have built-in procedures to accommodate lost link situations. Again, the level of autonomy plays a major part in what the UA does after losing its link, but in most cases the aircraft will fly a preplanned maneuver trying to reestablish any data link that might be available while making its way to a precoordinated location where it can be picked up again by the LOS system located at that facility. Transponder-equipped UA may set their transponders to squawk certain codes as part of their lost link procedure.

Lost link procedures will need to be developed for the proposed L-band system.

- Although the Department of Defense (DoD) uses a variety of frequencies for its UAS CC data links (operating in predominantly restricted airspace), no frequency bands are currently allocated specifically for unmanned aircraft use in the NAS. Current UAS Spectrum Usage includes a wide range of frequency bands for control of the UA. Systems operate on frequencies ranging from VHF (72 MHz) up to Ka-band (27 to 40 GHz). The factors driving the choice of frequency are related to limiting the size, weight and power of the airborne data link equipment—particularly antennas and power amplifiers—as well as data rates required. Many BLOS systems share the control link and the payload return link on one common carrier so the wide bandwidth needs of the payload return link may drive this choice more than the lower data-rate needs of the control link.

Spectrum provision for CC is essential for the safe operation of UA and their integration in the NAS. Appendix E discusses UAS spectrum requirements for the proposed L-DACS. Appendix F contains the details of the L-DACS applicability to UAS applications.

- Various messages are carried on the CC links to deliver information exchanges that ensure safe, reliable, and effective UA flight operation. The functions of the data link can be related to the following types of information that are exchanged:
- Telecommand messages: These messages are used for flight control and task execution and usually have higher priority than other message types. They include aerodynamic control messages, power plant control messages, and messages associated with changing the status of the avionics (e.g., frequency of the VHF ATC radio) or aircraft (e.g., raise and lower the landing gear).

- Nonpayload telemetry data: Telemetry data is sent from the UA to the control station and can include a broad range of information. The first type of information relates to the flight characteristics of the UA. This data includes items such as position, flight trajectory, altimeter setting, altitude, heading, speed, route clearance, and arrival time. The pilot uses this data to maintain full awareness of the flight of the UA and to determine the changes needed to ensure safe flight. The second type of information relates to the health and status of UA. Health and status data provides critical information about the condition of the subsystems, sensors, and hardware of the UA. The pilot at the control station uses this information to maintain full awareness of the ability of the UA to function and to diagnose problems. The pilot can then handle potential or actual problems by taking preventive measures or corrective actions to ensure continued functioning and thus safe flight. The third type of information relates to situation awareness data. This type of data describes the operational environment of a UA. Examples of this data are weather conditions and terrain information.
- Navigation aids: Pilot-to-UA uplink that enables the pilot to control the settings of the UA's navigation receivers, and the UA-to-pilot downlink that carries data from those receivers to the pilot's display.
- ATC voice relay: Spectrum is required for relaying (via the UA) voice message traffic between air traffic controllers and the pilot.
- ATS data relay: A nationwide system providing ATS data services of various kinds is expected to be in place by the 2020s. It seems likely that the messages associated with those services will need to be relayed to and from the pilot via the UA.
- Target-track data: Essential sources of target-track data will include
 - The sense-and-avoid (S&A) system (whose architecture is still undefined)
 - traffic information services, broadcast (TIS-B)
 - Automatic dependent surveillance (ADS)-broadcast (ADS-B)
 - ADS-rebroadcast (ADS-R)
 - ADS-contract (ADS-C)
- Nonpayload video downlink data: This data serves to enhance the pilot's situational awareness, especially during takeoff and landing.

The types of messages discussed above apply to the proposed L-band system. As noted earlier, voice communication is not currently considered for the manned aircraft applications and therefore was not the focus of prior FCCs.

- The capacity of the CC links used on current UAS is proprietary to the link manufacturer. However, a survey of publicly available literature indicates that data rates ranging from 1200 bps to 200 kbps are successfully used today to control UA.

To date, UA operations have been limited to segregated airspace.¹² Studies are being conducted to determine the implications of operating UAS in nonsegregated airspace. Currently, UAS use in the NAS is restricted to operating under a certificate of authorization, providing it a special waiver for conducting a flight in the NAS.

¹²As noted in the proposed changes to Annex 16 of 5B/296-E in Ref. 44, the following definitions of types of airspaces were adopted in this document:

- ATC separation assurance—Air traffic control is responsible for safe separation of all aircraft. This comprises Classes A, B, and, if the UAS is operated in accordance with instrument flight rules (IFR), Class C.
- Limited or no ATC separation assurance—Air traffic control is not responsible for safe separation of all airspace users. This comprises Classes D, E, F, and G.
- Segregated—A defined volume of airspace reserved for exclusive use of a particular user.

6.2 Need for Change and Impact on Existing Unmanned Aircraft System Operations

Application of UAS is anticipated to increase over the next decade and beyond, ranging from small local surveillance aircraft to large, unmanned, transoceanic freight carriers. These systems offer low-cost alternatives to manned aircraft applications and present numerous applications opportunities. At the same time, the volume and variety of systems pose new challenges to the airspace management and ATC infrastructure.

Challenges associated with the addition of unmanned aircraft vary from those similar to manned aircraft to UAS specific. Various performance characteristics and different moving patterns—manned aircraft typically go from one location to another, UAS may stay over one location for an extensive period of time—may affect existing NAS operations. This, in turn, would affect departure and arrival and ATC procedures including A/G and A/A communication. As noted in the RTCA DO-304 (Ref. 37), UAS must be able to respond to ATC instructions without degrading the NAS safety any more than a response to a manned aircraft, dictating the performance requirements for the communication links, including latency requirement between the UAS and a remote pilot, compatibility with existing systems, and so on.

In support of spectrum selection and allocation, the SC-203 conducted a comparative analysis of various frequency bands rating them in respect to suitability for UAS applications (in Ref. 44). A relatively high rating was assigned to a lower part of the L-band (960 to 1024 MHz).

Further analysis of industry papers and related ITU-R activities should be conducted to assess the latest spectrum recommendations for UAS communications.

6.3 Unmanned Aircraft System ConUse and Functional Analysis

Figure 28 shows the architectural framework leading to operational functions analysis, as adopted by SC-203.

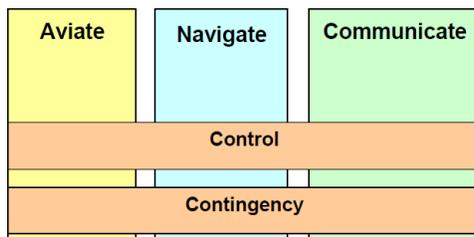


Figure 28.—High-level unmanned aircraft operational functions (Ref. 36).

As defined by the RTCA DO-304 (Ref. 45), the communicate functions involve data and information exchange between the UAS and entities external to UAS, including ATC and non-ATC. Control and contingency functions cut across the boundaries of all three basic functions (aviate, navigate, and communicate). The control functions involve data and information exchange between the UA and control segments of UAS, networking, data bus protocols, and related issues covering internal data and information exchange within a UAS segment. Contingency functions involve procedures or programmed operation that provide for a predictable behavior in the event of system failure such as loss of control link.

The RTCA DO-304, Appendix F, contains a table correlating functional allocation and operations depicted in Figure 28 to systems. (e.g., during preflight phase, route planning, the communications function would be used to check spectrum availability and coverage for intended flight and for all alternate locations) (Ref. 45).

In an ongoing effort to find an RF spectrum to support the CC¹³ links of UAS, UAS L-band is being considered as one of the possible systems to support UAS operations.

The proposed communication system should be designed and implemented to support a seamless integration of UAS operations into current ATC procedures while maintaining the required safety-of-flight levels.

For safe operations of UA under LOS and BLOS conditions, three functions of radio communications between UA and the control station (CS) are to be supported:¹⁴

1. ATC Relay

The link (the downlink bringing the ATC information to the CS and the uplink allowing the remote pilot to communicate with ATC) between air traffic control and the CS via the UA will relay all ATC and A/A communications received and transmitted by the UA in nonsegregated airspace. For communicating with ATC, the UA will use the same equipment as a manned aircraft.

2. Command and Control

The link will provide a two-way communication between the CS and the UA. The uplink will be used to send commands to the aircraft for navigation purposes. This is the command link that would probably necessitate low data rates. The downlink will be used to send the flight status of the UA to the remote pilot. It is anticipated that in some flight conditions or in specific airspaces it could be necessary to downlink video streams. Such a requirement could lead to data rates of several hundreds of kbps per UA.

In areas under the responsibility of the aeronautical authorities, it is expected that the Command and Control communications will have to be compliant with ICAO standards to be further specified on this function. Nevertheless, in the periods where the UA will follow a full autonomous flight, the up and down C2 [Command and Control] links could have very weak rates or be temporarily disrupted.¹⁵

3. Sense-and-Avoid

This function is analogous with the piloting principle “see-and-avoid” used in all air space volumes where a pilot is responsible for ensuring separation from nearby aircraft, terrain and obstacles (e.g., weather).

The system will support a two-way communication between the remote pilot and the UA. The uplink will allow the remote pilot to control the operation of this function according to the conditions of the flight likely requiring high bit rates. The downlink from the UAV to the CS or remote pilot will provide an indication that the function operates as desired. The necessity to send video streams must be considered avoiding duplication between command and control and sense-and-avoid video downlinks.

Similarly to the command and control considerations, it is expected that the “S&A data” (sense-and-avoid data) RF communication requirements will have to be compliant with future ICAO standards for the safe flight of the UA in areas under the responsibility of the aviation authorities.¹⁶

Thus, the three functions above can be further decomposed to show the following classes of LOS communications traffic to be supported by the proposed L-band system:

¹³The RTCA UAS Spectrum document (Ref. 43) limits the term “CC” to nonpayload links intended primarily to ensure the safety and regularity of UA flight. Payload applications such as the downlinking of surveillance data for non-safety purposes were excluded from the scope and not considered in estimating nationwide CC bandwidth requirements or evaluating candidate spectral bands.

¹⁴Based on the research documented in the proposed changes to Ref. 44.

¹⁵Based on the research documented in the proposed changes to Ref. 44.

¹⁶Based on the research documented in the proposed changes to Ref. 44.

- Pilot/UA control links, including telecommand and telemetry
- Pilot/UA NavAids data exchanges
- Relaying ATC voice messages to and from UA pilots
- Relaying ATS data messages to and from UA pilots
- UA-to-pilot downlinking of non-payload target track data
- UA-to-pilot downlinking of data from UA-borne weather radars
- UA-to-pilot downlinking of safety-related video data from UA to pilots
- UA-to-pilot downlinking of safety-related sense and avoid automated decisionmaking from UA to pilots

The proposed system is to support a handover to transfer

- a direct (LOS) RF communication to one dedicated CS¹⁷ to another (LOS) dedicated CS and/or a direct (LOS) to an indirect (BLOS) RF communication link or vice versa.

6.4 Unmanned Aircraft System Applications

Both commercial and Government applications could be provided over the L-band system. As defined by the ITU¹⁸ and illustrated in Figure 29, commercial applications would provide services that are sold by contractors in the course of carrying out normal business operations, while Governmental applications ensure public safety by addressing different emergencies and involve issues of public interest and include scientific matters.

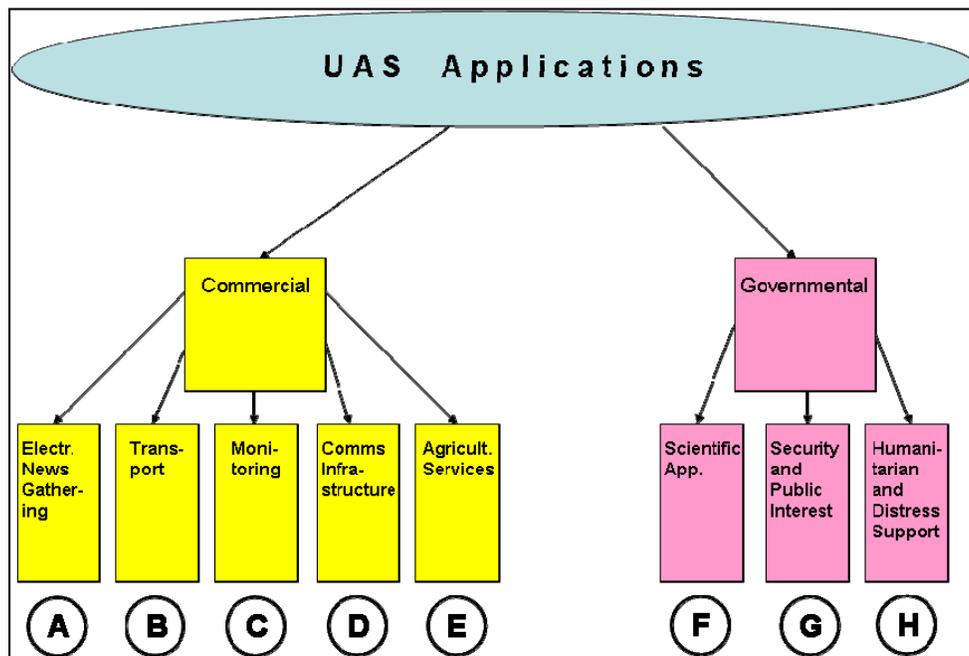


Figure 29.—Unmanned aircraft system applications (from proposed changes to Ref. 44).

¹⁷CS (control station)—One or more facilities or devices from which a UA is controlled remotely as defined in Proposed changes to Annex 16 of 5B/296-E in Ref. 44.

¹⁸Based on the research documented in the proposed changes to Ref. 44.

6.5 Operational Scenarios

Example operational scenarios for each type of application are presented in Table 20. Additional scenarios and detail can be found in Reference 46.

TABLE 20.—UAS OPERATIONAL SCENARIOS
[From proposed changes to Ref. 44.]

Mission type	Scenario description
A	Movie making, sports games, popular events like concerts
B	Cargo planes with reduced manning (one-man-cockpit)
C	Inspections for industries (e.g., oil fields, oil platforms, oil pipelines, power line, rail line)
D	Provision of airborne relays for cell phones in the future
E	Commercial agricultural services like crop dusting
F	Earth science and geographic missions (e.g., mapping and surveying or aerial photography) and biological and environmental missions (e.g., animal monitoring, crop spraying, volcano monitoring, biomass surveys, livestock monitoring, or tree fertilization)
G	Coastline inspection, preventive border surveillance, drug control, anti-terrorism operations, strike events, search-and-rescue of people in distress, public interest missions (e.g., remote weather monitoring, avalanche prediction and control, hurricane monitoring, forest fires prevention surveillance, insurance claims during disasters, and traffic surveillance)
H	Famine relief, medical support, aid delivery. Search and rescue activities.

6.6 Unmanned Aircraft System Requirements

6.6.1 Spectrum Requirements

Based on the research conducted by the ITU,¹⁹ a terrestrial LOS UAS system would require 34 MHz of spectrum.²⁰ (Refer to Appendix E that presents Sections 5.0 and 6.0 of Ref. 44 for details.)

A follow on research is documented in the Preliminary Draft New Report ITU-R M.[UAS-BANDS-EXIST-ALLOC]: Frequency band study to support control links for unmanned aircraft systems (UAS) (Ref. 47). The document notes the highly favorable physical properties of the L-band for UAS control links. Negligible rain losses and low free-space losses should permit reliable long-range LOS communication between relatively low-power radios using omnidirectional and medium-gain antennas. In addition to propagation characteristics, smaller UA whose size, weight, and power (SWAP) budgets do not allow the use of satellite terminals would also benefit from a small size of omnidirectional antennas suitable for airborne use in this band. Reference 47 demonstrates that

...even though much of the band is heavily used by incumbent navigation systems, substantial sub-bands (960–977 and 1151–1156 MHz) are not used by airborne Navaid

¹⁹Assumptions and results presented in proposed changes to Annex 16 of 5B/296-E in Ref. 44.

²⁰The total UAS spectrum requirements are: 34 MHz for a terrestrial LOS system; 49 MHz for a spot-beam satellite system; 169 MHz for a regional-beam satellite system, which can be shared between several satellites, thereby reducing the overall spectrum requirement.

transmitters and contain no fixed ground-based assignments in most of the world. It appears feasible for UAS CNPC [Control and non-payload communications] to share 12 or more megahertz of spectrum in this band without depriving existing systems of needed spectrum. Such an allocation would not be sufficient to meet all the spectral needs of UAS CNPC, but it would furnish small UA with badly needed access to protected spectrum and would provide UA of all types with the band diversity that is essential for reliable pilot-to-UA communications.

6.6.2 Safety and Latency Requirements

RTCA DO-304 (Ref. 45) notes the additional operational complexity associated with the UA. Unlike in manned aircraft operation, a pilot is remote from the aircraft with different people at potentially dispersed locations engaged in subsets of operation adding latency to aircraft operation.

Safe operations of future UAs in nonsegregated airspace could need independent back-up communications.

A UA designed to fly in controlled airspace must be able to operate in both high and low density airspace. The air traffic control system would not necessarily be able to restrict it to low density airspace only. Hence (from Ref. 45)

- It is recommended that larger UAs be equipped with a terrestrial link capability wherever possible.
- A UA may use a GEO satellite link in low density sectors and probably in high density sectors where the total number of UAs in that sector is low.

The impact of latency on UAS command and control systems is a prime factor when considering the safety of operations. Latency will be of the utmost importance when establishing a safety case for the operation of UAs, particularly in non-segregated airspace. Current air traffic management relies heavily on voice communications although information via data links is being progressively implemented. Hence new operational requirements for the future data link environment will also need to be developed (Ref. 35).

6.6.3 Other Requirements

The COCR Version 2.0 (Ref. 5) does not specifically address the requirements to support UAS command and control links (i.e., telecommand and telemetry). It does note that (Ref. 5):

[a]ll other communications services with UASs are considered to be the same as those with manned aircraft, i.e., UAS operation is transparent for the ATM system. In the future, in some parts of the world, the number of these vehicles may represent a large portion of an Air Traffic Service Unit's (ATSU's) traffic load. When providing ATS to a UAS, this may involve the relay of communication and execution instructions to and from a remote pilot; however, operational performance requirements between an ATSU and an UAS remain the same as those between an ATSU and any manned aircraft.

It should also be noted that UAS vary widely in their design and capabilities. This, in turn, would affect communication system requirements.

6.7 Additional Safety Considerations and Assumptions

As noted in the RTCA DO-304 (Ref. 45), the basic premise underling all the assumptions is that the existing NAS is safe and UAS should integrate safely into the existing NAS structure, complying with the rules and requirements placed on current NAS users.

Communication safety and security controls should assure that

- A human pilot is always in control of an UA while it is operating.
- UAS complies with ATC procedures and instructions while in ATC.
- Prevention procedures are in place for unauthorized assumption of control.
- Security of the control and communication links between the UA and control station is provided.
- Requirements and contingency procedures are in place that UAS would follow in the event of control link failure, loss of traffic control communication, or flight termination.
- UAS must have the ability to determine whether the link is temporarily failed or truly lost to initiate procedural loss link safeguards (Ref. 45).
- The contingency procedures may include a code for lost link control, preprogrammed contingency flight path for UA to follow, a way for the pilot to communicate the expected behavior of the UA to the controller, and a fail-safe way to terminate the flight without hazard to public safety (Ref. 45).
- UAS communication link is compatible with other communication systems. This involves
- Mitigation of interference with unintentional continuous transmissions
- Other collision-avoidance systems used by the existing users of NAS

6.8 Unmanned Aircraft System Architecture and Interfaces

A notional system architecture consisting of three segments and the associated internal and external interfaces are shown in Figure 30. The detailed description as well as notional diagrams of each segment can be found in RTCA DO-304 (Ref. 45) and are not replicated here.

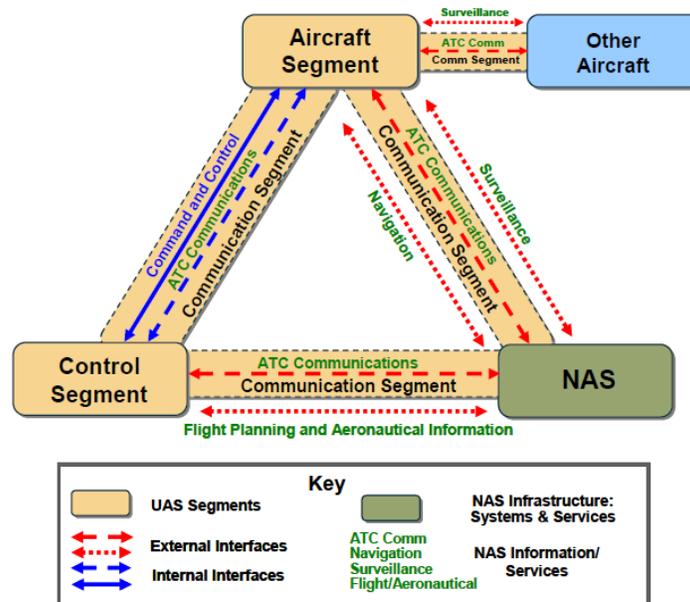


Figure 30.—Unmanned aircraft system (UAS) notional architecture (Ref. 45). Acronyms are defined in Appendix A.

7.0 Preliminary Inputs to L-DACS Design

7.1 Scope

This section describes the set of support activities conducted in cooperation with the FAA's European partners leading the L-band Future Communications System development.

Subsections 7.2.1 and 7.2.2 outline current EUROCONTROL and FAA long-term plans regarding the L-band communications system research and development. Due to changes in the proposed European partners' schedule, some of the activities planned to be completed and detailed in this document were not included in this task. Specifically, further interference analysis and the development of a joint interference testing program have been postponed until corresponding European L-band activities resume. Additionally, refinement of the upper layers of the L-DACS1 protocol stack has been postponed.

Both of the originally proposed technologies (L-DACS1 and L-DACS2) are still being considered for L-band system application; findings presented here are technology independent.

Based on discussions, guidance, and direction received from the FAA and NASA, Phase I Task 7-2E deliverable provides an assessment of L-DACS implementation/transition issues noting various factors that may affect the development process and is combined with the Phase I 7-2A and 7-2B deliverables.

Inputs to Design Specifications are limited to the outputs from the previous analyses presented in the ConUse, System Performance Requirements and Architecture sections of this document and the L-band System Engineering Preliminary Safety and Security Risk Assessment and Mitigation (Phase I deliverable 7-2D, Ref. 15) as well as those completed prior to Task 7.

EUROCONTROL/FAA Teleconferences were held on a regular basis as part of the Task 7 scope. Updates to the L-band system research and development schedule, as appropriate, are included in this document.

7.2 L-DACS Implementation and Transition Issues

7.2.1 FAA L-Band System Development Plans

The 2007 World Radio Communications Conference (WRC-07) approved adding an AM(R)S allocation for 960 to 1164 MHz to the International Table of Frequency Allocations. The proposed band is to be used for an L-DACS for terrestrial en route communications as part of the FCI. This assignment assumes a co-allocation on a noninterfering basis with Aeronautical Radio Navigation Systems (ARNS) in the same band, primarily distance measuring equipment (DME). Consequently, further interference studies and technology analysis are required to assure compliance with this requirement.

