Communications Operating Concept and Requirements for the Future Radio System

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Future Communications Study
Operational Concepts and Requirements Team

EUROCONTROL

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ACRONYMS and ABBREVIATIONS

2-D	Two Dimensional (latitude and longitude)
3-D	Three Dimensional (latitude, longitude and altitude)
4-D	Four Dimensional (latitude, longitude, altitude, and time)
ACAS	Aircraft Collision Avoidance System
ACC	Area Control Centre
ACL	ATC Clearances
ACM	ATC Communications Management
ACMS	Aircraft Condition Monitoring System
ADAP	Automated Downlink of Airborne Parameters
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance – Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
AEEC	Airlines Electronic Engineering Committee
AGDL	Air/Ground Data Link
A-EXEC	Automatic Execution Service
AIC	Aeronautical Information Circular
AIRSEP	Air-to-Air Self-Separation Service
AMAN	Arrival Manager
AMC	ATC Microphone Check
AMN	Airspace Management and Navigation
AM(S)S	Aeronautical Mobile (Route) Service
AMS(R)S	Aeronautical Mobile Satellite (Route) Service
ANSP	Air Navigation Service Provider
AO	Airline Operations
AOA	Autonomous Operations Area
AOC	Aeronautical Operational Control
AP	Action Plan
APP	Approach Control
APT	Airport
ARMAND	Arrival Manager Information Delivery Service
AS	Airborne Surveillance
ASAS	Airborne Separation Assistance System
A-SMGCS	Advanced-Surface Movement Guidance and Control System
ASPA	Airborne Spacing
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFM	Air Traffic Flow Management
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATS	Air Traffic Services
ATSA	Airborne Traffic Situational Awareness
ATSU	ATS Unit
bps	bits per second
Bps	Bytes per second
C&P	Crossing and Passing
CASCADE	Co-operative ATS through Surveillance and Communication Applications

	Deployed in ECAC
C-ATSU	Controlling ATSU
CDM	Collaborative Decision-making
CDTI	Cockpit Display of Traffic Information
CFMU	Central Flow Management Unit
CNS	Communication, Navigation and Surveillance
COCR	Final Communications Operating Concepts and Requirements
COS	Class of Service
COTRAC	Common Trajectory Co-ordination
CPDLC	Controller-Pilot Data Link Communication
CTOT	Calculated Takeoff Time
CWP	Controller Working Position
D-ALERT	Data Link Alert
D-ATIS	Data Link ATIS
D-ATSU	Downstream ATSU
DCL	Departure Clearance
D-FIS	Data Link Flight Information Service
D-FLUP	Data Link Flight Update Service
DLL	Data Link Logon
DLORT	Data Link Operational Requirements Team
DMAN	Departure Manager
DME	Distance Measuring Equipment
D-ORIS	Data Link Operational En-Route Information Service
D-OTIS	Data Link Operational Terminal Information Service
D-RVR	Data Link Runway Visual Range
DSB-AM	double side band - amplitude modulation
DSC	Downstream Clearance
D-SIG	Data Link Surface Information and Guidance
D-SIGMET	Data Link Significant Meteorological Information
D-TAXI	Data Link Taxi Clearance Delivery
DYNAV	Dynamic Route Availability
E2E	end to end
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference
EFB	Electronic Flight Bag
EICAS	Engine Indicating and Crew Alerting System
EMER	Emergency
ENR	En route
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FCI	Future Communications Infrastructure
FCS	Future Communications Study
FDPS	Flight Data Processing System
FIS	Flight Information Service
FLIPCY	Flight Plan Consistency
FLIPINT	Flight Path Intent
FM	Frequency Modulation

FMP	Flight Management Position
FMS	Flight Management System
FPL	Flight Plan
FRS	Future Radio System
FUA	Flexible Use of Airspace
g	Gravity
GA	General Aviation
GAT	General Air Traffic
GBAS	Ground-Based Augmentation System
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
GRECO	Graphical Enabler for Graphical Co-ordination
GS	Ground Surveillance
HF	High Frequency
HMI	Human Machine Interface
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ICOCR	Initial Communications Operating Concepts and Requirements
IFPS	Initial Flight Plan Processing System
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
ITP	In Trail Procedure
ITU	International Telecommunication Union
JPDO	Joint Planning and Development Organisation
kbps	kilobits per second
kHz	kilo-Hertz
KIAS	Knots Indicated Air Speed
kph	kilometres per hour
MASPS	Minimum Aviation System Performance Standards
mE	milli-Erlangs
MEL	Minimum Equipment List
METAR	Meteorological Aerodrome Report
MHz	mega-Hertz
MLM	Mid-Level Model
MLS	Microwave Landing System
MNPS	Minimum Navigation Performance Specification
MOS	Mean Opinion Score
m/s^2	metres per second squared
ms	milliseconds
MTCD	Medium Term Conflict Detection
n/a	Not available
NAS	National Airspace System (USA)
NGATS	Next Generation Air Transportation System
NM	nautical mile
NOP	Network Operations Plan
NOTAM	Notice to Airmen

OAT	Operational Air Traffic
OCD	Operational Concept Document
OEP	Operational Evolution Plan
OOOI	Out-Off-On-In
OPA	Operational Performance Assessment
ORP	Oceanic, Remote, Polar
OSA	Operational Safety Assessment
PAIRAPP	Paired Approach
PIAC	Peak Instantaneous Aircraft Count
PIB	Pre-flight Information Bulletin
PIREP	Pilot Report
PLAN	Planning
PPD	Pilot Preferences Downlink
PSR	Primary Surveillance Radar
QoS	Quality of Service
RCP	Required Communication Performance
RCTP	Required Communication Technical Performance
RF	radio frequency
RNAV	Area Navigation
RNP	Required Navigation Performance
ROV	Remotely Operated Vehicle
rsvd	reserved
RTA	Required Time of Arrival
RTD	Required Time of Departure
RTF	Radio Telephony
RTCA	RTCA, Inc.
RVR	Runway Visual Range
RVSM	Reduced Vertical Separation Minima
s	seconds
S&M	Sequencing and Merging
SAAM	System for Assignment and Analysis at a Macroscopic Level
SAP	System Access Parameters
SARPS	Standards and Recommended Practices
SARS	Severe Acute Respiratory Syndrome
SATCOM	Satellite Communications
SBAS	Space-Based Augmentation System
SC	Special Committee
SID	Standard Instrument Departure
SPR	Safety and Performance Requirements
SRS	Standard Routing Scheme
SSR	Secondary Surveillance Radar
STAR	Standard Terminal Arrival Route
STATFOR	Statistics and Forecast Service
STRAT	Strategic
SUV	Special Use Vehicles
TAC	Tactical
TAF	Terminal Area Forecast

TBD	To be determined
TBS	To be supplied
TD	Transit Delay
TFM	Traffic Flow Management
TIS-B	Traffic Information Service – Broadcast
TMA	Terminal Manoeuvring Area
TOD	Top of Descent
TWR	Tower Control
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aerial System
UCT	Coordinated Universal Time
UPT	User Preferred Trajectory
URCO	Urgent Contact Service
U.S.	United States
VDL	VHF Digital Link
VHF	very high frequency (108 – 137 MHz)
VOR	VHF Omnidirectional Range
VTOL	vertical takeoff and landing
WRC	World Radio Conference

1 INTRODUCTION

1.1 Background

EUROCONTROL and the FAA have initiated a joint study under a Memorandum of Agreement through an Action Plan (AP 17) to identify potential future communications technologies to meet safety and regularity of flight communications requirements, i.e. those supporting Air Traffic Services (ATS) and safety related Aeronautical Operational Control (AOC) communications.

The Future Communications Study (FCS) has two main activities 1) to identify the future requirements based on emerging global future Air Traffic Management (ATM) concepts taking into account the needs of civil aviation and State aircraft operating as **General Air Traffic (GAT)** (i.e. Operational Air Traffic (OAT) is not considered) and 2) to identify the most appropriate technologies to meet these communication requirements. This document covers the first activity by identifying the future concepts and, from them, defines resulting Communication Operating Concepts and Requirements (COCR). The COCR will assist in the second activity by allowing key requirements to be matched against candidate technologies – existing or future. To achieve this goal the COCR identifies the requirements placed on the communications that take place through the aircraft and ground radios. These are collectively referred to as the Future Radio System (FRS). In developing the COCR an approach was taken to make it technology-independent.

The operational requirements are drawn from the ATM and AOC operating concepts expected to be implemented in the highest density airspace regions of the world to achieve the required capacity, safety and security. In particular, the ICAO Global ATM Operating Concept [1] and the IATA ATM Roadmap [9] were considered. Lower density regions of the world have also been considered, but the communication requirements for those regions may be less demanding and therefore these regions can continue to utilise current systems for a longer period of time.

The two primary drivers for the FRS are: 1) to provide an appropriate communication infrastructure to support future air traffic growth, and 2) the need for a consistent global solution to support the goal of a seamless air traffic management system.

Air/ground and air/air data communications for ATS are a relatively recent development and necessitate a complex end-to-end system involving interaction amongst humans, automation and Communications, Navigation, and Surveillance (CNS) systems. Therefore many operational and technical questions need to be answered before contemplating full operations.

The study considers two main phases in the evolution of communications to support Air Traffic Management. The first phase (Phase 1) is based on existing or emerging data link services which for the purposes of this study completes around 2020; initial steps under this phase are starting in some regions of the world now. Phase 2 represents a new paradigm in the use of data communication where some new data link services are introduced and it is the main form of communication. This places greater reliance on the data communication system.

The primary differences between the two phases are the highly integral nature of Phase 2 with the use of data communications inherent in the operating method, more automation in the aircraft and on the ground, and the advanced data link services which exploit this relationship. In Phase 2, the paradigm shift from a tactical "Management by Intervention" to a more strategic "Management by Planning and Intervention by Exception" philosophy has evolved.

Analogue voice communications capabilities remain central to the provision of ATM during Phase 1. In Phase 2 voice is used for exceptional circumstances or areas that do not require extensive data link implementation. The FRS should be capable of supporting, at least, the data communications required through air/ground and air/air using broadcast, multicast and/or addressable modes such as point-to-point. Voice communication may be supported by the FRS provided it meets the requirements defined in this document.

States and Regions will have differing needs and timeframes for the introduction of data link services to meet their requirements. Figure 1-1 illustrates the expected evolution of the phases based on the concept changes described in this document.

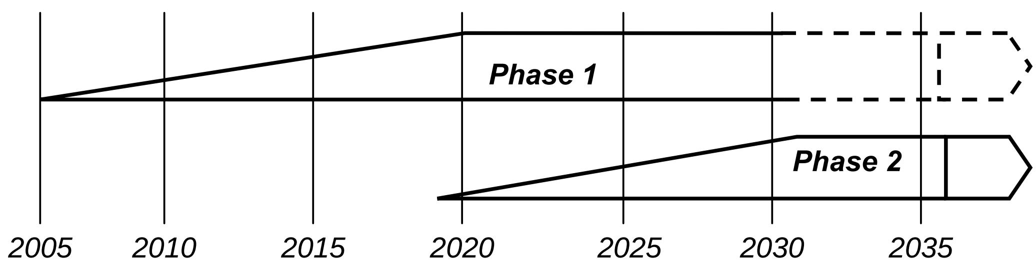


Figure 1-1: Concept Evolution Over Time – Phase 1 and Phase 2

In some regions of the world, data link services described under Phase 1 are already being introduced through trials or implementation programmes. Other regions may begin Phase 1 implementation at any time, or not at all, based on their ATM needs. Similarly the more advanced services described in Phase 2 may never be implemented in some regions for various reasons such as traffic density or lack of an adequate business case. This is depicted in Figure 1-1 by the dashed lines showing continued use of Phase 1 concepts in some regions while other have implemented those defined under Phase 2.

The performance requirements provided in this document are a "snapshot" of what demands a full set of Phase 1 services anticipated to be in place in some regions around 2020 would place on the communications system. The performance requirements for Phase 2 represent the same for a fully matured set of services anticipated to be in place in some regions in the 2030 timeframe.

This document does not imply the need for a particular aircraft or ground system to implement any of the services contained in this document. Co-ordination between the regional stakeholders will determine the operational services that benefit the local environment as part of a global infrastructure.

1.2 Scope

The scope of the COCR document is to identify concepts, requirements and trends that will be the basis for selecting the FRS. Air Navigation Service Providers (ANSPs) and industry are in the formative stages of determining many of the underlying future concepts considered in this document. While not meant to be a complete representation of the future global airspace operating concepts, this document provides useful input in the ongoing effort to define them.

Civil-military interoperability has also been addressed in the development of the COCR through co-ordination with the relevant military representatives (e.g. the EUROCONTROL Military Unit). This helped refine requirements in the areas of integrity, reliability, and security, which have been taken into account. Certification aspects for both civil and military ATM systems should then be carefully considered.

The aviation community is currently considering the requirements for operating unmanned aerial vehicles (UAVs) or remotely operated vehicles (ROVs) within the ATM infrastructure. Studies considering the implications of operating UAVs in unsegregated airspace are underway in several regions of the world and, when complete, could serve as a basis for further work in this area.

As this work is still at an early stage the additional communications associated with the command and control links (i.e. telecommand and telemetry) have not been addressed in this version of the document. However, these links may generate a significant volume of communication traffic and therefore should be considered when further information becomes available. Apart from the command and control links associated with UAVs or ROVs, all other communications services with these aircraft are considered to be the same as those with manned aircraft i.e. UAV operation is transparent for the ATC system. In some parts of the world the number of these vehicles may represent a large portion of an ATSU's traffic load in the future. Any function that would relay an instruction sent from an ATSU to the UAV or ROV, which must then be communicated from the UAV or ROV to a remote pilot, and then the command that is sent to execute the instruction, has to meet operational performance requirements just like any other aircraft in the system. Given information on the operating concepts and requirements, the load generated by these types of aircraft could be estimated.

Other services associated with security applications have not been considered in this study. A number of new services in support of monitoring and controlling of the physical security of aircraft and the air traffic system are currently under consideration. These include services to provide realtime video transmission from the cockpit, and to provide direct communications between aircraft and security organisations. These services are still being defined and it is not clear whether the FRS, a passenger communications system, or a new dedicated communications system would be used to provide them. Therefore, new security services of the nature described above are not discussed further in this document. However, information security requirements associated with the ATS and AOC services defined in Section 2 are discussed in Section 4.3.

1.3 Context

The ATM environment in the timeframe of the future communication study will continue to consist of ground HMIs, voice switches, Flight Data Processing Systems (FDPS - the Automation System), ground communications systems, routers, networks, radio ground stations, airborne radios, and communication end systems (e.g., airborne Communications Management Units (CMUs) and ground Data Link Application Processors). These components, combined in an end-to-end chain must meet the required performance and safety for voice and data applications.

In this document the term FRS[1] is used to refer to the physical implementation of the radio components of a communication system that meets these requirements. The scope of the FRS is illustrated in Figure 1-2. The FRS is part of the overall Future Communications Infrastructure (FCI), which includes all the components (e.g., processors, applications, and networks) needed for Air Traffic Service Providers, Aeronautical Operational Control, and individual aircraft to communicate with each other.

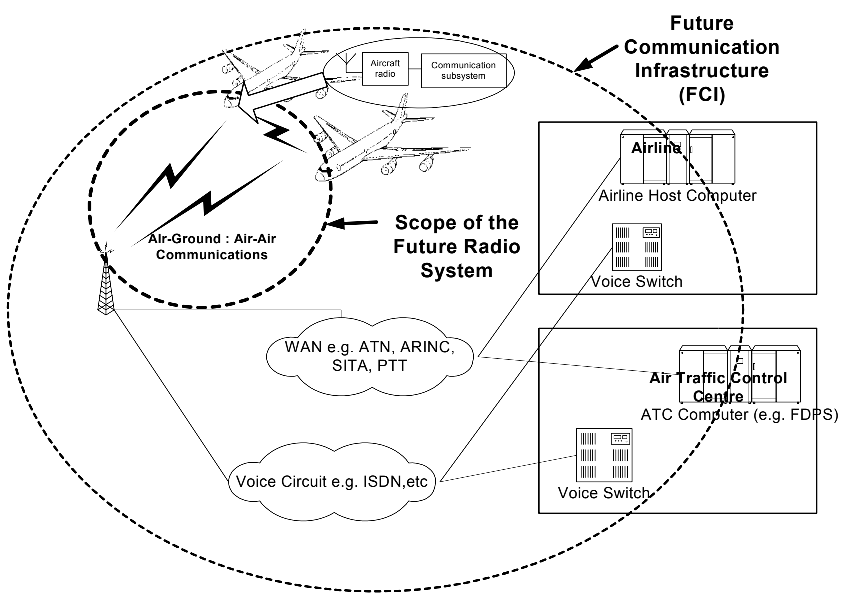


Figure 1-2: Scope of the Future Radio System (FRS) as part of the FCI

1.4 Approach

The following steps describe the approach adopted in producing the overall communication operating concepts and requirements for the FRS. Initially, to determine the overall context for future communications, numerous Concepts of Operations, Vision Statements and Plans being developed and circulated by ANSPs around the world were reviewed. The basic steps are listed below.

1. The first step was complete when a notional vision and universal operating concepts for air traffic management was developed.

[1] A singular reference to technology is used, but the FRS may be a combination of technologies.

2. Identification and definition of Air Traffic Services and Aeronautical Operational Control services that would be necessary to achieve the vision comprised the second step.

3. The operating environment, in which these services would be provided, was then defined to ensure all implications of each service were addressed.

4. Step four consisted of safety and security assessments for the air traffic services.

5. Using the output of 4, the high-level requirements each service would have to meet (so that the specified outcome or benefit of the service could be achieved safely and efficiently) were established and those requirements were allocated to the Future Radio System.

6. Next, the voice and data capacity the FRS would require in order to deliver the services was calculated.

7. By walking through a few sample applications of the previous results, the seventh and final step attempted to put the COCR effort into perspective and facilitate future use.

1.5 Document Organisation

This document is organised as follows:

Section 1 (Introduction): This section includes background and document scope. It also describes the document organisation.
Section 2 (Operational Services): This section describes the operational services that are referenced in the Section 3 scenarios.
Section 3 (Operational Concepts for Communications): This section discusses operational trends and presents real world, "day in the life" scenarios to describe the anticipated operational concepts.
Section 4 (Safety and Security Operational Requirements): This section discusses high-level safety and security communications requirements.
Section 5 (Operational Performance Requirements): This section describes communication performance requirements.
Section 6 (Communication Loading Analysis): This presents a detailed communication system loading analysis based on anticipated message sizes, message frequencies, initial performance requirements and estimated aircraft densities.
Section 7 (Application in a Real World Environment): In this section a hypothetical example is given of how the COCR could be applied to assessment of future communication technologies.
Section 8 (Conclusions): This section provides concluding remarks on the overall document.

All acronyms and abbreviations are defined in the Acronym and Abbreviation section at the beginning of the document.

1.6 Document References

The primary references used in this document are shown below. A complete reference list is shown in Appendix 6. Document reference numbers appear throughout the document as [x].

1 ICAO Global ATM Operational Concept

2 RTCA/EUROCAE - Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace – RTCA DO-290/EUROCAE ED-120

3 EUROCONTROL - Operational Requirements for Air/Ground Co-operative Air Traffic Services – AGC ORD-01

4 European Commission - Roadmap for the Implementation of Data Link Services in European Air Traffic Management (ATM: Non ATS Applications)

5 RTCA - Minimum Aviation System performance Standards for Automatic Dependent Surveillance – Broadcast –DO-242A

6 US Department of Transportation - Next Generation Air Transportation System Integrated Plan (NGATS), December 2004

7 RTCA - National Airspace System Concept of Operations and Vision for the Future of Aviation

8 EUROCONTROL ATM Operating Concept Volume 1, Concept of Operations, Year 2011

9 IATA - ATM Implementation Roadmap – Short and Medium Term – Release Version 1.0 – 15th October 2004

10 EUROCONTROL Air/ground data volumes in Europe – version 0.B – July 2000

11 EUROCONTROL/FAA. Security Analysis Supporting the Communications Operating Concept and Requirements for the Future Radio System. September 2005.

12 EUROCONTROL/FAA Principles of Operation for the Use of Airborne Separation Assurance Systems Version: 7.1 Date: 19 June 2001

13 RTCA/EUROCAE - Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communication – RTCA DO-264/EUROCAE ED-78A

14 FAA Safety Management System (SMS) Manual

15 EUROCONTROL Safety Regulatory Requirement (ESARR 4) Set 1 Severity Indicators

2 OPERATIONAL SERVICES

2.1 Introduction

This section describes the ATS and AOC services that are expected to be available or desirable during the timescale of this study. Section 3 divides the transition/evolution process into Phases 1 and 2 and provides scenarios demonstrating how the services in each phase could be used.

The focus and definition of the following services is data communications. In the timeframe of Phase 1, voice will continue to support most of these services in continental environments, when the time criticality of the exchange requires it. However, as experience is gained in the use of data services to replace voice, new ways of conducting operations will emerge under Phase 2.

2.2 Air Traffic Services

For ease of understanding, Table 2-1 and Table 2-2 show the ATS services supporting the user in each domain and for each concept phase. More detailed definitions of each service follow the figures.

Service Domains	Airport	Departure TMA	En-Route	Oceanic/ Remote	Arrival TMA	Airport
Phase 1 Services						
- DLL	✈		✈	✈		
- ACM	✈	✈	✈	✈	✈	✈
- ACL	✈	✈	✈	✈	✈	✈
- DCL	✈					
- DSC			✈	✈		
- PPD	✈	✈	✈	✈	✈	
- FLIPCY	✈	✈	✈	✈		
- FLIPINT	✈	✈	✈	✈		
- AMC	✈	✈	✈	✈	✈	✈
- D-ATIS	✈		✈		✈	
- OTIS	✈		✈		✈	
- ORIS			✈	✈		
- SIGMET	✈		✈	✈	✈	
- FLUP	✈					
- RVR	✈		✈		✈	
- D-SIG	✈				✈	
- D-TAXI	✈				✈	
- ITP				✈		
- S&M			✈			
- C&P			✈			
- D-ALERT (Once/yr/aircraft)						
- SAP		✈	✈		✈	
- ARMAND			✈			
- ADS-B/TIS-B	✈	✈	✈	✈	✈	✈
- Net Connect	✈		✈	✈		
- Net Keep Alive	✈	✈	✈	✈	✈	✈

Table 2-1. Air Traffic Data Link Services - Phase 1

Service Domains	Autonomous	Airport	Departure TMA	En-Route	Oceanic/ Remote	Arrival TMA	Airport
Phase 2 Services							
- DLL		✈		✈	✈		
- ACM		✈	✈	✈	✈	✈	✈
- ACL		✈	✈	✈	✈	✈	✈
- DCL		✈					
- DSC				✈	✈		
- PPD		✈	✈	✈	✈	✈	
- FLIPINT		✈	✈	✈	✈		
- AMC		✈	✈	✈	✈	✈	✈
- D-ATIS		✈		✈		✈	
- D-OTIS		✈		✈		✈	
- D-ORIS				✈	✈		
- D-SIGMET	✈	✈		✈	✈	✈	
- FLUP		✈					
- D-RVR		✈		✈		✈	
- D-SIG		✈				✈	
- D-TAXI		✈				✈	✈
- ITP				✈	✈	✈	
- S&M				✈	✈		
- C&P				✈	✈		
- D-ALERT (One/aircraft/year)							
- ARMAND				✈			
- ADS-B	✈	✈	✈	✈	✈	✈	✈
- COTRAC	✈	✈	✈	✈	✈		
- URCO (One/aircraft/year)							
- DYNAV				✈	✈		
- AIRSEP	✈						
- PAIRAPP						✈	
- A-EXEC				✈	✈		
- WAKE	✈	✈	✈	✈	✈	✈	✈
- Net Connect	✈	✈		✈	✈		
- Net Keep Alive	✈	✈	✈	✈	✈	✈	✈

Table 2-2: Air Traffic Data Link Services - Phase 2

Although some services, such as D-TAXI, have been defined to be used as a data link service, the information they contain will also continue to be provided by voice for non-equipped aircraft or time critical exchanges.

The following list of ATS services, described more fully in the subsections that follow, are NOT considered to be operationally effective if implemented by voice.

1. ATC Microphone Check (AMC)
2. Automatic Dependent Surveillance – Broadcast (ADS-B)
3. Auto-Execute (A-EXEC)
4. Common Trajectory Co-ordination (COTRAC) Data Link Alert (D-ALERT)
5. Data Link Automatic Terminal Information Service (D-ATIS)
6. Data Link Logon (DLL)
7. Data Link Operational Route Information Service (D-ORIS)
8. Data Link Operational Terminal Information Service (D-OTIS)
9. Data Link Runway Visual Range (D-RVR)
10. Data Link Significant Meteorological Information (D-SIGMET)

11. Data Link Surface Information and Guidance (D-SIG)
12. Data Link Flight Update (D-FLUP)
13. Dynamic Route Availability (DYNAV)
14. Flight Plan Consistency Check (FLIPCY)
15. Flight Plan Intent (FLIPINT)
16. System Access Parameters (SAP)
17. Traffic Information Service – Broadcast (TIS-B)
18. Urgent Contact (URCO)
19. Wake Vortex Footprint (WAKE)

2.2.1 ATS Voice Services

All current air/ground and air/air voice communications functions will continue to be needed in the timeframe of the Future Communication Study. Despite existing limitations, certain technologies that support voice communications have some advantages over data. These include high availability low end-to-end latencies, the ability to convey human feelings, flexibility of dialogue, and provision of a party line. The operational result of the party-line effect that is inherent in analogue communications is still required to support broadcast of Flight Crew intent to those requiring it, e.g. traffic arriving and departing at uncontrolled airports.

In addition, a unidirectional (ground/air) broadcast voice will continue to be required to support dissemination of FIS information. The use of this voice broadcast service could be diminished over time to the extent that data services supplant the need for continued use of this service.

2.2.2 Controller/Flight Crew Air Traffic Services

2.2.2.1 ATC Clearance (ACL)

An aircraft under the control of an ATSU transmits reports, makes requests and receives clearances, instructions and notifications through ACL. The ACL service specifies dialogue exchanges via air/ground communications between Flight Crews and Controllers working the specific position/sector associated with the aircraft's physical location. Some ACL exchanges, e.g. Altimeter Settings and SSR transponder code assignments, can be done without human intervention. ACL can be done via voice, data link, or a combination of voice and data-link communications in all flight phases (except only in the buffer zone for the AOA domain). This service is the basic building block for trajectory conformance management.

In Phase 2 this service is largely superseded by COTRAC for equipped aircraft.

2.2.2.2 ATC Microphone Check (AMC)

When the voice channel is blocked, such as when an aircraft has a stuck microphone, the AMC Service provides a means of contacting other aircraft, as well as the one with the stuck microphone, via data link. This allows a message to be dispatched to one, some, or all aircraft being controlled by that sector/position.

The AMC Service is a one-way uplink, which requires no response and is initiated by the Controller. It may be sent via broadcast, point to point, or point to multi-point methods.

2.2.2.3 Data Link Taxi Clearance (D-TAXI)

An aircraft preparing to depart from an airport, or an aircraft that has just landed or is on final approach, must obtain a series of clearances from the C-ATSU in order to proceed from its gate/stand to the runway or from the runway to its gate/stand. The objective of the D-TAXI Service is to provide automated assistance to Controllers and Flight Crews to perform these communication exchanges for ground-movement operations.

Ground automation produces the route for the controller who approves and sends the clearance. D-TAXI messages require a response from the Flight Crew.

2.2.2.4 Departure Clearance Service (DCL)

A flight due to depart from an airfield must first obtain departure information and clearance from the C-ATSU. The DCL Service enables the Flight Crew to request and receive their departure clearance and related route of flight information by data link. It consists of a request from the flight crew and a response from the controller or ATSU automation.

2.2.2.5 Downstream Clearance (DSC)

In specific instances, Flight Crews need to obtain clearances or information from ATSUs that will be responsible for control of the aircraft in the future.

The DSC Service provides assistance for requesting and obtaining clearances from a D-ATSU. Only the Flight Crew can initiate the DSC Service with a D-ATSU. The D-ATSU Controller replies with a clearance that must be acknowledged by the Flight Crew.

Any clearances received must only apply to the route within the D-ATSU airspace. Exceptions to this rule must be co-ordinated with the C-ATSU prior to activation.

In Phase 2 this service is largely superseded by COTRAC for equipped aircraft.

2.2.2.6 Pilot Preferences Downlink (PPD)

Flight Crew may have preferences or limitations on the way a flight is to be conducted for various operational reasons. In order to execute pertinent control strategies, Controllers need to be aware of these preferences. The PPD Service allows the Flight Crew, in all phases of a flight to provide the Controller with a set of preferences not available in the filed flight plan (e.g., maximum flight level) as well as requests for modification of some flight plan elements (e.g., requested flight level).

It automates the provision to Controllers of selected Flight Crew preferences even before the aircraft reaches their sector.

PPD consists of a one-way exchange which is generated from the flight crew to the ATSU any time they enter the information. PPD information can also be sent upon ground request. The controlling ATSU passes the PPD information along to the next ATSU as part of the ground-ground co-ordination if the information is still pertinent. The Controller accesses the ground database to assess these parameters in the normal course of planning traffic flows.

2.2.2.7 Dynamic Route Availability (DYNAV)

The objective of the DYNAV Service is to automate the provision of route changes when alternative routings can be offered by the ATSU, even before the flight is under their control.

For example, Flight Crews can be offered a single route consisting of up to 50 2-D waypoints or position names that has become available due to e.g., lifting of military Special-Use Airspace reservations, initiation or dissipation of weather phenomena or other operational restrictions. DYNAV is initiated by the ground automation system or the Controller.

The result is an ACL or COTRAC exchange to transmit the clearance for the DYNAV route.

2.2.2.8 Arrival Manager (AMAN) Information Delivery Service (ARMAND)

The ARMAND service automatically transmits relevant advisories directly from the ground automation to Flight Crews that are within the optimum-planning horizon of the AMAN, but may be beyond the limits of the ATSU that contains the flight's destination airport.

The ARMAND service transmits target, expected or revised approach-time advisories relevant to the destination airport. This exchange may subsequently be followed by an ACL transaction to cross a significant point at a specified time. These exchanges are consistent with the principle of not modifying the aircraft's route in another sector's airspace.

When COTRAC becomes available, ARMAND will be superseded for those that are equipped.

2.2.2.9 Common Trajectory Co-ordination (COTRAC)

The purpose of COTRAC is to establish and agree on 4-D trajectory contracts in real time using graphical interfaces and automation systems, in particular the FMS. COTRAC allows new trajectory contracts involving multiple constraints (latitude/longitude, altitude, airspeed, etc.).

The initial implementations of COTRAC will most likely be utilising 2-D trajectories of e.g. departure point, top of climb, top of descent and arrival fix crossing constraints. As air and ground system capabilities expand, COTRAC is expected to become a fully integrated 4-D trajectory exchange tool.

The following are the messages used to develop the 4-D trajectory contract.

- *Trajectory-based flight plan*: A flight plan enhanced from the current form to include a series of 4-D points, including key points (i.e., top-of-descent, etc.), estimated times of arrival (ETAs), required times of arrival (RTAs) (as needed), required time of departure (RTD) (if needed), and additional information such as CNS performance characteristics (e.g. RNP-4, RCP-120), tolerance of time variability from the proposed departure, and priority ranking relative to other flights proposed by that user. The times at the points along the trajectory, as desired and predicted by the user, are referred to as ETAs. The trajectory-based flight plan is the filed flight plan that will later be negotiated prior to flight and is a ground-ground communication.

- *Trajectory Constraints*: Uplink from the ground that specifies the constraints e.g., RTAs, 4-D waypoints, etc., which must be complied with when initiating the COTRAC service. This message is responded to with a Trajectory Request.

- *Trajectory Request*: Request from the aircraft in response to a trajectory constraint message, or it can be a Flight Crew request for a change of the existing trajectory. It will include a series of 4-D points, including RTAs. This message is responded to with a Trajectory Clearance.

- *Trajectory Clearance*: Based on the constraint and request exchanges, a trajectory clearance is uplinked which establishes a contract between the air and the ground on the trajectory to be flown. The clearance is closed with an operational response.

- *Trajectory Non-compliance*: Report from the aircraft that one or more of the constraints, previously agreed for the remaining or an interim portion of the flight, can no longer be complied with. Depending on the dynamics of the situation, the response to this message is a Trajectory Constraint, or a Trajectory Clearance. This message happens as a result of an event report which is generated by the FLIPINT service.

2.2.2.10 Automatic Execution Service (A-EXEC)

The purpose of the A-EXEC service is to provide an automated safety net to capture those situations where wake turbulence separation is being used and a non-conformance event occurs with minimal time remaining to resolve the conflict.

Subject to local implementations, aircraft that have the auto execute command function are separated based on wake vortex footprints. In these scenarios, when an event of non-conformance occurs triggering an imminent loss of wake vortex separation, the system generates a resolution to be sent to the aircraft for automatic execution without the Flight Crew or Controller in the loop. The A-EXEC service uses the following message to perform its function.

- *"A-EXEC" Command*: A command generated by the ground system in the event of imminent loss of wake vortex separation. The command implements one or more manoeuvres, which provide a safety net. Human intervention is not possible because the reaction time required exceeds the time available to execute the resolution.

It is anticipated that this service would be used on a limited basis for critical situations as the goal is to establish and maintain conformance with the COTRAC by modification in advance such that a sufficient separation buffer exists.

The resulting situation after completion of the A-EXEC command depends on the dynamics of the situation. Additional A-EXEC, ACL, COTRAC, or voice commands may be issued as required.

