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C-Band Airport Surface Communications System Standards Development

Phase II Final Report

Volume 1: Concepts of Use, Initial System Requirements, Architecture, and AeroMACS Design Considerations

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April 2011

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Preface

This National Aeronautics and Space Administration (NASA) Contractor Report summarizes and documents the work performed to develop system standards for the proposed C-band (5091- to 5150-MHz[1]) airport surface communications system.

The report consists of two volumes:

- Volume I is devoted to the Concepts of Use, Initial System Requirements, and Architecture and includes AeroMACS Design Considerations.
- Volume II describes AeroMACS Prototype Evaluation and presents Final AeroMACS Recommendations.

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.

[1]With a possible future extension into the 5000- to 5030-MHz band, pending a decision at the World Radiocommunications Conference in 2012.

Executive Summary

ES.1 Introduction

This report is being provided as part of the 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 is separated into two distinct subtasks—each aligned with specific work elements and deliverable items identified in the Federal Aviation Administration's (FAA) project-level agreement (PLA) and with the FAA fiscal years 2009 and 2010 New ATM Requirements—Future Communications Project and spending plan for these subtasks.

The purposes of subtask 7−1, and the subjects of this report, are the definitions of the concepts of use (ConUse), high-level system requirements, and architecture; the performance of supporting system analyses; the development of test and demonstration plans; and the establishment of operational capability in support of C-band aeronautical data communications standards to be advanced in both international (International Civil Aviation Organization, ICAO) and national (RTCA) forums.

The future C-band (5091 to 5150 MHz[1]) airport surface communication system is referred to as the Aeronautical Mobile Airport Communications System (AeroMACS).

Assumptions and constraints for this report follow:

- The 5091- to 5150-MHz spectrum allocation for AeroMACS use at the World Radiocommunications Conference (WRC–2007) is provisioned only for use on the airport surface. This allocation is within the aeronautical mobile (route) service (AM(R)S) band. Therefore, AeroMACS applications are constrained to mobile applications on the airport surface. This is interpreted to include communications for non-mobile (i.e., fixed) applications provisioned within a mobile AeroMACS network that supports the safety and regularity of flight.
- The proposed AeroMACS is assumed to provide an increase in overall air-to-ground (A/G) communications systems capacity by utilizing the new spectrum (i.e., in addition to existing very high frequency, VHF spectrum).
- The scope of this ConUse and requirements report includes airport surface A/G communications and ground-to-ground (G/G) communications.
- AeroMACS will be designed specifically for data communication. Voice communication may be provided as a digital data communications service (e.g., voice over internet protocol (VoIP)).
- This report assumes that the data communications system developed as part of the FAA Data Communications Program (Data Comm) will precede an A/G AeroMACS implementation and deployment.
- Although some critical services could be supported, AeroMACS networks will also target non-critical services, such as weather advisory and aeronautical information services implemented as part of an airborne access to System Wide Information Management (SWIM) program.
- AeroMACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the C-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, the duration, and so on.

The work is being performed in two phases. This report builds on Phase I results as presented in the Phase I report (Ref. 1). This Phase II document is separated into two volumes. Volume I is devoted to the concepts of use, system requirements, and architecture and provides some additional detail for the concepts developed during Phase I. New studies conducted during Phase II, including airport categorization and channelization methodology, expand the AeroMACS design considerations section.

The second volume addresses the AeroMACS prototype architecture and performance evaluation and presents final AeroMACS recommendations resulting from the tests.

ES.2 ConUse

A process recommended in the "National Airspace System: System Engineering Manual" (SEM, Ref. 2) was adopted as a guide in developing ConUse and requirements for the proposed system. Figure ES–1 summarizes the steps.

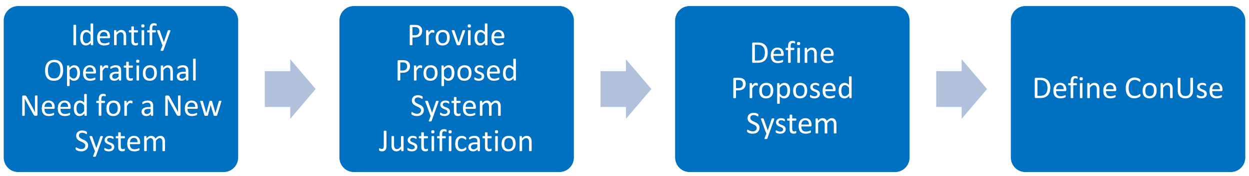

Figure ES–1.—ConUse development process. Acronyms are defined in Appendix A.

ES.2.1 Identify Operational Needs for a New System

Operational needs for a new system are supported by describing the current system and its associated problems and capability shortfalls. "System Requirements Document, Next Generation Air/Ground Communications (NEXCOM)" provides a good description of the FAA's current analog A/G voice communications system used for ATC (Ref. 3).

The Next Generation Air Transportation System (NextGen) concept of operations (ConOps) summarizes the current attributes (and associated constraints) of the voice-based A/G communications system as follows (Ref. 4):

- Limited data communications for air traffic management (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-sight (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 limit the introduction of new or expanded services. These, in turn, could potentially compromise safety of operation and increase operating costs. Saturation of spectrum is the problem specifically mitigated by the introduction of a new C-band system (AeroMACS); the other operational problems would also be mitigated with AeroMACS.

Current G/G communications on the airport surface are conducted predominantly over a combination of wire and optical fiber cabling and a limited number of point-to-point line-of-site radio links.

The limitations imposed by the current G/G communications infrastructure could result in restrictions in the deployment of new ATM services, resulting in the following service limitations (Ref. 4).

- Limited ATM (e.g., traffic) information on the flight deck
  Limited data shared among stakeholders for collaborative decision making (CDM) processes
- Information sharing in support of operational security performed manually instead of electronically
- Not all stakeholders able to access data they need
- Stakeholders unable to use custom data sources

ES.2.2 Provide Proposed System Justification

Rather than being a National Airspace System (NAS) service itself, G/G and A/G communications are enablers of NAS services. It is important to note that the FAA's "Final Program Requirements for Data Communications" (Ref. 5) recognizes that "the scope of the mission shortfalls identified herein [is] broader than will be addressed solely by a data communications capability." Because of the limitations and constraints of implementing data communications using very high frequency digital link (VDL) Mode 2 over a congested aeronautical VHF band, the FAA's Data Comm Program will focus principally on implementing the most critical air traffic services (ATS). This will provide opportunities for AeroMACS networks to augment data communications on the airport surface by enabling communications of less critical and essential ATSs to address the shortfalls listed. Even though each of the shortfalls listed above is meant to be addressed to some extent by Data Comm using VDL Mode 2, there are opportunities to overcome these shortfalls to an even greater extent during the later program segments of Data Comm (e.g., late Segment 2 and Segment 3) using link technologies such as AeroMACS with greater bandwidth capabilities. This would augment the benefits already attained through the earlier VDL Mode 2 Data Comm segment implementations (i.e., Segments 1 and 2) by providing a broader scope of services.

ES.2.3 Define Proposed System and ConUse

Some FAA objectives defined in the FAA's NextGen portfolio are based on the requirement to support future air traffic growth. AeroMACS will be designed and developed to help meet those objectives in part by expanding the data communications capacity in the airport surface domain. Global harmonization is being ensured by developing the proposed AeroMACS component of the FRS as a collaborative effort of the U.S. and European partners.

As recommended by the Future Communications Study (FCS) technology assessment, the proposed airport surface communications system (i.e., AeroMACS) is based on the Institute of Electrical and Electronics Engineering (IEEE) 802.16 standard and its extension, IEEE 802.16e–2005 (Ref. 6), and will be implemented in the aeronautical C-band (5091 to 5150 MHz). A new standards profile for airport applications is currently being developed within an RTCA special committee (SC–223) to operate in the C-band and make use of the scaling properties inherent in the IEEE 802.16e standard. An updated version of the standard, IEEE 802.16-2009, provides the basis of ongoing profile selection.

The proposed AeroMACS could provide supplemental means to the ATC communications required by the operating rules (e.g., VHF voice communications) in continental airspace (albeit on the airport surface) and will adhere to the data link characteristics noted in the "Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace (Continental SPR Standard)" (Ref. 7).

Figure ES–2 and Table ES–1 show the potential AeroMACS services in three categories: air traffic, airline, and airport.

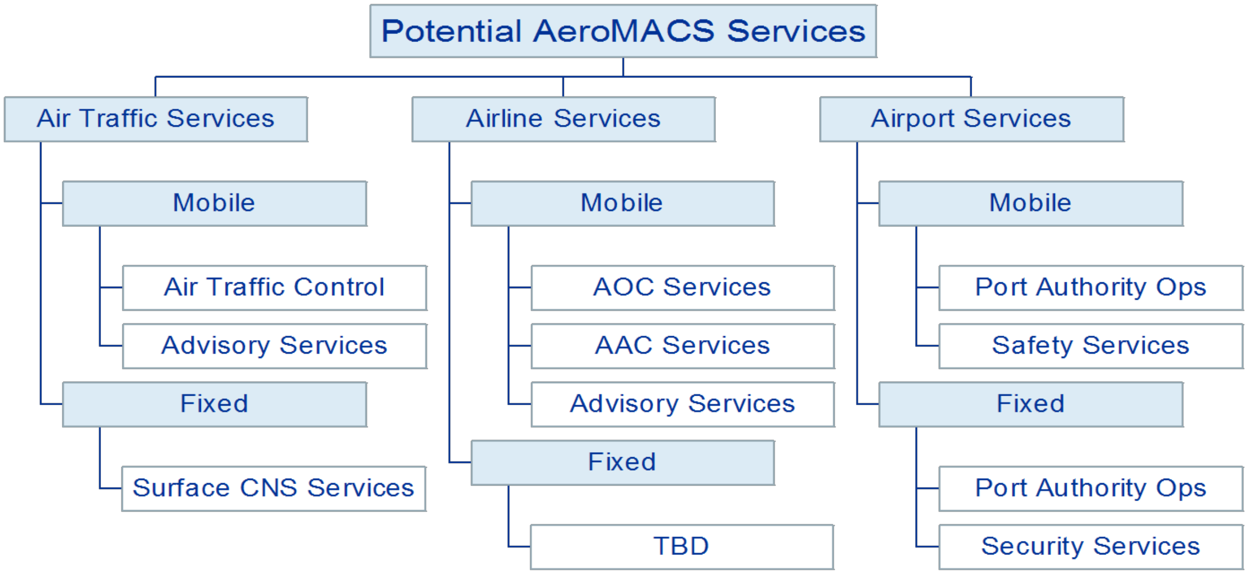

Figure ES–2.—Potential AeroMACS Service Categories in United States (Ref. 8).

TABLE ES–1.—AEROMACS SERVICE EXAMPLES AND PROVISION OPTIONS (REF. 8)

Air Traffic Services	
Service Examples	• Air traffic control commands beyond Data Comm Segment 3 • Surface communications, navigation, and surveillance (CNS) fixed assets
Provision Options	• Government-owned (licensed)/Government-operated (GO/GO) • Government-owned (licensed)/Commercially-operated (GO/CO) • Non-competed service extension via FAA Telecommunications Infrastructure (FTI) • Open commercial competition by FAA
Airline Services	
Service Examples	• (AOC) • Airline Administrative Communications (AAC) • Advisory information • System Wide Information Management (SWIM) • Aeronautical Information Management (AIM) • Meteorological (MET) data services
Provision Options	• Commercially-owned (licensed)/Commercially-operated (CO/CO) • Non-competed service extension via exiting AOC service providers • Airline service provision internally • Open commercial competition by airlines
Airport Operator/Port Authority Services	
Service Examples	• Security video • Routine and emergency operations • De-icing/snow removal
Provision Options	• Local Government-owned (licensed)/Commercially-operated (GO/CO) • Commercially-owned (licensed)/Commercially-operated (CO/CO) • Open commercial competition by Operator/Port Authority

This report focuses on the ATS and advisory data services that are defined in the communications operating concept and requirements (COCR) and are not expected to be provided by the FAA Data Comm Program through Segment 2 (Refs. 8 and 9). The following list shows candidate COCR services potentially enabled by AeroMACS:

- Flight information services
  - Data link operational terminal information service (D–OTIS)
  - Data link runway visual range (D–RVR)
  - Data link surface information and guidance (D–SIG)
  - Data link significant meteorological information (D−SIGMET)
- Flight position, flight intent, and flight preferences services
  - Pilot preferences downlink (PPD)
  - Flight plan consistency (FLIPCY)
  - Wake service (WAKE)
- Emergency information service
  - Urgent contact (URCO)—if in conjunction with other more routine services

Additional data services that may be provided via AeroMACS may be identified as NextGen and Single European Sky ATM Research (SESAR) progress. In addition, AeroMACS could provide the means for A/G data transfer on the airport surface to support the FAA's Aircraft Access to SWIM (AAtS) program.

Table ES–2 lists the operational scenarios and concepts envisioned for the midterm NextGen airport surface flight phase. Although most, if not all, of these concepts are currently envisioned for Data Comm, they are technology independent and, thus, equally valid for an AeroMACS implementation.

TABLE ES–2.—NEXT GENERATION AIR TRANSPORTATION SYSTEM (NextGen) MIDTERM OPERATIONAL CONCEPTS FOR THE AIRPORT SURFACE PHASE

Phase of flight	NextGen midterm communications operational concept (from Ref. 10)
Flight planning	Access to flight planning information will be available to authorized users via a secure network and will include a publish/subscribe capability so that users can receive automatic updates when conditions change along the proposed flight path.
Push back, taxi, and departure	As the time for the flight approaches, the final flight path agreement will be delivered as a data message to pilots who access the agreement before beginning the flight.

Table ES–3 illustrates the potential operational use of the proposed AeroMACS based on the COCR services previously identified as potential applications (Ref. 9).

TABLE ES–3.—USE OF THE PROPOSED AEROMACS IN THE AIRPORT FLIGHT DOMAIN
[Acronyms are defined in Appendix A.]

Operational services	Airport domain phases			
	Predeparture airport domain	Departure taxi airport domain	Arrival airport domain	Arrival taxi airport domain
Flight information services	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET	D–OTIS[a] D–RVR[a] D–SIG	D–RVR[a] D–SIG
Flight position, flight intent, and flight preferences services	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE
Emergency information service				
Services suitable for Airborne SWIM (generally weather advisory and aeronautical information services)	Aviation Digital Data Service (ADDS), AWOS Data Acquisition Service (ADAS), Expanded Terminal and Tower Data Service, General Information Message Distribution Service, Information Display System (IDS) Data Service, NextGen Network Enabled Weather (NNEW) service,[b] NOTAM distribution service, TMA Flight Data Service, WARP/WINS NEXRAD service			

[a]At the time of this report D–OTIS and D–RVR are listed as part of the RTCA SC–214 scope (Ref. 8). As noted throughout this report, the services are considered candidates for AeroMACS if not implemented by the Data Comm program.
[b]It is possible that the information provided through the NNEW service could range from advisories for routine forecasts though safety-critical transmission of certain hazardous weather warning messages, which might limit the extent to which this service could be provided over commercial links. This requires further investigation.

Table ES–4 lists the airline operational control (AOC) data services noted in the COCR v.2.0 (Ref. 10). Position Report (POSRPT) is not included in the table because it is not provided on airport surface. Some of the services listed, for example Software Loading (SWLOAD), would be provided the ground, while others may be applicable to wheels on and off the ground scenarios with AeroMACS enabling these service on the airport surface only.

The AOC services in Table ES-4 may be mapped to the Flight Regularity category (Ref. 9) and may be transported over the AM(R)S link. Services with larger bandwidth requirements, for example WXGRAPH, UPLIB, SWLOAD, may be more suitable to provide via AeroMACS while services involving smaller traffic volumes may be more appropriate for a VDL–2 system.

TABLE ES–4.—COCR V.2.0 AOC DATA SERVICES

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

The New AOC/AAC Services document provided by SANDRA (Ref. 12) specifies additional services not mentioned by the COCR, but recommended based on industry feedback and the standardization activities. This document is a work in progress.

The RTCA SC–223 has formed a User Services and Applications Survey (USAS) Working Group (WG) to collect information from various AeroMACS stakeholders. The group compiled the data for the existing and future applications in the following functional domains:

- Air Traffic Control/Air Traffic Management (ATC/ATM)
- Aeronautical Information (AIM)
- Airlines/Cargo Operations (Airline/Cargo Ops)
- Airport Operation (Airp Ops)
- Airport Infrastructure (Airp Infr)

SESAR Project P 15.2.7 input was incorporated noting the new AOC services proposed by SANDRA (Ref. 11).

At the time of this report, the list of applications compiled by the USAS WG was not validated for AM(R)S use or duplication with the FAA Data Comm program. Rather it attempts to present a superset of communication services that can potentially be enabled by AeroMACS.

Appendix E presents USAS WG's projection of the most likely applications to be supported by AeroMACS. The version presented in Appendix E is a work in progress document with the estimated completion time December 31, 2010.

ES.3 AeroMACS Network Requirements

A middle-out approach was adopted to identify the high-level requirements applicable to AeroMACS. 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. 13), the COCR (Ref. 12), and Data Comm performance requirements and their applicability to the current needs for AeroMACS was performed.

AeroMACS could provide a communication link to transfer surveillance and weather information,[2] facilitate flight and resource management, enhance CDM, and enable the exchange of aeronautical information in the future NAS. The tables in Appendix B document the select RTCA NAS ConOps (Ref. 14) found applicable to the proposed AeroMACS.[3]

The desired AeroMACS functional capabilities have been derived from the identified NAS ConOps presented in Appendix B and mapped to (1) high-level aeronautical A/G and G/G communication functions and (2) specific COCR ATS services. Table ES–5 lists the AeroMACS high-level functional capabilities and presents this mapping . This encompasses a top-down approach to the development of functional requirements.

TABLE ES–5.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 14)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	S-1; S-3; S-4; W-2; W-3; W-8; W-9; W-10; W-12; W-13; W-14; W-15; FM-1; FM-6; FM-8; FM-12; FM-14; FM-15; FM 17; FM-23; A-2; A-6; A-12; A-15	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET FLIPCY WAKE PPD
Support addressed communication for delivery of information to individual and multiple users	S-1; W-10; FM-6; FM-8	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET FLIPCY PPD
Support broadcast communication for delivery of information to multiple users	S-1; S-4; W-2; W-3; W-12; W-14; FM-8; A-12	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET WAKE

[2] In today's environment both, surveillance and weather information would be uplinked to the aircraft on the ground. In the future, a downlink may be applicable to transfer this data to the controller.

[3] Although the RTCA document describes the NAS evolution in terms of three time periods—near (up to 2005), mid (2005 through 2010), and far (beyond 2010)—most concepts identified in the document are found applicable for the proposed AeroMACS, which will necessarily be implemented beyond 2010.

TABLE ES–5.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 14)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Support delivery of real-time information in a timely manner	S-1; S-3; W-16; FM-1; FM-2; FM-9; FM-10; FM-12; FM-15; FM-18; FM-25; FM-26; RM-3; RM-7; A-4; A-7; A-11		D–RVR[a] D–SIG D–SIGMET FLIPCY WAKE PPD
Enable demand, periodic, and event communication	S-1; W-12		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-1; A-5		All services
Support multiple quality-of-service (QoS) provisions			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 users	S-1; FM-12; FM-14; FM-20; A-11		All services
Avoid single points of failure	RM-6		All services
Provide a scalable solution			All services
Provide standards-based solution			All services

[a]At 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 AeroMACS if not implemented by the Data Comm program.

High-level AeroMACS functional requirements were then constructed from the functional capabilities as shown in Table ES–6.

TABLE ES–6.—AeroMACS HIGH-LEVEL FUNCTIONAL REQUIREMENTS

System functions	AeroMACS high-level functional requirements
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	The system shall enable ground-to-air (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. The system shall enable G/G communication for fixed-to-fixed users.
Support addressed communication for delivery of information to individual and multiple users.	The system shall support addressed communications to individual users. The system shall support addressed communications to multiple users.
Support broadcast communication for delivery of information to multiple users.	The system shall support broadcast communication 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 QoS provisions.	This functional capability points toward performance requirements.
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 users.[a]	The system shall support FAA ground users. The system shall support non-FAA ground 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 a standards-based solution.	The system shall provide standards-based solution.

[a]To 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.

Although the top-down approach employs the classic “clean-sheet” system engineering process, the bottom-up approach addresses how the AeroMACS fits into the existing environment.

Functions identified in the NAS SR−1000 document—plan flights, monitor flights, control traffic, support flight operations, monitor NAS operations, and plan NAS usage—cut across all the AeroMACS capabilities shown in Table ES–6.

The functional requirements applicable for an AeroMACS operating on the airport surface (shown in Table 7) were extracted from the NAS requirements specified in the NAS SR–1000. Unless specifically stated otherwise, these could apply to A/G or G/G communications, for fixed-to-mobile or fixed-to-fixed applications.

TABLE ES–7.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
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)
Monitor flights	Collect aircraft navigation information (collect dependent surveillance information)	The NAS shall retrieve actual flight information. (10000)
		The NAS shall acquire actual flight information from aircraft outside of independent surveillance coverage. (03320)
	Monitor aircraft status	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 disseminate essential information on missing aircraft. (13130)
	Report (disseminate) aircraft status	The NAS shall display position information, to specialists, for aircraft that were detected independent of aircraft equipage in qualifying aerodromes. (24530)
		The NAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations. (12820)
		The NAS shall disseminate aircraft flight information for each controlled aircraft to specialists. (02720)
		The NAS shall disseminate the current location for each participating aircraft to ATCSCC [air traffic control system command center] Specialists. (10940)
		The NAS shall disseminate the current location for each participating aircraft to Traffic Management Coordinators. (10980)
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 disseminate weather advisories via direct specialist to pilot communications. (09290)

TABLE ES–7.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
Support flight operations	Manage weather information	The NAS shall maintain communication links adequate to avoid user delay in gaining access. (07090)
		The NAS shall disseminate weather information to users continuously. (07110)
		The NAS shall disseminate current weather effect along the users proposed flight path.(07470)
		The NAS shall disseminate forecast weather in effect along the users proposed flight path. (07480)
		The NAS shall disseminate intensity levels of weather by route of flight to users. (08260)
		The NAS shall disseminate intensity levels of weather by geographic area to users. (08300)
		The NAS shall disseminate weather advisories to users in response to a request. (09300)
		The NAS shall broadcast the latest approved aerodrome conditions on communications media accessible by aircraft on the ground. (09340)
		The NAS shall broadcast the latest approved terminal area conditions on communications media accessible by aircraft on the ground. (09360)
		The NAS shall respond to user requests for weather information from NAS facilities through common carrier communications networks. (09370)
		The NAS shall disseminate selected weather information directly to appropriately equipped aircraft. (09420)
		The NAS shall provide flexible and convenient access to required weather information to users. (19380)
	Operate navigation aids[b]	The NAS shall disseminate navigational accuracy correction values for supplemental navigation systems to users. (17040)
		The NAS shall disseminate correction values for navigational aids to users. (16790)
		The NAS shall disseminate available supplemental terminal navigation guidance information error correction values to users. (14820)

TABLE ES–8.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS

NAS functions		Communication requirements[a]
Monitor NAS operations	Monitor NAS flight operations	The NAS shall disseminate future delay advisories in effect along the users proposed flight path. (07500)
		The NAS shall disseminate traffic advisories upon user request. (09120)
		The NAS shall provide traffic advisories to aircraft on the surface. (30270)
	Maintain NAS infrastructure	The NAS shall disseminate airway usage information to users. (00030)
		The NAS shall disseminate route usage information to users. (00050)
		The NAS shall disseminate aeronautical information to users via external data interfaces. (07430)
		The NAS shall disseminate aeronautical information per user request. (07130)
		The NAS shall disseminate aeronautical information upon user request continuously. (07340)
		The NAS shall disseminate aeronautical data for a maximum of 8 specified locations per request. (07400)
		The NAS shall disseminate the status of supplemental navigation systems to users. (17010)
		The NAS shall disseminate status of supplemental navigation systems to users. (16770)
		The NAS shall disseminate flow control information to users via external data interfaces. (07920)
		The NAS shall disseminate derived restrictions to the user. (11700)
		The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)
		The NAS shall disseminate terrain information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03900)
		The NAS shall disseminate manmade obstacle information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03940)
		The NAS shall disseminate ground information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (25520)
		The NAS shall disseminate filtered terrain information to users. (25560)
		The NAS shall disseminate filtered ground information to users. (25570)
		The NAS shall disseminate filtered manmade obstacle information to users. (25580)
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)
	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)

[a]Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 13).
[b]These services are typically provided via satellite communication (SATCOM) but could be provided via a ground-based system.

Performance requirements were derived to define system capabilities based on the developed functional requirements and considering the propagation characteristic of the C-band. This report summarizes the NAS performance requirements found to be relevant to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 13). Note that these are high-level NAS requirements that do not specify how they should be implemented.

Typically high-level requirements are technology independent. Perhaps unique to the development of the AeroMACS requirements is the identification a priori, by virtue of the extensive FCS technology assessment and ICAO endorsement, of the recommended technology by which AeroMACS will be implemented, that is, IEEE 802.16e and the updated standard, IEEE 802.16-2009 (Ref. 15). This allows the identification and development of quite specific requirements depending on the desired application or service to be provided. The report provides a preliminary approach for identifying and developing AeroMACS requirements in the context of the IEEE 802.16e and 802.16-2009 broadband communications standards, and their characteristics.

Although actual parameters will depend on the architecture of the communication network, the size of the network, and the provisions for redundant communication support, typical performance parameters for the physical and link layer requirements for individual communication services are presented in Table ES–9.

TABLE ES–9.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality of service (QoS) class	Performance parameters	Typical values[a]	Supported by IEEE 802.16-2009
Low to medium speed point-to-point data link	Backup for sensor cable link (i.e., weather sensor)	nrtPS	Data rate PER Delay Jitter	100 kbps 1.0×10^{-3} 1 sec 100 μsec	Yes
High-speed point-to-point data link	Backbone-linking base station (BS); link to relay gateway node in remote area	UGS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec 100 nsec	Yes
Point-to-multipoint broadcast data	Scheduled broadcast of weather info, NOTAM	nrtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 1 sec <1 μsec	Yes
Point-to-point command and control data	Remote operation of ADS–B ground station	rtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-6} 100 msec <1 μsec	Yes
Command and control network	Operation of surface devices at remote airport	Best effort	Data rate PER Delay Jitter	200 kbps 1.0×10^{-4} 200 msec <10 μsec	Yes
Digital voice network	Provide *N* circuits for ATC or AOC operations	rtPS; ERT–VR service	Data rate PER Delay Jitter	10 kbps × *N* 1.0×10^{-3} 100 msec <100 μsec	Yes
Point-to-point video link	Airport surveillance; robotic vehicle	UGS	Data rate PER Delay Jitter	600 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes

TABLE ES–9.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality of service (QoS) class	Performance parameters	Typical values[a]	Supported by IEEE 802.16-2009
Basic mobile	Handoff control for voice; low-speed data sessions	UGS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes
Multimedia	CDM	rtPS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec <10 μsec	Yes

[a]End-to-end delay, one direction.

ES.4 Architectural Description

The initial AeroMACS network architecture is based on the IEEE 802.16e-2005 communications standard that was recently incorporated into the IEEE 802.16-2009 standard (Ref. 14). The primary mode for operation of an IEEE 802.16-2009-based system is a point-to-multipoint architecture. The standard is Internet Protocol (IP) based and provides secure connectivity between users and services. Figure ES–3 depicts is a notional depiction of a wireless point-to-point system in an airport context that illustrates several applications that could potentially be supported by an AeroMACS network. Detailed descriptions of the end-to-end network architectures are provided in later sections of this report.

AeroMACS is envisioned to provide communications for both mobile and fixed infrastructure. An AeroMACS network can support fixed infrastructure in areas of scarce communications, providing wide bandwidth wireless links in place of cables that can be expensive and disruptive to install. Once an AeroMACS network is installed at an airport, a communications link can be instantiated by simply placing an AeroMACS radio at the remote data site interfaced through Ethernet ports, and by programming the network to authenticate and authorize service for the remote data terminal. AeroMACS provides the flexibility to quickly implement new links to remote sites for primary, backup, and emergency communications. The benefit that AeroMACS provides for mobile application communications is unequaled in terms of flexibility and traffic bandwidth.

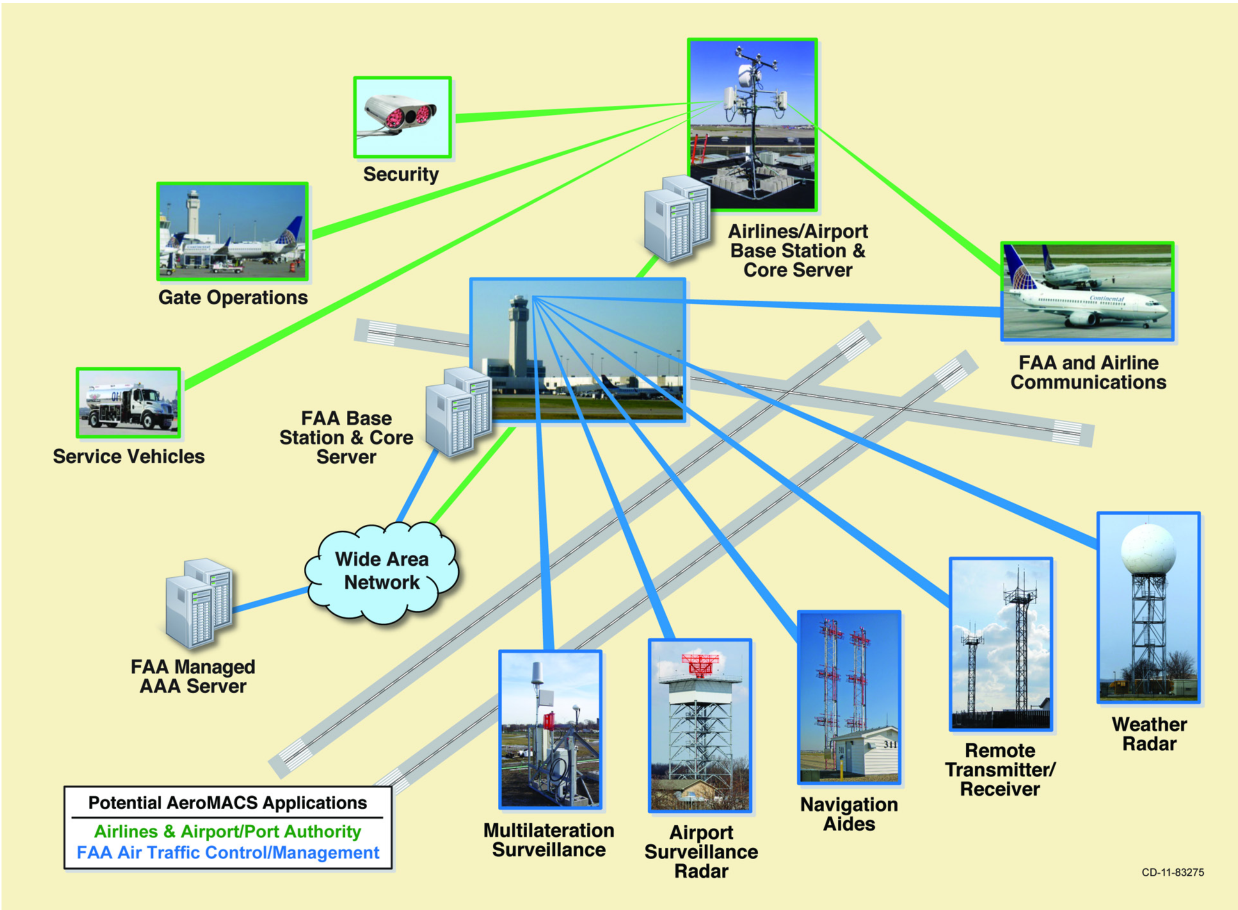

Figure ES–3.—Airport point-to-multipoint communications service. Acronyms are defined in Appendix A.

The system architecture framework can be applied at all airport locations. Deploying an AeroMACS architecture solution at a particular airport requires several tradeoffs to obtain the best performance, including the

- Location and number of base stations (BSs)
- Number of base transceiver station (BTS) antenna sectors to employ per BS
- Type of backhaul system to connect the BSs and support the access service network (ASN)
- Number of subscriber station (SS) terminals that can be serviced by a BS

A design process, including a site survey, coverage model, spectrum analysis, and capacity analysis, provides a formal method of adapting the standard architecture to each airport. Capabilities of existing airport communication systems should be surveyed and factored into the need for new capacity. Components will vary by airport because of differences in size, layout, and applications.

Table ES–10 lists the parameters that must be included in design considerations for an AeroMACS network.

TABLE ES–10.—AeroMACS NETWORK DESIGN CONSIDERATIONS

Design category	Parameters	Considerations and system design parameters
Base station (BS)	Mounting placement	Total network data throughput Line-of-sight/non-line-of-sight (LOS/NLOS) coverage area Low-level blockage avoidance
	Number of BS and base transceiver station (BTS) sectors	BS throughput Channel bandwidth and available spectrum
	Multiple input, multiple output (MIMO) order	BS cell-radius requirements Transmitter (Tx) power Near-line-of-site and blocked-path performance Multipath mitigation Mobility dropouts Interference to out-of-band users will be decreased by MIMO because total radiated power can be reduced.
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Number and placement of BSs BTS sector and subscriber station (SS) Tx power
	Controlled-pattern antennas	Use beam steering and beam-shape adaptation to increase throughput and avoid interference.
	Frequency band	5091- to 5150-MHz aeronautical mobile (route) service (AM(R)S) band approved during the 2007 World Administrative Radio Conference (WARC 2007). Addition of 5000- to 5030-MHz band is under consideration.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughput over coverage area.
SS	Mounting height	Avoid low-level structural and temporary blockages.
	MIMO order	Tx power Near-line-of-site and blocked-path performance Multipath mitigation Mobility dropout avoidance
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Tx power Near-line-of-site and blocked-path performance Multipath mitigation Mobility dropouts
	Frequency band	Controlled and set by BTS sector connection SS must have matching frequency capability.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control the direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughputs over coverage area.

TABLE ES–10.—AeroMACS NETWORK DESIGN CONSIDERATIONS

Design category	Parameters	Considerations and system design parameters
Channel bandwidth	Throughput rate	Highest throughput application sets the minimum channel bandwidth.
	Mobility performance	A wider bandwidth enables better channel equalization and better tracking of multipath variations during mobility.
	Multipath performance	Better equalization of short-path multipath with wider channel bandwidths
	Efficient use of spectrum	Number of channels that fit within the 59-MHz allocated AM(R)S spectrum. Refer to Section 6.2.2 for a detailed discussion about center frequency selection.
	Co-channel interference	There are fewer options for nonoverlapping frequency reuse in a large number of cells with wide channel bandwidths.
	Hardware limitations	20-MHz channel bandwidth requires fast digital processing and may not be implemented by a particular hardware supplier. 5 MHz and 10 MHz are currently supported by the industry.
Modulation	Adaptive or fixed	Fixed modulation requires the use of lowest order modulation and lowest data throughput; higher order modulation will cause dropouts during mobility.
	Modulation rates	Use of all specified options maximizes data throughput for fixed and mobile SSs.
	Forward error correction (FEC) coding rate	Use of all specified options maximizes data throughput for fixed and mobile SSs.
BTS power class	Fade margin	Fade margin allowance is set during network design to establish link reliability.
	Co-channel interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects the signal-to-noise ratio and modulation rate at the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for NLOS operation.
	Power amplifier power-output limitations	Orthogonal-frequency-division multiplexing (OFDM) modulation has a high peak-to-average ratio, making high Tx power expensive.
SS power class	Fade margin	Fade margin allowance is set during network design to maintain link reliability.
	Co-channel interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects signal-to-noise ratio and modulation rate from the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for mobile operation.
	Power amplifier power-output limitations	OFDM modulation has a high peak-to-average ratio, making high power expensive.

TABLE ES–10.—AeroMACS NETWORK DESIGN CONSIDERATIONS

Design category	Parameters	Considerations and system design parameters
Media Access Control (MAC) layer and physical layer	Maximum mobile speed	120 km/hr is a value derived from other specified parameters and provides guidance about achievable maximum speed. The COCR requirement is 160 kt (296 km/hr) IEEE 802.16-2009 specification does not directly support COCR 160-kt requirement. A cost/benefit analysis is needed to assess the benefits of achieving this speed. 50 kt is established as the maximum mobile speed for the following reasons: 1. 40 kt was established during RTCA SC-223 discussions as the maximum taxi speed thought to occur at a commercial airport 2. An operating margin of 10 kt was requested by EUROCAE
	Repeater operation (IEEE 802.16j)	IEEE 802.16j is an amendment to IEEE 802.16e standard that is incorporated in the IEEE 802.16-2009 standard. BS repeater functionality may provide fill-in coverage in shadow areas with minimal added radiation and interference. Use of this feature will be dependent on commercial WiMAX industry implementation of the repeater functionality in hardware.
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	C-band AM(R)S spectrum allocation width does not support cost-effective FDD operation.
Quality of service (QoS)	Time delay	Services such as voice, and command and control applications will require guarantees on maximum time delay allowed.
	Time jitter	Services that are sensitive to jitter are to be identified. The use of frame buffering should be considered for each sensitive application.
	Message priority	Safety and reliability requirements will help specify message priorities.
	Scheduling	The scheduling algorithm will take message priority into account along with QoS requirements.
	Message integrity	Security and message integrity guarantees will depend on the type of QoS service flow selected.

ES.5 Inputs to Network Design

ES.5.1 Identify Operational Needs for a New System

An essential element in designing and deploying an AeroMACS network is a comprehensive RF design. An accurate design will ensure that the deployed wireless network provides the necessary coverage, capacity, and reliability, with minimal interference, that satisfies the service requirements. Although it is possible to gauge the performance of radio links through theoretical means, real-life deployments must take into account variables from the environment to achieve optimal performance and minimize coverage holes and RF cochannel interference. Figure ES–4 illustrates a top-level design flow for new AeroMACS network.

Before the design process can begin for an airport, general guidelines should be defined. Guidance on airport categorization, channelization methodology and power limitation recommendations are essential inputs to an AeroMACS network design. These guidelines are discussed in this report.

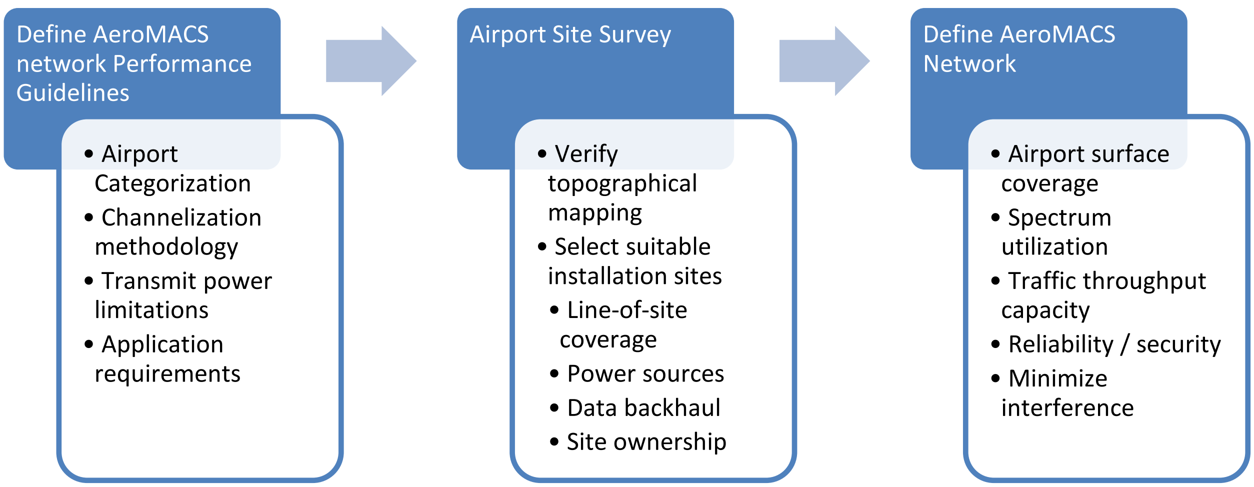

Figure ES–4.—AeroMACS network design process.

ES.5.2 Airport Categorization

The purpose of this airport categorization task is twofold. First, creating a set of airport categories based on common airport characteristics and design objectives would facilitate initial AeroMACS architecture designs and enable budgetary projections. Though each AeroMACS network will be implemented with its own unique characteristics, including the number of sites and channels required to provide adequate service, initial system designs and budgetary estimates often rely on typical parameters.

Second, the results are not intended to drive the final system design, but rather to offer high-level guidance to the potential AeroMACS technology and policy development sponsors and service providers. These may include the FAA Spectrum Office, various FAA Program Offices, airlines, airports, and others.

In addition to coverage and capacity considerations, a business plan and cost of the proposed system will play an integral role in defining airport categories.

General Aviation is the largest type of airport in the U.S. system. This statistic demonstrates that categories should not be limited to the commercial service hubs, as this would exclude a significant number of airports that could potentially implement AeroMACS.

Smaller airports may be interested in attracting new customers by offering additional services. A business plan will address if these services could be enabled by AeroMACS and offer sustainable financial benefits to an airport.

Airports with less FAA presence and infrastructure may have different goals and resources than large hubs with extensive FAA presence. Although FAA interest in an AeroMACS may be limited, opportunities for other sponsorships could open up.

The level of existing communication services at an airport needs to be taken into account. A business plan will take under consideration whether the purpose of AeroMACS is to augment existing services or provide a green field solution.

Airport categorization used by the FAA was found most pertinent to this task because it relates to both aspects of categorization— traffic type and volume—and geographical size.

Table ES–11 provides a summary of the proposed airport categories for AeroMACS resulting from this study.

TABLE ES–11.—PROPOSED AEROMACS AIRPORT CATEGORIES

FAA airport category	Potential AeroMACS users[a]	Potential AeroMACS architecture	Comments and guidelines
Large Hub (LH) Primary	FAA, airports, airlines, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks, food service and baggage carts	More than 2 sectored BSs Number of channels per BS depending on applications	AeroMACS may be used for air-to- ground communication as well as for the use of service vehicles on airport surface. LHs concentrate on airline passenger and freight operations and offer limited general aviation use. LHs have the greatest delays of all Commercial Service (CS) airports which may lead to aircraft spending more time in the airport, potentially increasing capacity requirements to support air to ground communication in this domain.
Medium Hub (MH) Primary	FAA, airports, airlines, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks, food service and baggage carts	2[b] sectored BSs Number of channels per BS depending on applications	AeroMACS may be used for air-to-ground communication as well as for the use of service vehicles on airport surface. Unlike LHs, MHs support a substantial amount of general aviation traffic in addition to carrier aviation. A business plan would target both categories, together or separately.
Small Hub Primary	FAA, airports, airlines, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks, food service and baggage carts	1 to 2[b] BSs Number of channels per BS depending on applications	AeroMACS may be used for air to ground communication as well as for the use of service vehicles on airport surface. Less than 25 percent of runway capacity is used by airline operations supporting many general aviation activities, making AeroMACS less attractive to airlines. Business plan may need to target AeroMACS for general aviation use.
Non-hub Primary	FAA, airports, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1 to 2[b] BSs Number of channels per BS depending on applications	AeroMACS may be used for air to ground communication as well as for the use of service vehicles on airport surface. Heavily used by general aviation with enplaning less than 0.05 percent of all commercial passenger enplanements

TABLE ES–11.—PROPOSED AEROMACS AIRPORT CATEGORIES

FAA airport category	Potential AeroMACS users[a]	Potential AeroMACS architecture	Comments and guidelines
Non-primary CS	Airports, FAA, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1[b] BS Number of channels per BS depending on	Used mainly by general aviation potentially making AeroMACS less relevant to the FAA.
Relievers	Airports, FAA, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1[b] BS Number of channels per BS depending on	Specialized airports providing pilots with attractive alternatives to using congested hubs. Have a significant number of based aircraft. AeroMACS may enable services to attract more users to a particular airport.
General Aviation	Airports, other service providers Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1[b] BS Number of channels per BS depending on	Often located in rural areas. With limited existing communication infrastructure at some airports, AeroMACS may offer a green-field solution. AeroMACS may enable services to attract more users to a particular airport.
Low Activity Landing Areas (Non-NPIAS)	AeroMACS business case might not be supportable		

[a]Further granularity can be achieved, if desired, by collecting and or obtaining statistics from the FAA or the airlines for different airport surface vehicles to quantify the potential users.
[b]More BSs may be required to provide indoor coverage. The use of one BS may be acceptable when AeroMACS is used as one path in a redundant communications system.

Guidelines presented in this section are based on system engineering judgment and the results of the tests performed within the NASA Glenn AeroMACS prototype implemented in the communications, navigation, and surveillance (CNS) test bed located on Glenn Research Center property and adjacent Cleveland Hopkins International Airport (CLE) property, also known as the NASA-CLE CNS Test Bed. The fidelity of these recommendations will increase as new data becomes available, both policy and technical, related to practical implementations of AeroMACS.

Results of the work being performed by RTCA SC–223 to better define services to be supported by AeroMACS may affect many of the categorization considerations presented here.

Additional research, for example, traffic analysis being conducted by Continental Airlines to estimate voice over Internet protocol (VoIP) requirements and potential data rate needs based on current traffic volume (in Erlangs), may be useful in estimating the design parameters per category, such as the number of channels per BS.

ES.5.3 Channelization Methodology

Channelization is the process of segmenting the available AM(R)S allocated spectrum of 5091- to 5150-MHz, with possible addition allocations within the 5000- to 5030-MHz band, to allow multiple independent applications or services to operate simultaneously on the airport surface. Channelization will provide for channel bandwidths of 5 MHz and possibly 10 MHz, as allowed by the AeroMACS profile.

A channelization plan ensures that a large set of requirements are met with services potentially supplied by multiple service providers. A common global channelization methodology is needed to assure seamless interoperability with ground-based and air-to-ground services.

A channelization methodology is constrained by the potential for multiple categories of service and multiple service providers. Three distinct categories of service exist: air traffic control, airline operations, and airport operations.

While a channelization methodology plan can be defined to a certain degree by analysis of technical factors, the final plan will be determined by FAA policy decisions regarding segregation of service traffic and service provider business plans. The discussion in Section 6.2.2.2.1 addresses the FAA policy of segregating the transport of air traffic operations traffic.

The purpose of this study is to establish a methodology for determining a channelization plan for AeroMACS in the AM(R)S band through an assessment of pertinent factors. Analysis follows the study map of Figure ES–5 and addresses each engineering study (ES).

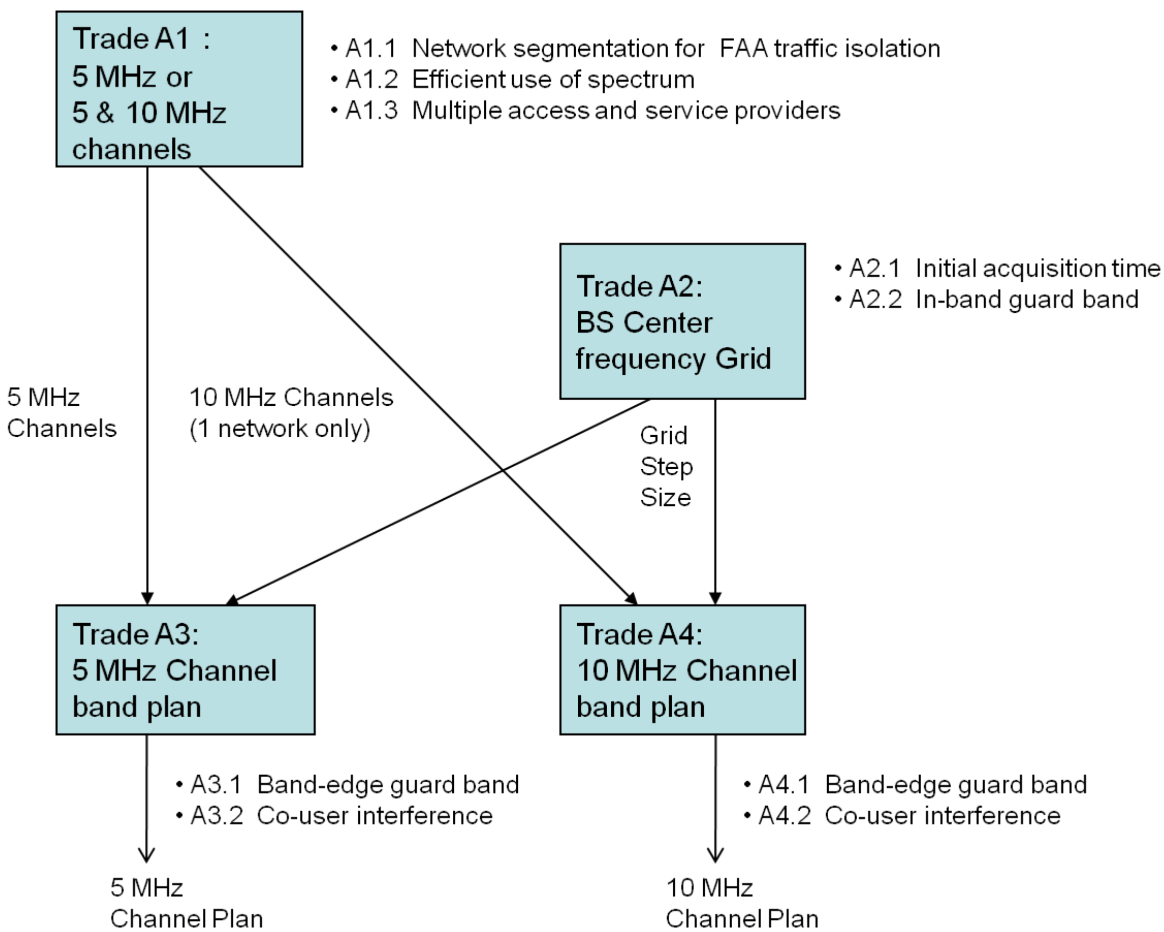

Figure ES–5.—Channelization trade study map.

Conclusions and recommendations from individual studies within this task are summarized in Table ES–12.