The joint FAA/EUROCONTROL AP-17 completed in 2007 resulted in the following recommendations to complete investigations for selection of L-band datalink (Ref. 22):

- Refine and agree on the interference environment and assumptions for the L-band compatibility investigations
- Complete the investigation of compatibility of prototyped L-DACS components with existing systems in the L-band particularly with regard to the onboard cosite interference and agree on the overall design characteristics
- Evaluate and validate the performance of the proposed solution in the relevant environments through trials and test bed development
- Considering the design tradeoffs, propose the appropriate L-DACS solution for input to a global aeronautical standardization activity

Accordingly, the FAA NextGen plan for 2009 (Ref. 48) included the following milestone activities:

- Develop ConUse, preliminary requirements, and architecture for L-band terrestrial communication system
- Develop an L-band communications system prototype to enable validation of proposed standard

Because of fewer VHF spectrum depletion concerns in the United States than in Europe for A/G communications, L-DACS development in the United States was determined to be a lower priority compared with the other future communications components, with L-band technology mainly considered to support far-term applications. Because system capacity and spectrum saturation in the VHF aeronautical communications band appears to be a more pressing issue in Europe, the need for an L-band system is more prevalent in that region. As such, FAA has assumed a support role to the EUROCONTROL efforts in respect to the L-band activities.

The first FY2009 NextGen milestone activity noted above will be met with the deliverables provided under Task 7, including this document, by developing L-DACS ConUse, requirements, and architecture for potential domestic en route applications in the NextGen timeframes. This document will serve as part of the second milestone activity. Its full execution will be postponed and will depend on the EUROCONTROL L-band system development plan and schedule.

Figure 12 depicts the FAA Communications roadmap with the proposed L-band system currently identified as a long-term research and development project.

As Data Comm is fully engaged in the development of VDL Mode 2 capabilities as of the time of this study, the FAA will follow the European lead in L-band system development and provide support in conducting the research and technology development for the FCI based on the ICAO endorsed findings and recommendations of the AP-17 FCS. Activities may include, but will not be limited to

- Supporting joint FAA/EUROCONTROL development and evaluation of the L-DACS system concepts, specifications, and prototype
- Co-developing a joint interference testing program
- Refining the upper layers of the L-DACS protocol stack

These activities will be highly dependent on cooperative planning with the European L-DACS team(s) and their schedules.

7.2.2 Technology Evaluation

Various candidate technologies were considered and evaluated for their support of the future aeronautical requirements under EUROCONTROL/FAA AP-17. Several L-band technologies were identified as candidates to support future en route communication due to favorable propagation characteristics and because of spectrum congestion in the VHF band.

Technology selection remains one of the primary goals in L-band system development. Various technologies for continental systems were analyzed during the AP-17 activities. None of the considered technologies were fully recommended primarily due to concerns about the operational compatibility (spectrum interference) with existing systems in the L-band and/or because of lack of sufficient technical maturity. The assessment of the candidate technologies did lead to the identification of desirable technology features to be used as a basis for the development of a spectrally compatible L-band data link solution. The resulting best candidates are described as follows:

Considering these features and the most promising candidates, two options for the L-band Digital Aeronautical Communication System (L-DACS) were identified. These options need further consideration before final selection of a single data link technology. The first option for L-DACS is a frequency division duplex (FDD) configuration utilizing OFDM modulation techniques, reservation based access control and advanced network protocols. This solution is a derivative of the B-AMC and TIA-902 (P34) technologies. The second L-DACS option is a time division duplex (TDD) configuration utilizing a binary modulation derivative of the implemented UAT system (CPFSK family) and of existing commercial (e.g., GSM) systems and custom protocols for lower layers providing high quality-of-service management capability. This solution is a derivative of the LDL and AMACS technologies. The following table depicts the key characteristics of the two options.

The L-DACS1 option represents the state of the art in the commercial developments employing modern modulation techniques and may lead to utilisation/adaptation of commercial products and standards. The L-DACS2 option capitalises on experience from aviation specific systems and standards such as the VDL3, VDL4 and UAT.

In addition to the air/ground capability, some of the assessed technologies could also support additional features such as air/air (point to point and/or broadcast) communications and digital voice. However the support of these capabilities needs further investigation. The L band data link investigations were primarily based on simulations and analytical investigations. Therefore there is the need to validate the theoretical findings and confirm expected performances using real equipment (Ref. 49).

In line with the AP-17, follow-on activities to further characterize the proposed L-DACS options, validate their performance, and lead to a single technology recommendation for the L-band (Ref. 49),

The SESAR Definition Phase recommended expediting the development and validation of the L band selected technology by developing initial prototypes to support feasibility assessment. Furthermore, it recommended making final technology selection in coordination with other regions by 2010, to allow the development of the technical specifications for inclusion in ICAO SARPs and Manuals.

Figure 31 presents the schedule for completing the selection of L-band technology as presented in September 2009.

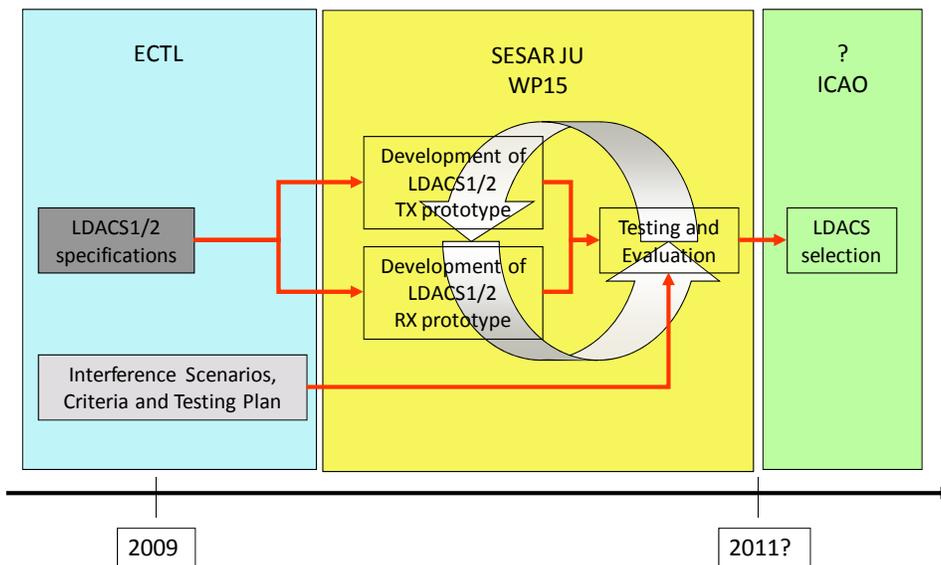


Figure 31.—EUROCONTROL L-band technology selection schedule (September) (Ref. 50). It should be noted that an earlier plan for L-DACS-related activities, as documented in Ref. 51, included 2010 instead of 2011 as completion of testing and evaluation and beginning of L-DACS selection.

To complete the selection of the L-DACS, the detailed specifications for L-DACS1 and L-DACS2 were to be developed in 2009 along with interference scenarios, compatibility criteria, and a testing plan. These activities were proposed to be followed by SESAR joint undertaking (JU) prototype development, testing, and evaluation in to assess the overall performance of L-DACS1 and L-DACS2 systems. The selection of the most appropriate system could then be considered in a global framework involving ICAO.

Figure 13 in Section 3.0 shows the target schedule for expedited L-DACS development as presented in the AP-17 final report in November 2007 (Ref. 22).

This schedule was initially used by the FAA to plan its support activities, especially those related to interference assessment and testing.

At this time, one or more prototypes for L-DACS systems are still being developed. While the activities proposed earlier are still planned, their execution is delayed. As noted above, FAA schedule and activities have been adjusted accordingly.

Figure 32 depicts a communication navigation surveillance/air traffic management (CNS/ATM) roadmap as presented in European Air Traffic Management Master Plan (Ref. 52).

The L-band system is identified as providing capability level 4 to complement VDL-2, in support of more demanding services. It is proposed to allow moving from airspace based to trajectory-based operations. The required research and development tasks include

- Developing and validating A/G architecture for the new L-band link
- Assessing and supporting consolidation of European-wide spectrum requirements
- Developing and validating the selection of the technology for the future terrestrial L-band datalink by developing initial prototypes to support feasibility assessment
- In coordination with other regions (e.g., United States), making final technology selection to allow the development of the technical specifications to be included in ICAO SARPS and manual

It should be noted that while system implementation is not proposed to start until 2016 with the R&D shown beginning 2013, technology selection was still planned to be completed by 2010.

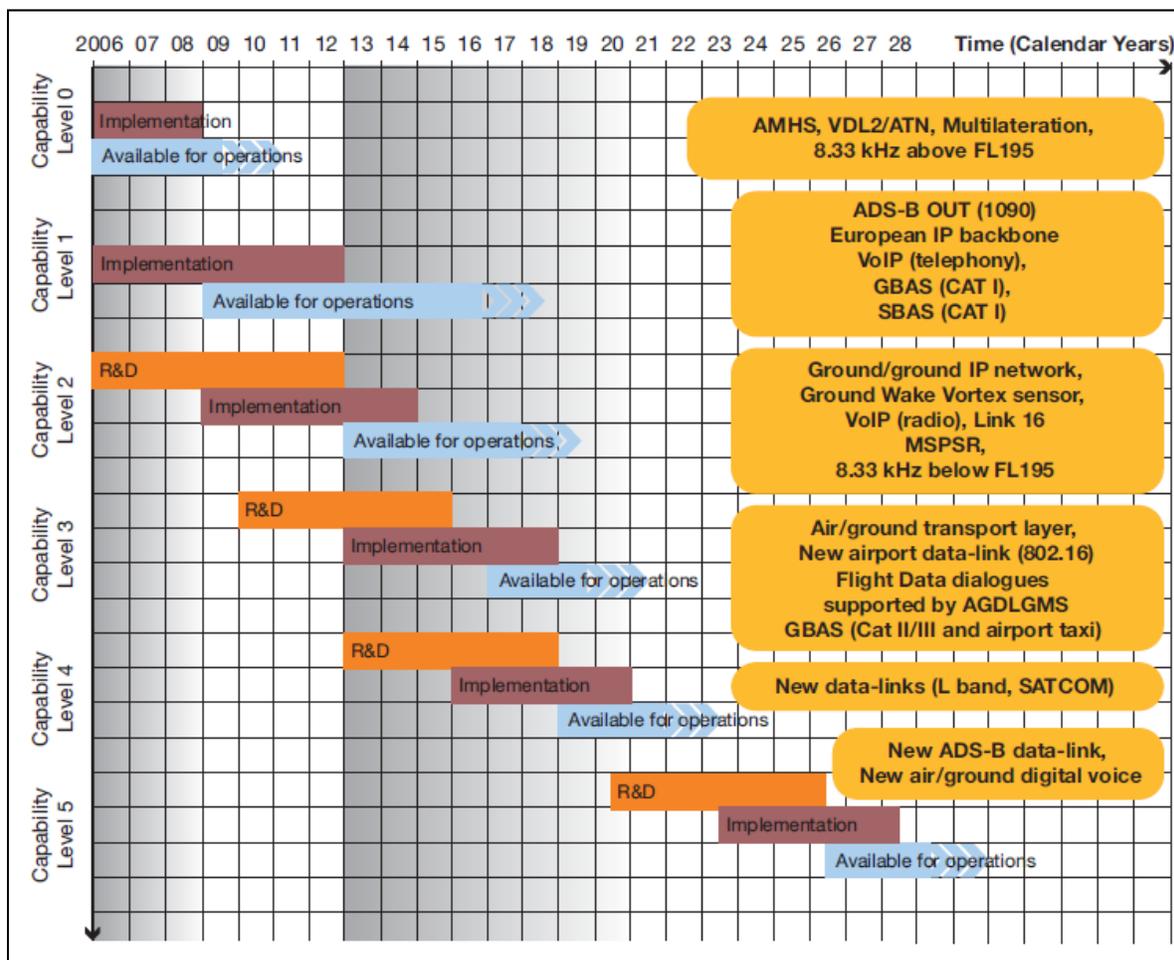


Figure 32.—SESAR CNS systems and infrastructure roadmap (Ref. 52). Acronyms are defined in Appendix A.

7.2.3 L-Band System Implementation

The COCR identifies two phases of implementation of operational service capabilities. The first phase is based on existing or emerging data communications services and is scheduled to be completed around 2020. Initial steps under this phase are currently being implemented. During the second phase data communications is to become the primary means of A/G communication supporting increased automation in the aircraft and on the ground.

The L-band system is proposed to be introduced during the second phase of FRS implementation. It should support A/G as well as A/A communications. A/A communications would be considered a second stage following the A/G communications implementation.

Although data communication is a primary objective for the proposed system, digital voice may be considered in the future set of capabilities.

Figure 33 shows the communications links included for the planned L-band system.

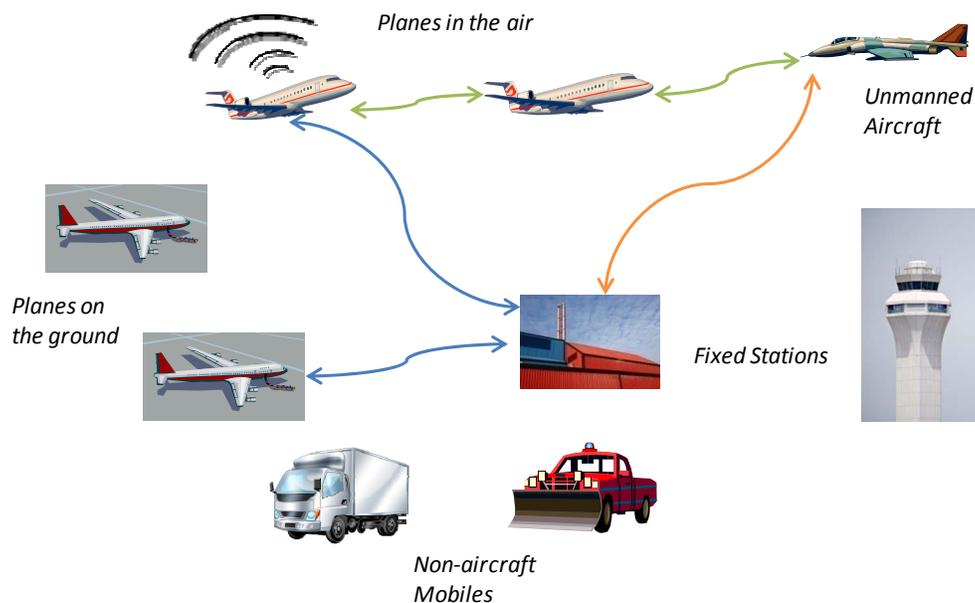


Figure 33.—Proposed L-band communications system capabilities.

In Figure 33

- Fixed-to-mobile communications includes links to aircraft in the air as well as on the ground (to be implemented at the first stage, shown in blue).
- Mobile-to-mobile communications applies to aircraft in the air (second stage, shown in green). No mobile-to-mobile services are currently identified involving aircraft on the ground.
- An L-band communications system is proposed to support UAS. Fixed-to-mobile application(s) involving unmanned aircraft may be implemented at the same time as other fixed-to-mobile services or independently (shown in orange). Mobile-to-mobile UAS to be implemented at the later stage (shown in green).
- Mobile-to-mobile and mobile-to-fixed communications do not include vehicles other than aircraft.
- Mobile-to-mobile (A/A) communications could be broadcast or addressed. Management questions are still to be resolved for addressed communications. Addressed communications implementation may require further development of various network layers.
- Fixed-to-fixed communication is not supported by the proposed system.

7.2.4 L-Band System Transition Issues

The L-band system is part of the long-term aeronautical communication plan and is unlikely to be implemented in the short term or midterm, even in Europe. However, transition issues need to be identified early in the system development process to assure they are properly addressed by the time of system deployment. Because the system will be implemented after many other NextGen components are already in place (e.g., DataComm and C-band aeronautical mobile airport communications system, or AeroMACS), it will have an advantage of benefiting from the work and lessons learned during prior transitions.

As noted in the NextGen Task Force Midterm report (Ref. 42), at this time

The NextGen Task Force is focusing on the difficult transition issues that must be addressed to achieve the goals of improving the performance of the NAS while transitioning to NextGen. This will require us to address policies, procedures, operational approval processes, certification, regulatory guidance, training, criteria and standards—along with technology. Most importantly, we must put ourselves in a position to clearly demonstrate improvements in capacity, efficiency and access in the next 3 to 5 years so the operator community will have the confidence and the commitment to make the business case for the technology investments needed for beyond 2015. We have a plan; now it is time to begin the really difficult work of execution, which is much more difficult than planning because it requires commitment to action.

A similar task force or entity focusing on operational transition for the long-term communication systems, including the L-band, should address the same operational capabilities elements considered for the mid-term transition (Ref. 53):

- Change in roles (e.g., pilot, controller)
- Required technology and equipage
- Available technology and equipage
- Required decision support tools
- Required policy change (DOT general, FAA general, FAA air traffic, FAA–AVS (advisory services), DoD)
- Required new procedures
- Implementation bandwidth
- Required airspace changes
- Required standards
- Required operational approval
- Required certification
- Political risk
- Links to planning documents
- Required training
- Other challenges
- Environmental considerations

Although the NextGen task force is not intended to produce technical guidance and requirements recommendations, its focus on government-to-industry consensus to resolve critical integration and implementation issues maximizes benefits of NextGen operational capabilities and aids in resolving business- and investment-related issues associated with implementing those capabilities.

Technical details are still being developed and operational capabilities are not yet fully defined for the L-band system. A final selection of services chosen as applications for the new system will greatly influence transition time and process. When implemented, the system will provide a long-term capacity solution and will allow the introduction of new communications services. A gradual transition to the new band and services will lead to mixed equipage aircraft cooperating for extensive periods of time.

A special consideration is given to the transition of UAS operations. As noted by the RTCA SC-203 (Ref. 45),

One aspect of the way ahead is to consider that not all UAS CC links need to operate in the same frequency bands or use the same technologies. All that is required is sufficient connectivity to allow individual UAs to operate in their desired airspace. Thus an evolutionary process is possible without mandating migration of existing UAS operations to the new bands and transmission systems as they become available. If an evolutionary process is chosen, some communications technologies could be made available for UAS operations quickly while others are being developed. It is important to note that with an evolutionary process, the short-term solutions will possibly have limited capacity so expansion of UAS operations beyond a limited capacity will require the introduction of the next solution.

7.2.5 Relationship between the Proposed Systems

Figure 34 illustrates how the proposed L-band system may relate to the VDL-2 and/or the AeroMACS systems.

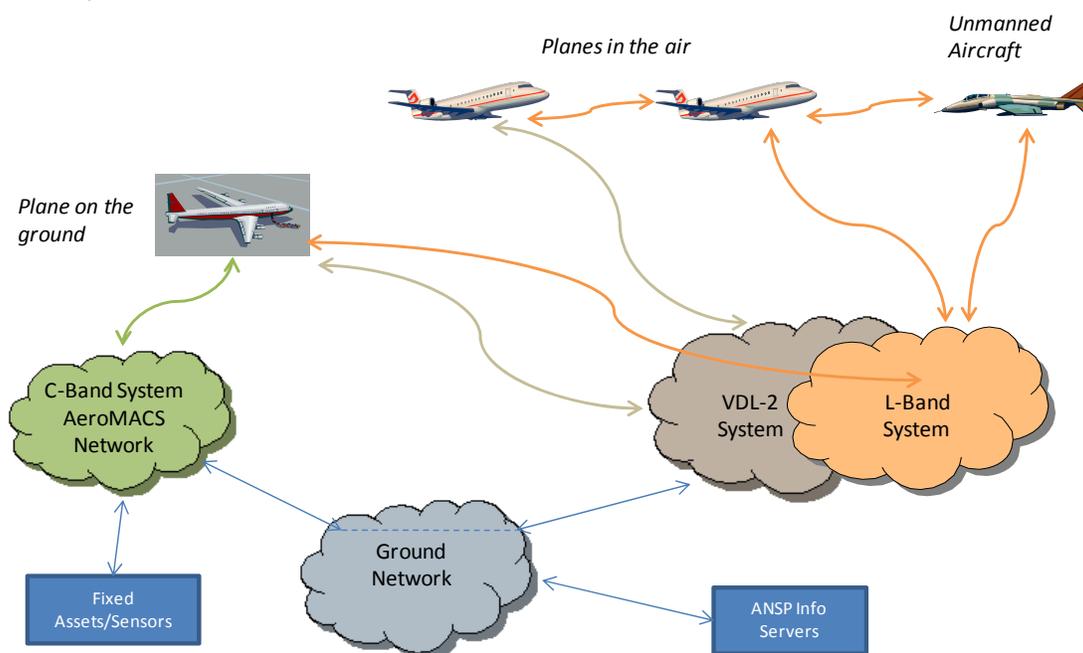


Figure 34.—Relationship between the L-band system and the VDL-2 and C-band systems. Acronyms are defined in Appendix A.

In Figure 34

- An aircraft on the ground may receive some services over an AeroMACS system and other services over a VDL-2 and/or L-band .
- An aircraft in the air may be on VDL-2 only, both VDL-2 and L-band or L-band-only systems depending on services and transition stage.
- A/A communications is shown as being provided on L-band only.

- UAS- related services are assumed and shown as provided on L-band.
- L-band and C-band systems are “connected” through the ground network only. L-band systems will not access C-band sensors or otherwise communicate with the C-band fixed assets directly.

As it may take 10 years or more to equip all aircraft with the new FRS equipment, operation on different data links could be expected for many years and planned for accordingly. Transition issues will include but not be limited to the controllers adjusting communications procedures from voice to a mixed voice/data to potentially data-only communications for some information transfers. With respect to voice vs. data communications, it should be noted, that voice communications are likely to remain as a backup in case of data communications failures and “voice-based procedures will remain as an alternative form of communications depending on the dynamics of the situation” (Ref. 5). Additionally, as noted earlier, the second stage of L-band implementation may include digital voice-based services.

As noted above, the proposed L-band system presents a long-term solution for filling in the gaps in the NAS communications services and could be implemented to complete and tie together future NextGen capabilities. At this stage, the implementation/transition issues identified in this document can only present a preliminary discussion and should be revisited as the L-band development progresses and other systems and services (DataCom VDL-2, AeroMACS C-band network, etc.) are deployed prior to L-band system implementation.

7.3 Summary of the Analyses

7.3.1 Design Specifications Development Process

Figure 35 presents a flow chart illustrating the system engineering process leading to the system requirements definition. Key system engineering processes are completed to serve as inputs to synthesis. Then, synthesis products are used to drive design specifications and lead to systems that satisfy the requirements. Each of the elements in the chart are not a one-step task but rather an iterative process undergoing multiple iterations before producing an output that could be used by a proceeding process. Additionally, as shown in Figure 35, processes are interrelated and loop back to verify and fine-tune the results.