Note. - The absence of a "human in the loop" during the execution of A-EXEC is expected to lead to significant safety and security concerns. See Section 4 for further discussion of the safety and security issues associated with A-EXEC.

2.2.3 Automated Downlink of Airborne Parameter Services

2.2.3.1 Flight Plan Consistency (FLIPCY)

The FLIPCY Service provides information for the ATSU automation to detect inconsistencies between the ATC flight plan and the one activated in the aircraft's Flight Management System (FMS).

FLIPCY consists of a ground-initiated request for a specific amount of route information from the aircraft. It can be for a period of time or number of waypoints into the future e.g. 15 minutes or 6 waypoints, relative to the requesting ATSU's airspace. The aircraft responds with the route data it can supply based on the request. FLIPCY is initiated prior to entry into an ATSU or after issuance of a departure clearance.

This information may generate an ACL uplink message to resolve any inconsistency revealed by the ATSU automation.

2.2.3.2 Flight Path Intent (FLIPINT)

The FLIPINT Service consists of the downlink of the trajectory predicted by the FMS (e.g. ADS-Contract) with some additional information, e.g. meteorological data, in order to support the FDPS trajectory prediction. ADS-Contract (ADS-C) has been traditionally used in non-radar airspace to supplement command and control functions of ATS, however in the context of the future concepts extrapolated in this document, ADS-C will become a traditional source of surveillance in any domain where the cost benefit has warranted its use over, or in conjunction with, other forms of surveillance.

FLIPINT can supersede the necessity to implement the FLIPCY service by utilising the downlinked information to check the consistency of the information with that which is stored in the ATSU automation.

Unlike ADS-B, ADS-C downlinks *addressed* position reports to ATSUs on a contract basis.

FLIPINT is established by the ATSU automation and the data is downlinked on demand, periodically or on occurrence of an event and will include the position in latitude and longitude, altitude, ground speed, and up to 128 subsequent waypoints with time, altitude, and speed projections as appropriate. The Controller also has the capability to modify or initiate the FLIPINT service manually.

2.2.3.3 System Access Parameters (SAP)

The scope of the SAP Service is to make specific, tactical flight information, i.e., current indicated heading, air speed, vertical rate, and wind vector, available to the Controller or ground automation by extracting the relevant data from the airborne system. The use of the SAP parameters by the ground system should be considered as a means to provide enhancements to the existing ATC surveillance functions.

The SAP service is established by the ATSU automation and conducted on a periodic or event driven basis and is available in all phases of flight. The Controller uses the data to reduce congestion on the voice channel by using the SAP information instead of asking for it from the Flight Crew.

2.2.4 Flight Information Services

2.2.4.1 Data Link Operational Terminal Information Service (D-OTIS)

The D-OTIS service provides Flight Crews with compiled meteorological and operational flight information derived from ATIS, METARs, NOTAMs, and PIREPs specifically relevant to the departure, approach and landing phases of flight. This service operates on demand, by event, or periodically.

2.2.4.2 Data Link Runway Visual Range (D-RVR)

The D-RVR Service provides Flight Crews with up-to-date RVR information related to an airport's runway(s). At any time of their choosing, the Flight Crews can request RVR information related to any airport's runway(s). This service operates on demand, by event, or periodically.

2.2.4.3 Data Link Operational En Route Information Service (D-ORIS)

The D-ORIS Service provides Flight Crews with compiled meteorological and operational flight information, derived from "En Route" weather information, from NOTAMs, and from other sources, specifically relevant to an area to be over-flown by the aircraft. This service operates on demand, by event, or periodically.

2.2.4.4 Data Link Significant Meteorological Information (D-SIGMET)

The purpose of D-SIGMET information is to advise Flight Crews of the occurrence or expected occurrence of weather phenomena that may affect the safety of aircraft operations. The preparation and issue of SIGMET reports is the prime responsibility of meteorological watch offices. SIGMET information messages are distributed on ground initiative to aircraft in flight through associated ATSUs.

D-SIGMET information may also be embedded in the D-OTIS or D-ORIS if applicable. This service operates on an event basis only.

2.2.4.5 Data Link Automatic Terminal Information Service (D-ATIS)

D-ATIS provides terminal information relevant to a specified airport(s) in any phase of flight (except in the AOA domain outside of the buffer zone). Weather, active runway(s), approach information, NOTAM information is provided by data link rather than by voice. This service operates on demand, by event, or periodically. The D-ATIS information may be included in the D-OTIS service.

2.2.4.6 Data Link Flight Update (D-FLUP)

The D-FLUP Service provides all the ATM-related operational data and information aimed at the optimisation of flight preparation supporting punctual departure at the departure airport. Examples of these data include flight specific information related to the departure sequence, CDM agreements, slot-time allocations, as well as expected target approach times. Special operations such as de-icing will be supported using this service. This service is event driven.

2.2.4.7 Data Link Surface Information and Guidance (D-SIG)

The D-SIG Service provides automated assistance to Flight Crews by delivering a current, static graphical airport map. D-SIG presents an updated and integrated representation of all the airport elements (e.g., taxiway closures, runway re-surfacing) necessary for ground movements to the Flight Crew. D-SIG is a one-way exchange initiated by the ground automation upon completion of the DCL process for departures or recognition of transition to initial approach for arrivals.

In Phase 1, it is not anticipated that aircraft avionics will have advanced to the stage of implementing a moving map where the D-TAXI instruction would be overlaid on the D-SIG. Therefore, the D-SIG information in Phase 1 is used for situational awareness only. In Phase 2, it is assumed that the integration of the displays has occurred and therefore the D-SIG information would be used for surface navigation in all flight conditions.

2.2.5 Traffic and Surveillance Services

The following services are functionally based upon Automatic Dependent Surveillance (ADS). ADS can operate in two ways, broadcast (ADS-B), or point-to-point. ADS is a function on an aircraft or a surface vehicle operating within the surface movement area that periodically provides (reports) its state vector (horizontal and vertical position, horizontal and vertical velocity) and other information. ADS is automatic because no external stimulus is required to elicit a transmission; it is dependent because it relies on on-board navigation sources and on-board transmission systems to provide surveillance information to other users.

In some airspace, and for some classes of users, a ground–to-air Traffic Information Service – Broadcast (TIS-B) will be implemented. TIS-B allows the broadcast of sensor-based traffic information and/or rebroadcast of ADS-B information. Traffic information is thereby displayed on associated aircraft avionics as relayed by the ground automation.

2.2.5.1 Airborne Separation Assistance System (ASAS)

There will need to be more air-to-air based services to support Phase 2 operations, including self-separation. These services are initiated through a predetermined sequence of air-to-air and air-to-ground exchanges between two or more flights and ground and must be accompanied by the appropriate set of standardised flight procedures.

- Airborne Separation Assistance System (ASAS): An aircraft system that enables the flight crew to maintain separation of their aircraft from one or more aircraft, and provides flight information concerning surrounding traffic.
- ASAS application: The range of ASAS applications is very wide, from the use of cockpit traffic displays enhancing visual operations to more autonomous aircraft operations. There is no "ASAS concept" per se; ASAS and its operational applications are only components of the overall ATM system. ASAS applications are designed to be fully integrated into ATM operations, and most of them involve the active co-operation of air traffic controllers and pilots.

In COCR Phase 1 there will only be Airborne Traffic Situation Awareness, and Airborne Spacing applications. Beginning in Phase 2, Airborne Separation and Airborne Self-Separation operations will be introduced. The latter will mature over time to an end state air to air service for use in autonomous airspace. Four classes of applications are defined in [12].

2.2.5.2 Airborne Traffic Situational Awareness (ATSAW) applications

These applications are aimed at enhancing the flight crew's knowledge of the surrounding traffic situation, both in the air and on the airport surface, and thus improving the flight crew's decision-making process for the safe and efficient management of their flight. No changes in separation tasks or responsibility are required for these applications. The following examples are representative of ATSAW.

2.2.5.2.1 ATSA Air Traffic Surveillance (SURV)

The ATC surveillance service uses the ADS-B positional information from equipped aircraft for separation or monitoring purposes. This service can be conducted in all domains with or without primary or secondary radar support. To provide this service, the aircraft need only be equipped with the capability to broadcast out. There is no requirement for a cockpit display of traffic information (CDTI) in order to receive ATC services using ADS-B.

2.2.5.2.2 ATSA Enhanced Visual Acquisition (EVA)

Flight crews will use the provided traffic information to supplement and enhance out-of-the-window visual acquisition. Flight crews will continue to visually scan out of the window while including the cockpit traffic display in their instrument scan. The information could be used to either initially detect an aircraft or to receive further information on an aircraft that was visually detected or called out by the controller. The EVA application provides a basis for the Enhanced Visual Approaches and Enhanced See and Avoid applications.

2.2.5.2.3 ASAS Wake Broadcast (WAKE)

The WAKE service provides information to other users for the purposes of enabling the display of a visual representation of an aircraft's wake turbulence footprint. The service requires both transmission of certain parameters as well as automation on-board the receiver to interpret and display the footprint. Transmitted parameters include aircraft type, weight and speed settings.

2.2.5.3 Airborne Spacing applications

These applications require the flight crews to achieve and maintain a given spacing with designated aircraft, as specified in a new ACL clearance instruction. Although the flight crews are given new tasks, separation provision is still the controller's responsibility and applicable separation minima are unchanged. They are the precursor to Airborne Separation applications which follow.

2.2.5.4 Airborne Separation applications

In these applications, the controller delegates separation responsibility and transfers the corresponding separation tasks to the flight crew, who ensure that the applicable airborne separation minima are met. The separation responsibility delegated to the flight crew is limited to designated aircraft, specified by a new clearance, and is limited in time, space, and scope. Except in these specific circumstances, separation provision is still the controller's responsibility. Implementation of these applications will require the definition of airborne separation standards.

2.2.5.4.1 ASAS In-Trail Procedures (ITP)

The ASAS ITP service uses the same broadcasts as ATC surveillance to allow one aircraft in a pair to perform a climb, descent, or station keep relative to the other. The service requires a CDTI and the capability to utilise ACL instructions.

2.2.5.4.2 ASAS Crossing and Passing (C&P)

The ASAS C&P service uses the same broadcasts as ATC surveillance to allow one aircraft in a pair to perform a crossing or passing manoeuvre relative to the other. The service requires a CDTI and the capability to utilise ACL instructions.

2.2.5.4.3 ASAS Sequencing and Merging (S&M)

The ASAS S&M service uses the same broadcasts as ATC surveillance to allow one aircraft in a pair to sequence and merge behind another aircraft. The service requires a CDTI and the capability to utilise ACL instructions.

2.2.5.5 Airborne Self-Separation applications

These applications require flight crews to separate their flight from all surrounding traffic, in accordance with the applicable airborne separation standards and rules of flight. Aircraft flying through autonomous airspace must be capable of Airborne Self-Separation.

2.2.5.5.1 ASAS Paired Approach (PAIRAPP)

The Paired Approach (PAIRAPP) service permits closely spaced simultaneous parallel approaches to runways with as little as 750 feet spacing between runway centrelines.

PAIRAPP extends current visual-based operations into IMC, by employing air-to-air data link to achieve reduced final-approach phase separation without requiring aircrews to visually acquire either the runway or their partner aircraft. Typically, COTRAC would bring aircraft to the point in their approaches where minimal standard separation is reached. Upon initiation of PAIRAPP, which uses addressed air-to-air data exchange between aircraft conducting the simultaneous approaches, the COTRAC service would be terminated. PAIRAPP would then allow the participating aircraft to close to, and maintain spacing necessary to conduct the simultaneous, parallel (e.g. wingtip-to-wingtip) approach.

2.2.5.5.2 ASAS Air-to-Air Self Separation (AIRSEP)

The Air-to-Air Self Separation (AIRSEP) service employs airborne exchange of data as necessary to ensure separation of airborne aircraft in en route, oceanic/remote and autonomous domains, without aid of ground ATC support. AIRSEP includes the following functions:

a. ***Conflict Probe*****:** Automated algorithms that detect or estimate the probability of conflicts with other flight trajectories, or detect problems due to e.g. airspace or weather restrictions, along the intended route of flight.
b. ***Trajectory Intent Exchange****:* The exchange between aircraft (i.e. automatic interrogation) of the projected intent beyond that which is currently being broadcast. Includes intent information to a sufficient distance beyond the conflict point and the wake vortex footprint in order to support resolution.
c. ***Conflict Negotiation***: The "machine to machine" negotiation of a trajectory modification generated by on-board automation. The negotiation exchange continues until satisfactory resolution is achieved. The number of times this exchange is repeated is limited by the time remaining to resolve the conflict.
d. ***Resolution Accept/Confirmation****:* The messages that ensure positive confirmation of the *Conflict Negotiation* message exchange.

2.2.6 Emergency and Ancillary Services

2.2.6.1 Urgent Contact Service (URCO)

The Urgent Contact (URCO) Service provides data link assistance for an ATSU to establish urgent voice or data link contact with Flight Crew who may or may not be under the control of the ATSU initiating the service. There is no requirement for the aircraft to be in the initiating ATSU's area of control in order to use the URCO service.

Flight Crews may use URCO in order to contact the current controlling authority in the event that other forms of communications have failed.

2.2.6.2 Data Link Alert (D-ALERT)

The objective of the D-ALERT Service is to enable Flight Crews to notify, by data link, appropriate ground authorities when the aircraft is in a state of emergency or an abnormal situation.

The message is sent to the C-ATSU, as they are the most knowledgeable party for determining which authorities e.g. fire/rescue, police, AOC, etc. should receive the details of the message. Appropriately equipped aircraft may distribute this message to their AOC simultaneously in order for co-ordination to take place with the C-ATSU.

2.2.7 Communications Management Services

2.2.7.1 Data Link Logon (DLL)

The Flight Crew activates the data-link system and enters the flight identification into the page. The additional data required, i.e. data link applications supported, to logon with ATS is stored inside the avionics and the remainder of the DLL takes place automatically without Flight Crew involvement. Logon and contact with the system encompasses the data link exchanges between an aircraft and an ATSU required to enable the other data link services.

2.2.7.2 ATC Communication Management (ACM)

When a flight is about to be transferred from one sector/ATSU to another, the Flight Crew is instructed to change to the voice channel of the next sector/ATSU. The ACM Service provides the air/ground exchanges between an Aircraft and its transferring ATSU as well as with its receiving ATSU to establish communications control of the flight. In addition, when data link communications are involved, the ACM service manages the data link connection transfer.

2.3 Aeronautical Operational Control (AOC) Services

AOC is an important element of ATM and is needed for continued efficient operation of airspace users. AOC services are concerned with the safety and regularity of flight and as such are defined in Annex 10 of the ICAO Convention. AOC applications involve voice and data transfer between the aircraft and the Aeronautical Operational Control centre, company or operational staff at an airport.

Note. The range of message types currently classified as AOC services was provided by IATA and is under review within the airline industry. As the goal of the FCS may include all communications for ATS and AOC, the services have been captured here as an aggregate set of AOC services that are currently defined or on the drawing board

Experience to date with AOC communications has shown that the bulk of message traffic has migrated to data communications. Requirements for AOC voice, including communication with the airspace user operations centres and between aircraft, will continue to experience a downward trend as more services utilise data link but it is anticipated that voice will continue to be required. Based on expected increases in air traffic, AOC data communications will grow as the result of both the increase in number of messages per aircraft and size and characteristics of the message content. This trend will continue with the availability of new technology that will be exploited by airspace users to support new applications. In some cases, services will be employed on a routine, periodic basis, while in other cases instances of use will require increased bandwidth because of the nature of the service.

As the role of AOC applications continues to grow, two particular forms lead to the highest communication loads:

1. **Communications at the Gate**: Significant information exchange occurs between the aeronautical operational staff and the aircraft when the aircraft is parked at the airport. This communication covers such things as Log Book transfers and even uplink of software updates. These applications require high integrity and significant data exchange, but are not time critical.
2. **Airborne Monitoring Applications**: A number of recent AOC applications have supported realtime monitoring of aircraft performance during flight. This is likely to be a growing trend. Research is also considering the possibility of providing telemetry data via data link to support accident investigation and other uses.

2.3.1 AOC Voice Services

All current Flight Crew to Operations Centre and Flight Crew to Flight Crew voice communications functions will continue to be needed in the timeframe of the FCS; however, the usage of these services will diminish over time as data usage increases. Thus, there are two types of voice communications services. The first is a point-to-point selective addressed voice service that handles Flight Crew to Operations Centre communications. The second is either a party-line or broadcast voice service that handles Flight Crew to Flight Crew voice communications. The party-line/broadcast service is especially applicable in oceanic and remote regions to aid in situational awareness.

2.3.2 AOC Data Services

Below is a description of the AOC data link Services that are expected to be in use during the timeframe of the two phases in the study. Table 2-3 below illustrates how these services are used during each phase of flight.

Service Domains	Autonomous	Airport	Departure	En-Route	Oceanic/Remote	Arrival	Airport
AOC Data Link Services							
- AOC Logon		✈			✈		
- OOOI		✈					✈
- NOTAMs		✈		✈	✈		
- Free Text	✈			✈	✈		
- Weather Request	✈	✈		✈	✈		
- Position Report	✈		✈	✈	✈		
- Flight Status	✈	✈		✈	✈	✈	
- Fuel Status	✈			✈	✈		
- Gate/Connecting Flight Status				✈			
- Engine Performance Reports			✈	✈			
- Maintenance Troubleshooting	✈			✈	✈		
- Flight Plan Request	✈	✈		✈	✈		
- Load Sheet Request		✈				✈	
- Flight Log Transfer		✈					✈
- Real Time maintenance	✈			✈	✈		
- Graphical Weather	✈	✈		✈	✈		
- Real Time Weather	✈	✈	✈	✈	✈	✈	
- Technical Log		✈					
- Technical Log Book Update		✈					
- Electronic Library Update		✈					
- Software Loading		✈					
- Cabin Log Book Transfer		✈					✈

Table 2-3 AOC Services by Flight Phase

2.3.2.1 AOC Data Link Logon (AOCDLL)

The Flight Crew activates the data-link system and enters the required flight identification information into the logon page in order for AOC to respond with the correct information. The AOCDLL provides an indication to AOC that the Flight Crew has arrived on-board the aircraft and are prepared to receive information that AOC generates on their behalf in order to conduct the flight.

2.3.2.2 Out-Off-On-In (OOOI)

Movement Service messages including Out-Off-On-In report data are automatically routed to the AOC Movement Control System. This service is a one-way downlink from the aircraft to AOC to report significant points in the flight's progress.

2.3.2.3 Notice to Airmen (NOTAM)

The NOTAM service delivers Automatic Terminal Information Service (ATIS) that includes any immediate NOTAMs available. The Flight Crew activates this service manually from a menu.

2.3.2.4 Free Text (FREETEXT)

The Free Text Service includes miscellaneous uplinks and downlinks via textual messages between the cockpit and AOC/other ground based units. This does not include cockpit-to-cockpit exchanges.

2.3.2.5 Textual Weather Reports (WXTEXT)

The Textual Weather Report Service includes Flight Crew requests for airport weather. The Weather Reports Service includes Meteorological Aerodrome Reports (METARs) and Terminal Area Forecasts (TAFs). The AOC System responds to Flight Crew requests by delivering the requested weather information to the cockpit.

2.3.2.6 Position Report (POSRPT)

The Position Report Service includes automatic downlink of position during the climb, cruise and descent portions of the flight. The primary purpose is delivery of position reports at required waypoints for use in AOC tracking systems. During all phases of flight, but principally en route, the Flight Crew can also manually initiate the POSRPT Service for such things as in-range reporting.

2.3.2.7 Flight Status (FLTSTAT)

The Flight Status Service includes, for example, malfunction reports including fault-reporting codes that allow maintenance and spares to be pre-positioned at the parking stand after landing. Fault reporting can be done manually, or automatically sent when triggered by an event.

2.3.2.8 Fuel Status (FUEL)

The Fuel Status Service downlinks fuel status en route and prior to landing. This service allows ground services to dispatch refuelling capability promptly after landing. The Flight Crew also reports the fuel status upon specific AOC request.

2.3.2.9 Gate and Connecting Flight Status (GATES)

This service for passengers and Flight Crew includes manual and automatic uplink of connecting flights, ETD, and gate assignments before landing. Information about rebooking may also be included in case of late arrival or cancelled flights.

2.3.2.10 Engine Performance Reports (ENGINE)

Aircraft Condition Monitoring System (engine and systems) reports are downlinked in real time automatically and on request. This is usually done in the en route phase.

2.3.2.11 Maintenance Problem Resolution (MAINTPR)

Through this service, maintenance personnel and Flight Crew are able to discuss and correct technical problems while the aircraft is still airborne. Although voice is customarily used for the discussion of the problem, this service may be used to provide the instructions for problem resolution in a textual format e.g. text message between maintenance personnel and Flight Crew.

2.3.2.12 Flight Plan Data (FLTPLAN)

This service provides the operators with the ability to request and receive the AOC-developed flight plan for comparison to that assigned by ATC and for loading into avionics. AOC flight plans have more information than flight plans filed with ATS.

2.3.2.13 Load Sheet Request/Transfer (LOADSHT)

Upon downlink request, the Load Sheet Control System uplinks planned load sheet and cargo documentation. A number of data calculations relating to aircraft loading, takeoff and landing are required to enhance safety and/or meet aviation regulations. The load sheet includes weight and balance information which insures resultant weights and centre of gravity are within the performance limits of the aircraft. A preliminary load sheet is transferred right after an AOCDLL. A final load sheet is typically transferred just before pushback, but can be transmitted as late as just before takeoff. The load sheet will also include a passenger manifest & fuel status.

A takeoff data calculation (TODC) is provided for the minimum takeoff speeds and flap settings. The calculation takes into account weights, aircraft technical parameters (e.g., thrust) and environmental parameters (e.g., wind, temperature, density altitude and runway length or conditions). If the TODC is sent before the final load sheet or if the planned takeoff runway is changed, an updated TODC may be required.

A landing data calculation (LDC) is a calculation similar to the TODC. The LDC is conducted towards the end of the flight in the TMA domain.

2.3.2.14 Flight Log Transfer (FLTLOG)

This service is used to track the aircraft's flight times, departure and destination information, etc. Flight log information may be manually requested by AOC or automatically downlinked.

2.3.2.15 Real Time Maintenance Information (MAINTRT)

This service allows aircraft parameters to be sent to the airline maintenance base in realtime to monitor the operational status of the aircraft and to troubleshoot problems identified during the flight. Information could include engine data, airframe systems, etc. This service allows information to be obtained more quickly than the normal maintenance-data acquisition via on-board recorders. It is typically event driven, triggering a flow of information until resolution is achieved. The maintenance personnel may request other parameters to be downlinked in addition to those triggered by the event.

2.3.2.16 Graphical Weather Information (WXGRAPH)

Weather information is sent to the aircraft in a form that is suitable for displaying graphically on displays in the cockpit, e.g., vector graphics. This service provides advisory information which supplements or replaces the textual weather information available in current AOC services. Graphical weather information is expected to be more strategic in nature, and will supplement on-board tactical weather radar, which has inherent range and display limitations.

2.3.2.17 Realtime Weather Reports for Met Office (WXRT)

Information derived by the aircraft on the environment in which it is flying (e.g., wind speed and direction, temperature) can be sent automatically in realtime to weather forecasting agencies to help improve predictions.

2.3.2.18 Technical Log Book Update (TECHLOG)

This service allows the Flight Crew to complete the aircraft's technical log electronically and send the updated log to the maintenance base. Information regarding the technical status, physical condition, and trouble reports of the aircraft can therefore be obtained much more quickly so that any remedial action can be taken at an early stage.

2.3.2.19 Cabin Log Book Transfer (CABINLOG)

This service allows the cabin crew to complete the aircraft's cabin-equipment log electronically and send the updated log to the AOC. Information regarding the status of the cabin equipment can therefore be obtained much more quickly so that any remedial action can be taken at an early stage.

2.3.2.20 Update Electronic Library (UPLIB)

The Electronic Library will replace many of the paper documents currently required to be carried in the cockpit (e.g., Aircraft Manual, SID's, STAR's, and Airspace Charts). The Update Electronic Library service enables this information to be updated electronically either by request or automatically. The transmitted information will be used to update various avionic systems, e.g., an Electronic Flight Bag (EFB) device. As such, this service carries safety-related information used for navigational purposes by the Flight Crew/Aircraft.

2.3.2.21 Software Loading (SWLOAD)

This service allows new versions of software to be uploaded to non-safety related aircraft systems whilst the aircraft is at the gate.

2.4 Network Management Services

Network management services are used to establish and maintain connections between each pair of aircraft and ground systems. Because the network management services are required to support ATS and AOC services, they are normally assigned the highest class of service with the highest priority. There are two network management services—network connection and network keep-alive.

2.4.1 Network Connection (NETCONN)

A network connection is established between each pair of aircraft and ground systems before ATS or AOC data services can be provided between aircraft and ground entities. It is normally maintained between the aircraft system and a ground system for the entire length of the flight.

A connection establishment may be initiated by the aircraft or ground system. When the aircraft system flies into the service area of a new ground system, it may have to establish a new connection with a new ground system and release a connection with the old ground system.

The network connection service is a point-to-point service. It is normally used in all phases of the flight in all domains.

2.4.2 Network Keep-Alive (NETKEEP)

Once a connection is established, network keep-alive messages are exchanged between the aircraft and ground systems when there is no traffic for a period of time to maintain the status of the connection.

The network keep-alive service is a point-to-point service. It is normally used in all phases of flight in all domains.

3 OPERATIONAL ENVIRONMENT FOR COMMUNICATIONS

3.1 Introduction

This section describes the ATM operational concepts and operating environment at the start and end of the period considered in the COCR. The ATM concepts will increase the efficiency of air traffic management thereby allowing air traffic growth. Operational service capabilities are implemented in phases to support the operational concepts. Each of these phases increases airspace capacity. For each phase, a typical scenario is provided to demonstrate how voice and data services would be used.

Note 1: The following sections use the terms Executive, Planning, Tower Runway, Ground and Clearance/Ramp Controller. These terms are used to generically differentiate Controller roles and typically represent a pair of Controllers working a sector or individual positions in a Tower. Locally, these Controllers may be referred to by various names, e.g., Surveillance, R-Side or Radar for Executive Controller and Sector Planner, D-Side, Data or Co-ordinator for Planning Controller or Local, Flight Data, etc. for Tower positions.

Table 3-1 and Table 3-2 below describe the characteristics of the airspace environment for Phase 1 and Phase 2.

Note: At an operational level, the Polar Region is considered to have the same characteristics and requirements as the Oceanic / Remote and has not been included separately. However with ultra long haul operations, more aircraft could operate over the polar region. Communication coverage in this region could therefore become more important.

	APT	TMA	ENR	ORP
Communication capability and performance	Voice is Primary for Tactical. Data is Primary for remaining communications.	Voice is Primary for Tactical. Data is Primary for remaining communications.	Voice is Primary for Tactical. Data is Primary for remaining communications.	Data communications are Primary. Third party voice service used for non-routine and emergency communications.
Navigation capability and performance	Precision Landing System Visual separation	RNAV/RNP 1	RNAV/RNP 4 RVSM	+/- 300 ft altimeter, RVSM, MNPS, Inertial +/-2 NM/hour drift rate, RNAV/RNP 10, RNAV/RNP 4
Surveillance capability and performance	Visual and voice communication Surveillance Monitoring	ACAS Surveillance service	ACAS Surveillance service	ACAS, Time/speed-based verification, Distance-based verification, Lateral deviation monitor ADS-C
Separation (Horizontal)	Longitudinal 2 or 3 minutes or wake turbulence criteria, whichever is greater	2.5-5 NM	5 NM	Lateral: 60 NM (MNPS), 100 NM, 50 NM, or 30 NM Longitudinal: is time-based: 5/10/15 min, or Distance-based: 50 NM or 30 NM
Separation (Vertical)	N/A	1000 ft	1000 ft 2000 ft RVSM	1000 ft 2000 ft RVSM
Traffic complexity	Complex with visual guidance	Complex route structure with complex arrival and departure routes	RNAV complex route structure	Composite separation, parallel tracks, crossing tracks

Table 3-1: Airspace Environmental Characteristics – Phase 1

	APT	TMA	ENR/ORP	AOA
Communication capability and performance	Data is Primary means of communications. Voice is used for non-routine, failure recovery, or emergency communications.	Data is Primary means of communications. Voice is used for non-routine, failure recovery, or emergency communications.	Data is Primary means of communications. Voice is used for non-routine, failure recovery, or emergency communications.	Data is Primary means of communications. Voice is used for non-routine, failure recovery, or emergency communications with other aircraft.
Navigation capability and performance	Precision Landing Systems Visual separation,	RNAV/RNP 0.5	RNAV/RNP 1 RVSM	RNAV/RNP 1
Surveillance capability and performance	Visual and voice communication. Surveillance Monitoring.	Surveillance service.	Surveillance Service using ADS-B & C. ACAS. Deviation monitor.	Airborne Surveillance using ADS-B and AIRSEP. ACAS.
Separation (Horizontal)	Longitudinal is wake turbulence criteria only, Lateral is 750 ft. between runway centrelines. CDTI.	Longitudinal is wake turbulence criteria only, Lateral is collision avoidance based. CDTI	Longitudinal is wake turbulence criteria only, Lateral is collision avoidance based. CDTI	Collision avoidance based. CDTI
Separation (Vertical)	N/A	1000 ft	1000 ft 2000 ft RVSM	Collision avoidance based. CDTI
Traffic complexity	Complex with visual guidance	Contract based trajectories connecting to complex arrival and departure routes.	Contract based trajectories.	User-preferred trajectories until ready to depart the area, then resume contract-based trajectories.

Table 3-2: Airspace Environmental Characteristics – Phase 2

The following are the aircraft performance assumptions and characteristics in the Phase 1 and 2 timeframe:

- Space, and Special-Use Vehicles are outside the scope of the FRS.
- Future speeds are based on the assumption that supersonic commercial aircraft may be in operation in Phase 2.
- Aircraft travelling over land masses (e.g., surface, TMA, En Route) will be limited to air speeds below Mach 1 (speed of sound) to prevent sonic booms, e.g., 0.95 mach.

- Air-Air speeds are based on the closing speed of two jet aircraft in the same wind environment.

Parameter	APT	TMA	ENR/ORP
Max Gndspeed (KTAS)	160	360	850
Max Airspeed (KTAS)	160	250	600
Max Air-Air (KTAS)	n/a	500	1200
Max Acceleration (m/s^2)	5	50	50

Table 3-3: Aircraft Performance Characteristics – Phase 1

Parameter	APT	TMA	ENR	ORP	AOA
Max Gndspeed (KTAS)	200	410	850	1465	790
Max Airspeed (KTAS)	200	300	600	1215	540
Max Air-Air (KTAS)	n/a	600	1200	2430	1080
Max Acceleration (m/s^2)	12.5	50	50	50	50

Table 3-4: Aircraft Performance Characteristics – Phase 2

3.2 Phase 1

Note 1: The information contained in this scenario is based on regions of the world with high-density airspace. Regions of the world with lower density of air traffic may choose to continue with voice-based procedures, but could benefit from transition to more data link-based communications for global harmonisation and aircraft procedural consistency.

Note 2: Even when data link is used in this scenario, voice-based procedures may be used as an alternative form of communication depending on the dynamics of the situation.

To support the anticipated growth of aircraft traffic, all ATM stakeholders (e.g., commercial aviation, general aviation, military users, neighbouring Air Navigation Service Providers (ANSPs), regulators, airport operators and other governing entities) must work together in a collaborative manner on planning and executing their aviation operations. All stakeholders may participate in, and benefit from, the advantages of using a wide pool of information. As part of this pool of information, the network operations planning process aims to maintain a continuous balance between demand and capacity, and to identify system constraints. Stakeholders have access to the planning process through a common network; they are able to retrieve information to be used for their tailored purposes or make a query to identify possible constraints, and, in a collaborative manner, use the information to negotiate and develop consensus on possible opportunities, plan new operations or to mitigate potential constraints.

The ATM system is continuously evolving. The focus of development and change until this point in time has been on the planning process, where communication and information exchange among ATM stakeholders have become increasingly more important. Decision-making processes have become more collaborative as common situational awareness among the ATM stakeholders has developed. The roles and responsibilities of the ATM stakeholders are evolving from controlling to managing traffic. The paradigm change from "management by intervention" to "management by planning and intervention by exception" is beginning to form in the ATM environment under Phase 1.

The most significant evolution completed in this period is flight planning through the implementation of a seamless layered planning process. Basic layered planning existed earlier, but by the time of Phase 1 it has started to evolve into a continuous planning process. Under Phase 1 the layered planning process generally satisfies an agreed and stable demand and capacity balance. This is accomplished through demand and capacity determination, active demand and capacity management, and re-planning for optimisation. These tasks continue across all layers of planning and are not restrained by the time constraints of the individual layer.

The layered planning process will not be described in detail as the focus of this document is on the aspects or capabilities that directly impact the demand on the digital aeronautical communication system (air/ground and air/air communications). However, application of the layered planning process will generate the following benefits:

- An improved picture of the predicted traffic situation enabling all ATM stakeholders to analyse and develop their business cases.
- The active involvement of all ATM stakeholders in the decision-making process also supporting and facilitating the use of company planning and company decision support tools.
- A collaborative decision-making process encompassing the ATM stakeholders concerned.
- Decision-making by informed ATM stakeholders.
- Communication of realtime events enabling ATM stakeholders to take advantage of changing conditions in real time, thus helping them to achieve their preferences.