TABLE ES–12.—CHANNELIZATION STUDY RESULTS SUMMARY

Study task	Study number	Constraints	Conclusions and recommendations
Network segmentation for ATC traffic isolation	ES1.1	- Two isolated networks per airport may be required by policy - Dual networks make 10-MHz channel bandwidth impractical for multiple sectorized BSs - Dual networks reduces number of airports within co-user interference limits	This is a policy-driven decision within the constraints stated
Efficient use of spectrum	ES1.2	- Band-edge guard bands are needed to limit out-of-band emissions - 10 MHz channel bandwidth causes wasted spectrum at AM(R)S band edges beyond that needed for band-edge guard bands	5-MHz channels provide greater spectrum efficiency
Multiple Access and Service Providers	ES1.3	- Number of Access Service Providers is limited by spectrum allocation	Implement single access provider with an option for multiple service providers
Effect on initial acquisition time	ES2.1	- SS/MS units search for BS center frequencies during initial network acquisition - Significant acquisition delays are multiplied by the number of search frequencies required - Search algorithm will vary by hardware manufacturer and can be customized - BS channel center frequency options must be standardized for global interoperability of SS/MS	Choose wide frequency spacing for BS channel center frequencies options. A grid based on 5-MHz increments specified in WirelessHUMAN standard is preferred for lowest acquisition time.
In-band frequency guard band	ES2.2	- Adjacent channel interference was found to have insignificant effect on link performance when evaluated in the NASA-Glenn test bed. - Use reduces efficient use of spectrum	In-band frequency guard band allocations are not required
Band-edge guard band	ES3.1, ES4.1	- Spectral mask chosen for AeroMACS requires band-edge guard bands to prevent excessive out of band emissions - 5- MHz channel width requires a 2.5-MHz guard-band allocation - 10-MHz channel width requires a 3-MHz guard band allocation	Band-edge guard band allocations are required
Co-user interference	ES3.2, ES4.2	- Co-user interference is minimized with efficient use of AM(R)S spectrum - Interference is increased when dual isolated networks per airport are required	Use single shared-services network with 5-MHz channel bandwidth

ES.5.4 Power Limitation Recommendations

Multiple BS sectors, each called a BTS, will typically be required for wide-area coverage across the airport surface of medium and large airports. A number of factors will be used to determine the transmitted power of each BTS, but two overriding factors will “bracket” the allowable power range. First, the transmit power must provide adequate received signal strength information (RSSI) and carrier-to-interference and noise (CINR) signal levels at the SS receiver to support the intended coverage area. The need to support a coverage area sets the lower bound for transmit power.

The second factor that brackets transmit power, this time on the high side, is the potential to interfere with co-users of the AM(R)S band. Of immediate interest is interference from AeroMACS in to the Mobile-Satellite Service (MSS) feeder uplinks that currently exist in the AM(R)S band. Practical limits on AeroMACS transmissions must be implemented so that the threshold of interference into MSS is not exceeded.

A comparison has been completed between the operating parameters used in the NASA-Glenn AeroMACS Prototype for runway drive tests compared to the conditions used in a MITRE study of co-user interference. Conditions for level of interference to co-users were similar to within 0.4 dB although many parameters differ such as channel bandwidth, antenna mode, and transmitter power output. A runway drive test that maintained at least 3 Mbps throughput rate to a range of 1.7 km provides an initial assessment supporting excellent performance while operating within interference constraints. Additional checks in the future under more severe propagation conditions are required in order to gain confidence that viable links can be supported.

ES.5.5 Upper Networking Layers Analysis

The proposed AeroMACS broadband wireless specification, based on the WiMAX Forum specification for broadband wireless, is meant to deliver increased capacity in support of the varied CONOPS requirements for the National Airspace System (NAS). The desired capabilities include a scalable, standards-based system that avoids single points of failure and supports mutual authentication of users and information access (Ref. 16). A key component in ensuring the reliability and resiliency of communications networks is a comprehensive approach to securing the end-to-end network.

Communications in an AeroMACS network is connection oriented. As a result, connections must be authenticated, authorized and established prior to any data transmissions. Further, the AeroMACS network elements must be authenticated and authorized to each other and to the network prior to the establishment of any logical connections. These mechanisms are examples of a multi-layered approach to communications security (Ref. 17).

A comprehensive communications network security approach involves a layered scheme to ensure the protection of the network at multiple layers. Commonly referred to as “Defense-in-Depth,” a layered security approach eliminates a single point of failure and relies on a continuous security policy, security training for its users, as well as the application of the appropriate technology to ensure the following:

- Confidentiality—protection from eavesdropping
- Integrity—user and management data is not modified while in transit
- Authentication—assurance that users and devices can authenticate each other
- Authorization—mechanism that verifies user and AeroMACS service associations
- Access Control—control authorized access to network resources
- Availability—prevent Denial of Service or of the AeroMACS network and its attendant resources.

Security in a communications network should be deployed at multiple levels to eliminate potential single points of failure. The 802.16–2009 standard defines a number of security enhancements that provide defense-in-depth to ensure confidentiality, authentication, authorization and integrity in addition to access controls for the communications infrastructure. They include the use of the Internet Engineering Task Force (IETF) extensible authentication protocol (EAP)-based AAA framework, used for mutual authentication and authorization of network elements and subscribers

The AAA framework is also utilized for service flow authorization, QoS policy control, and encryption. IEEE 802.16-2009 specifies 128-bit encryption at a minimum. Encryption is used to ensure the confidentiality and integrity protection of both management and data traffic. As an added measure of protection, the Federal Government mandates the use of FIPS-approved cryptographic algorithms contained in FIPS-validated cryptographic modules.

In addition, the WiMAX Forum specifies a range of security mechanisms that compliment the IEEE 802.16–2009 PHY and MAC layer security mechanisms. Solutions include the deployment of VPN technologies to provide end-to-end encryption of the data channels at the network layer. Further, the development of security policies that incorporate physical and administration controls with the logical technology controls will ensure that the NAS ConOps requirements will operate in a reliable, resilient, secure AeroMACS infrastructure.

The complete security assessment of AeroMACS is out of the scope of this report and is being addressed by NASA in a separate document (Ref. 18).

ES.6 Introduction to Volume II

Volume II describes modifications to the NASA Glenn Research Center (Glenn)/Cleveland Hopkins International Airport (NASA–CLE) Communications, Navigation, and Surveillance (CNS) Test Bed to add Institute of Electrical and Electronics Engineering (IEEE) 802.16 (Ref. 19) capability and testing and evaluation results using simulation, emulation, and or experimentation and testing. It also provides initial data to be input to the aeronautical mobile-specific IEEE 802.16 design specifications.

Developing an AeroMACS solution based on the IEEE 802.16–2009 standard requires detailed analysis, simulation, and test measurements on actual airport surfaces. This AeroMACS prototype in the NASA CLE CNS Test Bed is designed to implement many of the AeroMACS features and requirements that support modern data communications at an operational airport to help verify the performance of AeroMACS and validate some of the ConUse.

Figure ES–6 shows the placement of the AeroMACS Prototype network on Glenn property and the adjacent CLE airport surface.

NAS growth and improvement will provide continued safety, efficiency, and reliability to the flying public. The AeroMACS solution is designed to help increase airports’ capacity for departures and arrivals, as well as the safety and efficiency of surface movement, the security and flexibility of airport surface operations, and the situational awareness for airport surface users and stakeholders. AeroMACS will also help reduce delays, fuel consumption, and emissions. Finally, AeroMACS will be developed in cooperation with the European Organisation for the Safety of Air Navigation (EUROCONTROL) to advance the establishment of global standards and interoperability to effectively and efficiently enable rapid and thorough airport improvements as new applications augment and replace legacy systems.

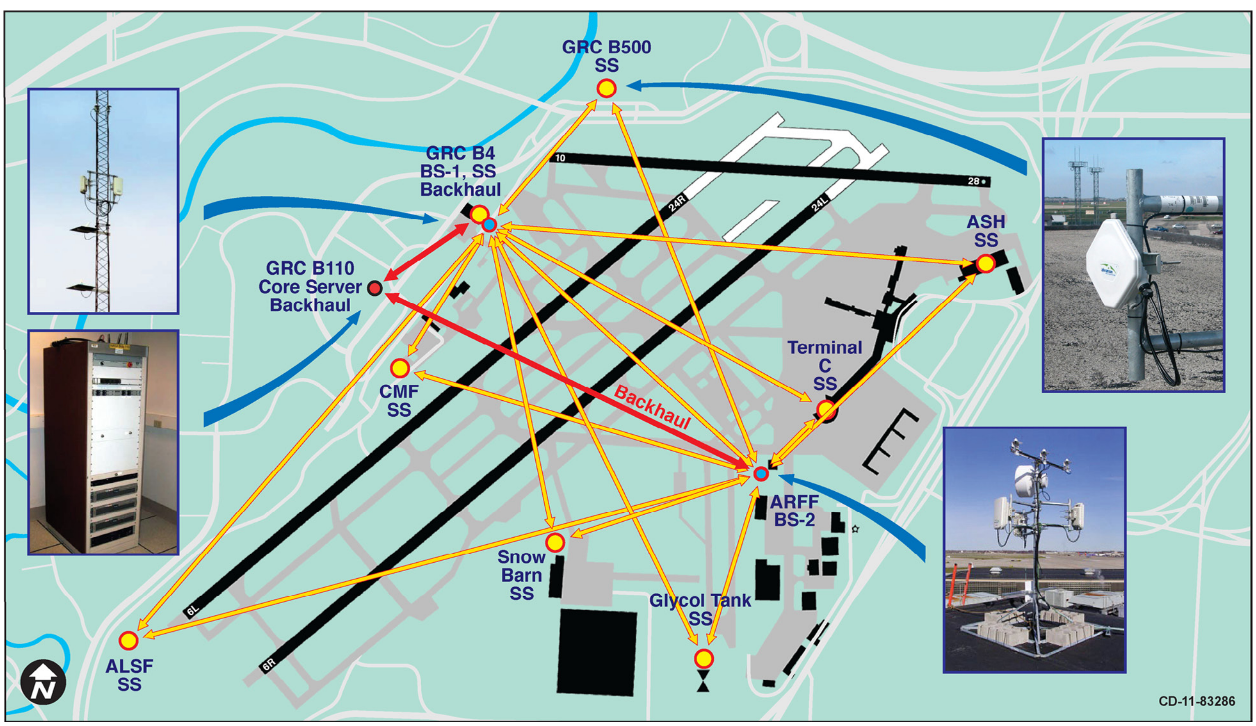

Figure ES–6.—NASA–CLE CNS Test Bed base station, backhaul, and core server locations. Acronyms are defined in Appendix A.

Special committee SC–223 was established within the RTCA aviation industry consortium to establish standards for AeroMACS. The principal products of this special committee are a set of final recommendations for a system profile to be delivered in September 2010 and a Minimum Operational Performance Standards (MOPS) document to be delivered in December 2011 (Ref. 20). EUROCONTROL established a similar work group, WG−82, that is chartered to develop an AeroMACS profile. SC–223 and WG−82 work cooperatively to develop a common profile document that will be provided as recommendations for consideration by ICAO.

Sets of system parameter profiles have been recommended for AeroMACS within this study. These profiles are based on the existing IEEE 802.16–2009 standard. A profile working group within RTCA SC–223 is tasked with further developing the AeroMACS profile and deciding whether parameters are mandatory or optional to implement.

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1.0 Introduction

1.1 Background

During the past five years, the NASA Glenn Research Center (Glenn) and ITT Corporation have conducted a three-phase technology assessment for the Federal Aviation Administration (FAA) under a joint FAA–European Organisation for the Safety of Air Navigation (EUROCONTROL) Cooperative Research Action Plan (AP–17), also known as the Future Communications Study (FCS). NASA Glenn, with the contracted support of ITT, provided a 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 the 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 Joint Planning and Development Office's (JPDO) "Next Generation Air Transportation System, Integrated Plan" (Ref. 21) and are represented in the "National Airspace System (NAS) Infrastructure Roadmaps" (Ref. 22).

Action Plan 30 (AP–30), a proposed follow-on cooperative research 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 EUROCONTROL's Single European Sky ATM Research program in Europe. Follow-on research and technology development recommended by ITT and 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 a FY09 solution set work plan for C-band and L-band future communications research in the section, "New Air Traffic Management (ATM) Requirements."

On February 27, 2009, the FAA approved a project-level agreement (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 the 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. On February 1, 2010, the FAA approved the follow-on PLA (FY10_G1M02– 02) to provide findings and recommendations to the RTCA and EUROCAE WG–82 on the aviation profile of the IEEE-802.16e (WiMAX) based standard for an aeronautical mobile airport communications system (AeroMACS), and to complete evaluation of a proposed L-band digital aeronautical communications system (L-DACS) in relevant environments to support new en route ATM requirements. The work described in this report covers ITT's portion of the PLA tasks related to C-band airport surface wireless communications development. The L-band portions of the PLA research are documented in a companion report (Ref. 23).

This report is being provided as part of the 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 project-level agreement and with the FAA FY09 and FY10 spending plan for these subtasks. The purpose of subtask 7–1, and the subject of this report, is to define the C-band airport surface ConUse, systems performance requirements, and architecture in a future C-band (5091 to 5150 MHz[4]) air-to-ground (A/G) communication system referred to as the Aeronautical Mobile Airport Communications System (AeroMACS).

The work is being performed in two phases. This report builds on the Phase I results presented in the Phase I report (Ref. 1).

[4]With a possible future extension into the 5000- to 5030-MHz band, pending a decision at the World Radiocommunications Conference in 2012.

The Phase II document is separated into two volumes. Volume I is devoted to the concepts of use, system requirements and architecture and provides some additional detail for the concepts developed during Phase I. New studies conducted during Phase II, including airport categorization and channelization methodology, and expand the AeroMACS design considerations section. Volume II document describes Phase II work to validate performance AeroMACS requirements and candidate architecture through test and evaluation of an AeroMACS prototype network built by ITT in the NASA-Glenn Test Bed. A description of the AeroMACS prototype network is provided, followed by descriptions and results of tests that evaluate AeroMACS performance using the prototype network. Final AeroMACS standards recommendations are provided.

1.2 Systems Overview

Systems covered by this document provide the following airport surface communications services shown within the dashed red boxes in Figure 1.

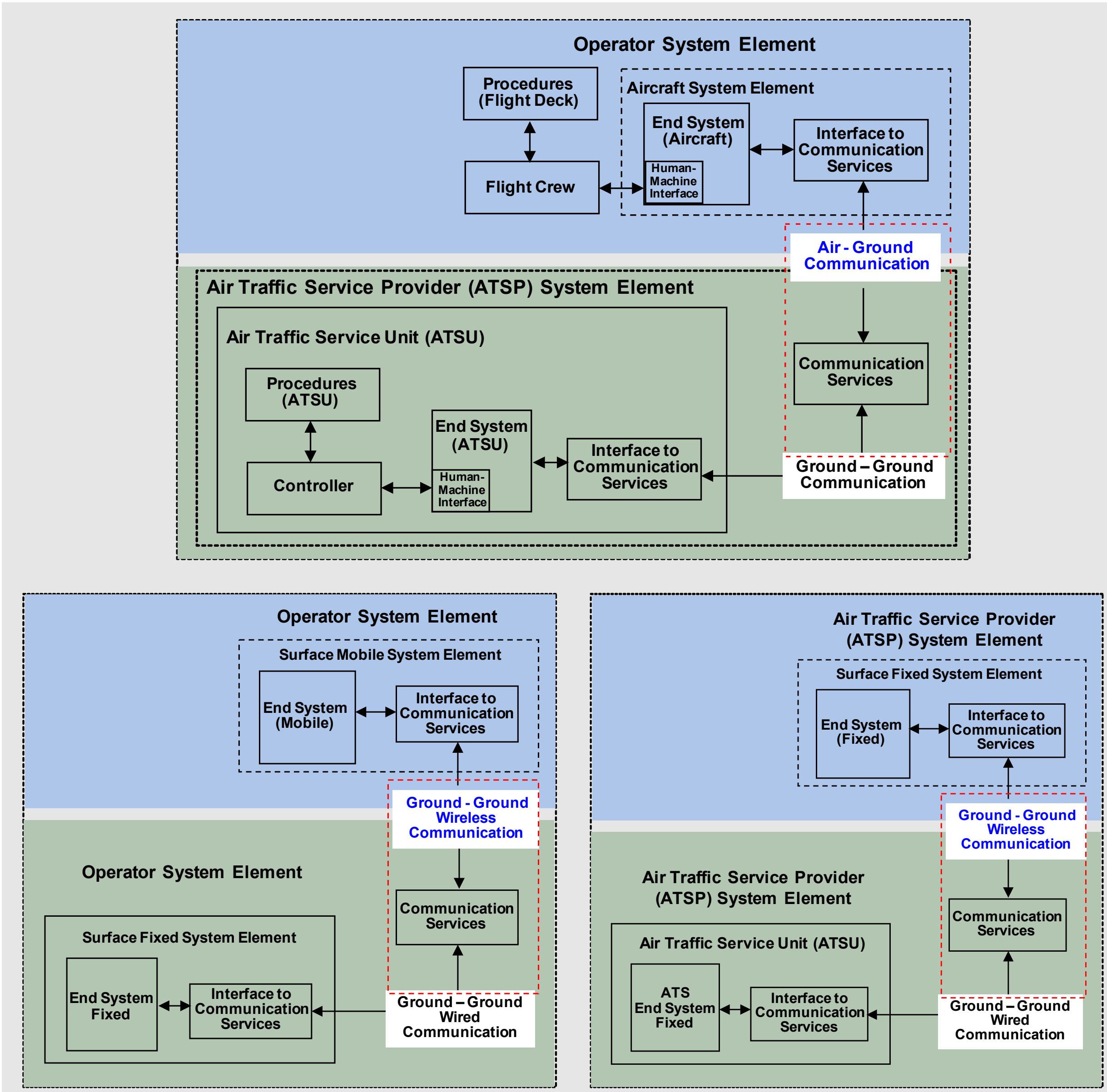

Figure 1.—Communications systems covered by this ConUse document (slightly altered version of Figure 1–1 in Ref. 7).

- Air traffic services (ATS) A/G flight safety communications between fixed ATS provider (ATSP) system elements and an aircraft
- ATS ground-to-ground (G/G) communications between fixed ATSP system elements (e.g., to provide connectivity between the components of a NAS surveillance system).
- G/G communications between fixed and mobile operator (e.g., airline) system elements (e.g., to provide connectivity for aeronautical operational or administrative messages supporting the operation or maintenance of facilities provided for the regularity of aircraft operations as described in Ref. 24).

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

1.3 Document Overview

This document is organized as follows:

- Section 1.0 provides background system information and describes the document scope, organization, and references.
- Section 2.0 presents the processes for developing the ConUse and the requirements.
- Section 3.0 is devoted to the ConUse of the proposed AeroMACS. After describing the ConUse development process, it presents the operational need for AeroMACS by describing current A/G and G/G communications systems and their associated problems and capability shortfalls. Section 3.3 shows the potential benefits of the new systems and describes the desired changes. The proposed system is then described. ConUse are presented, along with references to RTCA's NAS concept of operations (ConOps) guidance documents and descriptions of FAA's Data Communications Program (Data Comm) operational scenarios, NextGen operational concepts, and AeroMACS operational concepts based on the airport surface flight domain as well as those derived from the communications operating concept and requirements (COCR).
- Section 4.0 presents preliminary AeroMACS network requirements. It describes the development process for system requirements and presents results for the "middle-out" approach.
- Section 5.0 describes initial network architecture.
- Section 6.0 presents AeroMACS design considerations.
- Section 7.0 introduces the second volume of the report.
- Appendix A defines acronyms and abbreviations used in this report.
- Appendix B summarizes the RTCA NAS ConOps applicable to the proposed AeroMACS.
- Appendix C provides hierarchical diagrams of the functional requirements for the AeroMACS C-band communication system.
- Appendix D shows examples of airport categories based on propagation characteristics
- Appendix E shows RTCA SC–223 USAS Workbook Summary

2.0 ConUse and Requirements Development Processes

Multiple documents related to concepts of use and concepts of operations 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 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 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. ConOps describe "what is expected from the system, including its various modes of operation and time-critical parameters" (Ref. 2), whereas a ConUse is "an extension of a higher level ConOps with an emphasis on a particular NAS system and its operating environment" (Ref. 2). 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.

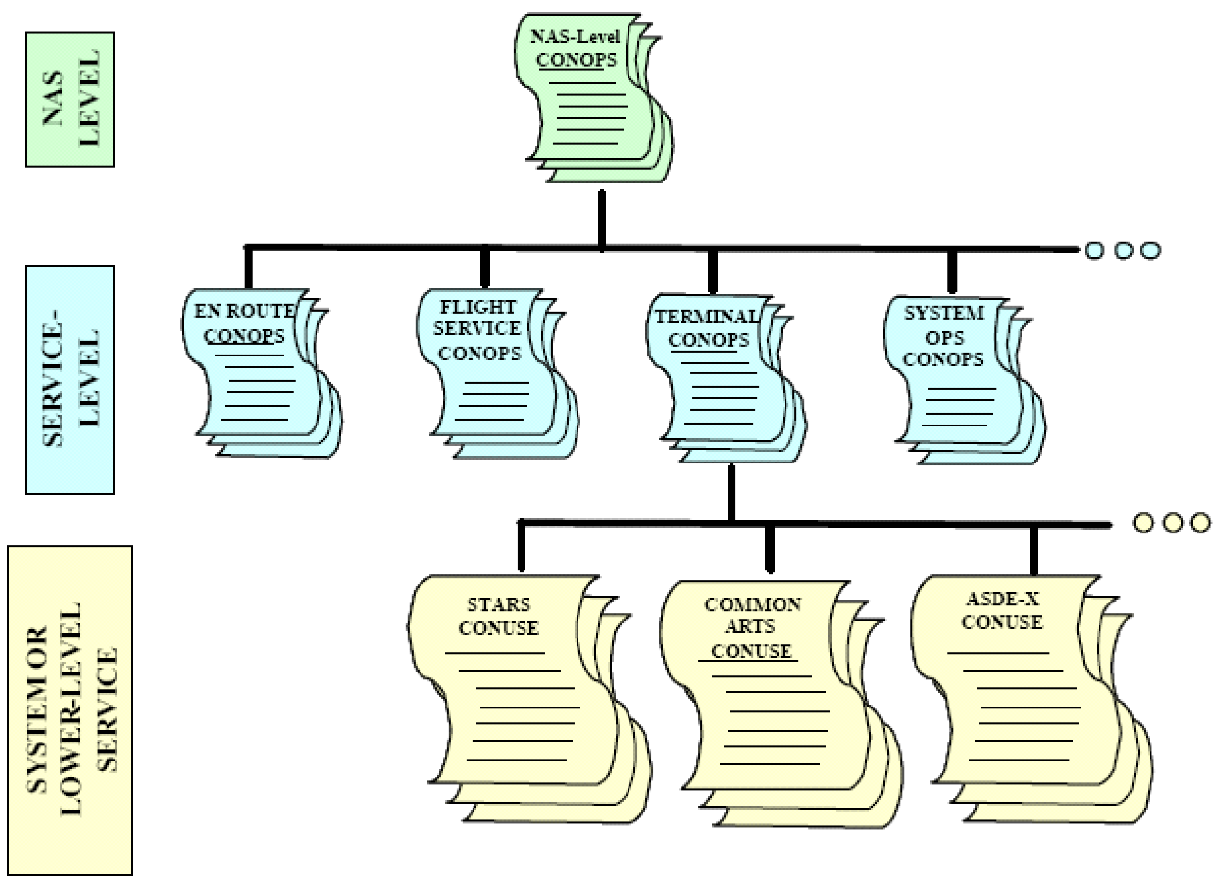

Figure 2.—National Airspace System (NAS) engineering concept document hierarchy (Ref. 2). Acronyms are defined in Appendix A.

These three levels can be summarized as follows:

- NAS-level ConOps comprise "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" (Ref. 2).
- Service-level ConOps provide "conceptual insight into a particular service of the NAS." These give "more detail and in-depth information about the desired operations within the service" (Ref. 20).
- 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." ConUse are more detailed and substantial, but they still express "the user's needs regarding a specific system within the NAS" (Ref. 2).

NAS-level and similar level international ConOps driving this ConUse and its associated requirements include RTCA's "National Airspace System: Concept of Operations and Vision for the Future of Aviation" (Ref. 14), the "Concept of Operations for the Next Generation Air Transportation System" (Ref. 4), and the ICAO's "Global Air Traffic Management Operational Concept" (Ref. 25). At the next lower layer, EUROCONTROL's "Operating Concept of the Mobile Aviation Communication Infrastructure Supporting ATM Beyond 2015" (Ref. 26) was used with the service-level ConOps—"Communications Operating Concept and Requirements for the Future Radio System (COCR)" (Ref. 11)—to provide reference guidance for A/G 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. 27) and "Final Program Requirements for Data Communications" (Ref. 5).

It should be noted that the ConOps and ConUse documents just referenced relate primarily to the provision of safety-critical A/G air traffic control (ATC) communications services; however, they also are applicable to the provision of airport surface G/G communications links that support other NAS safety critical services, such as surveillance, weather, flight planning, and aeronautical information. NAS ConOps applicable to the provision of aeronautical operational and administrative messages over G/G communications systems and supporting the regularity of flight operations are not available for reference, perhaps because NAS ConOps typically apply to the provision and operation of safety-critical services.

The ConUse and performance requirements described in this document apply to a future airport surface-band (5091- to 5150-MHz) communication system referred to as AeroMACS that will provide A/G and G/G communications services similar in scope to those described in the "FCI Aeronautical Data Services Definition Task Report" (Ref. 9) as well as other services shown in Figure 1. The 2009 FCI report follows from the previous FCS technology evaluation study (Ref. 28), which identified the IEEE 802.16e standard (Ref. 19), now included in the IEEE 802.16–2009 standard, as the recommended candidate for further development because it best meets the FCS technology assessment criteria and is designed for the C-band spectrum, which is a recommended band for supporting new data link communications capabilities for airport surface communications.

Because many, if not most, NAS systems are not entirely new, but rather, evolutionary improvements of existing NAS systems, a top-down process is not always sufficient. 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 bottoms-up approach, which takes into account existing concepts, systems, and requirements.

Figure 3 shows the middle-out approach adopted for the ConUse and requirements developed for AeroMACS. 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 G/G communications services. In addition to this top-down process, a bottom-up process of identifying and evaluating specific concepts and requirements developed for specific communications systems, such as Data Comm, Next Generation Air/Ground Communication (NEXCOM), and Link 2000+, along with appropriate NAS System Requirements (SR–1000, Ref. 13) and IEEE 802.16–2009 requirements (Ref. 15), was employed for this document.

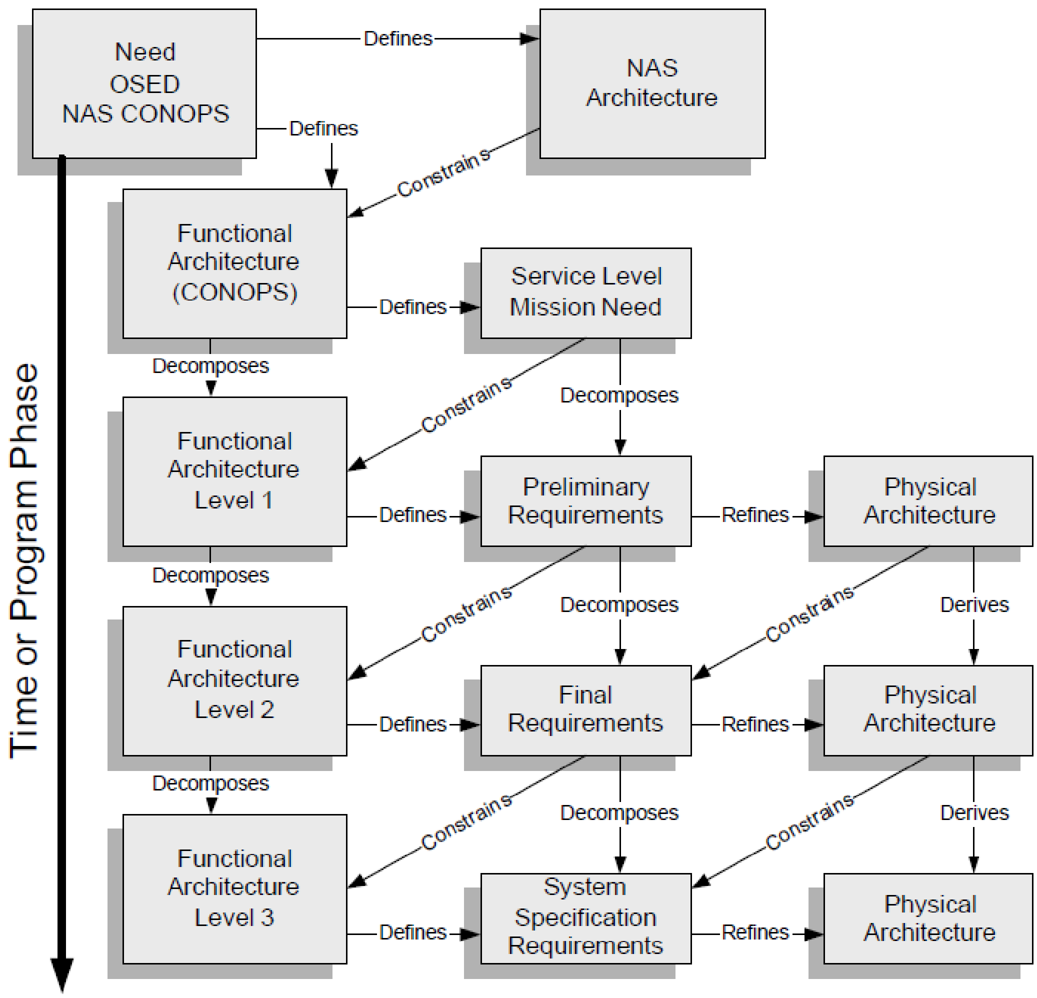

Figure 3.—Requirements management process flow (Ref. 2). Acronyms are defined in Appendix A.

3.0 ConUse

3.1 ConUse Development Process

A process recommended in the NAS system engineering manual (SEM, Ref. 2) was used as a guide in developing ConUse for the proposed AeroMACS. Figure 4 summarizes the steps. The following sections describe the findings for each of the steps shown in the figure.

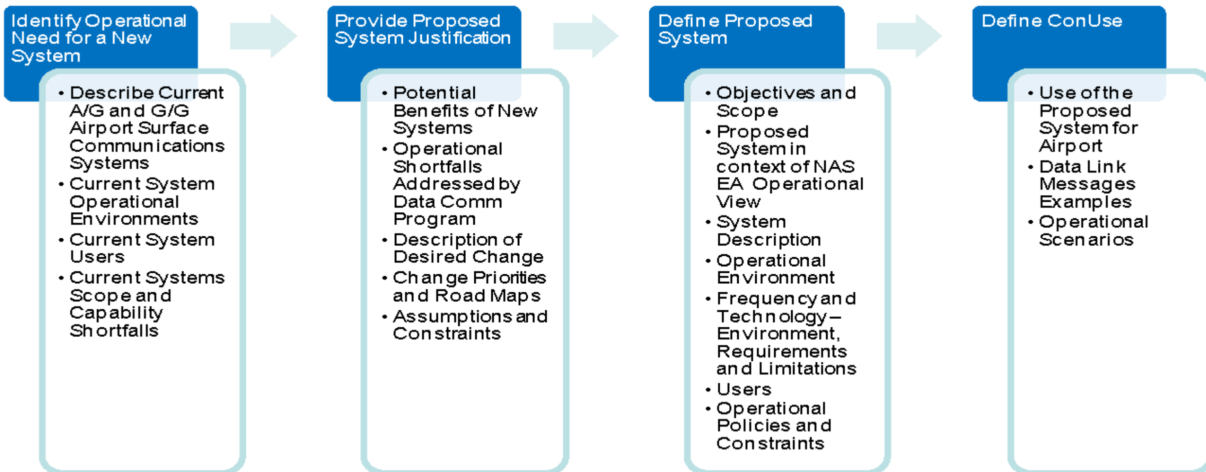

Figure 4.—ConUse development process. Acronyms are defined in Appendix A.

3.2 Operational Needs

This section defines the operational needs for AeroMACS by describing current and planned airport surface communications systems and their associated problems and capability shortfalls. Though not a current system, the planned data communications networks services 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 A/G AeroMACS on an airport surface. Data Comm should mitigate many of the current operational problems and shortcomings while leaving room for AeroMACS to provide additional gains in overcoming current A/G communications shortcomings.

3.2.1 Current Airport Surface Communications Systems

3.2.1.1 Current Air-to-Ground Communication System

The "System Requirements Document, Next Generation Air/Ground Communications (NEXCOM)" provides a good description of the FAA's current analog A/G voice communications system used for ATC (Ref. 3):

> The current A/G Communications System for ATC consists of voice-based networks that use DSB-AM [double-sideband amplitude-modulation] radios and operate in the 117.975 to 137 Megahertz (MHz) VHF band for civil aircraft and the 225- to 400-MHz UHF [ultra-high-frequency] band for military aircraft. The radios operate with the same frequency used for controller-to-pilot (uplink, UL) and pilot-to-controller (downlink, DL) transmissions in a simplex "push-to-talk" mode. There is a dedicated, non-interconnected radio network for each operational environment (EnRoute, 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 Back-Up Emergency Communications (BUEC) in the En route, Emergency Communications System (ECS) in the large TRACONS [terminal radar approach control facilities] 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 5 shows this system for en route A/G communications. Similar architectures are in place for terminal area and airport surface area A/G communications. Figure 6 depicts a typical remote transmitter/receiver (RTR) site configuration used for A/G communications for the terminal area and for the airport surface. Appendix A of the NEXCOM System Requirements Document provides a detailed description of the current A/G voice communications architecture and facilities.

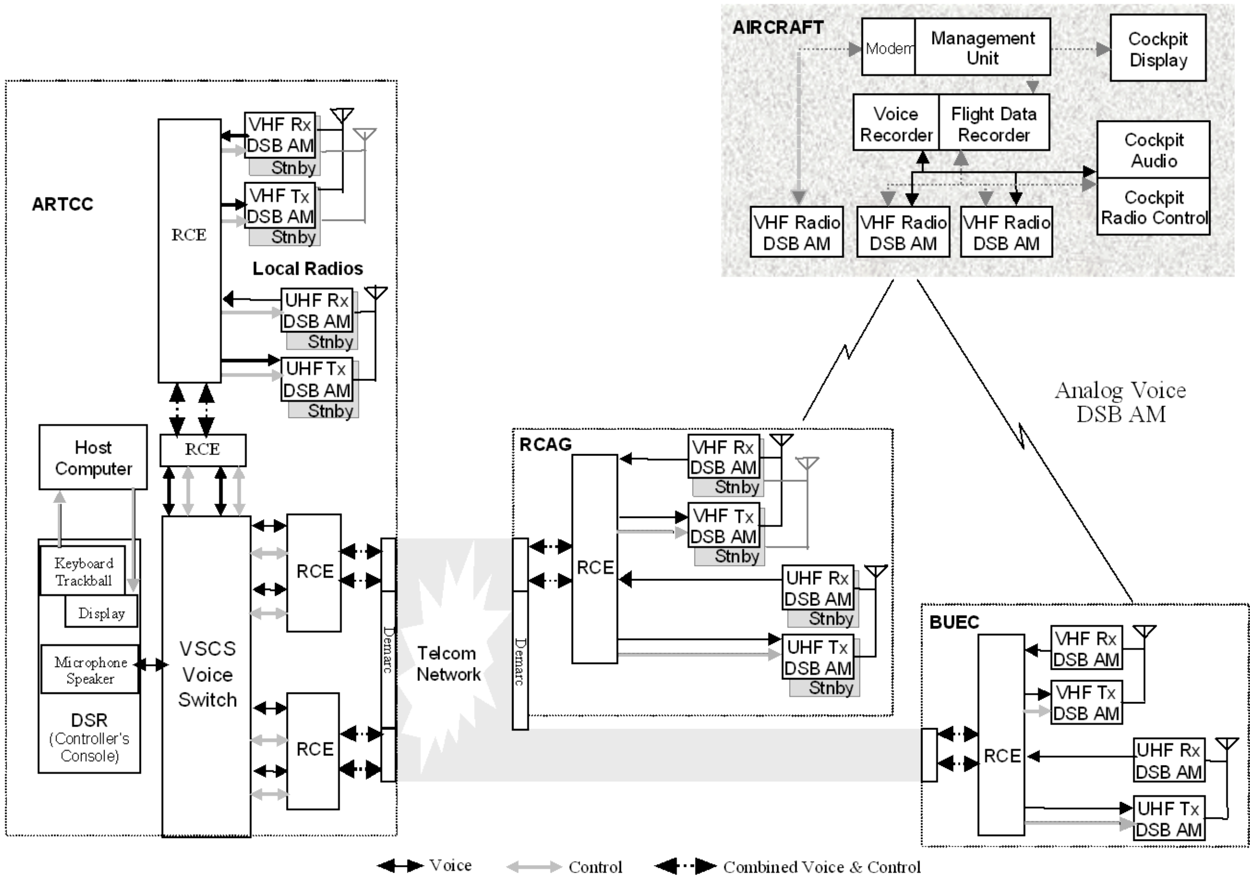

Figure 5.—Current en route air-to-ground (A/G) communications system (Ref. 3). Acronyms are defined in Appendix A.

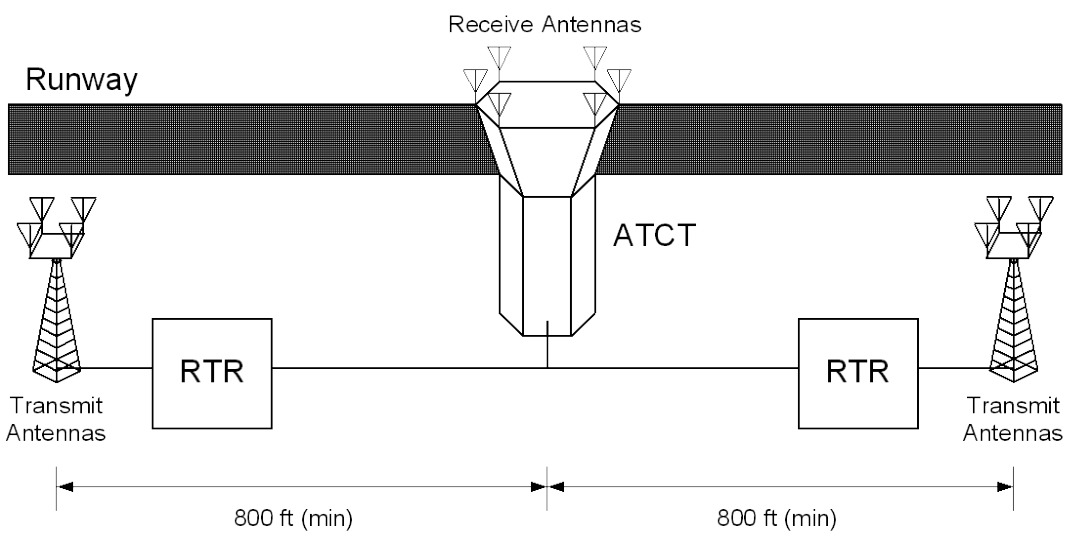

Figure 6.—Typical remote transmitter/receiver (RTR) site configuration (Ref. 3); air traffic control tower (ATCT).

3.2.1.2 Current Airport Surface Ground-to-Ground Communication Systems

Current G/G communications on the airport surface are conducted predominantly over a combination of wire and optical fiber cabling and a limited number of point-to-point line-of-sight (LOS) radio links. Most often, airport surface systems are interconnected by direct telecommunications services, including underground cable systems implemented by the airport.

Shielded, twisted-pair copper lines carry low-data-rate and voice communications between fixed locations. Fiber-optic cables perform a similar function but have expanded bandwidth capability. Point-to-point radio links can handle narrow to wide data bandwidths without the use of difficult-to-install underground cables.

G/G communications handle data exchanges between a wide variety of applications on the airport surface. Table 1 lists examples of present and future applications that require G/G communications.

TABLE 1.—AIRPORT SURFACE SYSTEMS THAT COULD BE SUPPORTED BY AEROMACS

Service	Airport Surface Systems Supported
Sensor data collection/dissemination for situational awareness	Multilateration (MLAT) Airport Surface Detection Equipment, Model X
	Automatic dependent surveillance—broadcast (ADS–B) ground sites
	Air surveillance radar
	Airport lighting systems
	Network-enabled weather data; automated surface observation systems (ASOS), low-level wind shear alert system, Terminal Doppler Weather Radar, Integrated Terminal Weather System, icing
Cable/Telco replacement and augmentation	Backup and primary alternative to cabled connections
	Extend cable loop infrastructure to remote surface assets
	Temporary fixed-asset connection during surface construction or service restoration
	Remote transmitter/receivers (RTRs)
	Remote maintenance and monitoring

3.2.2 Current System Operational Environments

Rather than being a NAS service itself, G/G and A/G communications are *enablers* of NAS services and provide the following functionality (Ref. 13):

> 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 [instrument landing system], VOR [VHF omnidirectional range] and space-based systems and aircraft transmitted beacon code data.

Reference 29, which gives an As-Is System View 2 (SV–2) of the NAS, describes how NAS interfaces, as identified in Reference 13 (NAS SV–1) 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. The As-Is SV–2 figures were developed depicting an overall telecommunications infrastructure and providing separate views for five information flow areas:

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

3.2.2.1 Current Air Traffic Control Air-to-Ground Communications System Operational Environments

Figure 7 presents an overview chart depicting an SV–2 telecommunications view and associated data for the command and control functional flow area. Note that the “Terminal Voice” link depicted in the figure also would include airport surface voice communications between aircraft on the ground and radio equipment (typically RTR sites, as shown in Figure 8) serving ATCTs.

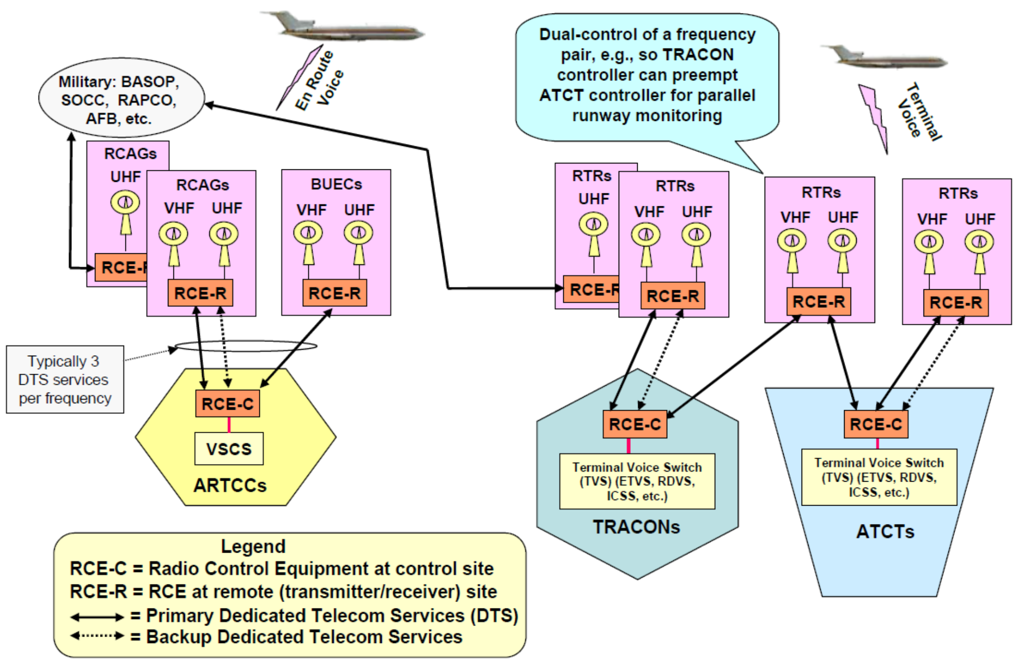

Figure 7.—System View 2 (SV–2) command and control detailed air-to-ground communications view for 2009 to 2010 (Ref. 29). Acronyms are defined in Appendix A.

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. 13)[5]:

- 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)

For the most part, these functions are currently implemented in the NAS via voice communications; though the NAS SR–1000 (Ref. 13) 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 above are needed to provide several of the NAS service capabilities defined in the NAS SR–1000. Table 2 provides a mapping of NAS-level functions to the 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 voice communications to provide specific NAS service capabilities. For example, A/G voice 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 voice-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 service “Capability” row):

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

Some of the NAS service capabilities listed earlier, such as separation assurance and A/G-communications-enabled flight planning service capability, are considered to be safety critical for the NAS. Because of the need to support such 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 (so-called, 5-9s) and an end-to-end latency of 250 msec[6] for the most critical voice communications services.

For continental airspace, A/G voice communications is provided in the terminal maneuvering area (TMA), en route, and in 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.

[5]In the listing, the subfunction is shown, followed by the parent function in parentheses.
[6]This 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.

TABLE 2.—MAPPING AIR-TO-GROUND VOICE COMMUNICATIONS FUNCTIONS TO NATIONAL AIRSPACE SYSTEM (NAS) SERVICE CAPABILITIES (REF. 13)
[Acronyms are defined in Appendix A.]

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

3.2.2.2 Current Airport Surface Ground-to-Ground Communications System Operational Environments

Besides the various NAS service capabilities and functions enabled by A/G communications for command and control as described in the preceding section, numerous surveillance, weather, and aeronautical data NAS services are supported by systems operating on the airport surface. For the most part, these systems are interconnected by direct telecommunications services, including underground cable systems implemented at the airport. The NAS services potentially supported by systems operating on the airport surface are indicated by red dashed boxes in Figure 8.

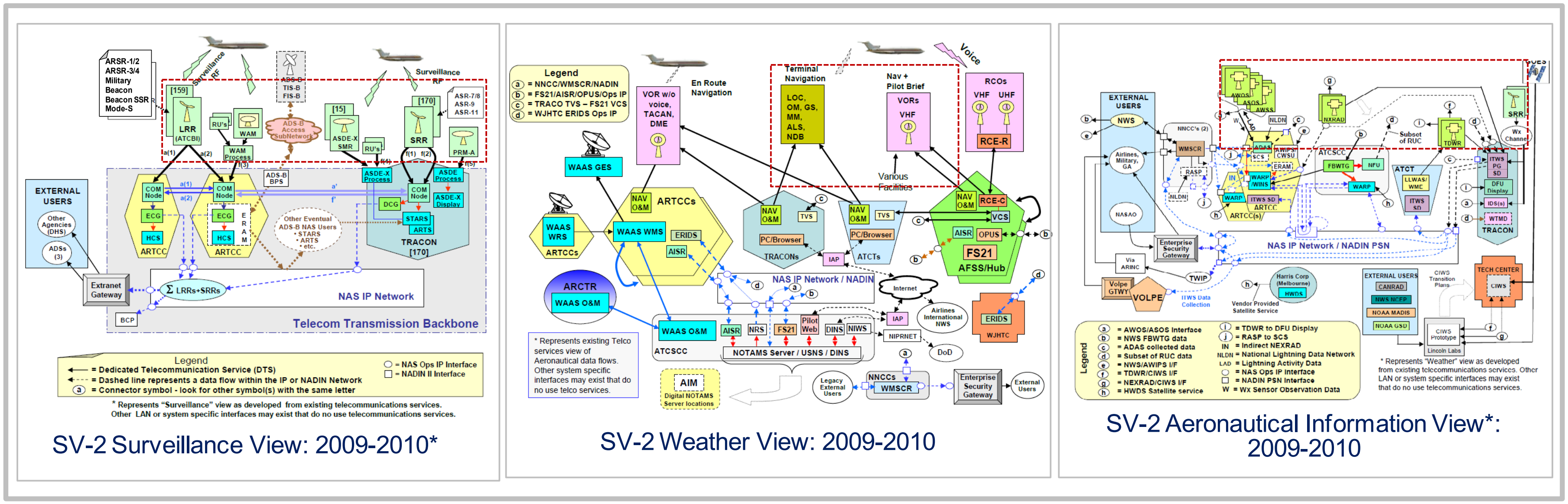

Figure 8.—System View 2 (SV–2) 2009 to 2010 data flow views (Ref. 29). Acronyms are defined in Appendix A.

3.2.3 Current System Users

The users of the current VHF A/G and G/G communications systems include the following (Ref. 30):

(1) Scheduled air transport carriers (including international, trunk, regional, commuter, and air freight carriers)
(2) Nonscheduled air carriers
(3) General aviation (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 and 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 Capability Shortfalls

3.2.4.1 Current Air Traffic Control Air-to-Ground Communications System Scope and Capability 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 3.2.2.1. Currently, they are characterized by (Ref. 11), "high availability, low end-to-end latencies, the ability to convey human feelings, flexibility of dialogue, provision of a party-line, and use for nonroutine, time-critical, or emergency situations."

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. 4):

- 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-sight (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, and the scope of operation is constrained to be radio LOS, 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.

Current system limitations also include spectrum constrains, nonsecure communications, and susceptibility to noise.

Figure 9 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 the introduction of new or expanded services. These, in turn, could potentially compromise safety of operation and increase operating costs.

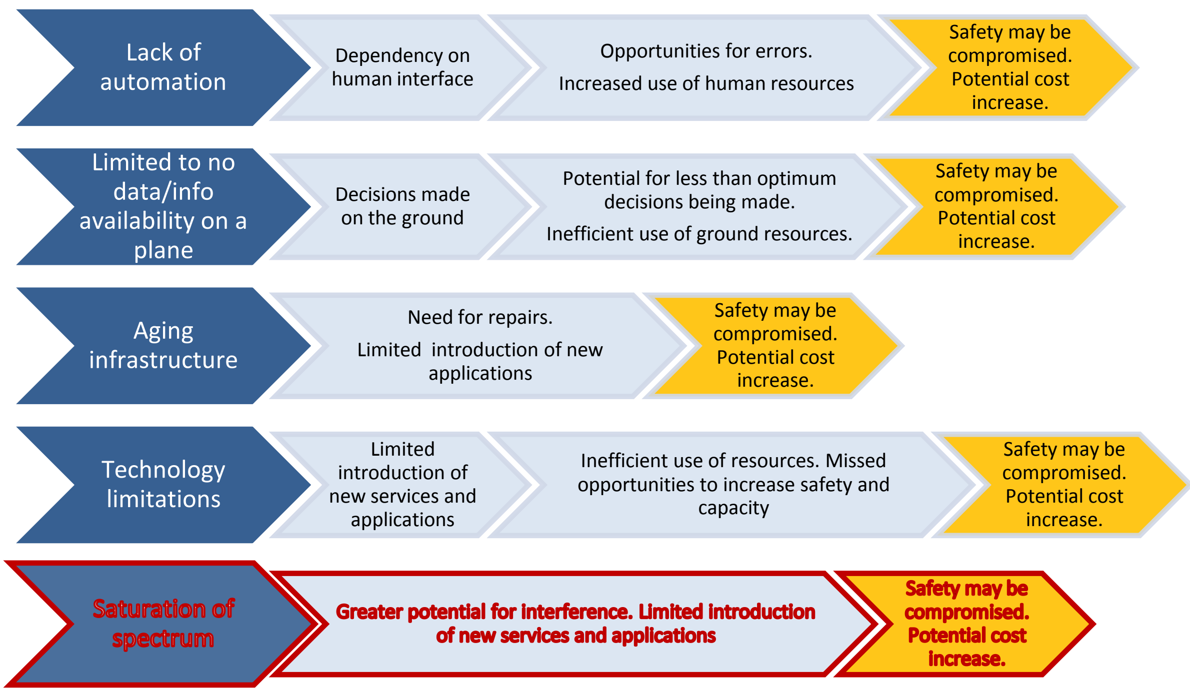

Figure 9.—Current National Airspace System air-to-ground communications operational problems.