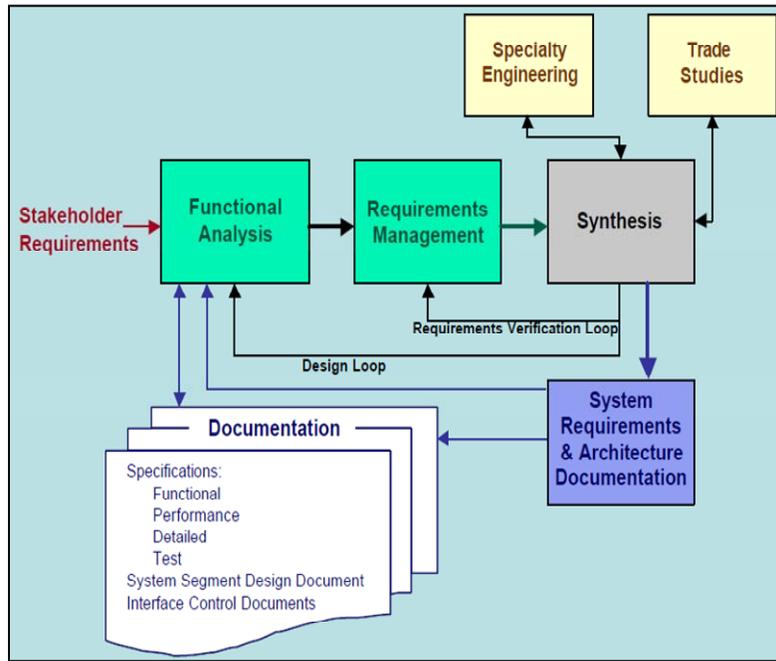


Figure 35.—Federal Aviation Administration (FAA) System Engineering Manual (SEM) requirements and architecture definition process (Ref. 9).

Multiple system engineering processes providing the requirements and architecture for the proposed L-band system have been completed to date.

Operating concepts and requirements for the FRS have been defined and reflected in the COCR Version 2.0 (Ref. 5). The FCI aeronautical data services definition task produced a list of services identified as potential applications for an L-band system. An L-band system can be viewed as part of the FRS providing a subset of services described in the COCR. As such, many of the requirements identified in the COCR would apply to the proposed L-DACS.

The ConUse (Section 3.0), System Performance Requirements (Section 4.0), and Architecture (Section 5.0) describe L-band system concepts that result in functional system requirements and drive the proposed system architecture.

Preliminary safety and security risk analyses (typically performed as part of the specialty engineering process shown in the Figure 35) define system design specifications required to provide a necessary level of safety and system security.

Initial prototype design specifications for L-DACS1 and L-DACS2 were developed in Europe and are part of the iterative system development process. Interference scenarios have been defined to support future testing. Matching these specifications to system requirements and continuing the interference testing process will be part of requirements management and final technology selection. The final technology selection will be based on several technology assessment studies conducted to date.

Monitoring stakeholder requirements is an ongoing effort to assure the proposed system meets the evolving customer needs.

7.3.2 Spectrum Requirements and Channelization

7.3.2.1 Spectrum Allocation

AM(R)S spectrum²¹ is currently at or near saturation in high-traffic areas. Additional spectrum is required to support future navigation and surveillance systems and to allow for planned introduction of UAS into ATS airspace. WRC-07 agenda was called “to consider additional allocations for the AM(R)S in parts of the bands between 108 MHz and 6 GHz, in accordance with Resolution 414 (WRC-03)” (Ref. 54).

Although the initial focus is on bands currently available to aviation, potential bands were reviewed taking into account regulatory issues, as safety services require a higher degree of spectrum protection, an international scope of aviation for global allocations and interoperability, and technical requirements. As stated in the Spectrum Issues and the WRC-07 FAA Preparation presentation at the 2007 ICNS Conference (Ref. 55), results from the studies included the recommendation to utilize a portion of the 960- to 1215-MHz band (portions of the L-band) for an LOS system with low-moderate data throughput. At the WRC-07, a coallocation for AM(R)S spectrum was approved in the 960- to 1164-MHz band. That is the band that L-DACS is designed by EUROCONTROL in which to operate.

The attributes of L-band selected to provide en route communications include (Ref. 55)

- Good propagation characteristics providing for an LOS transmission with moderate transmit power
- Internationally standardized current use
- 960- to 977-MHz used globally for national allotments
- Availability of a large portion of spectrum (up to 60 MHz is needed with a number of distinct channels based on prior studies)
- Options for designed compatibility with incumbent users

²¹Spectrum designated for providing safety and regularity of flight services via terrestrial (A/G, A/A) communications. Allocations designated as “(route)” or “(R)” for ATC and AOC.

- WRC Conference Preparatory Committee Methods (CPMs): 960- to 1024- or 960- to 1164-MHz with no change to the current allocation always being a (usually unstated) CPM. The current U.S. WRC proposal supports 960- to 1024-MHz with regulatory protections for existing uses. It should be noted that there is a considerable difference in operational environment above 1024 MHz (secondary surveillance radar (SSR), radio navigation satellite system (RNSS), etc.)

Ongoing analysis of industry papers and ITU-R-related activities should be conducted as part of the follow-on work to assess the latest spectrum recommendations.

7.3.2.2 Interference Studies

Several civil and military systems operate, or will operate, in parts of the 960- to 1215-MHz band, as shown in Figure 36. Detailed compatibility analyses are required between the proposed L-band system and the incumbents.

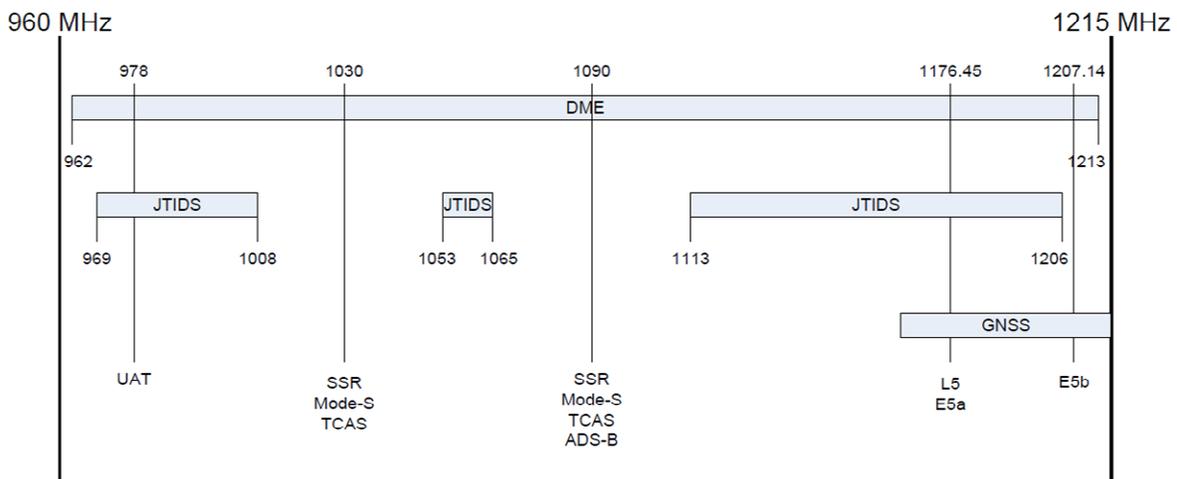


Figure 36.—Systems operating in the 960- to 1215-MHz band (Ref. 56). Copyright Mileridge Ltd.; Used with permission. Acronyms are defined in Appendix A.

Several studies have been conducted in Europe to characterize L-band frequency environment and identify potential interference problems.

The B-AMC²² Project Deliverable D1 (Ref. 56)—Spectrum Characterization—identifies and analyzes three spectrum sharing options offering the following conclusions:

- Option 1: B-AMC utilizing spectrum between successive DME channels deploying the proposed system as an inlay in the L-band (960 to 1164 MHz). B-AMC frequency planning is required to implement the system utilizing channels between successive DME channels.
- Option 2: assigning frequencies to B-AMC channels in areas where they are not used locally by DME. A combination of selecting B-AMC channels with a certain frequency offset from nearby DME systems, and ensuring that a minimum separation distance is maintained to allow avoiding causing interference to DME, SSR, and UAT.
- Option 3: utilizing the lower part of the band (960 to 978 MHz) for B-AMC considering interference with the Global System for Mobile Communications (GSM), which is operated in the lower adjacent band. The report notes that insufficient information is available to determine whether it is technically feasible to implement this option.

²²As noted in Figure 36, B-AMC and TIA-902 (P34) provide the basis for L-DACS1 technology.

The subsequent systematic interference investigations report documents the impact of DME interference onto the performance of the B-AMC system to determine the level of tolerable interference power. It concludes that (Ref. 57)

When selecting appropriate centre frequencies for the B-AMC system, all interferers with the power level below -100 dBm can be neglected. Moreover, the interference situation in each channel can be simplified to one representative interferer with representative power and duty cycle, hence facilitating the ranking of different candidate centre frequencies with respect to interference condition.

The conducted studies highlighted the need for interference testing. Proposed L-band interference scenarios (Ref. 58) were developed by DLR to define the procedures for generating interference scenarios that model interference from the incumbent systems to the proposed L-band system. Though interference depends on many factors, the document defines general procedures that should apply to any L-band frequency range.

As the DME systems present the main source of interference in the aeronautical L-band, strong emphasis is put on modeling interference with these systems. The document describes creating a DME interference simulator, discusses the methodology for generating interference scenarios taking into account DME ground stations, and investigates interference originating from aircraft interrogating these stations. Examples of interference scenarios for B-AMC reverse and/or forward links are given as appropriate. Interference from other L-band systems is addressed by modeling JTIDS, UAT, and SSR pulses.

An additional study has been conducted by Roke Manor to investigate coexistence issues between DME systems and a B-AMC system providing a future A/G communication service in the L-band while assessing relevant system design issues. The DME and B-AMC coexistence study report draws the following conclusions and makes recommendations to EUROCONTROL (Ref. 59. Copyright Roke Manor Research; used with permission):

- As it is not clear whether benefits of OFDM on the reverse link outweigh the need for a highly linear airborne power amplifier, it is recommended to examine methods to reduce peak-to-mean ratio of OFDM in the reverse link (e.g., by using a single carrier FDMA or a similar technique).
- Interference link budgets indicate that coexistence of B-AMC and DME systems is possible with a guard band of one DME channel between them. It is recommended to investigate whether key FCS system parameters could be selected in line with a commercial OFDM standard (e.g., WiMAX) to an extent that would facilitate partial reuse of COTS solutions.
- Without a guard band, and disregarding the effects of terrain, existing DME stations in Europe could cause up to -75 dBm peak and -87 dBm mean interference into a B-AMC receiver at a 9000-m altitude, assuming optimal frequency planning. It is recommended to assess whether it is possible to have the required guard band between DME and B-AMC through frequency coordination, taking into account the DME deployment in Europe and the effects of terrain.

The draft B-AMC frequency plan addresses interference and compatibility issues (Ref. 60).

The draft frequency planning approach described in this report is restricted to the scenarios involving only B-AMC and DME systems. Moreover, as with current DME/TACAN planning, only ground-air scenarios with airborne victim DME and B-AMC receivers have

been investigated. As the En-Route coverage is the most demanding case with respect to the usage of spectral resources, this case has been investigated in detail—TMA and airport planning have been delegated to the future work.

The document specifies basic frequency planning rules according to B-AMC Deployment Option 2—inlay deployment with a 0.5-MHz frequency offset between B-AMC and existing DME channels and presents an initial draft frequency plan for the deployment of B-AMC within Europe (Ref. 60. Copyright University of Salzburg; Used with permission.)

Within the initial planning exercise, large 120 nm En-Route B-AMC cells have been considered, with ground B-AMC TX power of +38 dBm. As expected, simultaneously considering the interference from the B-AMC GS [ground station] towards airborne DME receivers and the interference from DME GSs towards airborne B-AMC receivers have imposed strong restrictions upon the pool of available B-AMC frequencies. In the consequence, for some B-AMC cells an appropriate B-AMC inlay frequency could not be found (at least not without re-arranging DME allocations). In order to further increase the percentage of assignable B-AMC cells, the following supplementary conceptual refinements have been discussed:

- Extension of the FL/RL B-AMC frequency range (985.5- to 1008.5-MHz to 979.5- to 1018.5-MHz)
- Reduction of B-AMC cell radius for some B-AMC cells (from 120 nm to 60 nm), with the corresponding reduction of the B-AMC TX power (from 38 dBm to 32 dBm)
- Placement of B-AMC en route ground stations at sufficient distance from DME stations (fine adjustment of B-AMC ground station positions)
- Investigation of an alternative B-AMC “overlay” concept with 0-MHz frequency offset to existing DME frequencies.

The set of scenarios for several combinations of proposed improvements has been developed and investigated. The following general conclusions apply to that case:

- The B-AMC en route system can be operated as a cellular system with different cell sizes.
- For a large number of B-AMC cells in Europe, appropriate B-AMC candidate frequencies can be determined, which do not violate the stringent interference requirements (−106.6-dBm threshold with 12-dB margin) towards the DME system.
- Taking into account the dense distribution of DME and TACAN stations in Europe, as an overall conclusion the obtained preliminary results are quite positive. However, detailed evaluation of the B-AMC interference situation is required, covering all interference scenarios mentioned in subchapter 3.1.3 [of Draft B-AMC Frequency Plan report] and considering appropriate reuse distances.

Recommendations include the following:

- Investigating other interference cases that could not be considered in this report (A/A and A/G) and their impact upon frequency planning should be included as a topic for future work.
- Common agreement about the acceptable interference threshold for DME/B-AMC receivers should be achieved in the environment with multiple interferers.
- The draft criteria for frequency planning used in this work should be refined, dependent on the outcome of the above activities.

All the studies described in this section were conducted for B-AMC/L-DACS1 systems. While general spectrum constraints will apply to any L-band system regardless of the technology, studies for L-DACS2 also need to be conducted should this technology be considered for a proposed L-band system. Common assumptions, metrics, and interference criteria for both candidate technologies should be established and followed to enable an objective comparison between them.

In June 2010, the Preliminary Report on Interference Mitigation Techniques. SESAR Project P.15 2.4 – Task EWA04-1 T1a (Ref. 61) was delivered. This Task T1a report documents the latest SESAR JU activities related to the investigation of appropriate interference mitigation techniques for L-DACS1 receiving systems. Specifically, it considers the aircraft L-band cosite interference scenario, while leaving evaluation of other interference scenarios as subject of the follow-on Task 1b activity.

The Task T1a report consists of the following:

- Analysis of the cosite interference environment, including a description of the types of interference likely to be encountered, and detailed descriptions of the transmitter characteristics of several potential interferers: DME (Distance Measurement Equipment), UAT (Universal Access Transceiver) and SSR (Secondary Surveillance Radar) Mode S
- Summary of L-DACS1 characteristics to a level necessary for the understanding of the analyses performed and described in the report
- Assessment of the potential interference levels at the victim L-DACS1 receiving systems for each of the three identified interfering systems
- Description of the candidate interference mitigation techniques
- Preliminary analysis of mitigation technique implementation on L-DACS receiving system hardware and waveform structures
- Conclusion and further T1b work to come

The report concludes that (Ref. 61)

... it is necessary to carefully combine the frequency offset between the interferers and the victim RX, the receiver filtering and several of the above signal processing IM [interference mitigation] techniques to achieve the required interference rejection. For instance, cross polarization used with signal canceller, pulse blanking, or array of dual-polarized antennas may be good choices, which have to be more thoroughly studied in T1b.

It should be noted that, though earlier activities included preliminary consideration of the impact of L-DACS on the incumbent L-band systems, current European L-DACS interference mitigation are focused exclusively on the impact of the incumbent L-band system transmissions on L-DACS receiving systems. It is recommended that further evaluation on the impact of L-DACS transmissions on the incumbent L-band system receiving systems be performed when the L-DACS design has sufficiently matured.

7.3.3 Design Specifications and Prototype Development

EUROCONTROL has funded studies to provide the specifications for the L-DACS. The following reports were created for L-DACS1 and L-DACS2 candidate systems identified in ICAO and in the SESAR definition phase to support the FCI in the continental en route and TMA environments:

- L-DACS1 System Definition Proposal: Deliverable D3-Design Specifications for L-DACS1 Prototype, Edition 1.0, April 27 2009, Frequentis, DLR, University of Salzburg, and Selex (Ref. 62)
- L-DACS1 D2 Final Deliverable Edition: 1.0, Frequentis, DLR, University of Salzburg, and Selex, February 13, 2009 (Ref. 63)
- L-DACS2 System Definition Proposal: Deliverable D1 Edition 0.34, EGIS AVIA, March 11, 2009 (Ref. 64)
- L-DACS2 Transmitter and Receiver Prototype Equipment Specifications: Deliverable D3 Edition 1.2, EGIS AVIA, June 18, 2009 (Ref. 65)

System specification studies capture the parameters relevant for the prototype development. The prototypes are (Ref. 62)

aiming at demonstrating that the L-DACS system does not introduce unacceptable interference towards receiver of other L-band systems, as well that the L-DACS system itself satisfactory operates under presence of L-band interference coming from such external systems.

Prototype development and subsequent system testing will facilitate final L-band system technology selection. Both, ground and airborne, as well as cosite²³ scenarios will be investigated. Criteria and scenarios study key deliverable will include

- Compatibility criteria
- Testing plan
- Interference scenarios
- Interference scenarios and use of suppression bus for a cosite case

SESAR Project 15.2.4 deliverables from the Early Tasks of the project, including L-DACS1 Specification, Multilink Operational Concept and L-DACS Evaluation Criteria will be provided to the U.S. for review and comment. A detailed plan of the P15.2.4 is expected in February 2011 with the full project activities to follow. Continued research, development and testing activities closely coordinated between EUROCONTROL and FAA will allow realization of desired system capabilities while adhering to the strictest safety and security requirements.

²³DME receiver and FRS transmitter on board an aircraft.

Appendix A.—Acronyms and Abbreviations

The following list identifies acronyms and abbreviations used throughout this document.

A/A	air to air
A/G	air to ground
ACARS	Aircraft Communications Addressing and Reporting System
ACL	air traffic control clearance
ACSTS	Aerospace Communications Systems Technical Support
ADAS	AWOS Data Acquisition Service
ADDS	Aviation Digital Data Service
ADS	automatic dependent surveillance
ADS-B	automatic dependent surveillance—broadcast
ADS-C	automatic dependent surveillance—contract
ADS-R	automatic dependent surveillance—rebroadcast
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Airport Communications System
AFB	Air Force Base
AFIS	airport/aerodrome flight information service
AGDLGMS	Air Ground Data Link Ground Management System
AIRSEP	air-to-air self separation
AMHS	air traffic services message handling system
AM(R)S	aeronautical mobile (route) service
AMS(R)S	aeronautical mobile satellite (route) service
AMACS	all-purpose multichannel aviation communication system
ANSP	air navigation service provider
AOA	autonomous operations area
AOC	aeronautical (airline) operational control
AP-17	Action Plan 17
APT	Airport
ARINC	Aeronautical Radio Incorporated
ARNS	Aeronautical Radio Navigation Services
ARTCC	air route traffic control center
ASDE-X	airport surface detection equipment, model X

ATC	air traffic control
ATCRBS	air traffic control radar beacon system
ATCSCC	air traffic control system command center
ATCT	air traffic control tower(s)
ATFCM	air traffic flow and capacity management
ATIS	Automatic Terminal Information Service
ATM	air traffic management
ATO	Air Traffic Organization
ATS	air traffic services
ATSP	air traffic service provider
ATSU	air traffic service unit
AVS	advisory services
AWOS	Automated Weather Observing System
B-AMC	Broadband Aeronautical Multicarrier Communication System
BASOP	base operations
BLOS	beyond line of sight
BUEC	backup emergency communications
C&P	crossing and passing
CATM	collaborative air traffic management
CC	control and communications
CDA	continuous descent arrivals or continuous descent approach
CDM	collaborative decision making
CDTI	cockpit display of traffic information
CMU	communications management unit
CNS	communication, navigation, surveillance
COCR	communications operating concepts and requirements
ConOps	concepts of operations
ConUse	concepts of use
CPFSK	continuous phase frequency shift keying
CPM	conference preparatory committee method
CS	control station
CTA	controlled times of arrival
Data Comm	Federal Aviation Administration Data Communications Program

DC	data communications
DCL	departure clearance
DCNS	data communications networks services
DME	distance measuring equipment
DoD	Department of Defense
D-ATIS	digital automatic terminal information service
D-ORIS	data link operational route information service
D-OTIS	data link operational terminal information service
D-RVR	data link runway visual range
D-SIG	data link surface information and guidance
D-SIGMET	Data Link Significant Meteorological Information
DSC	downstream clearance
DSS	decision support system
D-TAXI	data link taxi clearance
DTS	Dedicated Telecom Services
DYNAV	dynamic route availability
EA	enterprise architecture
EAR	Export Administration Regulation
ECCN	Export Classification Control Number
ECS	emergency communications system
EIS	emergency information services
ENR	en route
ERAM	en route automation modernization
ETVS	enhanced terminal voice switch
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FCI	future communications infrastructure
FCS	Future Communications Study
FDD	frequency-division duplex
FDPS	flight data processing system
FFBD	functional flow block diagram
FIS	flight information service

FLIPCY	flight plan consistency
FMS	flight management system
FOC	Flight Operations Center
FPR	final program requirements
FRS	future radio system
FY	fiscal year
GA	general aviation
G/A	ground-to-air
G/G	ground-to-ground
GBAS	ground-based augmentation system
GBT	ground-based transceiver
GI	general information
GIS	geographical information system
GMSK	Gaussian minimum shift keying
GNI	ground network interface
GSM	Global System for Mobile Communications
HP	high performance
HPA	high performance airspace
HVAC	heating, ventilation, and air conditioning
ICAO	International Civil Aviation Organization
IDS	information display system
IEEE	Institute of Electrical and Electronics Engineers, Inc
IFR	instrument flight rules
ILS	instrument landing system
IM	infrastructure management
IOC	initial operating capability
IP	internet protocol
ISE	information security engineering
ITP	in-trail procedures
ITU	International Telecommunication Union
IWP	integrated work plan
JPDO	Joint Planning and Development Office
JTIDS	Joint Tactical Information Distribution System

L-DACS	L-Band Digital Aeronautical Communications System
LDL	L-Band digital link
LOS	line of sight
M&C	monitoring and control
M&S	merging and spacing
MAC	Media Access Control
MTBF	mean time between failures
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASCR	NAS common reference
NAS EA	National Airspace System Enterprise Architecture
NAVAIDS	navigation aids
NEXRAD	Next Generation Radar
NEXCOM	Next Generation Air/Ground Communications
NextGen	Next Generation Air Transportation System
NNEW	NextGen Network Enabled Weather
NOCC	National Operations Control Center
NOTAM	Notice to Airmen
OFDM	orthogonal frequency division multiplexing
OI	operational improvement
OPA	operational performance assessment
ORP	oceanic, remote, polar
OSD	operational services and environment description
OV	operational view
PAIRAPP	paired approaches
PIREP	pilot report
PLA	project-level agreement
PPD	pilot preferences downlink
QoS	quality of service
RAPCO	radar approach control
RCAG	remote communications air/ground facility
RCE-C	remote control equipment at control site
RCE-R	remote control equipment at remote (transmitter/receiver) site

RCP	required communication performance
RCTP	required communication technical performance
RDVS	rapid deployment voice switch
RE&D	research, engineering and development
RF	radiofrequency
RFI	radiofrequency interference
RJ	regional jet
RMS	remote-monitoring subsystem
RNAV	area navigation
RNP	required navigation performance
RNSS	Radio Navigation Satellite System
RTCA	RTCA, Inc. (founded as Radio Technical Commission for Aeronautics)
RTR	remote transmitter/receiver
RVR	runway visual range
S&A	sense and avoid
SAMS	special use airspace management system
SARPs	standards and recommended practices
SAP	system access parameter
SAS	Single Authoritative Source
SATCOM	satellite communication
SBAS	satellite-based augmentation system
SE	system engineering
SEM	System Engineering Manual
SESAR	Single European Sky ATM Research
SITA	Société Internationale de Télécommunications Aéronautiques
SOA	service-oriented architecture
SOC	Service Operations Center
SOCC	Security Operations Control Center
SPR	safety and performance requirements
SR	system requirement
SSE	system safety engineering
SSR	secondary surveillance radar
SUA	special use airspace

SURV	surveillance
SV	system view
SWIM	System Wide Information Management
SWLOAD	software loading
SYSCO	system-supported coordination
TACAN	tactical air navigation
TAP	tailored arrival procedure
TBA	traffic information broadcast by aircraft
TBO	trajectory-based operations
TCAS	Traffic Collision Avoidance System
TDD	time-division duplex
TDLS	Terminal Data Link System
TFM	traffic flow management
TFR	temporary flight restrictions
TIA	Telecommunications Industry Association
TIS-B	traffic information services, broadcast
TM	traffic management
TMA	terminal maneuvering area
TMIs	traffic management initiatives
TRACON	Terminal Radar Approach Control Facility
TRL	technical readiness level
TSOs	technical standard orders
TVS	terminal voice switch
UA	unmanned aircraft
UAS	unmanned aircraft system
UAT	universal access transceiver
UHF	ultra high frequency
URCO	urgent contact
VDL	very high frequency digital link
VHF	very high frequency
VoIP	digital voice over internet protocol
VOR	very high frequency omnidirectional radio range
WAKE	wake vortex

WARP	Weather and Radar Processor
WINS	Weather Information Network Server
WRC	World Radio Communications Conference
Wx	weather
4-D	four-dimensional
4DT	four-dimensional trajectory

Appendix B.—National Airspace System Concept of Operations Applicable to the Proposed L-band Digital Aeronautical Communications System

L-band Digital Aeronautical Communications System (L-DACS) could provide a communication link to transfer surveillance and weather information, facilitate flight and resource management, and enable exchange of aeronautical information in the future NAS. Table 21 through Table 25 document the select RTCA National Airspace System (NAS) Concepts of Operation (ConOps) found applicable to the proposed L-DACS.