The Planning Controller represents the lowest planning level within the layered planning process. The Planning Controller's primary task is to plan and establish a conflict-free and efficient traffic flow within his/her area of responsibility. Because of his/her extended geographical and time-related planning horizon, he/she is able to act early on expected complexity and conflicts and look for efficient solutions. Furthermore, he/she is able to react more efficiently and flexibly to user requests, such as direct routings, prioritisation of individual flights, or special support for on-time arrivals.

A gradual shift in emphasis from an Air Traffic Control (ATC) environment defined by tactical interventions, towards an operating environment based on reliable planning, is beginning. As a consequence, the role of Controllers is evolving into more of a monitoring and managerial role in certain areas. Examples of this change are seen in the beginning steps of pre-negotiated operations, where the Flight Crew executes a previously agreed-upon trajectory contract. However, the Controller retains the responsibility for separation, or co-ordinates and issues instructions where responsibility is delegated to the Flight Crew for a specific procedure of limited duration (e.g., spacing). Consequently, the Flight Crew's role has begun to change and now includes assumption of these responsibilities previously residing with the Controller. All this is supported by new or enhanced functions of the ATM system encompassing air and ground applications.

Operational changes are also being implemented for the management of ground movements. They are optimised to provide maximum use of the ground infrastructure, even in adverse weather conditions, by using new ATM system capabilities. The airspace structure is just beginning dynamic adjustment of control sector boundaries according to demand, allowing for limited implementation of user-preferred trajectories.

All of the changes identified above, technical and operational, will have an impact on the business models of ATM stakeholders. The ATM stakeholders must cope with changing requirements on human skills, new and harmonised operational procedures that cross ATM stakeholder business boundaries, changing requirements on their systems, and newly implemented rules and regulations catering, for example, to environmental issues.

3.3 Phase 1 Scenario

Note 1: It is assumed that data transactions always take longer than voice transactions due to the need to access, display, comprehend, and respond to data messages.

*Note 2: The Services (including acronyms) referred to in the following sections are defined and described in the acronym list before Section 1 and in Section 2 based on the EUROCONTROL Operational Requirements for Air/Ground Co-operative Air Traffic Services [3] plus other services developed from additional sources. The concept is then extrapolated to reflect the future associated with the Phase 1 & 2 timeframes beyond that which the reference document provided. Also, the Services listed in the following scenarios are not all-inclusive of the Services listed in Section 2. An acronym in **bold** type indicates a message transaction process using the services defined in Section 2 is occurring.*

3.3.1 Pre-Departure Phase

Note: In all of the following phases, the information known to one system (e.g., tower FDPS) will be provided to all users over a network-based infrastructure. Therefore, no specific events of notification are stated in the steps below.

The aircraft operator provides gate/stand information, aircraft registration/flight identification and estimated off-block time to other users (Airport, ATC, etc.) via the ground-ground communications system. The Flight Crew prepares the aircraft for the flight and in particular, provides the necessary inputs and checks in the Flight Management System (FMS). They activate the data link system, which initiates a network connection establishment between the aircraft and ground systems, and send an AOC Data Link Logon **(AOCDLL)** to AOC. Aircraft and ground systems may exchange network keep-alive messages during the flight when there is no traffic for a period of time. Logon and contact with the ATSU automation system is performed by the Data Link Logon (**DLL)** service. The DLL contains the address and application data required to enable point-to-point data link services. The Flight Crew requests the Flight Plan (**FLTPLAN**) from AOC and enters the AOC-provided flight plan data into the

FMS. The Flight Crew consults relevant aeronautical information (e.g., Planning Information Bulletins, Notices to Airmen (NOTAMs), and Aeronautical Information Charts) concerning the flight. Realtime information on the flight's departure is now available in the ATSU automation system.

The Flight Crew initiates a request for a Data Link Operational Terminal Information Service (**D-OTIS)** contract for the departure airfield. The Flight Information Service (FIS) system response provides all relevant information for the weather, Automatic Terminal Information Service (ATIS), and field conditions plus the local NOTAMS.

The Flight Crew requests a departure clearance from the system via the Departure Clearance (**DCL)** service. The tower sequencing system integrates the flight into an overall arrival/departure sequence taking into account any Air Traffic Flow Management (ATFM) constraints and assigns the appropriate runway for take-off. The Controller supported by available automation provides the **DCL** response including an updated calculated take-off time (CTOT) via data link to the Flight Crew. The **DCL** response is checked against what was provided from AOC for consistency, and any changes are updated in the FMS. The ATSU automation updates the integrated Arrival/Departure Manager system (AMAN/DMAN) and ATC centres along the route of flight with the CTOT. A suitable time after delivery of the **DCL** response, the ATSU performs a Flight Plan Consistency (**FLIPCY)** check of the FMS flight plan data. Should an aircraft be capable of performing the FLIPINT service, this could be used to satisfy the consistency check.

In low visibility conditions, the Flight Crew may also use the Data Link Runway Visual Range (**D-RVR)** service to request RVR information for the departure and the destination airports. For data-link equipped aircraft preparing to taxi, the current graphical picture of the ground operational environment is uplinked and loaded using the Data Link Surface Information Guidance (**D-SIG)** Service.

The Loadsheet Request (**LOADSHT**) is sent to AOC. The Loadsheet Response (**LOADSHT)**, with the "dangerous goods notification information" and the last minute changes to the weight and balance of the aircraft are sent by the AOC and are automatically loaded into the avionics. Some of this data will remain available for the Data Link Alert (**D-ALERT)** service throughout the flight, should an emergency occur. During this pre-flight phase, the Data Link Flight Update (**D-FLUP)** service is accessed to see if there are any delays/constraints anticipated to the preparations for the flight. The Flight Crew specifies preferences that should be considered by the Controllers using the Pilot Preferences Downlink (**PPD)** service.

The Flight Crew requests a "Start Up and Push Back Clearance" via the Data Link Taxi (**D-TAXI)** Service. The ATSU sequencing system calculates the planned taxiing time and after comparison with the issued CTOT, issues the **D-TAXI** response. For appropriately equipped aircraft, the **D-TAXI** route is superimposed over the **D-SIG** information previously received. The Flight Crew pushes back and starts up the engines in accordance with Airport procedures. The push back generates an Out-Off-On-In (**OOOI)** message to AOC advising that the flight has left the gate/stand.

As the aircraft pushes back, its Automatic Dependent Surveillance-Broadcast (**ADS-B)** system is activated. The Advanced Surface Movement Guidance and Control System (A-SMGCS) picks up the broadcast surveillance message and associates the aircraft with the FDPS flight plan. The ATSU's sequencing tool updates the times for the overall arrival/departure sequence. For short-haul flights (<250 NM), the updated information is provided to the integrated AMAN/DMAN at the arrival airport.

The conflict probe system of the first ATSU analyses any potential conflicts caused by the proposed trajectory of the departing flight and informs the Planning Controller concerned with the flight. The Planning Controller uses the information to update the planning process.

Note: Under Phase 1 it is envisioned that ADS-B/Traffic Information Service-Broadcast (TIS-B) is predominantly available in regional pockets of implementation. The use of ADS-B/TIS-B for ATS surveillance is therefore confined to these regions. Once ADS-B/TIS-B is activated, it provides a continuous broadcast of traffic positional information that can be used by any receiver to perform other services. Therefore, events subsequently described will not continually state this function.

3.3.2 Departure Taxi

The Flight Crew requests the **D-TAXI** clearance from the tower ground Controller. The tower ground Controller issues the **D-TAXI** response. The Flight Crew manoeuvres the aircraft according to the taxiing instructions. The tower ground Controller monitors the taxiing of the aircraft assisted by A-SMGCS and intervenes if required.

The ATSU automation system generates a transfer message for the tower ground Controller that control will be passed to the tower runway Controller frequency automatically via **ACM** on reaching the handover point. The tower runway Controller issues the "Line Up and Wait Clearance" by voice to the Flight Crew in accordance with the traffic situation. The tower runway Controller issues the "Take Off Clearance" via voice to the Flight Crew in accordance with the traffic situation.

The ATSU automation system forwards the **DLL** information via ground/ground communications to subsequent ATSUs so that data linking with respective downstream Controllers can be conducted.

The Flight Crew commences the take off run. The ATSU automation system detects that the aircraft is airborne and disseminates that information to the flow manager, neighbouring sectors' and centres' Planning Controllers, and air defence and makes it available for other users. An **OOOI** message is sent to AOC that the aircraft is airborne.

The ATSU automation system generates a transfer message for the tower runway Controller and via **ACM** provides the frequency to contact the next sector Executive Controller to the aircraft via data link.

3.3.3 Departure in TMA

When the aircraft is airborne, the Flight Crew contacts the first sector Executive Controller using voice. The ATSU automation system determines the exit conditions from the first sector. The conflict probe checks to see if the entry conditions into the next downstream sector are conflict free and forwards co-ordination information to the downstream sector.

The Executive Controller issues instructions via the ATC Clearances (**ACL**) service (via voice or data), depending on the tactical nature of the situation, to the Flight Crew to achieve the exit conditions to enter the next sector and provides this clearance information to the ATSU automation system. The conflict probe provides the Planning Controller and Executive Controller with information about potential interactions with other aircraft or airspace for up to 30 minutes from present position. The Controller team takes necessary action to alleviate these conflicts using the necessary services. The Flight Crew flies the aircraft according to the instructions given. The System Access Parameters (**SAP**) service is initiated by the ATSU automation system and the downlinked information is provided to the various ground components (e.g., for smoothing of trackers), or on request for display of parameters to Controllers. The ATSU automation system monitors the aircraft behaviour in accordance with the given clearances. The tracking system issues warnings to the Executive Controller in case of non-compliance. The Executive Controller intervenes if the situation requires action. The tracking system uses the ADS-B and radar data to monitor whether the aircraft performance is in accordance with the ground-predicted trajectory, and updates the trajectory where necessary.

The Executive Controller transfers control of the aircraft to the next sector Executive Controller. The data link processing system provides the next frequency to the Flight Crew via the **ACM** service and transfers the data link capability management to the next sector/ATSU. A new network connection is established between the aircraft and an En Route domain ground system before the connection with the departure TMA domain ground system is released.

3.3.4 En Route/Oceanic/Remote

Note: In the timeframe of Phase 1 a typical continental flight will pass through four En Route facilities. Long haul flights will traverse numerous En Route facilities. The number of sectors traversed within each En Route facility is typically two. The exchanges that occur from a communications stand-point are the same in each en route facility, so the following description does not specify inter vs. intra facility transfers or ATSU automation system events unless necessary for clarity of the scenario.

The ATSU automation system confirms/sets the exit/entry conditions with the sectors in the en route phase. At each entry into a subsequent ATSU, **FLIPCY** is performed to verify the FMS route against what is held in the ATSU FDPS. The ATSU automation system establishes a Flight Plan Intent **(FLIPINT)** contract (e.g., periodic, event, etc.) with equipped aircraft while in each ATSU’s area of jurisdiction to ensure consistency between on-board routes against ATSU FDPS routing. The Executive Controller decides and performs, or has the Planning Controller perform, **ACL** as necessary, and initiates handovers to the next sector/ATSU. The ATSU automation system supports handover by communicating the event to the Flight Crew and the downstream sector/ATSU via **ACM**. The Flight Crew contacts or monitors the frequency of the receiving sector Executive Controller when the handover is performed. Meanwhile, the aircraft reaches top of climb and generates an Engine Performance Report (**ENGINE**) to the AOC. The Controller team accesses the **PPD** information from the aircraft to determine if any of the Flight Crew preferences affect or could improve the planned trajectory. The Flight Crew initiates an ACL to request a modification to the current trajectory. The Planning Controller assesses the request against the conflict probe. If no conflicts are found, and after informing the Executive Controller, the response is sent via **ACL**. An aircraft system notices a minor fault in one of the cross bleed valves that generates a Flight Status (**FLTSTAT**) message to AOC for maintenance action upon arrival.

During this phase of flight, the Flight Crew initiates the request for a Downstream Clearance **(DSC)** with the Downstream-ATSU (D-ATSU) for the Oceanic/Remote portion of the flight. The D-ATSU receives this request and determines whether the requested profile can be approved. In order to issue the clearance for the Oceanic/Remote portion of the flight, a change to the aircraft's current trajectory is necessary. The Planning Controller in the D-ATSU co-ordinates the changed entry point with the Controlling-ATSU (C-ATSU) Planning Controller. The result is provided to the D-ATSU Planning Controller for authorisation and the **DSC** response is sent to the aircraft. The required change to the current trajectory to comply with the DSC is co-ordinated with the Executive Controller in the C-ATSU and is then sent to the aircraft via **ACL** and an update is provided to the flight data processing system. The **ACL** could also have been made by voice if necessary.

Prior to entry into the oceanic/remote domain, a weather report is provided to the Planning Controller indicating that moderate to severe turbulence may be expected over this portion of the flight. This information is sent to the aircraft via the Data link Significant Meteorological Information **(D-SIGMET)** service. A new network connection is established between the aircraft and the Oceanic/Remote domain ground system before the connection with the En Route domain ground system is released.

The aircraft progresses through the Oceanic/Remote domain. The Flight Crew requests a more efficient altitude via **ACL**. Due to traffic, the **ACL** response includes the requirement to execute an In-Trail Procedure **(ITP)** using **ADS-B** information on the flight deck display between a pair of **ADS-B**-equipped aircraft. The progress of the flight is monitored by an **ADS** contract between the aircraft and the ANSP. Any events that cause the aircraft to be in non-compliance with the planned trajectory are communicated with appropriate alerting to the Executive Controller. Before the aircraft returns to the En Route domain, a new network connection is established between the aircraft and the En Route domain ground system before the connection with the Oceanic/Remote domain ground system is released.

The ATSU automation system recognises the position of the aircraft approaching the En Route domain and sets the exit conditions (target time) taking into account restrictions at the destination airport (if applicable in this sector). The AMAN calculated time is sent to the aircraft via the Arrival Manager Delivery **(ARMAND)** service and any modifications to the aircraft's trajectory are communicated via **ACL**. The aircraft position causes a Fuel Status (**FUEL**) message to be sent to AOC.

The conflict probe system provides the Planning Controller and the Executive Controller information about potential conflicts with other aircraft within a specified time, e.g., the next 15 minutes.

The Planning Controller analyses interactions with other aircraft that are reported to him/her by the conflict probe system. The Planning Controller probes "What if" solutions for interactions. The conflict probe system may offer alternatives to the existing route and the Planning Controller assesses these alternatives, and then the alternatives are provided via the Dynamic Route Availability **(DYNAV)** service for Flight Crew assessment. The Planning Controller enters the Flight Crew-selected alternative and updates the flight trajectory in the ATSU automation system. The Executive Controller is notified about the required change to the trajectory of the aircraft and issues the **ACL** instructions to the Flight Crew to achieve exit conditions to enter the next sector.

The Planning Controller, in co-ordination with the Executive Controller, occasionally issues instructions by data link to the Flight Crew via **ACL** for cases where a manoeuvre is planned at a later stage, (e.g., >2 minutes from current flight position). Otherwise, the Executive Controller provides instructions via **ACL** (voice or data) as determined by the tactical nature of the situation. The Flight Crew flies the aircraft according to the instructions given. The ATSU automation system recognises the aircraft's position relative to exiting the ATSU and compiles a Data Link Operational En Route Information Service **(D-ORIS)** report specific to the remaining portion of the area to be over-flown and sends it to the aircraft.

The ATSU automation system uses the **ADS-B** and radar information to monitor that the aircraft behaviour is in conformance with the given clearances and, in case of non-conformance, issues warnings to the Executive Controller who intervenes via voice or data if a situation requires action.

The Executive Controller initiates a transfer of the aircraft to the next sector. The data link processing system provides the next frequency to the Flight Crew via **ACM** and transfers the air/ground data link services to the next sector.

The AMAN system notifies the Planning Controller and the Executive Controller about Top of Descent (TOD) at a time parameter prior to the TOD position. The conflict probe indicates a conflict will occur if the aircraft is to comply with the TOD calculation. A Sequencing and Merging **(S&M)** operation is required to mitigate the conflict. As the Aircraft reaches the TOD position, an **ACL** instruction containing **S&M** instructions is issued to implement the needed trajectory. An **ARMAND** is initiated containing the Standard Terminal Arrival Route (STAR) allocation; runway for landing, and AMAN constraints.

Prior to entry into the arrival TMA domain, a new network connection is established between the aircraft system and the arrival TMA domain ground system before the connection with the En Route domain ground system is released.

3.3.5 Arrival in TMA

The system updates AMAN with changes to the arrival sequence. AMAN calculates constraints by taking into account the actual traffic situation and makes the information (time to lose/gain or hold) available to the concerned Planning Controller and Executive Controllers in upstream sectors/ATSUs. If required, the conflict probe system calculates a conflict-free alternative trajectory for the flight to comply with the AMAN constraints. The Planning Controller of the receiving sector checks the **PPD** service information to see if the conflict probe system-provided trajectory could be improved with these preferences. The Planning Controller accepts the proposal and co-ordinates the sending of the **ACL** instruction with the Executive Controller.

Based on the information obtained via **SAP** and **PPD**, the executive controller determines which aircraft may execute a spacing application and issues **S & M** clearances to those aircraft via **ACL**.

At this time, the Executive Controller determines that the voice communication frequency in use has been blocked. In order to address this concern and free the voice channel for communications, the Planning Controller initiates an uplink of the ATC Microphone Check **(AMC)** service to all aircraft with which communication is required. Within moments, the blockage of the frequency is resolved and the Executive Controller returns to voice communications for tactical instructions as necessary.

The flight information system provides requested Data Link Automatic Terminal Information Service **(D-ATIS)** information to the aircraft. The Aircraft Operator informs the Flight Crew via data link and informs the Tower Ground Controller via ground/ground communications about stand/gate allocation.

The Executive Controller instructs the Flight Crew to descend. The FMS flies the aircraft according to the given instructions to the Initial Approach Fix (IAF) and generates a final Fuel Status (**FUEL**) report to AOC for refuelling planning. The tracking system uses **ADS-B** and radar data to monitor that the aircraft behaviour is in accordance with the given clearances and issues warnings to the Executive Controller in case of non-compliance. The Executive Controller can intervene via voice if a situation requires immediate action. The ATSU automation generates a **D-SIG** of the arrival airport surface.

The Executive Controller issues instructions to the Flight Crew to follow the calculated profile for final approach via **ACL**. The Flight Crew reports: "Established on Final Approach." The Executive Controller instructs the Flight Crew to monitor the Tower Runway Controller via **ACM**.

Prior to entry into the Airport domain, a new network connection is established between the aircraft system and the Airport domain ground system before the connection with the TMA domain ground system is released.

3.3.6 Arrival in the Airport Domain

The Tower Runway Controller monitors the traffic situation and intervenes if required. The Tower Runway Controller issues the "Landing Clearance" to the Flight Crew. The Tower System provides a recommended **D-TAXI** runway exit and the taxi-in route plan to the Tower Runway Controller. The Tower Runway Controller issues the **D-TAXI** instructions to the Flight Crew via **ACL,** which is overlaid on the D-SIG received prior to the final approach.

The Flight Crew lands the aircraft. The avionics detects touch down and disseminates this **OOOI** information to the AOC. The common network system makes this information available to other users. The A-SMGCS informs the Tower Runway Controller about the aircraft vacating the runway. The Tower Runway Controller instructs the Flight Crew to contact the Tower Ground Controller via **ACM** (voice or data).

3.3.7 Arrival Taxi

The A-SMGCS uses **ADS-B** and radar data to notify the arrival sequence of the aircraft to the Tower Ground Controller. The Tower Ground Controller uses the **D-TAXI** information to verify the aircraft's assigned route from the landing runway nominated exit point to the gate/stand.

The Flight Crew contacts the Tower Ground Controller. The Tower Ground Controller clears the Flight Crew to follow the **D-TAXI** route plan. The Flight Crew manoeuvres the aircraft according to the instructions. The Tower Ground Controller monitors the traffic situation and intervenes if required. A-SMGCS calculates the target taxi-in period in realtime and uses a combination of **ADS-B** and radar information to monitor the traffic situation for the detection of potentially hazardous situations (e.g., aircraft speed, conflict between aircraft and with service vehicles or obstacles or airport infrastructure) and issues warnings to the Tower Ground Controller as required.

When the aircraft arrives at the gate/stand, the aircraft sends an **OOOI** to the AOC who makes the information available for other users. AOC responds to the OOOI message with a Flight Log Transfer (**FLTLOG**) message to inform the crew of the next flight assignment. The Flight Crew informs the Tower Ground Controller: "Finished with engines." Data associated with the performance of the aircraft during flight and maintenance information are sent to the airline. The network connection between the aircraft and ground system is terminated.

3.4 Phase 2

The ATM system has been evolving constantly since introduction of Phase 1. All ATM stakeholders are fully participating in the Layered Planning Process and the use of Collaborative Decision-Making (CDM) Processes is routine and commonplace. This has improved and widened the database for situational awareness and consequently makes the CDM Processes faster and decreases uncertainty in decision-making.

The adherence to the concept of Layered Planning and the philosophy of CDM has driven the development of homogeneous procedures, and the integration of systems and services for exchange of information. The integration has evolved over time from simple standardisation of interfaces in the beginning, via local "islands of integration," e.g., at aerodromes, to a system-wide integration including air and ground elements as well as planning and executive levels.

In Phase 2 the organisation of the airspace is now either Managed, or Unmanaged. The composition of Managed Airspace is structured routes surrounding arrival and departure airspace and airspace where user preferred trajectories are provided within given constraints. Unmanaged Airspace includes designated airspace where autonomous operations are conducted and airspace where ATS is not provided; this is illustrated in Figure 3-1 below. The degrees of freedom in flight planning and flight execution are governed by traffic density and level of equipage.

All traffic within Managed Airspace is known to the ATSP(s) involved. In Unmanaged Airspace, the ATSP may or may not be aware of the aircraft operations depending on the ground system architecture. However, as depicted in Figure 3-1, the airspace surrounding autonomous operations areas is managed and therefore the ATSP has knowledge of what aircraft entered or departed that airspace, but there is no ATC service being provided.

The level of service offered by the ATSU corresponds to the mode of operations in the different parts of the airspace. From a communications perspective, there is still a need for a communications buffer to exist on the managed/unmanaged airspace boundary in order for aircraft within managed airspace to be provided with separation assurance.

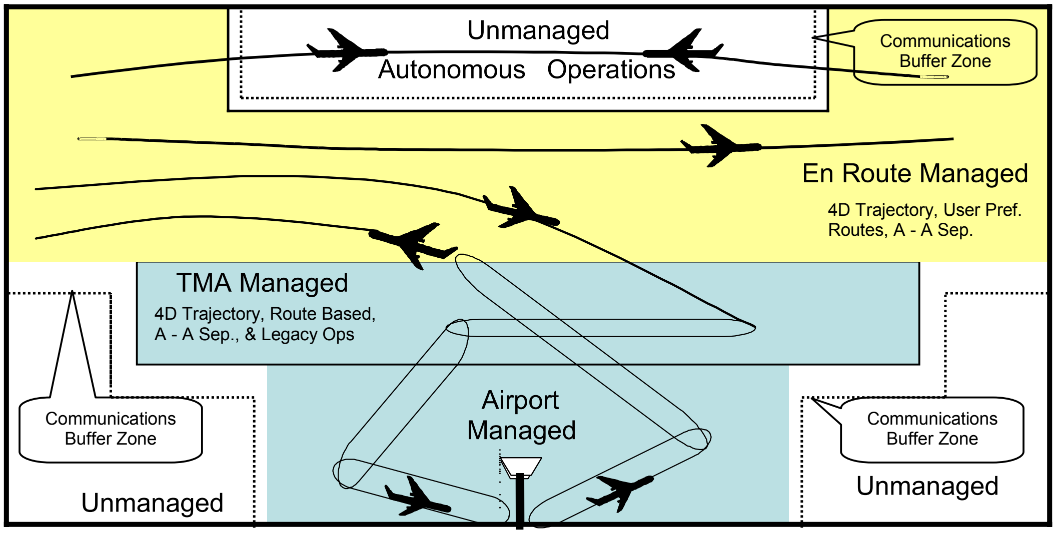


Figure 3-1: Airspace Organisation in Phase 2

In Phase 2, the integration of air/ground systems has evolved to an extent enabling common use of up-to-date information in a seamless and economical way. The information used in integrated systems comprises data from various sources, be it in the air or on the ground (e.g., FMS, AMAN), of different natures (e.g., intent data, forecast data), and of different urgency and priority (e.g., emergency communication, planning information). Common rules and standards are in place for the use of integrated systems and for the treatment of information and data. As communication and information exchanges between ATM stakeholders became more important, decision-making processes became collaborative as common situational awareness of the ATM stakeholders developed, and the roles and responsibilities evolved. The route based airspace design has predominantly been eliminated, replaced by spacing and sequencing applications. The size of Autonomous Operation areas has continued to increase. This paradigm change has defined the ATM environment of Phase 2.

The use of trajectory negotiations has become the norm. The evolution of Common Trajectory Co-ordination (COTRAC) has taken place, helped by the reorganisation of airspace and the emergence of avionics that allow the creation of 4-D trajectories, unrestricted by the number of points needed for their definition.

The implementation of the correct mix of services described in Section 2, along with supporting automation systems, has allowed an increase in the number of aircraft monitored by a given Controller team. Sector boundaries are now routinely changed to accommodate the division of labour amongst Controllers as traffic/weather conditions warrant. The communications resources associated with the airspace are all network-based and are reassigned as needed to provide coverage for the new sector layouts.

The most significant change to the operating concept previously described under Phase 1 is the commonplace use of transferred separation responsibility to Flight Crews from Controllers. Use of the cockpit display to provide air traffic situation awareness (ATSAW) of all aircraft in the vicinity and determine their short term intent has provided the basis for this routine sharing or transferring of separation responsibilities. In some regional implementations, separation standards in all domains have been reduced to that which is required to avoid the wake turbulence of other aircraft or to meet a particular time of arrival at a significant point. To ensure safety levels are maintained where wake vortex separation is used, the ground and airborne systems must have the capability to detect conflicts, provide resolutions, and in rare cases implement the resolutions of the required manoeuvre by the aircraft, without human intervention, e.g. auto execution. The avionics capabilities now include conflict probing and resolution software used for managing conflicts when conducting autonomous operations.

Autonomous operations are performed in dedicated volumes of the managed airspace to accommodate the demand patterns. The dimensions of this airspace are tailored to the need for safe operation of aircraft in autonomous mode. This may encompass only a few flight levels in high-density airspace or bigger areas in low-density airspace, which offer the best possible freedom of movement. The aim will be to adjust the volumes of airspace allocated to Autonomous Operations to maximise the benefits for capable aircraft, while providing an incentive for aircraft operators with less capable aircraft to upgrade their avionics.

Autonomous Operations Areas (AOA) are managed by ATC at the entry and exit points, and for a buffer where separation assurance is provided. If due to circumstances which occurred during the flight through the Autonomous Operations Area , e.g. air to air conflicts, an aircraft is unable to comply with the COTRAC upon exit, communications with the appropriate ATSU must occur ~100 NM prior to departing the AOA. Aircraft wishing to participate in this self-separation operation must be equipped with the correct on-board automation allowing intent and conflict resolution sharing via "machine-to-machine" negotiations. The ADS-B application monitors other aircraft and triggers the conflict probe software when the need arises. The longer term projected intent is determined by interrogating the involved aircraft via a point-to-point data link. The information shared provides enough 4-D positional information beyond the detected conflict zone to assess the best resolution. Upon analysing the positional information, on-board avionics co-ordinate manoeuvres that resolve the conflict and present the resolution in graphical form to the Flight Crew for activation. Some aircraft are capable of executing these manoeuvres without human intervention when set for that mode. Communications between the Flight Crews may or may not be necessary depending on the geometry of the conflict.

Where once a hub and spoke operation was the norm with many medium size (e.g., 100-140 passenger) aircraft, the industry now consists mainly of larger (e.g., 225 or more passenger) aircraft conducting trans- and inter-continental travel operating from the major metropolitan airports. Additionally, limited passenger services between airports and downtown locations using aircraft capable of vertical takeoff and landings (VTOL) are used on an increased basis.

Another revolution that has taken place is in the aircraft population. In some regions, a new breed of "microjets" has been developed to satisfy the need for unrestricted access to travel on an as-needed basis. The microjets, carrying 6-12 passengers, cater to short haul domestic travel e.g.; 750 NM, to/from your own home town or secondary suburban airports. They operate primarily from rural airports; basically on-demand, or with little to no prearranged travel planning required and they are competitively priced with the conventional commercial air transportation industry. Some estimates[2] project that this type of aircraft can represent 40% of the daily traffic load.

Another new type of aircraft operation that is now common and routine is remotely operated aircraft (ROA) or unmanned aerial vehicles (UAV) operating GAT in many types of airspace. In the U.S., estimates approach ~20,000 of these aircraft in operation in 2030 predominantly for military, cargo, agricultural or security operations.

Note: For safety purposes, it is highly desirable that these aircraft use a separate communications link for actual manoeuvring of the aircraft versus the ATS communications link.

This shift in the aircraft population has stretched the capacity of the ATM system. While it took some time to integrate these aircraft into the planning and decision-making process, once all shareholders understood how to work with the system, the increased burden of these operations became manageable. UAVs, microjets, and all other aircraft operate alongside each other without any user needing to be treated differently.

A new type of Managed airport has also evolved. In order to assist in maintaining a higher degree of safety and efficiency at low to medium density airport environments, "virtual" towers where an automation platform replaces the Controller function issues weather and sequencing information based on the aircraft provided position and intent data. This provides a benefit to the local airport users as well as a saving to the ATSP in reduced resources required to provide that level of service.

Managing the flow of traffic has also become a routine task. The majority of traffic is metered from take off to arrival using four dimensional trajectory negotiations. Users need only notify the Controller if there is a need to change the trajectory, otherwise communication with the aircraft is mostly controlled by the System as it monitors the traffic.

CDM allows for aircraft to join together and create a "flight" of aircraft proceeding in the same direction to similar destinations. These operations are performed using similar procedures as is done with military operations flights today. Airborne display and automation systems provide assistance in the maintenance of separation from other aircraft in the flight.

The ATM system performance requirements have now evolved to the point where services such as **A-EXEC** require latency and availability levels that prevent catastrophic consequences. For example, in order to benefit from the services in this environment, the ATM system must receive non-conformance reports from aircraft that are projected to deviate by more than a specified time (e.g. 10 seconds) from a previously co-ordinated longitudinal axis, or more than a specified distance (e.g. 1000

[2] The U.S. JPDO has estimated that ~13,000 of these aircraft will be in operation in 2025.

feet) laterally. This criterion causes constant finite adjustments to the agreed **COTRAC**s as environmental conditions cause non-conformance issues.

As data is now the primary means of communications, associated system developments have occurred to ensure highly reliable and deterministic provision of communications. Traffic densities have increased in some domains to such an extent that the failure of the data communications does not allow safe recovery based solely on voice.

Any intervention by Controllers due to system failures relies on a service baseline that was in place in Phase 1 timeframe.

3.5 Phase 2 Scenario

The network management services described in Phase 1 scenario continue to be used in Phase 2 to support ATS and AOC services.

Note 1: It is assumed that data transactions involving the Flight Crew or Controller always take longer than voice transactions due to the need to access, display, comprehend, and respond to data messages.

*Note 2: The Services listed in the following scenarios are not all-inclusive of the Services listed in Section 2. An acronym in **bold** type indicates a message transaction process using the services defined in Section 2 is occurring.*

3.5.1 Pre-Departure Phase

The mode of operation described under the Phase 1 scenario is now in common use for all aircraft. In particular, aircraft equipage has evolved to the point where every aircraft is now equipped with a cockpit display capable of high definition graphics. This allows the use of advanced concepts in ATM, based on graphical depictions of the surrounding aircraft situation, to be commonplace.

The issuance of a **DCL** now involves the negotiation of a highly constrained trajectory using the **COTRAC** service. The negotiation of the trajectory is done in accordance with the principles of CDM (involving the airspace user) to ensure that the airspace users' needs are considered. The final point in the clearance includes the required constraint of the arrival airport provided by the ground system.

3.5.2 Departure

The aircraft follows the 4-D trajectory previously negotiated through **COTRAC**. The ATSU conflict probe system is now configured for up to a 2-hour look ahead from the active present position. The Controller team takes necessary action to alleviate these conflicts using the necessary services, predominantly the fine-tuning of the COTRAC agreement of involved/impacted aircraft.

3.5.3 En Route/Oceanic/Remote/Autonomous Operations

As the use of the services and the nature of ATC have evolved, the communications requirements have evolved also. Trust in the system's performance has become commonplace. Routine exchanges are no longer needed. Everything the flight must do is embedded in the **COTRAC** agreement. Communications transfers via **ACM** occur automatically without Controller/Flight Crew involvement. **FLIPINT** agreements between the aircraft system and the ATSU automation system are now in place with all aircraft and reports are only generated when an event occurs beyond the parameters set in the **COTRAC** agreement. The aircraft's COTRAC trajectory takes into account the computational process of the arrival time constraint set by the AMAN system. Changes to this contract are more in the context of overall trajectory maintenance.

However, when a non-compliance notification is received by the ATSU with less than 2 minutes remaining for resolution of the new conflict, two options are available. The first option is to notify the Controller with a warning message and allow the resolution to be achieved via voice.

The second option is ONLY applicable for aircraft equipped to do the **A-EXEC** service which allows for reduced separation e.g. 2 NM or wake turbulence footprint. In this case, **A-EXEC** is initiated when the time remaining does not allow for the delays associated with human-in-the-loop performance. The ATSU automation must determine what the appropriate trajectory modifications are and initiate the transaction to the aircraft with an **A-EXEC** flag set to execute the manoeuvre without the Flight Crew acknowledgement.