Though saturation of spectrum is highlighted in red as the problem specifically mitigated by the introduction of a new C-band system (AeroMACS); the other operational problems would also be mitigated with AeroMACS.

As the NAS evolves to achieve the JPDO's and FAA's NextGen vision and ConUse, many of the transformational services and planned operational improvements will be enabled via data communications. Unfortunately, the current A/G communications system lacks data communications capability for ATS. In moving toward NextGen, this shortcoming will become more acute and will 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 has been developed. These are repeated in Table 3 to specifically identify the shortfalls that Data Comm intends to address.

It is important to note that the "Final Program Requirements for Data Communications" (Ref. 5) recognizes that "the scope of the mission shortfalls identified herein is broader than will be addressed solely by a data communications capability." Because of the limitations and constraints of implementing data communications using very high frequency digital link (VDL) Mode 2 over a congested aeronautical VHF band, Data Comm will focus principally on implementing the most critical air traffic services. This provides opportunities for AeroMACS network to augment data communications on the airport surface by enabling communications of less critical and essential air traffic services to address the shortfalls listed in Table 3.

Even though Data Comm means to use VDL Mode 2 to address, to some extent, each of the shortfalls in Table 3, there are opportunities to overcome these shortfalls to even a greater extent during the later program segments of Data Comm (e.g., late Segment 2 and Segment 3) using link technologies such as AeroMACS with greater bandwidth capabilities, which could augment the benefits already attained through the earlier VDL Mode 2 Data Comm segment implementations (i.e., Segments 1 and 2) by providing a broader scope of services.

TABLE 3.—CURRENT SHORTFALLS RELATED TO AIRPORT SURFACE AIR-TO-GROUND VOICE COMMUNICATIONS
[From a subset of the shortfalls described in Ref. 31.]

Safety shortfalls
Situations conducive to producing errors, confusion, and read-back and hear-back errors arising from voice congestion and voice communication quality
No alternative means to enable A/G communication support for contingency plans when the primary voice communication is not available
Capacity shortfalls
Inability to rapidly and accurately communicate complex clearances containing multiple latitude/longitude-defined route elements
Inefficient dissemination of airspace congestion, weather advisory, and NAS infrastructure status information
Inefficient communication of complete departure clearances and revisions necessitated by traffic management initiatives
Inability to provide for the maximum efficient use of the airspace and strategic plans by adjusting individual flights to reduce contention for resources and ensure that no resource is allowed to remain idle in the face of demand
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
Efficiency and productivity shortfalls
Inability to support airspace user operational requirements, utility, performance, and other flight operations preferences— Avionics and airframe manufacturers need consistent global communication capability requirements.
Inability to exchange user-preferred trajectories in real time; 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
No 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 would increase predictability for flights and allow aircraft operators to reduce costs, optimize flight routes, improve utility, and reduce dependency on voice communications.
No integration of A/G communications with other aspects of the automation environment— Instructions to and requests from airspace users must be independently exchanged via voice A/G 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.
Inability to automate many repetitive and time-consuming tasks; precludes labor resources from focusing on more productive tasks.
No capabilities inherent in modern, network-based communications; therefore, less efficient dynamic resource management

3.2.4.2 Current Airport Surface Ground-to-Ground Communications Systems Scope and Capabilities Shortfalls

The existing airport communications infrastructure lacks the flexibility for reconfiguration and for accepting new services because of its limited bandwidth and interface capabilities. In addition, many control, signal, and communications cables serving FAA facilities at major airports are 25 to 30 years old. In many cases, the cables are badly deteriorated, lack remote maintenance monitoring functions, and do not provide redundant paths for critical functions. Underground cables are also at risk from inadvertent "cable cuts" and are vulnerable to surges due to lightning strikes. It is expensive to deploy and maintain underground cabling as a replacement for existing cables or an expansion for new services.

The limitations imposed by the current G/G communications infrastructure could result in restrictions in the deployment of new ATM services, leading to the following service limitations (Ref. 4):

- Limited ATM (e.g., traffic) information on the flight deck
- Limited data shared among stakeholders for collaborative decision making (CDM) processes
- Information sharing in support of operational security performed manually instead of electronically
- Not all stakeholders able to access data they need
- Stakeholders unable to use custom data sources

3.3 New Airport Surface Communications Systems Justification

3.3.1 Potential Benefits of New Airport Surface Communications Systems

3.3.1.1 Potential Benefits of New Airport Surface Air-to-Ground Air Traffic Control Communications Systems

The NextGen ConOps states that transforming 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. 4). Likewise, the joint EUROCONTROL/FAA FCS 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. 31).

The following excerpts (Ref.4) from JPDO's NextGen ConOps comprehensively describe NextGen A/G network services. These excerpts 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 [air navigation service provider] on the operational aspects of flights. In certain defined airspace, data communications are the primary means of communicating clearances, routine communications, and 4DT [four-dimensional trajectory: latitude, longitude, altitude, and time] 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 4, which illustrates a projected allocation between voice and data communications during this period. As suggested by the table, 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 4.—COMMUNICATION ALLOCATION BETWEEN VOICE AND DATA LINK (D/L)
[Information from Ref. 32.]

		Airport surface	
		Primary	Backup
Pilot-controller dialog	Emergency messages	Voice	D/L
	Tactical clearances	Voice and some D/L	Voice and D/L
	Strategic clearances	D/L	Voice
	Information messages	D/L	Voice
Other exchanges and broadcasts	Pilot-pilot dialog	Voice[a]	D/L
	Flight information exchange	D/L	Voice
	Air traffic management exchange	D/L	Voice
	Information broadcast	D/L	Voice
	Air-to-air surveillance	D/L	

[a]No specific requirement identified except current Traffic Information Broadcast by Aircraft (TIBA) procedure.

Although a gradual addition of data communications to the existing VHF voice systems should accommodate capacity requirements in the near term to midterm, additional spectrum is required to provide enough capacity to satisfy a growing demand for data communications in the far term. An AeroMACS built to augment VHF voice and data communications systems already in place, including those implemented as part of Data Comm, would increase overall communications system capacity, thus relieving congestion and allowing for the introduction of additional services.

3.3.1.2 Potential Benefits of New Airport Surface Ground-to-Ground Communications Systems

The benefits of a new broadband and networked airport surface G/G communications system are similar to those enabled by improved A/G communications in that common data can readily be provided to the flight planners and the flight deck. Current NAS modernization and the future NextGen air traffic system will increase the demands for CNS information sharing and standardization among stakeholders. An AeroMACS could provide the following benefits:

- Standardized ATM information (e.g., surveillance and weather information) provided to the ANSP, flight deck, and aircraft operators[7]
- Information sharing among security stakeholders, facilitating collaboration, risk management, and decision making
- Reliable and secure integration of voice, video, and data at all airport surface locations
- System Wide Information Management (SWIM) networked integration of data sources and users
- Flexible, expandable, and affordable delivery of needed information and services, independent of user physical location
- Reduced VHF spectrum congestion

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 3. It is anticipated that Data Comm will support the following improvements in airspace use and capacity (Ref. 5):

- 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. 5; see Figure 10):

- The first segment will facilitate data communications deployment and introduce initial 4–D 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.

[7]G/G communications would provide connectivity between weather and surveillance sensors and associated network equipment, while an A/G link would provide the end product (e.g., weather or surveillance data) to the aircraft.

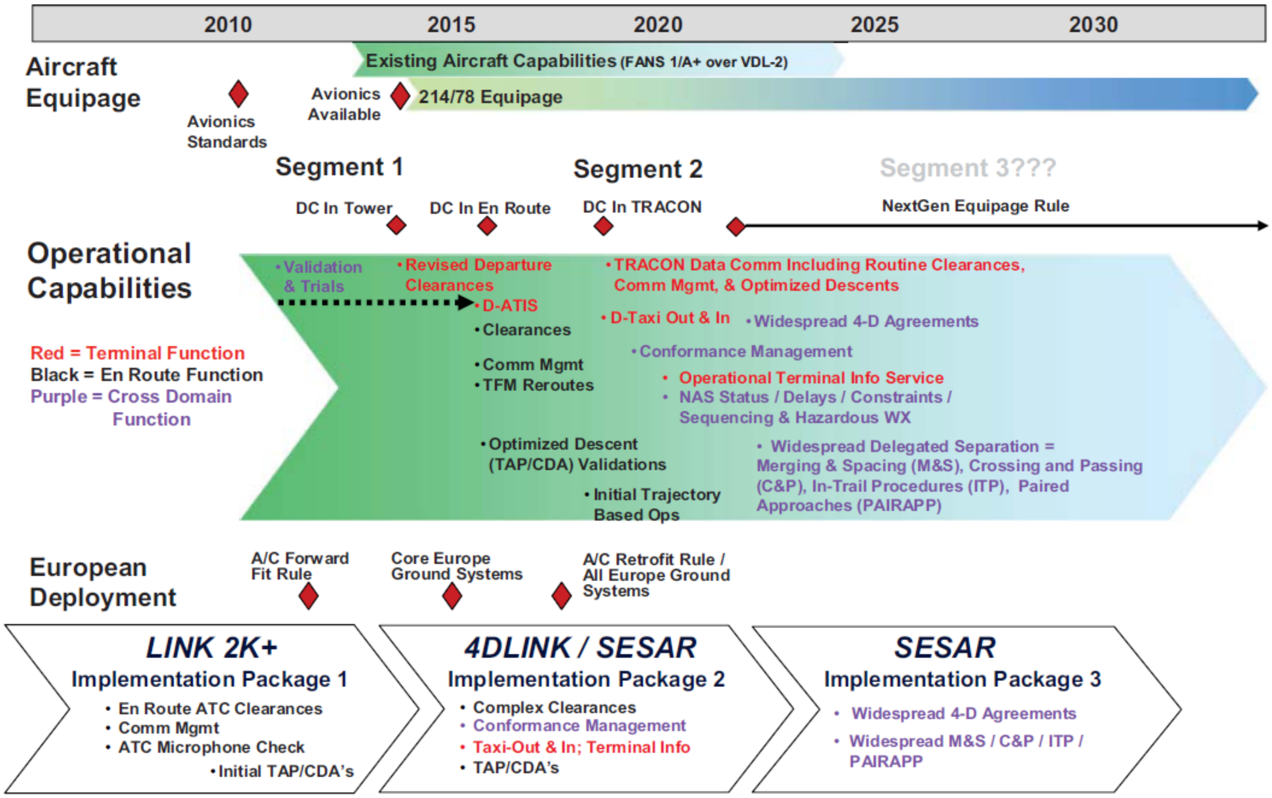

Figure 10.—Operational capabilities of Data Comm (Ref. 33). Acronyms are defined in Appendix A.

An AeroMACS implementation in the United States might follow or overlap with Segment 2 VDL Mode 2 implementation and enable additional services and operational capabilities not covered by VDL Mode 2 for Data Comm. Figure 10 depicts the planned capabilities for Data Comm and, for comparison, 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 (on the airport surface), might benefit from a higher performance technology implementation like AeroMACS. In addition to potentially augmenting the critical data communications services provided by VDL Mode 2 for Data Comm, AeroMACS could enable new noncritical services.

Figure 11 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 (AeroMACS), the U.S. is currently looking at AeroMACS to augment, not to replace, the VDL Mode 2 data link enabling the FAA Data Comm services.

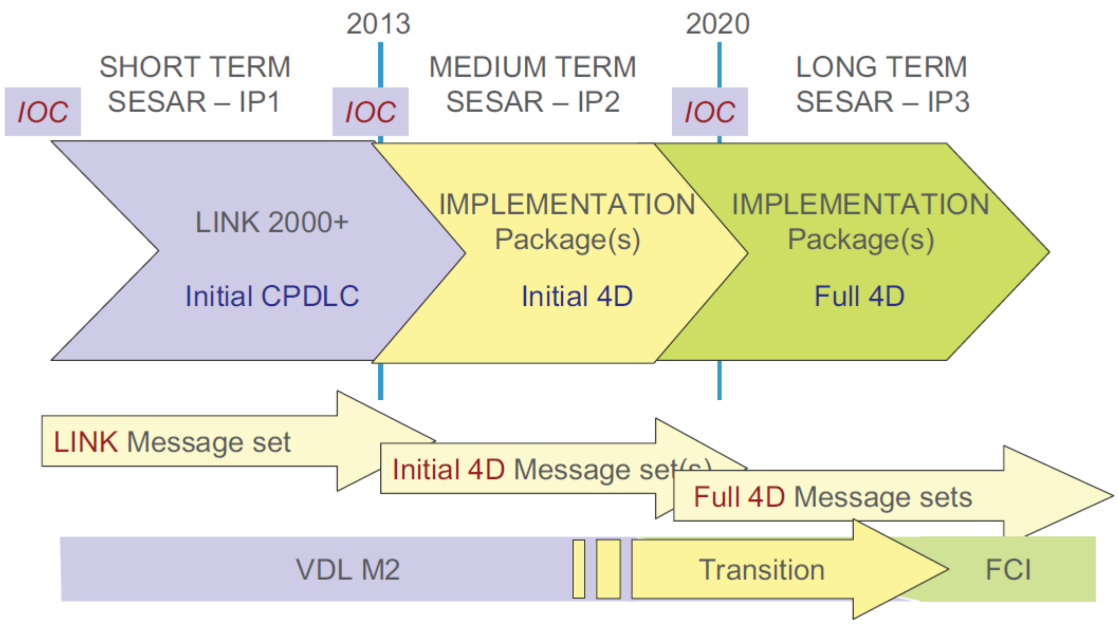

Figure 11.—Data Link Evolution (LINK 2000+ Update. AEEC DataLink Users Forum, 13-14 July 2010, Brussels.) Used with permission.

3.3.3 Description of Desired Changes

3.3.3.1 Desired Changes for Air-to-Ground Air Traffic Control Communications Systems

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 AeroMACS could further reduce congestion on VHF voice channels and increase A/G communications capacity on the airport surface by offering spectrum for additional services not offered by Data Comm. With Data Comm and AeroMACS, the overall A/G information exchange could become more dynamic and efficient, potentially reducing operational errors and improving safety.

For airport surface A/G ATC communications, AeroMACS is not proposed to replace any current systems or services; rather, it is intended to augment them. Furthermore, it is assumed that the critical services proposed for implementation by Data Comm as an addition and/or replacement of voice communication will be in place by the time A/G AeroMACS is implemented.

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

3.3.3.2 Desired Changes for Airport Surface Ground-to-Ground Communications Systems

The desired changes for G/G communications have many similarities to the changes desired for A/G communications by contributing to improvements in airspace use and capacity. Deployment of AeroMACS for G/G information exchange would augment and/or replace existing airport surface G/G communications systems by providing more flexible data exchange—new communications nodes could be added much more quickly and at significantly reduced costs in comparison to changes to the current cabled systems. Communications would become more dynamic and efficient, potentially reducing operational errors and improving safety.

3.3.4 Change Priorities and Roadmaps

Figure 12 demonstrates how the C-band system development fits into the FCS proposed communications evolutional roadmap for European and U.S. ATM (as envisioned in 2007).

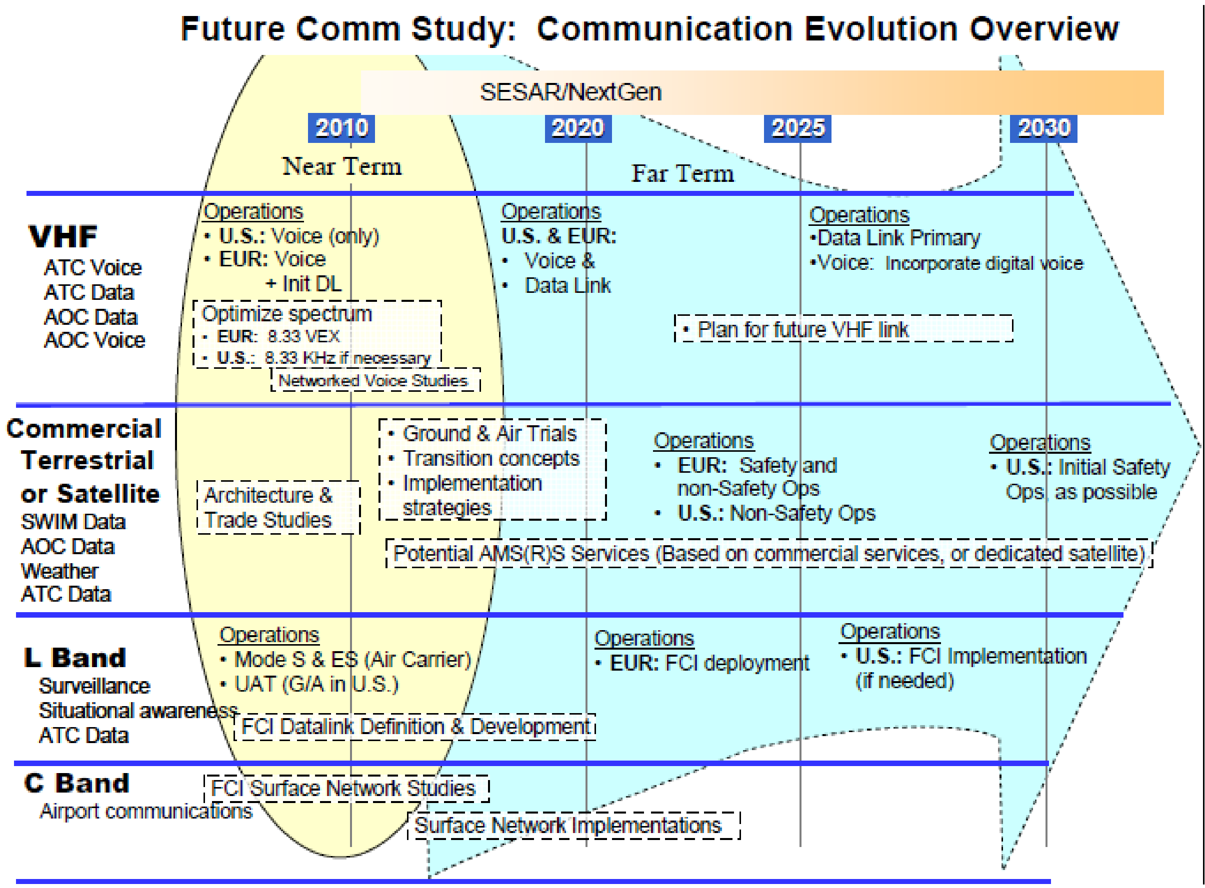

Figure 12.—Evolution overview of aeronautical mobile communications (Ref. 31; note that this schedule is subject to change). Acronyms are defined in Appendix A.

Figure 13 depicts the proposed C-band (and L-band) communications systems far-term strategy as part of the NAS Enterprise Architecture Communication Infrastructure Roadmap.

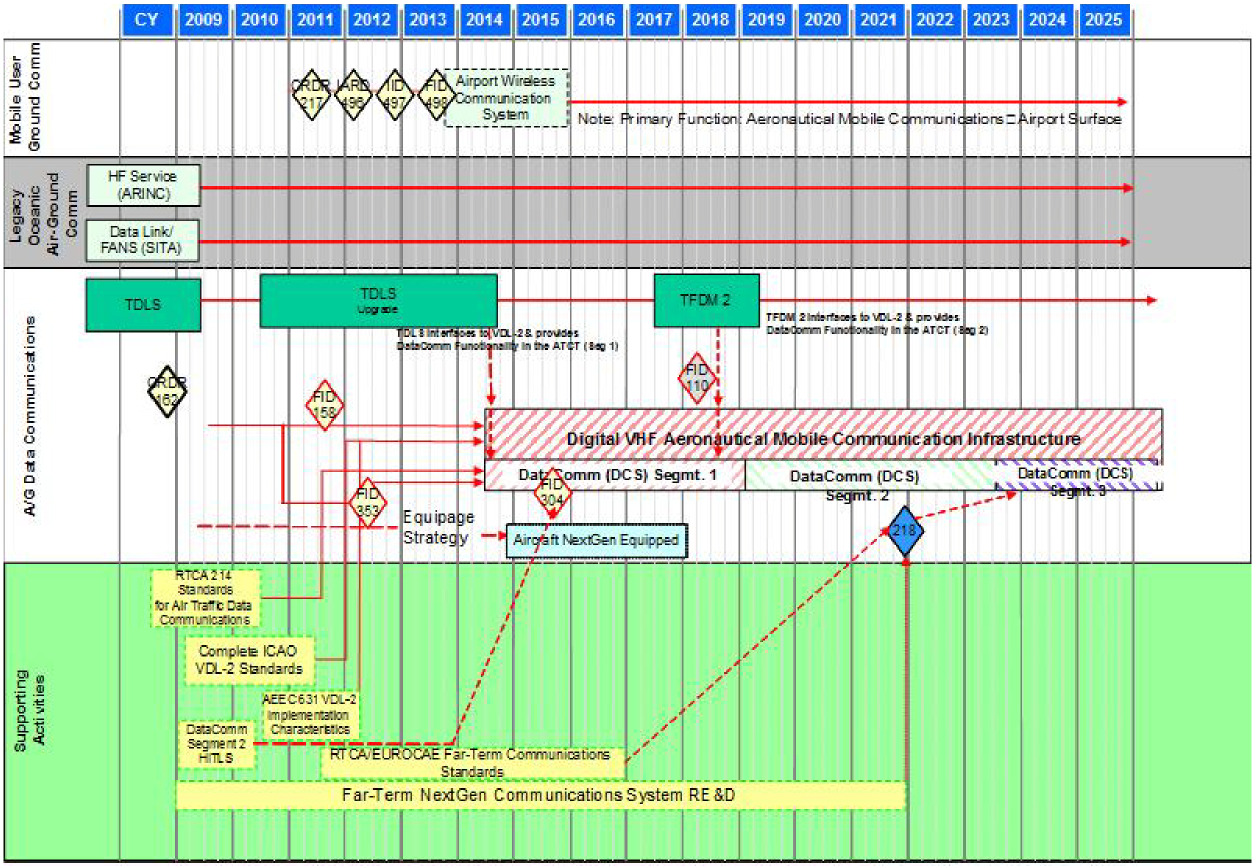

Figure 13.—Federal Aviation Administration communications roadmap (Ref. 34). Acronyms are defined in Appendix A.

3.3.5 Assumptions and Constraints for AeroMACS

Assumptions and constraints for this document follow:

- The 5091- to 5150-MHz spectrum allocation for AeroMACS use at the World Radiocommunications Conference (WRC–2007) is provisioned only for use on the airport surface. This allocation is within the aeronautical mobile (route) service (AM(R)S) band. Therefore, AeroMACS applications are constrained to mobile applications on the airport surface. This is interpreted to include communications for nonmobile (i.e., fixed) applications provisioned within a mobile AeroMACS network that supports the safety and regularity of flight.
- The proposed AeroMACS is assumed to provide an increase in overall A/G communications systems capacity by utilizing the new spectrum (i.e., in addition to existing VHF spectrum).
- The scope of this ConUse and requirements report includes airport surface A/G communications and G/G communications.
- AeroMACS will be designed specifically for data communication. Voice communication may be provided as a digital data communications service (e.g., VoIP).
- This report assumes that the data communications system developed as part of the FAA Data Communications Program (Data Comm) will precede an A/G AeroMACS implementation and deployment.

- Although some critical services could be supported, AeroMACS networks will also target noncritical services, such as weather advisory and aeronautical information services implemented as part of an airborne access to SWIM program.
- AeroMACS is to be designed and implemented in a manner that will not disrupt other existing services operating in the C-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, the duration, and so on.

3.4 Proposed AeroMACS networks

3.4.1 Objectives and Scope

Consistent with the need to overcome the specific current communications system problems and shortfalls discussed earlier, the two primary general drivers for a future radio system 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. 11). Some FAA objectives defined in the FAA's NextGen portfolio are based on the requirement to support future air traffic growth. AeroMACS will be designed and developed to help meet those objectives in part by expanding the data communications capacity in the airport surface domain. Global harmonization is being ensured by developing the proposed AeroMACS component of the FRS as a collaborative effort of the U.S. and European partners.

3.4.1.1 AeroMACS 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.[8] AeroMACS could fulfill part of the proposed NextGen vision by supporting implementation of the following solution sets:

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

[8]The seventh solution set, not shown in the figure, is "safety, security, and environment."

Figure 14.—Next Generation Air Transportation System (NextGen) operational view in 2025 (Ref. 35). Acronyms are defined in Appendix A.

The following subsections briefly describe the specific operational improvements (OIs) that could be enabled by AeroMACS for these three solution sets.[9]

[9]These descriptions are extracted from the NAS Enterprise Architecture web portal (Ref. 24).

Increase flexibility in the terminal environment (excerpts from Ref. 34)

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).

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

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.

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. 34)

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 or gate times of arrival), this end state of 4DTbased 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. 34)

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 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, on-board 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. 34)

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. 34)

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 or 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 replanning 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 timeframe 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.

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.

103123—Full Integration of Weather Information into NAS Automation and Decision Making: Further advances in weather information content and 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 or arrival/departure planning) to ensure continued safe and efficient flight.

3.4.1.2 AeroMACS Operational Environment for Next Generation Air Transportation System

Along with the As-Is SV–2 of the NAS developed by the FAA Air Traffic Organization (ATO) planning organization, such as shown in Figure 8, were a series of separate “to-be” views for 2025. Figure 15 presents an SV–2 2025 rollup data flow view for the proposed NAS. The figure was annotated with labels and dashed red boxes to highlight the five NAS information flow areas that may be enabled by AeroMACS:

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

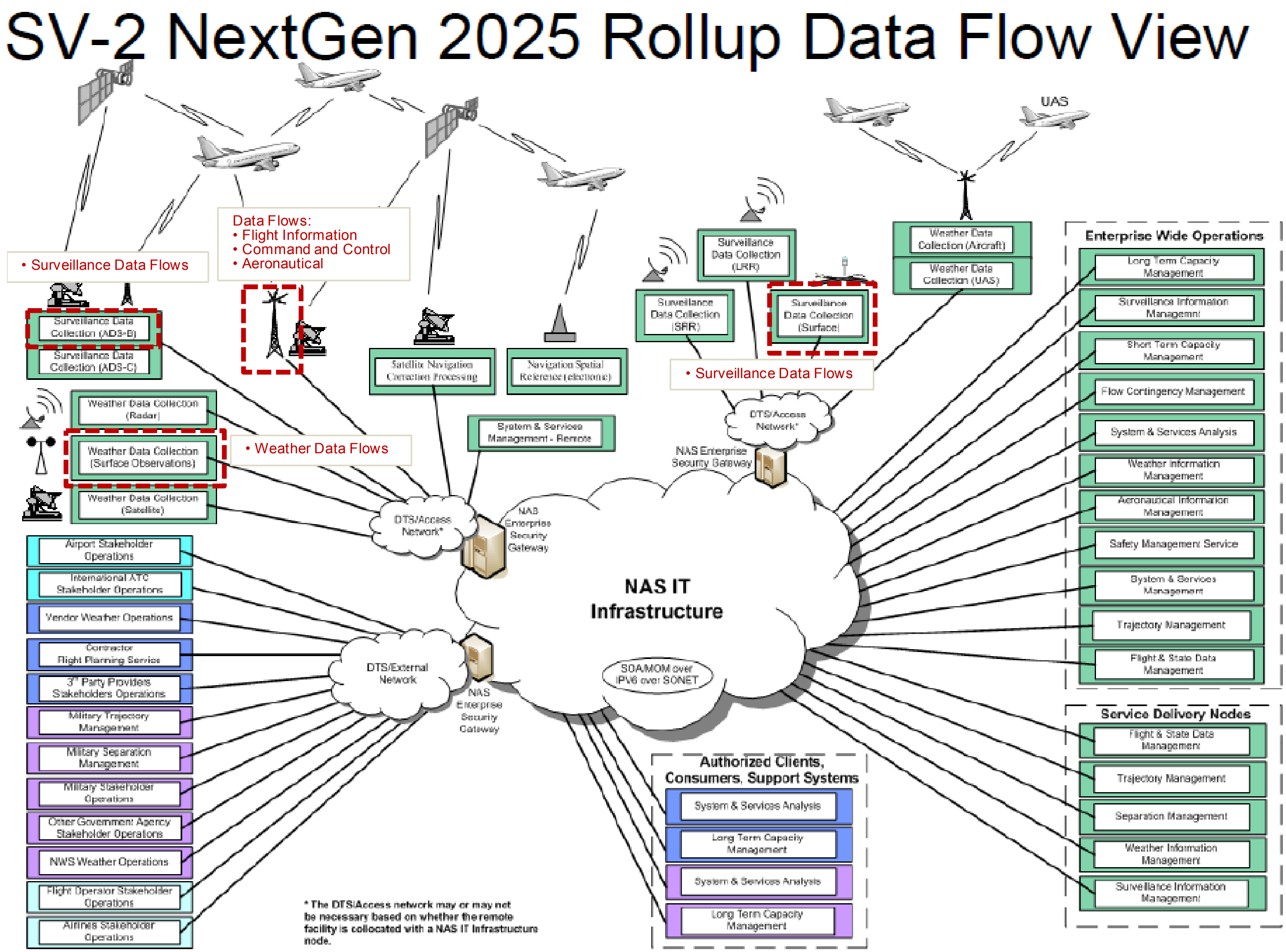

Figure 15.—System view 2 (SV–2) Next Generation Air Transportation System (NextGen) 2025 rollup data flow view (Ref. 36). Acronyms are defined in Appendix A.

3.4.2 Proposed System Description: AeroMACS

As noted earlier, the FCS technology assessment recommended a system based on the IEEE 802.16 standard and its extension, IEEE 802.16e-2005 (Refs. 6 and 19) implemented at the aeronautical C-band as the preferred technology to implement a future airport surface communications system (i.e., AeroMACS). This standard and its extension were later incorporated into the IEEE 802.16–2009 standard, which will be referenced as appropriate. The waveforms described in IEEE 802.16–2009 standard are very flexible and scalable to handle a wide range of communication services. The Worldwide Interoperability Microwave Access (WiMAX) Forum, an industry consortium that promotes the use of wideband wireless systems based on a carefully selected and agreed upon subset of the IEEE 802.16 standards, has developed several profile applications that will be supported by device manufacturers. A new standards profile for airport applications is currently being developed within an RTCA special committee (SC–223) to operate in the C-band (5091 to 5150 MHz) and make use of the scaling properties inherent in IEEE 802.16-2009 standard. The updated version of 802.16 and 802.16e, IEEE 802.16–2009, provides the basis of ongoing the profile selection. The IEEE 802.16–2009 standard defines the waveform capabilities needed for various uses. It has considerable flexibility at the physical and Media Access Control (MAC) layers that will lead to a number of tradeoffs in adapting this type of waveform to the needs of an AeroMACS. Some of the tradeoffs to be considered follow:

- Bandwidth (capacity) versus number of base stations (BSs)
- Allocation methodology for mapping channel assignments
- Number of power control levels
- Allocation of capacity for voice circuits

The proposed AeroMACS could provide supplemental means for the ATC communications required by the operating rules (e.g., VHF voice communications) in continental airspace (albeit on the airport surface) and will adhere to the data link characteristics noted in the "Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace (Continental SPR Standard)" (Ref. 7).

3.4.3 AeroMACS Frequency and Technology: Environment, Requirements, and Limitations

To ensure traceability, presented here are the following observations regarding airport surface communications and the suitability of the aeronautical C-band resulted from the "Future Aeronautical Communication Infrastructure Technology Investigation" (Ref. 28):

- The propagation conditions to some extent determine which band is able to support which types of volume. The airport surface is best served by short range systems operating in the C-band because of the attenuation conditions at this frequency.
- There is capacity that is not utilized in the aeronautical C-band (5000 to 5010 MHz, 5010 to 5030 MHz, and/or 5091 to 5150 MHz). Because of severe path-loss problems, this band is most applicable to the airport surface where the distances are relatively short. Some concepts for surface management communications require substantially higher data rates than are needed in other airspace domains and may warrant a specific technology solution.
- For the aeronautical C-band (5000 to 5010 MHz, 5010 to 5030 MHz, and/or 5091 to 5150 MHz), IEEE 802.16–2009 is extremely well matched to the aeronautical surface in terms of capability and performance.
  - This technology is designed to work in this band and initial IEEE 802.16–2009 performance evaluations in the modeled aeronautical microwave-landing-system (MLS) band channel show favorable results
  - Private service providers have shown interest in the IEEE 802.xx family of wireless protocols (favorable business case that may be driven by factors beyond ATS and AOC communications, and may involve private service providers, including airport authorities)

These conclusions help to drive the AeroMACS ConUse and system requirements presented in this document.

3.4.4 User Impact

Users of the system will include service providers and airspace users (on the airport surface) of A/G and G/G communications:

- Safety and regularity of flight—addressed by air traffic controllers and NAS specialists on the ground and flight crews in aircraft at the airport
- Commercial data transfer related to airline operations and provisions of services to passengers

The introduction of AeroMACS 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 the new system on the user base.

It should be noted that the relationship between the capacity demand and changes in the user base can be viewed as a repeating cycle of events. The proposed introduction of an AeroMACS will increase the overall capacity of the system and open up opportunities for addition of data services not provided under Data Comm. Many of those, most notably services associated with the Airborne SWIM Program, would provide for wider system use. Not only more users would be expected to take advantage of the new data communications capabilities, the types of users allowed to participate would increase 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. The availability of a new frequency band, such as C-band, in addition to the VHF frequencies supporting the existing voice and data communications services, will alleviate long-term capacity problems.

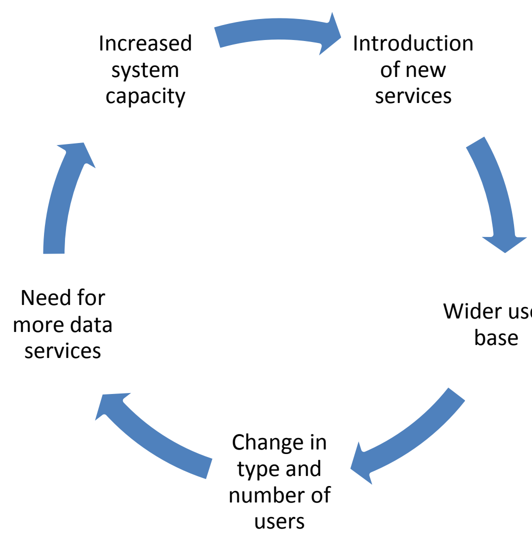

Figure 16.—Communication system capacity demand and user base changes.

The expanded use of advanced technologies in general and of AeroMACS 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. 4).

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, and hazardous). Users will have improved real-time planning with continuous update of the flight profile.

3.4.5 Operational Policies and Constraints

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

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

The NextGen ConOps details operational policy issues that would affect the NextGen system (Ref. 37). To support the proposed AeroMACS development and implementation, policies might need to be developed and/or revised in the following areas:

- International and domestic regulations
- Safety management standards
- Processes to streamline certification and reduce costs of aircraft and ground equipment
- Privacy and liability legal concerns related to information sharing,
- Communications priority and congestion relief (e.g., market-driven versus aircraft type)
- Government role versus private sector role
- Financing and maintenance responsibilities

3.5 AeroMACS ConUse

3.5.1 RTCA National Airspace System Concepts of Operation Guidance

As noted in Section 2.0, the definitions of the AeroMACS ConUse were based on guidance and information provided by several higher order ConOps. A key NAS ConOps source driving the AeroMACS ConUse is RTCA's NAS ConOps (Ref. 4). Appendix B presents a comprehensive listing derived from Reference 13 of future communications concepts applicable to airport surface operations to enable the transfer of the following NAS information types:

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

3.5.2 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 to be made off the ground

The Data Comm FPR (Ref. 5) lists operational scenarios envisioned to be enabled by the data communications system. In general, these scenarios would also be applicable to an AeroMACS implementation, especially those presented for Segment 2 and beyond, during which Data Comm VDL Mode 2 operational capabilities could be augmented by AeroMACS. Operational scenarios from Segments 2 and 3 of Data Comm that are applicable to the airport surface environment follow (Ref. 5).

- Departure Airport (Tower) Scenarios
  - (S2,3) Proposed routes including standard routing through traditional airspace, and 4-D trajectory based routing for transit through High Performance Airspace are developed and loaded into the flight management system via A/G data communications for aircrew review.
  - (S2,3) At the request of the flight crew, ATM-related operational data for the flight (e.g., departure sequence, collaborative decision making agreements, and slot-time allocations) are relayed by data communications to the flight crew in preparation for departure.
  - (S2,3) After issuance of the departure clearance, the automation system generates a request via data communications to the aircraft automation to report its active route. This information is compared with the departure clearance to verify consistency.
  - (S2,3) Once the flight crew compares and validates the departure clearance against the filed flight plan, the flight crew requests a taxi route instruction using data communications. The assigned controller reviews the taxi route instruction suggested by the automation for the aircraft, and upon approval, sends the taxi route instruction via data communications. Taxi revisions via data communications are now provided not only to reroute aircraft, but also to reorder aircraft.
  - (S2,3) Enhanced capabilities and increased access to surface data and flight status provide traffic management automation with information about the flight's location, taxi sequence, and the departure queues. As a result, the TFM [traffic flow management] automation provides departure clearance revisions at an operationally appropriate amount of time in advance of the departure.
  - (S2,3) Once the aircraft has been cleared for takeoff via voice, data communications manages the data communications eligibility transfer to the TRACON position and surface ATC data communications cease.
  - (S3) In advance of a planned departure, users now file 4D trajectory-based flight plans for operations in HPA [high-performance airspace]. Users and air traffic service providers [ATSPs] collaboratively negotiate 4-D trajectory agreements from takeoff to approach, based on user requests and anticipated constraints. This agreement is embedded in the departure clearance. The final point in the clearance also includes the required time constraint for the arrival fix.

- Arrival Airport (Tower) Scenarios

  – (S2,3) The tower ground controller clears the flight crew to taxi via voice or data communications depending upon the dynamics of the situation and monitors the traffic situation as they maneuver the aircraft to the arrival gate.
  – (S3) After the aircraft lands, the tower runway controller confirms the previously provided runway exit and directs the flight crew to contact the ground controller.

3.5.3 Proposed Services for AeroMACS

Figure 17 and Table 5 show the potential AeroMACS services in three categories: air traffic, airline, and airport.

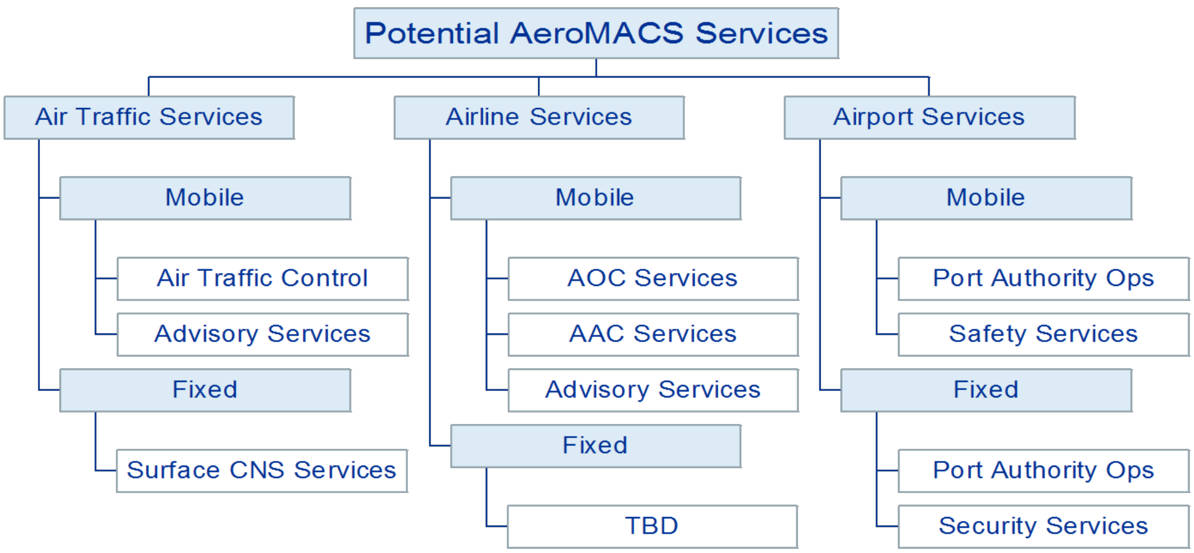

Figure 17.—Potential AeroMACS service categories in the United States (Ref. 8).

TABLE 5.—AEROMACS SERVICE EXAMPLES AND PROVISION OPTIONS (REF. 8)

Air Traffic Services	
Service Examples	• Air traffic control commands beyond Data Comm Segment 3 • Surface communications, navigation, and surveillance (CNS) fixed assets
Provision Options	• Government-owned (licensed)/Government-operated (GO/GO) • Government-owned (licensed)/Commercially-operated (GO/CO) • Non-competed service extension via FAA Telecommunications Infrastructure (FTI) • Open commercial competition by FAA
Airline services	
Service examples	• Airline Operational Control (AOC) • Airline Administrative Communications (AAC) • Advisory information • System Wide Information Management (SWIM) • Aeronautical Information Management (AIM) • Meteorological (MET) data services
Provision options	• Commercially-owned (licensed)/Commercially-operated (CO/CO) • Non-competed service extension via exiting AOC service providers • Airline service provision internally • Open commercial competition by airlines

TABLE 5.—AEROMACS SERVICE EXAMPLES AND PROVISION OPTIONS (REF. 8)

Airport operator/port authority services	
Service examples	• Security video • Routine and emergency operations • De-icing/snow removal
Provision options	• Local Government-owned (licensed)/Commercially-operated (GO/CO) • Commercially-owned (licensed)/Commercially-operated (CO/CO) • Open commercial competition by Operator/Port Authority

3.5.3.1 Air Traffic Services

Reference 9 classifies all of the COCR ATS data services as safety critical. It further identifies services that are not planned to be implemented by Data Comm through Segment 3 and identifies them as possible candidates for implementation via C-band and/or L-band. It must be stressed that both C-band and L-band systems are being developed for the future communications infrastructure to accommodate the safety and regularity of flight services. These are designed to operate over a protected spectrum for aviation, so any COCR ATS 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 2, which are proposed as candidates for AeroMACS.

- Flight information services
  - Data link operational terminal information service (D–OTIS) Data link runway visual range (D–RVR)
  - Data link surface information and guidance (D–SIG)
  - Data link significant meteorological information (D–SIGMET)
- Flight position, flight intent, and flight preferences services
  - Pilot preferences downlink (PPD)
  - Flight plan consistency (FLIPCY)
  - Wake service (WAKE)
- Emergency information service
  - Urgent contact (URCO)—if in conjunction with other more routine services

Additional data services that may be provided via AeroMACS may be identified as NextGen and Single European Sky ATM Research (SESAR) progress.

3.5.3.2 AOC Services

COCR AOC Data Services Table 6 lists the AOC data services noted in the COCR v.2.0 (Ref. 11). Position Report (POSRPT) is not included in the table because it is not provided on airport surface. Some of the services listed, for example Software Loading (SWLOAD), would be provided the ground, while others may be applicable to wheels on- and off-the-ground scenarios with AeroMACS enabling these services on the airport surface only.

TABLE 6.—COCR V.2.0 AOC DATA SERVICES

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

Services with larger bandwidth requirements, for example WXGRAPH, UPLIB, SWLOAD, may be more suitable to provide via AeroMACS while services involving smaller traffic volumes may be more appropriate for a VDL Mode 2 system.

3.5.3.2.1 Additional AOC Services Not Covered by the COCR

The New AOC/AAC Services document (Ref. 12)[10] provided by the European SANDRA Program specifies additional services 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 feedback is still needed from Airbus and major airlines.

[10]The source document used (New AOC/AAC Services. SANDRA. 22 March 2010. Draft) is a work in progress. As such, the list of services presented here may change.

TABLE 7.—PROPOSED NEW AOC/AAC SERVICES

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). **Note**: this 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.	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

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 (Ref. 11) in terms of the required message sizes, data rates and phase of flight usage.

The AOC services in Table 7 may be mapped to the Flight Regularity category (Ref. 38) and may be transported over the AM(R)S link.

As noted earlier, services with large bandwidth requirements may be more suitable to provide via FCI (e.g., L-DACS and AeroMACS) while services involving smaller traffic volumes may be more appropriate for a VDL-2 based system.

As part of the follow-on AeroMACS development work, we recommend following the activities of the Airlines Electronic Engineering Committee (AEEC) Data Link Systems subcommittee that is developing a specification for the Media Independent Aircraft Messaging (MIAM). MIAM is intended to support the transport of very large messages over the ACARS (and eventually other) networks. While the current EUROCONROL effort focuses largely on applying MIAM to the VDL Mode2 networks (Ref. 39), it should also be evaluated in respect to AeroMACS.

3.5.3.2.2 Airborne System Wide Information Management (SWIM) Suitable Services

Introduction of AeroMACS would support transitioning from Aeronautical Information Services (AIS) to Aeronautical Information Management (AIM) (Ref. 12) notes a 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 the 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 air-to-air (A/A) communications infrastructure components. Each of these components would enable efficient data exchange between authorized users in the respective domain. An AeroMACS could provide means for the A/G data transfer among fixed and mobile users on the airport surface.

An implementation of AeroMACS 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 AeroMACS could be designed to ensure 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
- Ensure FAA-compliant secure data exchange among the NAS user community

Figure 18 shows how SWIM (with the communication links with aircraft and other mobile users on the airport surface potentially provided via AeroMACS) fits in the overall FAA Information exchange model.

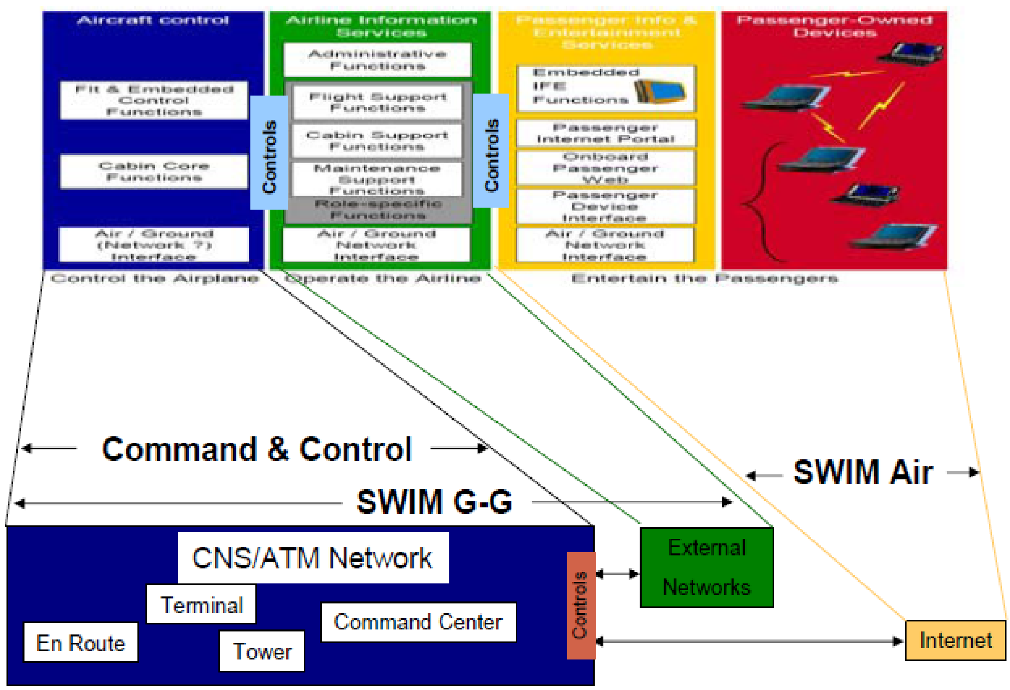

Figure 18.—Information exchange model (Ref. 40).

Although it is anticipated that some advisory Airborne SWIM (also referred to as Aircraft Access to SWIM or AAtS) services could be provided over the commercial (i.e., unprotected (non-AM(R)S)) spectrum—as shown in the figure—it is likely that in the future other Airborne SWIM services, such as graphical weather subscription and aeronautical information updates could go beyond advisory use and directly impact safety and/or regularity of flight. As such, their service provision would have to make use of protected spectrum to support safety and/or regularity of flight.[11] This class of potential AAtS services would be suitable targets for an AeroMACS implementation.

As part of SWIM, AeroMACS would enable the exchange of information between diverse users adopting a service-oriented architecture. Services would be offered from individual providers as well as centralized providers.

[11]For example, current aeronautical (airline) operational control (AOC) communications is conducted over the AM(R)S spectrum to support regularity-of-flight operations rather than safety-of-flight operations.

Figure 19 shows the A/G and G/G SWIM elements. It depicts Airborne SWIM (potentially provided over AeroMACS whenever aircraft wheels are in contact with the surface) 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.