In addition to the relevant section number, the “Relevant text” column presents the specific text from the NAS ConOps document (Ref. 1) pertaining to the identified type of information being exchanged and/or service provided.

Section 4 of Reference 1 is devoted to surface operations. The proposed L-band system would mostly facilitate communication with an aircraft in the air (wheels off the ground), and the select surface communications operational concepts presented here were found relevant. It is assumed that the L-DACS could enable transfer of data and information from ground locations to an aircraft prior to landing to facilitate movement on the surface.

TABLE 21.—THE ROLE OF SURVEILLANCE INFORMATION: RTCA NATIONAL AIRSPACE SYSTEM (NAS)
CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED L-DACS
[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
S-1	1.5.2	Traffic information collected by surveillance systems is transmitted to properly equipped aircraft. Thus equipped users have position information of appropriate aircraft available to support flight deck decisions.
S-2	1.5.3 2nd bullet	Enhanced CNS systems and automation in aircraft complement automation aids on the ground permitting more autonomous operations. This improved autonomy combined with greater ability to share information permits workload to be distributed between service provider and operator in a balance appropriate for the operations being conducted.
S-3	4.1.31	Accurate airport environmental information, including traffic, permits appropriately equipped aircraft to navigate on the airport surface with almost no forward visibility ^a .
S-4	4.2.21	The proliferation of CDTI avionics and supporting ground infrastructure takes place in this time frame. The ground system that receives aircraft position reports also broadcasts traffic information and a complete set of graphical and text weather products. Safety is enhanced by situation displays that depict airborne and surface traffic as well as aerodrome information.
S-5	4.3.21 1st paragraph	In addition, ground-based surveillance data is shared with users as a safety enhancement for preventing incursions.
S-6	5.1.1 3rd paragraph	Pilot situational awareness increases through the introduction of CDTI, as well as better weather and navigation information, increases safety and efficiency of approaches and departures and leads to better runway utilization.
S-7	5.1.3 2nd paragraph	Virtually all aircraft are equipped to provide position and intent information, and to receive position and intent data from other aircraft.
S-8	6.1.2	En route surveillance is accomplished through a combination of primary radar, beacon interrogation, and broadcasts of aircraft position and speed. As more sources of position data become available, more traffic is under some form of improved surveillance. An increasing number of aircraft are equipped with satellite based navigation, digital communications, and the capability to automatically transmit position data.

TABLE 22.—THE ROLE OF SURVEILLANCE INFORMATION: RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED L-DACS
[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
W-1	1.4 2nd bullet	In addition to this pool of common information, SWIM provides context-sensitive information to NAS elements that require the information. (This includes flight deck access to the information, such as weather and resource status.)
W-2	1.5.2 9 bullet	A SWIM system is developed by the service provider to distribute timely and consistent information across the NAS for both user and service provider planning ... The system serves as an avenue for greater exchange of electronic data and information between users and service providers including ... Dynamic information including but not limited to current and forecast weather, radar summaries, hazardous condition warnings, information on updated airport and airspace capacity constraints temporary flight restrictions (TFR), and special use airspace (SUA).
W-3	1.5.3 6th bullet	There are continued advancements in the scope and accuracy of the weather information available to the service provider and use throughout the NAS, including automatic simultaneous broadcast of hazardous weather alerts for wind shear, turbulence, microburst, gust fronts; and areas of precipitation, lightning, icing, and low cloud ceilings and visibility. SWIM provides access to this information to all service providers and to participating aircraft via data link. Improved weather information integrated into DSSs and disseminated via data link reduces encounters with hazardous weather.
W-4	2.1.1	TFM service providers monitor traffic, weather, and infrastructure... Improved information exchange among users and service providers enables shared insight about weather, demand, and capacity constraints which enhances the users understanding of NAS status and TFM initiatives.
W-5	2.1.3 4th paragraph	The National Weather Service tracks and projects weather systems using constantly updated data. Using this data fused with the automatically received data from airborne platforms , flow managers have accurate information to use in developing TFM initiatives.
W-6	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information including airport status and acceptance rate, composite weather information developed collaboratively by the FAA and users to assure a common projection of future weather.
W-7	3.1.2 1st paragraph	A common geographical information system (GIS) format is used to store all NAS information including terrain, obstacle, weather, and navigation, surveillance and communication coverage information. This information is available via SWIM to all service providers and users.
W-8	3.2.1 4th paragraph	Data-link-equipped users load the flight plan directly into the flight management system (FMS). The user obtains a complete weather briefing for the proposed route via the FOC computer. In addition, system-wide information is obtained via the FOC SWIM interface.
W-9	3.2.3 3rd paragraph	Greater use of electronic flight planning, navigation database updates and weather briefing services via SWIM results in the routine transfer of preflight planning data to the flight deck. Dynamic safety-critical (e.g., turbulence, icing) and other flight plan is data linked directly to aircraft for use during flight.
W-10	3.3.2 3rd paragraph	There is a wider use of information automatically down-linked from the flight deck. The information (incorporated into SWIM) includes current flight conditions and aircraft performance characteristics. Information uses include better weather prediction, creation of normalized turbulence maps, and improved safety analysis.
W-11	4.1.11 2nd paragraph	The introduction of data-linked meteorological information improves overall situational awareness. Properly equipped aircraft receive graphical weather information via data link, including current observations, pilot reports, hazardous phenomena in both graphic and text format, and winds aloft information.
W-12	4.1.21 3rd paragraph	Clearances, airport information, and weather conditions (e.g., current, forecast, hazardous) are provided over data link to more users at more airports.
W-13	4.1.21 4th paragraph	The system provides access to airport environmental information, arrival, departure, and taxi schedules, airborne and surface surveillance information, flight information, ATIS and other weather information, and TFM initiatives.
W-14	4.1.31 1st paragraph	Hazardous weather alerts are automatically and simultaneously broadcast to aircraft via data link and service providers via SWIM.

TABLE 22.—THE ROLE OF SURVEILLANCE INFORMATION: RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED L-DACS
[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
W-15	4.2.11 1st paragraph	Many users continue to use Aircraft Communications Addressing and Reporting System (ACARS) as a source of data linked information. ATIS and other weather information are received via data link or by voice.
W-16	4.2.21 3rd paragraph	The ground system that receives aircraft position reports also broadcasts traffic information and a complete suite of graphical and text products, including precipitation/lightning, icing, low ceiling/visibility maps, surface hazards, and wind shear and turbulence information, as well as site-specific weather reports and forecasts. Safety is enhanced through the use of situation displays that depict airborne and surface traffic as well as aerodrome information.
W-17	4.3.11 1st paragraph	SWIM and ACARS enhance the service provider’s ability to provide data products such as NOTAMs and meteorological information to the airport vicinity. Although weather information and advisories continue to be available via traditional means, there is increased use of automation to collect and package the information and increased use of data link to disseminate routine and hazardous weather and traffic information.
W-18	4.3.21 1st paragraph	SWIM provides access to weather and information via data link to flight crews , allowing them to develop near-real-time picture of the surrounding environment. SWIM and data link also expedite the service provider’s task of providing data products such as NOTAMs and meteorological information for the airport vicinity when changed or needed y the user.
W-19	5 5th and 6th bullets	Automatic exchange of information between aircraft and ground-based DSSs improves the accuracy and coordination of arrival profiles. Aircraft wind and weather information is shared with the service provider and users.
W-20	5 7th bullet	Accurate weather information is available to service providers. In addition, automatic broadcast of hazardous weather alerts for wind shear, microburst, gust fronts are delivered simultaneously and presented graphically to the user and service provider.
W-21	5.1.1 3rd paragraph	This [increased pilot situation awareness through CDTI] coupled with better weather and navigation information, increases the safety and efficiency of approaches and departures, resulting in better runway utilization.
W-22	5.1.2 2nd paragraph	Data link and flight deck displays enable pilots to monitor current meteorological data, automated hazardous weather alerts, and surrounding traffic , thus reducing the number of verbal miscommunications of this routine information.
W-23	5.1.2 5th paragraph	Improved weather data and displays, including increasingly accurate information on weather severity and location, minimize disruption in departure and arrival traffic.
W-24	5.2.2 1st paragraph	Real time weather information and maps are available via SWIM on the flight deck.
W-25	5.2.3 4th paragraph	When operationally advantageous and mutually agreed upon, flight deck separation is authorized by ATC. Most [DoD] aircraft are equipped with satellite-based navigation aids and many have data link capability and onboard collision avoidance avionics.
W-26	5.3.2 4th paragraph	The service provider has improved capabilities to assist pilots in avoiding hazardous weather. Enhanced weather data and weather alerts are depicted on service provider displays, and are immediately available, via SWIM, to the user. These displays improve the service provider’s ability to coordinate with pilots and with other service providers to ensure the avoidance of hazardous weather.
W-27	6.1.2 4th paragraph	These services include certain ATC clearances, current and forecast weather, NOTAMs and hazardous weather warnings, updated charts, current weather, SUA status, and other required data that are up-linked (or data-loaded) to the aircraft to facilitate better planning.
W-28	6.3.1 3rd paragraph	There is improved weather information available to service provider pilots. This information, available from common weather sources, increases the service provider’s effectiveness in controlling aircraft in airspace that contains hazardous weather and in providing weather advisories to pilots.

TABLE 23.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS)
[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
FM-1	1.5.1 8th bullet	The high-altitude airspace permits aircraft operations along user-preferred profiles from entry through cruise to final exit. Entry to and exit from the airspace are based on preferred profiles for climb and descent. Within that airspace, aircraft operate closer to their optimum altitudes by increasing the available flight levels using 1000-ft rather than 2000-ft separation.
FM-2	1.5.2 8th bullet	Terminal-area procedures are expanded to provide increased efficiency, flexibility, predictability, and airspace accessibility. When the projected demand for volumes of airspace is at or near capacity and after collaboration between users and TFM, there are temporary route structures with transition points for moving to and from user trajectories.
FM-3	1.5.2 9th bullet	A SWIM system is developed to distribute timely and consistent information....[Including]: Flight information on each flight, including the filed flight profile and all amendments, first movement of the aircraft, wheels-up, position data in flight, touchdown time, gate or parking assignment, and engine shutdown.
FM-4	1.5.2 13th bullet	The flight planning system accommodates all uses of the airspace as the flight profile evolves to include real time SUA operations scheduling information.
FM-5	1.5.2 14th bullet	By integrating all airspace management systems, the NAS achieves the technical goal of providing in a timely manner the airspace necessary to execute the flight profile. The ATM system manages airspace based on each user's needs, including proximity to the user's base of operations. As a result, more airspace, including special use, is made available to more users with increased efficiency.
FM-6	2.1.2. 1st paragraph	Collaboration via DSSs and intelligent agents supports negotiation of revised flight trajectories in real time.
FM-7	2.1.3	Flow-constrained areas are managed by allocating access, collaborative rerouting, and realigning sectors and associated resources.
FM-8	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information, including airport status and acceptance rate and composite weather information developed collaboratively by the FAA and users to ensure a common projection of future weather. Improved individual support capabilities use investigative operations and develop individual strategies to mitigate demand-capacity imbalances and their effect on the individual user fleets. Sharing strategies with the ATCSCC allows service providers to evaluate conditions based on user intention rather than published schedules.
FM-9	2.2.1 2nd paragraph	Working with the service providers, users better manage en route congestion by collaboratively evaluating the situation, developing re-routes around the area, and providing a more refined allocation of flights to the reroutes.
FM-10	2.2.2 1st paragraph	With the increasing ability to maintain common situation awareness, users plan flight profiles that consider known constraints and provide the best advantage to their operations.
FM-11	2.2.2 2nd paragraph	... In addition, the flight planning system expands to offer users the opportunity to provide alternative profiles for flights. These alternative profiles are tested on a continuing basis as trial plans that are selected if conditions do not develop as foreseen. The users and service providers collaborate by modifying/exchanging these alternatives throughout the course of the flight.
FM-12	2.2.3 1st paragraph	... Within that constraint and allocation, the NAS has the ability to conduct a system-supported coordination (SYSCO) ⁸ auto-negotiation of the flight profile to best meet the user's need within that user's NAS resource allocation. The systems interactively re-plan each flight against both current constraints and any ancillary problems that arise through the execution of the initiative. For airborne flights, new profiles that do not require a tactical change to trajectory are provided to the flight deck for approval and execution and are included into the NAS as profile updates. For flights that have nearer-term tactical changes, the new profile is provided to the flight deck and service provider as trial plans and are implemented when appropriate.
FM-13	3 1st bullet	Elements of SWIM are used to obtain and distribute flight-specific data and aeronautical information, including international coordination of planned flight trajectory.
FM-14	3 6th bullet	Real-time trajectory updates reflect more realistic departure times, resulting in more accurate traffic load predictions, and increased flexibility due to the imposition of fewer restrictions.

TABLE 23.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS)

[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
FM-15	3 2nd bullet	As the information available through SWIM increases, a more collaborative role for users evolves based on the access to accurate real-time NAS information for improved flight planning. Examples of this information include current and predicted SUA status, infrastructure status, traffic density, and prevailing TFM initiatives.
FM-17	3 3rd bullet	Decision support suites are available for both interactive preflight planning with the service provider as well as changes by the pilot and/or dispatcher during the course of the flight.
FM-17	3.1.1 3rd paragraph	There is real-time sharing of system demand and the virtual ATM information, enabling service providers to collaboratively interact with the user and to mutually develop solutions to problems.
FM-18	3.1.2 2nd paragraph	Flight plan information is incorporated into the flight profile. This profile can be as simple as the user's preferred path or as detailed as a time-based trajectory that includes the user's preferred path and preferred climb and descent profiles. The climb and descent profiles may include extended periods of continuous change. This is similar in nature to a discretionary clearance (climb or descent) but is part of the flight planning process and, ultimately, the approved flight profile. This negotiated profile is available both to the user and to service providers across the NAS.
FM-19	3.1.2 3rd paragraph	To generate the flight profile, users access current and predicted weather, traffic density, restrictions, and SUA status information . When the profile is filed, it is automatically checked against various conditions and constraints. Potential problems are displayed automatically to the user for reconciliation. Upon filing, the flight profile created at the initiation of planning is updated, as are all affected projections of NAS demand.
FM-20	3.1.2 4th paragraph	At the completion of the planning process, the user supplies the service provider with both the flight profile that best balances the NAS constraints and the user's preferred flight profile. This information, including any subsequent changes, is available electronically to all service providers until the termination of the flight.
FM-21	3.1.3 1st and 2nd paragraph	Interactive flight planning capabilities with immediate access to real-time data are fully implemented and are available throughout the flight to the flight deck, FOC, and service provider. User-preferred routing is available to all properly equipped aircraft for both domestic and international flights. Controlled times of arrival (CTA) are the primary method for regulating flows in the planning, tactical, and strategic timeframes. The flight profile evolves with changes to operations to allow greater flexibility in user preferences, including the planning and filing of parabolic flight profiles.
FM-22	3.2.1 2nd paragraph	The TFM information network enables a two-way exchange of real-time information . Using flight plan information, flow managers determine when either airport or airspace demand is predicted to exceed capacity, thereby warranting some type of flow management initiative. NAS users receive information about projected areas of concern and revise their plans on a real-time basis.
FM-23	3.2.1 4th paragraph	Data link-equipped users load the flight plan directly into the aircraft Flight Management System (FMS) . The user obtains a complete weather briefing for the proposed route via the FOC computer. In addition, system-wide information is obtained through the FOC SWIM interface.
FM-24	3.2.2 1st paragraph	SWIM ensures a continuously updated information base of NAS items, including service constraints and infrastructure status. The flight planner uses this data to prepare a flight profile by performing a probe for the user-preferred route against the known system constraints. User DSSs using information available via SWIM analyze the route that most closely balances user preferences and constraints. The use of CTAs continues to expand across NAS resources. As conditions change during the planning phase or during the flight, the user is notified, and he/she is able to interactively determine the impact of the changes on the flight and modify the flight profile as desired.
FM-25	3.2.2 2nd paragraph	The status of active and proposed flights, as well as real-time updates to reflect more realistic departure times (e.g., the latest planned departure times) are available to users. SWIM and SYSCO facilitate more effective collaborative decision making (CDM) between the FOC and service provider.

TABLE 23.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS)

[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
FM-26	3.2.2 paragraph 3	Most aircraft are equipped with advanced navigation and some form of data link communications. Properly equipped aircraft can also access the NAS status information, and pilots can participate in the collaboration to develop new flight profiles while airborne. These proposed flight profile changes are coordinated electronically with the service provider.
FM-27	3.2.2 4th paragraph	Users without an FOC capability access the same flight data used by all other system users and service providers via appropriate devices. They are able to enter a command and be transferred to a service provider for clarification of the information. Depending on the user's equipment, this dialog is by voice or through electronic messaging. For users equipped with data link, the capability exists to load a flight profile directly into the aircraft FMS. Other users can store the flight profile information on disk and upload it into the aircraft's avionics for use.
FM-28	3.2.2 8th paragraph	Shared access to all commercial space operations schedules is provided via SWIM.
FM-29	3.2.2 9th paragraph	SWIM enables domestic and international users and service providers to access flight profiles and associated SUA data.
FM-30	3.2.3 1st paragraph	SWIM and Omni-SYSCO support an interactive flight planning capability for all properly equipped users to aid in filing user-preferred departure-to-destination flight profiles.
FM-31	3.3.2 1st and 2nd paragraphs	SWIM information improves the user's ability to create a flight profile, which facilitates the automatic generation of a flight profile containing either the user's preferred flight path or a more detailed time-based trajectory within the known ATM system constraints. Potential problems are automatically displayed to the planner for reconciliation. Upon filing, the flight profile is updated, as necessary, along with all affected projections of NAS demand. As conditions change, SWIM (in concert with SYSCO) allows the planner to access information used to determine the impact of the changes on the flight. Intelligent agents are introduced in this period to identify the best alternatives in light of ATM system changes and user preferences. SWIM information is available to all users and service providers until the termination of the flight. Information such as runway preferences and aircraft weight or information to support flight following can be added during the planning phase or during flight.
FM-32	4.1.2 1 3rd paragraph	Clearances, airport information, and weather conditions (e.g., current, forecast, hazardous) are provided over data link to more users at more airports. Taxi routes and positions of other aircraft are data linked and displayed in appropriately equipped aircraft. The receipt of taxi routes over data link relieves communication frequency congestion. Pilot situational awareness and safety are enhanced with an integrated display of the aircraft's position, taxi route, and hazards.
FM-33	4.1.2 1 4th paragraph	Access to real-time data for surface movement DSSs makes for an increasingly integrated NAS. The system provides access to airport environmental information; arrival, departure, and taxi schedules; airborne and surface surveillance information; flight information; ATIS and other weather information; and TFM initiatives.
FM-34	4.1.21 5th paragraph	On taxi out, the flight's time-based trajectory is updated in SWIM, and projections are made based on prevailing traffic conditions. At wheels-up, this trajectory is again updated. This continuous updating of the flight profile improves real-time planning for both the user and the service provider.
FM-35	4.3.1 1 4th paragraph	The service provider's ability to plan surface movement improves as timely traffic information becomes available. Both the initial values and subsequent adjustments are incorporated into the surface management information system to ensure consistency and an integrated approach across systems.
FM-36	5 9th bullet	Shared access to SWIM supports an automated exchange of gate and runway preference data to stakeholders.
FM-37	5.3.2 6th paragraph	The user's runway assignment preference is available within SWIM, and is used in conjunction with departure and arrival DSSs and integrated surface management capabilities to coordinate an optimal assignment and sequence.
FM-38	5.3.2 6th paragraph	Data from SWIM allows service providers to monitor traffic demand, NAS infrastructure status, and other conditions in order to allocate resources, including changes in staffing. Service providers also update the NAS about the available capacity of airport and surrounding airspace resources and the current status of SUA. This facilitates more effective collaboration with FOCs and improved formulation of TFM agreements.

TABLE 23.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS)

[Acronyms are defined in Appendix A.]