In En-route/Oceanic/Remote airspace environments, Unmanaged Airspace may be designated for autonomous operations where self-separation applications are routinely conducted. These applications have followed a natural progression from earlier spacing applications, e.g. **S&M, C&P, and ITP**. Aircraft that have equipped for autonomous operations are managed via **COTRAC** up to the entry point into the AOA and are expected to comply with the existing **COTRAC** upon exiting the autonomous operations area. Any changes to the exit conditions require the aircraft to initiate a trajectory change request prior to departure from the AOA. When an aircraft detects a potential conflict, the **AIRSEP** service activates to determine the trajectory of the other aircraft involved, negotiates a solution, and provides the solution to the Flight Crew.

3.5.4 Arrival in TMA

Arriving at the entry point into the TMA, the COTRAC operation continues. When necessary due to the traffic density, aircraft are instructed via **ACL** to use the appropriate services to self-separate in the final approach phase from traffic landing on the same or closely spaced parallel runways. As the aircraft approaches the final approach course, the **PAIRAPP** service is initiated. This is the point where the COTRAC is terminated and the PAIRAPP service takes over to transfer separation responsibility from the Controller to the Flight Crew. These services, provided in combination, are the natural extension of the early spacing applications such as S&M used in Phase 1 En Route airspace. The arrival taxi phase is now established before the aircraft begins the final approach for landing. The **D-SIG** surface map and **D-TAXI** overlay is communicated in advance of the landing clearance so that the Flight Crew can determine any impacts to its configuration.

3.5.5 Arrival Taxi

All the services introduced under the Phase 1 timeframe continue to be in use to some extent unless superseded by services such as the now mature COTRAC service. However, as airspace requirements and aircraft equipage increase, more aircraft are eligible for data services.

4 Safety and Security Operational Requirements

Operational requirements for new air traffic management and support services are derived from a number of sources. Two of the most important sources are the analyses conducted to ensure that air traffic services are provided with the requisite safety and security. This section summarises the processes, interim products and resultant operational requirements derived from safety assessments of selected air traffic services, and from information security analysis of the FRS concept.

4.1 Operational Safety Requirements

4.1.1 Background

To determine the operational safety requirements for the FRS, several services from Section 2 were selected for assessment. These services, COTRAC, S&M and A-EXEC, were chosen for their potential to originate some of the most stringent or demanding safety-related requirements. Analysis of the remaining services has either been done for Phase 1 operations by current or on-going data link implementations or will be completed for Version 2 of the COCR.

Safety assessments of the services were conducted in general accordance with [13]. The assessments used the FAA Safety Management System Manual (SMS) severity definitions and EUROCONTROL's Safety Regulatory Requirement (ESARR 4) Set 1 Severity Indicators. [14] and [15].

The initial operational safety assessment (OSA) effort is the hazard analysis, which identifies potential hazards that may arise during the use of the service. The effects and consequences encountered as a result of such hazards are then established and evaluated. Table 4-1 outlines the hazard effects and the standardised classification scheme used to describe the severity of those hazards.

Hazard Class	**1 High Catastrophic (HC)**	**2 High Severe (HS)**	**3 High (H)**	**4 Medium (M)**	**5 Low (L)**
Effect on Operations	Normally with hull loss. Total loss of flight control, mid-air collision, flight into terrain or high speed surface movement collision.	Large reduction in safety margins or aircraft functional capabilities.	Significant reduction in safety margins or aircraft functional capabilities.	Slight reduction in safety margins or aircraft functional capabilities.	No effect on operational capabilities or safety
Effect on Occupants	Multiple fatalities.	Serious or fatal injury to a small number of passengers or cabin crew.	Physical distress, possibly including injuries.	Physical discomfort.	Inconvenience.
Effect on Flight Crew	Fatalities or incapacitation.	Physical distress or excessive workload impairs ability to perform tasks.	Physical discomfort, possibly including injuries or significant increase in workload.	Slight increase in workload.	No effect on flight crew.
Effect on Air Traffic Service	Total loss of separation.	Large reduction in separation or a total loss of air traffic control for a significant period of time.	Significant reduction in separation or significant reduction in air traffic control capability.	Slight reduction in separation or slight reduction in air traffic control capability. Significant increase in Controller workload.	Slight increase in Controller workload.

Table 4-1: Description of Hazard Severity

Each class of hazard can be tolerated to a certain degree. For example, hazards of Class 5 can occur with more frequency than hazards of Class 4, due to the reduced severity of a Class 5 hazard. Since hazards can rarely be eliminated with complete certainty, even Class 1 hazards can be tolerated if they are extremely rare (e.g., once every 100 years.) Safety Objectives have been defined to quantify and categorise the degree of tolerance in terms of probability of occurrence, as shown in Table 4-2.

Safety Objective	Definition
Frequent	=>1 occurrence in 10^{-3} per operational hour
Probable	=<1 occurrence in 10^{-3} per operational hour
Remote	=<1 occurrence in 10^{-5} per operational hour
Extremely Remote	=<1 occurrence in 10^{-7} per operational hour
Extremely Improbable	=<1 occurrence in 10^{-9} per operational hour

Table 4-2: Safety Objective Definitions

Figure 4-1 combines the safety objectives (frequency or probability of occurrence) with each hazard class (severity) and identifies the risk acceptance level of each combination. The safety objective for each hazard class is to reach a probability that is acceptable.

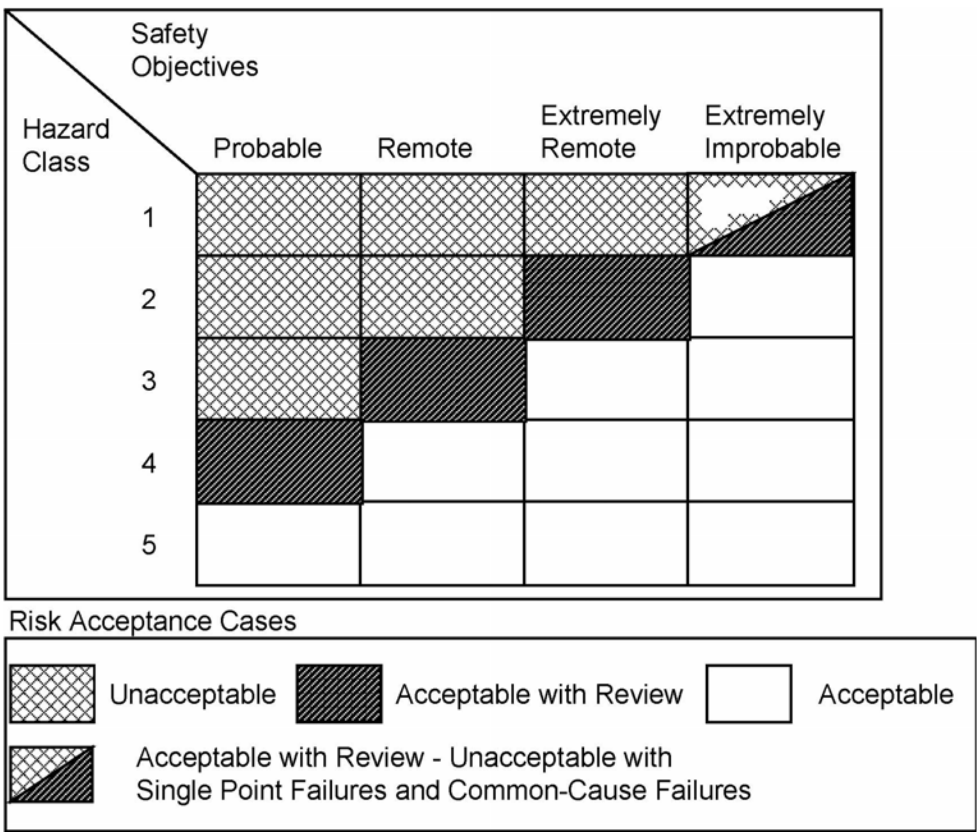


Figure 4-1: Hazard Classes and Safety Objectives

For example, reference to Figure 4-1 indicates the acceptable Safety Objective for a hazard in Hazard (severity) Class 3 is Remote (no more than 1 in 10^{-5} per operational hour) with appropriate safety review. Without the specified review, the probability of a Class 3 Hazard may not exceed Extremely Remote, or 1 in 10^{-7} per operational hour. This process is repeated to establish the acceptable probability of occurrence for each hazard.

Once the Safety Objective for each Hazard is established, the assessment determines how the hazard can be mitigated to comply with the Safety Objective. Essential to this effort is identification of existing controls that reduce the probability of the hazard occurring, and/or the severity and likelihood of the worst credible effect. Existing controls are procedures, equipage or environmental factors that exist or operate in the environment in which the service is used, and contribute in some way to the safe utilisation of the service. An inventory of existing controls is established, as their absence would have negative consequences on the service provision and use.

The existing requirements are shown in Table 4-3 and Table 4-4.

The result of each final element of the safety assessment is the Recommended Requirements. Recommended Requirements are procedures, equipment, and/or functional or environmental imperatives that must be implemented to reduce (i.e., mitigate) the probability of hazards in order to meet specified Safety Objectives. Recommended safety requirements often establish how often or likely it is that an event may occur, in order for the service, and the system enabling it, to be considered safe. The likelihood, or probability of occurrence, is quantified using the same Safety Objective terms. Recommended requirements are employed during system specification as the basis for functional and performance requirements, and facilitate architectural decisions in the design phase.

4.1.2 Safety Assessments

High-level operational safety analyses of the COTRAC and S&M services were performed only for the data communications link intended to support each service. Operational safety and performance assessments of the A-EXEC service incorporated analysis of all contributing subsystems, components and communications.

These analyses were based on the current state of knowledge of the services (from their respective initial environment descriptions). Results of these analyses will require updating as operating concepts, system requirements, and supported services evolve. Nevertheless, early safety assessments are useful in guiding developers to consider safety implications at an early stage. Validated (complete and accurate) safety and performance requirements for communication services making use of the FRS (both air and ground) will need to occur prior to operational use. This would include the service provider, as appropriate.

4.1.2.1 Prerequisite Safety Requirements

The COTRAC, S&M, and A-EXEC services safety analyses presume the existence of the safety requirements in this section. If any of these requirements are not in place, the risks associated with COTRAC, S&M, and A-EXEC must be re-assessed. These safety requirements are listed in two tables: Table 4-3 lists general ATM requirements and Table 4-4 lists data link specific requirements. These requirements are not re-listed under each specific service.

Number	Requirement
1	The ATM system shall be capable of detecting and providing alerts for non-conformance.
2	The ATM system shall be capable of providing resolution for non-conformance.
3	The ATM system shall be capable of detecting and providing alerts for potential conflicts.
4	The ATM system shall be capable of providing resolution for potential conflicts.
5	The ATM system shall be capable of detecting and providing alerts for potential separation violation.
6	The ATM system shall be capable of providing resolution for separation violation.
7	No clearance shall be given to execute any manoeuvre that would reduce the spacing between two aircraft to less than the separation minimum. (ICAO PANS-RAC 4444: para 5.2.1.1)[47]
8	A controlled flight shall be under the control of only one air traffic control unit at any given time. (ICAO Annex 11: para 3.5.1)[48]
9	The aircraft shall accept clearances / instructions only from the current control or downstream authority.
10	Only the aircraft shall initiate downstream clearances.
11	Downstream clearances shall not affect current airspace.
12	The source of all control messages shall be identified to the aircrew.
13	All ground-air messages shall contain the facility identification.
14	All air-ground messages shall contain the aircraft identification.
15	Each aircraft shall have a unique identification.
16	An aircraft shall only accept messages addressed to that aircraft.
17	Alternate means of communications shall be available (e.g. a/g voice comm., air-to-air voice comm., pilot ability to provide feedback via Transponder).
18	Aircrew shall acknowledge ATC clearances and instructions.
19	ATC clearances shall be delivered in the order (i.e. sequence) they are sent.

Table 4-3: General ATM Requirements

Number	Requirement
1	The ATM system shall be capable of detecting late/expired data link messages (e.g., Messages shall be time stamped).
2	Procedures shall exist for late message handling.
3	Corrupted data link messages shall be rejected.
4	Failure of air-ground data link communications shall not affect air-air communications.
5	The ATM system shall be capable of detecting air-ground data link communications failures.
6	The ATM system shall be capable of providing alerts when the air-ground data link communications fails.
7	The ATM system shall be capable of error detection and correction.
8	The ATM system shall detect and report unsuccessful data link communications (e.g., failure to deliver).

Table 4-4: Data Link Specific Requirements

4.1.2.2 COTRAC Communications Link OSA

An operational safety assessment (OSA) was performed on communications elements of the COTRAC service. The OSA was strictly limited to hazards caused by the communication link; hazards caused by the COTRAC automation, the controller, or the aircrew were considered out-of-scope.

4.1.2.2.1 COTRAC Communications Link Hazard Analysis

A review of hazards and primary stressors identified during the COTRAC communications link OSA identified the hazards and primary stressors. Each of the fifteen hazards identified were analysed, and categorised by cause.

4.1.2.2.2 COTRAC Communication Link Recommended Requirements

The COTRAC communications link OSA identified the Recommended Requirements shown in Table 4-5. For the FRS to support the COTRAC service safely, these recommended requirements (procedures, equipage, functional and environmental) must be fulfilled. Should any of the recommended requirements not be achieved or the requirements in Table 4-3 and Table 4-4 not be implemented, the COTRAC communication hazards must be re-assessed.

Number	Requirement
1	The likelihood of the loss of the COTRAC communication capability shall be no greater than remote.
2	The probability of not detecting a non-delivered or corrupted message shall be no more than extremely remote.
3	The ATM system shall alert the controller and aircrew when COTRAC fails.
4	ACAS (or functional equivalent) shall be available.
5	Separation minima values shall allow human-in-the-loop intervention.
6	Procedures to revert back to non-COTRAC operations shall be identified (e.g., tactical).
7	The applied separation minima shall not be less than what is required to provide a safe escape when intervention is required.
8	The ATM system shall be capable of detecting if a response message is not received from the aircraft to which it was intended.

Table 4-5: COTRAC Specific Recommended Requirements

4.1.2.3 S&M Communication Link OSA

An operational safety assessment (OSA) was performed on the S&M communications elements. The OSA was strictly limited to hazards caused by the communication link; hazards caused by the S&M application, the controller, or the aircrew were considered out-of-scope.

4.1.2.3.1 S&M Communications Link Hazard Analysis

A review of hazards and primary stressors identified during the S&M Communications Link OSA identified the hazards and primary stressors. Each of the twenty-two hazards identified were analysed, and categorised by cause.

4.1.2.3.2 S&M Communication Link Recommended Requirement

The S&M communications link OSA identified the Recommended Requirements shown in Table 4-6 considering the cited existing controls. For the FRS to support the S&M service safely, these recommended requirements (procedures, equipage, functional and environmental) must be fulfilled. Should any of the recommended requirements not be achieved or the requirements in Table 4-3 and Table 4-4 not be implemented, the S&M communication hazards must be re-assessed.

Number	Requirement
1	Air-to-air surveillance shall be available.
2	The likelihood of the loss of the S&M Air/ground communication capability shall be no greater than remote.
3	There shall be a definition of the separation responsibility allocated to the aircraft.
4	Procedures to transition to non-S&M service shall be specified.
5	Procedures shall be developed for when airborne surveillance of target aircraft is lost during an S&M manoeuvre.

Table 4-6: S&M Specific Recommended Requirements

4.1.2.4 A-EXEC Service OSA

An operational safety assessment (OSA) was performed on the A-EXEC service. The OSA included hazards caused by the A-EXEC software application, computers, communication system, surveillance, navigation, and flight automation subsystems and interfaces. Hazards caused by the aircrew, air traffic controllers, and maintainers were considered out-of-scope.

4.1.2.4.1 A-EXEC Service Hazard Analysis

A review of hazards and primary stressors identified during the A-EXEC OSA was undertaken. Each of the sixteen hazards identified were analysed, and categorised by cause.

4.1.2.4.2 A-EXEC Service Recommended Requirements

The A-EXEC service OSA identified the following Recommended Requirements shown in Table 4-7 considering the cited existing controls. The recommended requirements are procedures, equipage and environmental requirements that must be implemented as mitigators for A-EXEC service hazards. Should any of the recommended requirements not be achieved or the requirements in Table 4-3 and Table 4-4 not be implemented, the A-EXEC service hazards must be re-assessed.

Number	Requirement
1	The probability of A-EXEC service failure shall be no greater than extremely improbable. *Note: A potential approach is to provide an air-based A-EXEC service that can take over when ground A-EXEC is unavailable, in which case the likelihood of the simultaneous loss of both ground and air A-EXEC service shall be no greater than extremely improbable.*
2	There shall be an independent (automated) means of maintaining separation when A-EXEC fails and intervention is required, with a severity of no worse than level 3. *Note: Potential implications: - A-EXEC clearance/separation must allow the time/distance for the independent means to detect loss of A-EXEC service and to execute (non-A-EXEC) methods to maintain or reinstate safety margins. There must be a non-human-in-the-loop method to maintain aircraft at safe separation or to transition them to human-in-the-loop separation, with no worse than major injury to personnel and a significant reduction in safety margins (severity 3). This requirement could be met by an independent A-EXEC implementation.*
3	The ATM system shall alert the controller when A-EXEC service is unavailable *Notes: - This could be one or more aircraft; but considered independent failures; (if all aircraft are affected see FRS-A-EXEC Service1) - Ground may or may not be aware of aircraft failure. (E.g., until ground attempts an Execute transmission and it is not acknowledged)*
4	An A-EXEC clearance shall have the capability of being generated, sent (by the ground system), received, processed and executed (by the aircraft system) without human intervention.
5	The ATM system shall be capable of generating and transmitting automatic resolution trajectories (i.e. controller intervention is not required.).
6	The ATM system integrity shall ensure that the probability of not detecting a non-delivered message is no more than extremely remote.
7	The ATM system shall ensure that the probability of not detecting a mis-delivered A-EXEC message is no more than extremely remote.
8	The ATM system shall ensure that the probability of not detecting a corrupted A-EXEC message is no more than extremely remote.
9	The ATM system shall ensure that the probability of receiving an out-of-sequence A-EXEC message is no more than extremely improbable. *Note: Possible approach: time critical clearances transmitted in one complete message.*
10	The ATM system shall ensure that the probability of not detecting an out-of-sequence A-EXEC message is no more than extremely remote.
11	The likelihood of an undetected A-EXEC service (including subsystem) error that produces unsafe trajectories shall be no greater than extremely improbable (this includes the Execute application and navigation/surveillance subsystems).
12	The ATM system shall be capable of detecting potential conflicts and resolving such conflicts without controller/aircrew involvement (air or ground, or both air and ground).
13	The ATM system shall be able to detect a ground/air A-EXEC system failure or lack of availability in sufficient time that alternate means of communications can be activated in time to mitigate the loss of A-EXEC communications.
14	When the A-EXEC ground communication capability fails, alternate means not requiring communication (e.g., procedural) or not requiring ground-based communication shall be available to maintain separation.
15	The aircraft shall be capable of determining, without human intervention, that a message is not from the controlling authority.
16	The aircraft shall reject, without human intervention, any A-EXEC message that is not from the aircraft's controlling authority.
17	The aircraft shall not accept A-EXEC messages from downstream authorities.

18	The aircraft shall automatically accept and execute A-EXEC clearance only from its controlling authority.
19	Procedures to revert back to non-A-EXEC operations shall be identified (e.g., tactical).

Table 4-7: A-EXEC Specific Recommended Requirements

4.2 Operational Performance Assessment

4.2.1 Background

An Operational Performance Assessment (OPA) is conducted to determine the performance a system or service must achieve to be considered safe. OPA results typically include determination of the availability, integrity, and transaction times necessary to enable safe use of the service. These performance parameters are essential ingredients that often drive system selection or design.

4.2.2 COTRAC OPA

An OPA was performed on the COTRAC service concept described in Section 2.2.2.9. There are also performance requirements associated with automation e.g., airborne and ground: route generation, depiction, loading, conflict and out-of-conformance detection, and the generation of alerts which are not considered here.

To determine the COTRAC communication performance requirements, three areas were considered:

- the COTRAC messages exchanged,
- the situation in which COTRAC messages are used, and
- the environment in which COTRAC is used.

4.2.2.1 COTRAC Messages

First, the COTRAC messages were evaluated. The COTRAC messages consist of:

- Trajectory-based flight plan (ground-ground message),
- Trajectory Constraints (air-ground uplink message),
- Trajectory Request (air-ground downlink message),
- Trajectory Clearance (air-ground uplink message), and
- Trajectory Non-compliance (air-ground downlink message)

With the exception of the COTRAC flight plan message, COTRAC messages are essentially CPDLC ACL messages: they are requests, acknowledgements, and clearances. Thus, basing the COTRAC performance requirements on CPDLC ACL message exchange is a logical approach.

The COTRAC flight plan message is only a planning message and is not considered in the performance requirements.

4.2.2.2 The Situations in Which COTRAC Messages Are Used

Next, the situations in which COTRAC exchanges occur were determined as follows:

- To provide an initial COTRAC clearance,
- To provide a response to an aircrew request,
- To more efficiently manage airspace, and
- To intervene when required.

Of these situations, when intervention is required, providing a COTRAC clearance to resolve a potential conflict could have the most stringent requirements.

Note: COTRAC is not the only way to resolve a potential conflict for an aircraft on a COTRAC trajectory.

4.2.2.3 The Environment in Which COTRAC Is Used

The environment in which COTRAC is being used was then considered. The communication performance requirements were based on COTRAC operating as follows:

- COTRAC is utilised for trajectory management from the departure to the arrival phases of flight and may include the associated procedures,
- COTRAC separation minima are not distinct; and separation minima have not changed from 2005, and
- While COTRAC is in use, manual intervention is supported.

4.2.2.4 Performance Requirements

As a result of the analysis of COTRAC, communication performance requirements were derived and are shown in Table 4-8.

Performance Parameters	Allocations
RCTP 95% Transaction Time (TT_{95})	10 s
Loss of Availability of $A_{PROVISION}$ (Probability/flight hour)	Service < 1 x 10^{-5}
Loss of Integrity (acceptable rate/flight hour)	Service < 1 x 10^{-7}

Table 4-8: COTRAC Transaction Performance Requirements

4.2.3 S&M OPA

Note: S&M performance requirements will be developed for Version 2 of this document.

4.2.4 A-EXEC OPA

An OPA was performed on the A-EXEC service described in Section 2. The resulting performance requirements are extremely preliminary. As the A-EXEC service definition matures, future efforts must address potential issues, such as the implications of aircraft encounters while maintaining minimal wake vortex separation, co-ordination between the A-EXEC service and any independent conflict avoidance system, aircrew HMI and auto pilot integration.

4.2.4.1 Assumptions

This quick look assessment considered A-EXEC manoeuvres as time critical. The analysis approach considered various conflict scenarios. A-EXEC may safely resolve some conflict scenarios within the available response time, while other scenarios may not provide enough time for resolution solely via data link.

Some common scenarios in today's environment could result in unrecoverable time-critical situations in an ATS environment that attempts to exploit the potential separation benefits enabled by the A-EXEC service. For these scenarios, an ultra-fast data link may be necessary, but not sufficient, mitigation. Improved procedures and practices may also be required. For example, it is common today for aircraft to fly in opposing directions. This has proven to be safe since pilots and controllers follow procedures and do not ascend/descend into oncoming traffic. However, a mis-delivered or corrupted A-EXEC manoeuvre could initiate this conflict, potentially without time for recovery via A-EXEC or other means. The problem is exacerbated by the likelihood that A-EXEC-capable aircraft will be flying at higher speeds than today, further reducing available response time. It is probably more efficient to mitigate the hazards associated with these scenarios via procedures and practices, rather than to develop a faster FRS to support the A-EXEC service. In fact, hazards may be realised that require increased separation for opposing direction high-speed traffic, thus curtailing anticipated benefits of the A-EXEC service.

To calculate the time available before incident, the OPA made worst-case assumptions about a number of aircraft performance and operations. For example, aircraft in several scenarios were assumed to be travelling at a velocity of 588 KIAS in En Route airspace, and 250 KIAS in TMA below 10,000 ft. Review of near mid-air collision event descriptions indicated closure speed in excess of 500 KIAS can occur in today's environment. While not the norm, these factors were incorporated in scenarios considered in the analysis.

4.2.4.2 A-EXEC Transaction Time Computation

In the most demanding scenarios, the A-EXEC response time consists of detecting the conflict, developing avoidance manoeuvres, transmitting auto-execute manoeuvres to one or more aircraft, and receiving acknowledgement from the aircraft. Time to conflict is the time from detection of a potential separation violation resulting in a conflicting course (with other aircraft, wake turbulence, obstacles or terrain) until time of conflict if speed and/or course are not changed.

Figure 4-2 illustrates a notional example sequence of events that precede the conflict that must be avoided. Assumptions are made and tested for each component and allotted time, to develop the conflict timeline. Manoeuvring time is the minimum time required for aircraft to avoid conflict via a ¼ g manoeuvre. By subtracting manoeuvring time from time to conflict, we identify the available response time for the A-EXEC service to function.

The safety analysis suggests that A-EXEC must either always be available or an alternative or backup system is required in case of A-EXEC failure. The latter case indicates time may need to be allocated for the alternative system to function. If this alternative works in parallel with A-EXEC, then there will be no impact on the time available for the A-EXEC functions; otherwise, A-EXEC allocations must allow time for the alternative system to perform as exemplified in Figure 4-2 below.

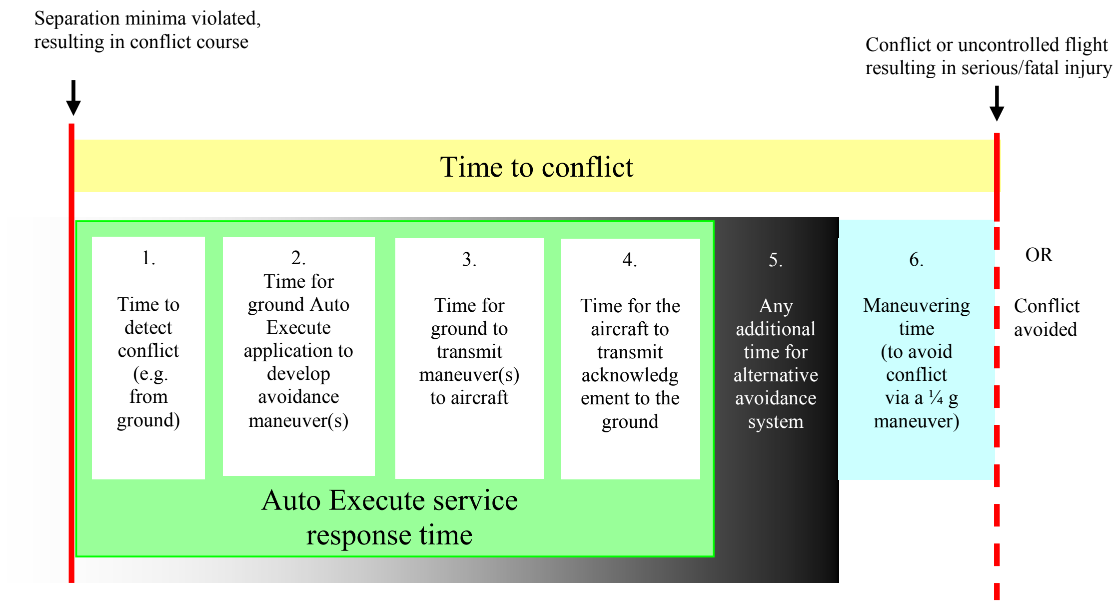


Figure 4-2: A-EXEC Response Time Components (exemplifying allocation for an alternative avoidance system that is not completed in parallel with A-EXEC)

The analysis assumed twenty seconds of manoeuvring time are required to avoid an impending conflict safely via a ¼ g manoeuvre. This assumption will need to be validated for aircraft operating within the Phase 2 timeframe. In some scenarios, the time to conflict is less than the 20 seconds required for ¼ g avoidance manoeuvres. For example, in head-on scenarios at Mach 0.95 there may not be enough time for automated systems to react, so procedures may be required to avoid getting into such time-critical situations.

Closure rates for a commercial jet overtaking a high performance general aviation/business jet were examined in addition to a commercial jet overtaking slower propeller aircraft. The conclusion was that A-EXEC should not be the primary mitigation means since closure at high speeds with slower aircraft may not allow enough time for A-EXEC to mitigate these events. The current practice requiring aircraft to travel at similar speed at the same altitude must be maintained, and new procedures may be required.

The OPA did not assess vertical descent and climb scenarios due to lack of accurate performance data on the time required for an aircraft to slow after climbing/descending at maximum rates. The estimates that were calculated suggested very short response time would be required, and reinforced the idea that even an ultra-fast A-EXEC response may not be sufficient. Practices and procedures may be required to avoid getting into time-critical scenarios associated with vertical climb/descent at maximum rates between adjacent vertical tracks.

4.2.4.3 A-EXEC Recommended Performance Requirements

The A-EXEC Operational Performance Analysis yielded the Recommended Requirements listed in Table 4-9. Severity of the underlying hazards was the primary factor in determining the continuity, availability and integrity requirements.

Performance Parameters	TMA	ENR
RCTP 95% Transaction Time (TT_{95})	< 3.3 s	< 3.3 s
Loss of Availability of Provision ($A_{PROVISION}$) (Probability/ flight hour)	Service < 1 x 10^{-9}	Service < 1 x 10^{-9}
Loss of Integrity (acceptable rate/ flight hour)	Service < 1 x 10^{-9}	Service < 1 x 10^{-9}

Table 4-9: A-EXEC Service Recommended Performance Requirements

These results are sensitive to a number of factors, which could be manipulated to alter the net performance requirements. Shorter manoeuvring times would provide an alternative mitigation for some scenarios, since shorter manoeuvring time allows more time for A-EXEC to detect, solve, and transmit the manoeuvre. This analysis assumed 20 seconds would be required to execute the requisite manoeuvres. The variables that could reduce manoeuvring time include allowing manoeuvres greater than ¼ g, increased response/ performance capabilities of future aircraft, and co-ordinated avoidance manoeuvres by multiple aircraft when possible.

Preliminary results: Extensive simulation will be required to enhance confidence in these estimates. The OPA addressed issues well beyond the FRS boundaries, and as such, appropriate level of stakeholder involvement will be required to support subsequent studies. With strict adherence to new procedures and practices it may be possible for the available response time to be increased (e.g., to 4.5s or more). However, it is likely that the available response time would be shortened if wake vortex separation/encounters (less than currently employed) were addressed. Lacking a clear description of operational use of wake vortex separation across environments and domains, it was not possible to assume separations below present levels in this analysis.

More severe manoeuvres might be restricted to an alternative or back up conflict avoidance system that only functions when A-EXEC fails. If A-EXEC rarely fails, it might be acceptable for the alternative system to impose more severe manoeuvres than the ¼ g manoeuvres assumed to be issued by A-EXEC. More severe manoeuvres may avoid collision or hull loss, but may result in injuries or fatalities.

4.2.4.4 A-EXEC Supplemental OPA Results

While the operational performance assessment focused on performance, it also identified scenarios that need to be mitigated with procedures. For example, the assessment identified scenarios where insufficient time would be available for issuance and conduct of A-EXEC manoeuvre. Also reinforced was the importance of segregated airspace and equipage for surveillance (initially established by the COTRAC OSA), especially when operating at reduced minima. While some scenarios require procedures to maintain separation, an end-to-end ultra-fast system supporting A-EXEC may provide a few additional seconds to manoeuvre the aircraft in order to avoid a deviating aircraft.

The OPA identified recommended procedures and practices including:

- Limit airspeed where mixed type aircraft could exist, similar to today's restriction of 250 KIAS below 10,000 ft.,
- Provide surveillance and non-conformance monitoring for all A-EXEC aircraft, and
- Segregate A-EXEC equipped aircraft from all other aircraft.

4.3 Information Security

This section develops operational information security requirements for the FRS following a logical, risk-based approach based against business goals.

Only a summary of the security analysis performed to derive security requirements, focusing on its most pertinent aspects, is included here. Complete details of the security analysis can be found in [11].

The security requirements developed apply to both voice and data when a new RF link is used. It is expected that existing procedural means will continue to be used to help mitigate security concerns in existing voice links.

The security threat severity categories used have been aligned as far as possible with the safety hazard classes defined in 4.1. Use of identical definitions is not possible in this case because security considers impacts other than safety impacts – for example financial impacts and impacts of business needs – and these other impacts must be included in the security definitions.

4.3.1 Business Goals for Information Security

The business goals for information security of the Future Communications Infrastructure are proposed as follows:

1. **Safety** – The FCI must sufficiently mitigate attacks, which contribute to safety hazards. See section 4.1.2 for a discussion of safety hazards.
2. **Flight regularity** – The FCI must sufficiently mitigate attacks, which contribute to delays, diversions, or cancellations to flights.
3. **Protection of business interests** – The FCI must sufficiently mitigate attacks which result in financial loss, reputation damage, disclosure of sensitive proprietary information, or disclosure of personal information.

The business goals must be met in a manner that is cost-effective in terms of total cost of ownership (including development costs, set-up costs, operating costs including communication overhead, and support costs) and without allowing security itself to reduce the safety of the system (for example by denying service to aircraft that are unable to authenticate their identity).

4.3.2 Process to determine security requirements

Information security concerns the protection and defence of information and information systems. It aims to ensure an appropriate level of confidentiality, integrity, and availability of information in the face of deliberate attacks.