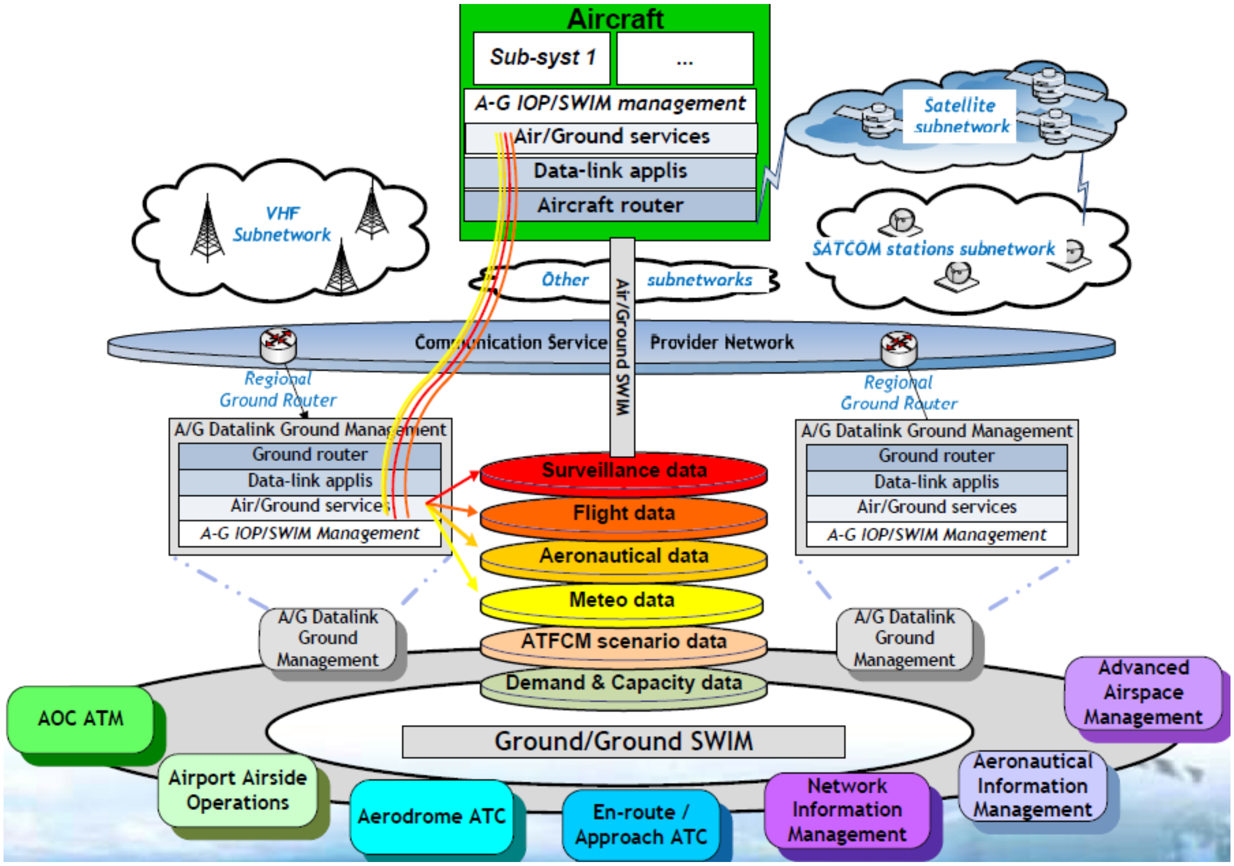

Figure 19.—Air-to-ground data link management and aircraft participation in System Wide Information Management (SWIM) (slightly modified from Ref. 41). Copyright Thales Air Systems; used with permission. Acronyms are defined in Appendix A.

These mostly weather advisory and aeronautical information services that could be provisioned via AeroMACS include

- Aviation Digital Data Service (ADDS)
- AWOS Data Acquisition Service (ADAS)
- Expanded Terminal and Tower Data Service
- General Information Message Distribution Service
- Information Display System (IDS) Data Service
- NextGen Network Enabled Weather (NNEW) service[12]
- NOTAM distribution service
- TMA flight data service
- Weather and Radar Processor (WARP)/Weather Information Network Server (WINS) Next Generation Radar (NEXRAD) service

[12]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.

Reference 42 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 AeroMACS 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. 43). The proposed AeroMACS 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 re-file 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 to 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. 43).

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

Figure 20 illustrates full flight plan constraint evaluation and feedback OI in the context of SWIM showing interactions with other OIs.

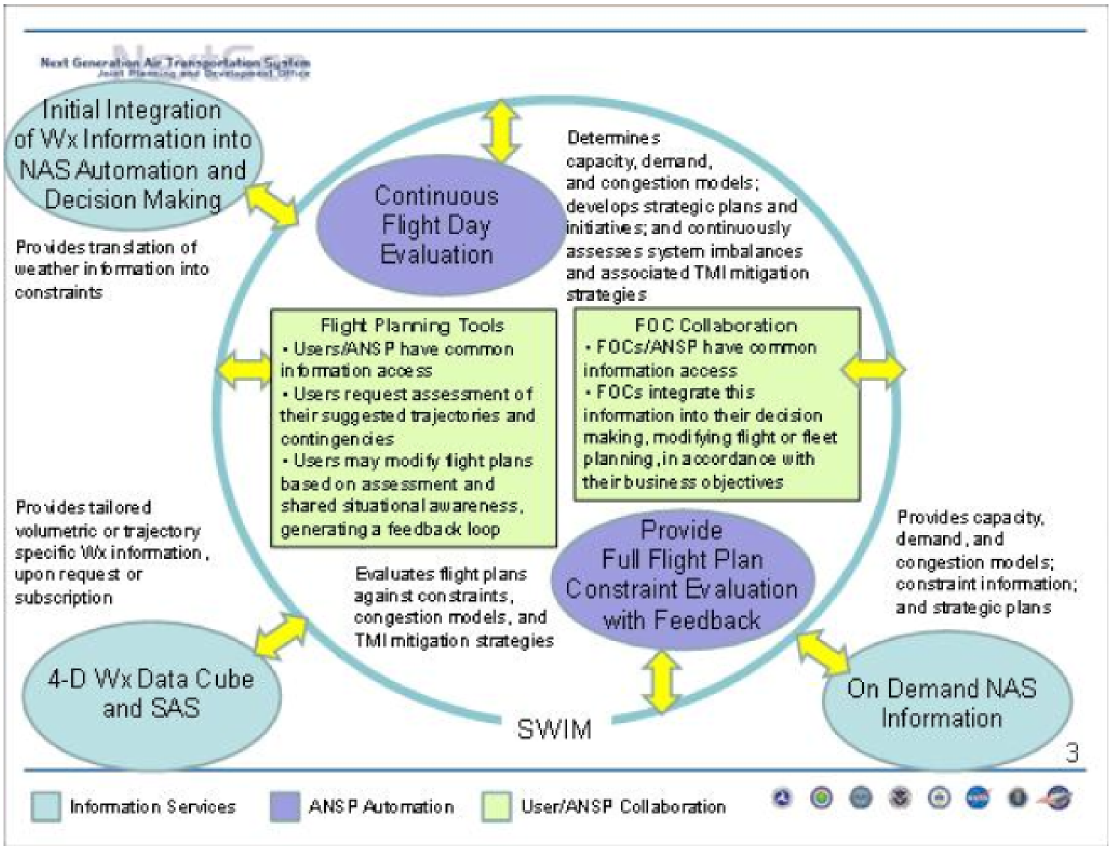

Figure 20 .—Full flight plan constraint evaluation and feedback OI in the context of SWIM showing interactions with other OIs mid-term operational scenario (Ref. 42).

Figure 21 illustrates the introduction of SWIM services over time. Implementation of the proposed AeroMACS could overlap with SWIM Segments 3 and 4 when Airborne SWIM is introduced.

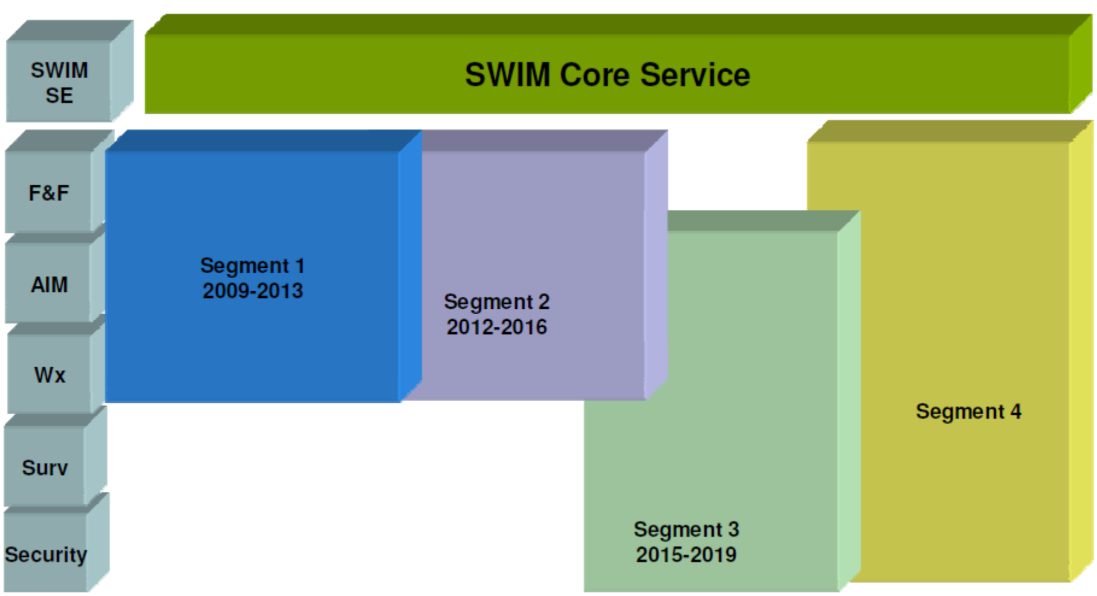

Figure 21.—System Wide Information Management (SWIM) execution by segments (Ref. 37). Acronyms are defined in Appendix A.

3.5.3.3 Unmanned Aircraft Systems (UAS)-Related Services

Services specific to the operation of UAS in the NAS and potentially suitable for implementation via AeroMACS whenever the unmanned aircraft (UA) is on the ground 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 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 decision making from UA to pilots

A notional system architecture consisting of three segments and the associated internal and external interfaces are shown in Figure 22. The detailed description as well as notional diagrams of each segment can be found in RTCA DO–304 (Ref. 44) and are not replicated here.

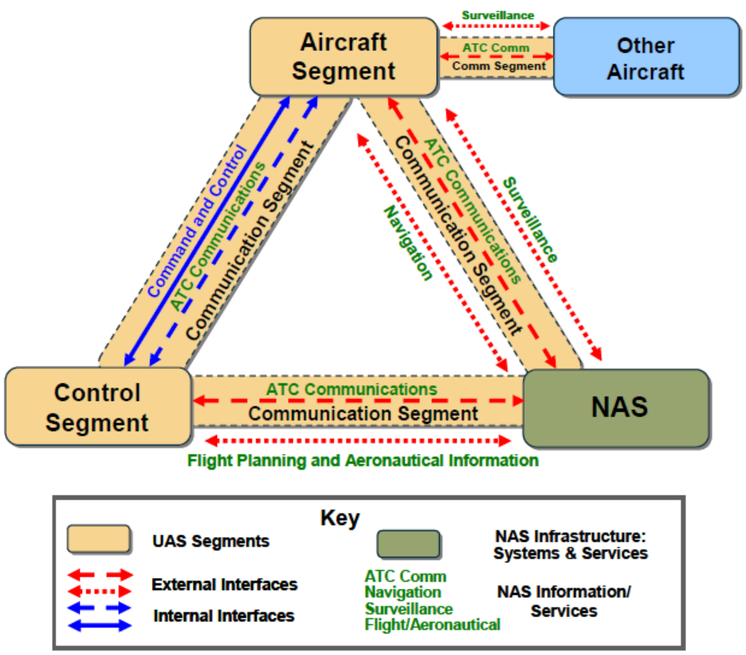

Figure 22.—Unmanned aircraft system (UAS) notional architecture (Ref. 42). Acronyms are defined in Appendix A.

Communication in either of the segments in Figure 22 can be provided via AeroMACS. It should be noted, however, that because of current spectrum requirements, AeroMACS would only be used when the UA has “wheels on the ground.” Other links (i.e., VHF, L-band, or others) would provide en-route communications services.

3.5.3.4 RTCA SC–223 User Services and Applications Survey Working Group

The RTCA SC–223 has formed a User Services and Applications Survey (USAS) Working Group (WG) to collect information from various AeroMACS stakeholders. The group compiled the data for the existing and future applications in the following functional domains:

- Air Traffic Control/Air Traffic Management (ATC/ATM)
- Aeronautical Information (AIM)
- Airlines/Cargo Operations (Airline/Cargo Ops)
- Airport Operation (Airp Ops)
- Airport Infrastructure (Airp Infr)

SESAR Project P 15.2.7 input was incorporated noting the new AOC services proposed by SANDRA.

The second level of information collection included technical parameters and potential performance requirements for each of the application in various functional domains.

At the time of this report, the list of applications compiled by the group was not validated for AM(R)S use or duplication with the FAA Data Comm program. Rather, it attempts to present a superset of communication services that can potentially be enabled by AeroMACS.

Appendix E presents WG's projection of the most likely applications to be supported by AeroMACS. It should be noted that at the time of this report the WG is still updating the spreadsheet. The version presented in Appendix E is a work-in-progress document with the estimated completion time December 31, 2010.

3.5.4 Next Generation Air Transportation System Communications Operational Concepts

Figure 23 shows a typical flight profile and the ATS functions supporting users in each domain.

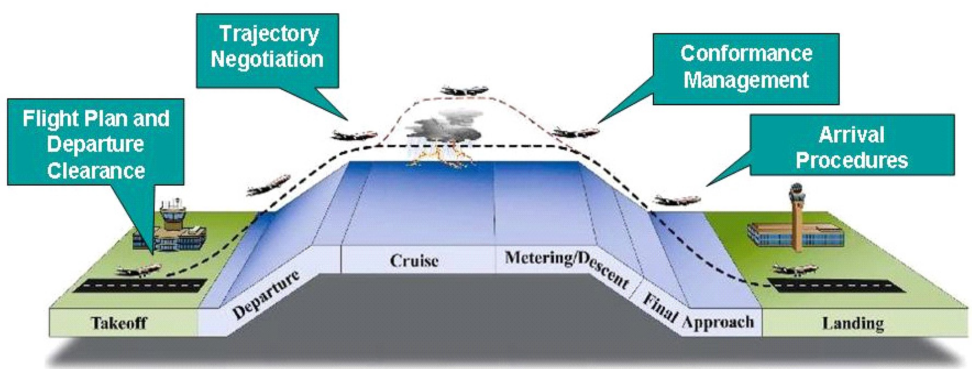

Figure 23.—Typical National Airspace System (NAS) flight profile and air traffic services (ATS) functions (Ref. 5).

Table 8 lists the operational scenarios and concepts envisioned for the midterm of the NextGen airport surface flight phase shown in Figure 23. Although most, if not all, of these concepts are currently envisioned for Data Comm, these are technology-independent and, thus, equally valid for an AeroMACS implementation.

TABLE 8.—NEXT GENERATION AIR TRANSPORTATION SYSTEM (NEXTGEN) MIDTERM OPERATIONAL CONCEPTS FOR THE AIRPORT SURFACE

Phase of flight	NextGen midterm communications operational concept (from Ref. 10)
Flight planning	Access to flight planning information will be available to authorized users via a secure network and will include a publish/subscribe capability so that users can receive automatic updates when conditions change along the proposed flight path.
Push back, taxi, and departure	As the time for the flight approaches, the final flight path agreement will be delivered as a data message to pilots who access the agreement before beginning the flight.

3.5.5 Potential AeroMACS Operational Services Derived from the Communications Operating Concept and Requirements

Operational concepts also can be defined according to the different geographic flight domains. Table 9 illustrates the potential operational services suitable for implementation via AeroMACS for the airport surface based on the COCR services previously identified as potential applications (Ref. 9).

TABLE 9.—USE OF THE PROPOSED AeroMACS IN THE AIRPORT FLIGHT DOMAIN
[Acronyms are defined in Appendix A.]

Operational services	Airport domain (APT) phases			
	Predeparture airport domain	Departure taxi airport domain	Arrival airport domain	Arrival taxi airport domain
Flight information services	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET	D–OTIS[a] D–RVR[a] D–SIG[a]	D–RVR[a] D–SIG[a]
Flight position, flight intent, and flight preferences services	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE	PPD FLIPCY WAKE
Emergency information service				
Services suitable for Airborne SWIM (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,[b] NOTAM distribution service, TMA Flight Data Service, WARP/WINS NEXRAD service			

[a]At 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 AeroMACS if not implemented by the Data Comm program.
[b]It is possible that the information provided through the NNEW service could range from advisories for routine forecasts though safety-critical transmission of certain hazardous weather warning messages, which might limit the extent to which this service could be provided over commercial links. This requires furtherer investigation.

Examples of operational messages that could be transmitted over the proposed AeroMACS data link in support of the services for the airport surface flight domain are presented in Table 10. The messages are grouped according to the information type, as defined by the function identifications (IDs) in Appendix C.

TABLE 10.—EXAMPLE AEROMACS DATA LINK MESSAGES

Information type (including corresponding function ID)	Message examples
Transceive air traffic service (ATS) to on-ground aircraft message C.1.1.1.2	Contract requesting data Contract acknowledgements Operational terminal information service (OTIS) 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 Urgent contact message (URCO), addressed and/or broadcast communications

TABLE 10.—EXAMPLE AEROMACS DATA LINK MESSAGES

Information type (including corresponding function ID)	Message examples
Transceive on-ground aircraft to ATS message C.1.1.2.2	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 match, vertical rate, selected level, and wind vector (system access parameters), 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

4.0 AeroMACS network requirements

4.1 AeroMACS Functional Requirements Development Process

Section 2.0 presented an overview of the ConUse and system requirements development process used for this task. As stated in Section 2.0, a middle-out approach was adopted to identify the high-level requirements applicable to AeroMACS. 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. 13), the COCR (Ref. 11), and Data Comm performance requirements and their applicability to the current needs for AeroMACS was performed. Thus, the top-down approach employs the classic "clean-sheet" system engineering process, and the bottom-up approach addresses how AeroMACS fits into the existing environment.

Volume II of this report presents further recommendations of the AeroMACS requirements from the tests and references the documents developed by the RTCS SC–223.

4.1.1 AeroMACS Functional System Requirements—Top-Down Approach

This section presents a top-down determination of functional requirements through (1) a functional analysis for generic aeronautical communications systems based on prior work and (2) a functional analysis based on the ConUse defined in Section 3.0.

4.1.1.1 Prior Functional Analysis Applicable to AeroMACS

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. 2). For its top-down functional analysis, this report leverages prior functional analysis work performed to characterize generic aeronautical A/G, G/G, and A/A communications systems: the "National Airspace System Communications System Safety Hazard Analysis and Security Threat Analysis" (Ref. 25). Figure 24 depicts the hierarchy at the highest level. Appendix C presents a more complete hierarchical decomposition of functions as diagrams and in an outline format derived from this reference document, but modified as appropriate for AeroMACS (e.g., A/A functions are deleted).

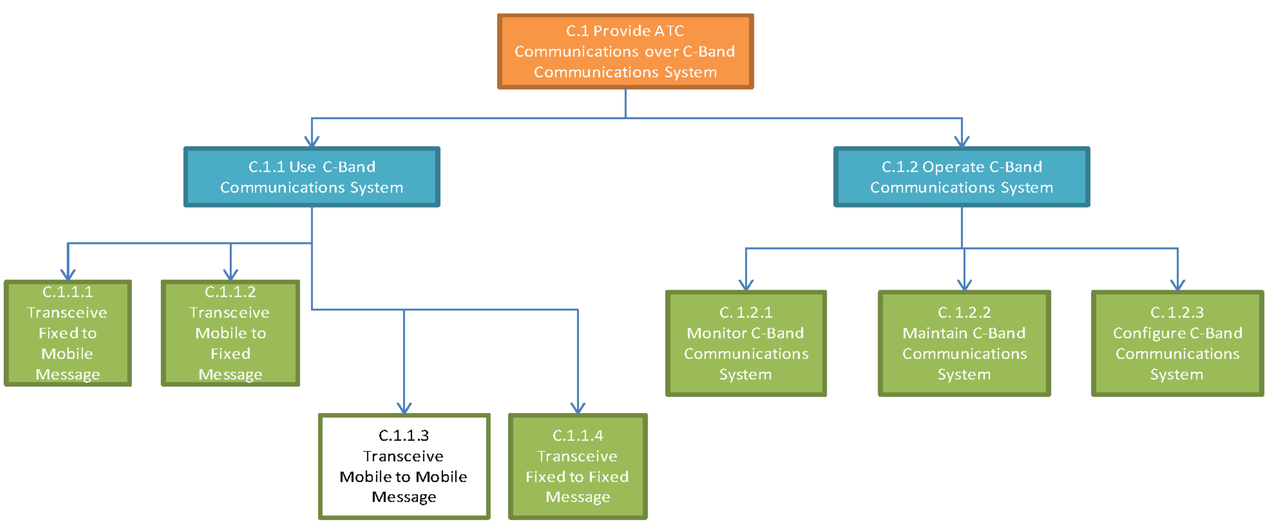

Figure 24.—High-level hierarchy of C-band communications system. Acronyms are defined in Appendix A.

4.1.1.2 AeroMACS Concepts-of-Operations-Based Functional Analysis

AeroMACS could provide a communication link to transfer surveillance and weather information[13], facilitate flight and resource management, enhance CDM, and enable exchange of aeronautical information in the future NAS. The tables in Appendix B document the select RTCA NAS ConOps (Ref. 14) found to be applicable to the proposed AeroMACS.[14]

The desired AeroMACS functional capabilities were derived from the identified NAS ConOps presented in Appendix B and mapped to (1) the high-level aeronautical A/G and G/G communication functions described in Section 4.1.1.1 and (2) specific COCR ATS services. Table 11 lists the AeroMACS high-level functional capabilities and presents this mapping. This encompasses a top-down approach to the development of functional requirements.

TABLE 11.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 14)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	S-1; S-3; S-4; W-2; W-3; W-8; W-9; W-10; W-12; W-13; W-14; W-15; FM-1; FM-6; FM-8; FM-12; FM-14; FM-15; FM 17; FM-23; A-2; A-6; A-12; A-15	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET FLIPCY WAKE PPD
Support addressed communication for delivery of information to individual and multiple users	S-1; W-10; FM-6; FM-8	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET FLIPCY PPD
Support broadcast communication for delivery of information to multiple users	S-1; S-4; W-2; W-3; W-12; W-14; FM-8; A-12	C.1.1.1.2 C.1.1.2.2 C.1.1.4.1	D–OTIS[a] D–RVR[a] D–SIG D–SIGMET WAKE
Support delivery of real-time information in a timely manner	S-1; S-3; W-16; FM-1; FM-2; FM-9; FM-10; FM-12; FM-15; FM-18; FM-25; FM-26; RM-3; RM-7; A-4; A-7; A-11		D–RVR[a] D-SIG D–SIGMET FLIPCY WAKE PPD
Enable demand, periodic, and event communication	S-1; W-12		All services

[13]In today's environment both surveillance and weather information would be uplinked to the aircraft on the ground. In the future, a downlink may be applicable to transfer this data to the controller.
[14]Although the RTCA document describes the NAS evolution in terms of three time periods—near (up to 2005), mid (2005 through 2010) and far (beyond 2010)—most concepts identified in the document are applicable to the proposed AeroMACS, which will necessarily be implemented beyond 2010.

TABLE 11.—MAPPING AeroMACS FUNCTIONALITY TO THE NATIONAL AIRSPACE SYSTEM (NAS) CONCEPTS OF OPERATION (ConOps)
[Acronyms are defined in Appendix A.]

Desired AeroMACS capabilities	NAS ConOps references (Ref. 14)	Functional hierarchy reference	Communications operating concept and requirements (COCR) air traffic services (ATS)
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-1; A-5		All services
Support multiple quality-of-service (QoS) provisions			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 users	S-1; FM-12; FM-14; FM-20; A-11		All services
Avoid single points of failure	RM-6		All services
Provide a scalable solution			All services
Provide standards-based solution			All services

[a]At 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 AeroMACS if not implemented by the Data Comm program.

High-level AeroMACS functional requirements can then be constructed from the functional capabilities in a straightforward manner, as shown in Table 12.

TABLE 12.—AeroMACS HIGH-LEVEL FUNCTIONAL REQUIREMENTS

System functions	AeroMACS high-level functional requirements
Enable air-to-ground (A/G) and ground-to-ground (G/G) communications for fixed-to-mobile as well as fixed-to-fixed services.	The system shall enable ground-to-air (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. The system shall enable G/G communication for fixed-to-fixed users.
Support addressed communication for delivery of information to individual and multiple users.	The system shall support addressed communications to individual users. The system shall support addressed communications to multiple users.
Support broadcast communication for delivery of information to multiple users.	The system shall support broadcast communication 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 QoS provisions.	(This functional capability points toward performance requirements.)
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 users.[a]	The system shall support FAA ground users. The system shall support non-FAA ground 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 a standards-based solution.	The system shall provide standards-based solution.

[a]To 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.

4.1.2 AeroMACS Functional System Requirements—Bottom-Up Approach

4.1.2.1 National-Airspace-System-Level Functional Requirements for AeroMACS Services

Functions identified in the NAS SR–1000 (Ref. 13)—plan flights, monitor flights, control traffic, support flight operations, monitor NAS operations, and plan NAS usage—cut across all the AeroMACS capabilities shown in Table 13. Table 2 in Section 3.2.2.1 mapped NAS-level A/G communication functions to NAS service capabilities, highlighting services potentially enabled by A/G voice communication. As expected, the NAS functions potentially enabled through an AeroMACS go well beyond those shown in Table 2. Consequently, Table 13 highlights the capabilities of the proposed AeroMACS enabling NAS functionality specified in the NAS SR–1000. The colored boxes denote services potentially enabled by A/G communication, with the blue boxes representing voice and/or data communication and the green boxes representing data communication only.

TABLE 13.—MAPPING RELEVANT NATIONAL AIRSPACE SYSTEM (NAS) COMMUNICATIONS FUNCTIONS TO NAS SERVICE CAPABILITIES (REF. 13)

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 14, functional requirements applicable for an AeroMACS operating on the airport surface were extracted from the NAS requirements specified in the NAS SR–1000. Unless specifically stated otherwise, these could apply to A/G or G/G communications for fixed-to-mobile or fixed-to-fixed applications.

TABLE 14.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
[Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 13).]

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)
Monitor flights	Collect aircraft navigation information (collect dependent surveillance information)	The NAS shall retrieve actual flight information. (10000) The NAS shall acquire actual flight information from aircraft outside of independent surveillance coverage. (03320)
	Monitor aircraft status	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 disseminate essential information on missing aircraft. (13130)
	Report (disseminate) aircraft status	The NAS shall display position information, to specialists, for aircraft that were detected independent of aircraft equipage in qualifying aerodromes. (24530) The NAS shall transmit conflict-free flight path recommendations to expedite resolution of emergency situations. (12820) The NAS shall disseminate aircraft flight information for each controlled aircraft to specialists. (02720) The NAS shall disseminate the current location for each participating aircraft to ATCSCC [air traffic control system command center] specialists. (10940) The NAS shall disseminate the current location for each participating aircraft to Traffic Management Coordinators. (10980)
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 disseminate weather advisories via direct specialist to pilot communications. (09290)

TABLE 14.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
[Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 13).]

NAS functions		Communication requirements
Support flight operations	Manage weather information	The NAS shall maintain communication links adequate to avoid user delay in gaining access. (07090)
		The NAS shall disseminate weather information to users continuously. (07110)
		The NAS shall disseminate current weather effect along the users proposed flight path. (07470)
		The NAS shall disseminate forecast weather in effect along the users proposed flight path. (07480)
		The NAS shall disseminate intensity levels of weather by route of flight to users. (08260)
		The NAS shall disseminate intensity levels of weather by geographic area to users. (08300)
		The NAS shall disseminate weather advisories to users in response to a request. (09300)
		The NAS shall broadcast the latest approved aerodrome conditions on communications media accessible by aircraft on the ground. (09340)
		The NAS shall broadcast the latest approved terminal area conditions on communications media accessible by aircraft on the ground. (09360)
		The NAS shall respond to user requests for weather information from NAS facilities through common carrier communications networks. (09370)
		The NAS shall disseminate selected weather information directly to appropriately equipped aircraft. (09420)
		The NAS shall provide flexible and convenient access to required weather information to users. (19380)
	Operate navigation aids[a]	The NAS shall disseminate navigational accuracy correction values for supplemental navigation systems to users. (17040)
		The NAS shall disseminate correction values for navigational aids to users. (16790)
		The NAS shall disseminate available supplemental terminal navigation guidance information error correction values to users. (14820)

TABLE 14.—NATIONAL AIRSPACE SYSTEM (NAS) FUNCTIONS
[Numbers in the table correspond to communication requirements in the NAS SR–1000 (Ref. 13).]

NAS functions		Communication requirements
Monitor NAS operations	Monitor NAS flight operations	The NAS shall disseminate future delay advisories in effect along the users proposed flight path. (07500)
		The NAS shall disseminate traffic advisories upon user request. (09120)
		The NAS shall provide traffic advisories to aircraft on the surface. (30270)
	Maintain NAS infrastructure	The NAS shall disseminate airway usage information to users. (00030)
		The NAS shall disseminate route usage information to users. (00050)
		The NAS shall disseminate aeronautical information to users via external data interfaces. (07430)
		The NAS shall disseminate aeronautical information per user request. (07130)
		The NAS shall disseminate aeronautical information upon user request continuously. (07340)
		The NAS shall disseminate aeronautical data for a maximum of 8 specified locations per request. (07400)
		The NAS shall disseminate the status of supplemental navigation systems to users. (17010)
		The NAS shall disseminate status of supplemental navigation systems to users. (16770)
		The NAS shall disseminate flow control information to users via external data interfaces. (07920)
		The NAS shall disseminate derived restrictions to the user. (11700)
		The NAS shall disseminate alternate courses of action relative to flight restrictions to users. (11790)
		The NAS shall disseminate terrain information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03900)
		The NAS shall disseminate manmade obstacle information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (03940)
		The NAS shall disseminate ground information compliant with terrain, ground and obstacle information accuracy requirements, to users upon request. (25520)
		The NAS shall disseminate filtered terrain information to users. (25560)
		The NAS shall disseminate filtered ground information to users. (25570)
		The NAS shall disseminate filtered manmade obstacle information to users. (25580)
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)
	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)

[a]These services are typically provided via satellite communication (SATCOM) but could be provided via a ground-based system.

4.1.2.2 National-Airspace-System-Level Functional Requirements for AeroMACS Infrastructure

The following is a summary of NAS infrastructure (communications) requirements found applicable to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 13). The list supports the high-level functional requirements presented in the document.

- The NAS shall provide data channels in the frequency band appropriate for air-ground 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 air-ground communications continuously… (part of 20330)
- The NAS shall provide reconfiguration of communications capabilities without degradation of air-ground 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 provide processing and communications capacities to support the required backup capabilities and to meet the response time requirements 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)

4.2 AeroMACS Performance Requirements

4.2.1 National-Airspace-System-Level Performance Requirements Applicable to AeroMACS

Performance requirements were derived to define system capabilities based on the functional requirements developed in preceding sections. Table 15 summarizes NAS performance requirements found to be relevant to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 13). Note that these are high-level NAS requirements that do not specify how they should be implemented. A/G and G/G communications are considered to be possible implementation solutions.

TABLE 15.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 13.]

NAS function	Performance requirement
Control traffic	The NAS shall disseminate hazardous weather avoidance recommendations to users within 1 minute of request. (08440)
	The NAS shall communicate aircraft actions to users within 1 minutes of implementing a weather avoidance plan. (08460)
	The NAS shall alert participating aircraft to predicted conflicts with obstructions within 10 seconds of prediction. (09170)
	The NAS shall notify users of non-adherence to ATC clearance within 10 seconds of the detection of the deviation. (02010)
	The NAS shall alert appropriately equipped users to the collision danger within 10 seconds after the prediction is made. (03660)

TABLE 15.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 13.]

NAS function	Performance requirement
Support flight operations	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)
	The NAS shall notify users affected by the presence of hazardous weather within 2 minutes of acquisition. (08170)
	The NAS shall update hazardous weather broadcasts at least once every 30 minutes. (09400)
	The NAS shall disseminate automated weather observations once per minute to designated interfaces. (05270)
	The NAS shall disseminate terminal area hazardous weather information to users within one minute of detection. (06990)
	The NAS shall display requested routine weather information to the user within a mean response time of 3.0 seconds of the request. (23380)
	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)
	The NAS shall display requested routine weather information to the user within a maximum response time of 10.0 seconds of the request. (23400)
	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)
	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)
Monitor NAS operations	The NAS shall alert users to a full navigation system failure affecting NAS operations within 10 seconds of the failures detection. (17110)
	The NAS shall alert users to a partial navigation system failure affecting NAS operations within 10 seconds of the failures detection. (17130)
	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)
	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)
	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)
	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)

TABLE 15.—NATIONAL AIRSPACE SYSTEM (NAS) PERFORMANCE REQUIREMENTS
[Numbers in the table correspond to performance requirements in Ref. 13.]

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

4.2.2 Communications Operating Concept and Requirements (COCR) Performance Requirements Applicable to AeroMACS

The performance requirements shown in Table 16 resulted from the operational performance assessment conducted as part of the COCR (Ref. 11). That assessment determined the performance that a system or service must achieve and led to a determination of the availability, integrity, and transaction times. 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 was used to determine the communication performance requirements. The operational requirements are 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 16 are based on COCR ATS future radio system performance requirements (Ref. 11) 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 APT, TMA, and ENR domains.

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

TABLE 16.—AEROMACS DATA REQUIREMENTS

Service type	Confidentiality	Latency, sec	Integrity	Availability of provision
Addressed	Medium	1.4	5.0×10^{-8}	0.999995
Broadcast	Medium	0.4	5.0×10^{-8}	0.999995

4.3 Other AeroMACS Requirements

4.3.1 Spectrum Requirements Applicable to AeroMACS

One of the main objectives of the proposed AeroMACS network is to increase communications system capacity. A channel plan will be developed driven by frequency availability to support broadband services. Section 6.2.2 discusses channelization methodology for AeroMACS design.

The proposed system should provide seamless operations around the globe. International standards are being developed to achieve full interoperability.

Table 17 summarizes NAS spectrum requirements applicable to the proposed AeroMACS as documented in the NAS SR–1000 (Ref. 13).

TABLE 17.—NATIONAL AIRSPACE SYSTEM (NAS) SPECTRUM REQUIREMENTS APPLICABLE TO THE PROPOSED AEROMACS
[Numbers in the table correspond to performance requirements in the NAS SR–1000 (Ref. 13).]

Category	Performance requirement
Secure spectrum with the Federal Aviation Administration (FAA)	The NAS shall secure and protect national radio spectrum for the FAA and the US 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)

TABLE 17.—NATIONAL AIRSPACE SYSTEM (NAS) SPECTRUM REQUIREMENTS APPLICABLE TO THE PROPOSED AEROMACS
[Numbers in the table correspond to performance requirements in the NAS SR–1000 (Ref. 13).]

Category	Performance requirement
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)

By International Telecommunications Union (ITU) regulation, AM(R)S allocated spectrum can only be used to support aeronautical mobile safety or regularity of flight services. However, in the United States, fixed applications that directly impact safety and regularity of flight may be provisioned by an AM(R)S mobile communications network infrastructure.

4.3.2 User Requirements Applicable to AeroMACS

Table 18 summarizes aviation user requirements based on those documented in Reference 51 and found to be potentially applicable to AeroMACS.

TABLE 18.—AVIATION USER REQUIREMENTS

The system shall be capable of supporting all categories of users including the following (Ref. 46): 1. Scheduled air transport carriers (including international, trunk, regional, commuter and air freight carriers) 2. Nonscheduled air carriers 3. General Aviation (GA) (including operators of turbine-powered and reciprocating–engine aircraft) 4. Nonscheduled air carriers 5. General Aviation (GA) (including operators of turbine-powered and reciprocating–engine aircraft) 6. Rotorwing Aircraft (including helicopters and gyrocraft) 7. Unpowered aircraft (including gliders and lighter-than-air) 8. Military aircraft 9. Certain ground and maritime vehicles (e.g., airport service vehicles, those vehicles coordinating in a search-and-rescue mission)
The new system shall satisfy any data communications requirements for use in any authorized category of communications service including ATS, AOC, and AAC.
The avionics equipment shall communicate with any compatible ground system.

4.3.3 Regulatory Requirements Applicable to AeroMACS

The following list summarizes regulatory requirements based on those documented in Reference 5 and found to be potentially applicable to AeroMACS.

- 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.

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 Reference 9 as potential ATS or AOC applications for provision by AeroMACS are included in the table.

TABLE 19.—MAPPING OF ITU PRIORITY LEVELS TO COCR SERVICES (REF. 38)

ITU Priority Level		COCR Services	
		ATS	AOC[a]
1	Distress calls, distress message, and distress traffic		
2	Communications preceded by the urgency signal		
3	Communications related to radio direction-finding		
4	Flight safety messages	D–RVR D–OTIS FLIPCY D–SIG WAKE D–SIGMET PPD	Notice to Airmen (NOTAM) Flight Plan Data (FLTPLAN) Load Sheet Request/Transfer (LOADSHT) Update Electronic Library (UPLIB)
5	Meteorological messages		Textual Weather Reports (WXTEXT) Real-time Weather Reports for Met Offices (WXRT) Graphical Weather Information (WXGRAPH)
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) EFFuplink[b] EFFdownlink[b] CONF[b] PERF[b] VQAR[b] CVM[b] CabMAINTTRT[b] TELEMED[b] REFUEL[b] DEICING[b]

TABLE 19.—MAPPING OF ITU PRIORITY LEVELS TO COCR SERVICES (REF. 38)

ITU Priority Level		COCR Services	
		ATS	AOC[a]
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]

[a]Most 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.
[b]These 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.
[c]Although listed in the COCR, this service may not be applicable application for a wireless communications system.

4.3.4 Safety and Security Requirements Applicable to AeroMACS

A fundamental safety requirement is that new communications systems shall not cause degradation in safety when compared with the existing communications systems. The overall objective is to improve safety. A C-band initial safety and security analysis and the associated requirements applicable to AeroMACS are covered in separate documents (Refs. 45 and 47).

4.4 Guidance for the Development of AeroMACS Requirements Based on IEEE 802.16–2009

The preceding sections presented high-level functional and performance requirements applicable to AeroMACS that encompass most of the known A/G and G/G communications services for mobile-to-fixed and fixed-to-fixed applications on the airport service. They should be considered NAS high-level guidance in the development of specific system requirements necessary for any particular service for implemented over AeroMACS.

Typically high-level requirements are technology independent. Perhaps unique to the development of the AeroMACS requirements is the identification a priori, by virtue of the extensive FCS technology assessment, of the recommended technology by which AeroMACS will be implemented, that is, IEEE 802.16–2009. This allows the identification and development of quite specific requirements depending on the desired application or service to be provided. The following sections provide a preliminary approach for identifying and developing AeroMACS requirements in the context of the IEEE 802.16–2009 broadband communications standard and its characteristics.

4.4.1 Introduction

The applications discussed in Section 3.5.3 require the support of several types of communication services. Much of the initial requirements analysis work was done in the COCR study (Ref. 11), which conducted analysis to specify requirements for continuity, integrity, availability of provision, and availability of use for various ATS communication services. The services analyzed were primarily narrowband services, but the study indicated the level of performance that would be needed by a wideband service as well.

An initial safety analysis was carried out for future airport surface communication systems that considered the possibility of wideband communication systems (Ref. 48). This analysis dealt with various aspects of hazards and safety risks relative to ConUse and provided initial top-level risk assessments. Safety risk assessments deal with the criticality of communication services and the ability of these services to maintain levels of performance in operation. The results from a safety and reliability analysis will help determine link performance requirements and the level of redundancy needed in the communication system. In addition, a safety analysis will help determine the monitoring and maintenance intervals needed for the communication system and the supporting network management functions.

Security levels and services also are considered in developing requirements that can be applied at the link/MAC and physical layers. At the physical layer, transmission security may be required to prevent unauthorized monitoring or spoofing of the transmitted signals. At the MAC layer, low-level authentication and identification may be needed. Security above the link and local network layers will include message encryption and higher level authentication services.

These are important inputs to developing a quality-of-service (QoS) protocol/policy and physical layer requirements for AeroMACS.

4.4.2 Classes of Communications Services for AeroMACS

The applications described in Section 3.5.3 require communication services to perform their functions. The following subsections give brief descriptions of classes of communication services that may be required. For this discussion, a “point” is a central source or user of data, and “multipoint” means that the data traffic is sent to multiple users. This does not refer to the AeroMACS network architecture of a central BS (point) servicing multiple subscriber stations (SSs—multipoint).

4.4.2.1 Low-to-Medium-Speed Point-to-Point Data Link

This link transports data from a sensor or ground station to a processing or monitoring unit. Data rates are low to moderate (<200 kilobits per second (kbps)). These links can be part of a polling network where several links are tied to the central station.

4.4.2.2 High-Speed Point-to-Point Data Link

A high-speed data link can be used to link sensors that produce high-speed data to a central processor, or to link multisensor network access points or a subnetwork to a larger network. Data rates ≥200 kbps are needed.

4.4.2.3 Point-to-Multipoint Broadcast Data

This type of communication service enables the multicast or broadcast of scheduled or priority messages to a large group of users or a selected subset of users (multipoint). Data updates and critical messages will have low to moderate data transmission rates (<200 kbps).

4.4.2.4 Point-to-Point Command and Control Data

This type of service is for near-real-time control of a device or system. It relies on short-turnaround feedback from the device being controlled. Control of runway lighting is one example for this type of service. The command UL and feedback link are low rate (<100 kbps), but they require low error rates. The UL may carry higher data rates (e.g., video at <2 megabits per second (Mbps)) and can tolerate higher error rates than the control link.

4.4.2.5 Voice Network

Digital voice networks have several advantages over analog voice circuits. For example digital voice circuits can be encrypted. However, they have requirements on maximum delay corresponding to the human response times (typically less than 200 msec one way). This usually dictates a time-division multiple-access (TDMA) system to guarantee maximum delay time. Capacity requirements will depend on the number of voice circuits used.

4.4.2.6 Video Link

Depending on the resolution and frame rates needed for an application, video transmission can require significant capacity, typically on the order of 1 Mbps for a single link. Thus, a relatively small number of video circuits per BS sector (in comparison to a voice circuit) are likely to be supported in a multiservice communication system.

4.4.2.7 Multimedia

Multimedia services combining voice, data, and video can require a large amount of communication resources depending on how the services are combined for use. For CDM, voice plus data (graphics) may be all that is needed. An example would be an application like Cisco's WebEx. The addition of video to CDM will require a significant increase in demand for capacity from the network.

4.4.2.8 Basic Mobile

This class of communication service requires the necessary QoS and network functions for handoff between BS sectors to support basic voice and data services.

4.4.2.9 Enhanced Mobile

This class of mobile service provides increased capacity to handle interactive applications such as CDM while on the move.

4.4.3 Developing AeroMACS Service Quality-of-Service Requirements Based on IEEE 802.16–2009

Developing a QoS function for a modern communication system involves three main areas of consideration:

(1) Defining a set of QoS parameters and metrics that can be used to monitor and classify different grades of communication services
(2) Determining service priorities and preemption if needed
(3) Developing a protocol for managing and scheduling services

The IEEE 802.16–2009 standard includes five QoS categories. These categories use a number of performance parameters to quantify performance. The five QoSs included in the IEEE 802.16–2009 standard follow:

(1) Unsolicited grant service (UGS) supports fixed-size data packets and allocated capacity. Digital voice circuit over the Internet (VoIP) is an example.
(2) Real-time polling services (rtPS) are designed to support networked video and voice applications on a high-speed network that supports multiple streams.
(3) Non-real-time polling service (nrtPS) supports delay-tolerant data streams that transmit at periodic intervals, such as file transfers.
(4) Best-effort service provides a best effort for delivering data packets without guaranteeing delivery. This is the type of service normally provided by the Internet.
(5) Extended real-time variable rate (ERT–VR) service supports real-time applications that can have variable packet sizes. Digital voice with silence suppression is an example.

Table 20 relates the five QoS categories to the applications that will benefit from the QoS category and the parameters that define each QoS category (Ref. 49).

TABLE 20.—IEEE 802.16-2009 QUALITY OF SERVICE CATEGORIES AND DEFINING PARAMETERS

Defining parameters	Unsolicited grant service, UGS	Real-time polling service, rtPS	Non-real-time polling service, nrtPS	Extended real-time polling service	Best effort
	Applications				
	Traffic over T1 or E1 lines, VoIP[a] without silence suppression	Streaming audio and streaming video	FTP and TCP[b] applications that require a minimum data rate	VoIP with voice-activity detection (bursty traffic)	Web browsing and file transfer
Real-time service flow	X	X		X	
Fixed-size data packets	X			X	
Scheduled packet transmission	X	X		X	
Minimum reserve rate		X	X		
Maximum sustained rate		X	X		X
Maximum latency tolerance		X			
Time jitter tolerance	X			X	
Traffic priority		X	X	X	X
Dynamic traffic allocations				X	
Unicast polls (guaranteed service request opportunities in congestion)			X		

[a]VoIP, digital voice over Internet Protocol.
[b]FTP, File Transfer Protocol; TCP, Transmission Control Protocol.

4.4.4 Quality of Service Support of AeroMACS Communication Services

Table 21 shows an analysis of the communications services that were discussed in Section 4.4.2 with example airport applications and applicable QoS service classes. Typical values of performance are included for data rate, packet error rate (PER), delay (time latency), and time jitter.

TABLE 21.—COMMUNICATION SERVICE REQUIREMENTS
[Acronyms are defined in Appendix A.]

Communication service	Example airport application	Quality-of-service (QoS) class	Performance parameters	Typical values[a]	Supported by IEEE 802.16-2009
Low-to-medium-speed point-to-point data link	Backup for sensor cable link (i.e., weather sensor)	nrtPS	Data rate PER Delay Jitter	100 kbps 1.0×10^{-3} 1 sec 100 μsec	Yes
High-speed point-to-point data link	Backbone-linking BS; link to relay gateway node in remote area	UGS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec 100 nsec	Yes
Point-to-multipoint broadcast data	Scheduled broadcast of weather info, NOTAM	nrtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 1 sec <1 μsec	Yes
Point-to-point command and control data	Remote operation of ADS–B ground station	rtPS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-6} 100 msec <1 μsec	Yes
Command and control network	Operation of surface devices at remote airport	Best effort	Data rate PER Delay Jitter	200 kbps 1.0×10^{-4} 200 msec <10 μsec	Yes
Digital voice network	Provide *N* circuits for ATC or AOC operations	rtPS; ERT–VR service	Data rate PER Delay Jitter	10 kbps × N 1.0×10^{-3} 100 msec <100 μsec	Yes
Point-to-point video link	Airport surveillance; robotic vehicle	UGS	Data rate PER Delay Jitter	600 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes
Basic mobile	Handoff control for voice; low-speed data sessions	UGS	Data rate PER Delay Jitter	200 kbps 1.0×10^{-3} 200 msec <10 μsec	Yes
Multimedia	CDM	rtPS	Data rate PER Delay Jitter	1 Mbps 1.0×10^{-3} 100 msec <10 μsec	Yes

[a]End-to-end delay, one direction.

These typical performance parameters are for the physical and link-layer requirements for individual communication services. The actual values will depend on the architecture of the communication network, the size of the network, and the provisions for redundant communication support. The performance values shown in the table are typical of the type of communication service offered. For example, one-way voice delay is derived from subjective analysis involving human reactions in human conversation with push-to-talk communications. Jitter requirements are somewhat dependent on the implementation—for example, the extent to which data buffering is used. Packet error rate performance typically depends on the use of retransmissions and the size of the message. Future work should refine these performance values according to the specific services to be implemented.

The final column of Table 21 is an assessment of whether the requirement is supported by the performance of a system that is based on the IEEE 802.16–2009 standard. The communications systems and their operating requirements are expected to be supported in all cases that were examined.

5.0 Architectural Description

5.1 Initial Surface Communications System Architecture

This section describes a system architecture framework for an airport surface communications reference model that can be applied at all airport installations. The number of components to be deployed will vary according to the size and data capacity needs of the airport. The communication architecture is based on the IEEE 802.16 standard for the network functions with the IEEE 802.16e–2005 amendment (Ref. 19), now updated to the IEEE 802.16–2009 standard for the mobile air interface.

5.2 Overview

The primary mode for operation on an IEEE 802.16–2009-based system is a point-to-multipoint architecture. Figure 25 depicts a notional wireless point-to-multipoint system in an airport context.

In this architecture, SSs, which include fixed and portable nodes and mobile stations (MSs) are wirelessly linked to the BS access points. The BSs are linked to a common access service network (ASN) which manages services among BSs. The ASN can include one or more BSs and could be localized to one part of the airport (for example, an area assigned to a major carrier). For a small number of BSs, distributed ASN functions can be used that are installed at each BS. The ASNs are linked to a Connectivity Service Network (CSN) through gateways (not shown in Figure 25). The CSN provides access to services on the airport intranet and fire-walled access to the Internet.

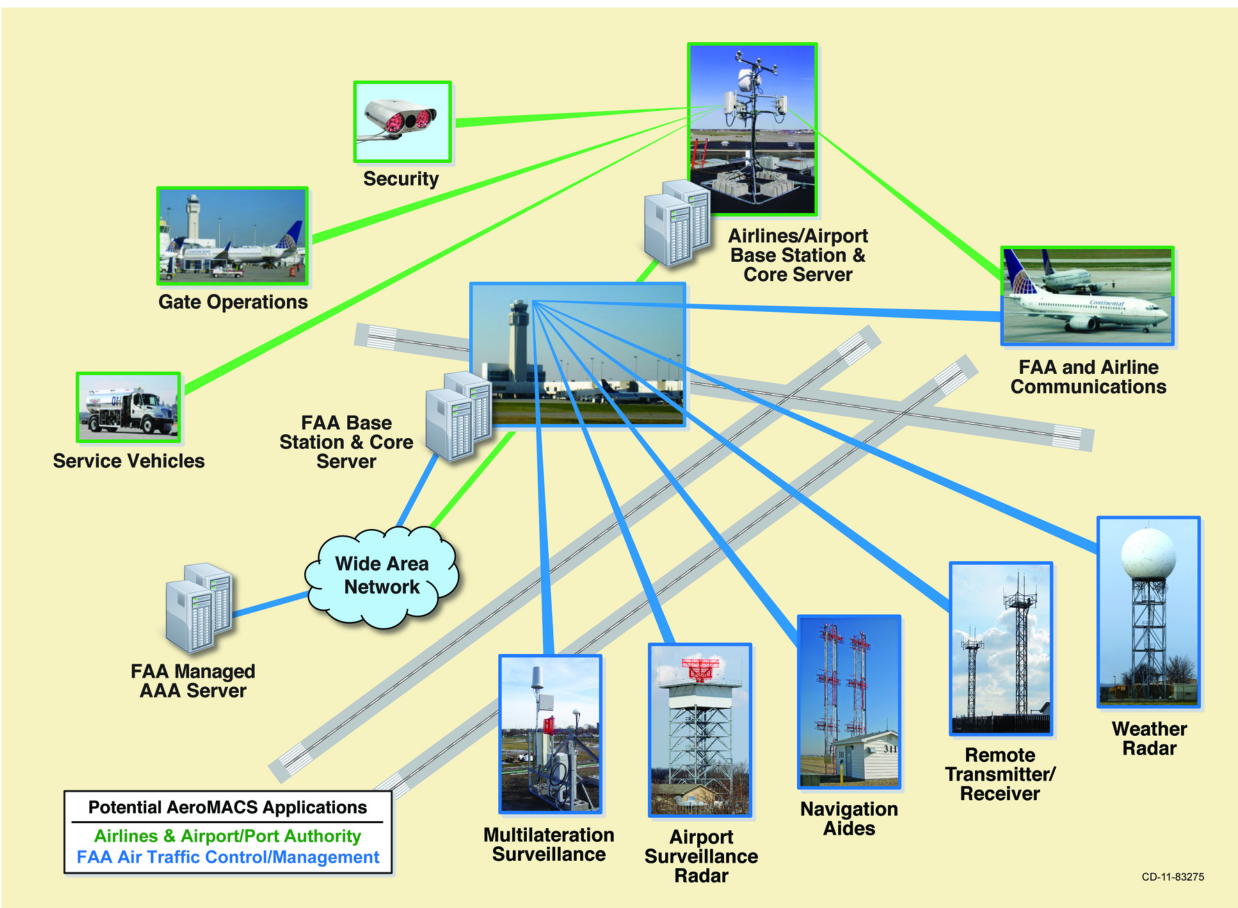

Figure 25.—Airport point-to-multipoint communications service. Acronyms are defined in Appendix A.