ID	NAS ConOps section	Relevant text
FM-39	6.1.2 3rd paragraph	Flights routinely operate on user-preferred trajectories with fewer aircraft constrained to a fixed route structure. The requirement to operate on structured routes only exists in high density areas to avoid terrain and active SUA and to facilitate the transition between areas with differing separation standards. Demand and capacity imbalances are resolved, in collaboration with the users, via voluntary changes in trajectories or through the establishment of temporary routes and transition points. User-preferred trajectories are accommodated earlier in the flight and continue closer to the destination.
FM-40	6.1.2 5th paragraph	The status of active and proposed flights and NAS infrastructure is available to NAS users and service providers. This allows users to collaborate with ATM in deciding TFM initiatives.
FM-41	6.2.1 1st paragraph	The FOC monitors the status of the NAS and relays status information to pilots. FOC and aircraft provide preference information , which the service provider considers when making in-flight route changes.
FM-42	6.2.2 1st paragraph	There is increased collaboration between the FOC and ATM as the FOC interactively probes proposed route changes. Modified routes are developed collaboratively between the FOC and the service provider and then data linked to the aircraft and downstream ATC facilities. In addition, working with TFM specialists, the FOC helps to define and implement TFM initiatives to relieve airspace congestion.

TABLE 24.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE (NAS) CONCEPT OF OPERATIONS (CONOPS)

ID	NAS ConOps section	Relevant text
A-1	1.5.1 1st bullet	Collaboration supports determining when, where, and how transitional route structures are established in the airspace to meet a short-term problem.
A-2	1.5.2 7th bullet	As required navigation performance (RNP)/RNAV capabilities increase, the low-altitude airspace structure remains largely unchanged. Widespread area navigation equipment and expanded surveillance coverage with new technology provide increased access to airports and airspace in all weather conditions.
A-3	1.5.2 8th bullet	There are temporary route structures with transition points for moving to and from user trajectories.
A-4	1.5.2 9th bullet	A SWIM system is developed by the service provider to distribute timely and consistent information across the NAS including <ul style="list-style-type: none"> • Static data, such as electronic navigation data, maps, charts, airport facility guides, and published Notices to airmen (NOTAMs) is available directly from the Internet as well as various intranets • Dynamic information, including, but not limited to, current and forecast weather, • Radar summaries, hazardous condition warnings, information on updated airport and airspace capacity constraints, temporary flight restrictions (TFR), and special use airspace (SUA) schedules • Flight information • Schedule information
A-5	1.5.2 12th bullet	Traffic information collected by surveillance systems is transmitted to properly equipped aircraft to support flight deck decisions.
A-6	1.5.2 14th bullet	The ATM system manages airspace based on each user's needs, including proximity to the user's base of operations.
A-7	1.5.2 17th bullet	Tools and procedures are in place for frequent evaluation (up to several times a day) of the airspace structure and anticipated traffic flows, with adjustments made accordingly.
A-8	1.5.3 2nd bullet	Enhanced CNS systems and automation in aircraft complement automation aids on the ground, permitting more autonomous operations. This improved autonomy, combined with greater ability to share information, permits the workload to be distributed between the service provider and user in a balance appropriate for the operations being conducted.
A-9	1.5.3 4th bullet	Seamless communications and coordination, coupled with information accessible through SWIM, allow real-time reassignment of airspace between facilities to meet contingencies such as equipment outages.

TABLE 24.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE (NAS) CONCEPT OF OPERATIONS (CONOPS)

ID	NAS ConOps section	Relevant text
A-10	2.1.3 2nd paragraph	Flow-constrained areas are managed by allocating access, collaborative rerouting, and realigning sectors and associated resources.
A-11	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information including airport status and acceptance rate, ...
A-12	2.2.1 3rd paragraph	Working with the service providers, users better manage en route congestion by collaboratively evaluating the situations, developing reroutes around the flow constrained areas, and providing a more refined allocation of flights to the reroutes.
A-13	2.3.2 3rd paragraph	Information about arrival capacity allocations, reroute programs and other restrictions is automatically recorded, as is information from local facilities....
A-14	3 1st bullet	Elements of SWM are used to obtain and distribute flight-specific data and aeronautical information, including international coordination of flight trajectory.
A-15	3.1.1 3rd paragraph	There is real time sharing of system demand and the virtual ATM information... User flight planning systems account for system constraints such as flow restrictions, hazardous weather, SUA and infrastructure outages.
A-16	3.1.2 1st paragraph	A National Airspace System common reference (NASCR) and index that incorporates a common Geographical Information System (GIS) format is used to store all NAS information including terrain, obstacle, weather, and navigation, surveillance and communication coverage information. This information is available via SWIM to all service providers and users.
A-17	3.1.2 3rd paragraph	To generate the flight profile, users access current and predicted weather, traffic density, restrictions, and SUA status information.
A-18	3.2.2 7th paragraph	DoD and FAA service providers maintain and have access to a continuously updated database of airspace and flow restrictions. Using this data, the DoD flight planner prepares a proposed flight profile, performing a probe for active or scheduled SUAs, weather, and airspace and flow restrictions.
A-19	3.2.2 9th paragraph	Space vehicle flight profiles describe user needs and take into account flow conditions and constraints. SWIM enables domestic and international users and service providers to access flight profiles and associated SUA data.
A-20	41 6th bullet	Airport layouts on moving maps and corresponding standardized airport signage provide flight crews with increased situation awareness and reduce runway incursions.
A-21	4.1.21 1st paragraph	Moving map displays enhance pilot familiarity with the airport, leading to better planning and increased safety.
A-22	4.1.21 4th paragraph	Access to real-time data for surface movement DSSs makes for an increasingly integrated NAS. The surface management information system facilitates coordination between decision makers at all levels of the airport operation—service provider, flight crews, FOC, ramp, airport operator, and airport emergency centers. The system provides access to airport environmental information; arrival, departure, and taxi schedules; airborne and surface surveillance information; flight information; ATIS and other weather information; and TFM initiatives. This data sharing allows service providers to coordinate local operations with airline ramp and airport operators, thus improving overall airport operations.
A-23	4.1.31 1st paragraph	Using data link, pilots receive ATIS-type messages with Runway Visual Range (RVR), braking action and surface condition reports, current precipitation, runway availability, and wake turbulence and wind shear advisories. Hazardous weather alerts are automatically and simultaneously broadcast to aircraft via data link and service providers via SWIM.
A-24	4.2.11 2nd paragraph	Airport maps are electronically available to properly equipped users.
A-25	4.2.2 1 3rd paragraph	The proliferation of CDTI avionics and supporting ground infrastructure takes place in this time frame. The ground system that receives aircraft position reports also broadcasts radar-derived traffic information and a complete set of graphical and text products... Safety is enhanced by situation displays that depict airborne and surface traffic as well aerodrome information.
A-26	4.3.1 1 1st paragraph	SWIM and ACARS enhance the service provider's ability to provide data products such as NOTAMs and meteorological information for the airport vicinity. Although weather information and advisories continue to be available via traditional means, there is increased use of automation to collect and package the information and increased use of data link to disseminate routine and hazardous weather and traffic information.

TABLE 24.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE (NAS) CONCEPT OF OPERATIONS (CONOPS)

ID	NAS ConOps section	Relevant text
A-27	5 10th bullet	Status information concerning the NAS infrastructure components that support arrival/departure operations is shared with all stakeholders.
A-28	5.1.1 3rd paragraph	Arriving aircraft receive expanded airport information through data link for display on the flight deck. The information includes RVR, braking action and surface condition reports, and runway availability as well as wake turbulence and wind shear advisories.
A-29	5.1.2 2nd paragraph	All communication frequencies needed for operation in the airport vicinity are available for display to the flight deck, with any changes from the published list uplinked over data link. Data link and flight deck displays enable pilots to monitor current meteorological data, automated hazardous weather alerts, and surrounding traffic , thus reducing the number of verbal miscommunications of this routine information. Pilots conduct approaches using independent navigation systems and begin monitoring the approach path on a moving map display.
A-30	5.1.3 1st paragraph	Seamless data link is available for most pilot and service provider communications. Some emergency communications are automatically sent to both pilot and the service provider to further increase safety by eliminating the time necessary for a human to relay the message. Examples of such messages are wind shear alerts (generated either by airborne or ground equipment) and airborne and surface collision resolution advisories.
A-31	5.2.2 1st paragraph	Real time weather information and maps are available via SWIM on the flight deck.
A-32	6 5th bullet	Changes in airspace structures and route definitions in addition to the positions and predicted time-based trajectories are updated and registered within the NASCR for easy access via SWIM.
A-33	6.1.2 4th paragraph	Properly equipped aircraft receive an increased number of services via data link. These services includes certain ATC clearances, current and forecast weather, NOTAMs and hazardous weather warnings, updated charts, SUA status, and other required data that are up-linked (or data-loaded) to the aircraft to facilitate better planning.
A-34	6.2.2 4th paragraph	For properly equipped aircraft, updates to navigation terrain and obstacle databases are provided over data link.
A-35	7.3.3 3rd paragraph	Airspace sectorization changes dynamically based on weather, demand, and user preferences. These changes are accomplished through automated coordination (SYSCO) with all affected domestic and international service providers.

TABLE 25.—IDENTIFICATION OF THE ROLE OF RESOURCE MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS)

ID	NAS ConOps section	Relevant text
RM-1	1.5.2 16th bullet	By taking advantage of advanced information and communications capabilities, airspace design and underlying sector configurations are no longer constrained by the current geographic boundaries, particularly in high altitude. Tools and procedures are in place for frequent evaluation (up to several times a day) of the airspace structure and anticipated traffic flows, with adjustments made accordingly. This increased flexibility permits changes to the configuration of air traffic facilities.
RM-2	1.5.3 2nd bullet	Enhanced CNS systems and automation in aircraft complement automation aids on the ground permitting more autonomous operations. This improved autonomy combined with greater ability to share information permits the workload to be distributed between service provider and user in a balance appropriate for the operations being conducted.
RM-3	1.5.3 4th bullet	Seamless communications and coordination, coupled with information accessible through SWIM, allow real-time reassignment of airspace between facilities to meet contingencies such as equipment outages.
RM-4	1.5.3 7th bullet	There are continued improvements in the collection and processing of NAS infrastructure data. These data are used to prioritize and schedule NAS infrastructure activities.
RM-5	1.5.3 8th bullet	NAS infrastructure assets (e.g., radars, communications, etc.) are assigned and reassigned dynamically to mitigate infrastructure problems as well as in response to changes in sectorization and airspace assignment. All NAS resources are registered in the NAS Common Reference System (NASCR), and monitored and managed through SWIM.
RM-6	2 8th bullet	Infrastructure operations are performed from a national perspective.
RM-7	2 9th bullet	Infrastructure maintenance is performed from the viewpoint of customer requirements for the services with an understanding of the effects of the activities on service delivery to NAS infrastructure users.
RM-8	2.1.1 1st and 2nd paragraphs	TFM service providers monitor traffic, weather, and infrastructure. ... Air Traffic Control System Command Center (ATCSCC) service providers monitor NAS performance and adjust TFM initiatives as needed.
RM-9	2.1.2 3rd paragraph	Because NAS users have increased flexibility in planning routes and schedules, and because the NAS relies less on routine restrictions and fixed routes, managing NAS resources becomes more dynamic and adaptive.
RM-10	2.1.3 2nd paragraph	Flow-constrained areas are managed by allocating access, collaborative rerouting, and realigning sectors and associated resources.
RM-11	2.4.3	NAS infrastructure assets are assigned and reassigned dynamically to mitigate infrastructure problems as well as in response to changes to in sectorization, traffic demand, and airspace assignment. SWIM provides access to all NAS management and resource information.
RM-12	2.2.1 3rd paragraph	Working with service providers, users better manage flight operations by collaboratively evaluating the situation, developing reroutes around the flow constrained areas, and providing a more refined allocation of flights to the reroutes.
RM-13	2.5.1	In coordination with the National Operations Control Center (NOCC), infrastructure management (IM) service providers monitor NAS infrastructure performance and determine needed actions. Service providers perform remote management and monitoring of systems, while others perform onsite maintenance for fault correction, preventive maintenance, and equipment installation and removal.
RM-14	2.5.3	NAS infrastructure assets are assigned and reassigned dynamically to mitigate infrastructure problems as well as to respond to changes to in sectorization and airspace assignment. SWIM provides access to all NAS. Management and resource information. The redundancy in the NAS is applied expeditiously to maintain flow and reduce operational impact.
RM-15	3.1.1 paragraph 3	There is real-time sharing of system demand and the virtual ATM information, enabling service providers to collaboratively interact with the user and to mutually develop solutions to problems. User flight planning systems account for system constraints such as flow restrictions, hazardous weather, SUA, and infrastructure outages.

TABLE 25.—IDENTIFICATION OF THE ROLE OF RESOURCE MANAGEMENT INFORMATION—RTCA
NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS)

ID	NAS ConOps section	Relevant text
RM-16	5.3.2 7th paragraph	Data from SWIM allows service providers to monitor traffic demand, NAS infrastructure status, and other conditions in order to allocate resources, including changes in staffing. Service providers also update the NAS about the available capacity of airport and surrounding airspace resources and the current status of SUA. This facilitates more effective collaboration with FOCs and improved formulation of TFM agreements.
RM-17	6.3.2 4th paragraph	With the completion of the National Airspace Redesign, airspace is restructured to meet future traffic requirements. Static restrictions due to fixed sector boundaries are reduced or eliminated. The airspace structure is frequently evaluated and adjusted in anticipation of expected traffic flows, or in response to weather and NAS infrastructure changes. Additionally, airspace boundaries are adjusted dynamically without respect to facilities, for transient events or circumstances for limited periods of time.

Appendix C.—Hierarchical Diagrams of Functional Requirements

This appendix contains the functional analysis of the L-band communication system presented as a series of hierarchical diagrams. The “L” preceding all of the numerical functional levels is used to represent L-band.”

The analysis and diagrams are adopted from the National Airspace System (NAS) Communications System Safety Hazard Analysis and Security Threat Analysis document (Ref. 66).

Solid blocks in the diagrams represent system functions that are part of the L-band system scope assumptions; background blocks show NAS functions that are currently not part of the L-band functionality.

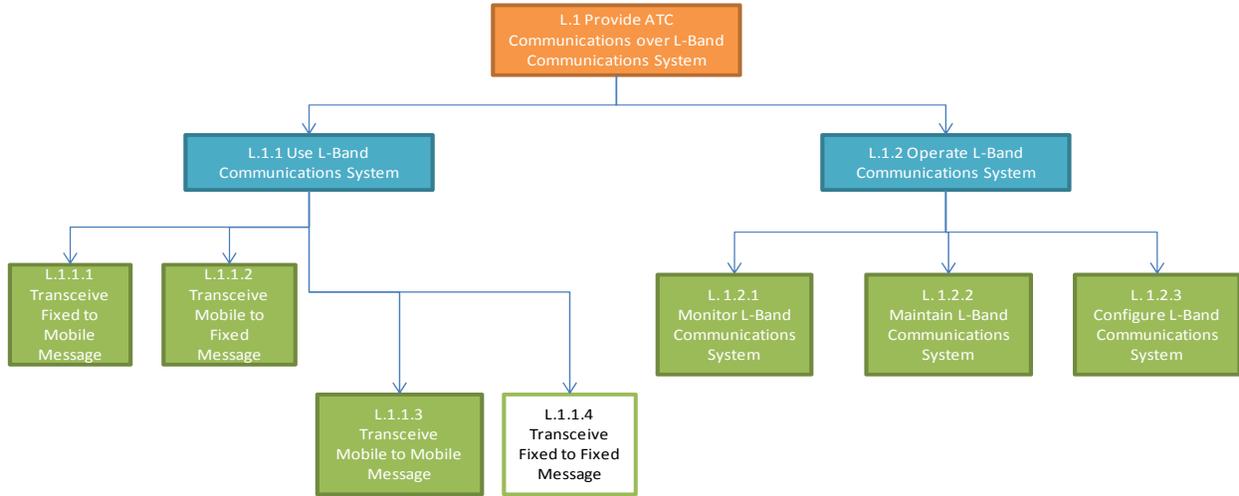


Figure 37.—L-band communications system high level.

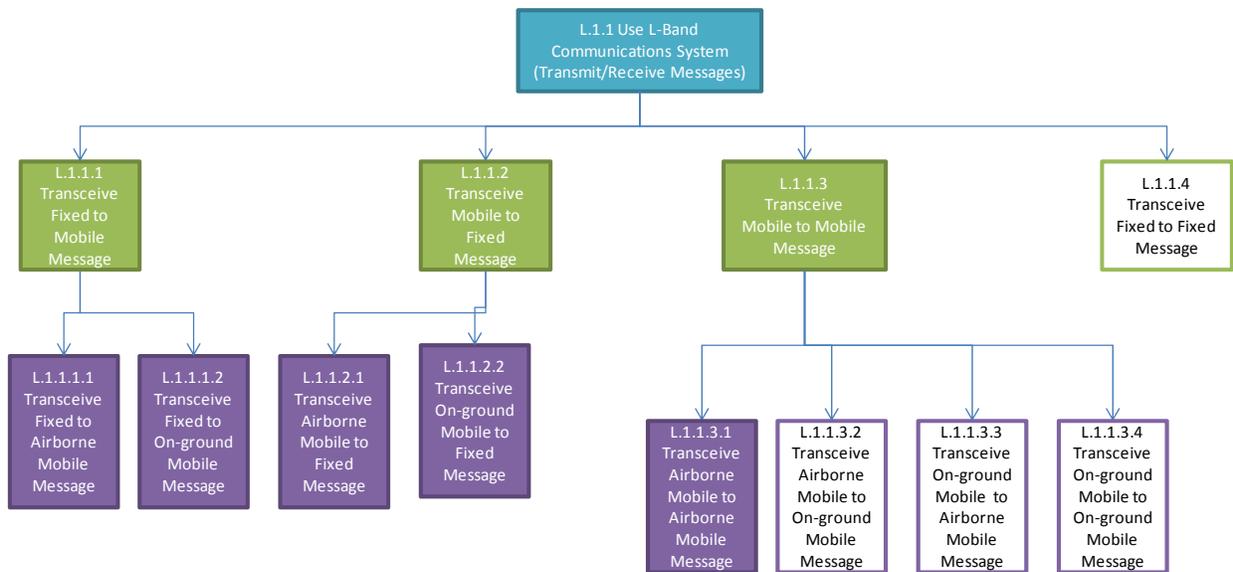


Figure 38.—Decomposition of use L-band communications system (transmit/receive messages).

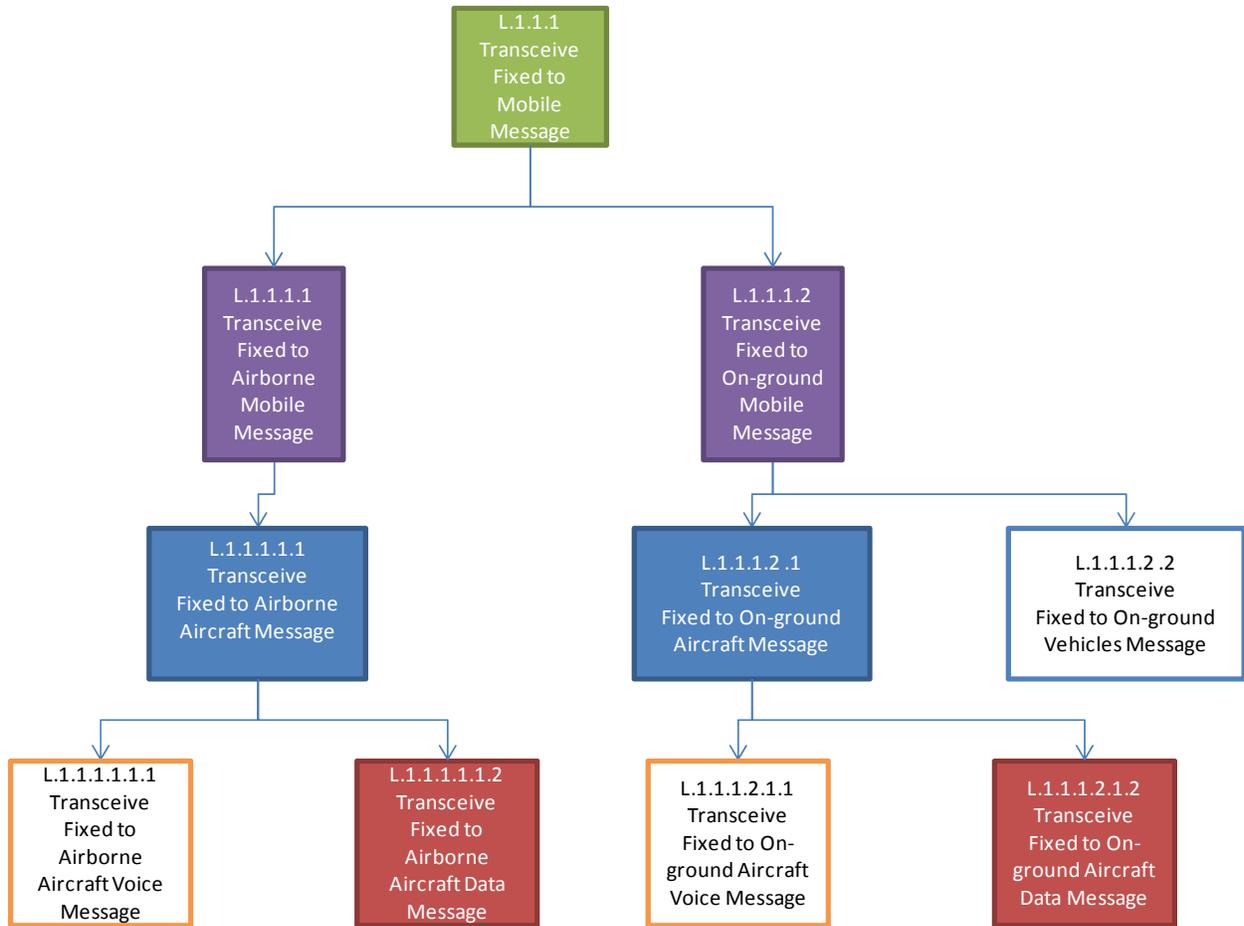


Figure 39.—Decomposition of transceive fixed-to-mobile message.