The evolutionary, attack-response nature of information security means that it is important to follow a defined process in order to develop security requirements so that the motivation for requirements is well understood and the analysis can be revisited and revised as attacks change. The process used to develop security requirements for the FRS is summarised in Figure 4-3 below.

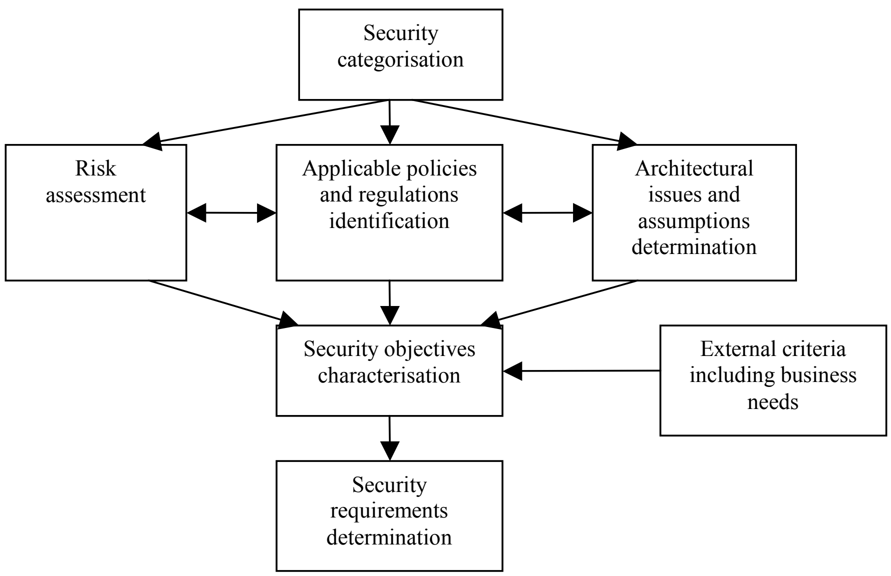


Figure 4-3: Information Security Requirement Process

The initial step, security categorisation, provides an initial assessment of the intrinsic sensitivity of the information being handled by the system, and acts to focus efforts during the remainder of the process (evaluation of a threat severity, etc.).

Next, the risk assessment described in Section 4.3.3 analyses the threats to the system, their likelihood, and potential impact. Mitigating these threats to an acceptable level will be the main driver during security requirement determination. Concurrently, applicable policies and regulations are identified, and architectural issues and assumptions are determined in Section 4.3.4. The focus is on areas that may need to be considered during security requirement determination.

Subsequently security objectives are characterised. These objectives summarise the results of the previous process steps and act as an opportunity to input external criteria such as business drivers into the process.

Finally the security requirements themselves are derived in Section 4.3.5, based primarily on the security objectives and the results of the risk assessment.

Note that security categorisation, policy and regulation identification, and security objective characterisation are not discussed further here. See [11] for details of these process steps.

4.3.3 Risk assessment

Risk assessment is a crucial component of the information security requirements development process. Mitigating risk to an acceptable level is one of the main goals of the security requirements of a system. Of course mitigating risk to an acceptable level can only be achieved based on an accurate understanding of what the risk to the system is. Understanding risk is what risk assessment aims to provide.

Risk assessment consists of two steps: threat identification, which is described in Section 4.3.3.1, and assessment of threat likelihood and threat severity, which is described in 4.3.3.2.

4.3.3.1 Threat Identification

The main threats to the FCI that have been identified are listed in Table 4-10 below.

Threat Identifier	Threat Description
T.DENIAL	System resources may become exhausted due to system error, non-malicious user actions, or denial-of-service (DoS) attack.
T.DENIAL.FLOOD	An attacker floods a communications segment of the FCI with injected messages in order to reduce the availability of the FCI.
T.DENIAL.INJECT	An attacker injects malformed messages into a communications segment of the FCI in order to reduce the availability of the FCI.
T.DENIAL.INTERFERE	An attacker injects deliberate RF interference into an RF communication segment of the FCI in order to reduce the availability of the FCI.
T.ENTRY	An individual other than an authorised user may gain access via technical or non-technical attack for malicious purposes.
T.ENTRY.ALTER	An attacker delays/deletes/injects/modifies/re-directs/re-orders/replays or otherwise alters messages on a communications segment of the FCI in order to reduce the integrity of the FCI.
T.ENTRY. EAVESDROP	An attacker eavesdrops messages on a communications segment of the FCI in order to reduce the confidentiality of the FCI.
T.ENTRY. IMPERSONATE	An attacker impersonates a user of the FCI in order to reduce the confidentiality or integrity of the FCI, or simply to gain free use of the FCI.

Table 4-10: FCI High-Level Threats

4.3.3.2 Threat Likelihood and Threat Severity

An initial assessment of threat likelihood and threat severity is provided in Table 4-11 below. The assessment assumes that the FCI contains no specific security controls or intrinsic security mitigations (such as the inherent mitigation of deliberate RF interference by certain spread spectrum radio systems).

Threat likelihood is ranked as “unlikely”, “likely”, or “highly likely” based on how likely it is that the threat will be realised. Threat likelihood is assessed based on two factors:

- **Motivation** which considers how strong motivation to realise the threat is likely to be. A value in the range 1-3 is assigned to motivation, with 3 representing strong motivation and 1 representing weak motivation.
- **Required capabilities** which considers how much financial and technical capability is likely to be required to realise the threat. A value in the range 1-3 is assigned to required capabilities, with 3 representing a low requirement, and 1 representing a high requirement.

Threat likelihood values are assigned by multiplying the motivation and required capabilities values – a result of 1 to 3 corresponds to “unlikely”, 4 to 6 corresponds to “likely”, and 7 to 9 corresponds to “highly likely”.

Threat severity is ranked based on the potential impact of the threat if it is realised, using the following categories:

- None – if there is no perceivable impact on safety, flight regularity, or business interests.

- Low - if there is a limited adverse effect on safety, flight regularity, or business interests.
- Medium - if there is a serious adverse effect on safety, flight regularity, or business interests.
- High – Severe - if there is a severe adverse effect on safety, flight regularity, or business interests.
- High – Catastrophic - if there is a catastrophic effect on safety, flight regularity, or business interests.

To calculate severity, potential impacts on safety, flight regularity, and business needs are considered, and a value in the range 1-5 assigned to each, with 1 being the most serious impact and 5 being the least serious impact. Threat severity is then assigned based on the maximum of the three values assigned, with a maximum value of 1 corresponding to "high – catastrophic", 2 corresponding to "high – severe", etc.

It is important to realise that the assessment in Table 4-11 is necessarily only a preliminary assessment at this early stage in the development of the FCI. The assessment will need to be regularly revisited and revised in order to ensure that it remains up-to-date with attack innovations and development decisions.

Threat Identifier	**Likelihood**			**Severity**			
	Motivation	**Required Capabilities**	**Overall**	**Safety**	**Flight Regularity**	**Business Needs**	**Overall**
T.DENIAL							
T.DENIAL.FLOOD	3	2	Likely	2	3	3	High - Severe
T.DENIAL.INJECT	3	2	Likely	2	3	3	High - Severe
T.DENIAL. INTERFERE	3	3	Highly likely	2	3	3	High - Severe
T.ENTRY							
T.ENTRY.ALTER	3	2	Likely	1	4	2	High - Catastrophic
T.ENTRY. EAVESDROP	3	3	Highly likely	5	5	2	High - Severe
T.ENTRY. IMPERSONATE	3	2	Likely	1	4	2	High - Catastrophic
Motivation *1 = weak, 3 = strong* *Required capabilities* *1 = high, 3 = low*				*Severity* *1 = most serious* *5 = least serious*			

Table 4-11: Threat Likelihood and Severity

4.3.4 Architectural Issues and Assumptions

There are a wide variety of security controls or countermeasures and it is necessary to consider various architectural issues in order to determine which controls should be used to protect the FCI.

Controls based on cryptography and encryption can be applied at a variety of protocol layers. One important question is which layer or layers of the FCI should include cryptographic protection. The answer to this question will clarify the extent to which controls impinge on the specification of the FRS.

In addition, procedural controls such as voice read-back and waveform controls such as frequency hopping can be used to mitigate certain threats. Redundancy can be built into the provision of any part of the FCI, through duplication of elements such as radios, and alternate network paths. A firewall can be placed at any network interconnection, and apply rules for packet filtering based on parameters such as originator and destination address.

The properties of these controls are summarised in Table 4-12 below.

	Involves	Example	Good for
Procedural controls	Human users	Voice readback	T.ENTRY.ALTER
End-to-end cryptographic protection	End systems	ATN Security, S/MIME, SSL/TLS	T.ENTRY.ALTER T.ENTRY.EAVESDROP T.ENTRY.IMPERSONATE
Network level cryptographic protection	Boundary Intermediate Systems (BIS)	IPSec	T.ENTRY.ALTER T.ENTRY.EAVESDROP T.ENTRY.IMPERSONATE
Link level cryptographic protection	Radio, logical characteristics	Wireless LAN, GSM security measures	T.DENIAL.FLOOD T.DENIAL.INJECT T.ENTRY.ALTER T.ENTRY.EAVESDROP T.ENTRY.IMPERSONATE
Waveform controls	Radio, RF characteristics	Spread spectrum	T.DENIAL.FLOOD T.DENIAL.INTERFERE
Redundancy	Secondary radio system (same or different technology)	VHF voice alternate radio site (ground), spare channels	T.DENIAL.FLOOD T.DENIAL.INTERFERE
Firewall	Routers	COTS firewall products	T.DENIAL.FLOOD T.DENIAL.INJECT

Table 4-12: Properties of Security Controls

The conclusions of the architectural discussion are that:

- Cryptographic protection appears to be the preferred approach to mitigate T.ENTRY.ALTER, T.ENTRY.EAVESDROP, and T.ENTRY.IMPERSONATE.
- Cryptographic protection at the link layer, network layer, or application layer can be used to mitigate T.ENTRY.ALTER, and T.ENTRY.IMPERSONATE. There are trade-offs involved in deciding which protocol layer to protect. For example, application layer protection may be preferred from a security perspective since it secures the packet end-to-end. But link layer protection may be preferred from a cost perspective since a single secure channel can be used to protect a large number of services.
- Cryptographic protection at the link layer, network layer, or application layer can also be used to mitigate T.ENTRY.EAVESDROP. However since only a small number of services require mitigation of T.ENTRY.EAVESDROP and encryption could affect the safety of ATS services, it is expected that end-to-end cryptographic protection will be used in this case.

- One control that mitigates T.DENIAL.INJECT is link level cryptographic protection. This would impact the FRS specification. Use of a firewall to selectively filter received data is an alternative, which would not impact the FRS specification.
- A system configuration, which involves radio set and channel redundancy may be a cost effective way to mitigate T.DENIAL.INTERFERE and T.DENIAL.FLOOD, since such redundancy is already expected to be required to address safety issues associated with equipment failure.
- Procedural controls cannot be considered for generic use within the FCI, since some of the operational drivers for phase 2 (see Section 2.4) are not amenable to procedural controls. Auto-execute services provide a good example of the limitations of procedural controls.

4.3.5 Security Requirements

This section specifies the security requirements developed based on the analysis that has been performed. First, security requirements for the FCI are developed, and then security requirements for the FRS are extrapolated based on the FCI requirements. The confidentiality, integrity and availability rankings referenced in the security requirement text can be found in 5.2.

The FCI security requirements that have been identified are specified in Table 4-13 below.

Id	Requirement	Associated Threats
R.FCI-SEC.1a	The FCI shall support reliability and robustness to mitigate denial of service attacks when providing services with "high – severe" or "high – catastrophic" availability ranking.	T.DENIAL.FLOOD T.DENIAL.INJECT T.DENIAL.INTERFERE
R.FCI-SEC.1b	The FCI should support reliability and robustness to mitigate denial of service attacks when providing services with "medium" availability ranking.	T.DENIAL.FLOOD T.DENIAL.INJECT T.DENIAL.INTERFERE
R.FCI-SEC.2a	The FCI shall support message authentication and integrity to prevent message alteration attacks when providing services with "high – severe" or "high – catastrophic" integrity ranking.	T.DENIAL.INJECT T.ENTRY.ALTER T.ENTRY.IMPERSONATE
R.FCI-SEC.2b	The FCI should support message authentication and integrity to prevent message alteration attacks when providing services with "medium" integrity ranking.	T.DENIAL.INJECT T.ENTRY.ALTER T.ENTRY.IMPERSONATE
R.FCI-SEC.3a	The FCI shall support encryption to mitigate eavesdropping when providing services with "high – severe" confidentiality ranking.	T.ENTRY.EAVESDROP
R.FCI-SEC3b	The FCI should support encryption to mitigate eavesdropping when providing services with "medium" confidentiality ranking.	T.ENTRY.EAVESDROP
R.FCI-SEC.4a	The FCI shall support entity authentication to mitigate impersonation attacks when providing services with "high – severe" or "high – catastrophic" integrity ranking.	T.ENTRY.ALTER T.ENTRY.IMPERSONATE
R.FCI-SEC.4b	The FCI should support entity authentication to mitigate impersonation attacks when providing services with "medium" integrity ranking.	T.ENTRY.ALTER T.ENTRY.IMPERSONATE
R.FCI-SEC.5	The operation of the FCI security function shall not diminish the ability of the FCI to operate safely and effectively.	

Table 4-13: FCI Security Requirements

FRS security requirements that have been extrapolated from the FCI security requirements based on the discussion in Section 4.3.1 are specified in Table 4-14 below.

Requirement Id	Requirement	Associated FCI Requirements
R.FRS-SEC.1a	The FRS shall provide a measure of resistance against deliberate insertion of RF interference when providing services with “high – severe” or “high – catastrophic” availability ranking.	R.FCI-SEC.1
R.FRS-SEC.1b	The FRS should provide a measure of resistance against deliberate insertion of RF interference when providing services with “medium” availability ranking.	R.FCI-SEC.1
R.FRS-SEC.2a	The FRS shall support message authentication and integrity as an option to prevent message alteration attacks when providing services with “high – severe” or “high – catastrophic” integrity ranking.	R.FCI-SEC.2 R.FCI-SEC.5
R.FRS-SEC.2b	The FRS should support message authentication and integrity as an option to prevent message alteration attacks when providing services with “medium” integrity ranking.	R.FCI-SEC.2 R.FCI-SEC.5
R.FRS-SEC.3a	The FRS shall support entity authentication as an option to mitigate impersonation attacks when providing services with “high – severe” or “high – catastrophic” integrity ranking.	R.FCI-SEC.4 R.FCI-SEC.5
R.FRS-SEC.3b	The FRS should support entity authentication as an option to mitigate impersonation attacks when providing services with “medium” integrity ranking.	R.FCI-SEC.4 R.FCI-SEC.5

Table 4-14: FRS Security Requirements

The A-EXEC service raises some new security problems because it is the first communications service introducing a "high - catastrophic" confidentiality, integrity, or availability ranking. Providing sufficient security for this service requires further research.

5 OPERATIONAL PERFORMANCE REQUIREMENTS

5.1 Introduction

This section provides operational performance requirements that are based on prior safety and performance work, the Operational Performance Assessments in Section 4.2, and inputs from operational subject matter experts.

This section presents the following information:

- Operational Service High Level Risk/Hazard Assessment
- Data Communication Requirements
- FRS Allocated Data Communication Requirements
- FRS Classes of Service
- Voice Communication Requirements.

A risk/hazard analysis is the typical starting point for the development of safety and performance requirements (SPR). Assessment of risks/hazards and derivation of associated safety/performance requirements is currently constrained by service definitions that, in some cases, are not fully developed. However in order to carry out this study a set of initial performance requirements were produced using available information supplemented by expert opinion. In order to provide some basis for performance requirements, a ***high level*** operational risk/hazard assessment was conducted. For this assessment, the service level included all methods of delivery, e.g., voice and/or data. From this service level assessment, a high level data communication level risk/hazard assessment was developed. Although the data level risk/hazard assessment was conducted for services in both the Phase 1 and Phase 2 environments, this high level assessment was only used to develop the Phase 2 requirements. The Phase 1 requirements rely heavily on work conducted in [2] in which data is used as a supplemental form of communication. For Phase 2, data communications have become a primary method of communication.

The FRS data performance requirements were allocated based the overall end-to-end data communication requirements. The FRS boundary point is defined and the assumptions used in the allocation process are described. In order to facilitate a communication loading analysis, a number of classes of service are defined based on grouping services with similar performance requirements.

The voice communication performance requirements are described separately.

5.2 Operational Service High Level Risk/Hazard Assessment

Table 5-1 and Table 5-2 provide the results of the high level operational service risk/hazard assessment for ATS and AOC, respectively. The column headers are defined as follows:

- Service: The acronym for the service name.

- Confidentiality (E): This column represents the relative operational impact of violation of confidentiality.
- Integrity (I): This column represents the relative operational impact of corruption of the integrity.
- Availability (A): This column represents the relative operational impact of the loss of use/provision of the service.
- Method(s): This column indicates which method(s) are available for delivering the service. In some cases, the service can be delivered by either voice or data means. In other cases, the service is defined as a data-only service. For AOC, some services could be implemented by paper exchanges at the gate or via manual entry of information by the Flight Crew. The availability of multiple methods may allow the requirements for any one method to be reduced, given alternate methods/means exist to deliver the service.

The letter designations used to reflect the risk/hazard assessment are defined in section 4.1. Specifically, confidentiality and integrity/availability severity is defined in section 4.3.3.

Service	Phase 1				Phase 2			
	E	I	A	Method(s)	E	I	A	Method(s)
ACL	L	HS	HS	Data, Voice	L	HS	HS	Data, Voice
ACM	N	HS	HS	Data, Voice	N	HS	HS	Data, Voice
ADS-B	M	HS	M	Data	M	HS	HS	Data
A-EXEC	-	-	-	Data	L	HC	HC	Data
AIRSEP	-	-	-	Data	L	HS	HS	Data
AMC	N	M	M	Data	N	M	M	Data
ARMAND	N	M	M	Data, Voice	N	M	M	Data, Voice
C&P	L	HS	HS	Data, Voice	L	HS	HS	Data, Voice
COTRAC	-	-	-	Data	L	HS	H	Data
D-ALERT	M	HS	HS	Data	M	HS	HS	Data
D-ATIS	N	M	M	Data, Voice	N	M	M	Data, Voice
DCL	L	HS	M	Data, Voice	L	HS	M	Data, Voice
D-FLUP	N	M	L	Data, Voice	N	M	L	Data, Voice
DLL	N	HS	HS	Data	N	HS	HS	Data
D-ORIS	N	M	L	Data, Voice	N	M	L	Data, Voice
D-OTIS	N	M	M	Data, Voice	N	M	M	Data, Voice
D-RVR	N	H	L	Data, Voice	N	H	L	Data, Voice
DSC	L	HS	M	Data, Voice	L	HS	M	Data, Voice
D-SIG	N	M	L	Data	N	HS	M	Data
D-SIGMET	N	HS	M	Data, Voice	N	HS	M	Data, Voice
D-TAXI	L	HS	M	Data, Voice	L	HS	H	Data, Voice

DYNAV	-	-	-	Data	L	H	M	Data
FLIPCY	L	HS	M	Data	L	HS	H	Data
FLIPINT	L	HS	M	Data	L	HS	H	Data
ITP	L	HS	HS	Data, Voice	L	HS	HS	Data, Voice
PAIRAPP	-	-	-	Data, Voice	L	HS	HS	Data, Voice
PPD	N	L	L	Data, Voice	N	L	L	Data, Voice
S&M	L	HS	HS	Data, Voice	L	HS	HS	Data, Voice
SAP	N	M	L	Data	N	H	M	Data
TIS-B	M	HS	M	Data	n/a	n/a	n/a	Data
URCO	-	-	-	Data	N	HS	HS	Data
WAKE	N	H	M	Data	N	HS	HS	Data

Table 5-1: Service Risk/Hazard Assessment (ATS) – Phase 1 & 2

Service	**Phase 1 & 2**			
	E	**I**	**A**	**Method(s)**
AOCDLL	N	HS	H	Data
CABINLOG	L	L	L	Data, Paper
ENGINE	L	M	M	Data
FLTLOG	M	L	L	Data, Paper
FLTPLAN	L	HS	H	Data, Manual
FLTSTAT	M	L	L	Data, Voice
FREETEXT	M	L	L	Data
FUEL	L	L	L	Data
GATES	L	L	L	Data
LOADSHT	M	HS	H	Data, Voice
MAINTPR	M	M	L	Data, Voice
MAINTRT	M	M	L	Data
NOTAM	N	M	M	Data, Voice
OOOI	L	L	L	Data
POSRPT	L	M	M	Data, Voice
SWLOAD	L	L	L	Data
TECHLOG	M	M	M	Data, Paper
UPLIB	M	HS	M	Data
WXGRAPH	L	M	M	Data
WXRT	N	M	M	Data, Voice
WXTEXT	L	M	L	Data

Table 5-2: Service Risk/Hazard Assessment (AOC) – Phase 1 & 2

5.3 Data Communication Requirements

This section describes the following:

- Data Communication Performance Assumptions
- Data Communication Performance Values

5.3.1 Assumptions

The following describes the assumptions used in developing the data communication performance requirements contained in Table 5-3, Table 5-4 and Table 5-5. In general, the Phase 1 requirements are primarily based on information contained in [2], [3], and [5]. The Phase 2 requirements are based on inputs from subject matter expects and on the initial operational performance assessments (OPAs) presented in Section 4.2.

5.3.1.1 Risk/Hazard Assessment

The risk/hazard assessments associated with data communications are derived from the service level assessment presented in the previous section. For example, for services that could be conducted by more than one method, e.g., data or voice, the risk/hazard assessment for availability was reduced for data communications. For services that are defined as data only, the risk/hazard assessment at the data level is the same as that for the service.

5.3.1.2 Latency

The required one-way transit delays for data communications in Phase 1 are derived from [2] (see bolded values) in tandem with input from operational subject matter experts. The one-way transit delays represent one-half of the two-way technical transaction time. The latencies for services not evaluated in [2] were assigned similar values to their equivalent in that document.

The Phase 2 latencies are based solely on input from operational subject matter experts except for the COTRAC and A-EXEC services. An initial OPA for these two services is presented in sections 4.2.2 and 4.2.4 respectively.

5.3.1.3 Integrity

The operational concept for Phase 1 uses services consistent with the safety and performance requirements defined in [2] and therefore this was used as the basis for integrity requirements in this document.

The Phase 2 integrity requirements are based on the risk/hazard assessment.

5.3.1.4 Availability

The operational concept for Phase 1 uses services consistent with the safety and performance requirements defined in [2] and therefore this was used as the basis for integrity requirements in this document.

The Phase 2 integrity requirements are based on the risk/hazard assessment. The availability of use (A_U) values were assumed to be two orders of magnitude lower than the availability of provision (A_P) when the A_P was 10^{-7} or stricter. Otherwise, the A_U values were assumed to be an order of magnitude lower.

5.3.2 Data Performance Values

Table 5-3, Table 5-4 and Table 5-5 provide the initial performance requirements for data communications. The bolded values in Table 5-3 are taken from [2].

Service	Risk/Hazard (Data Method)			Latency (RCTP - 1 way)					Integrity	Availability	
				APT	TMA	ENR	ORP	AOA			
	E	I	A	TD_{95}	TD_{95}	TD_{95}	TD_{95}	TD_{95}	I_{UCT}	A_P	A_U
ACL	L	HS	H	**8.0**	**8.0**	**8.0**	60.0	-	**1.0E-5**	**0.999**	**0.993**
ACM	N	HS	H	**8.0**	**8.0**	**8.0**	60.0	-	**1.0E-5**	**0.999**	**0.993**
ADS-B	M	HS	M	1.0	6.0	12.0	12.0	-	1.0E-5	0.999	0.993
A-EXEC	-	-	-	-	-	-	-	-	-	-	-
AIRSEP	-	-	-	-	-	-	-	-	-	-	-
AMC	N	M	M	**8.0**	**8.0**	**8.0**	60.0	-	**1.0E-3**	0.999	0.993
ARMAND	N	M	M	-	-	20.0	-	-	1.0E-5	0.999	0.993
C&P	L	HS	H	-	8.0	8.0	60.0	-	1.0E-5	0.999	0.993
COTRAC	-	-	-	-	-	-	-	-	-	-	-
D-ALERT	M	HS	HS	8.0	8.0	8.0	60.0	-	1.0E-5	0.999	0.993
D-ATIS	N	M	M	**20.0**	**20.0**	**20.0**	60.0	-	**1.0E-5**	**0.999**	**0.993**
DCL	L	HS	M	**20.0**	-	-	-	-	**1.0E-5**	**0.999**	**0.993**
D-FLUP	N	M	L	20.0	-	-	-	-	1.0E-5	0.999	0.993
DLL	N	HS	HS	**12.0**	**12.0**	**12.0**	60.0	-	**1.0E-5**	**0.999**	**0.993**
D-ORIS	N	M	L	-	20.0	20.0	60.0	-	1.0E-5	0.999	0.993
D-OTIS	N	M	M	20.0	20.0	20.0	60.0	-	1.0E-5	0.999	0.993
D-RVR	N	H	L	10.0	10.0	20.0	60.0	-	1.0E-5	0.999	0.993
DSC	L	HS	M	-	-	**50.0**	60.0	-	**1.0E-5**	**0.999**	**0.993**
D-SIG	N	M	L	20.0	20.0	-	-	-	1.0E-5	0.999	0.993
D-SIGMET	N	HS	M	20.0	20.0	20.0	60.0	-	1.0E-5	0.999	0.993
D-TAXI	L	HS	M	8.0	8.0	-	-	-	1.0E-5	0.999	0.993
DYNAV	-	-	-	-	-	-	-	-	-	-	-
FLIPCY	L	HS	M	**30.0**	**30.0**	**30.0**	60.0	-	**1.0E-5**	**0.999**	**0.993**
FLIPINT	L	HS	M	30.0	30.0	30.0	60.0	-	1.0E-5	0.999	0.993
ITP	L	HS	H	-	-	-	60.0	-	1.0E-5	0.999	0.993
PAIRAPP	-	-	-	-	-	-	-	-	-	-	-
PPD	N	L	L	30.0	30.0	30.0	60.0	-	1.0E-5	0.999	0.993
S&M	L	HS	H	-	8.0	8.0	-	-	1.0E-5	0.999	0.993
SAP	N	M	L	-	10.0	10.0	-	-	1.0E-5	0.999	0.993
TIS-B	M	HS	M	1.0	6.0	12.0	12.0	-	1.0E-5	0.999	0.993
URCO	-	-	-	-	-	-	-	-	-	-	-
WAKE	N	H	M	1.0	6.0	12.0	12.0	-	1.0E-5	0.999	0.993

Table 5-3: Data Performance Requirements (ATS) – Phase 1

Service	Risk/Hazard (Data Method)			Latency (RCTP - 1 way)					Integrity	Availability	
				APT	TMA	ENR	ORP	AOA			
	E	I	A	TD_{95}	TD_{95}	TD_{95}	TD_{95}	TD_{95}	I_{UCT}	A_P	A_U
ACL	L	HS	HS	3.0	3.0	3.0	3.0	3.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
ACM	N	HS	HS	3.0	3.0	3.0	5.0	5.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
ADS-B	M	HS	HS	1.0	3.0	3.0	3.0	3.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
A-EXEC	L	HC	HC	-	1.65	1.65	1.65	-	1.0E-9	1-(1.0E-9)	1-(1.0E-7)
AIRSEP	L	HS	HS	-	-	-	-	10.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
AMC	N	M	M	3.0	3.0	3.0	3.0	3.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
ARMAND	N	M	M	-	-	10.0	-	-	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
C&P	L	HS	HS	-	5.0	5.0	5.0	-	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
COTRAC	L	HS	H	-	5.0	5.0	5.0	5.0	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
D-ALERT	M	HS	HS	5.0	5.0	5.0	5.0	5.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
D-ATIS	N	M	M	5.0	5.0	10.0	20.0	20.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
DCL	L	HS	M	5.0	-	-	-	-	1.0E-7	1-(1.0E-4)	1-(1.0E-3)
D-FLUP	N	M	L	5.0	-	-	-	-	1.0E-4	1-(1.0E-3)	1-(1.0E-2)
DLL	N	HS	HS	3.0	5.0	10.0	20.0	20.0	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
D-ORIS	N	M	L	-	5.0	10.0	20.0	20.0	1.0E-4	1-(1.0E-3)	1-(1.0E-2)
D-OTIS	N	M	M	5.0	5.0	5.0	20.0	20.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
D-RVR	N	H	L	3.0	3.0	10.0	20.0	20.0	1.0E-5	1-(1.0E-3)	1-(1.0E-2)
DSC	L	HS	M	-	-	5.0	10.0	10.0	1.0E-7	1-(1.0E-4)	1-(1.0E-3)
D-SIG	N	HS	M	10.0	10.0	-	-	-	1.0E-7	1-(1.0E-4)	1-(1.0E-3)
D-SIGMET	N	HS	M	5.0	5.0	5.0	10.0	20.0	1.0E-7	1-(1.0E-4)	1-(1.0E-3)
D-TAXI	L	HS	H	5.0	5.0	-	-	-	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
DYNAV	L	H	M	-	-	10.0	20.0	-	1.0E-5	1-(1.0E-4)	1-(1.0E-3)
FLIPCY	L	HS	H	5.0	5.0	5.0	5.0	5.0	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
FLIPINT	L	HS	H	5.0	5.0	5.0	5.0	5.0	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
ITP	L	HS	HS	-	5.0	5.0	5.0	-	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
PAIRAPP	L	HS	HS	0.3	0.3	-	-	-	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
PPD	N	L	L	10.0	10.0	10.0	10.0	10.0	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
S&M	L	HS	HS	-	5.0	5.0	5.0	-	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
SAP	N	H	M	-	5.0	5.0	-	-	1.0E-5	1-(1.0E-4)	1-(1.0E-3)
TIS-B	-	-	-	-	-	-	-	-	-	-	-
URCO	N	HS	HS	3.0	3.0	3.0	3.0	3.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)
WAKE	N	HS	HS	1.0	3.0	3.0	3.0	3.0	1.0E-7	1-(1.0E-7)	1-(1.0E-5)

Table 5-4: Data Performance Requirements (ATS) – Phase 2

Service	Risk/Hazard (Data Method)			Latency (RCTP - 1 way)					Integrity	Availability	
				APT	TMA	ENR	ORP	AOA			
	E	I	A	TD_{95}	TD_{95}	TD_{95}	TD_{95}	TD_{95}	I_{UCT}	A_P	A_U
AOCDLL	N	HS	H	30.0	30.0	30.0	60.0	60.0	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
CABINLOG	L	L	L	60.0	-	-	-	-	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
ENGINE	L	M	M	60.0	60.0	60.0	120.0	120.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
FLTLOG	M	L	L	60.0	-	-	-	-	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
FLTPLAN	L	HS	H	30.0	30.0	30.0	60.0	60.0	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
FLTSTAT	M	L	L	30.0	30.0	30.0	60.0	60.0	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
FREETXT	M	L	L	60.0	60.0	60.0	120.0	120.0	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
FUEL	L	L	L	60.0	60.0	60.0	120.0	120.0	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
GATES	L	L	L	30.0	30.0	30.0	60.0	60.0	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
LOADSHT	M	HS	H	30.0	30.0	-	-	-	1.0E-7	1-(1.0E-5)	1-(1.0E-4)
MAINTPR	M	M	L	30.0	30.0	30.0	60.0	60.0	1.0E-4	1-(1.0E-3)	1-(1.0E-2)
MAINTRT	M	M	L	60.0	60.0	60.0	120.0	120.0	1.0E-4	1-(1.0E-3)	1-(1.0E-2)
NOTAM	N	M	M	60.0	60.0	60.0	120.0	120.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
OOOI	L	L	L	30.0	-	-	-	-	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
POSRPT	L	M	M	60.0	60.0	60.0	120.0	120.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
SWLOAD	L	L	L	60.0	60.0	60.0	120.0	120.0	1.0E-3	1-(1.0E-3)	1-(1.0E-2)
TECHLOG	M	M	M	60.0	-	-	-	-	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
UPLIB	M	HS	M	60.0	60.0	60.0	120.0	120.0	1.0E-7	1-(1.0E-4)	1-(1.0E-3)
WXGRAPH	L	M	M	30.0	30.0	30.0	60.0	60.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
WXRT	N	M	M	30.0	30.0	30.0	60.0	60.0	1.0E-4	1-(1.0E-4)	1-(1.0E-3)
WXTEXT	L	M	L	30.0	30.0	30.0	60.0	60.0	1.0E-4	1-(1.0E-3)	1-(1.0E-2)

Table 5-5: Data Performance Requirements (AOC) – Phase 1 & 2

5.4 FRS Allocated Data Performance Requirements

This section describes the following:

- FRS Boundary Point Description – the boundary point used for the allocation of data performance requirements.
- Allocation methodology and assumptions
- FRS Allocated Performance Values

5.4.1.1 FRS Boundary Point Description

ATM services are described in an operational context and requirements apply to the service as a whole including communication systems, automation systems, procedures and human participation. Ground end points (controllers, automation systems) connect to airborne end points (aircrew, flight automation systems) via a set of one or more networks and/or communication systems. The FRS is a system in the end-to-end communication chain.