AeroMACS is envisioned to provide communications for both mobile and fixed infrastructures. An AeroMACS network can support fixed infrastructure in areas of scarce communications, providing wide bandwidth wireless links in place of cables that can be expensive and disruptive to install. Once an AeroMACS network is installed at an airport, a communications link can be instantiated by simply placing an AeroMACS radio at the remote data site interfaced through Ethernet ports, and by programming the network to authenticate and authorize service for the remote data terminal. AeroMACS provides the flexibility to quickly implement new links to remote sites for primary, backup, and emergency communications. The benefit that AeroMACS provides for mobile application communications is unequaled in terms of flexibility and traffic bandwidth.

5.3 IEEE 802.16 Network Architecture

The IEEE 802.16 Network Working Group has developed a network reference model to assist in the deployment of IEEE-802.16–2009-based systems. It is designed to enable interoperability of vendor equipment and to provide a structure for the deployment of new systems. The architecture is Internet Protocol (IP)-based, meaning it relies on IP addressing to provide secure connectivity between users and access to common services. Figure 26 depicts a top-level view of this architecture.

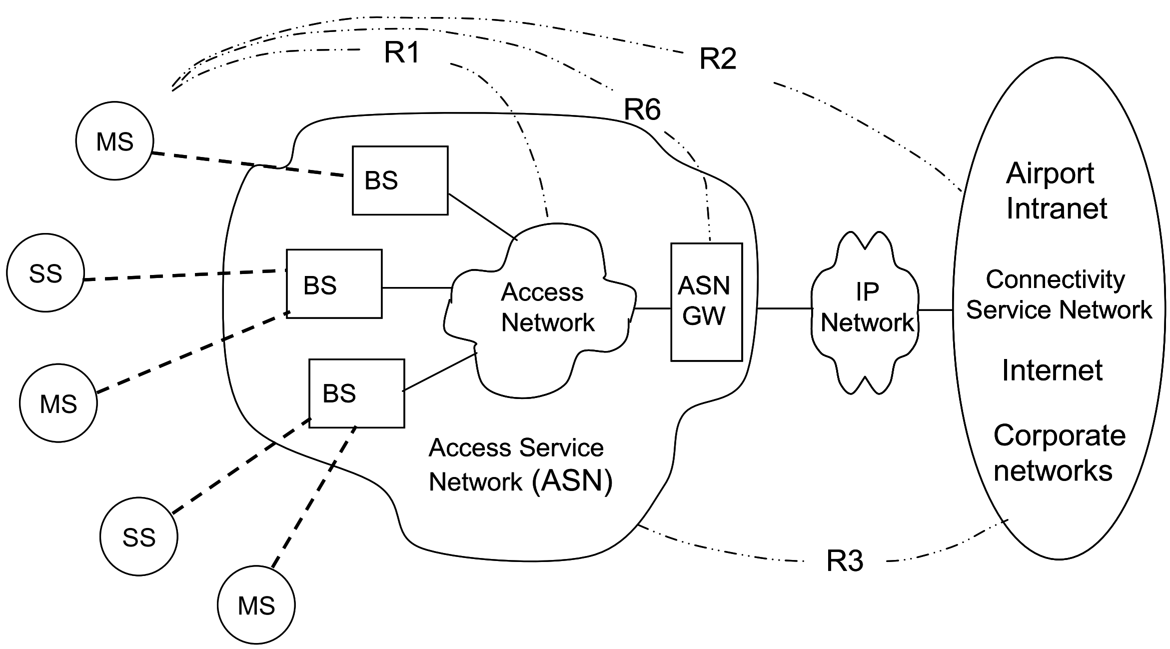

Figure 26.—IEEE 802.16 IP-based network architecture (based on Fig. 2.3 in Ref. 16).

The MS nodes can be anything mobile: aircraft, service vehicles, emergency, or other vehicles and pedestrians. The fixed SS nodes are stationary sites that could be surveillance weather stations, radar sites, or the equipment in operations buildings located on the airport surface. In AeroMACS, MS and SS nodes are both referred to as SS, since all user stations are handled as if they were mobile. The hardware for both is compliant with the mobile standards, whether physically mobile or stationary.

SS nodes are linked through wireless connections to the BS access points. There can be multiple SS nodes assigned to a single BS. Mobile SS nodes are transitory and must be serviced by a handoff protocol that enables the mobile SS to maintain connected service while moving between access point coverage areas. The BSs are connected to an access network that includes a gateway IP router. The access network manages the ASN to ensure its proper operation at the physical and MAC levels. This includes the management of mobile and stationary SSs operating within the ASN. It also provides access to higher level services through the access service network gateway (ASN–GW). The CSN provides connectivity to the closed airport intranet and fire-walled access to the open Internet. The airport intranet hosts local IP-based servers which provide various data services and applications to authorized airport users.

The ASN–GW aggregates subscriber and control traffic from BSs within an access network. It has an important role in subscriber management, network optimization, and forwarding of all SS traffic.

The BS nodes identified in this architecture will often have multiple coverage sectors using multiple radios, each with a directional transmit/receive antenna. Each radio and antenna pair forming a coverage sector is referred to as a base transceiver station (BTS).

The IEEE 802.16 network architecture further defines functional interfaces between the major components of the model as listed in Table 22. Eight functional interfaces that are defined within the network and between networks are listed in the table. The four interfaces shown in the figure (R1, R2, R3, and R6) are defined in Table 22. Three interfaces (R4, R5, and R7) are defined that would apply to airports with more than one ASN, gateway (GW), or CSN, such as when multiple service providers are present.

TABLE 22.—SELECTED IEEE 802.16 NETWORK INTERFACE DEFINITIONS
[Acronyms are defined in Appendix A.]

Interface reference point	Functional entities	Functions
R1	SS and the ASN	Implements the air interface (IEEE 802.16–2009) specifications and may additionally include protocols related to the management plane.
R2	SS and CSN	Provides authentication, service authorization, IP host configuration management, and mobility management. This is only a logical interface and not a direct protocol interface between the ASN and CSN.
R3	ASN and CSN	Supports AAA [authentication, authorization, and accounting], policy enforcement and mobility management. R3 also encompasses the bearer plane methods (e.g. tunneling) to transfer IP data between the ASN and the CSN.
R4	ASN and ASN	A set of control and bearer plane protocols that originate/terminate within the ASN that coordinates SS mobility between ASNs.
R5	CSN and CSN	A set of control and bearer plane protocols to support mobility between networks if multiple networks (airports) are supported by multiple CSNs and mobility handoff is needed.
R6	SS and ASN–GW	A set of control and bearer plane protocols for communication between the BS and the ASN–GW. Consists of intra-ASN bearer paths and IP tunnels for mobility tunnel management. R6 may also be a conduit for exchange of MAC states information between neighboring BSs.
R7	ASN–GW–DP and ASN–GW–EP	An optional set of control plane protocols for coordination between the two groups of functions identified in R6.
R8	BS and BS	A set of control plane message flows and possibly bearer plane data flows between BSs to facilitate fast and seamless handovers.

Figure 27 provides details about the functions that pass through the R1, R3, and R6 interfaces. The R2 interface is not indicated in the figure because it deals with services that pass between the SS node stations and the CSN. Interface R8 applies if, in the future, local mesh or ad hoc networking between SSs is implemented in an amendment to the standard.

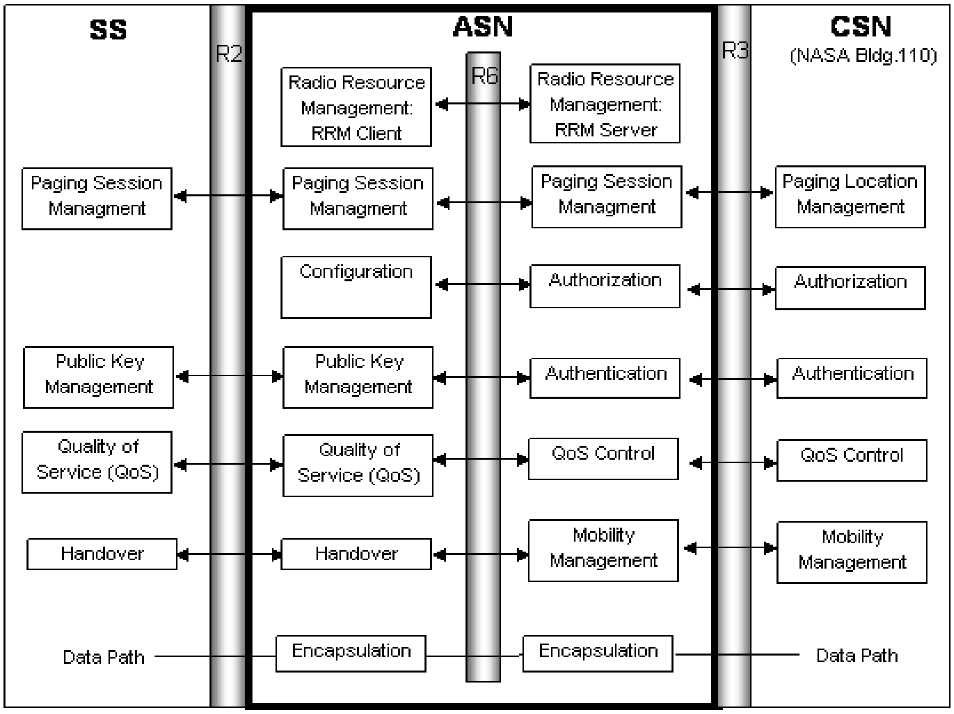

Figure 27.—Network interfaces and functions. Acronyms are defined in Appendix A.

Each airport location can be considered as a small enterprise with data communications occurring in the immediate vicinity of the airport property. Because of this, frequency planning for the R1 interface can consider only the BS sectors at a single airport unless other airports are within the radio LOS. Plans can be made to reuse the BS sector frequency within the C-band allocation within that small enterprise.

Commercial IEEE 802.16–2009 hardware that is presently available can be procured with either a centralized ASN–GW or a distributed ASN–GW in which the gateway function is resident in each BS. The use of a centralized ASN–GW server versus a distributed function presently depends on the number of BSs in a network, with the distributed approach typically supporting up to six BSs.

The functions at the R3 interface between ASN and CSN can be supported for relatively long distances over a secure IP network. One CSN will be able to support multiple small enterprises and could potentially support all airport surface communication networks across a national region.

The number of multisector BS sites to be installed at an airport will depend on many factors including the physical size of the airport, the expected data load requirements, and factors that affect wireless signal propagation such as terrain and building shadowing and the need for high QoS. Network reliability and service availability will improve with at least two BS visible to each SS for the majority of the coverage area. This will provide reliable wireless linkage in the case that one of the available paths between an SS and BS is interrupted by an obstruction or hardware failure. Each airport will be somewhat unique in these factors and will require customized designs for the placement and quantity of BS sites to provide the needed QoS.

Many options exist to implement a physical R3 interface between an ASN–GW and the CSN that is typically located at a central point and can be widely separated from the BSs. Making the R3 connection may be complicated by the limitations of existing IP network infrastructure in the airport environment. Positioning of the BS to achieve airport surface coverage may place it distant from an existing IP-based network. A microwave backhaul link may be used to connect BSs and ASNs to the CSN to avoid the installation of cables. Another option is to use an SS to establish an in-band backhaul link to establish a limited-bandwidth connection.

5.4 Physical System Architecture and Design Process

The general network architecture was outlined in Section 5.3. Designing an AeroMACS network at an airport will require several tradeoffs to obtain the best performance, including

- Location and number of BSs
- Number of antenna sectors to employ per BS
- Type of backhaul system to support the ASN
- Number of SS terminals that can be serviced by a BS

Section 6.0 describes the system design process for new airport installations.

6.0 AeroMACS Design Considerations

6.1 Airport AeroMACS Network Design Process

An essential element in designing and deploying an AeroMACS network is a comprehensive RF design. An accurate design will ensure that the deployed wireless network provides the necessary coverage, capacity, and reliability, with minimal interference, that satisfies the service requirements. Although it is possible to gauge the performance of radio links through theoretical means, real-life deployments must take into account variables from the environment to achieve optimal performance and minimize coverage holes and RF co-channel interference. Figure 28 illustrates a top-level design flow for new AeroMACS network.

The network design process begins with a physical site survey to gather information about the deployment location. A site survey provides an opportunity to validate any topography mapping information that may be available. It is also used to identify suitable installation locations for AeroMACS equipment. A site survey also provides input to the next three phases of the RF design process: coverage model, spectrum analysis, and capacity analysis.

Before the design process can begin for an airport, general guidelines should be defined. Guidance on airport categorization, channelization methodology and power limitation recommendations are essential inputs to an AeroMACS network design. These are discussed in the following sections.

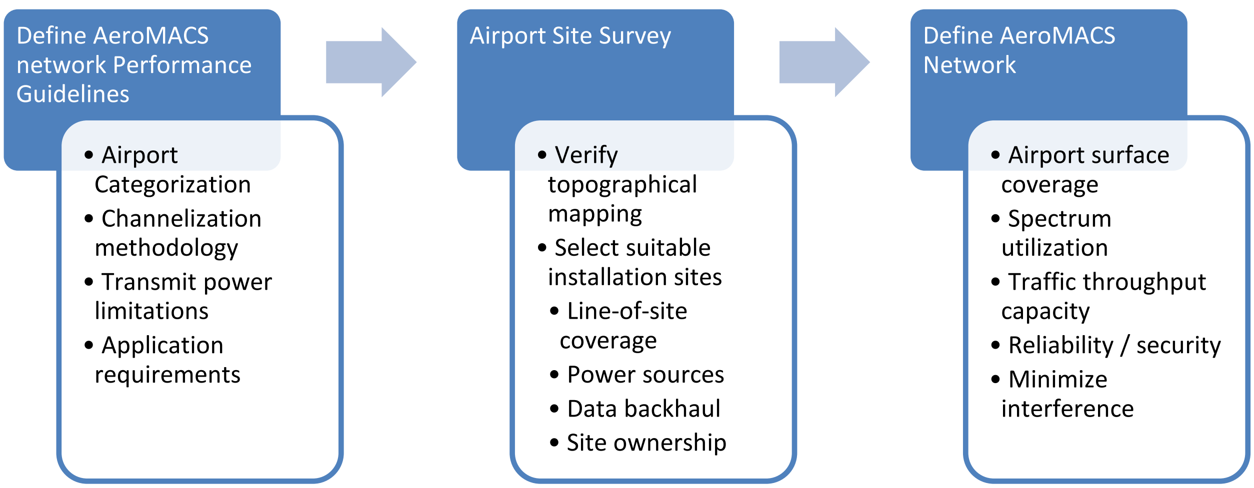

Figure 28.—AeroMACS network design process.

6.2 Inputs to Network Design

Channelization methodology and power limitations described below are considered important inputs that set the stage for the AeroMACS network design.

6.2.1 Airport Categorization

The purpose of this airport categorization task is twofold. First, creating a set of airport categories based on common airport characteristics and design objectives would facilitate initial AeroMACS architecture designs and enable budgetary projections. Though each AeroMACS will be implemented with its own unique characteristics, including the number of sites and channels required to provide adequate service, initial system designs and budgetary estimates often rely on typical parameters.

Second, the results are not intended to drive the final system design, but rather to offer high-level guidance to the potential AeroMACS technology and policy development sponsors and service providers. These may include the FAA Spectrum Office, various FAA Program Offices, airlines, airports, and others.

6.2.1.1 Methodology

The flow chart in Figure 29 summarizes the categorization process as follows:

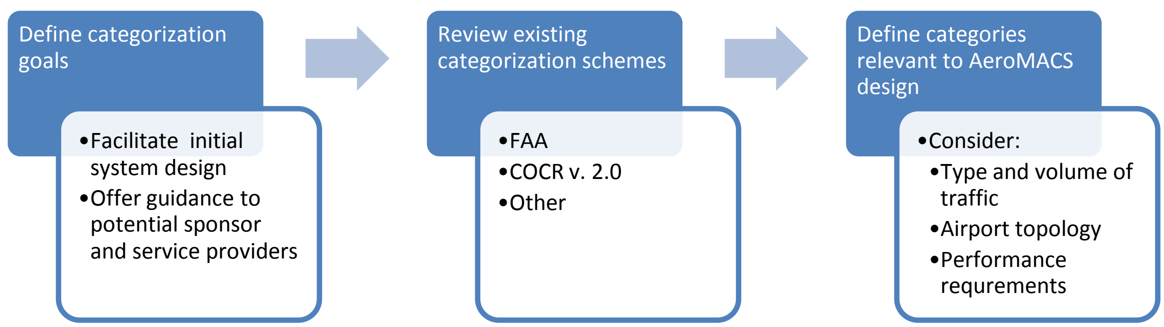

Figure 29. —Airport categorization process.

Table 23 illustrates this relationship.

TABLE 23.—MAPPING OF SYSTEM DESIGN TO AIRPORT CATEGORIZATION

System design / Airport categorization considerations	Coverage	Capacity	Quality
Type and volume of user and message traffic	Coverage objectives may differ for different types of traffic	The number of channels required will depend on the type and volume of traffic	Unexpected increase in traffic volume may cause quality to degrade
Airport topology	More BSs will potentially be required to provide coverage in non-LOS conditions	Non-LOS conditions may lead to smaller service areas of each of the BS with lower capacity requirements per BS	If not managed, frequency reuse may lower the overall S/(I+N) thus causing quality degradation.
Performance requirements	Coverage objectives may differ to support different performance requirements	Capacity objectives may differ to support different performance requirements.	Quality objectives may differ to support different performance requirements

Performance requirements were left out of the categorization process because of their dependency on services being provided.

Thus, to meet the above categorization goals, the following characteristics were considered:

- Type and volume of user traffic (i.e., potential service users)
  - How many users would be served
  - Type and volume of message traffic per user type
- Airport topology

It should also be noted that categorization was found most relevant to mobile applications. Accommodation of fixed service infrastructure within an AeroMACS design would be program dependent following point to point system architecture considerations. As such, this task focuses on categorizing airports with respect to AeroMACS enabling mobile applications only.

6.2.1.2 Existing Airport Categorization by Type of Users

Existing airport categorization schemes were reviewed to better understand the potential types of users per airport, their volume and distribution. Categories presented below are believed most relevant to the future AeroMACS operational deployment.

6.2.1.2.1 FAA Airport Categories

The United States Code (USC) defines airports by airport activities, including

- Commercial service (CS), primary and nonprimary
- Cargo service
- Reliever
- General aviation airports

Table 24 defines categories as follows:

TABLE 24.—FAA AIRPORT CATEGORIZATION

Airport classifications		Hub[a,b] type: percentage of annual passenger boardings	Common name
Commercial Service (CS): Publicly owned airports that have at least 2500 passenger boardings each year and receive scheduled passenger service §47102(7)	Primary: Have more than 10,000 passenger boardings each year §47102(11)	Large ≥ 1	Large hub
		Medium ≥ 0.25, but < 1	Medium hub
		Small ≥ 0.05, but < 0.25	Small hub
		Non-hub More than 10,000, but less than 0.05 percent	Non-hub primary
	Non-primary	Non-hub At least 2,500 and no more than 10,000	Non-primary commercial service
Non-primary (except commercial service)		Not applicable	Reliever §47102(18)

[a]The FAA's use of the term "hub airport" is somewhat different than that of airlines, which use it to denote an airport with significant connecting traffic by one or more carriers.
[b]The hub categories used by the FAA are defined in Section 40102 of Title 49 of the United States Code (USC) (2004).

The remaining airports, while not specifically defined in Title 49 USC, are commonly described as General Aviation airports. This category also includes privately owned, public use airports that enplane 2500 or more passengers annually and receive scheduled airline service.

Figure 30 presents the number of National Plan of Integrated Airport Systems (NPIAS) airports by type; Table 25 shows the percentage of enplanements, based aircraft, percentage of total development, and percentage of population within 20 miles of NPIAS airports.

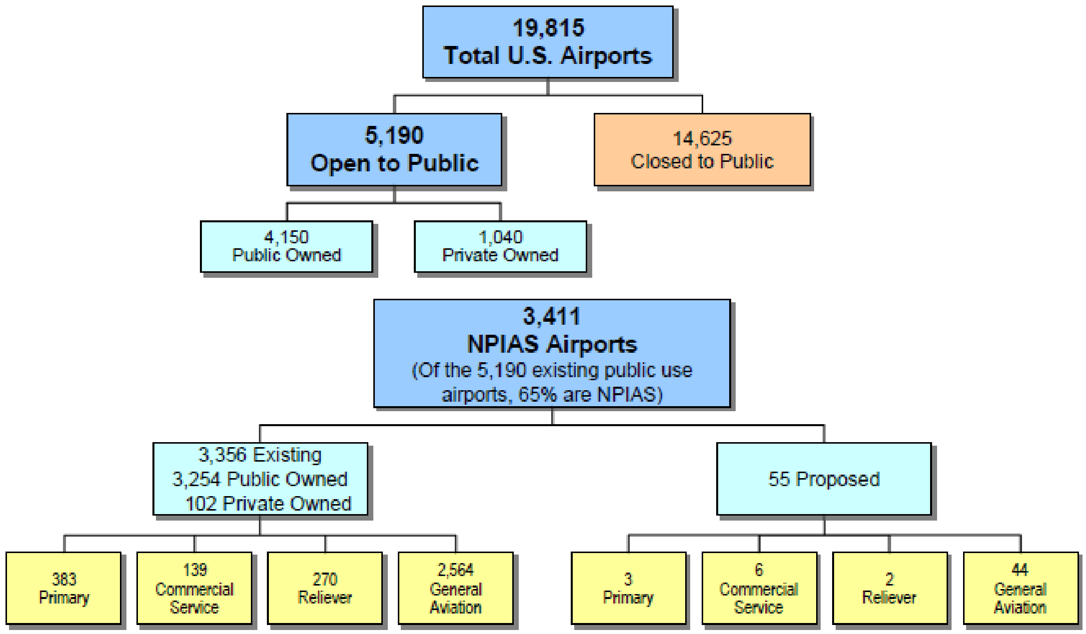

Figure 30. —Number of existing and proposed airports by ownership and use (January 2008) (Ref. 50).

TABLE 25.—AIRPORT STATISTICS (REF. 50)

Number of airports	Airport type	Percentage of 2006 total enplanements	Percentage of all based aircraft[a]	Percentage of NIPAS 2009–2013 cost	Percentage of population within 20 m of airport
30	Large hub (HB) primary	68.7	0.9	36	26
37	Medium hub (MH) primary	20.0	2.6	14	18
72	Small Hub (SH) primary	8.1	4.3	8	14
244	Non-hub primary	3.0	10.9	10	20
139	Non-primary CS	0.1	2.4	2	3
270	Relievers	0	28.2	7	56
2,564	General aviation	0	40.8	19	69
3,356	Existing NPIAS airports	99.9	89.8	100	98
16,459	Low activity landing areas (Non-NPIAS)	0.1	10.2	Not appropriate	Not calculated

[a]Based on active aircraft fleet of 221,942 aircraft in 2006.

6.2.1.2.2 COCR Airport Categorization

The COCR (Ref. 11) applies airport categorization based on number of daily operations (number of aircraft serviced in a 24-hr period) per Air Traffic Services Unit (ATSU). Phase 1 is assumed to be completed around 2020. Daily operations for Phase 2 (beyond 2020) are derived from the Phase 1 values by assuming a 2.5 percent annual growth rate over a 10-year period.

COCR High Density (HD) and Low Density (LD) airports are defined in Table 26 as follows:

TABLE 26.—DAILY OPERATIONS PER ATSU IN AIRPORT DOMAIN (APT)[a]

Density	Phase 1	Phase 2
High	1800	2304
Low	50	64

[a]APT domain is defined as an area 10 miles in diameter and up to ~5000 ft consisting of the airport surface and immediate vicinity of the airport. At this time, AeroMACS is limited to communication on the airport surface.

Additional data about the distribution of aircraft among airport air traffic control positions may also be useful when deciding on an AeroMACS site placement. Airport peak instantaneous aircraft counts (PIAC) defined in the COCR are in Table 27:

TABLE 27.—PEAK INSTANTANEOUS AIRCRAFT COUNTS (PIAC)

Airport position	Phase 1		Phase 2	
	HD	LD	HD	LD
Clearance/ramp	134	4	194	7
Ground	48	3	70	4
Tower	18	5	26	8
Total	200	12	290	19

AeroMACS is proposed to not only enable communications with aircraft, but also to support various services requiring communication with other vehicles. COCR estimated airport surface vehicle PIACs are presented in Table 28 and Table 29.

TABLE 28.—AIRPORT SURFACE VEHICLES PEAK COUNTS

APT position	Phase 1		Phase 2	
	HD	LD	HD	LD
Surface vehicles	32	4	32	8

TABLE 29.—TYPES OF SURFACE VEHICLES FOR A HD AIRPORT

Vehicle type	Number of vehicles
Buses	12
De-icing trucks	2
Snow trucks	8
Airport operations	6
Security and fire trucks	4
Total	32

Having nonaircraft data per type of airport would be very useful in estimating traffic type and volume for the related services. The numbers presented in the COCR appear to be low for most U.S. airport hubs. Additional up-to-date data should be collected at different airports and analyzed when available.

6.2.1.2.3 Additional Categorization Options

Additional airport categorization information was reviewed, such as

- Airport traffic volume and ranking provided by the Airport Council International (ACI) (Ref. 51)[15] Information is available for U.S. and international airports for
  - Total passengers: arriving + departing passengers + direct transit passengers counted once
  - Total cargo: loaded + unloaded freight + mail in metric tonnes. Data includes transit freight total
  - Movements: landing + take off of an aircraft.

- As defined by Title 14, Code of Federal Regulations (CFR) Part 139, Certification of Airports, airports are classified into four classes based on the type of air carrier operations served: (Ref. 71): Table 30 indicates the types of air carrier operations that each Part 139 airport class can serve.

  TABLE 30.—TYPES OF AIR CARRIER OPERATIONS FOR EACH AIRPORT CLASS

Type of Air Carrier Operation	Class I	Class II	Class III	Class IV
Scheduled Large Air Carrier Aircraft (30+ seats)	X			
Unscheduled Large Air Carrier Aircraft (30+ seats)	X	X		X
Scheduled Small Air Carrier Aircraft (10-30 seats)	X	X	X	

  Airport classification by the type of traffic (as noted in Section 6.2.1.2.1 above) is found more relevant to the proposed AeroMACS.

- The Airport Reference Code (ARC) "is a coding system used to relate airport design criteria to the operational and physical characteristics of the airplanes intended to operate at the airport (Ref. 38)." Accordingly, the code consists of two components combining the aircraft approach category that relates to aircraft approach speed and the airplane design group that relates to airplane wingspan or tailheight. "Generally, runways standards are related to aircraft approach speed, airplane wingspan, and designated or planned approach visibility minimums. Taxiway and taxilane standards are related to airplane design group," (Ref. 38).

  ARC categorization could be correlated with the other airport classifications. "Airports expected to accommodate single-engine airplanes normally fall into Airport Reference Code A-I or B-I. Airports serving larger general aviation and commuter-type planes are usually Airport Reference Code B-II or B-III. Small to medium-sized airports serving air carriers are usually Airport Reference Code C-III, while larger air carrier airports are usually Airport Reference Code D-VI or D-V" (Ref. 52).

  The ARC is found less applicable to AeroMACS than the USC system. AeroMACS is proposed to enable communication with the airport surface vehicles other than aircraft. Correlation of the ARC categories to vehicle volume and traffic would be too complex and not practical.

[15] Ranking only includes airports participating in the ACI annual stats collection.

6.2.1.3 Categorization of Airports Based on Airport Topology

Two often competing AeroMACS design objectives are (1) providing adequate RF coverage and (2) meeting the message traffic demand. System quality and end user perception of the service depend on both of these criteria.

An initial effort was made to group airports with similar coverage and capacity design characteristics to determine the following system parameters:

- Number of BS
- Number of sectors per BS[16]
- Number of channels per sector
- Total number of channels per airport

This process is described in the following paragraphs.

6.2.1.3.1 Coverage Design

Although coverage and capacity analyses and design are interrelated, typically coverage design is done first. AeroMACS coverage design will affect placement of the BSs as well their number and configuration (number of sectors per BS).

The final coverage requirements will depend on the services to be enabled by the communications system. This analysis is service independent and might assume that both movement and nonmovement areas are supported. Only outdoor coverage is considered, excluding indoor areas, for example baggage areas and terminals that may be of potential interest to airlines. Indoor coverage needs to be considered and designed on a case-by-case basis.

In general, coverage design will depend on the size of the airport (total area to be covered) and propagation environment. Propagation characteristics will vary between relatively open and dense areas. Dense areas can be defined as those with dense manmade obstructions and/or added complexity from the surrounding environmental characteristics (e.g., to account for terrain-challenged airports like Juneau, Alaska). Additionally, accounting for the orientation of the runways, apron structure shapes, and relative position of buildings on an airport surface allows categorizing airport environment based on different multipath propagation characteristics.

Various CS airport layouts were analyzed by reviewing the FAA airport diagrams and aerial view photos. Multiple runway designs were identified, including parallel, crossing, V-shaped, and mixed. Terminal locations could be grouped by their location relative to runways, for example, “in-between,” “along one side,” or “in one corner.” Apron structure shapes included “snowflake,” “grid,” “star,” and others. Airports can be grouped based on these characteristics. Appendix D shows two examples of such characterization.

It is possible to create a sample design using a propagation prediction tool for at least one airport in each of the above categories. This would provide a good estimate of the number of BSs needed to cover an airport to allow for a more accurate budget planning. However, this approach is most accurate for systems consisting of a large number of sites. The number of AeroMACS BS sites to provide total surface coverage will likely vary between one and five per airport. Depending on the criticality and availability requirements of services provisioned at some airports, two BSs may be the lower limit.

It is more practical to estimate the number of BSs based on test data from existing airport implementations. At this time, design data is available for one airport only: Cleveland Hopkins International (CLE). The ITT AeroMACS Prototype implemented in the NASA CLE CNS Test Bed

[16]A typical configuration for a busy airport may include three sectors per BS; six sectors per BS is a maximum practical configuration.

consists of 2 BSs. An estimated coverage radius for BS is 1.5 km.[17] The largest dimension of the CLE airport is about 3.5 km.

When an average coverage radius is known, the number of BSs can then be estimated by dividing the total area to be covered by a typical coverage area provided by each of the BSs in the respective environment. This calculation assumes that BSs are located inside (i.e., not on the edge) of coverage areas and are evenly distributed throughout the service area. Placing BS at the edge of the desired coverage area may increase the total number of stations required.

Omni or directional antennas will typically be deployed, with directional antennas likely used when sites are located at the edge of the service area. Sectored BSs with directional antennas may also be deployed to support higher capacity demand.

The actual number of sites will vary depending on antenna location. If antennas are placed above the clutter (i.e., on the tallest building or on a tower), propagation would approach free-space characteristics and fewer sites may be needed. The number of BSs and the height above the surface and structures will be adjusted accordingly for each airport during the design phase.

The number of BSs required will also depend on services provided and on other factors, such as the availability requirements.

6.2.1.3.2 Capacity Design

Both FAA and COCR categorization approaches reflect the potential traffic loading at an airport. Capacity planning, however, will largely depend on the services enabled by an AeroMACS.

In general, system design can be either coverage or capacity driven as illustrated in Table 31.

TABLE 31.—CORRELATION BETWEEN COVERAGE AND CAPACITY DESIGN

Capacity \ Coverage	Open Propagation Characteristics	Complex Propagation Characteristics
Higher demand	A	B
Lower demand	C	D

Capacity Driven (Higher demand row)

Coverage Driven (Complex Propagation Characteristics column)

A design for a “complex” propagation environment airport will be coverage driven, i.e., the number of BSs needed to provide adequate coverage may be sufficient to support capacity demands. On the other hand, an “open” airport may require additional sites and/or additional sectors at a site to provide sufficient capacity when traffic volume is high.

As capacity demand depends on the services being provided, channel requirements per BS would vary. Depending on the number of channels available to an airport, for the airports with high capacity demands, frequencies may need to be reused within an airport. A complex propagation environment allows for a closer frequency reuse without degrading quality. The total number of channels needed would also depend on the required frequency separation between different services.

6.2.1.4 Airport Categorization for AeroMACS

In addition to coverage and capacity considerations, a business plan and cost of the proposed system will play an integral role in defining airport categories.

[17]Based on measurements for a 90 degrees sector, 100 mW power. The extend of coverage will differ for different coverage objectives (target QPSK) or if power is changed

General Aviation is the largest type of airport in the U.S. system. This statistic demonstrates that categories should not be limited to the CS Hubs, as this would exclude a significant number of airports that could potentially implement AeroMACS.

Smaller airports may be interested in attracting new customers by offering additional services. A business plan will address if these services could be enabled by AeroMACS and offer sustainable financial benefits to an airport.

Airports with less FAA presence may have different goals and resources than large hubs with extensive FAA presence. While FAA interest in an AeroMACS may be limited, opportunities for other sponsorships could open up.

The level of existing communication services at an airport needs to be taken into account. A business plan will take under consideration whether the purpose of AeroMACS is to augment existing services or provide a green field solution.

Airport categorization used by the FAA was found most pertinent to this task because it relates to both aspects of categorization— traffic type and volume—and geographical size. Table 32 below summarizes some of the guidelines to be applied to each group of airports using the FAA categories as a basis.

TABLE 32.—PROPOSED AEROMACS AIRPORT CATEGORIES

FAA Airport Category	Potential AeroMACS Users[a]	Potential AeroMACS Architecture	Comments and Guidelines
Large Hub (LH) Primary	FAA, airports, airlines, other service providers. Aircraft; other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks, food service and baggage carts	More than 2 sectored BSs. Number of channels per BS depending on applications	AeroMACS may be used for air to ground communication as well as for the use of service vehicles on airport surface. LHs concentrate on airline passenger and freight operations and offer limited general aviation use. LHs have the greatest delays of all CS airports, which may lead to aircraft spending more time in the airport, potentially increasing capacity requirements to support air to ground communication in this domain.
Medium Hub (MH) Primary	FAA, airports, airlines, other service providers. Aircraft; other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks, food service and baggage carts	2[b] sectored BSs Number of channels per BS depending on applications	AeroMACS may be used for air to ground communication as well as for the use of service vehicles on airport surface. Unlike LHs, MHs support a substantial amount of general aviation traffic in addition to carrier aviation. A business plan would target both categories, together or separately.
Small Hub Primary	FAA, airports, airlines, other service providers. Aircraft; other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks, food service and baggage carts	1-2[b] BSs Number of channels per BS depending on applications	AeroMACS may be used for air to ground communication as well as for the use of service vehicles on airport surface. Less than 25% of runway capacity is used by airline operations supporting many general aviation activities, making AeroMACS less attractive to airlines. Business plan may need to target AeroMACS for general aviation use.
Non-hub Primary	FAA, airports, other service providers. Aircraft; other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1-2[ba] BSs Number of channels per BS depending on applications	AeroMACS may be used for air to ground communication as well as for the use of service vehicles on airport surface. Heavily used by general aviation with enplaning less than 0.05 percent of all commercial passenger enplanements

TABLE 32.—PROPOSED AEROMACS AIRPORT CATEGORIES

FAA Airport Category	Potential AeroMACS Users[a]	Potential AeroMACS Architecture	Comments and Guidelines
Non-primary CS	Airports, FAA, other service providers. Aircraft; other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1[b] BS Number of channels per BS depending on	Used mainly by general aviation potentially making AeroMACS less relevant to the FAA.
Relievers	Airports, FAA, other service providers. Aircraft; other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1[b] BS Number of channels per BS depending on	Specialized airports providing pilots with attractive alternatives to using congested hubs. Have a significant number of based aircraft. AeroMACS may enable services to attract more users to a particular airport.
General Aviation	Airports, other service providers. Aircraft; Other vehicles, including buses, de-icing, snow removal trucks, security and fire trucks	1[b] BS Number of channels per BS depending on	Often located in rural areas. With limited existing communication infrastructure at some airports, AeroMACS may offer a green-field solution. AeroMACS may enable services to attract more users to a particular airport.
Low Activity Landing Areas (Non-NPIAS)	AeroMACS business case might not be supportable		

[a] Further granularity can be achieved, if desired, by collecting and or obtaining statistics from the FAA or the airlines for different airport surface vehicles to quantify the potential users.
[b] More BSs may be required to provide indoor coverage

Guidelines presented in this section are based on system engineering judgment and the results of the tests performed within the AeroMACS Prototype. The fidelity of these recommendations will increase as new data becomes available, both policy and technical, related to practical implementations of AeroMACS.

Results of the work being performed by RTCA to better define services to be supported by AeroMACS will affect many of the categorization considerations presented here.

Additional research, for example, traffic analysis being conducted by Continental Airlines to estimate VoIP requirements and potential data rate needs based on current traffic volume (in Erlangs), may be useful in estimating the design parameters per category, such as the number of channels per BS.

6.2.2 Channelization Methodology

Channelization is the process of segmenting the available AMR(S) spectrum of 5091 to 5150 MHz, with possible additions, to allow multiple independent applications or services to operate simultaneously on the airport surface. Channelization will provide for channel bandwidths of 5 MHz and possibly 10 MHz, as allowed by the AeroMACS profile.

A channelization plan ensures that a large set of requirements are met with services potentially supplied by multiple service providers. A common global channelization methodology is needed to assure seamless interoperability with ground-based and A/G services.

A channelization methodology is constrained by the potential for multiple categories of service and multiple service providers. Three distinct categories of service exist: air traffic control, airline, and airport operations.

Although a channelization methodology plan can be defined to a certain degree by analysis of technical factors, the final plan will be determined by FAA policy decisions regarding segregation of service traffic and service provider business plans. The discussion in Section 6.2.2.2.1 addresses the FAA policy of segregating the transport of Air Traffic Operations traffic.

6.2.2.1 Channelization Study Overview

The following sections provide an assessment of the factors and constraints that determine the channelization plan. The analysis followed the study map in Figure 31. Each engineering study (ES) shown in the figure is discussed in a subsequent section of this report.

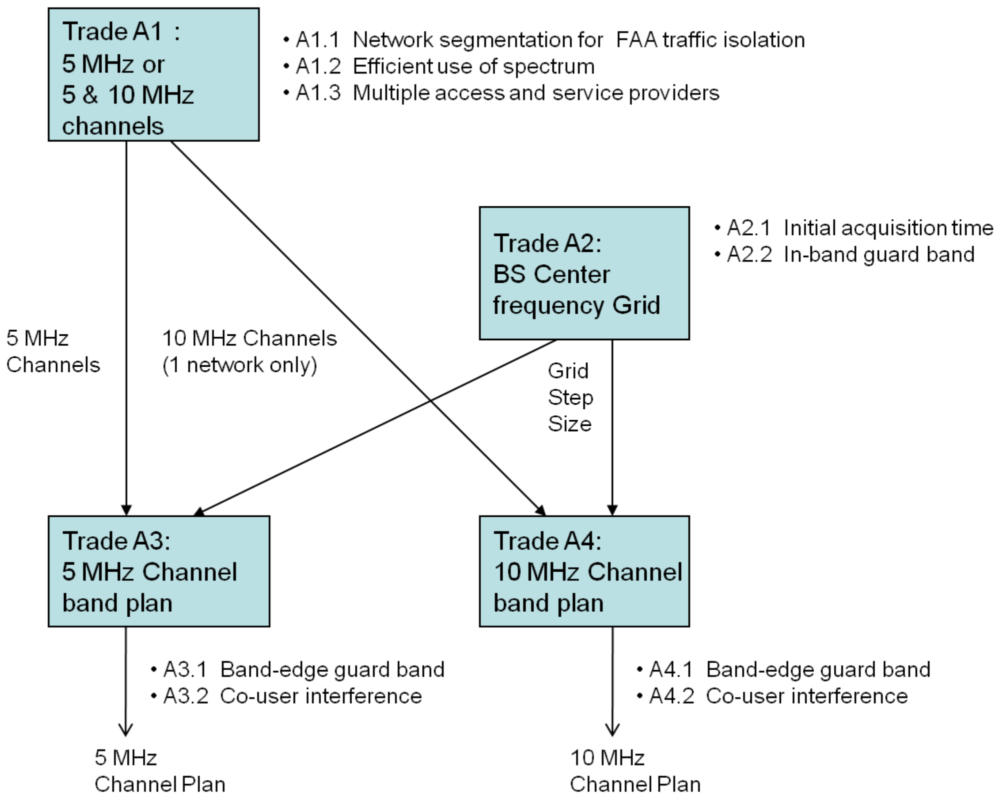

Figure 31.—Channelization trade study map.

6.2.2.2 Channel Bandwidth Studies

6.2.2.2.1 Network Segmentation (ES1.1)

The FAA has an interest in using AeroMACS to expand existing G/G fixed operational telecommunications capabilities and is also considering a number of A/G applications. Government and FAA policies could have a large impact on the architectures of AeroMACS networks that will support the Air Traffic Control (ATC), airline, and airport operations user domains.

The FAA policy of not allowing use of FAA telecommunications resources for non-Governmental functions, if implemented for AeroMACS, will prevent the use of a single integrated AeroMACS network that supports all three user domains. Instead, a separate and isolated network will be required for the support of FAA applications. Besides the obvious costs of duplicate hardware and maintenance to support multiple AeroMACS networks, such a policy will have an impact on the allocation of AM(R)S spectrum.

The FAA policy that requires network separation is FAA Order 1379.95—WAN Connectivity Security (09/12/2006). This order requires FAA to maintain separation between FAA and non-FAA networks.

The installation of two isolated networks will require that both be accommodated within the AM(R)S band. The use of 5-MHz channels, for example, provides 10 to 11 channels within the 59 MHz AM(R)S band. The channelization plan could allocate five channels to a FAA network and five channels to a non-FAA network.

The amount of signal power that is radiated at an airport is also impacted by the number of networks installed, which increases the potential for interference with co-users of the AM(R)S band. Dual networks will increase the total radiated power at an airport and thereby will increase the interference level. Co-user interference is discussed in Section 6.2.2.4.2

The decision whether to restrict use of an AeroMACS network to Government functions exclusively is a policy decision that currently has not been made at this date. Both a single network case for shared services and a dual-network case for isolated FAA services will be considered in this study.

6.2.2.2.2 Efficient Use of Spectrum (ES1.2)

Efficient use of the allocated AM(R)S band from 5091 to 5150 MHz will depend on the width of channel that is assigned to the BSs in the initial system design of the airport network. This section will examine the degree of efficiency for AM(R)S band utilization for 5- and 10-MHz channel bandwidths.

All BSs within an AeroMACS network must be configured to operate at the same bandwidth. The 59 MHz-wide AM(R)S band will support up to 11 channels with 5-MHz channel bandwidth. The actual allowable number of channels may be less than 11 because of in-band and band-edge guard bands as discussed in later sections. The algorithm for calculating the number of channels is Equation (1), where the integer value is taken of the spectrum bandwidth divided by the channel bandwidth.

$$\text{No. channels} = \text{integer}[(5150 - 5091)\ \text{MHz} / 5\ \text{MHz}] = 11\ \text{channels} \quad (1)$$

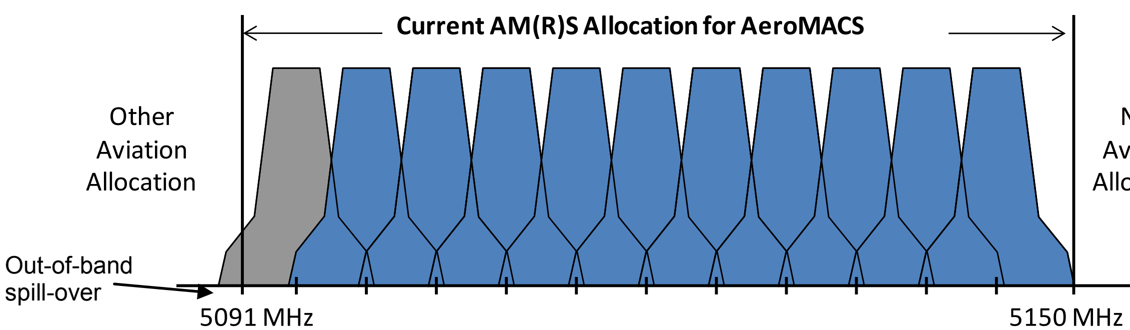

Figure 32.—Notional channel allocation for 5-MHz bandwidth.

Assignment of eleven 5-MHz channels is illustrated notionally in Figure 32 for the condition that no guard band is needed between channels. Channel center frequencies are placed on 5-MHz increments in frequency beginning at 5095 MHz. The uppermost channel is centered at 5145 MHz, which provides a 2.5 MHz guard band at the upper AM(R)S band edge. The lowest channel, centered at 5095 MHz, provides a more limited guard band and may not be allowable as discussed in Section 6.2.2.4.1. The portion of unused AM(R)S band is analyzed in Table 33 for an 11-channel assignment:

TABLE 33.—ANALYSIS OF AM(R)S BAND USAGE FOR 5-MHZ CHANNELS

Lower band edge	Calculation	
	5095.0 MHz –2.5 MHz –5091.0 MHz = 1.5 MHz	Lowest channel center frequency ½ channel bandwidth AM(R)S lower band edge Band-edge guard band
Upper band edge	5150.0 MHz –2.5 MHz –5145.0 MHz = 2.5 MHz	AM(R)S upper band edge ½ channel bandwidth Highest channel center frequency Band-edge guard band

The use of eleven 5-MHz channels and a 2.5-MHz band-edge guard bands provides full use of the AM(R)S band with some spill-over into the lower aviation band. If ten 5-MHz channels are used instead, 4.0 MHz of the AM(R)S band will be unused.

A notional channel assignment for 10 MHz channels is shown in Figure 33. The 59 MHz-wide AM(R)S band will support up to five channels when all channels have a 10 MHz bandwidth. The algorithm for calculating the number of channels is provided in Equation (2), where the integer value is taken of the spectrum bandwidth divided by the channel bandwidth.

$$\text{No. channels} = \text{integer}[(5150 - 5091)\ \text{MHz}\ 10\ \text{MHz}] = 5\ \text{channels} \tag{2}$$

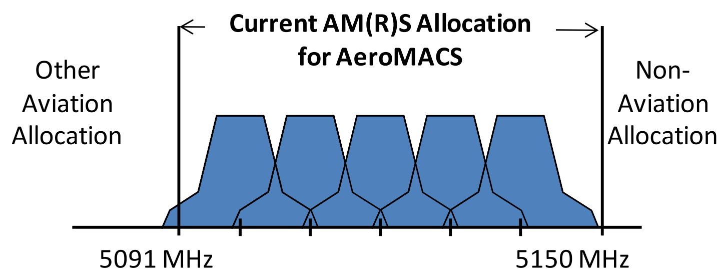

Figure 33. —Notional channel allocation for 10-MHz bandwidth.

An analysis of the use of 10-MHz channels in the AM(R)S band is given in Table 34.

TABLE 34.—ANALYSIS OF AM(R)S BAND USAGE FOR 10-MHZ CHANNELS

Lower band edge	Calculation	
	5100.0 MHz –5.0 MHz –5091.0 MHz = 4.0 MHz	Lowest channel center frequency ½ channel bandwidth AM(R)S lower band edge Band-edge guard band
Upper band edge	5150.0 MHz –5.0 MHz –5140.0 MHz = 5.0 MHz	AM(R)S upper band edge ½ channel bandwidth Highest channel center frequency Band-edge guard band

The use of five 10-MHz channels and a 2.5-MHz band-edge guard bands effectively means that 4 MHz of the AM(R)S band is unused for information channels or band-edge guard bands. Comparing 3.5 MHz of unused AM(R)S band for 10-MHz channels to full use for eleven for 5 MHz channels leads to the conclusion that 10 MHz channels provides a less-efficient use of the 59-MHz AM(R)S band allocation.

6.2.2.2.3 Multiple Service Providers (ES1.3)

The WiMAX Network Reference Architecture provides a flexible framework that can accommodate a variety of AeroMACS deployment scenarios. Network architectures for single or multiple network access providers (NAPs) and single or multiple network service providers (NSPs) are accommodated in the framework.

Relationships between NAPs and NSPs and the assignment of network functions at a single airport are illustrated in Figure 34. Multiple NAPs could be implemented in an AeroMACS network for the purpose of isolating types of traffic. For example, one NAP could be implemented to handle critical ATS data with a second NAP handling less critical traffic for AOC and airport operations. Base station hardware, ASN gateway server hardware and software, and spectrum allocations are required to implement each NAP. Spectrum bandwidth limitations make greater than two NAP installations per airport impractical for multisector BS installations.

Having multiple NSPs at an airport is more practical to implement in term of resources because instantiation of a NSP requires a CSN server and software and can be served by a single NAP. NSPs can be responsible for differing applications. However, the multiple NSPs will need to respond to overall policies for service provisions and QoS assignments. These policies would presumably be established by FAA.

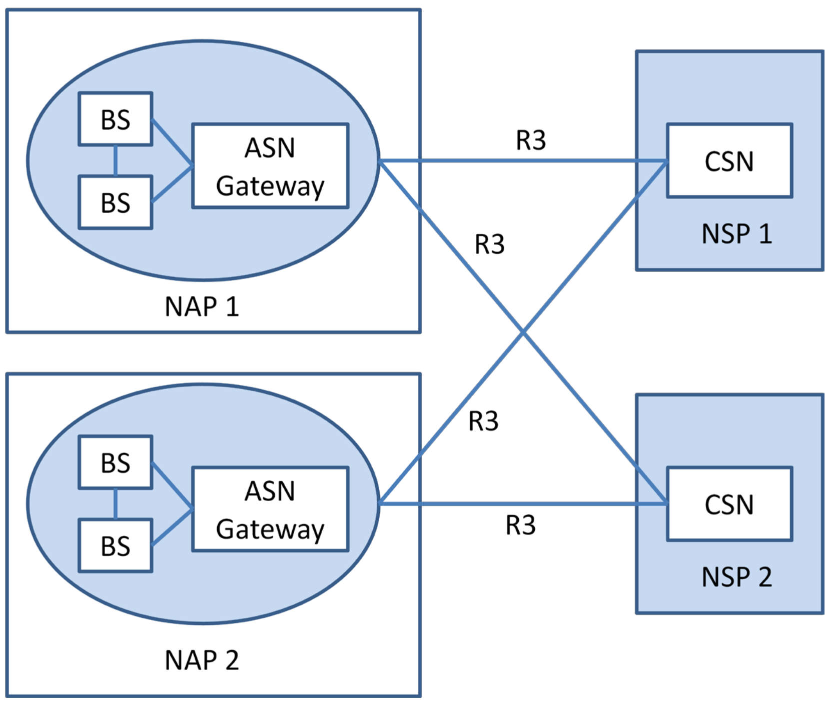

Figure 34.—Network access provider (NAP) and network service provider (NSP) network sharing.