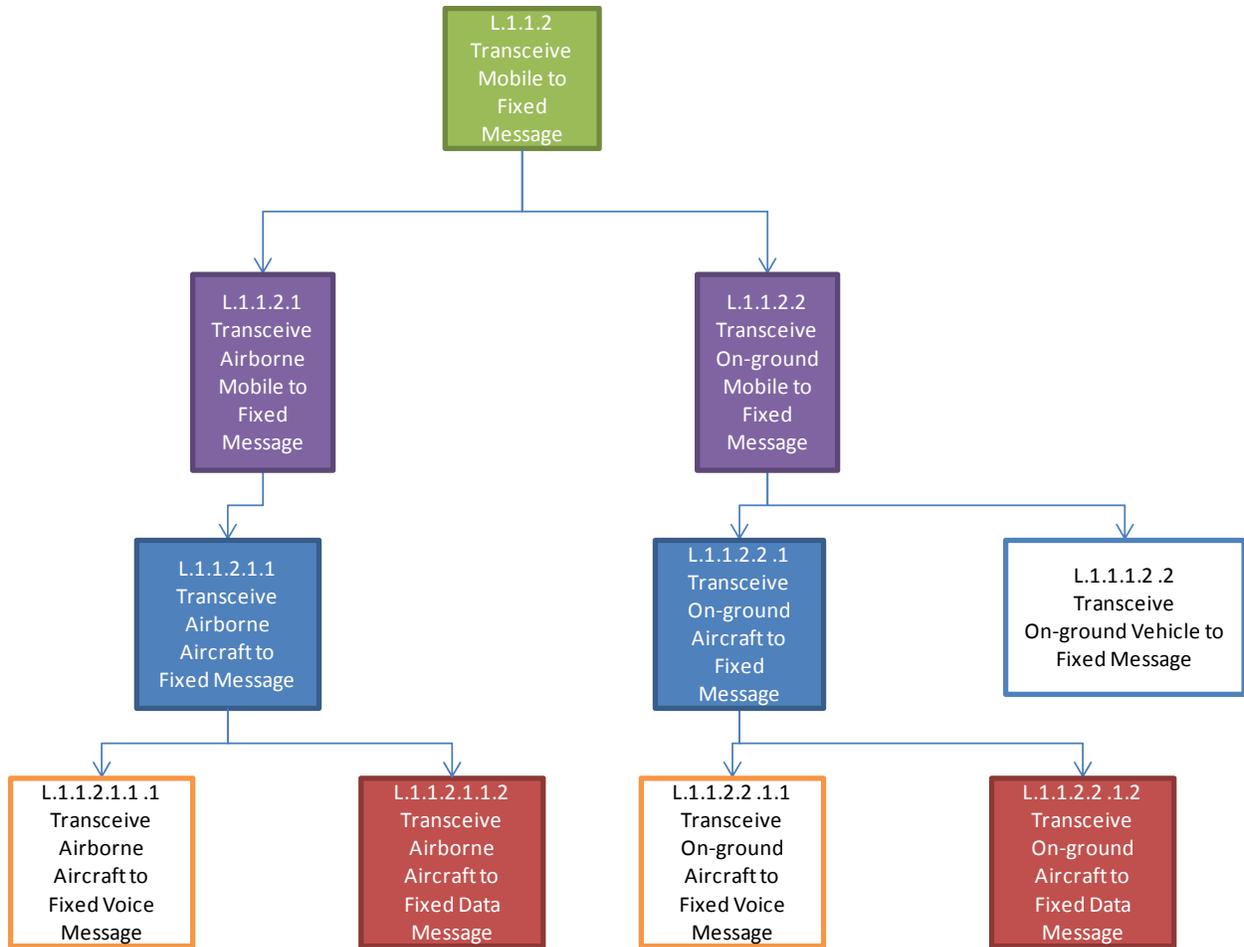


Figure 40.—Decomposition of transceive mobile-to-fixed message.

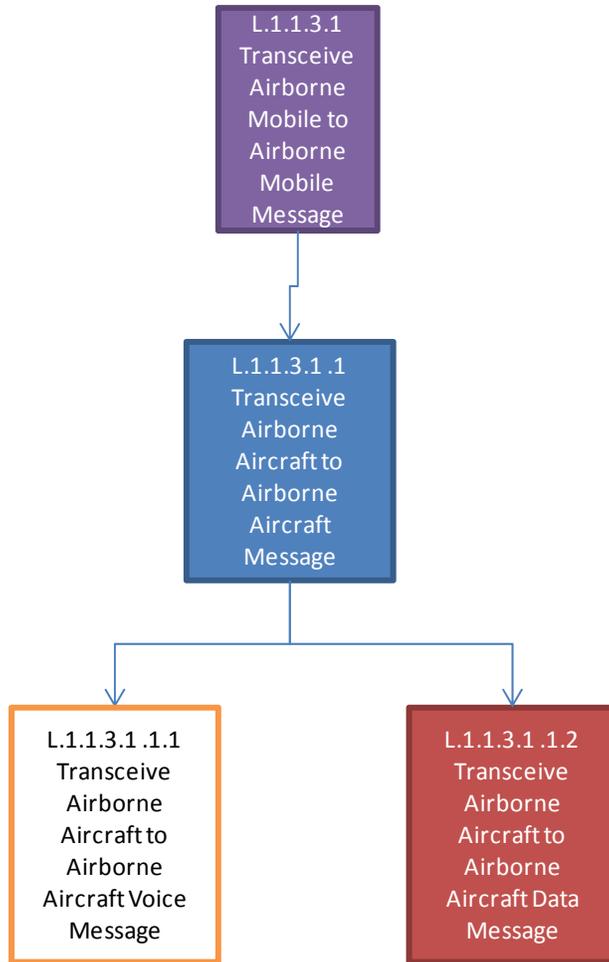


Figure 41.—Decomposition of transceive airborne-mobile-to-airborne-mobile messages.

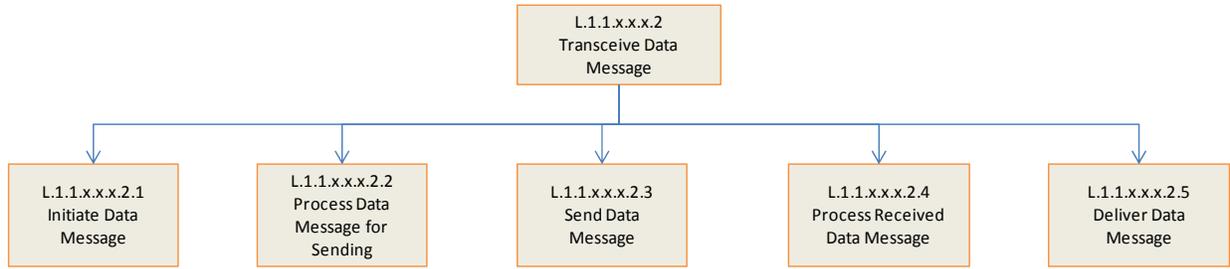


Figure 42.—Generic decomposition of transceive data message.

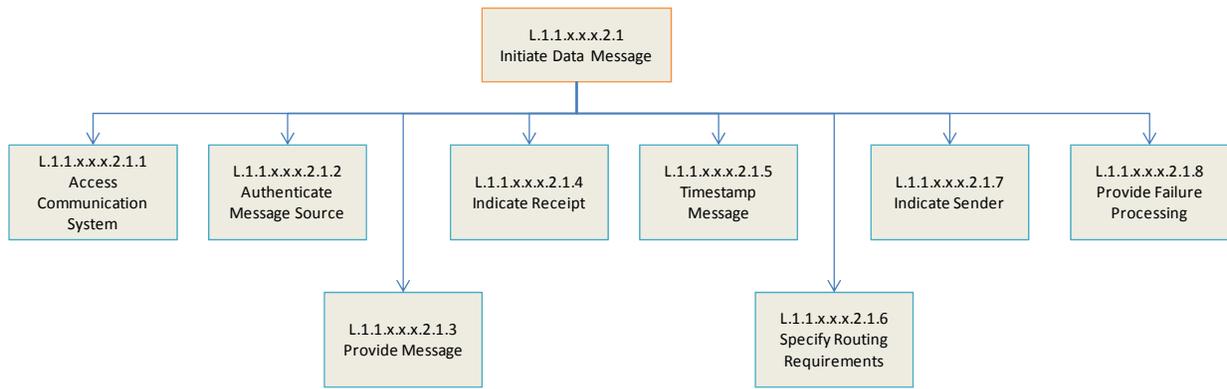


Figure 43.—Generic decomposition of initiate data message.

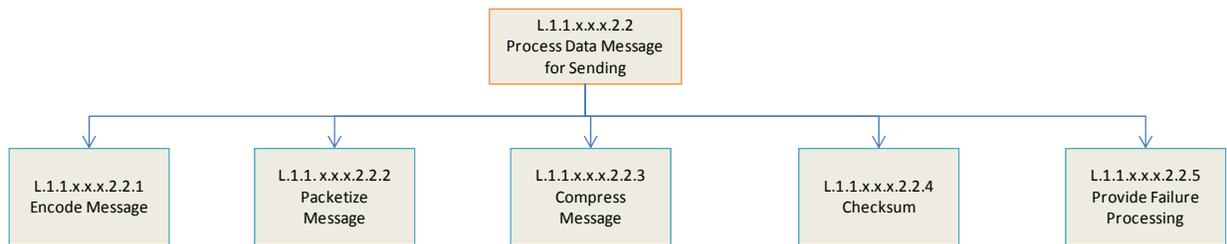


Figure 44.—Generic decomposition of process data message for sending.

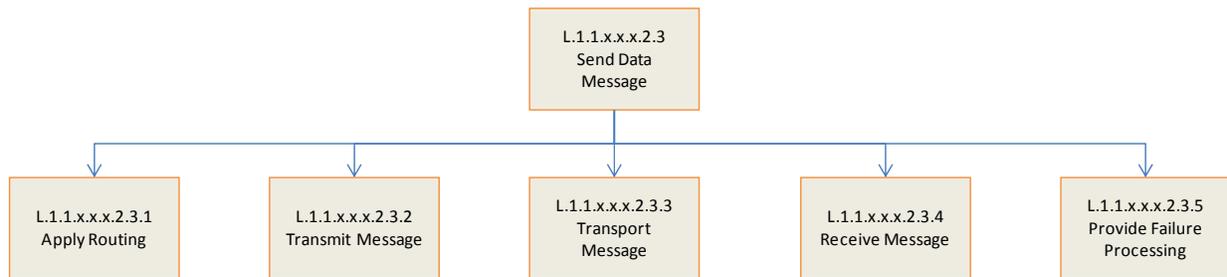


Figure 45.—Generic decomposition of send data message.

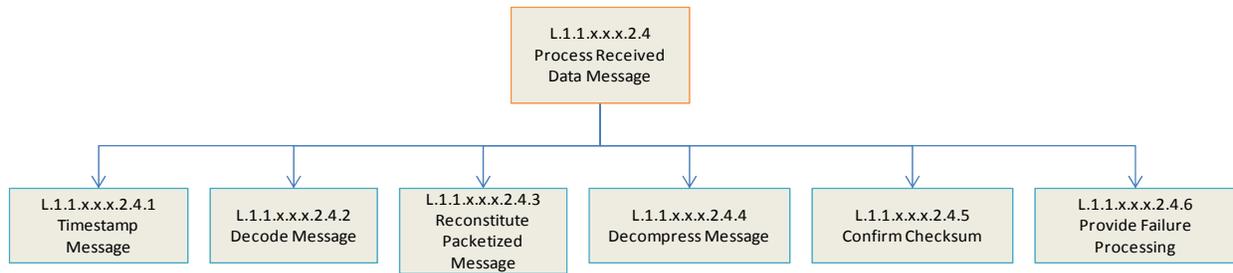


Figure 46.—Generic decomposition of process received data message.

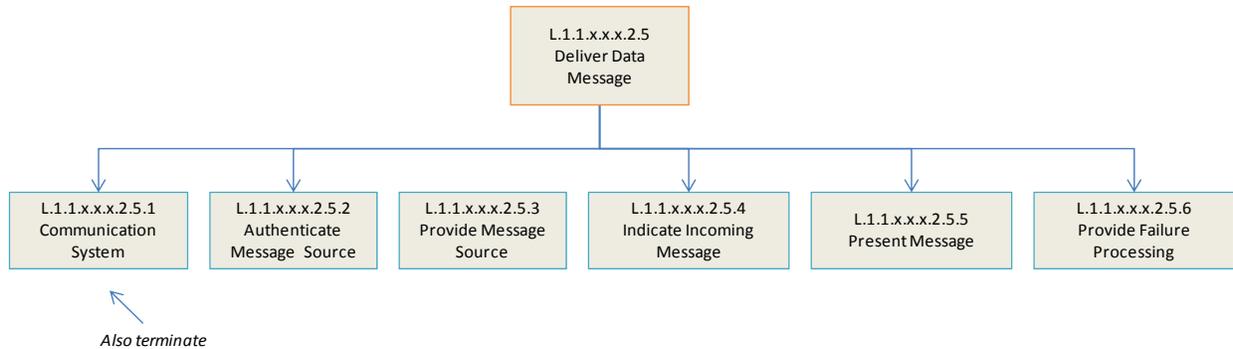


Figure 47.—Generic decomposition of deliver data message.

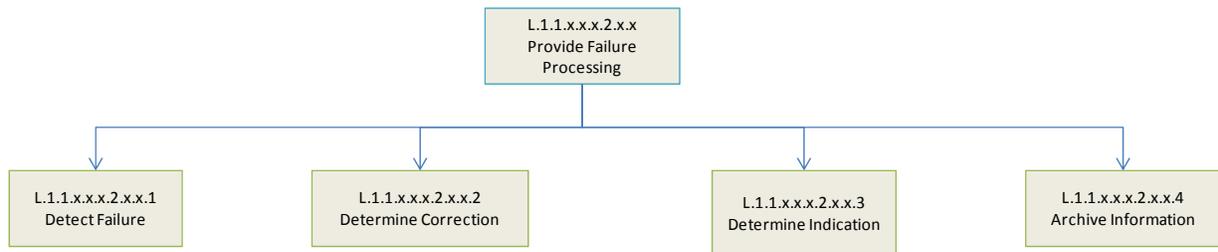


Figure 48.—Generic decomposition of provide failure processing.

List of failure detection subfunctions

- Authentication failures
- Function unavailability
- Message unintelligible or garbled
- Message inaudible
- Message or message components missing or faulty
- Invalid or incorrect message components
- Checksum failures
- Invalid recipient

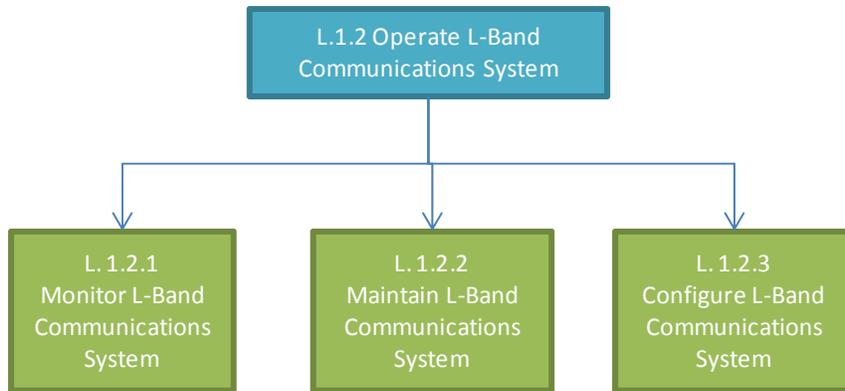


Figure 49.—Decomposition of operate L-band communications system.

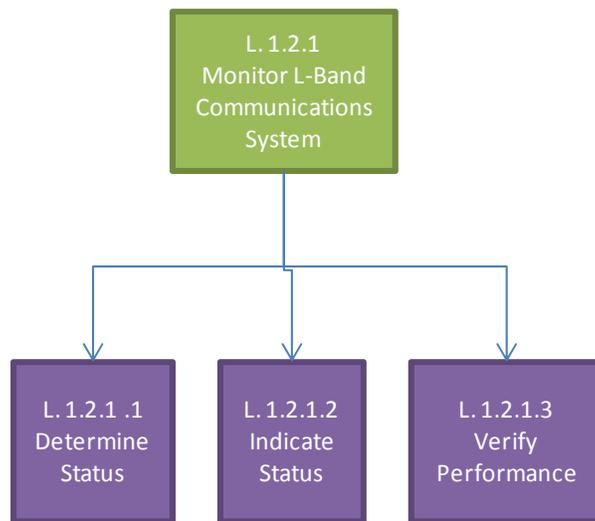


Figure 50.—Decomposition of monitor L-band communications system.

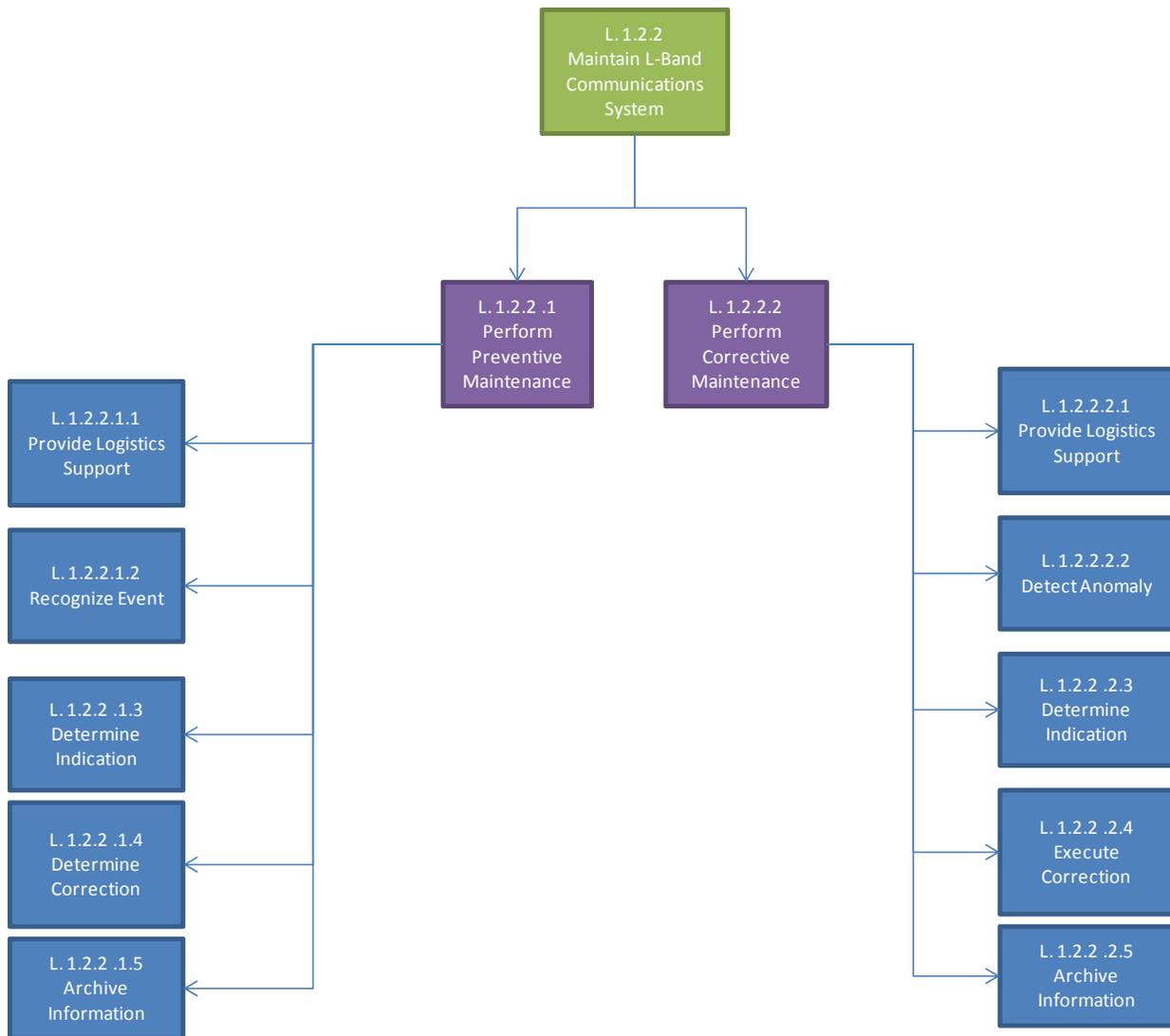


Figure 51.—Decomposition of maintain L-band communications system.

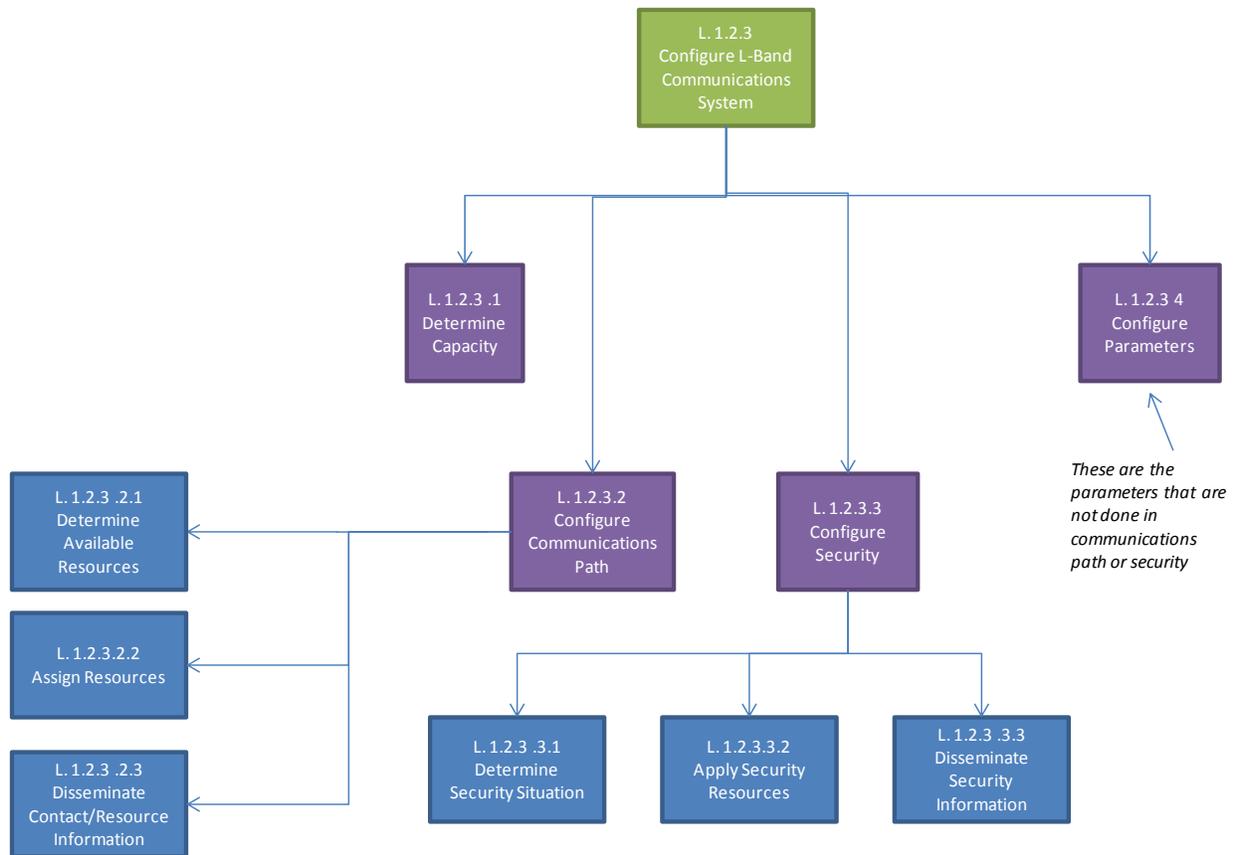


Figure 52.—Decomposition of configure L-band communications system.