The FRS Boundary Point can be described in terms of both physical and logical perspectives. There are some physical aspects that remain constant regardless of the technology selection or implementation approach. For example, there will be FRS communication equipment in the aircraft and on the ground. Other physical aspects are very technology specific, e.g. the immediate physical interface for the FRS equipment (examples include T1, RS-232, and proprietary hardware interfaces). From a logical point of view, the FRS boundary can be illuminated by describing functions that lie on either side of the interface. In addition, since communication networks typically involve multiple communication layers, the boundary can be described within the context of a communication protocol stack.

In order to allocate performance requirements to the FRS, one must first define the interface boundary for the FRS. The COCR has defined the logical interface to the FRS subnetwork at the boundary between the internetworking and intranetworking layers of the reference protocol stack. While the COCR does not specify a required reference protocol stack, Figure 5-1 provides an illustration showing the boundary point within several example protocol stacks.

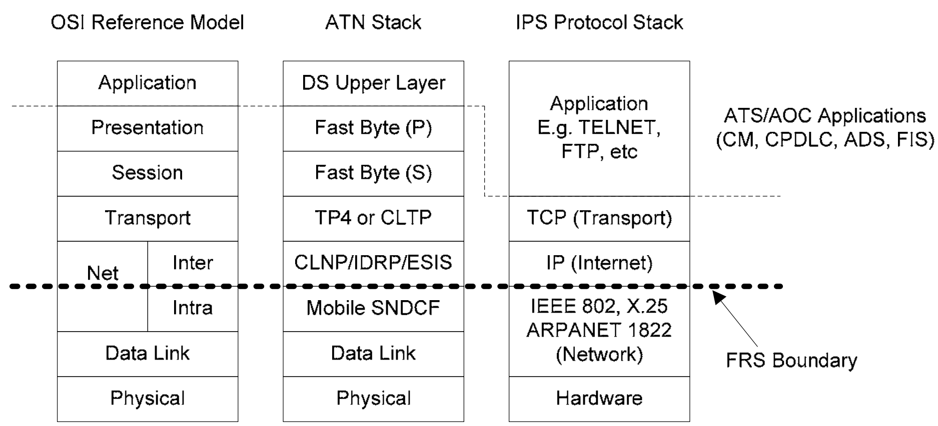


Figure 5-1: FRS Boundary Point Examples

From a functional point of view, the FRS performance requirements span the following functional blocks: subnetwork interface function, subnetwork layer, data link layer, ground and airborne FRS radio units, antennas and RF media.

From a physical point of view, the logical FRS boundary point will likely be located in the Air/ground (ground unit) and Airborne Router equipment. Since a ground router might not be co-located with the FRS radio equipment, it is important to note that performance contributions associated with such a remote connection (e.g. delays, availability, integrity) are specifically excluded from the FRS allocated performance requirements.

5.4.2 Allocation Assumptions

Typically, the allocation of performance to communication segments (or systems) is based, at least in part, on the ability of the particular segment to meet the requirement. Most safety and performance work has allocated requirements to the ground and airborne segments with the boundary point at the aircraft antenna. Unfortunately, this segment boundary does not align with the boundaries of interest for the FRS. Part of the FRS system lies within the ground segment and the other part within the airborne segment. The FRS allocation is made using the end-to-end technical performance numbers while considering the ATS/Airborne segment allocations made in prior safety work.

The allocation process used for Air/Air and AOC services is the same as that used for ATS services in that the ability of each component, segment or system to meet the allocated requirement is considered.

The following subsections provide detailed information on the assumptions and rationale used for allocating latency, integrity, and availability requirements to the FRS.

Security in the application level is covered in Section 6 by considering an overhead associated with message sizes. Other security requirements are covered in section 4.3.5.

5.4.2.1 Latency

The RCTP one-way latency requirement is specified in terms of a probability, e.g., a 95% percentile delay. As defined in [13], a statistical analysis should be conducted in order to properly allocate the performance parameters between system segments and/or components. Much of the prior allocation work has used an algebraic allocation methodology, possibly because the statistical distribution of events was not well characterised.

If statistical allocations were made instead of algebraic ones, the 95% allocation for each subsystem/component would be larger (assuming use of any one of a number of common distributions, e.g. normal, exponential, lognormal, Poisson, which might be applied to message delays for typical systems). Thus, the algebraic allocations are more restrictive than a statistical allocation method. This more restrictive method can still result in ‘valid’ allocations if, for example, the resultant allocations are deemed as reasonable and acceptable by associated stakeholders. For [2], these algebraic allocations were internationally accepted.

For most services, the COCR assumes a statistical allocation of latency based on a Poisson distribution. The allocation among system components is done using mean (average) delay values.

For data services that are characterised as ***air-to-ground*** (includes AOC services), the major segments in the end-to-end connection include: the ground end/host system automation segment, the ground network segment, the FRS segment, the airborne end system (the airborne equipment external to the FRS - refer to the FRS Boundary Point discussion). The percentage allocations for each of these segments are 25%, 25%, **40%,** and 10%, respectively. Details of the allocation process are given in Appendix 5.

For data services that are characterised as ***air-to-air*** (includes ADS-B/TIS-B, PAIRAPP, and AIRSEP), the FRS allocation is assumed to be **80%**. This figure results after 10% is allocated to each airborne end system. Note: Since the statistical distribution of the air-to-air delays is not well known, an algebraic allocation is used.

The allocation percentages for Phase 1 and Phase 2 are the same.

5.4.2.2 Integrity

Integrity requirements on the FRS were calculated based on the assumption that it must contribute no more than **50%** of the errors. This generous allocation is made to the FRS because of significantly higher data error rates associated with RF transmission.

5.4.2.3 Availability

Availability requirements on the FRS were calculated based on the assumption that it must contribute no more than **50%** of the errors. This generous allocation is made to the FRS because of the impact of interference on operational availability. If it were not for interference, the allocation to the FRS would be much lower since the expected inherent availability (equipment performance) is not significantly different from other communication equipment.

5.4.3 FRS Allocated Performance Values

Table 5-6**,** Table 5-7and Table 5-8 provide the initial performance requirements for the FRS.

Service	Latency (RCTP - 1 way)					Integrity	Availability	
	APT	TMA	ENR	ORP	AOA			
	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$TD_{95\text{-}FRS}$	$I_{UCT\text{-}FRS}$	$A_{P\text{-}FRS}$	$A_{U\text{-}FRS}$
ACL	3.8	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965
ACM	3.8	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965
ADS-B	0.80	4.8	9.6	9.6	-	5.0E-6	0.9995	0.9965
A-EXEC	-	-	-	-	-	-	-	-
AIRSEP	-	-	-	-	-	-	-	-
AMC	3.8	3.8	3.8	26.5	-	5.0E-4	0.9995	0.9965
ARMAND	-	-	9.2	-	-	5.0E-6	0.9995	0.9965
C&P	-	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965
COTRAC	-	-	-	-	-	-	-	-
D-ALERT	3.8	3.8	3.8	26.5	-	5.0E-6	0.9995	0.9965
D-ATIS	9.2	9.2	9.2	26.5	-	5.0E-6	0.9995	0.9965
DCL	9.2	-	-	-	-	5.0E-6	0.9995	0.9965
D-FLUP	9.2	-	-	-	-	5.0E-6	0.9995	0.9965
DLL	5.6	5.6	5.6	26.5	-	5.0E-6	0.9995	0.9965
D-ORIS	-	9.2	9.2	26.5	-	5.0E-6	0.9995	0.9965
D-OTIS	9.2	9.2	9.2	26.5	-	5.0E-6	0.9995	0.9965
D-RVR	4.7	4.7	9.2	26.5	-	5.0E-6	0.9995	0.9965
DSC	-	-	22.2	26.5	-	5.0E-6	0.9995	0.9965
D-SIG	9.2	9.2	-	-	-	5.0E-6	0.9995	0.9965
D-SIGMET	9.2	9.2	9.2	26.5	-	5.0E-6	0.9995	0.9965
D-TAXI	3.8	3.8	-	-	-	5.0E-6	0.9995	0.9965
DYNAV	-	-	-	-	-	-	-	-
FLIPCY	13.6	13.6	13.6	26.5	-	5.0E-6	0.9995	0.9965
FLIPINT	13.6	13.6	13.6	26.5	-	5.0E-6	0.9995	0.9965
ITP	-	-	-	26.5	-	5.0E-6	0.9995	0.9965
PAIRAPP	-	-	-	-	-	-	-	-
PPD	13.6	13.6	13.6	26.5	-	5.0E-6	0.9995	0.9965
S&M	-	3.8	3.8	-	-	5.0E-6	0.9995	0.9965
SAP	-	4.7	4.7	-	-	5.0E-6	0.9995	0.9965
TIS-B	0.80	4.8	9.6	9.6	-	5.0E-6	0.9995	0.9965
URCO	-	-	-	-	-	-	-	-
WAKE	0.80	4.8	9.6	9.6	-	5.0E-6	0.9995	0.9965

Table 5-6: FRS Allocated Data Performance Requirements (ATS) – Phase 1

Service	**Latency (RCTP - 1 way)**					**Integrity**	**Availability**	
	APT	**TMA**	**ENR**	**ORP**	**AOA**			
	$TD_{95\text{-}FRS}$	**$TD_{95\text{-}FRS}$**	**$TD_{95\text{-}FRS}$**	**$TD_{95\text{-}FRS}$**	**$TD_{95\text{-}FRS}$**	**$I_{UCT\text{-}FRS}$**	**$A_{P\text{-}FRS}$**	**$A_{U\text{-}FRS}$**
ACL	1.4	1.4	1.4	1.4	1.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
ACM	1.4	1.4	1.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
ADS-B	0.8	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
A-EXEC	-	0.74	0.74	0.74	-	5.0E-10	1-(5.0E-10)	1-(5.0E-8)
AIRSEP	-	-	-	-	8.0	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
AMC	1.4	1.4	1.4	1.4	1.4	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
ARMAND	-	-	4.7	-	-	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
C&P	-	2.4	2.4	2.4	-	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
COTRAC	-	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
D-ALERT	2.4	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
D-ATIS	2.4	2.4	4.7	9.2	9.2	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
DCL	2.4	-	-	-	-	5.0E-8	1-(5.0E-5)	1-(5.0E-4)
D-FLUP	2.4	-	-	-	-	5.0E-5	1-(5.0E-4)	1-(5.0E-3)
DLL	1.4	2.4	4.7	9.2	9.2	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
D-ORIS	-	2.4	4.7	9.2	9.2	5.0E-5	1-(5.0E-4)	1-(5.0E-3)
D-OTIS	2.4	2.4	2.4	9.2	9.2	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
D-RVR	1.4	1.4	4.7	9.2	9.2	5.0E-6	1-(5.0E-4)	1-(5.0E-3)
DSC	-	-	2.4	4.7	4.7	5.0E-8	1-(5.0E-5)	1-(5.0E-4)
D-SIG	4.7	4.7	-	-	-	5.0E-8	1-(5.0E-5)	1-(5.0E-4)
D-SIGMET	2.4	2.4	2.4	4.7	9.2	5.0E-8	1-(5.0E-5)	1-(5.0E-4)
D-TAXI	2.4	2.4	-	-	-	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
DYNAV	-	-	4.7	9.2	-	5.0E-6	1-(5.0E-5)	1-(5.0E-4)
FLIPCY	2.4	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
FLIPINT	2.4	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
ITP	-	2.4	2.4	2.4	-	5.0E-6	1-(5.0E-8)	1-(5.0E-6)
PAIRAPP	0.24	0.24	-	-	-	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
PPD	4.7	4.7	4.7	4.7	4.7	5.0E-8	1-(5.0E-4)	1-(5.0E-3)
S&M	-	2.4	2.4	2.4	-	5.0E-4	1-(5.0E-8)	1-(5.0E-6)
SAP	-	2.4	2.4	-	-	5.0E-8	1-(5.0E-5)	1-(5.0E-4)
TIS-B	-	-	-	-	-	-	-	--
URCO	1.4	1.4	1.4	1.4	1.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)
WAKE	0.8	2.4	2.4	2.4	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)

Table 5-7: FRS Allocated Data Performance Requirements (ATS) – Phase 2

Service	Latency (RCTP - 1 way)					Integrity	Availability	
	APT	TMA	ENR	ORP	AOA[3]			
	TD_{95-FRS}	TD_{95-FRS}	TD_{95-FRS}	TD_{95-FRS}	TD_{95-FRS}	$I_{UCT-FRS}$	A_{P-FRS}	A_{U-FRS}
AOCDLL	13.6	13.6	13.6	26.5	26.5	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
CABINLOG	26.5	-	-	-	-	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
ENGINE	26.5	26.5	26.5	51.7	51.7	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
FLTLOG	26.5	-	-	-	-	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
FLTPLAN	13.6	13.6	13.6	26.5	26.5	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
FLTSTAT	13.6	13.6	13.6	26.5	26.5	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
FREETXT	26.5	26.5	26.5	51.7	51.7	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
FUEL	26.5	26.5	26.5	51.7	51.7	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
GATES	13.6	13.6	13.6	26.5	26.5	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
LOADSHT	13.6	13.6	-	-	-	5.0E-8	1-(5.0E-6)	1-(5.0E-5)
MAINTPR	13.6	13.6	13.6	26.5	26.5	5.0E-5	1-(5.0E-4)	1-(5.0E-3)
MAINTRT	26.5	26.5	26.5	51.7	51.7	5.0E-5	1-(5.0E-4)	1-(5.0E-3)
NOTAM	26.5	26.5	26.5	51.7	51.7	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
OOOI	13.6	-	-	-	-	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
POSRPT	26.5	26.5	26.5	51.7	51.7	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
SWLOAD	26.5	26.5	26.5	51.7	51.7	5.0E-4	1-(5.0E-4)	1-(5.0E-3)
TECHLOG	26.5	-	-	-	-	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
UPLIB	26.5	26.5	26.5	51.7	51.7	5.0E-8	1-(5.0E-5)	1-(5.0E-4)
WXGRAPH	13.6	13.6	13.6	26.5	26.5	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
WXRT	13.6	13.6	13.6	26.5	26.5	5.0E-5	1-(5.0E-5)	1-(5.0E-4)
WXTEXT	13.6	13.6	13.6	26.5	26.5	5.0E-5	1-(5.0E-4)	1-(5.0E-3)

Table 5-8: FRS Allocated Data Performance Requirements (AOC) – Phase 1 & 2

5.5 FRS Data Classes of Service

This section describes the categories of ***communication services***, i.e. classes of service (COS) that may be used to support the ***operational services*** while meeting performance requirements previously outlined. The COS categories described herein are not prescriptive, as other communication classes or groupings of operational services exist that still meet operational service requirements.

One of the benefits of grouping similar services into COS categories is that the number of items to manage is reduced. COS definition is a necessary step in estimating the communication loading as described in section 6. With a reduced set of classes, a particular service may not match exactly one class definition. In such a case, the service was placed in the next highest performance class that meets the service requirement.

[3] The AOA domain is only applicable in Phase 2.

5.5.1 Assumptions

The following assumptions were used during the definition of service classes.

- It is assumed that system network messages have the highest priority, ATS services have the next highest priority and AOC services have the lowest priority.
- The total number of classes per service volume is limited to a maximum of 6. The System Services are allocated 1 class, the ATS Services are allocated up to 3 classes, and the AOC Services are allocated up to 2 classes. While the number of classes per service volume is limited to 6, a different subset may be used between service volumes; hence, the number of classes in the master list is greater than 6.
- Class categories were chosen to maintain clear boundaries between ATS and AOC services (in order to facilitate separate links for these services, if desired). In addition, air/ground services are kept separate from air/air services, voice services are kept separate from data services, and point-to-point services are kept separate from broadcast services.
- For air/ground services, it is assumed that latency and priority are drivers for COS categorisation, at least more so than security, integrity, and/or availability requirements. An alternate approach would be to develop classes that differentiate based on availability requirements. It should be noted ATS is has separate service categories to those of AOC.
- For air/air services, both latency and availability were discriminators for developing service classes.

5.5.2 Class Categories

Table 5-9 Table 5-10 and Table 5-11 present the class categories for air/ground addressed data, air/air addressed data, and air/air broadcast data, respectively.

COS	$TD_{95\text{-}FRS}$	$I_{UCT\text{-}FRS}$	$A_{P\text{-}FRS}$	$A_{U\text{-}FRS}$	Service Type
DG-A	9.8	5.0E-8	1-(5.0E-8)	1-(5.0E-6)	System/Network
DG-B	0.74	5.0E-10	1-(5.0E-10)	1-(5.0E-8)	ATS A/G Data
DG-C	1.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)	
DG-D	2.4	5.0E-8	1-(5.0E-8)	1-(5.0E-6)	
DG-E	3.8	5.0E-6	0.9995	0.9965	
DG-F	4.7	5.0E-8	1-(5.0E-5)	1-(5.0E-4)	
DG-G	9.2	5.0E-6	0.9995	0.9965	
DG-H	13.6	5.0E-6	0.9995	0.9965	
DG-I	26.5	5.0E-6	0.9995	0.9965	
DG-J	13.6	5.0E-8	1-(5.0E-6)	1-(5.0E-5)	AOC A/G Data
DG-K	26.5	5.0E-8	1-(5.0E-5)	1-(5.0E-4)	
DG-L	51.7	5.0E-8	1-(5.0E-5)	1-(5.0E-4)	

Table 5-9. Data Classes of Service (Type DG – Air/Ground Addressed Data)

COS	$TD_{95\text{-}FRS}$	$I_{UCT\text{-}FRS}$	$A_{P\text{-}FRS}$	$A_{U\text{-}FRS}$	Service Type
DA-A	rsvd	rsvd	rsvd	rsvd	System/Network
DA-B	0.24	5.00E-08	1-(5.0E-8)	1-(5.0E-6)	ATS A/A Data
DA-C	8	5.00E-08	1-(5.0E-8)	1-(5.0E-6)	

Table 5-10 Data Classes of Service (Type DA – Air/Air Addressed Data)

COS	$TD_{95\text{-}FRS}$	$I_{UCT\text{-}FRS}$	$A_{P\text{-}FRS}$	$A_{U\text{-}FRS}$	Service Type
DB-A	0.8	5.00E-08	1-(5.0E-8)	1-(5.0E-6)	ADS-B/TIS-B/ WAKE Broadcast Data
DB-B	2.4	5.00E-08	1-(5.0E-8)	1-(5.0E-6)	
DB-C	0.8	5.0E-6	0.9995	0.9965	
DB-D	4.8	5.0E-6	0.9995	0.9965	
DB-E	9.6	5.0E-6	0.9995	0.9965	

Table 5-11. Data Classes of Service (Type DB – Air/Air Broadcast Data)

5.5.3 Class Assignments

Table 5-12, Table 5-13 and Table 5-14 contain COS assignments for Network Management, ATS, and AOC services, respectively.

Service	Phase 1 & 2				
	APT	TMA	ENR	ORP	AOA [4]
NETCONN	DG-A	DG-A	DG-A	DG-A	DG-A
NETKEEP	DG-A	DG-A	DG-A	DG-A	DG-A

Table 5-12: COS Assignments (Network Management) – Phase 1 & 2

Service	Phase 1					Phase 2				
	APT	TMA	ENR	ORP	AOA	APT	TMA	ENR	ORP	AOA
ACL	DG-E	DG-E	DG-E	DG-I	-	DG-C	DG-C	DG-C	DG-C	DG-C
ACM	DG-E	DG-E	DG-E	DG-I	-	DG-C	DG-C	DG-C	DG-D	DG-D
ADS-B	DB-C	DB-D	DB-E	DB-E	-	DB-A	DB-B	DB-B	DB-B	DB-B
A-EXEC	-	-	-	-	-	-	DG-B	DG-B	DG-B	-
AIRSEP	-	-	-	-	-	-	-	-	-	DA-C
AMC	DG-E	DG-E	DG-E	DG-I	-	DG-C	DG-C	DG-C	DG-C	DG-C
ARMAND	-	-	DG-G	-	-	-	-	DG-D	-	-
C&P	-	DG-E	DG-E	DG-I	-	-	DG-D	DG-D	DG-D	-
COTRAC	-	-	-	-	-	DG-D	DG-D	DG-D	DG-D	DG-D
D-ALERT	DG-E	DG-E	DG-E	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D

[4] The AOA domain is only applicable in Phase 2.

D-ATIS	DG-G	DG-G	DG-G	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D
DCL	DG-G	-	-	-	-	DG-D	-	-	-	-
D-FLUP	DG-G	-	-	-	-	DG-D	-	-	-	-
DLL	DG-E	DG-E	DG-E	DG-I	-	DG-C	DG-D	DG-D	DG-D	DG-D
D-ORIS	-	DG-G	DG-G	DG-I	-	-	DG-D	DG-D	DG-D	DG-D
D-OTIS	DG-G	DG-G	DG-G	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D
D-RVR	DG-E	DG-E	DG-G	DG-I	-	DG-C	DG-C	DG-D	DG-D	DG-D
DSC	-	-	DG-H	DG-I	-	-	-	DG-D	DG-D	DG-D
D-SIG	DG-G	DG-G	-	-	-	DG-F	DG-D	-	-	-
D-SIGMET	DG-G	DG-G	DG-G	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D
D-TAXI	DG-E	DG-E	-	-	-	DG-D	DG-D	-	-	-
DYNAV	-	-	-	-	-	-	-	DG-D	DG-D	-
FLIPCY	DG-H	DG-H	DG-H	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D
FLIPINT	DG-H	DG-H	DG-H	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D
ITP	-	-	-	DG-I	-	-	DG-D	DG-D	DG-D	-
PAIRAPP	-	-	-	-	-	DA-B	DA-B	-	-	-
PPD	DG-H	DG-H	DG-H	DG-I	-	DG-D	DG-D	DG-D	DG-D	DG-D
S&M	-	DG-E	DG-E	-	-	-	DG-D	DG-D	DG-D	-
SAP	-	DG-E	DG-E	-	-	-	DG-D	DG-D	-	-
TIS-B	DB-C	DB-D	DB-E	DB-E	-	-	-	-	-	-
URCO	-	-	-	-	-	DG-C	DG-C	DG-C	DG-C	DG-C
WAKE	DB-C	DB-D	DB-E	DB-E	-	DB-A	DB-B	DB-B	DB-B	DB-B

Table 5-13: COS Assignments (ATS) – Phase 1 & 2

Service	Phase 1 & 2				
	APT	TMA	ENR	ORP	AOA[5]
AOCDLL	DG-J	DG-J	DG-J	DG-K	DG-K
CABINLOG	DG-K	-	-	-	-
ENGINE	DG-K	DG-K	DG-K	DG-L	DG-L
FLTLOG	DG-K	-	-	-	-
FLTPLAN	DG-J	DG-J	DG-J	DG-K	DG-K
FLTSTAT	DG-J	DG-J	DG-J	DG-K	DG-K
FREETXT	DG-K	DG-K	DG-K	DG-L	DG-L
FUEL	DG-K	DG-K	DG-K	DG-L	DG-L
GATES	DG-J	DG-J	DG-J	DG-K	DG-K
LOADSHT	DG-J	DG-J	-	-	-
MAINTPR	DG-J	DG-J	DG-J	DG-K	DG-K
MAINTRT	DG-K	DG-K	DG-K	DG-L	DG-L
NOTAM	DG-K	DG-K	DG-K	DG-L	DG-L
OOOI	DG-J	-	-	-	-
POSRPT	DG-K	DG-K	DG-K	DG-L	DG-L
SWLOAD	DG-K	DG-K	DG-K	DG-L	DG-L
TECHLOG	DG-K	-	-	-	-
UPLIB	DG-K	DG-K	DG-K	DG-L	DG-L
WXGRAPH	DG-J	DG-J	DG-J	DG-K	DG-K
WXRT	DG-J	DG-J	DG-J	DG-K	DG-K
WXTEXT	DG-J	DG-J	DG-J	DG-K	DG-K

Table 5-14: COS Assignments (AOC) – Phase 1 & 2

5.5.4 Class of Service Implications

The following comments apply to the COS service assignments:

- The COS assignments above map services to priorities.
- The class of service is defined at the FRS boundary point. The ground network may be common for all domains and it may provide a limited set of priority levels. If a reduced set of classes is required, many more service categories may need to be placed into the next highest performance category. This typically will result in a higher required capacity for the FRS.

[5] The AOA domain is only applicable in Phase 2.

5.6 Voice Requirements

The following sections define the voice requirements to meet the operational requirements of Phase 1 and Phase 2 defined in Section 3.

5.6.1 Voice Performance Requirements

Table 5-15 and Table 5-16 provide the voice performance requirements for ATS and AOC communication, respectively. Performance values are based on information in [43], [44] and input from subject matter experts.

Service Type	**Party-line**								**Broadcast**
Domain	**APT**		**TMA**		**ENR**		**ORP**		**ALL**
Density	**HD**	**LD**	**HD**	**LD**	**HD**	**LD**	**HD**	**LD**	**ALL**
Call Establishment Delay	50 ms	100 ms	50 ms	100 ms	50 ms	200 ms	200 ms	20 s	20 s
Voice Latency	250 ms	350 ms	250 ms	350 ms	250 ms	485 ms	485 ms	485 ms	485 ms
A_P	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.999
A_U	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.998

Table 5-15: Voice Performance Requirements (ATS) – Phase 1 & 2

Service Type	**Selective Addressed**	**Party-line/Broadcast**
Domain	**ALL**	**ALL**
Density	**ALL**	**ALL**
Call Establishment Delay	20 s	20 s
Voice Latency	485 ms	485 ms
A_P	0.999	0.999
A_U	0.998	0.998

Table 5-16: Voice Performance Requirements (AOC) – Phase 1 & 2

The quality of the voice must be sufficient to meet the operational requirement in the airspace where it is used. Quality includes user acceptability and intelligibility.

6 COMMUNICATION LOADING ANALYSIS

6.1 Introduction

This section provides the estimated capacity requirements for ATS and AOC communication. In order to estimate capacities, the classes of service described in Section 5.5 are grouped into aggregate information flows. A loading analysis is done for each type of aggregate flow. This section contains three separate types of aggregate flows each with its own loading analysis:

- Voice Loading Analysis
- Air/ground Data Loading Analysis
- Air/Air Data Loading Analysis

The aggregated requirements for air/ground data represent information flowing over notional interfaces within the FRS. The FRS itself could comprise a variety of technologies either with a single channel or multiple channels therefore the queuing model as used may be replaced by the features of a specific technology. The capacity figures derived in this document represent how much data must flow between the air and ground interfaces to meet the requirement. Many other methods to meet the overall requirements can be adopted such as the use of multiple parallel queues or 'channels'. Each channel can then be assigned a specific COS for example. In all cases the raw data derived in Sections 5 and 6 can be used to feed these other methods of assessing specific technologies.

Many of the loading input assumptions used in this document are common for three types of analyses mentioned above. For example, the number of aircraft in a service volume may be used in both the voice and air/ground data loading analyses. Thus, the first subsection below presents the assumptions used for the analyses. The subsequent sections describe each loading analysis, the methodology used, the resultant capacity requirement, and an analysis of the results.

It should be clearly understood that the analyses contained in this section are intended to be technology independent. The capacity requirements are intended to provide a sense of overall information transfer rates and not the required RF bit transmission rates.

In addition, it should be clearly noted that many of the services described in this document have not been subject to a detailed safety and performance analysis. Some of the services are completely new and thus rough order of magnitude estimates were used for message sizes/quantities and performance characteristics. Notwithstanding, an effort was made to develop a set of requirements that are tied to a high-level operational hazard assessment. Comparisons were made with similar services for which safety work has been conducted. Subject matter experts assessed high level operational performance requirements.

6.2 Loading Input Assumptions

Each of the loading analyses relies on one or more of the following types of input data in order to generate loading estimates:

- Service Volume – Service volumes provide the operational context for identifying the number of users developing service usage information.
- Peak Counts – The Peak Instantaneous Aircraft Count (PIAC) represents worst case number of users for a given service volume. The number of Daily Operations per Domain is also provided.
- Service Instances – The service instances represent the typical number of times a service is used within a service volume.
- Service Message Quantities and Sizes – Each instance of a data service may involve one or more messages that are exchanged between parties. For voice loading the instance may involve series of voice transmissions, e.g. a controller issues an instruction and the aircrew provides a confirmation reply. Each message includes application data, network overhead, error check bits, and/or security data.
- Equipage and Voice/Data Utilisation: Service utilisation rates are dependent on whether users are equipped to use a particular service.
- Flight Duration per Service Volume – The flight durations for each service volume are provided. The service instances and flight duration per service volume are used to develop average message arrival rates.
- Quality of Service Requirements (e.g. Classes of Service): Performance characteristics such as service priority and latency requirements drive system capacity requirements. Faster transaction times typically result in higher communication loading rates.

The following sections present the input data assumptions used for the loading analyses.

6.2.1 Service Volumes

A typical flight may cross several airspace domains including Airport, Terminal Manoeuvring Area (TMA), En Route, Oceanic, Remote and/or AOA domains. For each domain, a typical ***service volume*** (SV) was chosen that represent the highest density sector in that domain in the timeframes under consideration. That is, the volume of airspace for that airspace type contains aircraft that are all controlled by a single Controller position. In the case of the Airport service volume, the entire domain was used as the service volume rather than a single position; thus this volume includes the clearance/ramp position, the ground position, and the tower/runway position. Thus, the airport service volume equates to a cylinder, 10 miles in diameter, from ground to an altitude of 5,000 feet.

The sizes of service volumes for Phase 1 are equivalent to control positions/sectors in existence today. Use of the new operational services in Phase 1 will allow higher numbers of aircraft to be serviced in the same volume. For Phase 2, it is assumed the TMA, En Route and Oceanic/Remote service volumes are about three times the size used in Phase 1.

Note. - In the En Route domain, an ATSU will have more than 1 sector, but a given aircraft will only fly through 1 sector in each ATSU due to the size expansion.

As these types of airspace can vary widely in their requirements depending on the level of air traffic, for each service volume a typical high-density and low-density example was defined. The autonomous service volume is the only volume that does not include high and low density examples.

While service volumes have an operational context, the volume may or may not be well matched to a particular communication technology. The aim is to identify a communication 'density' requirement for each service volume independent of communications technology. The designated operational coverage (DOC) for a particular technology will be dependent on the characteristics of that technology e.g. power, frequency, bit rate, etc. By combining the service volume into typical DOC for technologies the communication requirement can be obtained per DOC. Knowledge of the deployment of service volumes is important and sufficient details need to be provided to enable technology choices to be matched to the communication requirement.

6.2.2 Peak Counts

6.2.2.1 Peak Instantaneous Aircraft Counts (PIACS)

The service volume PIACs are based on projections produced by two separate computer-based air traffic models as well as some estimates from subject matter experts to account for new airspace types (e.g. Autonomous service volume) and projected growth in sectors not accounted for in the referenced computer models. This section first introduces the computer models and the model predictions. It subsequently provides the final estimated/extrapolated service volume PIACs.

Two separate computer models were used to estimate PIACs for airspace volumes in Phase 1 and Phase 2. These were -

- EUROCONTROL's System for Traffic Assignment and Analysis at a Macroscopic Level (SAAM) tool which can simulate air traffic and provide data about the traffic through specified airspace volumes. See Appendix 1 for a description of SAAM.
- The MITRE Corporation's Centre for Advanced Aviation System Development Mid Level Model uses a traffic demand forecasting known as the Terminal Area Forecast (TAF), which is a compilation of scheduled airline flights growth. TAF baseline data is benchmarked for 2004 by the FAA. TAF is further refined through the observations of the Enhanced Traffic Management System to determine unscheduled traffic. The model provides PIAC counts for 2004, 2013 and 2020. The PIAC counts for 2030 are extrapolated. See Appendix 2 for further details.

These two models complemented each other. The SAAM model is constrained by the growth in airport traffic and can supply information on all 'flow-control sectors' throughout ECAC.

The MLM supplied information on aircraft numbers operating in en route sectors over the USA in the 2020 timeframe based on current practices. The NAS MLM modelling concept was to move the additional traffic to satellite airports. This is consistent with the U. S. Next Generation Air Transportation System (NGATS) vision [6]. Complete modelling to simulate the full 3 times traffic growth scenario and the concepts for 2025 were not completed. U.S. concepts also included the addition of thousands of Micro jets and UAVs.

The operational concept in Phase 2 assumes that sector sizes are three times larger in the TMA, En Route, and Oceanic/Remote domains. This growth in service volume sizes could not be directly modelled in the SAAM and MLM models. However 2 adjacent sectors were included in the calculations for Phase 2 giving the required increase in sector size. The SAAM model uses 'flow sectors'; those used in the calculations approximated to ATC control sectors. The MLM NAS sectors are based upon actual control sectors. These aspects are discussed further in section 7.

Peak instantaneous aircraft counts (PIACs) were predicted for the years 2020 and 2030 using the SAAM and MLM models. The PIACs for the various service volumes are given in Table 6-1: below. Neither the SAAM nor the MLM could model the airport surface domain therefore this domain was treated separately using a number of sources. The airport domain in a busy US airport was used as the basis for requirements.

The autonomous service volume PIAC was estimated at 50% of the traffic density projected for the Phase 2 high density En Route service volume. Note: The autonomous service volume is significantly bigger than the En Route service volume.

Scenario	Date	APT		TMA		ENR		ONR		AOA
		HD	LD	HD	LD	HD	LD	HD	LD	
ECAC	2020	-	-	16	14	24	24	-	-	-
NAS	2020	200	12	-	-	41	-	10	5	-
ECAC	2030	-	-	44	39	45	59[6]	-	-	-
NAS	2030	290	19	-	-	95	-	34	18	70

Table 6-1: PIAC Projections for High Density and Low Density Service Volumes

For the airport service volume, additional details about the distribution of aircraft amongst the three control positions must be known since many of the instances of service usage are specific to a particular control position. Table 6-2 summarises the number of aircraft assumed to be in the clearance/ramp, ground, and tower positions in high-density airports in Phase 1 and Phase 2.