6.2.2.3 Channel Center Frequency Grid (ES2.1)

Two significant factors will be analyzed for their effect on channel center frequency assignments. First, the center frequency step size will be studied because a small step size could cause large acquisition times when a SS first enters a network as discussed in Section 6.2.2.3.1. Secondly, the use of a guard-band between channels, if needed, will shift channel center frequencies as discussed in Section 6.2.2.3.2.

6.2.2.3.1 Impact on Initial Network Acquisition Time (ES2.2)

The number of allocated channel center frequencies will have an effect on the time required for a SS to initially join a new network. Acquisition time is important, for example, when an aircraft lands at an airport and begins the authentication process to join the local AeroMACS network. The process of initial network discovery and authentication and the impact of the channel center frequency planning on acquisition time will be examined in this section. The process of joining a network in which a SS must discover the local services and be authenticated and authorized for service is illustrated in Figure 35 (Ref. 75). The process begins with an initial frequency scan to discover the base station channels that are available. Because the center frequency assignments of base station channels will vary by airport, a SS will begin by scanning through the AM(R)S band to detect BS channel assignments.

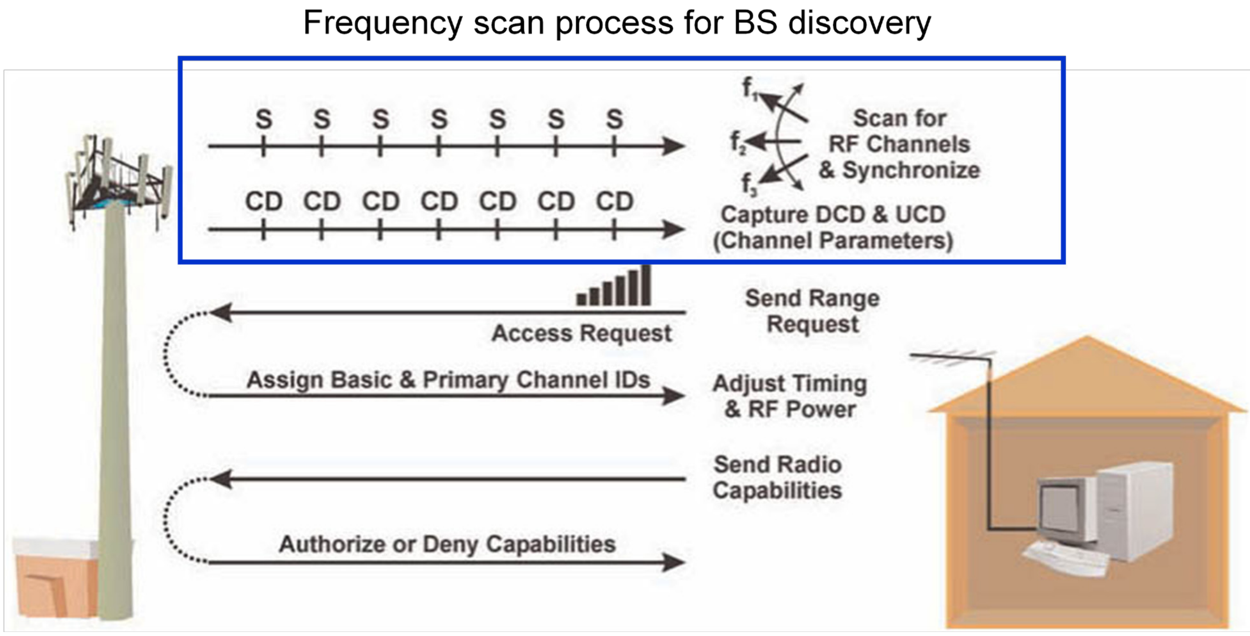

Figure 35.—IEEE 802.16 channel acquisition and initial ranging.

The IEEE 802.16–2009 standard defines that a SS will maintain a preprogrammed table of channel center frequencies to scan during this initial discovery. The method of using the scan table is not fully defined in the standard, but is left to the equipment manufacturer to design the scan method according to market needs. The algorithm for this scan is therefore dependent on manufacturer's choices.

The AeroMACS hardware implemented in the NASA-Glenn AeroMACS Prototype implements a scan algorithm that is hard-programmed within a COTS chipset. This algorithm implements the following steps:

(1) When a frequency scan round begins, the SS performs power measurements on each frequency that is pre-configured in the SS scan table. This process takes 10ms per frequency.
(2) If any energy is detected, the SS tries to acquire a MAP within the downlink frame in 3 frequency offsets per each center frequency (F, F–10.9 KHz, F+10.9 KHz). This process takes at least 530 ms per each frequency offset.
(3) If a valid BTS ID is detected, the SS will attempt access into the network at two frequency offsets (best 2 out of the above 3 spots). Each requires up to an additional 1300 ms to get establish a link (depending on the preamble samples it needs to collect).

As a conclusion, if the frequency is free (there is energy but not a valid BTS active) the scanning process takes 10 + 3×530 = 1.6 sec, and if a BTS has been detected on that frequency the process takes 10 + 3×530 + 2×1300 = 4.2 sec.

The IEEE 802.16–2009 standard requires that the SS be capable of frequency steps in 250-kHz increments. The step size during acquisition scan is determined by the frequency scan table that is programmed in the SS at the time of operational deployment.

Table 35 illustrates the impact of frequency step size, as implemented in the SS frequency scan table, for two step sizes. The 250-kHz step size represents the smallest step size supported by the standard. The 5-MHz step size, representing a large step, corresponds with the BS step size for COTS equipment that is available for the 5-GHz WirelessHUMAN market. The initial acquisition scan time is calculated for the algorithm described above for both step sizes. The frequency scan step size of 250 kHz results in a nominal scan time of 6 minutes, 18 seconds. A step size of 5 MHz allows the scan to nominally complete in 18 seconds. This illustrates the importance of a well planned frequency scan table.

For the reasons discussed, a step size of 5 MHz is recommended for AeroMACS to minimize the time for an aircraft SS unit to access a network upon arrival at an airport. A 5-MHz step size also maintains compatibility with the COTS market segment. A standardized frequency scan table is needed for global deployment to minimize the time for a mobile SS to acquire a new network.

TABLE 35.—ANALYSIS OF AQUISITION TIME

Fstep = 250 kHz Analysis	Fstep = 5 MHz Analysis
# steps = int{(5150 – 5091)MHz/250 kHz} = 236 steps	# steps = int{(5150 – 5091)MHz/5 MHz} = 11 steps
Acquisition scan time = 236 * 1.6 s = 378 s => 6 minutes, 18 s	Acquisition scan time = 11 * 1.6 s = 18 s

6.2.2.3.2 In-band Frequency Guard Band

In-band guard bands are frequency separations between edges of channels that are used to reduce cross-channel interference. Each 5 or 10 MHz AeroMACS channel will have transmitter energy that falls outside of the intended channel. This out-of-channel energy can cause interference in adjacent channels. Separating the channels with guard bands will reduce the level of cross-channel interference and in turn will lower packet error rates.

The use of in-band guard bands is undesirable for a number of reasons. First, their use will reduce the number of channels that can be allocated within the 59 MHz of AM(R)S spectrum. Second, the minimum guard bandwidth is 5-MHz for a system that is compliant with WirelessHUMAN standard for 5-GHz unlicensed bands. In addition, several methods to mitigate cross-channel interference are already built into the IEEE 802.16 standard and can be implemented with proper system design.

The standard implements cross-channel interference reduction through use of subcarrier suppression at channel edges. This edge suppression forms a guard band without purposely allocating an additional guard-band separation between channels. This section investigates the need for in-band guard band allocations that are in addition to what is implemented in the standard.

The overlap of adjacent channels is illustrated in Figure 36. The amount of energy that is radiated outside of a channel is defined by the spectral mask. This radiated energy will cause interference with adjacent channels if not adequately controlled.

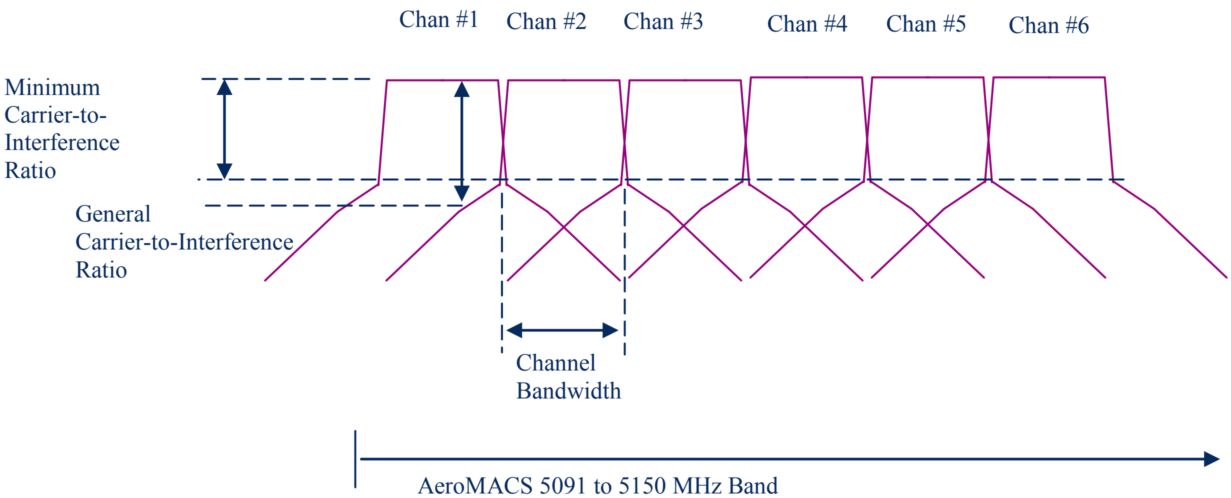

Figure 36.—Adjacent channel spectrum overlap.

The spectral mask recommended for AeroMACS is taken from Federal Communications Commission (FCC) part 47 paragraph 90.210 (Ref. 54). The AeroMACS spectrum mask requirement is based on "mask m" from paragraph 90.210 for all power levels authorized for the AeroMACS service. The power spectral density of the emissions must be attenuated below the output power of the transmitter as follows:

(1) On any frequency removed from the assigned frequency between 0 to 45% of the authorized bandwidth (BW): 0 dB.
(2) On any frequency removed from the assigned frequency between 45 to 50% of the authorized bandwidth: 568 log (%of (BW)/45) dB.
(3) On any frequency removed from the assigned frequency between 50 to 55% of the authorized bandwidth: 26 + 145 log (% of BW/50) dB.
(4) On any frequency removed from the assigned frequency between 55 to 100% of the authorized bandwidth: 32 + 31 log (% of (BW)/55) dB.
(5) On any frequency removed from the assigned frequency between 100 to 150% of the authorized bandwidth: 40 + 57 log (% of (BW)/100) dB.
(6) On any frequency removed from the assigned frequency between above 150% of the authorized bandwidth: 50 dB or 55 + 10 log (P) dB, whichever is the lesser attenuation.
(7) The zero dB reference is measured relative to the highest average power of the fundamental emission measured across the designated channel bandwidth using a resolution bandwidth of at least one percent of the occupied bandwidth of the fundamental emission and a video bandwidth of 30 kHz. The power spectral density is the power measured within the resolution bandwidth of the measurement device divided by the resolution bandwidth of the measurement device. Emission levels are also based on the use of measurement instrumentation employing a resolution bandwidth of at least one percent of the occupied bandwidth.

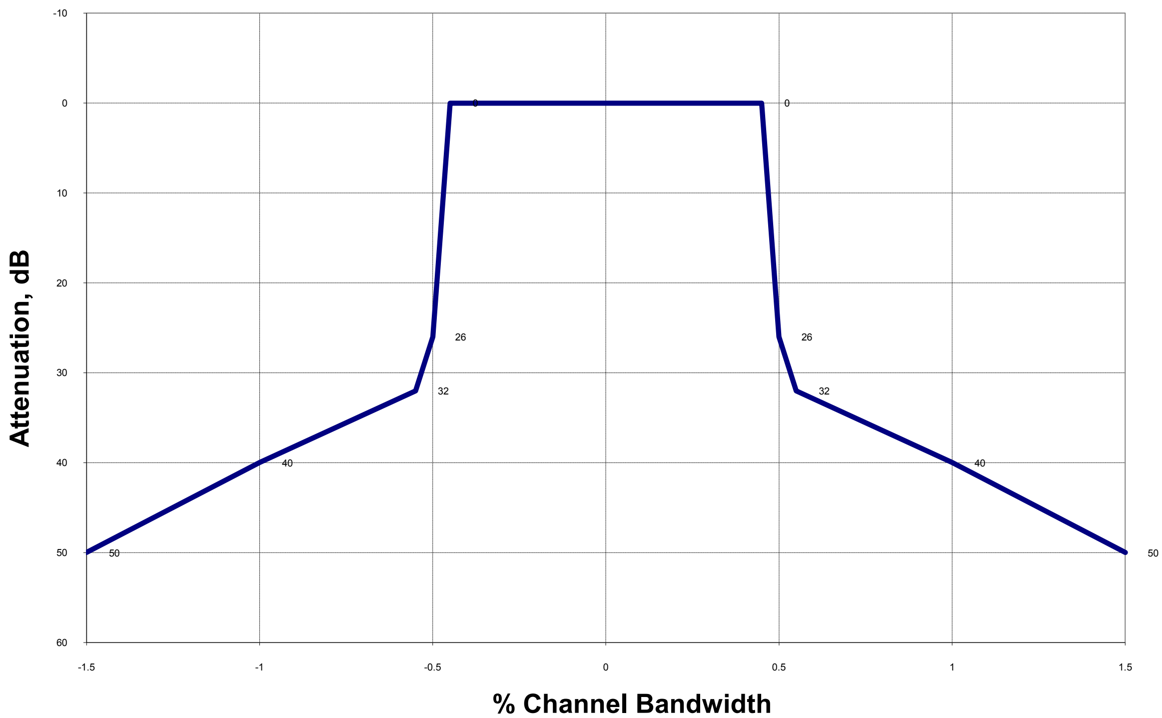

Figure 37.—FCC part 47 paragraph 90.210 Mask m.

Mask m attenuation is plotted graphically as percentage of bandwidth in Figure 37.

The amount of adjacent channel protection built into the IEEE 802.16–2009 standard on which AeroMACS is based can be analyzed using this spectral mask and properties of the AeroMACS channel defined by the standard. The standard requires that a certain number of subcarriers in the waveform be suppressed at the band edges. The number of suppressed carriers and their equivalent bandwidth are listed in Table 36 for 5- and 10-MHz channel bandwidths.

TABLE 36.—ANALYSIS OF AEROMACS CHANNEL PROPERTIES

Channel bandwidth	Number of lower subcarriers suppressed	Number of upper subcarriers suppressed	Allocated guard band, lower, MHz	Allocated guard band, upper, MHz	Channel-to-channel total guard band, MHz
5 MHz	46	45	0.503	0.492	0.996
10 MHz	92	91	1.006	0.996	2.002

The built-in guard band defined in the standard is 10 percent of the channel bandwidth at the upper and lower ends of each channel. The adjacent channel signal is suppressed by the spectrum mask at the closest subcarrier of the adjacent channel as follows:

(1) First adjacent carrier is removed from lower channel center frequency by 60 percent of channel bandwidth.
(2) First adjacent carrier falls in the range of 55 to 100 percent of the channel bandwidth
(3) Mask attenuation = 32 + 31 log (% of (BW)/55) dB = 33.2 dB

The spectral mask therefore provides greater than 32 dB of attenuation at the first subcarrier of an adjacent channel. This is the minimum attenuation that is expected for two reasons. First, the mask continues to increase attenuation as the frequency of separation increases. Secondly, a sectorized base station will increase attenuation for an adjacent channel because of pattern roll-off as illustrated in Figure 38. A SS at position 1 that is associated with BS sector 1 and transmitting at frequency F1, for example, will cause reduced adjacent-channel interference with BS sector 2 at frequency F2 because of pattern roll-off. Position 2 is a worst-case location because the adjacent sector antenna gain is its highest before the SS would be handed over to the adjacent sector.

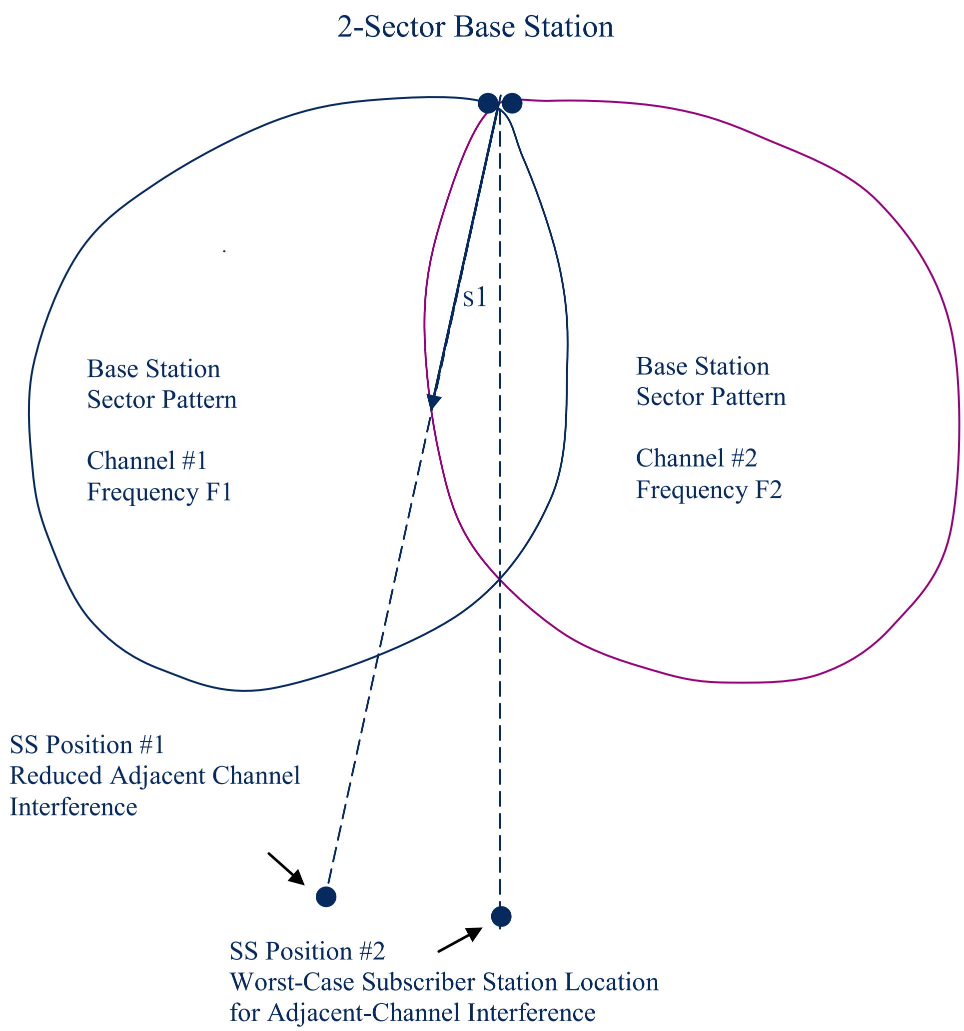

Figure 38.—Base station sector effects on adjacent channel interference.

The carrier-to-interference and noise (CINR) ratio required to support the highest modulation rate of QAM-64, FEC 3/4, is listed as 31.45 dB in Table 308 of the IEEE 802.16–2009 standard. Spectral mask attenuation of 32 dB at the first carrier of adjacent channels marginally support this requirement with no additional guard-band spacing added between channels.

The utility of in-band guard bands was tested in the NASA-Glenn AeroMACS Prototype. Results of this evaluation are in Section 3.2.3 of Volume II of this report.

6.2.2.4 Band Plan Studies

6.2.2.4.1 Band-Edge Guard Band (ES3.1, ES4.1)

RF emissions that spill outside of a channel bandwidth have the potential to cause interference to non-AeroMACS users and to services in frequency bands that are adjacent to the AM(R)S spectrum. A spectral mask describes the channel-edge roll-off characteristics of a transmitter and can be used to assess potential out-of-band interference issues.

All wireless local area networks (LANs) operate in the United States as part of the unlicensed National Information Infrastructure devices under FCC Part 15, Subpart E. Most of these devices require that emissions outside of the authorized band not exceed –27 dBm/MHz

A 100 mW AeroMACS transmitter set to 5 MHz channel bandwidth, for example, has a radiated power of 20 dBm across 5 MHz, which is equivalent to 13 dBm/MHz The required out-of-band attenuation to be controlled by the spectrum mask is therefore ≥40 dB in order to not exceed –27 dBm/MHz. Similarly, the spectrum mask attenuation must be ≥37 dB for 10 MHz channel bandwidth.

The spectral mask recommended for use with AeroMACS conforms to the requirements of FCC part 47 paragraph 90.210. The AeroMACS spectrum mask requirement is based upon mask m from paragraph 90.210 as described in Section 6.2.2.3.2.

Mask m provides an attenuation of 26 dB at 50 percent of channel bandwidth, which corresponds with the edge of a channel. Since ≥40 dB of attenuation is required in order to not exceed –27 dBm/MHz for 5 MHz channel bandwidth, an additional band-edge guard band will be required. Attenuation ≥40 dB is provided by mask m at 100 percent of bandwidth. The channel edge must therefore be placed at least 2.5 MHz away from the AM(R)S band edge for 5 MHz channels.

Band-edge guard band allocations will be needed for 10 MHz channel width since ≥37 dB of attenuation is required in order to not exceed –27 dBm/MHz. Mask m provides 37 dB of attenuation at 80 percent of bandwidth. Therefore, the channel edge must be placed at least 3.0 MHz away from the AM(R)S band edge for 10 MHz channels.

Mask m is illustrated in Figure 39 for a 5-MHz channel bandwidth. The 40-dB attenuation point is marked at 5 MHz above the channel center frequency and 2.5 MHz above the channel edge. The out-of-band emissions limit will be met with mask m when the channel center frequency is placed at least 5 MHz away from a band edge and the transmitter power is limited to 100 mW or less.

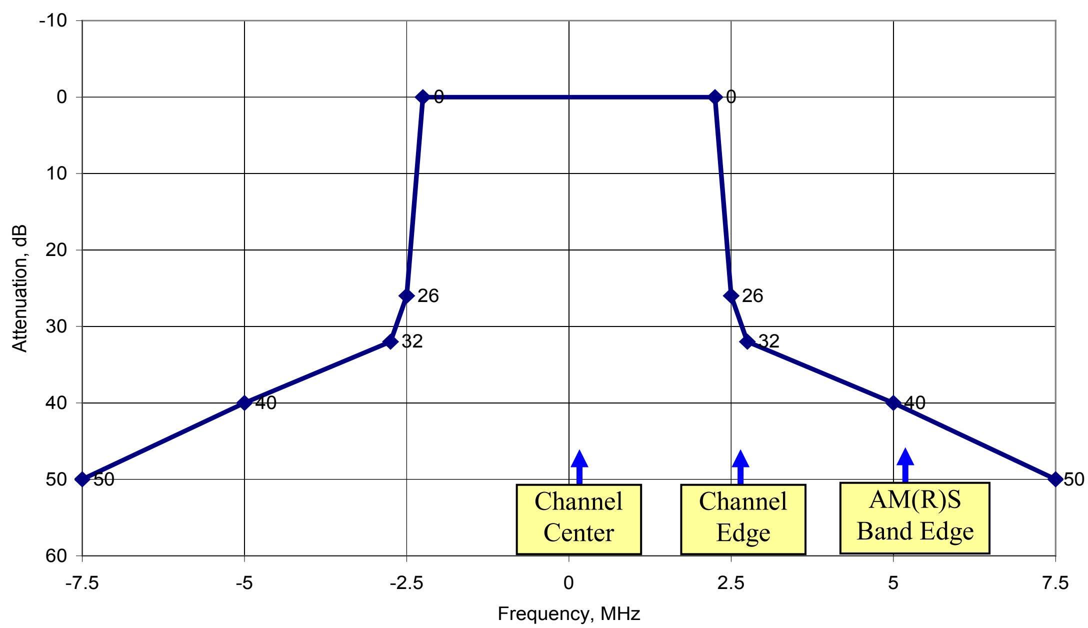

Figure 39.—FCC part 47 paragraph 90.210 mask m for 5-MHz channel bandwidth.

Mask m is illustrated in Figure 40 for a 10-MHz channel bandwidth. 37 dB of attenuation is marked at 8 MHz above the channel center frequency and 3 MHz above the channel edge. The out-of-band emissions limit will be met with mask m when the channel center frequency is placed at least 8 MHz away from a band edge, and the transmitter power is limited to 100 mW or less.

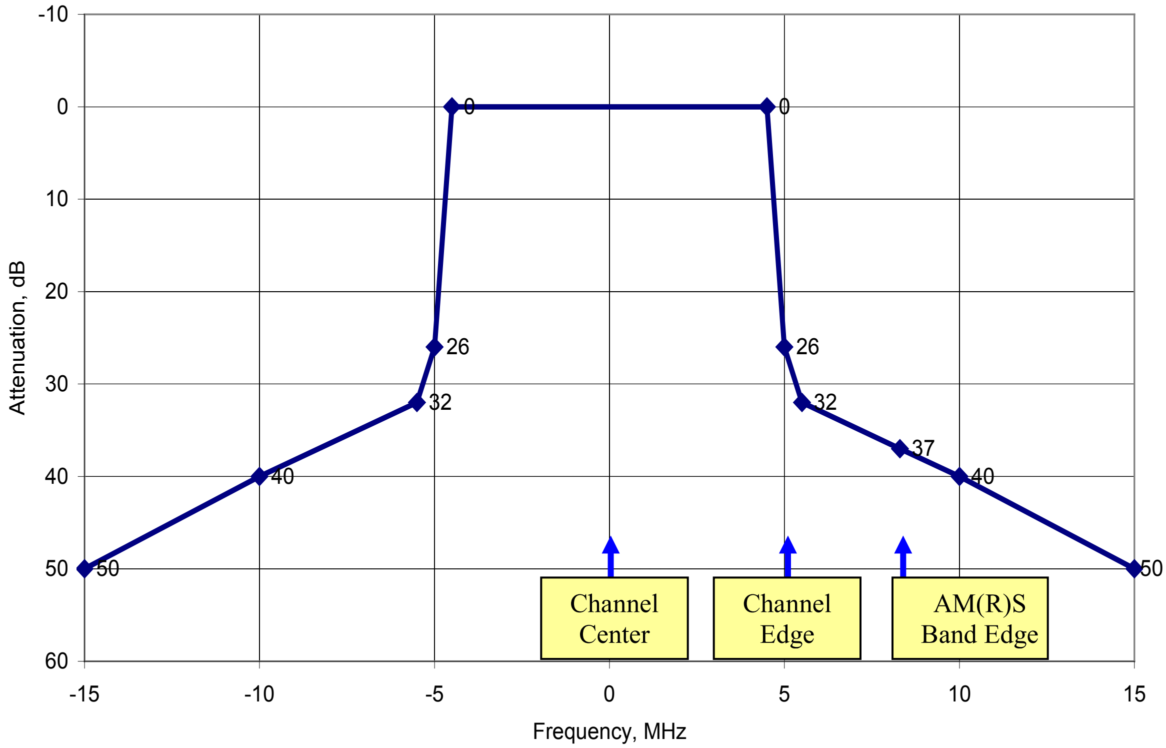

Figure 40.—FCC part 47 paragraph 90.210 mask m for 10-MHz channel bandwidth.

6.2.2.4.2 Co-user Interference

AeroMACS is a co-user in the AM(R)S band with other services. Of primary concern is potential interference from AeroMACS into the Mobile-Satellite Service (MSS) feeder uplinks that currently exist in the AM(R)S band. Practical limits on AeroMACS transmissions must exist so that the threshold of interference into MSS is not exceeded. Establishment of practical limits is discussed as part of power limitation recommendations in Section 6.2.3. The impact of channelization methodology on co-user interference will be introduced in this section. A channelization methodology for AeroMACS in the AM(R)S band will impact MSS interference because of the limited bandwidth of MSS receiver passbands relative to AeroMACS channel bandwidth.

Interference into MSS receivers results as a composite of all AeroMACS stations that are within view of an orbiting MSS satellite. Because of the orbital height and broad pattern of receive antennas, an MSS receiver will have visibility to transmissions from all CONUSE AeroMACS stations for periods within their orbit. It is therefore important that AeroMACS transmissions are distributed evenly across the AM(R)S band when considering transmissions from many airports. A corollary requirement is that no “hot spots” be formed within the AM(R)S band by establishment of a preferred frequency for BSs.

6.2.2.5 Channelization Methodology Summary

Conclusions and recommendations from individual studies within this task are summarized in Table 37.

TABLE 37.—CHANNELIZATION STUDY RESULTS SUMMARY

Study Task	Study Number	Constraints	Conclusions and Recommendations
Network segmentation for ATC traffic isolation	ES1.1	• Two isolated networks per airport may be required by policy • Dual networks make 10-MHz channel bandwidth impractical for multiple sectorized BSs • Dual networks reduces number of airports within co-user interference limits	This is a policy-driven decision within the constraints stated.
Efficient use of spectrum	ES1.2	• Band-edge guard bands are needed to limit out-of-band emissions • 10-MHz channel bandwidth causes wasted spectrum at AM(R)S band edges beyond that needed for band-edge guard bands	5-MHz channels provide greater spectrum efficiency.
Multiple access and service providers	ES1.3	• Number of Access Service Providers is limited by spectrum allocation	Implement single access provider with an option for multiple service providers.
Effect on initial acquisition time	ES2.1	• SS/MS units search for BS center frequencies during initial network acquisition • Significant acquisition delays are multiplied by the number of search frequencies required • Search algorithm will vary by hardware manufacturer and can be customized • BS channel center frequency options must be standardized for global interoperability of SS/MS	Choose wide frequency spacing for BS channel center frequencies options. A grid based on 5-MHz increments specified in WirelessHUMAN standard is preferred for lowest acquisition time.
In-band frequency guard band	ES2.2	• Adjacent channel interference was found to have insignificant effect on link performance when evaluated in the NASA-Glenn Test Bed. • Use reduces efficient use of spectrum	In-band frequency guard band allocations are not required.
Band-edge guard band	ES3.1, ES4.1	• Spectral mask chosen for AeroMACS requires band-edge guard bands to prevent excessive out of band emissions • 5-MHz channel width requires a 2.5-MHz guard- band allocation • 10-MHz channel width requires a 3-MHz guard-band allocation	Band-edge guard band allocations are required.
Co-user interference	ES3.2, ES4.2	• Co-user interference is minimized with efficient use of AM(R)S spectrum • Interference is increased when dual isolated networks per airport are required	Use single share-services network with 5-MHz channel bandwidth.

6.2.3 Power Limitation Considerations

Multiple BS sectors, each called a BTS, will typically be required for wide-area coverage across the airport surface of medium and large airports. A number of factors will be used to determine the transmitted power of each BTS, but two overriding factors will "bracket" the allowable power range. First, the transmit power must provide adequate received signal strength information (RSSI) and CINR signal levels at the SS receiver that will support the intended link coverage. The need to support a coverage area sets the lower bound for transmit power.

The second factor that brackets transmit power, this time on the high side, is the potential to interfere with co-users of the AM(R)S band. Of immediate interest is interference from AeroMACS in to the

Mobile-Satellite Service (MSS) feeder uplinks that currently exist in the AM(R)S band. Practical power limits on AeroMACS transmissions must exist so that the threshold of interference into MSS is not exceeded.

A MITRE study that examined potential co-user interference from AeroMACS will be used for a reference system for airport surface coverage and Tx power limitations (Ref. 55). A NASA study supported and validated the conclusions of the MITRE report (Ref. 56). Values from the MITRE study will be compared to test results using the NASA-Glenn AeroMACS Prototype.

6.2.3.1 Coverage Requirement

The MITRE study based its airport surface coverage and transmit power requirements analysis on a typical airport requiring three BSs, each BS having three BTS sectors, and each BTS sector having a 1.73 km coverage radius. The configuration used in the MITRE study provides coverage for an airport of a radius of 3 km.

Results from mobile drive tests on runway 24L/6R and airport peripheral roads can be used for a preliminary projection of the transmit power required to provide a 1.73 km coverage radius. The drive tests and results analysis are summarized in Section 3.2.2.3 of Volume II.

Drive tests on runway 24L/6R resulted in a minimum AeroMACS throughput rate of 3 Mbps for a maximum range of 5620 ft (1.71 km) for the conditions of the NASA Glenn “AeroMACS Prototype” column of Table 38. The maximum link range of this drive test closely supports the maximum range used by MITRE in their analysis. This also supports the sector coverage radius of 1.5 km that was assumed for the NASA CLE CNS Test Bed in the Coverage Design (Section 6.2.2.1) in this report volume.

TABLE 38.—COVERAGE AND Tx POWER PARAMETER COMPARISON

Parameter	AeroMACS prototype	MITRE study	Delta dB
Channel bandwidth	5 MHz	10 MHz	3
Power per transmitter	100 mW	170 mW	----
Antenna mode	MIMO	SISO	----
Total Tx power per BTS sector	200 mW	170 mW	0.7
BTS antenna gain (maximum)	15 dBi	15 dBi	0
Number of overlapping BTS stations	226[a]	497	–3.4
		Difference, dB	0.4

[a]226 is the number of BTS stations that overlap in channel frequency for 497 airports distributed across CONUS based on 5 channels in use at each airport and 11 5-MHz channels available. The NASA CLE CNS Test Bed is presently installed with 5 BTS sectors so is limited to 5 frequency channels.

AeroMACS mobile link performance exceeded 1.5 km range in the airport peripheral road test of December 16th that is described in Section 3.2.2.3 of Volume II. The ARV SS was connected with BTS 1-1 sector while travelling on the airport peripheral road around the end of runway 24L/6R. A traffic throughput rate of 6 Mbps was maintained for the duration of this drive test which had a maximum range to BTS 1-1 of 2.15 km. This result provides additional affirmation for adequate airport surface coverage using 100 mW BTS transmit power when MIMO antenna configurations are implemented.

6.2.3.2 Co-user Interference Limitation

Conditions for the MITRE interference study are listed under the MITRE Study column of Table 38. The impact of parameter differences between those used in the AeroMACS Prototype for the drive test and those in the MITRE study are summarized as follows:

- Channel bandwidth—The MITRE study is based on use of 10-MHz channel bandwidths, while the AeroMACS Prototype was set to 5-MHz channel bandwidths for the runway drive test. This causes a 3 dB increase in radiated power per Hertz because a set transmit power level is spread over half of the bandwidth for in the AeroMACS Prototype. A difference of 3 dB is listed in the "Delta dB" column of Table 38.
- Power per transmitter—The MITRE study limited the total transmitted power level per BTS to 170 mW (22.3 dBm). Each diversity channel used in the AeroMACS Prototype was set to 100 mW (20 dBm) during the runway drive test, which is the current limitation of the installed hardware.
- Antenna Mode—The MITRE study included only one transmit channel per BTS sector as would be the case in the nondiversity SISO antenna mode. The AeroMACS Prototype uses two transmitters per BTS sector for diversity transmission in MIMO antenna mode.
- Total Tx power per BTS sector—Total transmitter power per BTS sector is twice that of a single transmitter in the AeroMACS Prototype because of the 2-channel diversity antenna mode. The MITRE study is therefore based on a total transmitted power of 170 mW while the AeroMACS Prototype radiates 200 mW per BTS sector. A difference of 0.7 dB is listed in the Delta dB column of Table 38 to account for this difference.
- BTS antenna gain (maximum)—The BTS sector antenna gain of 15 dBi used in the MITRE study is the same as is used in the AeroMACS Prototype installed hardware.
- Number of overlapping BTS stations—The MITRE study is based on AeroMACS installation at 497 towered airports18 in the continental United States and 10-MHz channel bandwidths. As determined in Section 6.2.2.2, it is possible to fit five 10-MHz channels in the 59-MHz AM(R)S allocation. The same the 59 MHz AM(R)S allocation will support up to 11 channels of 5 MHz width. A "Delta dB" factor of 10×log(5/11) is listed because a smaller fraction of the 59 MHz AM(R)S allocation is occupied when five 5-MHz channels are implemented.

The net difference in interference level to co-users of the AM(R)S band is 0.4 dB for the AeroMACS Prototype as implemented compared to the conditions of the MITRE study. Use of 5-MHz channels will follow Scenario C of the study, which is one transmitter per frequency channel at an airport. A conclusion stated in the MITRE study is that all three scenarios studied resulted in the maximum aggregate receive power at the satellite receiver is below the interference threshold. The margin available for Scenario C is not stated. Further study is required to determine whether the 0.4 dB higher transmitted power of the AeroMACS Prototype configuration will exceed the interference threshold. Transmit power could be reduced to levels used in the MITRE study if needed, resulting in a traffic throughput rate reduction compared to the runway drive test results.

It should also be noted that the runway drive test results used in this comparison to MITRE interference study are for a relatively benign link condition of line-of-site between BS and SS without a complex multipath environment. More study is required to assess AeroMACS performance in non-line-of-sight, high-multipath conditions that will exist in highly congested terminal areas.

6.2.4 Recommendations for Power Limitations

A comparison has been completed between the operating parameters used in the NASA-Glenn AeroMACS Prototype for runway drive tests compared to the conditions used in the MITRE study of co-user interference. Conditions for level of interference to co-users were approximately within 0.4 dB although many parameters differ, such as channel bandwidth, antenna mode, and transmitter power output. The runway drive test performance that maintained at least 3 Mbps throughput rate to a range of 1.7 km provides an initial assessment supporting excellent performance while operating within interference constraints. Additional checks under more severe propagation conditions are required in order to gain confidence that viable links can be supported.

[18]The towered airport correspond with FAA Airport Categories of "Large Hub (LH) Primary" through "Relievers" listed in Table 32.

6.3 Coverage Model

The coverage model requires a map of the site along with coordinates of potential locations for BSs and SSs. The coverage model must account for the impact of the environment on the RF transmissions, including the effects of the topography, physical obstructions, and foliage. These effects introduce propagation delays that have been cataloged in reference models. In addition, clutter models or obstruction densities are also modeled in this phase. Clutter models represent the density of obstructions in the deployment site. Typical options include rural, urban, and suburban clutter models. An airport surface with its relatively open runways and taxi areas and congested terminal areas will be a combination of the three models.

In addition to considering site topology and propagation delays, general parameters of the AeroMACS solution must be identified. Notable parameters include BS and SS transmit/receive power, antenna gains, feeder losses, BS and SS heights, and orthogonal-frequency-division multiple access (OFDMA) radio-access-related parameters. In addition, the following are the relevant system design parameters:

- Radio access method
- Fade margin
- Antenna sensitivity and diversity
- Cochannel interference margin
- Duplex mode
- Modulation
- Error correction
- UL/DL ratios and throughput
- BS and SS noise figure
- Maximum output/input power

Finally, a link budget must be calculated that specifies the maximum path loss between each BS and SS. Receiver sensitivity of the equipment for supported modulation schemes can be obtained from the BS and SS vendor data sheets. Characteristics of the BS and SS and information about the placement and types of antennas are used to generate an accurate coverage map.

6.4 Spectrum Analysis

The spectrum analysis phase of radio planning involves analyzing a potential site for interference to the proposed AeroMACS. Interferers can include fundamental emissions plus transmitter harmonics and intermodulation emissions. An analysis involves measuring the maximum transmitter signal levels to determine how much energy is present in the surveyed RF band. The spectrum analysis can be conducted at ground level, but it is typically conducted from elevated locations including rooftops and tower sites at least 50 ft high.

6.5 Capacity Analysis

The capacity analysis involves calculating how much traffic can be supported given the UL/DL ratio and the anticipated traffic patterns with the specified bandwidth and modulation scheme. The parameters used for capacity calculations include

- Time-division duplexing (TDD) UL/DL ratio
- Mode of operation
- Channel bandwidth
- Subcarrier allocation scheme
- Guard ratio timing

The theoretical physical layer (PHY) throughput per modulation scheme can be calculated using the following formula (Ref. 47):

$$R_b = R_s\, MC/R_r \qquad (3)$$

where

- M modulation gain (2 for quadrature phase-shift keying (QPSK), 4 for 16-quadrature amplitude modulation (QAM), and 6 for 64-QAM)
- C coding rate (1/2, 3/4, 2/3, or 5/6)
- R_r repetition rate (1, 2, 4, or 6)
- R_b bit rate
- R_s symbol rate

Equation (3) accounts for the pilot overhead but does not account for the signaling overhead, which depends on the number of active connections and the service types used. Studies have found that signaling overhead may vary from 4 to 10 percent of PHY throughput. Estimating capacity using RF design tools takes into consideration the impact of multiple input, multiple output (MIMO) antenna schemas to enhance coverage and/or capacity.

Although theoretical and software-based tools provide a baseline for determining the capacity of an AeroMACS network, it will be necessary to make minor adjustments once the network has been implemented. Such optimization involves selecting appropriate network parameters that will support the QoS requirements. A test drive through the deployed network is the final step for collecting network data for analysis and optimization.

6.6 Design Tradeoffs for an AeroMACS Network

Table 39 lists many parameters that must be included in design tradeoffs for an AeroMACS network. The “Design category” column defines broad parameter categories, and the “Parameters” column lists in detail the parameters that interrelate during the design process. The “Considerations and system design parameters” column gives recommendations for the system tradeoffs, many of which are unique to the airport surface environment.

TABLE 39.—AEROMACS NETWORK DESIGN CONSIDERATIONS

Design category	Parameters	Considerations and system design parameters
Base station (BS)	Mounting placement	Total network data throughput Line-of-sight/non-line-of-sight (LOS/NLOS) coverage area Low-level blockage avoidance
	Number of BS and base transceiver station (BTS) sectors	BS throughput Channel bandwidth and available spectrum
	Multiple input, multiple output (MIMO) order	BS cell radius requirements Transmitter (Tx) power Near-line-of-site and blocked-path performance Multipath mitigation Mobility dropouts Interference to out-of-band users will be decreased by MIMO because total radiated power can be reduced.
	Antenna polarization	Cross-polarized versus spatially separated antennas

TABLE 39.—AEROMACS NETWORK DESIGN CONSIDERATIONS

Design category	Parameters	Considerations and system design parameters
	Maximum cell range	Number and placement of BSs BTS sector and subscriber station (SS) Tx power
	Controlled-pattern antennas	Use beam steering and beam-shape adaptation to increase throughput and avoid interference.
	Frequency band	5091- to 5150-MHz aeronautical mobile (route) service (AM(R)S) band approved during the 2007 World Administrative Radio Conference (WARC 2007). Addition of 5000- to 5030-MHz band is under consideration.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughput over coverage area.
SS	Mounting height	Avoid low-level structural and temporary blockages.
	MIMO order	Tx power Near-line-of-site and blocked-path performance Multipath mitigation Mobility dropout avoidance
	Antenna polarization	Cross-polarized versus spatially separated antennas
	Maximum cell range	Tx power Near-line-of-site and blocked-path performance Multipath mitigation Mobility dropouts
	Frequency band	Controlled and set by BTS sector connection SS must have matching frequency capability.
	Spectrum co-user interference (i.e., Globalstar satellite)	BTS sector antenna patterns control the direction of radiation. Use minimum BTS sector and SS Tx power to achieve required data throughputs over coverage area.
Channel bandwidth	Throughput rate	Highest throughput application sets the minimum channel bandwidth.
	Mobility performance	A wider bandwidth enables better channel equalization and better tracking of multipath variations during mobility.
	Multipath performance	Better equalization of short-path multipath with wider channel bandwidths
	Efficient use of spectrum	Number of channels that fit within the 59-MHz allocated AM(R)S spectrum. Refer to Section 6.2.2 for a detailed discussion about center frequency selection.
	Co-channel interference	There are fewer options for nonoverlapping frequency reuse in a large number of cells with wide channel bandwidths.
	Hardware limitations	20-MHz channel bandwidth requires fast digital processing and may not be implemented by a particular hardware supplier. 5-MHz and 10-MHz are currently supported by the industry
Modulation	Adaptive or fixed	Fixed modulation requires the use of lowest order modulation and lowest data throughput; higher order modulation will cause dropouts during mobility.
	Modulation rates	Use of all specified options maximizes data throughput for fixed and mobile SSs.
	Forward error correction (FEC) coding rate	Use of all specified options maximizes data throughput for fixed and mobile SSs.

TABLE 39.—AEROMACS NETWORK DESIGN CONSIDERATIONS

Design category	Parameters	Considerations and system design parameters
BTS power class	Fade margin	Fade margin allowance is set during network design to establish link reliability.
	Co-channel interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite feeder uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects the signal-to-noise ratio and modulation rate at the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for NLOS operation.
	Power amplifier power-output limitations	Orthogonal-frequency-division multiplexing (OFDM) modulation has a high peak-to-average ratio, making high Tx power expensive.
SS power class	Fade margin	Fade margin allowance is set during network design to maintain link reliability.
	Co-channel interference	Minimize Tx power to stay below the detection threshold of another BTS sector in a frequency reuse layout.
	Spectrum co-user interference (i.e., Globalstar satellite uplinks)	Minimize Tx power to reduce interference to co-users of the spectrum.
	Range	Tx power affects signal-to-noise ratio and modulation rate from the outer edge of cell coverage.
	LOS and NLOS operation	Fade margin allowance increases for NLOS operation.
	Mobile operation	Fade margin allowance increases for mobile operation.
	Power amplifier power-output limitations	OFDM modulation has a high peak-to-average ratio, making high power expensive.
Media Access Control (MAC) layer and physical layer (PHY)	Maximum mobile speed	120 km/hr is a value derived from other specified parameters and provides guidance about achievable maximum speed. The communications operating concept and requirement (COCR) is 160 kt (296 km/hr) Institute of Electrical and Electronics Engineering (IEEE) 802.16 specification does not directly support the COCR 160-kt requirement. A cost/benefit analysis is needed to assess the benefits of achieving this speed.
	Repeater operation (IEEE 802.16j)	IEEE 802.16j is a potential future amendment to the IEEE 802.16 standard BS repeater functionality may provide fill-in coverage in shadow areas with minimal added radiation and interference.
	Transmitter/receiver time-division duplex (TDD)/frequency-division duplex (FDD) mode	C-band AM(R)S spectrum allocation width does not support cost-effective FDD operation.
Quality of service (QoS)	Time delay	Services such as voice, and command and control applications will require guarantees on maximum time delay allowed.
	Time jitter	Services that are sensitive to jitter are to be identified. The use of frame buffering should be considered for each sensitive application.
	Message priority	Safety and reliability requirements will help specify message priorities.
	Scheduling	The scheduling algorithm will take message priority into account along with QoS requirements.
	Message integrity	Security and message integrity guarantees will depend on the type of QoS service flow selected.

6.7 Upper Networking Layers Analysis

The proposed AeroMACS broadband wireless specification, based on the WiMAX Forum specification for broadband wireless, is meant to deliver increased capacity in support of the varied CONOPS requirements for the National Airspace System (NAS). The desired capabilities include a scalable, standards based system that avoids single points of failure and supports mutual authentication of users and information access (Ref. 79). A key component in ensuring the reliability and resiliency of communications networks is a comprehensive approach to securing the end-to-end network.

Communications in an AeroMACS network is connection oriented. As a result, connections must be authenticated, authorized and established prior to any data transmissions. Further, the AeroMACS network elements must be authenticated and authorized to each other and to the network prior to the establishment of any logical connections. These mechanisms are examples of a multilayered approach to communications security (Ref. 57).

A comprehensive communications network security approach involves a layered scheme to ensure the protection of the network at multiple layers. Commonly referred to as "Defense-in-Depth," a layered security approach eliminates a single point of failure and relies on a continuous security policy, security training for its users, as well as the application of the appropriate technology to ensure the following (Ref. 16):

- Confidentiality—protection from eavesdropping
- Integrity—user and management data is not modified while in transit
- Authentication—assurance that users and devices can authenticate each other
- Authorization—mechanism that verifies user and AeroMACS service associations
- Access Control—control authorized access to network resources
- Availability—prevent Denial of Service or of the AeroMACS network and its attendant resources

6.7.1 WiMAX Network Reference Model

Air interface operation between the SSs and BSs at the MAC and PHY layers is specified by the IEEE 802.16–2009 standard. A security framework specified in the MAC security sublayer provides confidentiality and authentication across the broadband wireless network. End-to-end security beyond the radio interface is not specified in IEEE 802.16–2009. As a result, the WiMAX Network Reference Model was developed by the WiMAX Network Working Group to define end-to-end service requirements beyond the radio link. A WiMAX deployment includes more than the air interface to link the subscriber stations to applications and resources beyond the broadband network. Service requirements include IP connectivity, session management, security, QoS, and mobility management. The WiMAX network reference model (NRM) illustrated in Figure 41 is a logical representation of the end-to-end network architecture.