Following is the same hierarchical decomposition presented in the outline style. Because many of the low-level functions are common, they are shown in Insert below, included for the first data function (C.1.1.1.1.1.1 Transceive Fixed-to-Airborne Aircraft Data Message), and referenced thereafter.

Insert: Generic Data Message Functions

- L.1.1.x.x.x.2.1 Initiate Data Message
 - L.1.1.x.x.x.2.1.1 Access Communication System
 - L.1.1.x.x.x.2.1.2 Authenticate Message source
 - L.1.1.x.x.x.2.1.3 Provide Message
 - L.1.1.x.x.x.2.1.4 Indicate Recipient
 - L.1.1.x.x.x.2.1.5 Timestamp Message
 - L.1.1.x.x.x.2.1.6 Specify Routing Requirements
 - L.1.1.x.x.x.2.1.7 Indicate Sender
 - L.1.1.x.x.x.2.1.8 Provide Failure Processing
 - L.1.1.x.x.x.2.1.8.1 Detect Failure
 - L.1.1.x.x.x.2.1.8.2 Determine Correction
 - L.1.1.x.x.x.2.1.8.3 Determine Indication
 - L.1.1.x.x.x.2.1.8.4 Archive Information
- L.1.1.x.x.x.2.2 Process Data Message for Sending
 - L.1.1.x.x.x.2.2.1 Encode Message
 - L.1.1.x.x.x.2.2.2 Packetize Message
 - L.1.1.x.x.x.2.2.3 Compress Message
 - L.1.1.x.x.x.2.2.4 Add Checksum
 - L.1.1.x.x.x.2.2.5 Provide Failure Processing
 - L.1.1.x.x.x.2.2.5.1 Detect Failure
 - L.1.1.x.x.x.2.2.5.2 Determine Correction
 - L.1.1.x.x.x.2.2.5.3 Determine Indication
 - L.1.1.x.x.x.2.2.5.4 Archive Information
- L.1.1.x.x.x.2.3 Send Data Message
 - L.1.1.x.x.x.2.3.1 Apply Routing
 - L.1.1.x.x.x.2.3.2 Transmit Message
 - L.1.1.x.x.x.2.3.3 Transport Message
 - L.1.1.x.x.x.2.3.4 Receive Message
 - L.1.1.x.x.x.2.3.5 Provide Failure Processing
 - L.1.1.x.x.x.2.3.5.1 Detect Failure
 - L.1.1.x.x.x.2.3.5.2 Determine Correction
 - L.1.1.x.x.x.2.3.5.3 Determine Indication
 - L.1.1.x.x.x.2.3.5.4 Archive Information
- L.1.1.x.x.x.x.2.4 Process Received Data Message
 - L.1.1.x.x.x.2.4.1 Timestamp Message
 - L.1.1.x.x.x.2.4.2 Decode Message
 - L.1.1.x.x.x.2.4.3 Reconstitute Packetized Message
 - L.1.1.x.x.x.2.4.4 Decompress Message
 - L.1.1.x.x.x.2.4.5 Confirm Checksum
 - L.1.1.x.x.x.2.4.6 Provide Failure Processing
 - L.1.1.x.x.x.2.4.6.1 Detect Failure
 - L.1.1.x.x.x.2.4.6.2 Determine Correction
 - L.1.1.x.x.x.2.4.6.3 Determine Indication
 - L.1.1.x.x.x.2.4.6.4 Archive Information
- L.1.1.x.x.x.2.5 Deliver Data Message
 - L.1.1.x.x.x.2.5.1 Access Communication System

- L.1.1.x.x.x.2.5.2 Authenticate Message Source
- L.1.1.x.x.x.2.5.3 Provide Message Source
- L.1.1.x.x.x.2.5.4 Indicate Incoming Message
- L.1.1.x.x.x.2.5.5 Present Message
- L.1.1.x.x.x.2.5.6 Provide Failure Processing
 - L.1.1.x.x.x.2.5.6.1 Detect Failure
 - L.1.1.x.x.x.2.5.6.2 Determine Correction
 - L.1.1.x.x.x.2.5.6.3 Determine Indication
 - L.1.1.x.x.x.2.5.6.4 Archive Information

L-DACS Communication System Hierarchical Function Listing

- L.1 Provide ATC Communications over L-Band Communications System
 - L.1.1 Use L-Band Communication System (Transmit/Receive Messages)
 - L.1.1.1 Transceive Fixed to Mobile Message
 - L.1.1.1.1 Transceive Fixed to Airborne Mobile Message
 - L.1.1.1.1.1 Transceive Fixed to Airborne Aircraft Message
 - L.1.1.1.1.1.2 Transceive Fixed to Airborne Aircraft Data Message
 - L.1.1.1.1.1.2.1 Initiate Data Message
 - L.1.1.1.1.1.2.1.1 Access Communication System
 - L.1.1.1.1.1.2.1.2 Authenticate Message source
 - L.1.1.1.1.1.2.1.3 Provide Message
 - L.1.1.1.1.1.2.1.4 Indicate Recipient
 - L.1.1.1.1.1.2.1.5 Timestamp Message
 - L.1.1.1.1.1.2.1.6 Specify Routing Requirements
 - L.1.1.1.1.1.2.1.7 Indicate Sender
 - L.1.1.1.1.1.2.1.8 Provide Failure Processing
 - L.1.1.1.1.1.2.1.8.1 Detect Failure
 - L.1.1.1.1.1.2.1.8.2 Determine Correction
 - L.1.1.1.1.1.2.1.8.3 Determine Indication
 - L.1.1.1.1.1.2.1.8.4 Archive Information
 - L.1.1.1.1.1.2.2 Process Data Message for Sending
 - L.1.1.1.1.1.2.2.1 Encode Message
 - L.1.1.1.1.1.2.2.2 Packetize Message
 - L.1.1.1.1.1.2.2.3 Compress Message
 - L.1.1.1.1.1.2.2.4 Add Checksum
 - L.1.1.1.1.1.2.2.5 Provide Failure Processing
 - L.1.1.1.1.1.2.2.5.1 Detect Failure
 - L.1.1.1.1.1.2.2.5.2 Determine Correction
 - L.1.1.1.1.1.2.2.5.3 Determine Indication
 - L.1.1.1.1.1.2.2.5.4 Archive Information
 - L.1.1.1.1.1.2.3 Send Data Message
 - L.1.1.1.1.1.2.3.1 Apply Routing
 - L.1.1.1.1.1.2.3.2 Transmit Message
 - L.1.1.1.1.1.2.3.3 Transport Message
 - L.1.1.1.1.1.2.3.4 Receive Message
 - L.1.1.1.1.1.2.3.5 Provide Failure Processing
 - L.1.1.1.1.1.2.3.5.1 Detect Failure
 - L.1.1.1.1.1.2.3.5.2 Determine Correction
 - L.1.1.1.1.1.2.3.5.3 Determine Indication
 - L.1.1.1.1.1.2.3.5.4 Archive Information
 - L.1.1.1.1.1.2.4 Process Received Data Message
 - L.1.1.1.1.1.2.4.1 Timestamp Message

- L.1.1.1.1.1.2.4.2 Decode Message
- L.1.1.1.1.1.2.4.3 Reconstitute Packetized Message
- L.1.1.1.1.1.2.4.4 Decompress Message
- L.1.1.1.1.1.2.4.5 Confirm Checksum
- L.1.1.1.1.1.2.4.6 Provide Failure Processing
 - L.1.1.1.1.1.2.4.6.1 Detect Failure
 - L.1.1.1.1.1.2.4.6.2 Determine Correction
 - L.1.1.1.1.1.2.4.6.3 Determine Indication
 - L.1.1.1.1.1.2.4.6.4 Archive Information
- L.1.1.1.1.1.2.5 Deliver Data Message
 - L.1.1.1.1.1.2.5.1 Access Communication System
 - L.1.1.1.1.1.2.5.2 Authenticate Message Source
 - L.1.1.1.1.1.2.5.3 Provide Message Source
 - L.1.1.1.1.1.2.5.4 Indicate Incoming Message
 - L.1.1.1.1.1.2.5.5 Present Message
 - L.1.1.1.1.1.2.5.6 Provide Failure Processing
 - L.1.1.1.1.1.2.5.6.1 Detect Failure
 - L.1.1.1.1.1.2.5.6.2 Determine Correction
 - L.1.1.1.1.1.2.5.6.3 Determine Indication
 - L.1.1.1.1.1.2.5.6.4 Archive Information
- L.1.1.1.2 Transceive Fixed to On-Ground Mobile Message
 - L.1.1.1.2.1 Transceive Fixed to On-Ground Aircraft Message
 - L.1.1.1.3.1.2 Transceive Fixed to On-Ground Aircraft Data Message
 - Insert B
- L.1.1.2 Transceive Mobile to Fixed Message
 - L.1.1.2.1 Transceive Airborne Mobile to Fixed Message
 - L.1.1.2.1.1 Transceive Airborne Aircraft to Fixed Message
 - L.1.1.2.1.1.2 Transceive Airborne Aircraft to Fixed Data Message
 - Insert B
 - L.1.1.2.2 Transceive On-Ground Mobile to Fixed Message
 - L.1.1.2.2.1 Transceive On-Ground Aircraft to Fixed Message
 - L.1.1.2.2.1.2 Transceive On-Ground Aircraft to Fixed Data Message
 - Insert B
- L.1.1.3 Transceive Mobile-Mobile Message
 - L.1.1.3.1 Transceive Airborne Mobile to Airborne Mobile Message
 - L.1.1.3.1.1 Transceive Airborne Aircraft to Airborne Aircraft Message
 - L.1.1.4.1.1.2 Transceive Airborne Aircraft to Airborne Aircraft Data Message
 - Insert
- L.1.2 Operate L-Band Communication System
 - L.1.2.1 Monitor L-Band Communication System
 - L.1.2.1.1 Determine Status
 - L.1.2.1.2 Indicate Status
 - L.1.2.1.3 Verify Performance
 - L.1.2.2 Maintain L-Band Communication System
 - L.1.2.2.1 Perform Preventative Maintenance
 - L.1.2.2.1.1 Provide Logistics Support
 - L.1.2.2.1.2 Recognize Event
 - L.1.2.2.1.3 Determine Indication
 - L.1.2.2.1.4 Determine Correction
 - L.1.2.2.1.5 Archive Information
 - L.1.2.2.2 Perform Corrective Maintenance

- L.1.2.2.2.1 Provide Logistics Support
- L.1.2.2.2.2 Detect Anomaly
- L.1.2.2.2.3 Determine Indication
- L.1.2.2.2.4 Execute Correction
- L.1.2.2.2.5 Archive Information
- L.1.2.3 Configure L-Band Communication System
 - L.1.2.3.1 Determine Capacity
 - L.1.2.3.2 Configure Communication Path
 - L.1.2.3.2.1 Determine Available Resources
 - L.1.2.3.2.2 Assign Resources
 - L.1.2.3.2.3 Disseminate Contact/Resource Information
 - L.1.2.3.3 Configure Security
 - L.1.2.3.3.1 Determine Security Situation
 - L.1.2.3.3.2 Apply Security Resources
 - L.1.2.3.3.3 Disseminate Security Information
 - L.1.2.3.4 Configure Parameters

Appendix D.—N² Charts

Use L-band communication system (transmit/receive messages)	
	Operate L-band communication system

Figure 53.—Level 2 N² chart, L.1 L-DACS communication system.

Transceive fixed-to-mobile message		
	Transceive mobile-to-fixed message	
		Transceive mobile-to-mobile message

Figure 54.—Level 3 N² chart, L.1.1 provide air traffic control communications over L-band communications system.

Transceive fixed-to-airborne-mobile message	
	Transceive fixed-to-on-ground- mobile message

Figure 55.—Level 4 N² chart,L.1.1.1 transceive fixed-to-mobile message.

Initiate Data Message	Data Message				
	Process Data Message for Sending	Processed Data Message			
		Send Data Message	Received Data Message		
			Process Received Data Message	Processed Received Data Message	
				Deliver Data Message	Delivered Data Message

Figure 56.—Level 7 N² chart, L.1.1.x.x.x.2 transceive data message

Access Communication System	Access Parameters							
	Authenticate Message Source	Authenticated Message						
		Provide Message	Message Payload					
			Indicate Recipient	Message With Addressed Header				
				Timestamp Message	Timestamped Message			
					Specify Routing Requirements	Routing Parameters		
						Indicate Sender	Message With Addressed Header	
							Provide Failure Processing	Message Failure Data

Figure 57.—Level 8 N² chart, L.1.1.x.x.x.2.1 initiate data message.

Detect Failure	Message Failure Information			
	Determine Correction	Message Correction Parameters		
		Determine Indication	Message Status Information	
			Archive Information	Archived Messages

Figure 58.—Level 9 N² chart, L.1.1.x.x.x.2.x.x. provide failure processing.

Encode Message	Encoded Message				
	Packetize Message	Packetized, Encoded Message			
		Compress Message	Compressed, Packetized, Encoded Message		
			Add Checksum	Compressed, Packetized, Encoded Message with Checksum	
				Provide Failure Processing	Message Failure Data

Figure 59.—Level 8 N² chart, L.1.1.x.x.x.2.2 process data message for sending.

Apply Routing	Packetized Message				
	Transmit Message	Modulated and Transmitted Packets			
		Transport Message	Networked Messages		
			Receive Message	Received and Demodulated Packets	
				Provide Failure Processing	Message Failure Information

Figure 60.—Level 8 N² chart, L.1.1.x.x.x.2.3 send data message.

Timestamp Message	Timestamped Messages					
	Decode Message	Decoded Messages				
		Reconstitute Packetized Message	Message Packets			
			Decompress Message	Uncompressed Messages		
				Confirm Checksum	Message Payloads	
					Provide Failure Processing	Failure Indication

Figure 61.—Level 8 N² chart, L.1.1.x.x.x.2.4 process received data message.

Access Communication System						
	Authenticate Message Source	Message Source Authentication				
		Provide Message Source	Message Source			
			Indicate Incoming Message	Indicated Incoming Message		
				Present Message	Message Presented	
					Provide Failure Processing	Failure Indication

Figure 62.—Level 8 N² chart, L.1.1.x.x.x.2.5 deliver data message.

Transceive Airborne Mobile to Fixed Message	
	Transceive On-Ground Mobile to Fixed Message

Figure 63.—Level 4 N² chart, L.1.1.2 transceive mobile-to-fixed message.

Monitor L-Band Communication System		
	Maintain L-Band Communication System	
		Configure L-Band Communication System

Figure 64.—Level 3 N² chart, L.1.2 operate L-band communication system.

Determine Status	Status Information		
	Indicate Status	Status Information	
		Verify Performance	Performance Information

Figure 65.—Level 4 N² chart, L.1.2.1 monitor L-band communication system.

Perform Preventative Maintenance	
	Perform Corrective Maintenance

Figure 66.—Level 4 N² chart, L.1.2.2 maintain L-band communication system.

Provide Logistics Support					
	Recognize Event				
		Determine Indication	Status Information		
			Determine Correction	Corrective Information	
				Archive Information	Maintenance Log Information

Figure 67.—Level 5 N² chart, L.1.2.2.1 perform preventative maintenance.

Provide Logistics Support					
	Detect Anomaly	Sensor Information			
		Determine Indication	Status Information		
			Execute Correction	Maintenance Correction Information	
				Archive Information	Maintenance Log Information

Figure 68.—Level 5 N² chart, L.1.2.2.2 perform corrective maintenance.

Determine Capacity	Capacity Information			
	Configure Communication Path	Configuration Information		
		Configure Security	Security Configuration Information	
			Configure Parameters	Parameter Configuration Information

Figure 69.—Level 4 N² chart, L.1.2.3 configure L-band communication system.

Determine Available Resources	Resource Information		
	Assign Resources	Resource Assignment Information	
		Disseminate Contact/Resource Information	Contact/Resource Information

Figure 70.—Level 5 N² chart, L.1.2.3.2 configure communication path.

Determine Security Situation	Security Situation Parameters		
	Apply Security Resources	Resource Security Information	
		Disseminate Security Information	Security Information

Figure 71.—Level 5 N² chart, L.1.2.3.3 configure security.

Appendix E.—Spectrum Requirements for Unmanned Aircraft System (UAS) Communications

This appendix presents Section 5 (Spectrum Requirements for UAS Communications) and Section 6 (Conclusions) of the proposed changes to Annex 16 of 5B/296-E in Reference 44.

E.1 Single Unmanned Aircraft Throughput Needs

E.1.1 Methodology 1

Table 26 and Table 27 are based on the results of the Annex 1 (of Ref. 44).

TABLE 26.—TERRESTRIAL ESTIMATED NONPAYLOAD THROUGHPUT REQUIREMENTS OF A SINGLE UNMANNED AIRCRAFT IN BITS/S

Proposal	Command and control	Air traffic control relay	Sense-and-avoid	Video/weather radar
Airport surface	12 167	2×4855	9 120	270 000
	30 997			
Low altitude	12 167	2×4855	9 120	270 000 ^a
	30 997			
Medium altitude	5 062	2×4855	9 120	27 000
	23 892			
High altitude	5 062	2×4855	9 120	27 000
	23 892			

^aA factor representing a percentage value of video and weather radar data rate used at the low altitude could apply and is taken into account in Annex 3 of the Ref. 44.

TABLE 27.—SATELLITE ESTIMATED NONPAYLOAD THROUGHPUT REQUIREMENTS OF A SINGLE UNMANNED AIRCRAFT IN BITS/S

Proposal	Command and control	Air traffic control relay	Sense-and-avoid	Video/weather radar
Medium altitude	5 062	2 × 4855	9 120	27 000
	23 892			
High altitude	5 062	2 × 4855	9 120	27 000
	23 892			

E.1.2 Methodology 2

TABLE 28.—MAXIMUM NONPAYLOAD THROUGHPUT REQUIREMENTS^a OF A SINGLE UNMANNED AIRCRAFT IN BITS/S

Unmanned aircraft type	Control and Nav aids	Air traffic control relay	Nonpayload surveillance data ^b
Large	2 437	4 855	287 849
Medium	2 437	4 855	279 120
Small	1 862	0	0

^aAveraged over all operational phases.

^bIncludes video, weather radar, sense-and-avoid, etc.

E.2 Unmanned Aircraft System (UAS) Deployment Scenario

E.2.3 Methodology 1

Table 29 and Table 30 are based on the results of the Annex 2 [of the source document].

TABLE 29.—UNMANNED AIRCRAFT (UA) DENSITY
[60% OF UA available for operation.]

	UA/km ²
At surface	(3 UAs at an airport) 0.0002395
0–FL50 (1500 m)	0.0004017
FL50–FL195 (1500 to 6000 m)	0.0001560
>FL 195 (6000 m)	0.0000644
Total density	0.0008616

TABLE 30.—NUMBER OF UNMANNED AIRCRAFT (UA)
PER FOOTPRINT OF THE SATELLITE
[60% of UA available for operation.]

	GEO	LEO or GEO multispot
Without small	1711	106

E.2.4 Methodology 2

TABLE 31.—NUMBER OF UNMANNED AIRCRAFT (UA)
OPERATING AT PEAK TIMES^a

UA type	Per square kilometer	Per spot beam ^b	In regional-coverage beam ^c
Large	0.0000440	21	341
Medium	0.0001950	94	1515
Small	0.0008031	386	0
Total	0.0010421	501	1856

^aAssumed to be 75% of total population of each UA type.

^bCircular footprint 391 km in radius is assumed.

^cConterminous U.S. only. Small UA cannot carry regional-coverage SATCOM terminals. 7 800 000 km² (3 000 000 m²) coverage is assumed.

E.3 Aggregate Assessment of UAS Spectrum Needs

E.3.5 Methodology 1

The following table provides the UAS spectrum needs using the Methodology 1 and calculation presented in Annex 3 [of the source document]. It has to be noted that the video requirements is not yet decided as mandatory by the civil aviation authorities.

TABLE 32.—AGGREGATE SPECTRUM REQUIREMENTS

Terrestrial needs, MHz ^d	15.9	18.1	34
Satellite needs, MHz ^a	29	17	46

^aThe assessment of these spectrum requirements have been based on assumptions described in the PDN report ITU-R M [UAS-SPEC] (cells/spots radius, frequency reuse factor, etc.). Regarding sharing studies on WRC-11 Agenda item 1.3 in specific bands, these assumptions, and therefore the spectrum requirements, could be refined.

The detail of those requirements is shown in Figure 72, Figure 73, and Figure 74.

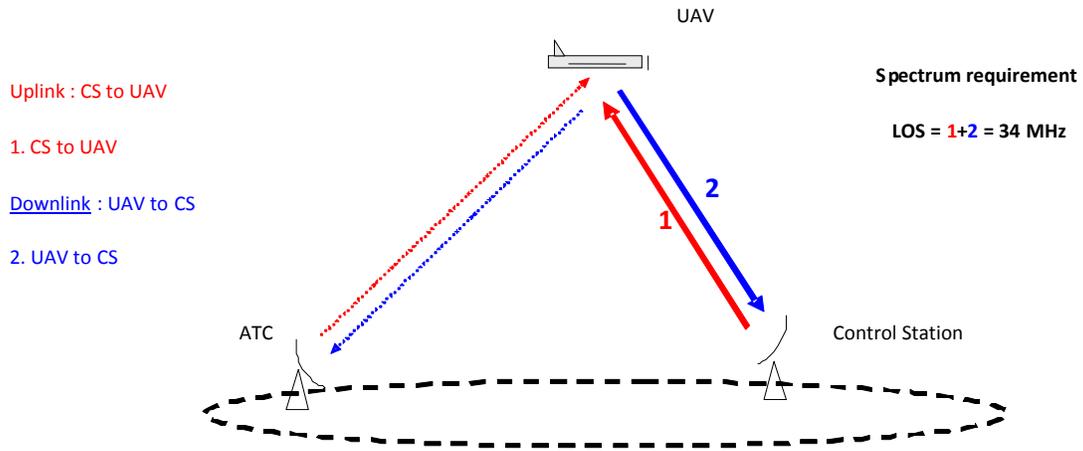


Figure 72.—Links involved for line of sight (LOS). Acronyms are defined in Appendix A.