APT 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

[6] The PIAC for the ECAC ENR LD volume is larger than the HD volume, but the size of the service volume is much larger resulting in an overall lower density – see section 7.

Table 6-2: Airport Controller Position PIACs – Phase 1 & 2

While not currently included within the loading analyses, it is important to note that in the airport environment, communication is necessary between a wide range of users in addition to the aircraft, e.g. surface vehicles. The FRS should have capacity to support this requirement although not necessarily in the same radio spectrum as aircraft. Table 6-3 provides the expected number of airport surface vehicles for Phase 1 and 2. Table 6-4 provides the number of the types of vehicles for a high-density airport.

APT	Phase 1		Phase 2	
	HD	LD	HD	LD
Surface Vehicles	32	4	32	8

Table 6-3: Airport Surface Vehicle Peak Counts – Phase 1 & 2

Vehicle Type	Number of Vehicles
Busses	12
De-icing Trucks	2
Snow Trucks	8
Airport Operations	6
Security and Fire Trucks	4
Total	32

Table 6-4: Types of Surface Vehicles in High-Density Airports

6.2.2.2 Daily Operations Per Domain

Table 6-5 and Table 6-6 provide the daily operations (number of aircraft serviced in a 24-hour period) per domain in Phase 1 and Phase 2, respectively. The Phase 2 daily operations are derived from the Phase 1 values by assuming a 2.5% annual growth rate over a ten-year period.

Density	Airport	TMA	En Route (40 sector domain)	Oceanic/ Remote
High	1800	3000	12000	1250
Low	50	300	400	100

Table 6-5 Daily Operations per Domain – Phase 1

Density	Airport	TMA	En Route (40 sector domain)	Oceanic/ Remote
High	2304	3840	15360	1600
Low	64	384	512	128

Table 6-6 Daily Operations per Domain – Phase 2

6.2.3 Equipage and Voice/Data Utilisation

Table 6-7 provides assumptions for data link equipage and ATS voice vs. data service utilisation. For loading purposes, it is assumed that 100% of the aircraft in all domains are equipped to support AOC data link communication and that AOC voice communication is so limited that it does not contribute to system loading.

	Phase	APT	TMA	ENR	ORP	AOA
% Data Link Equipage	1	75%	75%	75%	80%	-
	2	85%	85%	100%	100%	100%
% Services conducted using Voice	1	60%	60%	40%	5%	-
	2	15%	15%	5%	1%	1%

Table 6-7: Equipage and Voice/Data Utilisation Rates (ATS) – Phase 1 & 2

The data link equipage percentages reflect the assumed number of aircraft with some form of data link equipage. It is anticipated that there may be two levels of data link functionality. While the data link itself is assumed to be the same for all equipped aircraft, some of the aircraft will continue to support Phase 1 only types of services in Phase 2 APT and TMA domains. It is anticipated that 20% of the data link equipped aircraft in these domains have basic equipage (Type I aircraft), i.e. do not support COTRAC, DYNAV, URCO, PAIRAPP, AIRSEP, and A-EXEC. Of the remaining 80% (Type II aircraft), 75% provide simple WILCO responses to the COTRAC message while 25% negotiate the COTRAC utilising the message sequence structure of COTRAC.

While Table 6-7 provides the anticipated equipage and data utilisation percentages (on average), the air/ground data loading analysis has assumed 100% equipage for all service volumes in order to generate worst case data link loading. It also should be noted that the ATS and AOC data instances provided in section 6.2.4 already take the voice/data utilisation into account. The voice loading analysis uses both the data link equipage and ATS voice vs. data service utilisation rates to estimate voice loading.

6.2.4 Service Instances

Table 6-8 to Table 6-11 provide the expected number of usage instances for ATS, AOC and Network Management data services in Phase 1 and Phase 2.

For ATS instances, usage is provided on a per aircraft per service volume basis except for the A-EXEC and AMC services (see ** in tables) which are provided on a per service volume basis (not per aircraft). To translate these services into a per aircraft per service volume basis, one must know the number of aircraft, i.e. operations, that are served by the service volume over the applicable timeframe, e.g. one year or one week.

For Phase 2, Table 6-9 also provides two columns to present service instance applicability for each of the two types of data link equipped aircraft, i.e. basic data link (Type I) and COTRAC equipped (Type II), as described in Section 6.2.3. For example, the ARMAND service continues to be used by basic data link equipped aircraft in Phase 2. However, this service is typically not used by COTRAC equipped aircraft in Phase 2, because COTRAC functionality supersedes the need to use this service.

Note. - In Phase 2 sector sizes have become larger than Phase 1. In the En Route domain, an ATSU will have more than 1 sector, but a given aircraft will only fly through 1 sector in each ATSU due to the size expansion.

For the AOC instances, it is assumed that the number of instances is the same in Phase 1 and Phase 2; however, the number of messages per instance and/or the message sizes may be different in each phase.

For the Network Management instances, an ATN network protocol stack was used for purposes of estimation.

Note: The COCR does not specify or require a particular network stack.

Service	APT	TMA	ENR	ORP
ACL	1 (in ground position), both departure and arrival	2 per sector, both departure and arrival	5 per domain	2 per domain
ACM	3 per domain (1 in each position), both departure and arrival	1 per sector, both departure and arrival	1 per sector	1 per sector
ADS-B	Once every 1 s	Once every 6 s	Once every 12 s	Once every 12 s
A-EXEC	-	-	-	-
AIRSEP	-	-	-	-
AMC** (per service volume)	1 per domain, per week	1 per domain, per week	1 per domain, per week	1 per domain, per week
ARMAND	0	0	1 per domain, arrival only	0
C&P	0	0	1 per domain	1 per domain
COTRAC	-	-	-	-
D-ALERT	1 per aircraft per year	1 per aircraft per year	1 per aircraft per year	1 per aircraft per year
D-ATIS (Arrival)	0	1 per domain arrival for 70% of aircraft	1 per domain arrival for 70% of aircraft	0
D-ATIS (Departure)	1 (in ramp position), departure only for 70% of aircraft	0	0	0
DCL	1 (in ramp position), departure only	0	0	0
D-FLUP	1 (in ramp position), departure only	0	0	0
DLL	1 (in ramp position), departure only	0	1 per domain 30% of the time	1 per domain, 30% of the time
D-ORIS	0	0	1 per domain	1 per domain
D-OTIS	1 (in ramp position), departure only for 30% of aircraft	1 per domain, arrival only for 30% of aircraft	1 per domain for 30% of aircraft	0
D-RVR	1 (in ramp position), 30% of the time, departure only	1 per domain, 30% of the time during arrival	1 per domain, 30% of the time during arrival	0
DSC	0	0	1 per domain	1 per domain
D-SIG	1 (in ramp position), departure only	1 per domain, arrival only	0	0
D-SIGMET	1 (in ramp position), 30% of the time, departure only	1 per domain, 30% of the time during arrival	1 per domain, 30% of the time	1 per domain, 30% of the time
D-TAXI	1 (in ground position), both departure and arrival	1 per domain, arrival only	0	0
DYNAV	-	-	-	-
FLIPCY	1 (in ramp position), departure only	1 per domain, departure only	1 per domain	1 per domain
FLIPINT	1 (in ramp position), departure only	1 per domain, departure only	1 per ATSU	6 per sector
ITP	0	0	0	1 per domain
PPD	1 (in ramp position), departure only	1 per domain, both departure and arrival	1 per domain	1 per domain

S&M	0	1 per domain arrival only	1 per domain arrival only	0
SAP (Contract Setup)	0	1 per ATSU	1 per ATSU	0
SAP (Periodic Report)	0	Once every 10 s	Once every 10 s 30% of the time	0
TIS-B	Once every 1 s	Once every 6 s	Once every 12 s	Once every 12 s
URCO	-	-	-	-
WAKE	Once every 1 s	Once every 6 s	Once every 12 s	Once every 12 s

Table 6-8: Service Instances (ATS) – Phase 1

Service	Type[7]		APT	TMA	ENR	ORP	AOA (Type II only)
	I	II					
ACL	X	X	Type I&II: 1 (in ground position), both departure and arrival	Type I&II: 2 per sector, both departure and arrival	Type I: 5 per domain Type II: 1 per domain	Type I: 2 per domain Type II: 1 per domain	0
ACM	X	X	3 per domain (1 in each position), both departure and arrival	1 per sector, both departure and arrival	1 per sector	1 per sector	1 per domain (in buffer zone)
ADS-B	X	X	Once every 1 s	Once every 3 s	Once every 3 s	Once every 3 s	Once every 3 s
A-EXEC** (per service volume)	-	X	0	1 per year per domain	1 per year per domain	1 per year per domain	0
AIRSEP	-	X	0	0	0	0	2 per domain
AMC** (per service volume)	X	X	1 per week per domain	1 per week per domain	1 per week per domain	1 per week per domain	0
ARMAND	X	-	0	0	1 per domain, arrival only	0	0
C&P	X	-	0	0	1 per domain	1 per domain	0
COTRAC[8]	-	X	1 (in ramp position) departure only	1 per domain, departure only	1 per sector	1 per sector	1 per domain in the buffer zone
D-ALERT	X	X	1 per aircraft per year	1 per aircraft per year	1 per aircraft per year	1 per aircraft per year	0
D-ATIS (Arrival)	X	X	0	1 per domain on arrival for 30% of aircraft	1 per domain on arrival for 30% of aircraft	0	0
D-ATIS (Departure)	X	X	1 (in ramp position), departure only for 30% of aircraft	0	0	0	0
DCL	X	-	1 (in ramp position), departure only	0	0	0	0
D-FLUP	X	X	1 (in ramp position), departure only	0	0	0	0
DLL	X	X	1 (in ramp position), departure only	0	1 per domain, 30% of the time	1 per domain, 30% of the time	1 per domain (in buffer zone)

[7] Type I aircraft have basic data link equipage. Type II aircraft have COTRAC equipage. An 'X' in the column indicates the instances are applicable to that type of aircraft. A '-' in the column indicates the instances are not applicable for that type of aircraft.
[8] For Type II aircraft, 75% of the COTRAC exchanges are WILCO'd and 25% of them require a negotiation.

D-ORIS	X	X	0	0	1 per domain	1 per domain	0
D-OTIS	X	X	1 (in ramp position), departure only for 70% of aircraft	1 per domain, arrival only for 70% of aircraft	1 per domain for arrival for 70% of aircraft	0	0
D-RVR	X	X	1 (in ramp position), 30% of the time, departure only	1 per domain, 30% of the time, arrival only	1 per domain, 30% of the time, arrival only	0	0
DSC	X	-	0	0	1 per domain	1 per domain	0
D-SIG	X	X	1 (in ramp position), departure only	1 per domain, arrival only	0	0	0
D-SIGMET	X	X	1 (in ramp position), 30% of the time, departure only	1 per domain, 30% of the time, arrival only	1 per domain 30% of the time	1 per domain 30% of the time	0
D-TAXI	X	X	1 (in ground position), departure and arrival	1 per domain, arrival only	0	0	0
DYNAV	-	X	0	0	1 per domain for 30% of aircraft	1 per domain for 30% of aircraft	0
FLIPCY	X	-	1 (in ramp position), departure only	1 per domain, departure only	1 per domain	1 per domain	0
FLIPINT	X	X	1 (in ramp position), departure only	1 per domain, departure only	1 per ATSU	1 per ATSU	1 per domain (in buffer zone)
ITP	X	-	0	1 per domain, arrival only	1 per domain	1 per domain	0
PAIRAPP	-	X	4 times per second arrival only	4 times per second arrival only	0	0	0
PPD	X	X	1 (in ramp position), departure only	1 per domain, departure and arrival	1 per domain	1 per domain	0
S&M	X	-	0	1 per domain, arrival only	1 per domain	0	0
SAP (Contract Set-Up)	X	-	0	1 per ATSU	1 per ATSU	0	0
SAP (Periodic Report)	X	-	0	Once every 10 s	Once every 10 s 30% of the time	0	0
TIS-B	-	-	-	-	-	-	-
URCO	-	X	1 per aircraft per year	1 per aircraft per year	1 per aircraft per year	1 per aircraft per year	0
WAKE	X	X	Once every 1 s	Once every 3 s	Once every 3 s	Once every 3 s	Once every 3 s

Note 1: When COTRAC is not available, aircraft will use Phase 1 services

Table 6-9: Service Instances (ATS) – Phase 2 (

Service	PHASE 1/2				PHASE 2
	APT	TMA	ENR	ORP	AOA
AOCDLL	1 per ramp dep	0	0	1 per domain	0
CABINLOG	1 per ramp arr	0	0	0	0
ENGINE	0	1 per domain	1 per domain (when cruise altitude is reached)	0	0
FLTLOG	1 per ramp arr	0	0	0	0
FLTPLAN	1 per ramp dep	0	1 per domain	1 per domain	1 per domain
FLTSTAT	0	0	1 per domain	1 per domain	2 per domain
FREETEXT	0	0	2 per domain	2 per domain	1 per domain
FUEL	0	1 per domain	2 per domain	2 per domain	2 per domain
GATES	0	0	1 at top of descent	0	0
LOADSHT	2 per ramp dep	1per domain, arrival only	0	0	0
MAINTPR	0	0	1 per domain for 5% of flights	1 per domain for 5% of flights	1 per domain for 5% of flights
MAINTRT	0	0	2 per domain	2 per domain	2 per domain
NOTAM	1 per ramp dep	0	2 per domain	2 per domain	0
OOOI	1 ramp dep 1 rwy takeoff 1 rwy landing 1 ramp arr	0	0	0	0
POSRPT	0	Every 15 min	Every 15 min	Every 15 min	Every 15 min
SWLOAD	1 per ramp dep	0	0	0	0
TECHLOG	1 per ramp dep	0	0	0	0
UPLIB	1 per ramp dep	0	0	0	0
WXGRAPH	1 per ramp dep	0	Every 20 min	Every 40 min	Every 20 min
WXRT	Takeoff: 1 rpt every 6s	Climb/descend: 1 rpt every 60s	Climb/descend: 1 rpt every 60s[9] Cruise: 1 rpt every 3 min	Cruise: 1 rpt every 3 min	Cruise: 1 rpt every 3 min
WXTEXT	1 per ramp dep	0	2 per domain	2 per domain	1 per domain

Table 6-10: Service Instances (AOC) - Phase 1 & 2[10]

[9] In TMA domain, there is no cruise portion (aircraft are either climbing or descending). In the ER domain Phase 1, assume ½ the time aircraft are in climb/descend and the remaining ½ aircraft are in cruise mode. In Phase 2 leave the time for climb/descend the same and increase the cruise time to fit the sector duration time.

[10] Abbreviations: dep = departure, arr = arrival, rpt = report, rwy = runway

Service	PHASE 1/2				PHASE 2
	APT	TMA	ENR	ORP	AOA
NETCONN	1 (in ramp), departure only	0	1 per domain	1 per domain	1 per domain (in buffer zone)
NETKEEP	1 per 30 mins	1 per 30 mins	1 per 30 mins	1 per 30 mins	1 per domain (in buffer zone)

Table 6-11: Service Instances (Network Management) – Phase 1 & 2

6.2.5 Message Quantities and Sizes (per Instance)

Table 6-12 to Table 6-14 provide the average number of message quantities and sizes per service instance for ATS, AOC and Network Management services, respectively. Information is provided for both the uplink and downlink directions.

The message quantities and sizes are based on a number of referenced sources for some services and engineering estimates for the newer services [37], [38] and [40]. The air-to-ground messages include overheads associated with the network, integrity and security.

The DLL and AOCDLL messages include 72 octets for network overhead and 4 octets for integrity. The security overhead for both types of messages include key exchanges and the overhead size varies based on the assumed number of applications supported. It is assumed that the DLL service supports 3 applications and the AOCDLL service supports 2 applications.

The remaining air-to-ground messages include includes 72 octets for network overhead, 4 octets for integrity overhead, and 1 octet for security overhead. Note: It is assumed that the security authentication value can be XORed with the integrity checksum to save bandwidth. Encryption adds overhead to the logon message, but not to the other application messages.

Services	Uplink	Downlink
ACL	4 x 91	4 x 91
ACM	2 x 107	2 x 88
ADS-B	1 x 34	
A-EXEC	1 x 600	1 x 100
AIRSEP	6 x 497	
AMC	1 x 89	0 x 0
ARMAND	1 x 260	1 x 88
C & P	4 x 91	4 x 91
COTRAC (Interactive)	3 x 1969	4 x 1380
COTRAC (Wilco)	2 x 1613	2 x 1380
D-ALERT	1 x 88	1 x 1000
D-ATIS (Arrival)	5 x 100	3 x 93
D-ATIS (Departure)	3 x 101	2 x 96
DCL	3 x 98	3 x 88
D-FLUP	5 x 190	3 x 129
DLL	1 x 491	1 x 222
D-ORIS	9 x 478	3 x 93
D-OTIS	11 x 193	3 x 107
D-RVR	4 x 116	3 x 121
DSC	5 x 165	5 x 88
D-SIG	4 x 1340	3 x 129
D-SIGMET	4 x 130	3 x 129
D-TAXI	3 x 118	3 x 192
DYNAV	2 x 302	2 x 85
FLIPCY	2 x 97	2 x 131
FLIPINT	2 x 116	2 x 2774
ITP	4 x 91	4 x 91
PAIRAPP	1 x 34	
PPD	2 x 97	2 x 183
S&M	4 x 91	4 x 91
SAP (Contract Setup)	2 x 95	2 x 100
SAP (Report)	0 x 0	1 x 107
TIS-B	1 x 34	
URCO	2 x 93	2 x 85
WAKE	1 x 34	

Table 6-12: Message Quantities and Sizes (bytes) per Instance (ATS) – Phase 1 & 2

Service	Phase 1		Phase 2	
	Uplink	Downlink	Uplink	Downlink
AOCDLL	2 x 413	2 x 148	2 x 413	2 x 148
CABINLOG	0 x 0	1 x 477	0 x 0	1 x 477
ENGINE	1 x 88	1 x 727	2 x 88	2 x 727
FLTLOG	0 x 0	2 x177	0 x 0	2 x 177
FLTPLAN	17 x 285	17 x 90	9 x 968	9 x 92
FLTSTAT	0 x 0	1 x 157	0 x 0	1 x 157
FREETEXT	1 x 377	1 x 377	1 x 377	1 x 377
FUEL	0 x 0	3 x127	0 x 0	3 x 127
GATES	1 x 589	0 x 0	1 x 589	0 x 0
LOADSHT	2 x 913	2 x 93	2 x 913	2 x 93
MAINTPR	4 x 133	4 x 133	4 x 233	4 x 233
MAINTRT	5 x 88	5 x 127	5 x 88	5 x 127
NOTAM	3 x 265	2 x 134	4 x 287	2 x 134
OOOI	0 x 0	1 x 117	0 x 0	1 x 117
POSRPT	1 x 88	1 x 338	1 x 88	1 x 338
SWLOAD	2 x 4077	0 x 0	6 x 4077	0 x 0
TECHLOG	1 x 88	1 x 477	1 x 88	1 x 477
UPLIB	4 x 4077	4 x 88	24 x 4077	24 x 88
WXGRAPH	6 x 4246	6 x 93	5 x 21077	6 x 93
WXRT	0 x 0	1 x103	0 x 0	1 x 103
WXTEXT	5 x 680	2 x 103	5 x 680	2 x 103

Table 6-13: Message Quantities and Sizes (bytes) per Instance (AOC) – Phase 1 & 2

Services	Uplink	Downlink
NETCONN	2x154	2x148
NETKEEP	1 x 93	1 x 93

Table 6-14: Message Quantities and Sizes (bytes) per Instance (Network) – Phase 1 & 2

6.2.6 Flight Duration per Service Volume

The flight duration per service volume were estimated in tandem with evaluation of a typical flight profile. The number of sectors and ATSUs traversed in each domain were also estimated. Table 6-15 below provides a summary of this information.

Type	Phase Density	APT			TMA	ENR	ORP	AOA
		Ramp	Ground	Tower				
Domain Flight Time	P1-HD	3690 s (dep) [61.5 min] 1290 s (arr) [21.5 min]			486 s (dep) 848 s (arr)	5400 s [1.5 hr]	15300 s [4.25 hr]	n/a
	P1-LD	2310 s (dep) [38.5 min] 630 s (arr) [10.5 min]			378 s (dep) 660 (arr)	5400 s [1.5 hr]		
	P2-HD	2790 s (dep) [46.5 min] 1110 s (arr) [18.5 min]			388 s (dep) 678 s (arr)	4920 s [1.35 hr]	15300 s [4.25 hr]	5400 s [1.5 hr]
	P2-LD	1410 s (dep) [23.5 min] 570 s (arr) [9.5 min]			302 s (dep) 528 (arr)	4920 s [1.35 hr]		
#Sectors/ Positions Traversed per Flight	P1-HD	3			2	8	6	n/a
	P1-LD	2 (ramp & ground combined)			1	6		
	P2-HD	3			2	5	4	1
	P2-LD	2 (ramp & ground combined)			1	4		
#ATSUs Traversed per Flight	ALL	1			1	4	2	n/a
Sector/ Position Flight Time	P1-HD	2700 s (dep) 540 s (arr)	720 s (dep) 480 s (arr)	270 s	243 s (dep) 424 s (arr)	675 s [11.25 min]	2550 s [42.5 min]	n/a
	P1-LD	1800 s (dep) 240 s (arr)	360 s (dep) 240 s (arr)	150 s	378 s (dep) 660 (arr)	900 s [15 min]		
	P2-HD	1800 s (dep) 360 s (arr)	720 s (dep) 480 s (arr)	270 s	194 s (dep) 339 s (arr)	984 s [16.4 min]	3825 s [63.75 min]	5400 s [90 min]
	P2-LD	900 s (dep) 180 s (arr)	360 s (dep) 240 s (arr)	150 s	302 s (dep) 528 (arr)	1230 s [20.5 min]		

Table 6-15: Flight Durations and Sectors/ATSUs Traversed – Phase 1 & 2

The airport service volume was split into flight duration for each position (clearance/ramp, ground, and tower/runway), as was the case for PIACs and service instances. Different durations were assigned, based on whether the aircraft was in departure mode or arrival mode in the Airport for a particular flight. While the flight durations for the ground and tower positions are the same in Phase 1 and Phase 2, it is expected that the clearance/ramp flight duration will be shorter in Phase 2 due to more efficient turn-around.

For the TMA and ENR domains, it is assumed that domain flight times in Phase 2 are reduced due to better planning and the use of 4D trajectories which provide more direct routing. For the ENR domain, the Phase 2 sector sizes have become larger than Phase 1, thereby reducing the number of sectors traversed. An ENR ATSU will have more than 1 sector, but a given aircraft will only fly through 1 sector (on average) due to the size expansion.

6.3 Voice Loading Analysis

The objective of the voice loading analysis provides estimated seconds per hour of active talk time for the party line service in each of the service volumes. Additional information regarding the number of transmissions per hour is also provided. Only ATS controller/pilot voice communication is analysed as there is insufficient information to characterise AOC voice communication. The voice loading associated with broadcast channels such as for ATIS, VOLMET, and AWOS is 100%.

6.3.1 Methodology

The estimated seconds per hour of active PTT time and the instance information is developed using the following steps:

- A survey of existing voice studies was conducted to determine the average number of transmissions per aircraft (#tx/ac) per service volume and the average duration of each transmission (#sec/tx) [19].. For comparison with data link loading, the number of instances per aircraft (#instances/ac) is also estimated. An instance contains a sequence of related voice transmissions..
- The total number of seconds of voice per hour per service volume (#sec/hr/SV) is calculated using the metrics from the voice study survey in tandem with PIAC, flight times per service volume (SV), data link equipage rates, and voice/data utilisation rates presented in section 6.2.3. The loading analysis uses an average flight time for volumes that specify both arrival and departure aircraft durations.
- The total number of seconds of voice per hour per position (#sec/hr/position) is calculated from the number of positions per service volume (#positions/SV). In addition, the occupancy and number of transmissions per hour per position (#tx/hr/position) is calculated.

Unlike the other services volumes, the APT is comprised of multiple types of voice positions, i.e., ramp/clearance, ground, and tower. High-density airports may contain multiple instances of a particular type of position, e.g. two ground positions. Low-density airports do not require all three position types and may combine the ramp/clearance and ground positions. Since the referenced voice studies only provide data for ground and tower positions only these two positions are considered in the voice loading analysis. Accordingly, the PIAC and flight times used here correspond to these two positions. Further, it is assumed that for the high density airport, two ground positions and one tower position are required to handle the PIAC traffic. The FRS would need to support separate party-line channels for each position.

6.3.2 ATS Voice Transmission Characteristics

The voice transmission characteristics per service volume are based on a survey of studies [19] that evaluate both typical and worst-case conditions for various airspace domains assuming limited or non-existent use of data link. The ORP service volume values were estimated because of limited or non-existent reference data. The number of seconds per aircraft includes only active PTT time. The number of instances per aircraft in each service volume has been calculated by dividing the number of transmissions by the estimated number of transmissions required per instance. The APT number of transmissions and transmission duration are for ground and tower positions only.

Parameter	APT	TMA	ENR	ORP
#tx/ac	16.5	6.8	8.8	3
#sec/tx	3	2.8	3.3	3.3
#sec/ac	49.5	19.0	29.0	9.9
#tx/instance	2	2	2.8	2.8
#instances/ac	8.3	3.4	3.1	1.1

Table 6-16: ATS Voice Transmission Characteristics per Service Volume

6.3.3 Capacity Requirements

Table 6-17 and Table 6-18 provide the estimated capacity requirements for ATS voice communication for Phase 1 and Phase 2, respectively. Additional details on the tables are provided below.

PHASE 1	APT		TMA		ENR			ORP	
	HD	LD	HD	LD	NAS -HD	ECAC-HD	LD	HD	LD
#tx/ac	16.5	16.5	6.8	6.8	8.8	8.8	8.8	3	3
#sec/tx	3	3	2.8	2.8	3.3	3.3	3.3	3.3	3.3
#sec/ac	49.5	49.5	19.0	19.0	29.0	29.0	29.0	9.9	9.9
PIAC	66	8	16	14	41	24	24	10	5
% ac (voice only ac)	25%	25%	25%	25%	25%	25%	25%	20%	20%
% voice util (data link ac)	60%	60%	60%	60%	40%	40%	40%	5%	5%
flight duration/SV (#sec)	870	450	334	519	675	675	900	2550	2550
#sec/hr/ac	205	396	206	132	155	155	116	14	14
#sec/hr/SV (voice only ac)	3380	792	822	462	1588	929	697	28	14
#sec/hr/SV (data link ac)	6083	1426	1480	832	1905	1115	836	6	3
#sec/hr/SV (total)	9463	2218	2302	1294	3493	2044	1533	34	17
#positions/SV	3	2	1	1	1	1	1	1	1
#sec/hr/position	3154	1109	2302	1294	3493	2044	1533	34	17
# tx/hr/position	1051	739	822	462	1058	620	465	10	5
occupancy/position	88%	31%	64%	36%	97%	57%	43%	1%	0%

Table 6-17: Voice Capacity Requirements – Phase 1

PHASE 2	APT		TMA		ENR			ORP	
	HD	LD	HD	LD	NAS -HD	ECAC-HD	LD	HD	LD
#tx/ac	16.5	16.5	6.8	6.8	8.8	8.8	8.8	3	3
#sec/tx	3	3	2.8	2.8	3.3	3.3	3.3	3.3	3.3
#sec/ac	49.5	49.5	19.0	19.0	29.0	29.0	29.0	9.9	9.9
PIAC	96	12	44	39	95	45	59	34	18
% ac (voice only ac)	15%	15%	15%	15%	0%	0%	0%	0%	0%
% voice util (data link ac)	15%	15%	15%	15%	5%	5%	5%	1%	1%
flight duration/SV (#sec)	870	450	267	415	984	984	1230	3825	3825
#sec/hr/ac	205	396	257	165	106	106	85	9	9
#sec/hr/SV (voice only ac)	2950	713	1698	966	0	0	0	0	0
#sec/hr/SV (data link ac)	2507	606	1443	821	505	239	251	3	2
#sec/hr/SV (total)	5457	1319	3140	1788	505	239	251	3	2
#positions/SV	3	2	1	1	1	1	1	1	1
#sec/hr/position	1819	659	3140	1788	505	239	251	3	2
# tx/hr/position	606	440	1122	638	153	72	76	1	1
occupancy/position	51%	18%	87%	50%	14%	7%	7%	0%	0%

Table 6-18: Voice Capacity Requirements – Phase 2

The airport PIACs and flight duration above reflect the sum of the ground and tower positions. The resulting #sec/hr/SV values are for combined ground and tower positions.

The following notes provide information on the calculations used in the tables above.

- The #sec/hr/ac is calculated by dividing the #sec/ac by the flight duration.
- The #sec/hr/SV (voice only ac) is calculated by multiplying the #sec/hr/ac times the voice only aircraft count (i.e., PIAC x voice only percentage).
- The #sec/hr/SV (voice utilisation by data link ac) figures are calculated by multiplying #sec/hr/ac times the data link aircraft count times the voice utilisation percentage.
- The total #sec/hr/SV is the sum of the previous two calculations.
- The #tx/hr/position by dividing the total #sec/hr/position by the #sec/tx.

6.3.4 Analysis of Results

For Phase 1, the occupancy numbers are large compared to typical occupancy rates for some domains. This difference can be primarily attributed to the use of PIAC data instead of average aircraft counts (or aircraft per hour figures). Nonetheless, it is useful to look at PIAC-based loading to get a sense of worst case conditions especially when those worst case conditions are close to actual peak conditions. For example in the APT domain, the Los Angeles Airport [18] measured occupancy rates of 68% for a peak activity period spanning 1 hour. Note that if 4 positions were assumed for the APT, i.e.

two ground and two towers, the occupancy rate would drop to 66%. In the TMA domain, the New York TRACON arrival sectors have experienced 81% occupancy over a period of 1 hour [45]. In the ENR domain, the Vocalise study [35] has shown occupation rates over 77% over a 5 minute period and near 60% over a 15 minute period.

For Phase 2, the data link equipage and utilization rates are key factors that will allow the PIAC to grow while still allowing the voice channel to support the service volume.

6.4 Air/Ground Data Capacity Analysis

The air/ground data capacity analysis examined ATS and AOC communication requirements in separate aggregate flows and within a shared aggregate flow. The aggregate flows do not include ADS-B related or air-to-air related services such as PAIRAPP or AIRSEP.

A non-pre-emptive priority queuing model was used to develop the capacity requirements. Full details of the model and the methodology to employ it, can be found at Appendix 3.

In the model, messages in higher priority queues (e.g. classes of service) are serviced before messages in lower priority queues. Once the server in the model has begun to transmit a message from any particular priority queue, it continues to transmit the message even if a higher priority message should arrive during transmission.

6.4.1 Results

Table 6-19 and Table 6-20 provide the Phase 1 and Phase 2 estimated capacity requirements for the following three cases: ATS and AOC traffic on separate systems, and ATS and AOC traffic on the same system, assuming a single queue is used for both uplink and downlink message transmissions. To obtain upper bounds, all aircraft are assumed to be data link equipped in each domain. For each case, capacity requirements in kilobits per second (kbps) for uplink (UL), downlink, (DL), and combined UL and DL traffic are displayed. Results are shown for high density (HD) and low density (LD) airport (APT), TMA (TMA), enroute (ENR), oceanic/remote and polar (ORP), and, for Phase 2 autonomous operations area (AOA) service volumes (SV).

PHASE 1		APT SV		TMA SV		ENR SV			ORP SV	
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD
Separate ATS	UL	4.0	1.2	2.3	2.2	1.2	1.5	1.2	0.3	0.3
	DL	4.3	1.9	4.1	3.9	3.7	4.9	3.7	2.7	2.2
	UL&DL	7.4	2.0	5.3	5.0	4.1	5.6	4.1	2.8	2.2
Separate AOC	UL	15.6	2.7	0.3	0.3	8.6	11.9	8.6	3.3	2.8
	DL	3.5	0.7	0.8	0.8	0.8	1.3	0.8	0.4	0.3
	UL&DL	19.9	2.9	0.8	0.8	9.1	13.8	9.1	3.3	2.8
Combined ATS&AOC	UL	18.4	2.9	2.3	2.2	9.0	12.7	8.9	3.3	2.8
	DL	6.7	2.0	4.3	4.1	3.8	5.2	3.8	2.7	2.2
	UL&DL	25.5	3.3	5.6	5.3	11.4	17.7	11.3	4.5	3.4

Table 6-19: Air/Ground Capacity Requirements (kbps) – Phase 1

PHASE 2		APT SV		TMA SV		ENR SV			ORP SV		AOA
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD	
Separate ATS	UL	12.8	7.1	22.0	22.2	20.9	22.4	21.0	19.8	19.6	7.1
	DL	11.3	5.2	10.3	10.7	9.8	13.5	10.5	8.9	8.7	13.3
	UL&DL	19.6	7.3	24.5	25.1	23.5	27.0	24.0	20.3	19.9	13.6
Separate AOC	UL	113.0	14.1	0.3	0.2	52.4	96.1	64.1	24.0	18.2	56.2
	DL	6.7	1.2	2.4	2.2	1.4	2.7	1.8	0.6	0.4	1.1
	UL&DL	131.2	14.1	2.6	2.3	58.6	106.9	72.6	24.4	18.2	62.8
Combined ATS&AOC	UL	120.0	24.6	22.0	22.2	119.1	168.3	134.8	82.1	62.8	76.7
	DL	13.4	5.4	11.1	11.8	10.2	13.9	10.9	9.0	8.8	13.4
	UL&DL	144.3	24.8	25.2	25.8	119.4	168.9	135.2	82.2	62.9	80.5

Table 6-20: Air/Ground Capacity Requirements (kbps) – Phase 2

Table 6-21 below provides the Phase 2 data requirements as shown in Table 6-20 but without the A-EXEC service.