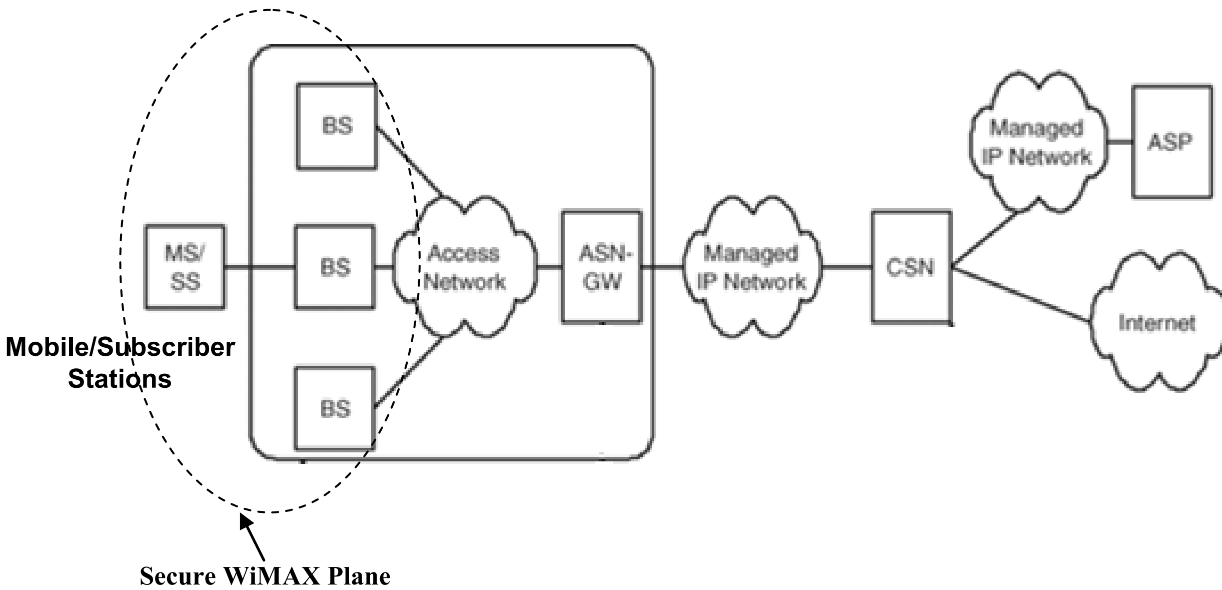

Figure 41.—WiMAX reference architecture.

The WiMAX reference architecture represents a Layer-2 network infrastructure used to establish connection-oriented channels for management and data transport at Layers 2 and 3. It is divided into three logical parts:

- Mobile/subscriber stations.—Access devices used by the individuals or entities to access the WiMAX radio interface
- Access Service Network (ASN).—Includes one or more base stations and one or more ASN gateways that form the radio access network. Functions of the ASN gateways include location management, paging, radio resource management and admission control
- Connectivity Service Network (CSN).—Provides IP connectivity and all of the IP core network functions. Functions include AAA, Billing, DHCP, and policy management of QoS and security. Mobility and roaming is also managed at the CSN

6.7.2 The AeroMACS Security Architecture

Access to the radio channel is defined at the PHY and MAC layers in an AeroMACS network. It is controlled by a series of initialization and authentication steps as specified by the IEEE 802.16–2009 specification. The initial establishment of a logical AeroMACS environment involves the establishment of security associations or mutual authentication between the base station and the subscriber station/mobile station in an AeroMACS network[19]. Mutual authentication support is based on encryption and key exchanges using the Privacy Key Management Version 2 (PKMv2) protocol.

The architecture uses an Internet Engineering Task Force (IETF) extensible authentication protocol (EAP) based AAA framework, which is also utilized for service flow authorization, QoS policy control, and secure mobility management. It also supports a variety of authentication mechanisms and credentials

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[19]Complete AeroMACS Security Assessment is outside the scope of this report. It is addressed by NASA Glenn reports.

including shared secrets, subscriber identity module (SIM) cards, universal SIM (USIM), universal integrated circuit card (UICC), removable user identity module (RUIM) and X.509 certificates. All of these mechanisms are suitable for EAP methods satisfying RFC 4017 (Ref. 57). The security functions of the AeroMACS security sublayer are illustrated in Figure 42:

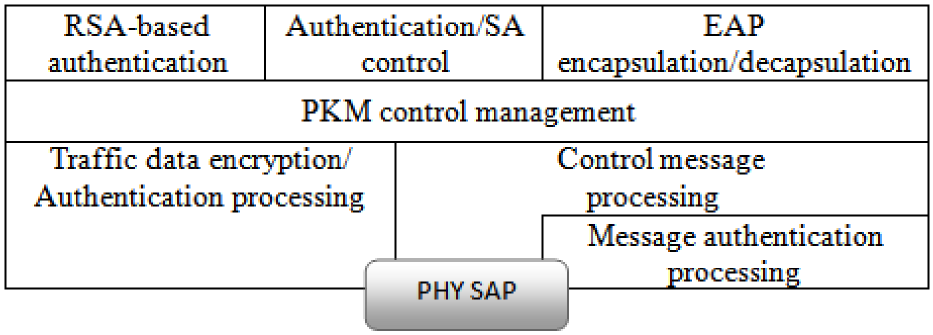

Figure 42.—IEEE 802.16-1009 MAC security sublayer functions.

Definitions

- PKM Control Management: Controls all security components. Various keys are derived and generated in this stack.
- Traffic Data Encryption/Authentication Processing: Encrypts or decrypts traffic data and executes the authentication function for the traffic data.
- Control Message Processing: Processing of various PKM-related MAC messages.
- Message Authentication Processing: Executes message authentication function.
- RSA-based Authentication: Performs the RSA-based authentication function using the SS's X.509 digital certificate and the BS's X.509 digital certificate, when the RSA-based authorization is selected as an authorization policy between an SS and a BS.
- EAP Encapsulation/Decapsulation: Interface with the EAP layer, when the EAP-based authorization or the authenticated EAP-based authorization is selected as an authorization policy between an SS and a BS.
- Authorization/SA Control: This stack controls the authorization state machine and the traffic encryption key state machine (Ref. 58).

6.7.3 AeroMACS Network Authentication and Authorization

The IEEE 802.16–2009 standard outlines a process for initialization of the radio access network as illustrated in Figure 43. The process begins when a Mobile/Subscriber Station is powered up and scans the allowed downlink (DL) frequencies to determine the presence of a network. Each MS/SS stores a list of operational parameters in nonvolatile memory to synchronize with the most suitable BS. When a BS responds with the suitable Uplink (UL) parameters, the SS performs initial ranging with the BS to synchronize the timing and power levels required to maintain the UL connection.

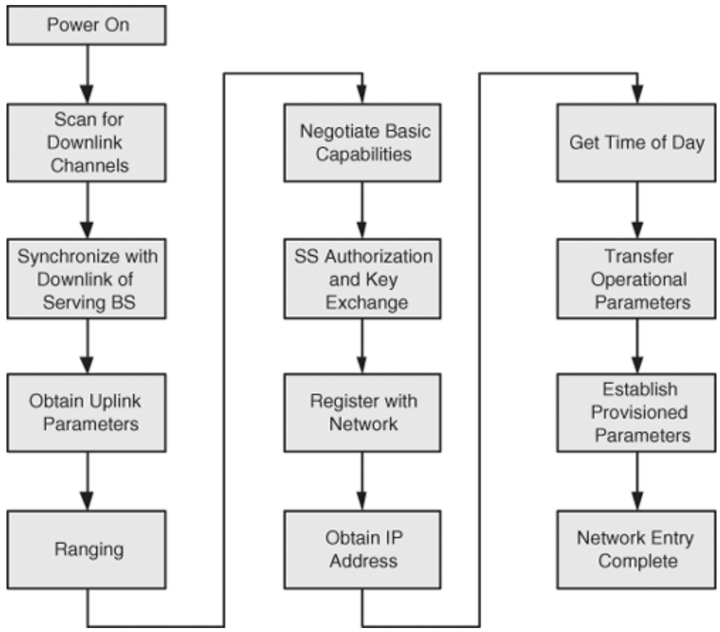

Figure 43.—Network authentication and authorization process.

After initial ranging to establish a secure management channel and negotiating basic capabilities including PHY modulation and coding schemes as well as bandwidth requirements, the security key exchange occurs. The PKMv2 protocol, as specified by IEEE 802.16–2009, is used to manage the key exchanges for authentication, authorization and registration between the SS and BS. Utilizing EAP with the PKMv2 protocol provides a mechanism for key exchange when mutual authentication is required, as recommended in the draft NIST SP 800–120, Recommendation for EAP Methods Used in Wireless Network Access Authentication (Ref. 59).

Each SS is assigned a X.509 digital certificate that is bound to the physical hardware during manufacturing. This enables the exchange of authorization keys, key encryption keys, message authentication keys and traffic encryption keys that enable the encryption of both the management and subsequent data traffic, thereby establishing security associations between the BS and SS in the network. The U.S. Government mandates Federal Information Processing Standard (FIPS) 140-2 Advanced Encryption Standard (AES) encryption algorithms. The IEEE 802.16–2009 standard specifies at a minimum, a128-bit AES encryption key.

The security associations are implemented by the MAC layer of the WiMAX standard under the MAC Security Sub-layer as illustrated in Figure 44. A security association defines the security parameters of a connection, which include encryption keys and algorithms. Security associations fall into three categories: authorization, unicast, and multicast services.

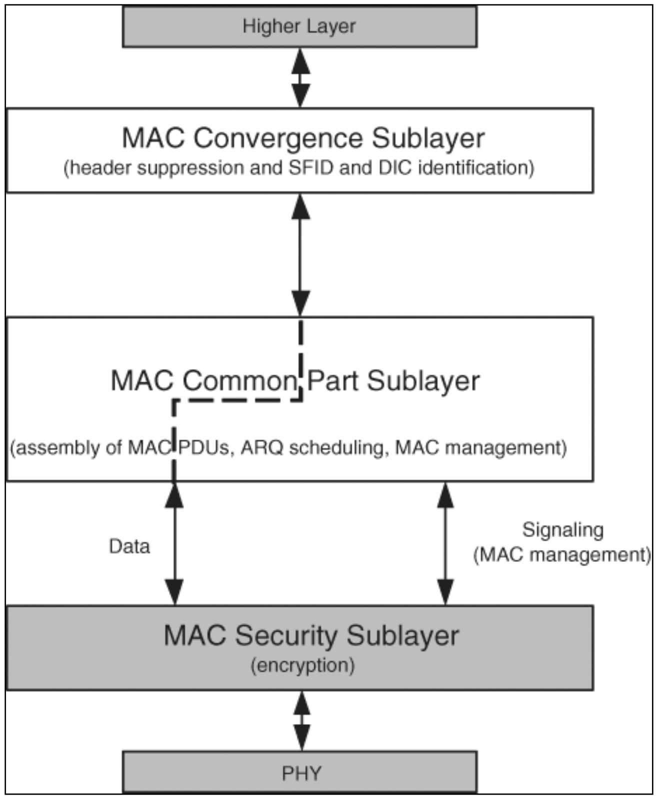

Figure 44.—WiMAX MAC security sublayer process.

After the security associations have been completed the BS establishes a connection with the SS the registration with the WiMAX network is complete. The SS can now obtain an IP address via the DHCP, acquire the current time and any other provisioned parameters and initiate a service flow (Ref. 16).

6.7.4 AeroMACS Potential Vulnerabilities

AeroMACS as a wireless medium is also susceptible to common wireless security threats. Common categories and threats include

- RF jamming.—a powerful RF signal introduced to the spectrum to overwhelm the system and deny service.
- Scrambling.—precise injections of RF interference during the transmission of specific management message thereby degrading overall system performance
- Management message manipulation.—Spoofing management messages to attempt unauthorized access to the network.
- Man-in-the-middle attacks.—a device or subscriber appears as a legitimate AeroMACS user in the network and introduces malicious communications into the data or management channel.
- Eavesdropping.—the utilization of a traffic analyzer within the range of a BS or SS to capture management or data channel traffic.

6.7.5 Recommendations for End-To-End Security

The varied service requirements in the NAS CONOPS require a flexible network architecture that can secure and separate the various network applications. Given the AeroMACS MAC layer security architecture previously mentioned is focused only on the air interface between SS and BS, an end-to-end approach should be implemented as to meet the NAS CONOPS requirements. The adherence to the security guidelines specified by the WiMAX Forum and the IEEE 802.16–2009 specification will mitigate the various types of threats to the AeroMACS network. The guidelines are summarized as follows:

- The AeroMACS security framework must support a variety of AeroMACS network topologies
- The architecture shall accommodate support for strong mutual SS authentication between an SS and the AeroMACS network, based on the IEEE 802.16 security frameworks.
- An SS should be able to support all commonly deployed authentication mechanisms and authentication in home and visited operator network scenarios based on a consistent and extensible authentication framework. An SS should be able to select between various authentication method(s).
- The architecture shall support data integrity, replay protection, confidentiality and non-repudiation using applicable key lengths within the AeroMACS Access Network.
- The architecture shall accommodate the use of SS initiated/terminated security mechanisms such as virtual private networks (VPNs).
- The architecture shall accommodate standard secure IP address management mechanisms between the SS and its CSN.
- The architecture shall support Fast BS Switching or Macro Diversity Handover. In the event of a change in service between a BS and SS, a procedure to have a SS associate with a secondary BS can be implemented. This is an optional specification, but its implementation can enhance availability, particularly in a mobile environment.

The complete security assessment of AeroMACS is out of the scope of this report and is being addressed by NASA in a separate document.

6.7.6 Additional NAS CONOPS Requirements

The NAS CONOPS requirements will require a separation of the service channels. Deploying virtual local area networks (VLANs) is a Layer 2 option for segmenting networks to increase capacity and performance while leveraging the same physical infrastructure. A VLAN expands the capacity of a broadcast domain with the creation of separate logical broadcast domains or networks. These networks can only be connected with a layer 3 switch or router. Classifying or tagging ports or Ethernet frames per the IEEE 802.1Q VLAN tagging standard allows for controlled deployment of VLANs across an enterprise network (Ref. 57).

The WiMAX standard supports the use of IEEE 802.1Q. Deploying VLANs at Layer 2 will provide the separation of the traffic flows in a WiMAX network. These VLANS can be extended to the back-end infrastructure by deploying VLANs on the wired infrastructure. However, the encryption of the traffic will only occur in the radio interface as outlined earlier since IEEE 802.16–2009 does not define encryption beyond the air interface. Encryption of the Layer 2 traffic beyond the air interface is not specified by the IEEE 802.16–2009 specification.

In addition, although the WiMAX specification defines communications at the MAC and PHY layers, end-to-end transmissions of higher-layer protocols is also supported. The MAC sublayer, illustrated in Figure 44, supports the mapping of higher layer protocols to the WiMAX MAC layer for end-to-end communications. Linking the WiMAX ASN and MS/SS layers to the CSN and external networks requires an IP network as illustrated in Figure 41.

The WiMAX specification provides the flexibility to extend IP and Ethernet communications across the ASN boundary with an IP Convergence Sublayer (IP-CS) and an Ethernet Convergence Sublayer (Eth-CS) as illustrated in Figure 41. The WiMAXMAC layer is connection-oriented and identifies a logical connection between the BS and the MS by a one-way connection identifier (CID). The CIDs for uplink and downlink connections are different. The CID can be viewed as a temporary and dynamic layer 2 address assigned by the BS to identify a unidirectional connection between the peer MAC/PHY entities and is used for carrying data and control-plane traffic. In order to map the higher-layer address to the CID, the CS keeps track of the mapping between the destination address and the respective CID. These IP and Ethernet channels would be provisioned as VLANS and extended across the end-to-end network without the need for an IP network between the ASN and CSN (Ref. 57). This capability in the NAS CONOPS would be useful for legacy applications that need to remain at layer 2 to meet QoS or performance requirements.

6.7.7 AeroMACS Network with VPN Overlay

The IEEE 802.16–2009 standard supports IEEE 802.1Q. Deployment of VLANs at Layer 2 will provide the separation of the traffic flows in an AeroMACS network. These VLANS can be extended to the back-end infrastructure by deploying VLANs on the wired infrastructure. However, the encryption of the traffic will only occur in the radio interface as outlined earlier since IEEE 802.16-2009 does not define encryption beyond the air interface (Ref. 79). Encryption of the Layer 2 traffic beyond the air interface is not specified by the IEEE 802.16–2009 specification.

A FIPS validated VPN overlay at Layer 3, with AES 128 encryption at a minimum, will extend encryption beyond the BS and ASN gateway. A VPN appliance or router should be placed in front of the CSN architecture as illustrated in Figure 45. Clients on the SS may use TLS and IPSEC solutions that will terminate at the VPN gateway. Utilizing a Layer 2 encryption device could hide the tagged layer 2 Ethernet frames, thus compromising the mechanism for classification of traffic flows and impeding mobility (Ref. 16).

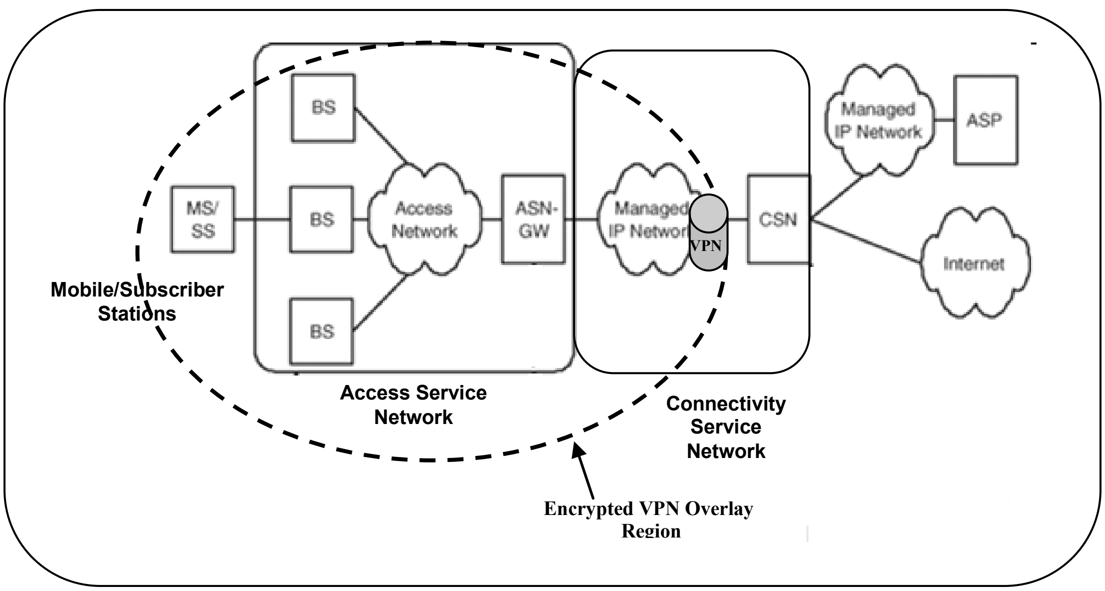

Figure 45.—WiMAX reference architecture with VPN overlay.

6.7.8 Upper Networking Layers Summary and Recommendations

Security in a communications network should be deployed at multiple levels to eliminate potential single points of failure. The 802.16–2009 standard defines a number of security enhancements that provide defense-in-depth to ensure confidentiality, authentication, authorization, and integrity in addition to access controls for the communications infrastructure. They include the use of the Internet Engineering Task Force (IETF) EAP-based AAA framework, used for mutual authentication and authorization of network elements and subscribers

The AAA framework is also utilized for service flow authorization, QoS policy control and encryption. IEEE 802.16-2009 specifies 128-bit encryption at a minimum. Encryption is used to ensure the confidentiality and integrity protection of both management and data traffic. As an added measure of protection, the Federal Government mandates the use of FIPS-approved cryptographic algorithms contained in FIPS-validated cryptographic modules.

In addition, the WiMAX Forum specifies a range of security mechanisms that compliment the IEEE 802.16–2009 PHY and MAC layer security mechanisms. Solutions include the deployment of VPN technologies to provide end-to-end encryption of the data channels at the network layer. Further, the development of security policies that incorporate physical and administration controls with the logical technology controls will ensure that the NAS CONOPS requirements will operate in a reliable, resilient, secure AeroMACS infrastructure.

6.8 Issues beyond the Scope of IEEE 802.16 Standard

The IEEE802.16–2009 standard deals principally with the PHY and MAC network layers. However, an operational AeroMACS network must include all networking layers in order to implement user authentication, allocation of services and QoS, security, and data delivery. Although an airport can be looked at as a small communications zone, many of the upper network layer functions must operate on a global basis so that aircraft can operate seamlessly at all locations.

The following list contains topics that are beyond the scope of the IEEE 802.16–2009 standard. These topics are also beyond the scope of RTCA SC-223. Many of these topics are being addressed by the WiMAX Forum for commercial network use and their solutions can be the basis for AeroMACS solutions.

AeroMACS topics beyond the scope of IEEE802.16–2009:

(1) Network architectures that will segregate safety-critical services from noncritical services and assure high QoS with low latency.
(2) Exchange of user authentication and authorization data on a global basis. AAA database must be distributed and consistent on a global basis.
(3) A method for secure exchange of authentication must be universally implemented on a global basis. User authentication information such as Private Key Management security certificates, username and passwords must be standardized. A database of this information must be immediately available to AeroMACS globally.
(4) AeroMACS may be implemented with multiple service providers at an airport. Management of mobility handover in upper network layers will impact network architectures.
(5) AeroMACS data traffic load requirement predictions must be established so that initial installations at airports will be capable of handling expanding services without re-design and modification. This requires a good understanding of ConOps, applications, and their data traffic loads.
(6) A governing body must be responsible for establishing which applications will be allowed to use AeroMACS consistent with AM(R)S spectrum limitations. Each application must be assigned a service level for Quality of Service.
(7) A policy should be in place to define and manage the channel allocation for each airport.
(8) Methods of maintaining AeroMACS profile documentation jointly between RTCA, EUROCAE, and the WiMAX Forum must be established so that potential changes can be managed as AeroMACS validation tests are conducted and as the WiMAX commercial industry continues to develop the WiMAX technology.

7.0 Introduction to Volume II

Volume II describes modifications to the NASA CLE CNS Test Bed to add AeroMACS network capability. Test and evaluation results from simulations and AeroMACS Prototype measurements are presented. It also provides initial data to be input to the aeronautical mobile-specific AeroMACS design specifications.

Design of an AeroMACS network requires detailed analysis and simulation as well as test measurements on candidate airport surfaces. Measurements carried out on candidate airport surfaces should provide sufficient data to calibrate key performance tradeoffs that will be modeled by computer simulations. One or more mobile SSs should be part of the experimental prototype to assess UL and DL performance coverage for initial measurements related to mobile operation. The prototype should provide initial quantitative data to aid in the installation of the first phase of an IEEE 802.16–2009-based AeroMACS network at other airports of similar complexity. Specific objectives include the following:

- Assess the full range of aviation profile options for the physical and MAC layer specification, and recommend initial values for each parameter in the profile.
- Verify functional operation of the physical and MAC layers within the recommended profile.
- Obtain measurements at various locations on the airport surface to calibrate coverage models for the UL and DL systems.
- Measure multichannel performance with sectored BS antennas to support airport layout design for future installations.
- Validate operation of AeroMACS while connected to other airport network systems; for example, connected to an airport IP network.

In addition, data collected from a prototype at a specific airport location should be analyzed relative to other experimental data from airport measurements. This will help to reinforce conclusions and uncover inconsistencies.

In order to meet the prototype objectives, it is recommended that at least two BSs be utilized that have overlapping coverage on the airport surface. In addition, fixed and mobile SSs should be utilized to obtain UL and DL coverage data and to be able to evaluate parameter settings under a variety of conditions.

An AeroMACS network having these considerations and conforming to the architecture described in Section 5.3 is now implemented in the NASA–Glenn CNS Test Bed. The physical installation, a set of four evaluation tests, and evaluation results are described in Volume II.

Special Committee SC–223 was established within the RTCA aviation industry consortium to establish standards for AeroMACS. The principal products of this special committee are a set of final recommendations for a system profile to be delivered in September 2010 and a Minimum Operational Performance Standards (MOPS) document to be delivered in December 2011(Ref. 20). EUROCONTROL established a similar work group, WG–82, that is chartered to develop an AeroMACS profile. SC–223 and WG–82 work cooperatively to develop a common profile document that will be provided as recommendations for consideration by ICAO. Section II describes this process and the resulting recommendations.

Appendix A.—Acronyms and Abbreviations

This appendix identifies acronyms and abbreviations used throughout this document.

A/A	air to air
AAtS	Aircraft Access to SWIM
A/C	aircraft
A/G	air to ground
AAA	authentication, authorization, and accounting
AAC	Airline Administrative Communications
AATS	Aircraft Access to SWIM
ACARS	Aircraft Communications Addressing and Reporting System
ACI	Airport Council International
ACSTS	Aerospace Communication Systems Technical Support contract
ADAS	AWOS Data Acquisition System
ADDS	Aviation Digital Data Service
ADS–B	automatic dependent surveillance—broadcast
ADS–C	automatic dependent surveillance—contract
ADSx	automatic dependent surveillance—next generation
AEEC	Airlines Electronic Engineering Committee
AeroMACS	Aeronautical Mobile Aircraft Communications System
AES	Advanced Encryption Algorithms
AFB	Air Force base
AFSS	Automated Flight Service Station
AIM	Aeronautical Information Management
Airp Ops	airport operation
AISR	Aeronautical Information System Replacement
ALS	airport lighting system
ALSF	approach lighting with sequenced flashing lights
AM(R)S	aeronautical mobile (route) service
AMS(R)S	aeronautical mobile satellite (route) service
ANSP	air navigation service provider
AOC	aeronautical operational control

AOCDLL	AOC Data Link Logon
AP–17, –30	Action Plan 17, 30
APT	Airport
ARC	airport reference code
ARCTR	aeronautical center in Oklahoma City, Oklahoma
ARFF	Aircraft Rescue and Firefighting building (at Cleveland Hopkins International Airport)
ARINC	Aeronautical Radio Incorporated
ARSR	air route surveillance radar
ARTCC	air route traffic control center
ARTS	Automated Radar Terminal System
ASDE–X	Airport Surface Detection Equipment—Model X
ASN	access service network
ASN–GW	access service network gateway
ASN–GW–DP	access service network gateway—decision point
ASN–GW–EP	access service network gateway—enforcement point
ASOS	automated surface observation systems
ASR	airport surveillance radar
ATC	air traffic control
ATCSCC	air traffic control system command center
ATCT	air traffic control tower
ATFCM	air traffic flow and capacity management
ATIS	Automatic Terminal Information Service
ATL	Atlanta International Airport
ATM	air traffic management
ATN	aeronautical telecommunications network
ATO	Air Traffic Organization
ATS	air traffic services
ATSP	air traffic service provider
ATSU	air traffic services unit
AWIPS	Advanced Weather Interactive Processing System
AWOS	Automated Weather Observing System
AZ	azimuth

BASOP	base operations
BER	bit error rate
BLOS	beyond line of sight
BS	base station
BTS	base transceiver station
BUEC	backup emergency communications
BW	bandwidth
BWI	Baltimore-Washington International Airport
C&P	crossing and passing
CABINLOG	Cabin Log Book Transfer
CANRAD	Canadian Radars
CDA	Continuous Descent Arrivals or Continuous Descent Approach
CDM	collaborative decision making
CDTI	cockpit display of traffic information
CFR	Code of Federal Regulations
CID	connection identifier
CINR	carrier-to-interference and noise
CIWS	Corridor Integrated Weather System
CLE	Cleveland Hopkins International Airport, Cleveland, Ohio
CMF	Consolidated Maintenance Facility
CNS	communication, navigation, and surveillance
CO	commercially-operated
COCR	communications operating concept and requirements
COM	communications
ConOps	concepts of operation
ConUse	concepts of use
CP	cyclic prefix
CPDLC	controller pilot data link communications
CPE	customer premise equipment (same as subscriber station)
CSN	Connectivity Service Network
CTA	Controlled Time of Arrival
D/L	data link
Data Comm	data communications

dATIS (D–ATIS)	Digital Automatic Terminal Information Service
DC	data communications
DCG	data communications gateway
DCS	data communications system
DFU	display functional unit
DHCP	Dynamic Host Configuration Protocol
DHS	Department of Homeland Security
DINS	Defense Internet NOTAM (Notice to Airmen) services
DL	downlink—base station to subscriber station data-flow direction
DME	distance measuring equipment
DoD	Department of Defense
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
DSB AM	double-sideband amplitude modulation
DSR	dynamic source routing
DSS	decision support system
D–TAXI (D-Taxi)	data link taxi clearance
DTS	Dedicated Telecom Services
DYNAV	dynamic route availability
EA	enterprise architecture
EAP	extensible authentication protocol
ECG	En Route Communications Gateway
ECS	emergency communications systems
ENGINE	Engine Performance Reports
ERAM	En Route Automation Modernization
ERIDS	En Route Information Display System
ERT–VR	extended real time—variable rate
ES	Engineering Study
ES	Extended Squitter
ETH-CS	Ethernet convergence sublayer
ETVS	Enhanced Terminal Voice Switch

EUR	Europe
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
F&F	flight and flow
FAA	Federal Aviation Administration
FANS–1/A+	Future Air Navigation System—1/A+ version
FBWTG	FAA Bulk Weather Telecommunications Gateway
FCI	future communications infrastructure
FCS	Future Communications Study
FDD	frequency-division duplex
FEC	forward error correction
FFT	fast Fourier transform
FIPS	Federal Information Processing Standard
FIS	flight information service
FLIPCY	flight plan consistency
FLTLOG	Flight Log Transfer
FLTPLAN	Flight Plan Data
FLTSTAT	Flight Status
FMS	flight management system
FOC	Flight Operations Center
FPR	Final Program Requirements
FREETXT	Free Text
FRS	future radio system
FTP	File Transfer Protocol
FUEL	Fuel Status
FY	fiscal year
G/A	general aviation
G/G	ground to ground
GA	general aviation
GATES	Gate and Connecting Flight Status
GBT	ground-based transceiver
GI	general information
GIS	geographical information system

Glenn	Glenn Research Center
GO	government operated
GPS	Global Positioning System
GS	ground station
GSC	ground station controller
GTWY	gateway
GW	gateway
HCS	host computer system
HF	high frequency
HPA	high performance airspace
IAP	Internet Access Point
ICAO	International Civil Aviation Organization
ID	identification
IDS	Information Display System
IEEE	Institute of Electrical and Electronics Engineering
IETF	Internet Engineering Task Force
ILS	instrument landing system
IP	Internet Protocol
IP CS	IP convergence sublayer
Iperf	network testing tool
ITP	In-Trail Procedure
ITU	International Telecommunications Union
ITWS	Integrated Terminal Weather System
JPDO	Joint Planning and Development Office
Kbps	Kilobits
LAN	local area network
LCGS	low-cost ground surveillance
LINK 2K+	European SESAR (Single European Sky ATM Research) program
LLWAS	Low-Level Wind Shear Alert System
LOADSHT	Load Sheet Request/Transfer
LOC	localizer
Loc	location
LOS	line of sight

LRR	long-range radar
M&S	merging and spacing
MAC	Media Access Control
MAINTPR	Maintenance Problem Resolution
MAINTRT	Real Time Maintenance Information
M-ary	digital transmission of two or more bits at a time
MASPS	minimum aviation system performance standards
Mbps	megabit per second
Mhz	megahertz
MIMO	multiple input, multiple output
MITRE CAASD	MITRE Corporation’s Center for Advanced Aviation System Development
MLAT	multilateration
MLS	microwave-landing-system
MM	middle marker
Mode S	Mode Select secondary surveillance Beacon System
MOPS	Minimum Operational Performance Standards
MS	mobile station
MSS	Mobile-satellite service
NADIN	National Airspace Data Interchange Network
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASA–CLE	NASA Glenn Research Center and Cleveland Hopkins International Airport
NASA-EA	National Airspace System Enterprise Architecture
NASAD	NAS architecture document
NASCR	NASA Common Reference System
NAS–SR	National Airspace System—System Requirements
NAV	navigation
NAVAIDS	navigation aids
NDB	nondirectional radio beacon
NEXCOM	Next Generation Air/Ground Communications
NEXRAD	Next Generation Radar
NextGen	Next Generation Air Transportation System

NFU	National Weather Service Filter Unit
NIPRNET	Nonclassified Internet Protocol Router Network
NIWS	NAS Integrated Web Services
NLOS	non line of sight
NMS	Network Management System
NNCC	National Network Control Centers
NNEW	NextGen Network Enabled Weather
NOAA	National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NPIAS	National Plan of Integrated Airport Systems
NRM	network reference mode
nRT	non real time
nrtPS	non-real-time polling service
NWIS	NAS-wide Information Services
NWS	National Weather Service
O&M	operations and maintenance
OAS	Oceanic Automation System
ODU	outdoor unit
OFDM	orthogonal-frequency-division multiplexing
OFDMA	orthogonal-frequency-division multiple access
OI	operational improvement
OM	outer marker
OOOI	Out-Off-On-In
Ops IP	operations IP
Ops	operations
OPUS	Online Positioning User Service
ORIS	operational en route information service
OSED	Operational Services and Environment Definition
OTIS	operational terminal information service
OV–1, OV–2	operational views
PAIRAPP	paired approach
PC	personal computer
PER	packet error rate

PHY	physical
PIAC	Airport Peak Instantaneous Aircraft Counts
PIREP	pilot report
PKMv2	Privacy Key Management Version 2
PLA	project-level agreement
PoE	Power over Ethernet
POSRPT	Position Report
PPD	pilot preferences downlink
Pri Hangar	primary hangar
PRM	Precision Runway Monitor
PSN	packet switched network
PV6	plan view 6
QAM	quadrature amplitude modulation
QoS	quality of service
QPSK	quadrature phase-shift keying
RAPCO	Radar Approach Control
RASP	Regional ADAS (Automated Weather Observation Station Data Acquisition System) Service Processor
RCAG	remote communications air to ground
RCE	radio control equipment
RCE–C	RCE at control site
RCE–R	RCE at remote (transmitter/receiver) site
RCO	remote communication outlet
RCP	required communication performance
RDVS	Rapid Deployment Voice Switch
RE&D	research, engineering and development
RF	radiofrequency
RRM	radio resource management
RSSI	received signal strength indication
RTCA	RTCA, Inc. (founded as Radio Technical Commission for Aeronautics)
rtPS	real-time polling service
RTR	remote transmitter/receiver
RU	remote unit

RUC	rapid update cycle
RUIM	removable user identity module
RVR	runway visual range
Rx	receiver
SAMS	Special Use Airspace Management System
SARPs	standards and recommended practices
SATCOM	satellite communications
SC	single carrier; special committee
SCa	single carrier access
SCS	Sensor Control Subsystem (ADAS, AWOS Data Acquisition System)
SE	system engineering
SEM	system engineering manual
SESAR	Single European Sky ATM Research
SIGMET	significant meteorological information
SIM	subscriber identity module
SITA	Société Internationale de Télécommunications Aéronautiques
SOA	service-oriented architecture
SOAMOM	service-oriented architecture messaging oriented middleware
SOC	Service Operations Center
SOCC	Security Operations Control Center
SONET	synchronous optical networking
SPR	safety and performance requirement
SR	system requirement
SRD	system requirements document
SRR	short-range radar
SS	subscriber station
SSR	secondary surveillance radar
StarACS	Star Automatic Configuration Server (for WiMAX (Worldwide Interoperability Microwave Access) networks)
STARS	Standard Terminal Automation Replacement System
surv	surveillance
SV–1, SV–2	system views
SWIM	System Wide Information Management

SWLOAD	Software Loading
SYSCO	system-supported coordination
TACAN	tactical air navigation
TAP/CDA	Tailored Arrival Procedure/Continuous Descent Approach (Arrival)
TBO	trajectory-based operations
TCP	transmission control protocol
TDD	time-division duplex
TDLS	tower data link system
TDMA	time-division multiple access
TDWR	Terminal Doppler Weather Radar
TECHLOG	Technical Log Book Update
TFDM	Tower Flight Data Manager
TFM	traffic flow management
TFR	temporary flight restrictions
THEVAN	Terrestrial Hybrid Environment for Verification of Aeronautical Networks
TIBA	Traffic Information Broadcast by Aircraft
TM	Traffic Management
TMI	Traffic Management Initiatives
TMA	terminal maneuvering area
TRACO	facility type for TRACON
TRACON	Terminal Radar Approach Control Facility
TVS	Terminal Voice Switch
TWIP	Terminal Weather Information for Pilots
Tx	transmitter
UAS	unmanned aircraft system
UAT	universal access transceiver
UDP	User Datagram Protocol
UGS	unsolicited grant service
UHF	ultra-high frequency
UICC	universal integrated circuit card
UL	uplink—subscriber station to base station data-flow direction
UPLIB	Update Electronic Library
URCO	urgent contact

USAS	User Services & Applications Survey
USC	United States Code
USIM	universal SIM
VCS	Voice Communications System
VDL	very high frequency digital link
VHF	very high frequency
VLAN	virtual local area network
VoIP	digital voice over Internet Protocol
VOLPE	John A. Volpe National Transportation Systems Center
VOR	very high frequency (VHF) omnidirectional range
VPN	virtual private network
VSCS	Voice Switching and Control System
WAAS	Wide Area Augmentation System
WAKE	wake vortex
WARC	World Administrative Radio Conference (now World Radiocommunication Conference)
WARP	Weather and Radar Processor
WG	working group
WiMAX	Worldwide Interoperability Microwave Access
WINS	Weather Information Network Server
WirelessHUMAN	wireless high-speed unlicensed municipal area network
WirelessMAN	wireless municipal area network
WJHTC	William J. Hughes Technical Center
WMD	wake mitigation departure
WMS	wide-area master station
WMSCR	Weather Message Switching Center Replacement
WRC	World Radiocommunication Conference
WRS	WAAS (wide-area augmentation system) reference stations
WTWD	Wake Turbulence Mitigation for Departures
Wx	weather
WXGRAPH	Graphical Weather Information
WXRT	Real-time Weather Reports for Met Office
WXTEXT	Textual Weather Reports

4–D	four dimensional (latitude, longitude, altitude, and time)
4DLINK	proposal for the next data link package that targets initial four-dimensional trajectories and airport services (This capability fits in Implementation Package 2 as identified by the Single European Sky ATM Research (SESAR) Master Plan.)
4DT	four-dimensional trajectory (latitude, longitude, altitude, and time)

Appendix B.—RTCA National Airspace System Concept of Operations Applicable to the Proposed Aeronautical Mobile Airport Communications System (AeroMACS)

AeroMACS 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 40 to Table 44 document the select RTCA NAS ConOps (Ref. 14) found applicable to the proposed AeroMACS.

In addition to the relevant section number, the "Relevant text" column presents the specific text from the NAS ConOps document pertaining to the identified type of information being exchanged and/or service provided. The "Relevant text" in these tables is copyrighted by RTCA, Inc., and is being used with permission.[20]

TABLE 40.—THE ROLE OF SURVEILLANCE INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED AEROMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
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 [communications, navigation, and surveillance] 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	4.1.3	Accurate airport environmental information, including traffic, permits appropriately equipped aircraft to navigate on the airport surface with almost no forward visibility.
S-4	4.2.2	The proliferation of CDTI [cockpit display of traffic information] 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	4.3.2 1st paragraph	… In addition, ground-based surveillance data is shared with users as a safety enhancement for preventing incursions.
S-6	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.

[20]The complete RTCA NAS ConOps (and other RTCA documents) may be purchased from RTCA, Inc., 1828 L St., N.W., Suite 805, Washington, DC 20036 (202–833–9339, http://www.rtca.org).

TABLE 41.—THE ROLE OF WEATHER INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED AEROMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
W-1	1.4 2nd bullet	In addition to this pool of common information, SWIM [System Wide Information Management] 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 9th 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 [traffic flow management] 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	2.2.1 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-6	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-7	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 [Flight Operations Center] computer. In addition, system-wide information is obtained via the FOC SWIM interface.
W-8	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-9	4.1.1 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-10	4.1.2 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-11	4.1.2 4th paragraph	The system provides access to airport environmental information, arrival, departure, and taxi schedules, airborne and surface surveillance information, flight information, ATIS [Automatic Terminal Information System] and other weather information, and TFM initiatives.
W-12	4.1.3 1st paragraph	Hazardous weather alerts are automatically and simultaneously broadcast to aircraft via data link and service providers via SWIM.
W-13	4.2.1 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-14	4.2.2 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.

TABLE 41.—THE ROLE OF WEATHER INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED AEROMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
W-15	4.3.1 1st paragraph	SWIM and ACARS enhance the service provider's ability to provide data products such as NOTAMs [Notices to Airmen] 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-16	4.3.2 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 [b]y the user.

TABLE 42.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
FM-1	1.5.2 9th bullet	A SWIM [System Wide Information Management] 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-2	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 [Special Use Airspace] operations scheduling information.
FM-3	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 [air traffic management] 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-4	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 [Federal Aviation Administration] 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 [air traffic control system command center] allows service providers to evaluate conditions based on user intention rather than published schedules.
FM-5	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-6	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.
FM-7	2.2.3 1st paragraph	…Within that constraint and allocation, the NAS has the ability to conduct a SYSCO [system-supported coordination] 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.
FM-8	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-9	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.
FM-10	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 [traffic flow management] initiatives.
FM-11	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-12	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.

TABLE 42.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
FM-12	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-13	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-14	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 [Flight Operations Center], 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-15	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-16	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-17	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 [decision support systems] using information available via SWIM analyze the route that most closely balances user preferences and constraints. The use of CTAs [Controlled Times of Arrival] 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-18	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 [system-supported coordination] facilitate more effective CDM [collaborative decision making] between the FOC and service provider.
FM-19	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 [flight management system]. Other users can store the flight profile information on disk and upload it into the aircraft's avionics for use.
FM-20	3.2.2 9th paragraph	… SWIM enables domestic and international users and service providers to access flight profiles and associated SUA data.
FM-21	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. …

TABLE 42.—IDENTIFICATION OF THE ROLE OF FLIGHT MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (ConOps) APPLICABLE TO THE PROPOSED AeroMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
FM-22	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-23	4.1.2 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-24	4.1.2 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 [Automatic Terminal Information System] and other weather information; and TFM initiatives. …
FM-25	4.1.2 5th paragraph	On taxi out, the flight's time-based trajectory is updated in SWIM, and projections are made based on prevailing traffic conditions.
FM-26	4.3.1 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

TABLE 43.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED AEROMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
A-1	1.5.2 9th bullet	A SWIM [System Wide Information Management] system is developed by the service provider to distribute timely and consistent information across the NAS …including… 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-2	1.5.2 12th bullet	Traffic information collected by surveillance systems is transmitted to properly equipped aircraft…to support flight deck decisions.
A-3	1.5.3 2nd bullet	Enhanced CNS [communication, navigation, and surveillance] 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-4	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.
A-5	2.2.1 1st paragraph	Users have access to an increasing amount of NAS information including airport status and acceptance rate, …
A-6	3 1st bullet	Elements of SW[I]M are used to obtain and distribute flight-specific data and aeronautical information, including international coordination of flight trajectory.
A-7	3.1.1 3rd paragraph	There is real time sharing of system demand and the virtual ATM [air traffic management] information… User flight planning systems account for system constraints such as flow restrictions, hazardous weather, SUA and infrastructure outages.
A-8	3.1.2 1st paragraph	A NASCR [NAS Common Reference System] 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-9	3.1.2 3rd paragraph	To generate the flight profile, users access current and predicted weather, traffic density, restrictions, and SUA status information …
A-10	3.2.2 9th paragraph	SWIM enables domestic and international users and service providers to access flight profiles and associated SUA data.
A-11	4.1.2 4th paragraph	Access to real-time data for surface movement DSSs [decision support systems] 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 [Flight Operations Center], 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 [Automatic Terminal Information Service] and other weather information; and TFM [traffic flow management] initiatives. This data sharing allows service providers to coordinate local operations with airline ramp and airport operators, thus improving overall airport operations.
A-12	4.1.3 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-13	4.2.1 2nd paragraph	Airport maps are electronically available to properly equipped users

TABLE 43.—IDENTIFICATION OF THE ROLE OF AERONAUTICAL INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED AEROMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
A-14	4.2.2 3rd paragraph	The proliferation of CDTI [cockpit display of traffic information] 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-15	4.3.1 1st paragraph	SWIM and ACARS [Aircraft Communications Addressing and Reporting System] enhance the service provider's ability to provide data products such as NOTAMs [Notices to Airmen] 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 44.—IDENTIFICATION OF THE ROLE OF RESOURCE MANAGEMENT INFORMATION—RTCA NATIONAL AIRSPACE SYSTEM (NAS) CONCEPT OF OPERATIONS (CONOPS) APPLICABLE TO THE PROPOSED AEROMACS

ID	NAS ConOps section	Relevant text (Ref. 14)
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 [communications, navigation, and surveillance] 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 [System Wide Information Management], 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/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	2.5.3	… NAS infrastructure assets are assigned/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-7	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. … User flight planning systems account for system constraints such as flow restrictions, hazardous weather, SUA and infrastructure outages.
RM-8	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 [Flight Operations Center] and improved formulation of TFM [traffic flow management] agreements.

Appendix C.—Hierarchical Diagrams of Functional Requirements

This appendix contains the functional analysis of the AeroMACS C-band communication system presented as a series of hierarchical diagrams (Figure 46 to Figure 61). The "C" preceding all of the numerical functional levels represents "C-band."

The analysis and diagrams were adapted from the National Airspace System Communications System Safety Hazard Analysis and Security Threat Analysis document (Ref. 45).

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

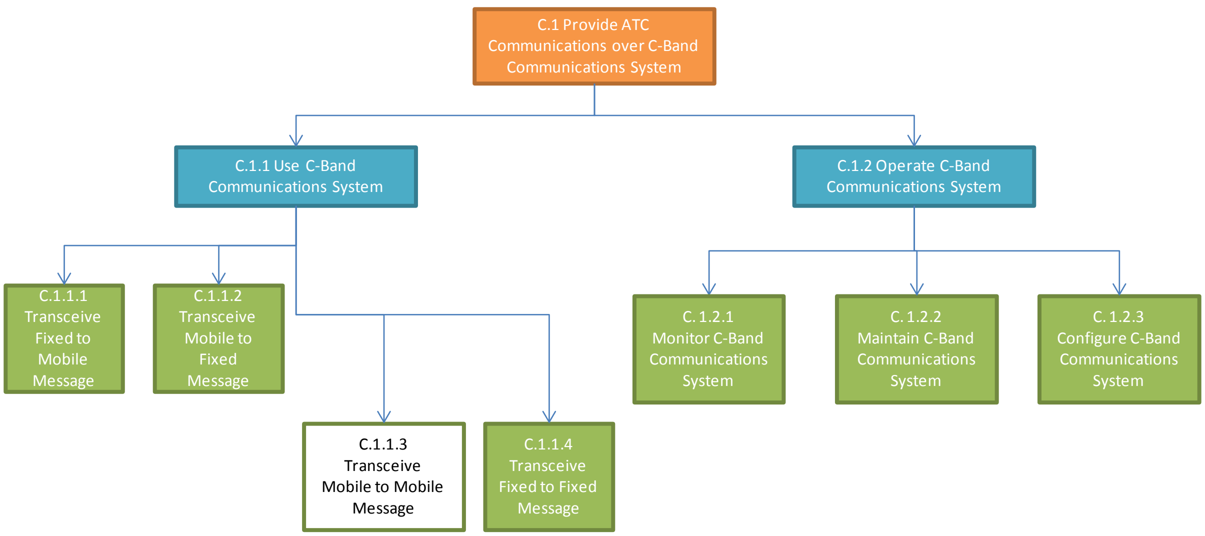

Figure 46.—High-level view of C-band communications system (adapted from Ref. 45).

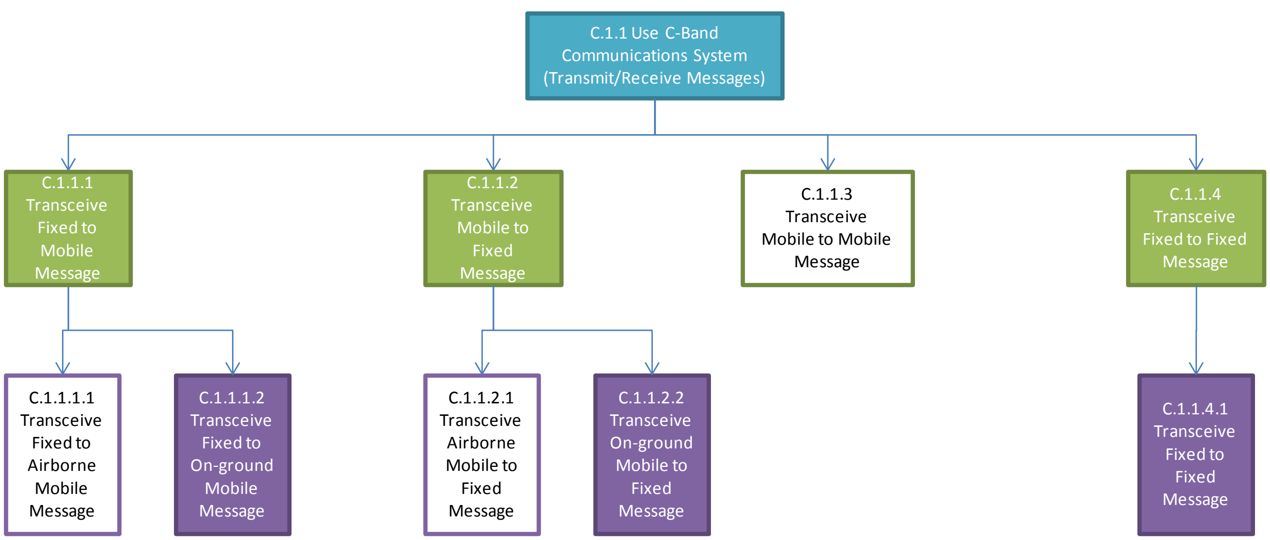

Figure 47.—Decomposition of use of C-band communications system to transmit/receive messages (adapted from Ref. 45).

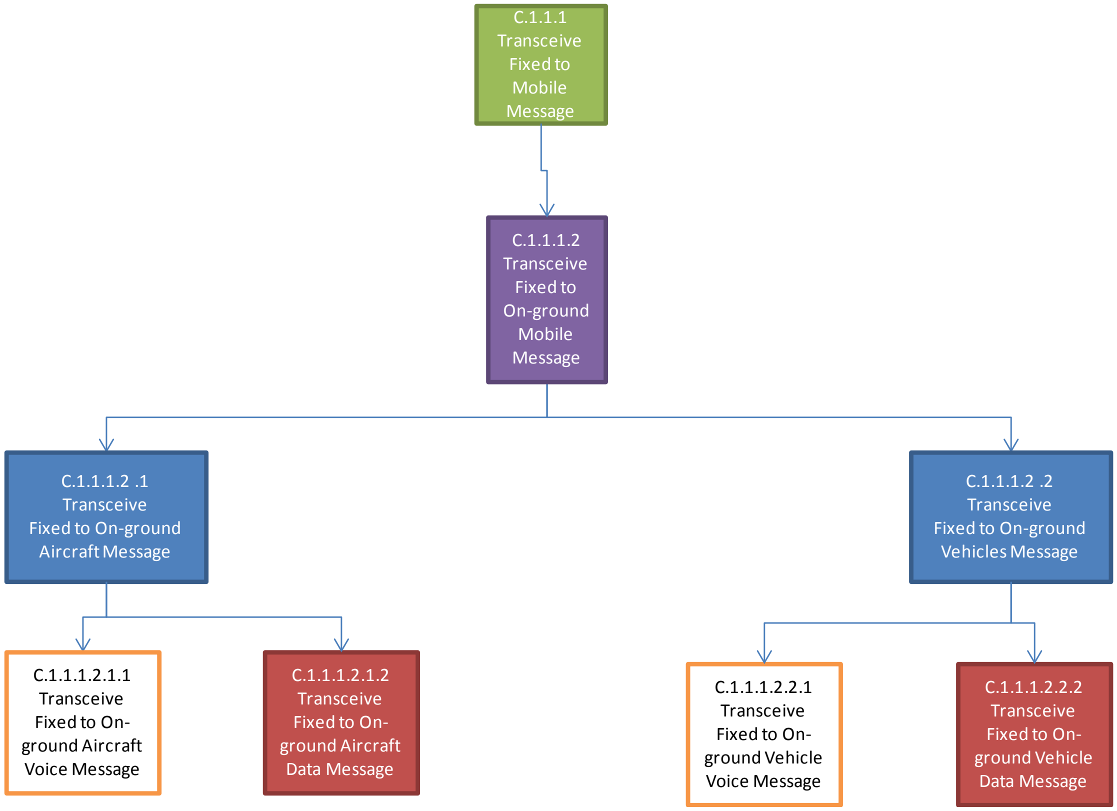

Figure 48.—Decomposition of transceive fixed-to-mobile message (adapted from Ref. 45).