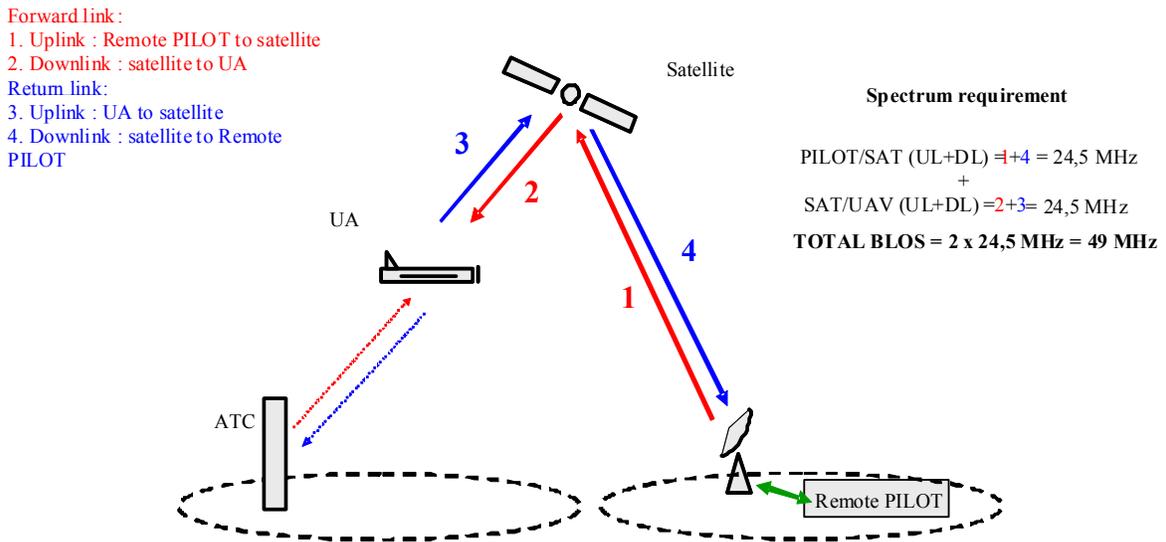


Figure 73.—Links involved for beyond line-of-sight (BLOS) via satellite (with onboard processing). Acronyms are defined in Appendix A.

Forward link :

- 1. Uplink : Remote PILOT to satellite
- 2. Downlink : satellite to UAV

Return link :

- 3. Uplink : UAV to satellite
- 4. Downlink : satellite to Remote PILOT

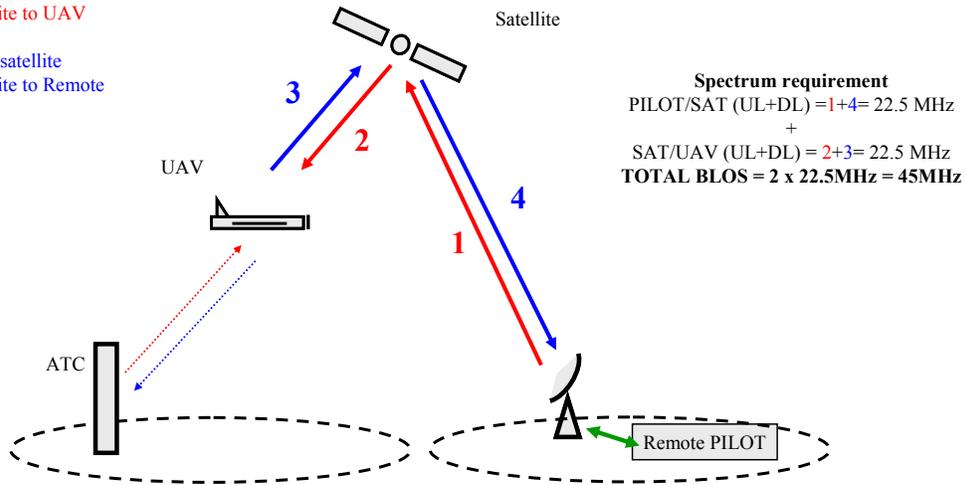


Figure 74.—Links involved for beyond line-of-sight (BLOS) via satellite (without onboard processing). Acronyms are defined in Appendix A.

The spectrum requirements figures for beyond line-of-sight (BLOS) cases correspond to satellite architectures with multi-spot coverage and either onboard processing as illustrated in Figure 72 (allowing direct connection between any UA and its control station (CS)) or no onboard processing as illustrated in Figure 73 (in which the CS connects to the earth station through wired/wireless line).²⁴

E.3.6 Methodology 2

Table 33 summarizes the bandwidth requirements calculated for each of the three major functional communications categories (Control and NavAids, air traffic control relay, and nonpayload Surveillance data) in each of the three alternative system implementations (line-of-sight (LOS), BLOS satellite spot beam, and BLOS satellite regional beam). Both satellite systems, particularly the regional-beam one, are clearly much more bandwidth-intensive than the terrestrial system. A hybrid system consisting of terrestrial and satellite components would have an aggregate bandwidth requirement somewhere between the “pure terrestrial” and “pure satellite” extremes. That hybrid bandwidth requirement would depend on the allocation of functions between the terrestrial and satellite components of the system, and on whether the satellite component has a spot-beam or regional-beam architecture. The assumed spot-beam system has a beam footprint of 391 km (243 m) in radius. The regional-coverage beam has a beam footprint of 7 800 000 km² (3 000 000 m²).

TABLE 33.—METHODOLOGY 2, COMPARISON OF AGGREGATE BANDWIDTH REQUIREMENTS

Functional category	Aggregate nationwide bandwidth requirement in megahertz		
	Line-of-sight terrestrial system	Beyond line-of-sight satellite system	
		Spot beam	Regional beam ^a
Command and control	1.61	11.76	19.62
Air traffic control relay	2.72	8.48	34.42
Sense and avoid	23.51	28.47	114.89
Total	27.84	48.71	168.93

^aRegional-beam system does not support small unmanned aircraft.

²⁴Wireless connections between the gateway and the CS may be needed in some cases. In such cases the spectrum requirement may be modified.

E.4 Conclusion

Based on the assumptions and results of Methodology 1 and Methodology 2, the total UAS spectrum requirements are

- 34 MHz for a terrestrial LOS system
- 49 MHz for a spot-beam satellite system
- 169 MHz for a regional-beam satellite system, which can be shared between several satellites, thereby reducing the overall spectrum requirement

Appendix F.—L-Band Spectrum Applicability for Unmanned Aircraft System (UAS) Applications

This section is adopted from Reference 43. In support of spectrum selection and allocation, the SC-203 conducted a comparative analysis of various frequency bands rating them in respect to suitability for unmanned aircraft system (UAS) applications. A relatively high rating was assigned to a lower part of the L-band (960 to 1024 MHz). The rationale for this relatively high rating is as follows.

The band is highly attractive for future UAS control use from a regulatory standpoint. It consists entirely of controlled-access aeronautical spectrum with an aeronautical mobile (route) service (AM(R)S) allocation. Its current worldwide spectrum allocation is internationally standardized and consistent from region to region.

Opportunities for finding bandwidth for AM(R)S in the 960- to 1024-MHz band depend primarily on exploiting certain characteristics of the distance measuring equipment (DME) and tactical air navigation (TACAN) transmitters that are its principal current users. First, in the 979- to 1024-MHz part of the band, all of those transmitters are at fixed ground locations. This would facilitate geographical frequency coordination between those DME/TACAN assignments and a future AM(R)S communications system. Second, a transmitted DME signal occupies a bandwidth narrower than its nominal 1-MHz channel width. If DME receivers are sufficiently selective, there may exist between adjacent DME channels a gap that could be utilized for AM(R)S (or UAS control and communications (CC)). Even if that is not the case for all DME receivers, many geographical areas have numerous unused DME channels that might be usable in their entirety by AM(R)S or UAS CC without radiofrequency interference to or from DME. Consequently the band has been awarded a neutral rating in the “Potentially Available Bandwidth” category.

The band scores relatively well for link range, capacity, latency, and availability. Its line-of-sight (LOS) limitation and its relatively high free-space propagation loss (in comparison with 108 to 137 MHz) result in neutral ratings for range and capacity, but its terrestrial usage and its freedom from significant atmospheric loss earn it favorable ratings for latency and availability.

Cosite compatibility on aircraft is a major concern in this band. A 960- to 1024-MHz UA-borne communications transmitter would pose an interference risk to a collocated DME or universal access transceiver (UAT) receiver and, most notably, to any collocated air traffic control radar beacon system (ATCRBS) or Mode S receiver operating at 1030 MHz. Present-day manned aircraft typically protect their onboard L-band (960 to 1215 MHz) devices from mutual cosite interference by means of a suppression bus that blanks the receivers each time a collocated in-band transmitter emits a pulse. If the transmitter has too high a duty cycle, this pulse-blanking method could unacceptably degrade receiver performance. If future airborne UA control transmitters operate in the 960- to 1024-MHz band, they may have to employ some combination of power control, radiofrequency filtering, and/or low-duty-cycle operation to avoid interfering with collocated DME, UAT, and 1030-MHz receivers. The problem is likely to be more severe when the UA control transmitter operates near the upper end of the 960- to 1024-MHz band, where radiofrequency filtering would afford the least protection to the 1030-MHz receivers. This cosite criterion is the only one for which the 960- to 1024-MHz band has received an unfavorable rating during the evaluation. However, it should be noted that the need for airborne transmissions in this band could be “finessed,” possibly at the cost of an additional airborne antenna, if a split-band UAS CC system is developed. For example, if uplink transmissions are situated in band 960- to 1024-MHz, but downlink transmissions are situated at C-band, the airborne cosite interference problem in this band would be eliminated.²⁵

²⁵This would shift the airborne cosite problem to a higher band, but this might be desirable from an overall systems engineering perspective. C-band, for example, might offer the opportunity for greater downlink bandwidth (thereby matching the projected asymmetry in uplink and downlink data rates), and the UAS community might willingly forgo microwave landing system (MLS). Furthermore, a C-band downlink could more easily support ground-based sectorized, multi-beam, or “smart” antennas designed to achieve high gain on the downlink, thereby allowing lower airborne transmit power and an overall reduction in background noise level for other users of the spectrum.

Because compact airborne antennas are feasible in the 960- to 1024-MHz band, it has received a favorable SWAP rating. New 960- to 1024-MHz ground radios would have to be installed, but they could cover most of the National Airspace System from the existing ground sites used by very high frequency (VHF)/ultrahigh frequency (UHF) air traffic control air-to-ground radios, so the band has been given a neutral rating under both of the “cost” criteria in the matrix. The band’s inherent security is deemed to be no worse than average for terrestrial air-to-ground radio links, so a neutral rating has been given for that criterion as well.

Appendix G.—References

1. National Airspace System: Concept of Operations and Vision for the Future of Aviation. First ed., RTCA, Washington, DC, 2002.
2. Concept of Operations for the Next Generation Air Transportation System. Version 2.0, Joint Planning and Development Office, June 13, 2007.
3. Global Air Traffic Management Operational Concept. ICAO Document 9854, 2005.
4. Operating Concept of the Mobile Aviation Communication Infrastructure Supporting ATM Beyond 2015. EUROCONTROL, April 30, 2002.
5. Communications Operating Concept and Requirement for the Future Radio System (COCR Version 2.0). EUROCONTROL/FAA Future Communications Study Operational Concepts and Requirements Team, ACP/1-IP/5, May 2007.
6. Data Communications Safety and Performance Requirements (SPR). Draft E (FAA Evaluation Release), April 30, 2009.
7. Final Program Requirements for Data Communications. FAA, May 13, 2009.
8. Zelkin, Natalie; and Henriksen, Stephen: L-Band System Engineering, Concepts of Use, Systems Performance Requirements, and Architecture. Phase I, NASA/CR—2010-216326, 2010.
9. National Airspace System: System Engineering Manual. Version 3.1, Federal Aviation Administration ATO Operations Planning, June 6, 2006.
10. System Requirements Document, Next Generation Air/Ground Communications (NEXCOM) Version 2.0. FAA-E-2958, FAA, Oct. 22, 2003.
11. Van Roosbroek, Danny: Status. RTCA SC-214/EUROCAE WG-78. DLK Standardization Activities, Eurocontrol/CND/CoE/CN/CO, DLK Users Forum, Attachment 4, July 20, 2010.
12. FCI Aeronautical Data Services Definition Task Report. 2043-0001, ITT Corp., March 31, 2009.
13. Joint Planning and Development Office: Next Generation Air Transportation (NextGen) System Integrated Work Plan (IWP). Version 1.0, 2009.
http://www.jpdo.gov/iwp/IWP_V1.0_No_Appendices.pdf Accessed March 21, 2011.
14. U.S. Department of Transportation: National Airspace System (NAS) Enterprise Architecture <https://nasea.faa.gov/> Accessed March 21, 2011.
15. Zelkin, Natalie; and Henriksen, Stephen: L-Band System Engineering—Preliminary Safety and Security Risk Assessment and Mitigation. NASA/CR-2010-216327, 2010.
16. Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace (Continental SPR Standard). RTCA DO-290, 2004.
17. Gilbert, Tricia, et al.: Future Aeronautical Communication Infrastructure Technology Investigation. NASA/CR—2008-215144, 2008.
18. U.S. Department of Transportation: National Airspace System, System Requirements Specifications. NAS SR-1000, rev. B (Functional View), NAS Architecture 6, June 2008.
19. AS-IS System View (SV-2)—Existing and Near-Term (2009–2010) Telecommunications Infrastructure. Presented by ATO-W, Telecommunications Services Group (TSG), NAS Enterprise Architecture Conference, June 24, 2009.
20. Stratoti, Stephen D.: NAS Enterprise Architecture, NextGen 2025 System Interface Description. SV-1p, System Context, FAA, June 24, 2009.
21. VHF Air-Ground Communications System Improvements Alternatives Study and Selection of Proposals for Future Action. RTCA DO-225, 1994.
22. Fistas, Nikos; Phillips, Brent; and Budinger, James: Future Communications Study—Action Plan 17. Final Conclusions and Recommendations Report, DASC2007-4B6, 2007.
23. Anderson, Gregg: Data Communications, How We Want to Fly! Data Link Users Forum, FAA, July 14, 2010.
24. Phillips, Brent; and Budinger, James: NextGen Air/Ground Communications Research, An Overview for FAA/John Marksteiner. FAA and NASA Glenn Research Center, Aug. 26, 2009.

25. Gilbert, Tricia, et al.: Additional Technologies and Investigations for Provision of Future Aeronautical Communications. NASA/CR—2008-214987, 2008.
26. Gilbert, Tricia, et al.: Identification of Technologies for Provision of Future Aeronautical Communications. NASA/CR—2006-214451 (TR06027), 2006.
27. NAS EA 2025 OV–1 and OV–2: Operational Context. MITRE/CAASD, FAA NAS EA Conference, June 24, 2009.
28. National Airspace System Enterprise Architecture (NAS EA) Portal. Service Roadmap: Increase Flexibility in the Terminal Environment, 2010.
<https://nasea.faa.gov/products/roadmap/main/display/16/tab/solutionSet/> Accessed March 21, 2011.
29. National Airspace System Enterprise Architecture (NAS EA) Portal. Service Roadmap: Initiate Trajectory Based Operations, 2010.
<https://nasea.faa.gov/products/roadmap/main/display/14/tab/solutionSet/> Accessed March 21, 2011.
30. National Airspace System Enterprise Architecture (NAS EA) Portal. Service Roadmap: Increase Arrivals/Departures at High Density Airports. 2010.
<https://nasea.faa.gov/products/roadmap/main/display/15/tab/solutionSet/> Accessed March 21, 2010.
31. National Airspace System Enterprise Architecture (NAS EA) Portal. Service Roadmap: Improve Collaborative ATM, 2010. <https://nasea.faa.gov/products/roadmap/main/display/17> Accessed May 5, 2010.
32. National Airspace System Enterprise Architecture (NAS EA) Portal. Service Roadmap: Reduce Weather Impact, 2010. <https://nasea.faa.gov/products/roadmap/main/display/18>
33. Zakrzewski, Ed.: 2025 System View (SV–2). NAS Enterprise Architecture Conference, ITT, June 24, 2009.
34. New AOC/AAC Services. SANDRA, Draft, March 22, 2010.
35. Roadwork for the Transition from AIS to AIM. ICAO. Air Navigation Commission, March 10, 2009.
36. Stroup, Ron: Avionics Roadmap for NextGen. ARINC SAI Meeting Orlando Florida, Oct. 2009.
37. Delille, Francois: Flight Object, Interoperability and SWIM. Air Traffic Alliance—A New Way of Thinking. Thales Air Systems, ICNS 2007 Conference, Herndon, May 2007.
38. Joint Planning and Development Office (JPDO) Next Generation Air Transportation System (NextGen) ATM-Weather Integration Plan. Version 2.0, September 24, 2010.
39. Hritz, Mike: System Wide Information Management (SWIM). SWIM TIM on Infrastructure and Technology, FAA, May 14, 2008.
40. ICAO Aeronautical Communications Panel 18th Meeting of the Working Group F. Montreal, Canada, 2009.
41. Signal-in-Space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility With Digital Voice Techniques, RTCA DO–224B, 2005.
42. Boithias, H., et al.: International Civil Aviation Organization Information Paper ACP–WGF 19/IP01, 18/07/08 Aeronautical Communications Panel (ACP) Working Group F #19. Agenda Item 7, Montreal, Canada 2008.
43. Control and Communications Product Team: SC–203 Unmanned Aircraft Systems. Issue Paper SC203-CC011_UAS Spectrum_vO_15May09, UAS Spectrum, RTCA, 2009.
44. Characteristics of Unmanned Aircraft Systems (UAS) and Spectrum Requirements To Support Their Safe Operation in Non-segregated Airspaces. Preliminary Draft New Report ITU–R M [UAS–SPEC], Document No. USWP5B09–25, ITU, Aug. 4, 2009.
45. Guidance Material and Considerations for Unmanned Aircraft Systems. RTCA DO–304, Washington, DC, RTCA, 2007.
46. DeGarmo, Matt: Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems (UAS). Draft, 224–09/SC203–036, RTCA, Oct. 23, 2009.
47. Preliminary Draft New Report ITU–R M.[UAS–BANDS–EXIST–ALLOC]: Frequency Band Study To Support Control Links for Unmanned Aircraft Systems (UAS). USWP5B10–19, Aug. 20, 2010.

48. FAA's NextGen Implementation Plan 2009. NextGen Integration and Implementation Office, Washington, DC, Revised Feb. 10, 2009.
49. EUROCONTROL, L-band Continental System. http://www.eurocontrol.int/communications/public/standard_page/LDACS.html Accessed March 21, 2011.
50. Pouzet, Jacky: Future Aeronautical Communication System—FCI: Update on European Activities. CoE/CN/COM Unit, DLK Users Forum, Brussels, Belgium, Sept. 2009.
51. Fistas, Nikos: Future Aeronautical Communication System—FCI. 9th ICNS Conference, Arlington, VA, 2009.
52. European Air Traffic Management Master Plan. Ed. 1, 2009.
53. NextGen Mid-Term Implementation Task Force Interim Report. RTCA, Washington, DC, 2009.
54. World Radiocommunication Conference (WRC-07), Geneva, 2007.
55. Biggs, Michael: Spectrum Issues and WRC-07 Preparation. Presented at the 2007 ICNS Conference, Session J, Aviation Spectrum, Herndon, VA, 2007.
56. Roberts, Darren: B-AMC Project Deliverable D1 Draft 1.0. Mileridge, Aug. 14, 2007.
57. Systematic Interference Investigations. DLR and USG, Jan. 31, 2008.
58. Proposed L-Band Interference Scenarios. Vol. 1.0, DLR, Feb. 2008.
59. Dobrosavljevic, Zoran: DME and B-AMC Co-Existence Study Report. Roke Manor Research, Ltd. Ed. 2.0, Roke Manor, Feb. 28, 2008.
60. Draft B-AMC Frequency Plan. University of Salzburg, March 27, 2008.
61. Preliminary Report on Interference Mitigation Techniques. SESAR. Project P.15 2.4—Task EWA04-1 T1a.
62. Sajatovic, Miodrag, et al.: L-DACS1 System Definition Proposal: Deliverable D3—Design Specifications for L-DACS1 Prototype. Ed. 1.0, Frequentis, DLR, University of Salzburg, and Selex, April 27, 2009, p. 13.
63. LDACS1 D2 Final Deliverable. Ed. 1.0, Frequentis, DLR, University of Salzburg, and Selex, Feb. 13, 2009.
64. L-DACS2 System Definition Proposal: Deliverable D1. Ed. 0.34, EGIS AVIA, March 11, 2009.
65. L-DACS2 Transmitter and Receiver Prototype Equipment Specifications: Deliverable D3 Edition 1.2, EGIS AVIA, June 18, 2009.
66. National Airspace System Communications System Safety Hazard Analysis and Security Threat Analysis. Version 1.0, FAA, Feb. 21, 2006.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>				
1. REPORT DATE (DD-MM-YYYY) 01-07-2011		2. REPORT TYPE Final Contractor Report		3. DATES COVERED (From - To)
4. TITLE AND SUBTITLE L-Band System Engineering Concepts of Use, Systems Performance Requirements, and Architecture Phase II: Final Report			5a. CONTRACT NUMBER NNC-05CA85C	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Henriksen, Stephen; Zelkin, Natalie			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER WBS 031102.02.03.12.0677.11	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) ITT Corporation Information Systems 12975 Worldgate Drive Herndon, Virginia 20170			8. PERFORMING ORGANIZATION REPORT NUMBER E-17673	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITOR'S ACRONYM(S) NASA	
			11. SPONSORING/MONITORING REPORT NUMBER NASA/CR-2011-217010	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Category: 04 Available electronically at http://www.sti.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 443-757-5802				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT This document is being provided as part of ITT's NASA Glenn Research Center Aerospace Communication Systems Technical Support (ACSTS) contract NNC05CA85C, Task 7: "New ATM Requirements--Future Communications, C-band and L-band Communications Standard Development." Task 7 was motivated by the five year technology assessment performed for the Federal Aviation Administration (FAA) under the joint FAA-EUROCONTROL cooperative research Action Plan (AP-17), also known as the Future Communications Study (FCS). It was based on direction provided by the FAA project-level agreement (PLA FY09_G1M.02-02v1) for "New ATM Requirements--Future Communications." Task 7 was separated into two distinct subtasks, each aligned with specific work elements and deliverable items. Subtask 7-1 addressed C-band airport surface data communications standards development, systems engineering, test bed development, and tests/demonstrations to establish operational capability for what is now referred to as the Aeronautical Mobile Airport Communications System (AeroMACS). Subtask 7-2, which is the subject of this report, focused on preliminary systems engineering and support of joint FAA/EUROCONTROL development and evaluation of a future L-band (960 to 1164 MHz) air/ground (A/G) communication system known as the L-band digital aeronautical communications system (L-DACS), which was defined during the FCS. The proposed L-DACS will be capable of providing ATM services in continental airspace in the 2020+ timeframe. Subtask 7-2 was performed in two phases. Phase I featured development of Concepts of Use, high level functional analyses, performance of initial L-band system safety and security risk assessments, and development of high level requirements and architectures. It also included the aforementioned support of joint L-DACS development and evaluation, including inputs to L-DACS design specifications. Phase II provided a refinement of the systems engineering activities performed during Phase I, along with continued joint FAA/EUROCONTROL L-DACS development and evaluation support.				
15. SUBJECT TERMS Aircraft communication; Ground-air-ground communication; Air traffic control				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 159
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U		
			19a. NAME OF RESPONSIBLE PERSON STI Help Desk (email: help@sti.nasa.gov)	
			19b. TELEPHONE NUMBER (include area code) 443-757-5802	