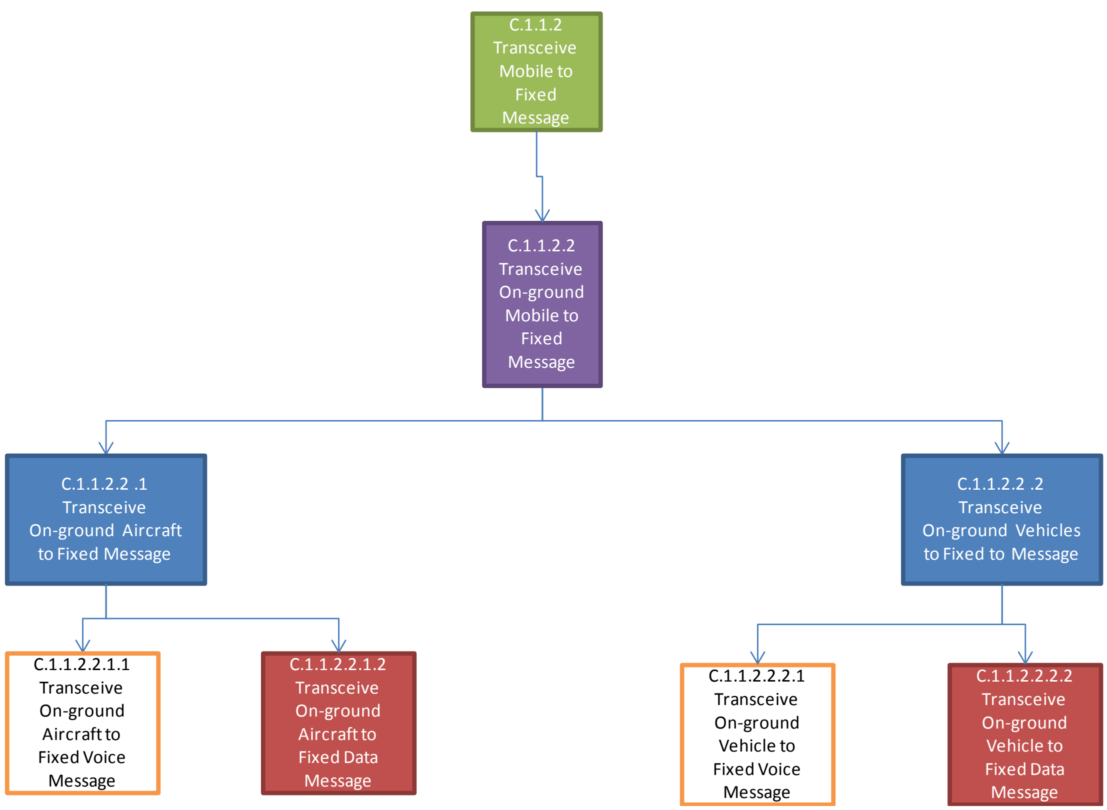

Figure 49.—Decomposition of transceive mobile-to-fixed message (adapted from Ref. 45).

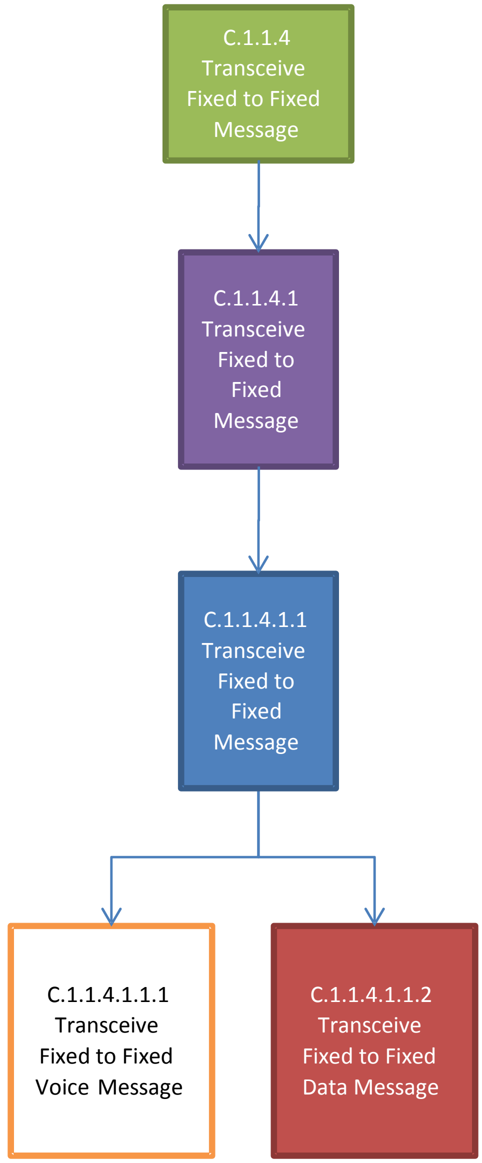

Figure 50.—Decomposition of transceive fixed-to-fixed message (adapted from Ref. 45).

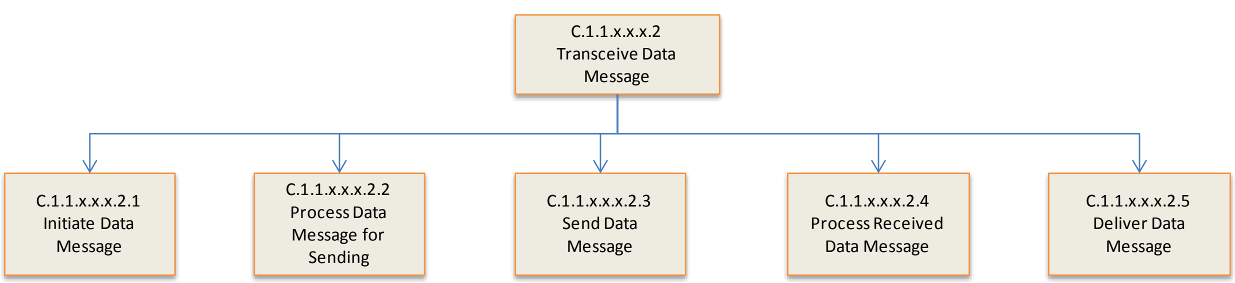

Figure 51.—Generic decomposition of transceive data message (adapted from Ref. 45).

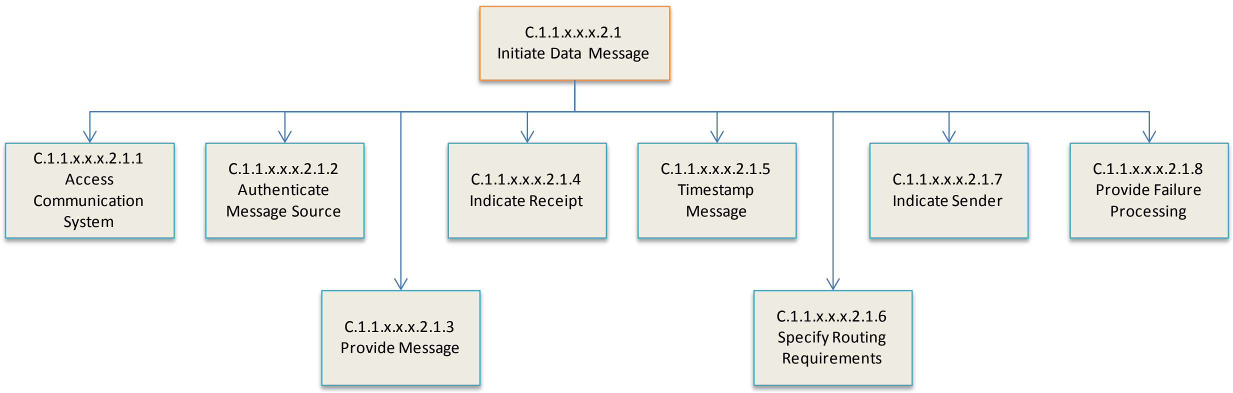

Figure 52.—Generic decomposition of initiate data message (adapted from Ref. 45).

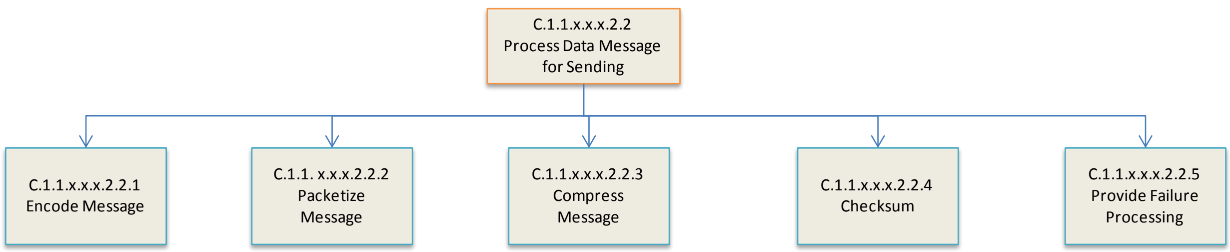

Figure 53.—Generic decomposition of process data message for sending (adapted from Ref. 45).

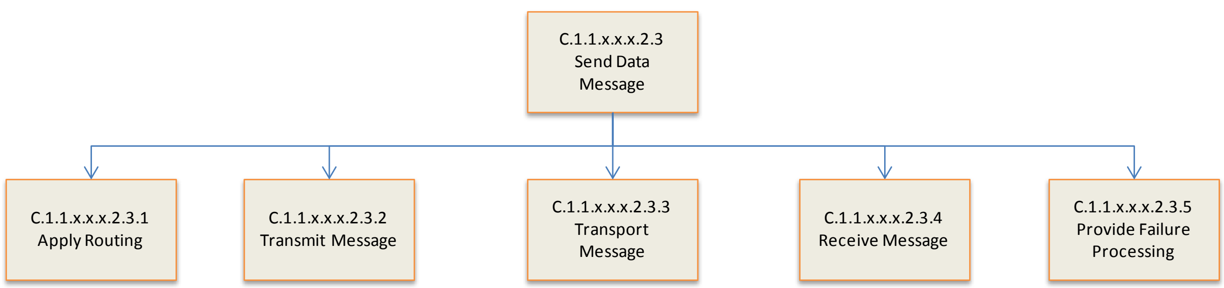

Figure 54.—Generic decomposition of send data message (adapted from Ref. 45).

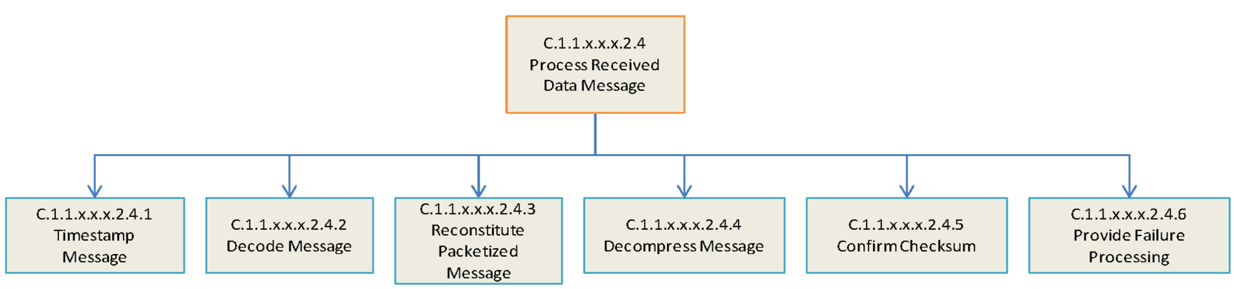

Figure 55.—Generic decomposition of process received data message (adapted from Ref. 45).

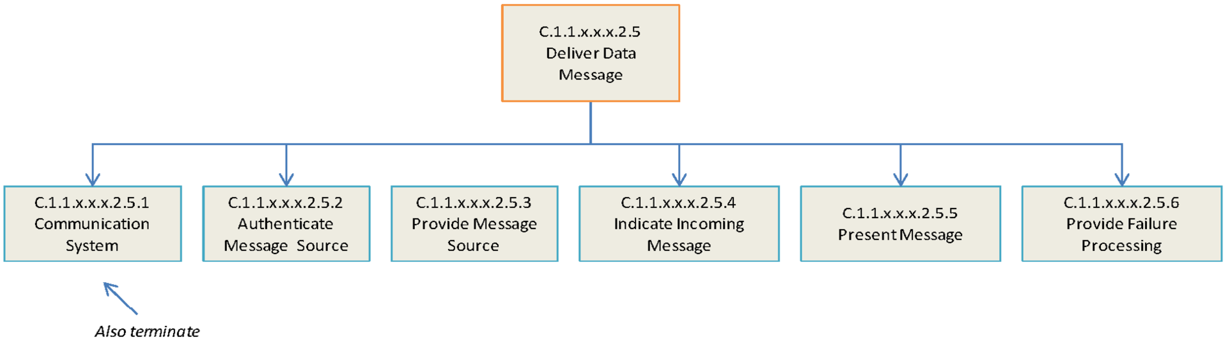

Figure 56.—Generic decomposition of deliver data message (adapted from Ref. 45).

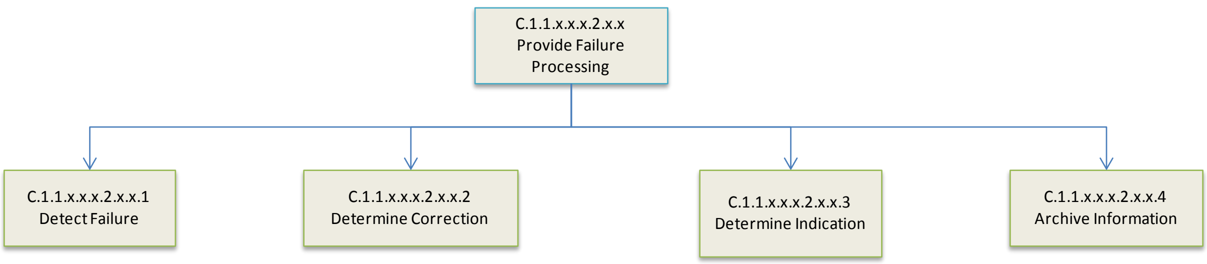

Figure 57.—Generic decomposition of provide failure processing (adapted from Ref. 45).

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

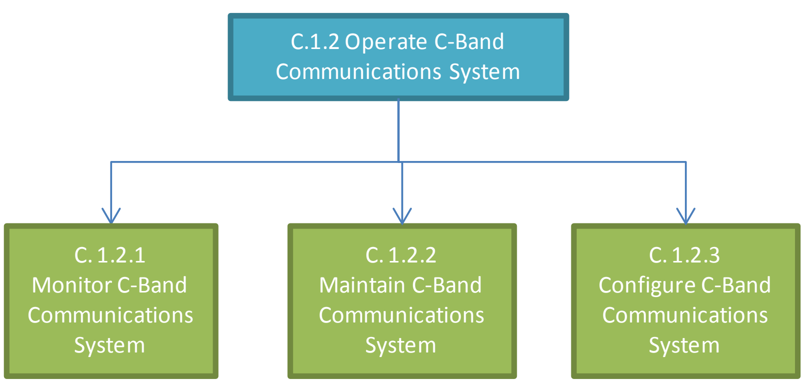

Figure 58.—Decomposition of operate C-band communications system (adapted from Ref. 45).

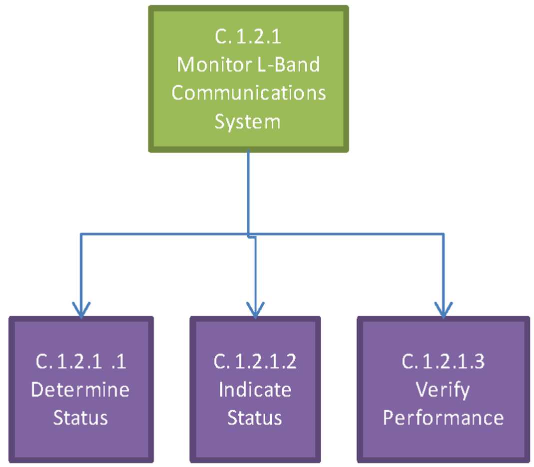

Figure 59.—Decomposition of monitor C-band communications system (adapted from Ref. 45).

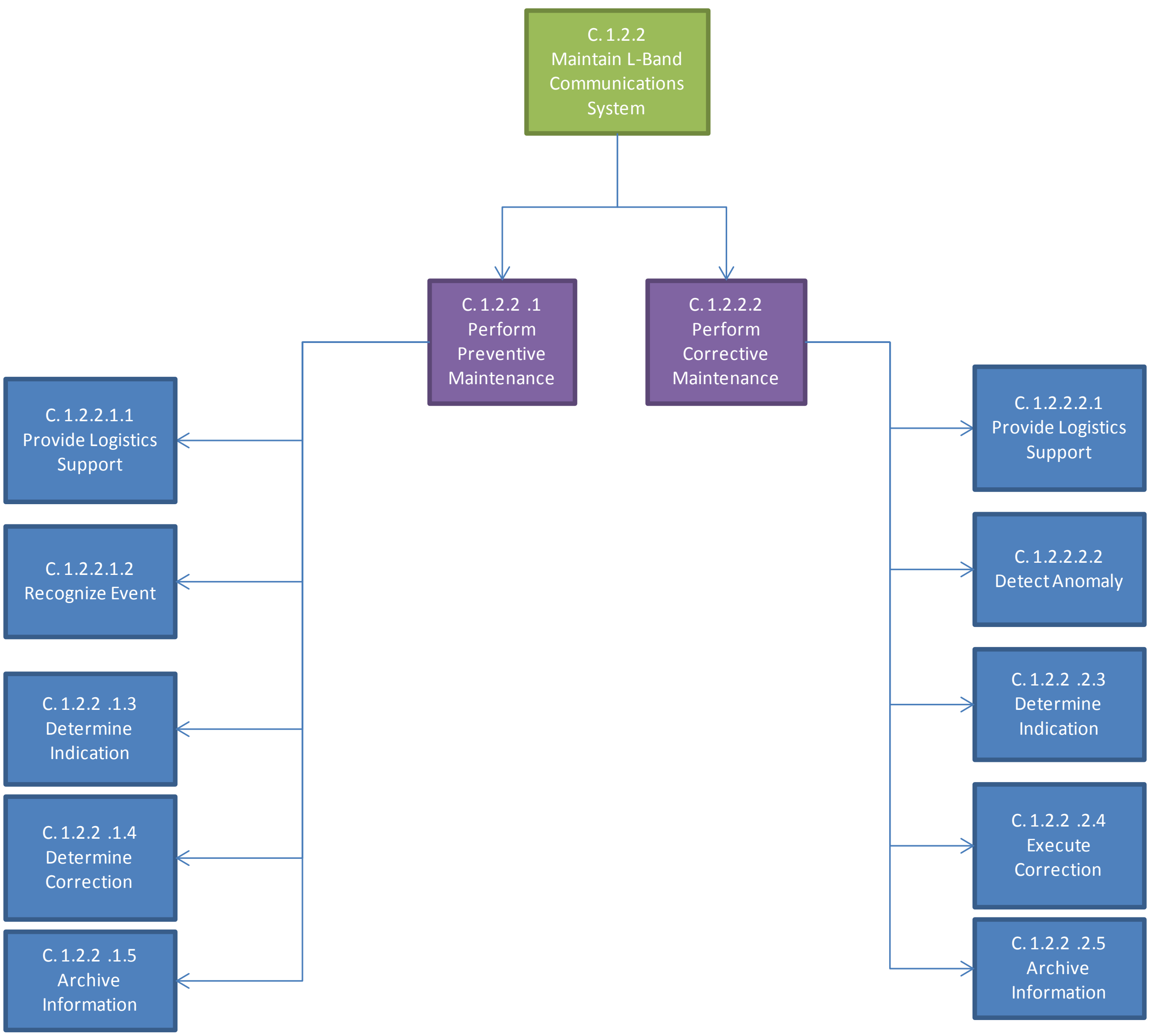

Figure 60.—Decomposition of maintain C-band communications system (adapted from Ref. 45).

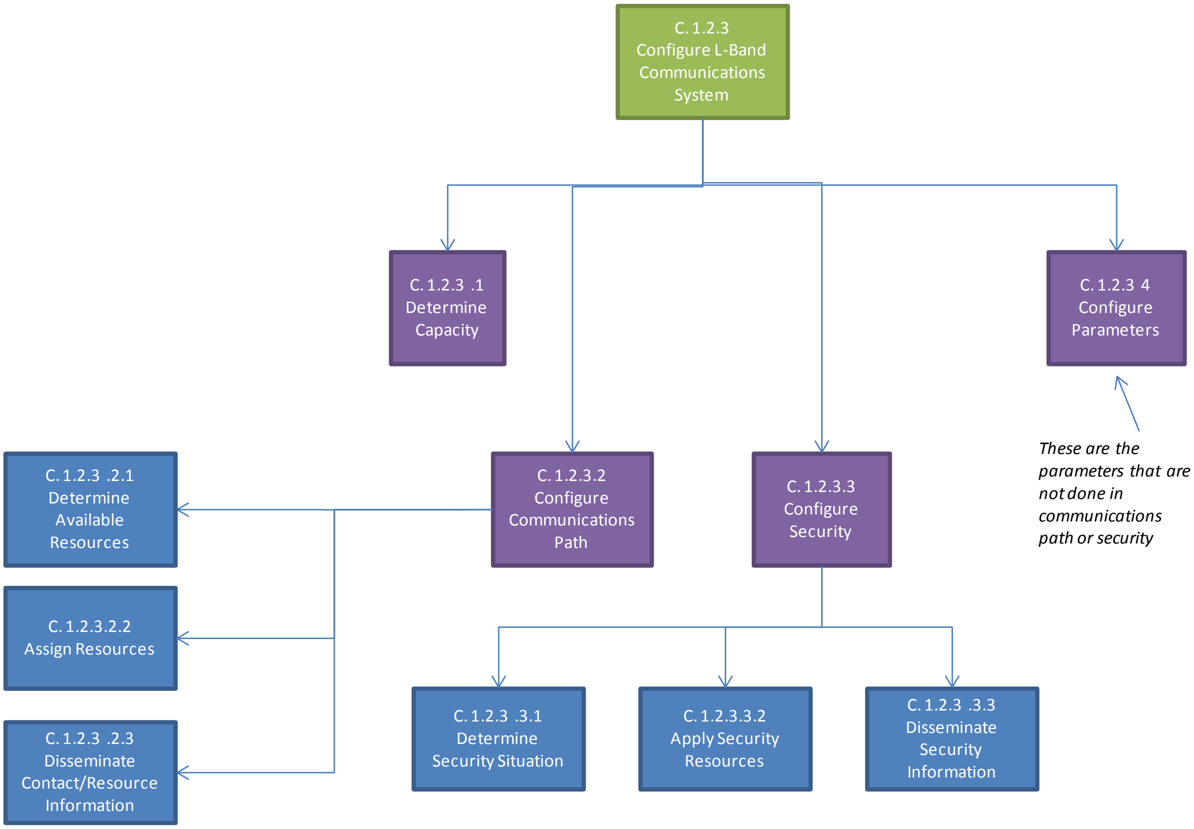

Figure 61.—Decomposition of configure C-band communications system (adapted from Ref. 45).

Appendix D.—Examples of Airport Categories Based on Propagation Characteristics

The following figures present examples of airports categorized based on propagation environment.

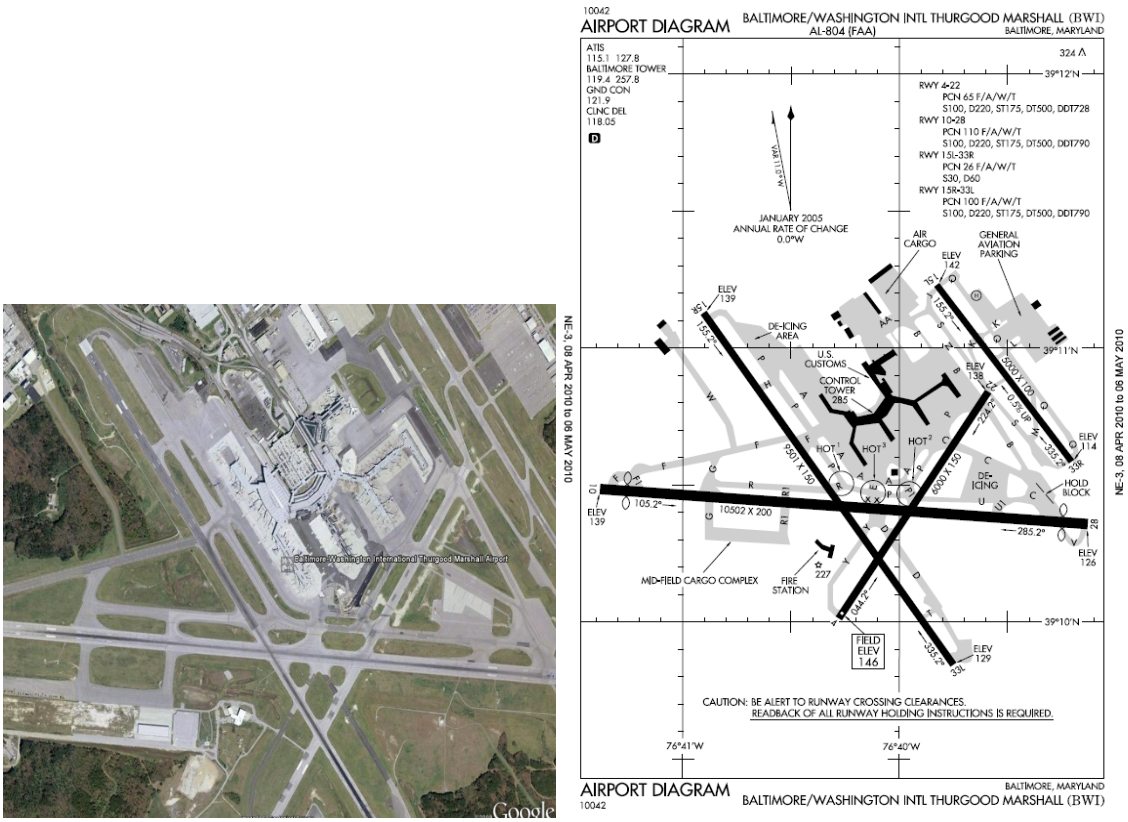

Figure 62.—Baltimore/Washington International (BWI) Airport. Parallel runways and terminals in between; snowflake-like aprons.

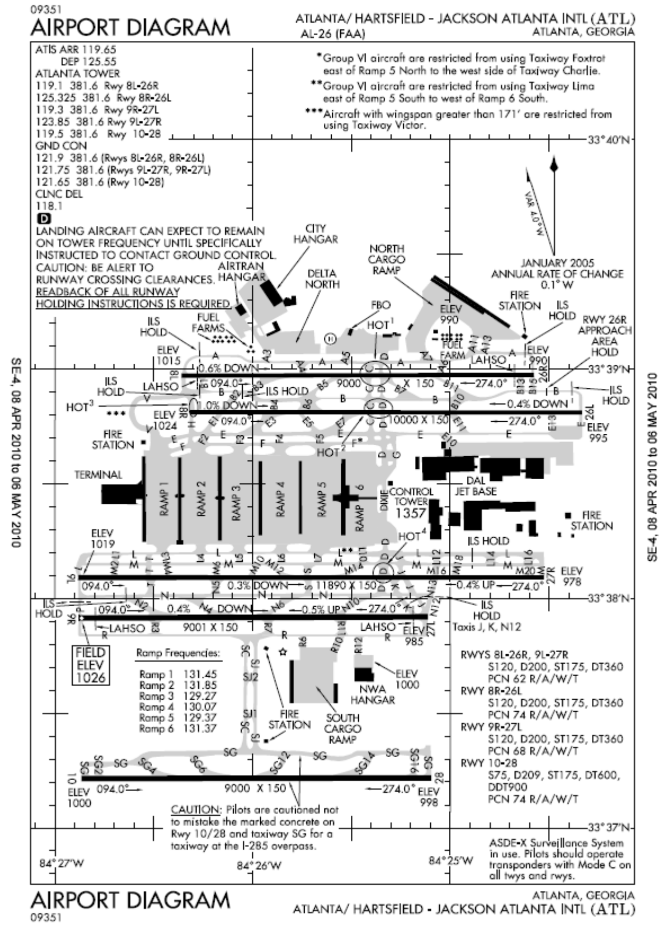

Figure 63.—Hartsfield-Jackson Atlanta International Airport (ATL). Parallel runways and terminals in-between; grid aprons.

Appendix E.—RTCA SC–223 USAS Workbook Summary

Appendix E summarizes the results of the ongoing work of the RTCA SC–223 USAS WG. The set of tables below presents the potential AeroMACS applications identified as "services and applications that deserve attention sooner in the data collection process" (Ref. 60). The information is extracted from the consolidated workbook that was updated based on the USAS ad-hoc WG meeting discussions on October 15, 2010, at the RTCA (Ref. 60)[21] and is presented per functional domain.

TABLE 45.—POTENTIAL AEROMACS APPLICATIONS: ATM-ATC FUNCTIONAL DOMAIN

Name	Owner	Existing/ future	Mobile/ fixed	Category	Performance requirements	Security requirements	Transport contents	End Points	Description/ Function
Current ACARS									
Pre Departure Clearance	FAA - Airline	Existing	Mobile	ATS	Data Rate: L Latency (RT): H Availability: VL	Private Network	ACARS Character -oriented datagram	Airport ATC Tower & Service Provider	Provides Departure Clearance information
SC-214 CPDLC Services									
DTAXI Graphical Message Service	FAA - ANSP	Future	Mobile	ATC	Data Rate: M Latency (RT): L Availability: H	Authentication	ATN message CPDLC exchange	AC-TFDM	Transmit a representation of the taxi route to the aircraft for display
4DTRAD for surface movement	AC & ANSP	Far Future	Mobile	ATC	Data Rate: M Latency (RT): M Availability: H	Authentication			
Security messaging (FAA requested)	FAA	Future	Mobile	ATC	Data Rate: M Latency (RT): M Availability: H	Authentication	ATN message exchange		
COCR Services (not in SC-214 and surface related)									
Metro logical Info D-SIGMET	FAA	Future	Mobile	ATC		Authentication	ATN message exchange		
Surface Informati on Guidance D-SIG	FAA	Future	Mobile	ATC		Authentication	ATN message exchange		
Wake Broadcast (WAKE)	FAA	Future	Mobile	ATC		Authentication	ATN message exchange		
Pilot preference s (PPD)	FAA	Future	Mobile	ATC		Authentication	ATN message exchange		
Urgent Contact (URCO)	FAA	Future	Mobile	ATC		Authentication	ATN message exchange		

[21]The version presented here is a work in progress document with the estimated completion time December 31, 2010.

TABLE 46.—POTENTIAL AEROMACS APPLICATIONS—AIS & MET FUNCTIONAL DOMAIN

Application Information/Data
SWAP Re-routing negotiations
Data Link Aeronautical Update Service (D-AUS)
Station NOTAMs –Textual aerodrome NOTAMs. –Includes a plain text option.
“Live 10-9” NOTAMs. (Aerodrome NOTAMs overlaid on AMDBs.)
10-7 Airport Notes Updates
En route SAA NOTAMs
Nav aid and procedure NOTAMs.
Runway configuration information
MET Data Link Weather Planning Decision Service (D-WPDS) (Per SC-206)
MET Data Link Weather Near-Term Decision Service (D-WNDS) (Per SC-206)
MET Data Link Weather Immediate Decision Service (D-WIDS) (Per SC-206)
Convection products –Convective SIGMET –Ground Radar –Forecast
Lightning
Turbulence –PIREP (Voice and Auto) –GTG (Graphical Turbulence Guidance) –SIGMET/AIRMET
Icing –PIREP –SIGMET/AIRMET –Current Icing Product (CIP) –Forecast Icing Potential (FIP)
Volcanic ash –SIGMET –Advisory
Cyclone –Tropical depression –Tropical storm –Hurricane/Typhoon
Atmosphere synopses –Surface Analysis –Surface Prog –Upper Air Analysis –Upper Air Prog
Wind –Aloft –Airport Surface

TABLE 46.—POTENTIAL AEROMACS APPLICATIONS—AIS & MET FUNCTIONAL DOMAIN

Application Information/Data
Temperature –Aloft –Surface
Pressure –Aloft –Surface
Windshear –Microburst –Windshear Alert –LLWS –PIREP
Precipitation –Ground Radar –METARs/SPECIs & TAFs –Area Forecast –Surface Analysis Forecast
Cloud –METAR/TAF –Satellite –AIRMET (IFR/Mountain Obscuration) –Area Forecast –PIREP
Visibility –RVR –METAR/TAF –Area Forecast
Ozone 14 CFR 25.183.
Space weather
Operational Category –VFR, MVFR, IFR, Low IFR
D-OTIS (DL Operational Terminal Information Service) –D-NOTAM
D-RVR (DL Runway Visual Range Service)
D-HZWX (DL - Hazardous Weather)
–D-SIGMET

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
VoIP Transmissions (Examples below)			
Fueling Crew		1 Fuel Handler 2 Fuel Dispatch Office	Coordination of fueling operations
Wheel Chairs		1 Wheel Chair Pusher 2 WC Coordination Office	Coordination of wheel chair service
Catering Crew			Coordination of catering, food, water operations
De Ice Crew		1 De Ice Crew 2 Dispatch Office 3 Aircraft—VHF	Coordination of De ice ops
Maintenance Crew		1 Maintenance Tech 2 Maint Supvr 3 Maint Ops Coord	Coordination of unscheduled maintenance
Ground Crew		1 Taxi Director Wing Walkers 2 Maint Crew 3 Jetway Driver 4 Catering Crew 5 Tow Tug Driver 6 Fueling Crew 7 Ground Ops Power 8 Air-conditioning 9 Bag Handlers 10 Concourse Supv 11 Red Coat Ops 12 Check in Ops 13 Customs 14 Immigration 15 Gate assignment 16 Cargo Handlers 17 Sanitation Crew 18 Aircraft Cleaning	Coordination of aircraft handling
Cargo Operations			Coordination of Cargo Operations
Bags		1 Bag handlers 2 Gate handlers 3 Check in 4 Bag Recovery	Coordination of passenger bags
Gate Info		1 Ground Crew 2 Station Ops	Aircraft gate assignments
Weather Ops		1 Station Ops 2 Ground Crews 3 Supervisors 4 Flight Crews	Coordinate change management due to weather issues
Gate Returns		1 Ground Crew 2 Supervisors 3 Specialty Crews	Coordinate gate assignment and ground support

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
Security			Coordinates ground security
Ground Clearance		1 Gate Crews 2 Pilots 3 Wt & Balance 4 Central Dispatch 5 Station Ops	Coordinates flight release
Fire Department		1 Ground Crew 2 Station Ops 3 Gate Ops 4 Supervisors	Emergency comm with fire dept
AIS Datalink Baseline Synchronization Service (D-BSS) (i.e., Complete Synchronization & Update Synchronization Per DO-308) Products include:			
–Aerodrome Charts (pre-composed)			
–Aerodrome Charts (data-driven)	Existing (Data loader, wireline, and/or wireless)	Owner/Operator or Service Provider to AC	BSS 28 days or less
–Standard Instrument Departures (SIDs) (pre-composed)			
–Standard Instrument Departures (SIDs) (data-driven)			
–Engine-Out Procedures (pre-composed)			
–Engine-Out Procedures (data-driven)			
–IFR En Route Charts (pre-composed)			
–IFR En Route Charts (data-driven)			
–VFR Aeronautical Charts (pre-composed)			
–VFR Aeronautical Charts (data-driven)			
–Standard Terminal Arrival Routes (STARs) (pre-composed)			
–Standard Terminal Arrival Routes (STARs) (data-driven)			
–Instrument Procedures (pre-composed)			
–Instrument Procedures (data-driven)			
–Charted Visual Approach Procedures (pre-composed)			
–Charted Visual Approach Procedures (data-driven)			
–Noise Abatement Procedures (pre-composed)			
–Noise Abatement Procedures (data-driven)			
–Terrain			
–Obstacles			

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
–FMS and GPS navigation data bases (ARINC 424 DB)			
–Other Onboard Loadable software	Existing (Dataloader, CD)		
System monitoring (routine)			
–Engine condition monitoring	ACARS		
–Airframe, avionics and systems condition monitoring	ACARS		
Electronic Logbooks	Intranet or Gatelink		
FOQA Data	Data loader or Gatelink		
Update of EFB Databases, Company manuals & SOPs highlighted in yellow for details			
–Flight Operations Manuals (FOM)	Intranet or Gatelink		
–Company Standard Operating Procedures (SOP)	Intranet or Gatelink		
–Airport diversion policy guidance, including a list of Special Designated Airports and/or approved airports with emergency medical service (EMS) support facilities	Intranet or Gatelink		
–Operations Specifications (OpSpecs)	Intranet or Gatelink		
–Cockpit observer briefing cards	Intranet or Gatelink		
–Airplane Flight Manuals (AFM) and Airplane Flight Manual Supplements (AFMS)	Intranet or Gatelink		
–For smaller aircraft, Pilot Operating Handbooks (POH), including POH section IX supplements	Intranet or Gatelink		
–Aircraft performance data (fixed, non-interactive material for planning purposes)	Intranet or Gatelink		
–Airport performance restrictions manual (such as a reference for takeoff and landing performance calculations	Intranet or Gatelink		
–Other aircraft performance data, including specialized performance data for use in conjunction with advanced wake vortex modeling techniques, land-and-hold-short operations (LAHSO) predictions, etc. (fixed, non-interactive material for planning purposes)	Intranet or Gatelink		
–Maintenance manuals (Instructions for continued airworthiness)	Intranet or Gatelink		
–Aircraft maintenance reporting manuals	Intranet or Gatelink		
–Aircraft flight log and servicing records	Intranet or Gatelink		

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
–Autopilot approach and autoland records	Intranet or Gatelink		
–Flight Management System/Flight Management and Guidance System problem report forms	Intranet or Gatelink		
–Aircraft parts manuals (Configuration control)	Intranet or Gatelink		
–Service bulletins/published Airworthiness Directives, etc.	Intranet or Gatelink		
–Air Transport Association (ATA) 100 format maintenance discrepancy write-up codes	Intranet or Gatelink		
–Required VHF Omni directional Range (VOR) check records	Intranet or Gatelink		
–Minimum Equipment Lists (MEL)	Intranet or Gatelink		
–Configuration Deviation Lists (CDL)	Intranet or Gatelink		
–Federal, state, and airport-specific rules and regulations	Intranet or Gatelink		
–Airport/Facility Directory (A/FD) data (e.g., fuel availability, LAHSO distances for specific runway combinations, etc.)	Intranet or Gatelink		
–Noise abatement procedures for arriving and departing aircraft	Intranet or Gatelink		
–Published (graphical) pilot Notices to Airmen (NOTAM)	Intranet or Gatelink		
–International Operations Manuals, including regional supplementary information and International Civil Aviation Organization (ICAO) differences	Intranet or Gatelink		
–Aeronautical Information Publications (AIP)	Intranet or Gatelink		
–Aeronautical Information Manual (AIM)	Intranet or Gatelink		
–Oceanic navigation progress logs	Intranet or Gatelink		
–Pilot flight and duty-time logs	Intranet or Gatelink		
–Flight crew required rest logs	Intranet or Gatelink		
–Flight crew qualification logs (such as aircraft qualifications, Class II flight crew qualifications, Category (CAT) III qualifications, high minimums logs, night currency logs, pilot-in-command (PIC) qualifications for special areas, routes and airports for part 121 certificate holders, and special airports qualifications)	Intranet or Gatelink		
–Captain’s report (i.e., captain’s incident reporting form)	Intranet or Gatelink		
–Flight crew survey forms (various)	Intranet or Gatelink		
–Flight Attendant Manuals	Intranet or Gatelink		

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
–EMS reference library (for use during medical emergencies)	Intranet or Gatelink		
–Trip scheduling and bid lists	Intranet or Gatelink		
–Aircraft's captain's logs	Intranet or Gatelink		
–Aircraft's CAT II/CAT III landing records	Intranet or Gatelink		
–Antiterrorism profile data	Intranet or Gatelink		
–Hazardous Materials (HAZMAT)/oxidizer look-up tables	Intranet or Gatelink		
–Emergency Response Guidance for Aircraft Incidents Involving Dangerous Goods (ICAO Doc 9481-AN/928)	Intranet or Gatelink		
–Customs declaration and United States Department of Agriculture (USDA) agriculture inspection / clearance form	Intranet or Gatelink		
–Special reporting forms, such as near mid-air collision (NMAC) reports, National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS), bird and wildlife encounters, owner-initiated Service Difficulty Reports (SDR), etc.	Intranet or Gatelink		
–Incidents of interference to aircraft electronic equipment from devices carried aboard aircraft	Intranet or Gatelink		
–Current fuel prices at various airports	Intranet or Gatelink		
–Realistic training module s, including "PC at home" training applications, "off-duty" training materials review, and pre-flight "mission" rehearsals	Intranet or Gatelink		
–Check airman and flight instructor records	Intranet or Gatelink		
–Aircraft operating and information manuals (performance information, weight and balance, systems, limitations, etc.)	Intranet or Gatelink		
–Flight operations manuals including emergency procedures	Intranet or Gatelink		
–Airline policies and procedures manuals	Intranet or Gatelink		
–Aircraft Maintenance Manuals	Intranet or Gatelink		
–Title 14 of the Code of Federal Regulations (14 CFR)	Intranet or Gatelink		
–Look-up and completion of various reporting forms, e.g., company-specific forms, NASA's ASRS reports, NMAC reports, wildlife strike and hazard reports, etc.	Intranet or Gatelink		

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
–Maintenance personnel sign-off of discrepancy form. (Maintenance discrepancy logs need to be downloaded into a permanent record at least weekly.)	Intranet or Gatelink		
–Flight crew qualifications recordkeeping, including aircraft qualifications, CAT II/III, high minimums, landing currency, flight and duty time, etc.	Intranet or Gatelink		
–PIC currency requirements	Intranet or Gatelink		
–The Flight Attendant Manual	Intranet or Gatelink		
–Passenger information requests—some are directed to the gate or to the agent meeting the flight (e.g., special meal requests, wheel chair requirements, unaccompanied minors, gate information for connecting flights, flights being held for connecting passengers, etc.)	Intranet or Gatelink		
–Cabin maintenance write-ups. (Maintenance discrepancy logs need to be downloaded into a permanent record at least weekly.)	Intranet or Gatelink		
–Approved electronic signature using public/private key technology (PKI)	Intranet or Gatelink		
–Takeoff, en route, approach and landing, missed approach, go-around, etc., performance calculations. Data derived from algorithmic data or performance calculations based on software algorithms.	Intranet or Gatelink		
–Power settings for reduced thrust settings	Intranet or Gatelink		
–Runway limiting performance calculations	Intranet or Gatelink		
–Cost index modeling	Intranet or Gatelink		
–Master flight plan/updating	Intranet or Gatelink		
–Interactive Plotting for Class II navigation	Intranet or Gatelink		
–Mission rehearsals	Intranet or Gatelink		
–Weight and balance calculations	Intranet or Gatelink		
–Maintenance discrepancy sign-off logs. (Maintenance discrepancy logs need to be downloaded into a permanent record at least weekly.)	Intranet or Gatelink		
–Cabin maintenance discrepancy reporting forms/location codes. (Maintenance discrepancy logs need to be downloaded into a permanent record at least weekly.)	Intranet or Gatelink		

TABLE 47.—POTENTIAL AEROMACS APPLICATIONS—AIRLINES/CARGO OPERATIONS (AIRLINE-CARGO OPS) AND D-BSS (BASELINE SYNC SERVICE) FUNCTIONAL DOMAIN

Name	Existing/Future	End Points	Description/Function
–Non-interactive electronic approach charts in a pre-composed format from accepted sources	Intranet or Gatelink		
–Panning, zooming, scrolling, and rotation for approach charts.	Intranet or Gatelink		
–Pre-composed or dynamic interactive electronic aeronautical charts (e.g., en route, area, approach, and airport surface maps) including, but not limited to, centering and page turning but without display of aircraft/own-ship position.	Intranet or Gatelink		
–Electronic checklists, including normal, abnormal, and emergency. See the current version of Advisory Circular (AC) 120-64, Operational Use & Modification of Electronic Checklists, for additional guidance. EFB electronic checklists cannot be interactive with other aircraft systems.	Intranet or Gatelink		
–Applications that make use of the Internet and/or other aircraft operational communications (AOC) or company maintenance-specific data links to collect, process, and then disseminate data for uses such as spare parts and budget management, spares/inventory control, unscheduled maintenance scheduling, etc. (Maintenance discrepancy logs need to be downloaded into a permanent record at least weekly.)	Intranet or Gatelink		
–Weather and aeronautical data	Intranet or Gatelink		
–Cabin-mounted video and aircraft exterior surveillance camera displays	Intranet or Gatelink		
Integrated Pilot Information Bulletin (PIB) [AIS & MET data] Also includes AIP data, as needed			
MEL / MRD / CDL	Paper / ACARS		
Dispatch Release	Paper / ACARS		
Initial & final weight and balance data	Paper / ACARS		
ATC ADS-B back-up surveillance data (to mitigate against reflected ADS-B signals)			
Refueling Data	Paper / ACARS		
FMS wind field data			
Hazardous cargo manifest documentation			
Before or after before engine checklist: AIS & MET Data Link Services			
Electronic transmission of misc documentation to crew, e.g., duplicate pilot or medical certificates, missing paper chart replacement			

TABLE 48.—POTENTIAL AEROMACS APPLICATIONS—AIRPORT OPERATION FUNCTIONAL DOMAIN

Name	Owner	Existing/ Future	Mobile/ Fixed	Category	Performance Requirements	Security Requirements	Transport Contents	End Points
FAR 139 Safety Self Inspection								
Navigational Aids System Maint.	Airport Authority	Existing	Existing is fixed, would like to migrate to Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:M	Authentication	Text & Light Graphics	OPS Server - Computer
Signage	Airport Authority	Existing	Existing is fixed, would like to migrate to Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:M	Authentication	Text & Light Graphics	OPS Server - Computer
Pavement Management System	Airport Authority	Existing	Existing is fixed, would like to migrate to Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:M	Authentication	Text & Light Graphics	OPS Server - Computer
FOD management	Airport Authority	Existing	Existing is fixed, would like to migrate to Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:M	Authentication	Text & Light Graphics	OPS Server - Computer
Snow Removal Monitoring and Ice Control	Airport Authority	Existing	Existing is fixed, would like to migrate to Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:M	Authentication	Text and Light Graphics	Ops - Vehicle
Wildlife Management System	Airport Authority	Existing	Existing is fixed, would like to migrate to Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:M	Authentication	Text and Light Graphics	Server - Computer/ Ipad
AVL – Geo Fencing and Movement Area Management	Airport Authority	Future	Mobile	Airport Operations: Airfield Operations	Data Rate: M Latency (RT):L Availability:M	Authentication	Text & graphics	Server - Computer/ Ipad
Public Safety Handheld & vehicle-mounted mobile data terminals								
Fire	Airport Authority	Future	Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:H	Authentication	Text & light graphics	Server - Hand held devices and vehicle mounted
Emergency Management (EMD)	Airport Authority	Future	Mobile	Airport Operations: Airfield Operations	Data Rate: L Latency (RT):L Availability:H	Authentication	Text & light graphics	Server - Hand held devices and vehicle mounted

TABLE 49.—POTENTIAL AEROMACS APPLICATIONS—AIRPORT INFRUSTRUCTURE FUNCTIONAL DOMAIN

Name	Owner	Existing/ Future	Mobile/ Fixed	Performance Requirements	Security Requirements	Transport Contents	Description/ Function	Comments
Airport Surface Detection Equipment X (ASDE-X)	FAA	E	F	Routine	BD1, ED3	SM Data	Surface Movement Data	(ATCT to ASDE, HDQ, VOR, ASR, IMDS, OPIP)
Airport Surface Detection Equipment 3 (ASDE-3)	FAA	E	F	Routine		SM Data	Surface Movement Data	
Remote Transmitter-Receiver (RT/R)	FAA	E	F	Critical		ATC Voice	Provides pilot-to-controller voice communications in the terminal area.	

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14. ABSTRACT
This report is 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" and was based on direction provided by FAA project-level agreements for "New ATM Requirements-Future Communications." Task 7 included two subtasks. Subtask 7-1 addressed C-band (5091- to 5150-MHz) airport surface data communications standards development, systems engineering, test bed and prototype development, and tests and demonstrations to establish operational capability for the Aeronautical Mobile Airport Communications System (AeroMACS). Subtask 7-2 focused on systems engineering and development support of the L-band digital aeronautical communications system (L-DACS). Subtask 7-1 consisted of two phases. Phase I included development of AeroMACS concepts of use, requirements, architecture, and initial high-level safety risk assessment. Phase II builds on Phase I results and is presented in two volumes. Volume I (this document) is devoted to concepts of use, system requirements, and architecture, including AeroMACS design considerations. Volume II describes an AeroMACS prototype evaluation and presents final AeroMACS recommendations. This report also describes airport categorization and channelization methodologies. The purposes of the airport categorization task were (1) to facilitate initial AeroMACS architecture designs and enable budgetary projections by creating a set of airport categories based on common airport characteristics and design objectives, and (2) to offer high-level guidance to potential AeroMACS technology and policy development sponsors and service providers. A channelization plan methodology was developed because a common global methodology is needed to assure seamless interoperability among diverse AeroMACS services potentially supplied by multiple service providers.

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