PHASE 2		APT SV		TMA SV		ENR SV			ORP SV		AOA
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD	
Separate ATS	UL	12.8	7.1	9.2	9.2	7.4	9.4	7.1	6.0	5.9	7.1
	DL	11.3	5.2	10.3	10.7	9.7	13.2	10.1	8.9	8.7	13.3
	UL&DL	19.6	7.3	16.6	16.8	11.8	17.8	12.5	9.2	8.9	13.6
Separate AOC	UL	113.0	14.1	0.3	0.4	52.4	96.1	64.1	24.0	18.2	56.2
	DL	6.7	1.2	2.4	2.5	1.4	2.7	1.8	0.6	0.4	1.1
	UL&DL	131.2	14.1	2.6	2.7	58.6	106.9	72.6	24.4	18.2	62.8
Combined ATS&AOC	UL	120.0	24.6	9.2	9.2	80.1	116.1	91.6	53.0	38.7	76.7
	DL	13.4	5.4	10.9	11.3	9.9	13.4	10.4	9.0	8.8	13.4
	UL&DL	144.3	24.8	17.0	17.3	80.4	117.4	92.0	53.1	38.8	80.5

Table 6-21: Air/Ground Capacity Requirements (kbps) excluding the A-EXEC service– Phase 2

Table 6-22and Table 6-23 provide the estimated Phase 1 and Phase 2 capacity requirements in kbps assuming a dedicated ‘channel’ for each aircraft.

PHASE 1		APT SV Dep	APT SV Arr	TMA SV Dep	TMA SV Arr	ENR SV	ORP SV
Separate ATS	UL	1.1	0.7	0.6	1.5	0.9	0.3
	DL	1.8	0.7	1.9	0.8	2.4	1.7
	UL&DL	1.8	0.7	2.0	1.5	2.5	1.7
Separate AOC	UL	2.4	0.2	0.2	0.2	4.3	2.4
	DL	0.3	0.3	0.3	0.3	0.3	0.3
	UL&DL	2.4	0.3	0.3	0.3	4.3	2.4
Combined ATS&AOC	UL	2.4	0.7	0.6	1.5	4.3	2.4
	DL	1.8	0.7	1.9	0.8	2.5	1.7
	UL&DL	2.4	0.7	2.0	1.5	4.3	2.5

Table 6-22Air/Ground Capacity Requirements (kbps) for Each Aircraft using A Separate ‘Channel’ – Phase 1

PHASE 2		APT SV Dep	APT SV Arr	TMA SV Dep	TMA SV Arr	ENR SV	ORP SV	AOA
Separate ATS	UL	6.9	1.8	19.5	19.5	19.5	19.4	6.7
	DL	6.2	1.9	6.8	3.3	6.7	8.5	12.5
	UL&DL	6.9	1.9	19.7	19.5	19.5	19.5	12.5
Separate AOC	UL	9.2	0.2	0.2	0.2	20.4	12.1	12.6
	DL	0.3	0.3	0.4	0.4	0.3	0.3	0.3
	UL&DL	9.2	0.3	0.4	0.4	20.4	12.1	12.6
Combined ATS&AOC	UL	9.2	1.8	19.5	19.5	28.6	25.4	12.7
	DL	6.2	1.9	6.8	3.4	6.7	8.5	12.5
	UL&DL	9.5	1.9	19.8	19.5	28.7	25.4	17.0

Table 6-23 Air/Ground Capacity Requirements (kbps) for Each Aircraft using A Separate ‘Channel’ – Phase 2

Table 6-24 below provides the Phase 2 data requirements without the A-EXEC service.

PHASE 2		APT SV Dep	APT SV Arr	TMA SV Dep	TMA SV Arr	ENR SV	ORP SV	AOA
Separate ATS	UL	6.9	1.8	5.6	3.8	5.7	5.7	6.7
	DL	6.2	1.9	6.8	1.6	6.7	8.5	12.5
	UL&DL	6.9	1.9	6.9	3.8	6.7	8.5	12.5
Separate AOC	UL	9.2	0.2	0.2	0.2	20.4	12.1	12.6
	DL	0.3	0.3	0.4	0.4	0.3	0.3	0.3
	UL&DL	9.2	0.3	0.4	0.4	20.4	12.1	12.6
Combined ATS&AOC	UL	9.2	1.8	5.6	3.8	20.4	12.1	12.7
	DL	6.2	1.9	6.8	1.7	6.7	8.5	12.5
	UL&DL	9.5	2.0	6.9	3.8	20.4	12.3	17.0

Table 6-24 Air/Ground Capacity Requirements (kbps) for Each Aircraft using A Separate 'Channel' excluding the A-EXEC service – Phase 2

6.4.2 Analysis of Results

Some comments on the results are contained in the two sections below.

6.4.2.1 General

Following are general comments data loading analysis:

- **Model Validation**: Although the model used is based on reasonable assumptions and formulas, both the model and its application in this loading analysis need to be validated.
- **Data Compression Impacts**: The results are based on the size of messages arriving at the FRS boundary. Consequently compression techniques that could be employed to reduce the number of bits sent over the physical link have not been taken into account as the COCR is technology independent.
- **Collisions and Media Access Delays**: The model does not include RF collisions, retransmissions due to bit errors, or RF media access delays (e.g. waiting for the next available slot).
- **Bps per Aircraft:** An important conclusion of the loading work done thus far is that the increase in transfer rate requirements is not linear with the increase in aircraft; hence, ***one cannot reasonably use a bps/aircraft number in tandem with aircraft count to predict required bit rates.*** As an example, one can compare the results for an ATS only link in the en route Phase 2 service volume. The US and EU PIACs for this volume are 95 and 45, respectively. The US PIAC is about nearly 111% larger than the EU, but the required information transfer rate is only 41% larger. The reason for the non-linearity resides in the projected occupancy of the link. ***In many cases, the message latency requirements drive the information transfer rate rather than the quantity of information.*** Thus, the link may not always be actively transmitting messages.
- **Non-Flight Specific Services:** The loading analysis above includes point-to-point delivery of FIS related services. An alternative loading analysis which assumes a separate broadcast of this data would reduce the required information transfer rates.

- **Message Sizes, Quantities and Latencies:** It should be restated that the results rely on a number of input assumptions (e.g. message sizes, number of messages per transaction, etc) and use performance figures based on a high level operational hazard assessment. Loading results are sensitive to these assumptions (refer to Section 6.2 for a list of assumptions). The one-way latency requirements were applied to each one-way message. Future work is required to complete detailed safety and performance work for each individual service and to refine message sizes and/or sequences in greater detail.
- **Driving COS Category**: In all cases, one of the several queues (i.e. classes of services) in the aggregate flow drives the required information transfer rate. In other words, only one of the categories has a 95% predicted delay that is equivalent to the COS category delay requirement. The other COS categories have predicted delays that are less than the COS category delay requirement. Further, it is not necessarily the highest performance (priority) category that ends up being the driving COS category. Sometimes the middle and low priority queues are the driving queues because the message size to delay ratios may be larger for these queues. Typically, changes to non-driving queues have lower impact and result in less significant changes in the required information transfer rates. It is also interesting to note that while the system/network service messages were assigned the highest priority, in general, the associated queue (Type DG-A) was not identified as the driving COS queue category.
- **COS Category Definitions:** It should be noted that alternative COS category definitions (and the resulting difference in placement of operational services) may significantly impact information transfer rate requirements. For example, a reduction in the number of categories in the master list may result in the up-levelling of a number of services which, in turn, may increase the required information transfer rate.
- **Message Segmentation**: The assumed message sizes were not adjusted to consider packet size limitations common with networks; that is, message segmentation was not assumed. It is anticipated that the results might be somewhat affected if this was taken into account. For example, if a large lower priority message was segmented, it would allow a higher priority message to be inserted in the data flow before the transmission of the lower priority message is completed.
- **Logical ACKnowledgement (LACK):** In the capacity requirement analysis, some CPDLC services used LACK. Further analyses are required to determine the impact of using LACK on the required capacities.

6.4.2.2 Specific Comments

The following are comments that apply to one or more of the results in the above tables:

- **A-EXEC Service**: The A-EXEC Service is a performance driver in the Phase 2 En route and Oceanic/Remote service volumes.
- **Capacity in Phase 2:** The increase in capacity requirements in Phase 2 for the Airport Domain can be attributed in part to increased message sizes and reduced latencies.

6.5 Air/Air Data Loading Analysis

The air/air data loading analysis looks at broadcast communication services (ADS-B, TIS-B, and WAKE) and addressed air/air communication services such as PAIRAPP and AIRSEP. Both the broadcast and the addressed services are evaluated together in a single aggregate flow. Unlike the other loading analyses (which use service volumes that correlate to controller sectors/positions), the air/air data loading analysis uses service volumes that correlate to air/air ranges. In order to prevent confusion with the service volumes used in other sections, this section will refer to these air/air communication volumes as ***transmission volumes.*** The PIAC values used herein correspond to the transmission volume and are different than those used for the other analyses.

The objective of the loading analysis is to estimate the required ***information transfer rate*** that must be supported by the FRS. As such, it does not consider the impacts of transmission collisions (common with 'unorganised' broadcast technology) or media access delays or scheduling overhead (common with 'organised' shared-media access technologies).

A simple model was used to develop the capacity requirements. The contributions to the loading from each of services are evident; thus, a separate evaluation of each service type against a technology can be conducted, if needed. Only worst case transmission volume densities are evaluated.

The following sections provide a brief description of the methodology, assumptions, capacity requirements, and an analysis of the results.

6.5.1 Methodology

The estimated ***information transfer rate*** is developed using the following steps:

- The transmission volume PIACs and service message sizes are estimated and the FRS transmission latency is calculated using an allocated percentage of the end-to-end (E2E) latency.
- The estimated information transfer rate for each air/air service type is calculated by multiplying the PIAC times the message size and dividing the result by the FRS latency requirement.
- The information transfer rate of the aggregate flow is computed by summing the results of each air/air service type.

6.5.2 Assumptions

The following assumptions are used in the air/air data loading analysis:

- **Transmission Volumes**: The transmission volumes for each domain are separate and independent. In other words, while the TMA and ENR domains may overlap from a transmission range standpoint, the analysis assumes the transmissions from an aircraft in the TMA but near the boundary of ENR do not interfere with transmissions in the ENR domain. The required transmission range for APT, TMA, and ENR domains are 5, 60 and 200 NM, respectively. It is assumed that the ranges for the ORP and AOA domains are the same as the ENR domain.

- **Equipage**: For the purposes of the loading analysis, all users in a transmission volume are equipped to support the air/air communication services, i.e. 100% equipage. This is a reasonable assumption if the loading due to ADS-B in the 100% equipage case is similar to the loading due to ADS-B and TIS-B in the mixed equipage case.
- **Update Rates**: The required transmission rate is equal to the required receive rate which is related to the assumed end-to-end latency. In other words, if the required update rate (receive rate) is once every 12 seconds, than the required information transfer rate is once every 12 seconds. The receiver must get the message before the next transmission is started by the sender. This corresponds to the update rate provided in section . For example, refer to the 12 second update rate specified for the Phase 1 ENR domain. This analysis focuses on information transfer rates. Present implementations of air/air broadcast services assume data transmissioni rates must be significantly greater than required information transfer rates to ensure delivery/receipt within latency requirements.
- **FRS Boundary Point and Latency Allocation Assumptions:** While the FRS boundary point for air/air communication in the airborne segment is viewed to be a 'location' analogous to that used for the voice and air/ground loading analyses, the interface is not assumed to use a communication stack with associated communication overhead. The latency allocation percentage assigned to the airborne equipment external to the FRS is 10%. With an aircraft located at each end of the link, the resulting FRS latency allocation is 80%.
- **ADS-B PIACs**: The APT transmission volume PIAC is calculated by adding 50 users to the APT service volume PIAC, i.e. the PIACs used for the voice and air/ground data loading analyses. The PIACs for the Phase 1 TMA and ENR volumes are assumed to be 750 and 1250, respectively. The Phase 2 PIACs for these volumes are based on an annual growth rate of 2.5% over a 10-year period. The PIACs for the ORP and AOA volumes are estimated based on aircraft densities inferred from the ORP and AOA service volumes. These service volumes are larger than the associated transmission volumes.
- **PAIRAPP PIACs**: The PAIRAPP service is used by aircraft on (or being sequenced to) final approach. Two or three aircraft would address each other with 0.3 second update rates. Numerous "pairs" would be using this service simultaneously within each airport/TMA region. It is assumed that 75 aircraft could be using the service at one time. The intended use of PAIRAPP is not completely compatible with the transmission volume boundaries selected for the air/air data loading analysis. The operation begins in the TMA domain and continues through the APT domain. For purposes of the loading analysis, it was assumed that all the aircraft in the tower position of the Airport service volume were conducting PAIRAPP separations. The balance of the aircraft (75 – tower PIAC) was assumed to be the TMA PAIRAPP PIAC.
- **AIRSEP PIACs**: It is assumed that 25% of the aircraft are conducting AIRSEP communication at any one point in time. The PIAC is thus 0.25 times the ADS-B PIAC value.
- **Message Sizes**: The message sizes are provided in section 6.2.5. The message size for the ADS-B is assumed to be 34 bytes, i.e. the message size associated with UAT transmissions per DO-282A. This is the worst case message size

associated with current air/air technologies. The PAIRAPP and WAKE message sizes are assumed to be the same as the ADS-B message size. While the PAIRAPP service uses a subset of the types of fields used in an ADS-B message, the required resolution of the data (e.g. position resolution) is larger. It is understood that this is a coarse estimate of the required message size; however, the PAIRAPP service is a new service and additional study work needs to be completed in order to refine the required message size. The AIRSEP message size is assumed to be a derivative of that used for the COTRAC service, since it is the air/air version of the same function. However, the quantity of information exchanged is smaller due to the smaller time horizons. The COTRAC is a complete trajectory while the AIRSEP only addresses the part of the trajectory needed to resolve the air-to-air conflict.

- **Service Applicability per Transmission Volume**: The ADS-B service is used in all transmission volumes. The PAIRAPP service is used in the APT and TMA transmission volumes. The AIRSEP service is only used in the AOA transmission volume.

6.5.3 Capacity Requirements

Table 6-25 and Table 6-26 provide the estimated capacity requirements for air/air communication in Phase 1 and Phase 2, respectively, assuming a single ‘channel’ is used for message transmissions.

Phase 1	**APT**	**TMA**	**ENR**	**ORP**	**AOA**
ADS-B/WAKE PIAC	250	750	1250	3	-
ADS-B/WAKE Range (nm)	5	60	200	200	-
ADS-B/WAKE MsgSize (bytes)	68	68	68	68	-
ADS-B/WAKE Update (mps/ac)	1	0.167	0.083	0.083	-
ADS-B/WAKE Latency E2E	1	6	12	12	-
ADS-B/WAKE Latency FRS	0.8	4.8	9.6	9.6	-
ADS-B/WAKE Capacity (kbps)	**170**	**85**	**70.8**	**0.161**	**-**
PAIRAPP PIAC	-	-	-	-	-
PAIRAPP MsgSize	-	-	-	-	-
PAIRAPP Update Rate (mps/ac)	-	-	-	-	-
PAIRAPP Latency E2E	-	-	-	-	-
PAIRAPP Latency FRS	-	-	-	-	-
PAIRAPP Capacity (kbps)	**-**	**-**	**-**	**-**	**-**
AIRSEP PIAC	-	-	-	-	-
AIRSEP MsgSize (bytes)	-	-	-	-	-
AIRSEP Update Rate (mps/ac)	-	-	-	-	-
AIRSEP Latency E2E	-	-	-	-	-
AIRSEP Latency FRS	-	-	-	-	-
AIRSEP Capacity (kbps)	**-**	**-**	**-**	**-**	**-**
TOTAL Capacity (kbps)	**170**	**85**	**70.8**	**0.161**	**-**

Table 6-25: Air/Air Capacity Requirements (kbps) – Phase 1

Phase 1	APT	TMA	ENR	ORP	AOA
ADS-B/WAKE PIAC	320	960	1600	14	42
ADS-B/WAKE Range (nm)	5	60	200	200	200
ADS-B/WAKE MsgSize (bytes)	68	68	68	68	68
ADS-B/WAKE Update (mps/ac)	1	0.333	0.333	0.333	0.333
ADS-B/WAKE Latency E2E	1	3	3	3	3
ADS-B/WAKE Latency FRS	0.8	2.4	2.4	2.4	2.4
ADS-B/WAKE Capacity (kbps)	**217.6**	**217.6**	**362.7**	**3.3**	**9.5**
PAIRAPP PIAC	13	62	-	-	-
PAIRAPP MsgSize	34	34	-	-	-
PAIRAPP Update Rate (mps/ac)	3.3	3.3	-	-	-
PAIRAPP Latency E2E	0.3	0.3	-	-	-
PAIRAPP Latency FRS	0.24	0.24	-	-	-
PAIRAPP Capacity (kbps)	**14.7**	**70.3**	-	-	-
AIRSEP PIAC	-	-	-	-	11
AIRSEP MsgSize (bytes)	-	-	-	-	497
AIRSEP Update Rate (mps/ac)	-	-	-	-	0.1
AIRSEP Latency E2E	-	-	-	-	10
AIRSEP Latency FRS	-	-	-	-	8
AIRSEP Capacity (kbps)	**-**	**-**	**-**	**-**	**5.7**
TOTAL Capacity (kbps)	**232.3**	**287.9**	**362.7**	**3.3**	**15**

Table 6-26: Air/Air Capacity Requirements (kbps) – Phase 2

6.5.4 Analysis of Results

The following comments apply to the air/air data loading analysis.

- As noted in the introductory paragraphs, the analysis looks at potential ***information transfer rates*** and thus does not include the impacts of transmission collisions, media access delays and/or scheduling/message overhead. For UAT, the message overhead includes synchronization and forward error correction (FEC) bits that would increase the overall message size by 76%. For 'unorganised' broadcast technologies, the collision rate increases with increasing message transmission densities. For these technologies, increasing transmission rates are met with diminishing returns. It is reasonable to assume that for these technologies the required RF transmission rates would, at least, need to be double that of the values reflected in the tables above for the higher message density transmission volumes.

7 Relationship of the results to a real world environment

7.1 Introduction

The requirements of the FRS have been derived in the above sections independently from any specific technology or geographic location. Whilst this does not constrain the choice of technology, this section provides realistic examples of how the generic requirements can be used in a practical way. The examples are not meant to be prescriptive, but just indicate how the results could be applied to estimate PIACs accounting for sector growth from Phase 1 to 2; to estimate PIACs for airspace volumes corresponding to the service volumes associated with particular technologies and to generally assess the application to modern, networked communications which might be devoid of geographic constraints. For example, one variation of this approach, not covered below, could employ PIAC distributions derived from volumes associated with existing en route sectors to allow assessment of large area volumes typically associated with satellite-based communications.

Two practical applications of the approach are documented in this chapter.

- Example One addresses application of the COCR in the ECAC
- Example Two addresses application to the U.S. NAS.

Other approaches can be adopted drawing on the raw data which were used to feed the queuing model used in the loading calculations as discussed in section 6.

7.1.1 Common Aircraft Density Calculation

In order to provide for consistency in results which could be applied anywhere in ICAO, a standard density measure was defined. Since it is expected that service volumes will still apply, even in the Phase 2 timeframe, the density was defined as -

Aircraft Density in Service Volume = Service Volume PIAC/Service Volume in nm^3

7.2 Example One (ECAC SV Density Calculations)

EUROCONTROL developed and operates a set of tools in order to assess quantitative information in support of development at Europe’s airports, on air routes and the airspace system. One such tool is System for Traffic Assignment and Analysis at a Macroscopic Level (SAAM). SAAM is an integrated system for wide or local design evaluation, analysis, and presentation of Air Traffic Airspace/TMA scenarios. Details of the SAAM tool are given in Appendix 1.

7.2.1 Modeling ECAC Airports, Terminal Areas and En route Airspace

In reviewing the SAAM results a range of PIACs were noted for the service volumes used in the model. It was identified that the sectors were of different volume and therefore the number alone did not give an indication of traffic density. Consequently the number of aircraft per unit volume was derived to compare air traffic densities.

The volume of the SAAM service volumes was calculated using the lat-long co-ordinates and height based on spherical geometry mathematics.

7.2.2 ECAC Traffic Density Process and Results

The results for the service volumes are shown in the tables below. As shown below, the SAAM tool is capable of calculating PIACs for Airport, TMA and En Route Service volumes.

Table 7-1 and Table 7-2 show the number of aircraft per unit volume of airspace at the peak time in that year – this is shown as aircraft per cubic nautical mile.

Service Volume	PIAC	Volume (NM^3)	Aircraft/NM^3
TMA LD	14	3039	0.004607
TMA HD	16	2831	0.005652
En Route LD	24	20782	0.001155
En Route HD	24	5119	0.004688

Table 7-1: Aircraft Density – Phase 1

Super Sector	PIAC	Volume (NM^3)	Aircraft/NM^3
TMA LD	39	9240	0.004221
TMA HD	44	7691	0.005721
En Route LD	59	33388	0.001767
En Route HD	45	10132	0.004441

Table 7-2 Aircraft Density in Phase 2 (Super Sectors)

7.2.3 Typical Application in a ECAC TMA

The results shown in Table 7-1 and Table 7-2 apply to a typical busy TMA sector, in this case a London TMA sector (EGTTWEL) around 2020. The sector starts around 5000 ft up to FL200. The size and shape of the sector changes with altitude. The results are therefore representative of information flowing through that test volume sector in the timeframe.

Although the study is technology independent, to illustrate how the results may be applied to assessing technology, the following figures have been produced. In practice a typical line-of-sight (LOS) communication system will have a designated operational coverage volume much larger than a sector. Typically at 5000 ft the theoretical radio horizon would be 87 NM and 194 NM at FL200 (assuming ground antenna at 0 ft).

7.2.4 Mapping the ECAC TMA Test Sector

Figure 7-1 below illustrates the test sector as part of the TMA at 5000 ft. The figure also shows a notional radio horizon based on 60% of the ideal 4/3R radio horizon centred on the test sector which may not be the case. A figure of 60% of the theoretical horizon was chosen arbitrarily to account for fading, multipath, etc. Of course the actual figure would be dependent on the particular technology e.g. link budget used, modulation schemes, etc.

At 5000 ft the figure shows the DOC (Designated Operational Coverage) of around 50 NMs. As can be seen the DOC easily covers the test sector and several others.

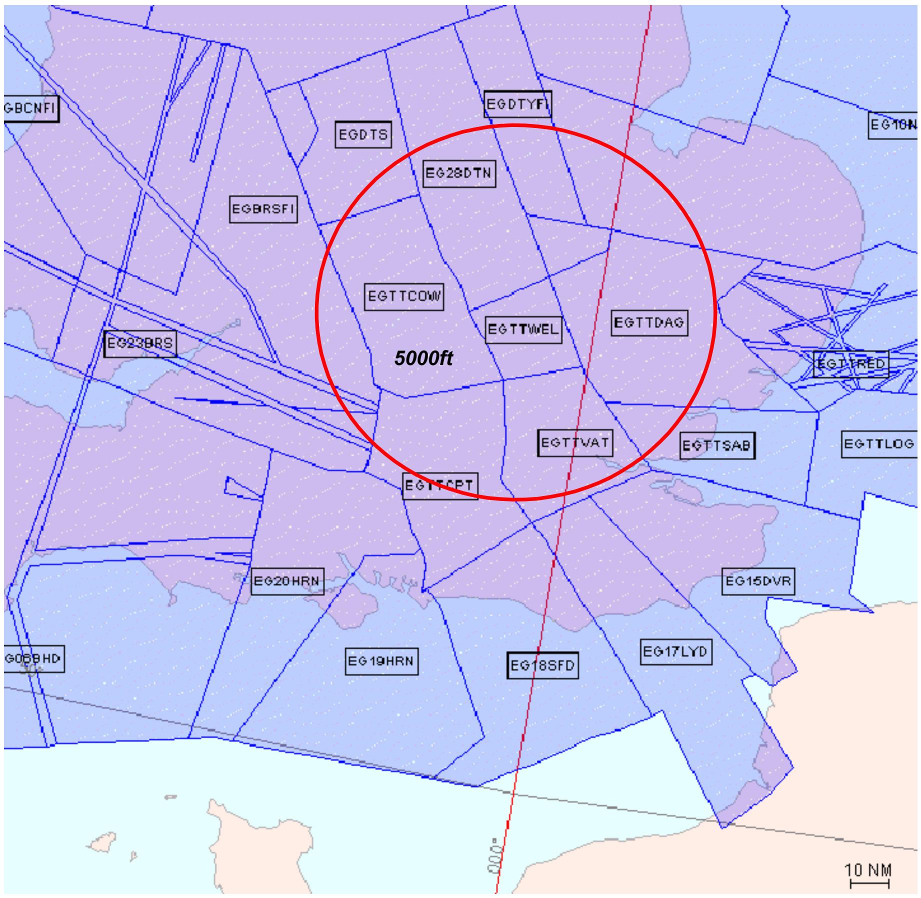


Figure 7-1: London TMA – 5000ft

Figure 7-2 below illustrates the sector as part of the TMA at FL200. The figure also shows a notional radio horizon based on 60% of the theoretical radio horizon.

It can be seen that the sector is now much larger however the DOC is very large and covers many other sectors. Around 14 sectors are within the coverage area of the LOS system.

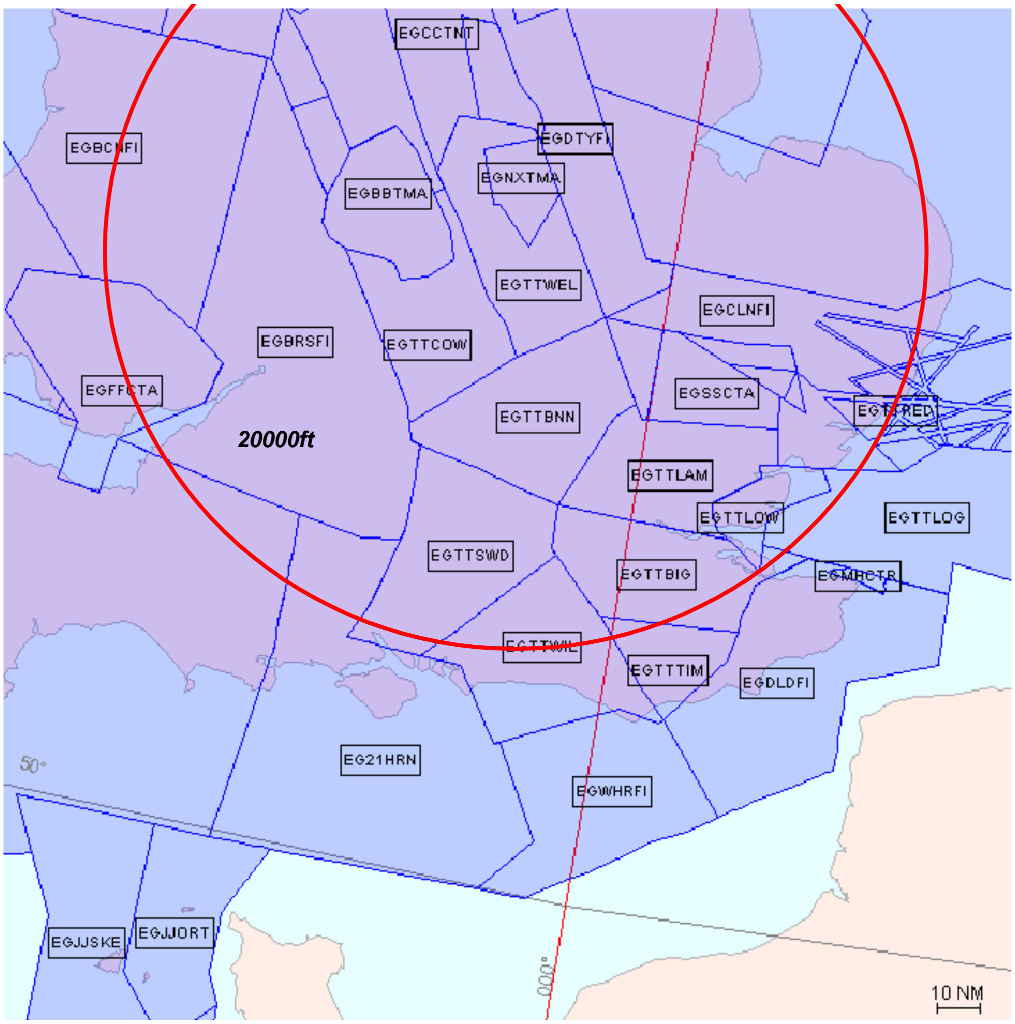


Figure 7-2: London TMA – FL200

Assuming around 6 sectors were supported within the DOC of a communication system then the worst case capacity needed would be 6 times that identified in the TMA results, however the loading analysis is not linear.

7.2.5 ECAC Super Sector Density Calculation

The density number of the EGTTWEL test sector can be used to estimate the PIAC for the volume corresponding to several TMA sectors. The real PIAC for EGTTWEL and two adjacent sectors was calculated using SAAM and compared with the approach of applying the density number of EGTTWEL to the volume of the 3 sectors. It was found that the resulting PIAC numbers are similar, as long as the density numbers are used for the same type of sector (high density TMA, low density TMA, high density En Route, low density En Rroute).

The results obtained for the test sector need to be applied to a different airspace volume dependant on the technology considered.

7.3 Example Two (U. S. NAS En route SV Density Calculation)

The NAS example was limited in that only en route modelling was available. Therefore NAS results shown below are strictly for the En route domain.

7.3.1 Modeling NAS En route

The results for the NAS were derived from an analysis of all existing en route control sectors using 2004 FAA benchmark demand as applied within the Mid Level Model (MLM). The traffic was grown across NAS en route sectors using existing Terminal Area Forecast (TAF) based demand scenarios. U. S. modellers performed runs of existing MLM scenarios for 2004, 2013, 2020 and then used regression analysis to obtain a 2030 PIAC distribution. The distributions developed are shown in Table 7-3 and Table 7-4.

Service Volume	PIAC	Volume (NM^3)	Aircraft/NM^3
TMA LD	14	3039	0.004607
THM HD	16	2831	0.005652
En Route LD	24	20782	0.001155
En Route HD	24	5119	0.004688

Table 7-3 Phase 1 NAS En Route Sector PIAC Distribution

Super Sector	PIAC	Volume (NM^3)	Aircraft/NM^3
TMA LD	39	9240	0.004221
TMA HD	44	7691	0.005721
En Route LD	59	33388	0.001767
En Route HD	45	10132	0.004441

Table 7-4 Phase 2 NAS En Route Sector PIAC Distribution

7.3.2 NAS Traffic Density Process and Results

A similar process to that outlined above for the ECAC was used to achieve aircraft density. The en route HD sectors for Phase 1 and 2 were identified by picking the sector with the highest PIAC from Figures 7-3 and 7-4 distributions. Atlanta Centre en route arrival sector 19 was chosen. Using an FAA tool, the spatial co-ordinates and lower and upper altitude floors of the HD sector were obtained. From this information, the volume and density of Sector 19 was calculated based on spherical geometry mathematics as in the ECAC calculation. Results are contained in Table 7-5 below.

Sector Name	PIAC	Volume (nm^3)	Aircraft per nm^3
En route HD (ZTL 019)	41	7300	0.0056

Table 7-5 Phase 1 NAS En Route Sector Density Calculation

7.3.3 NAS Super Sector Density Calculation.

Sectors typical of 2030 operations are expected to be on the order of three times larger than current sectors. Since PIACs are not necessarily proportional to volume, separate PIACs for these 'Super Sectors' were developed. Direct interpretation of Table 7-3, and underlying data, showed a maximum sector PIAC of 52 aircraft in the Atlanta Centre sector ZTL019. This was identified as the NAS en route HD sector for Phase 2. Adjacent sectors to the en route HD sector were chosen from those closest horizontally and vertically. The result was ZTL 016 and 020. These three sectors are actual en route arrival sectors feeding the Atlanta Hartsfield Airport. Aggregating these three sectors resulted in an approximation of a sector three times the size of today's sectors. The 2030 PIACs for these sectors were obtained from the results shown in Figure 7-4. The following formulas were used to aggregate the three sectors.

ZTL 016 PIAC + ZTL 19 PIAC + ZTL 20 PIAC = HD Super Sector PIAC

ZTL016 volume + ZTL019 volume + ZTL020 volume = HD Super Sector Volume

Using these formulas, an aggregate PIAC of 95 and Volume of 31,996 nm^3 was obtained for a 2030 HD Super Sector. Table 7-6 below shows the results.

Sector Name	PIAC	Volume (nm^3)	Aircraft per nm^3
En route (ZTL 16)	22	9816	0.0022
En route HD (ZTL 19)	52	7300	0.0071
En route (ZTL 20)	21	14880	0.0014
Super Sector	95	31996	0.0029

Table 7-6 Phase 2 NAS En Route Super Sector Density Calculation

7.3.4 Mapping the NAS En route Super Sector

The selected HD Super Sector is highlighted on a map of NAS en route sectors in Figure 7-3. Figure 7-4 and Figure 7-5 show additional detail on the three sectors aggregated to represent the 2030 HD Super Sector.

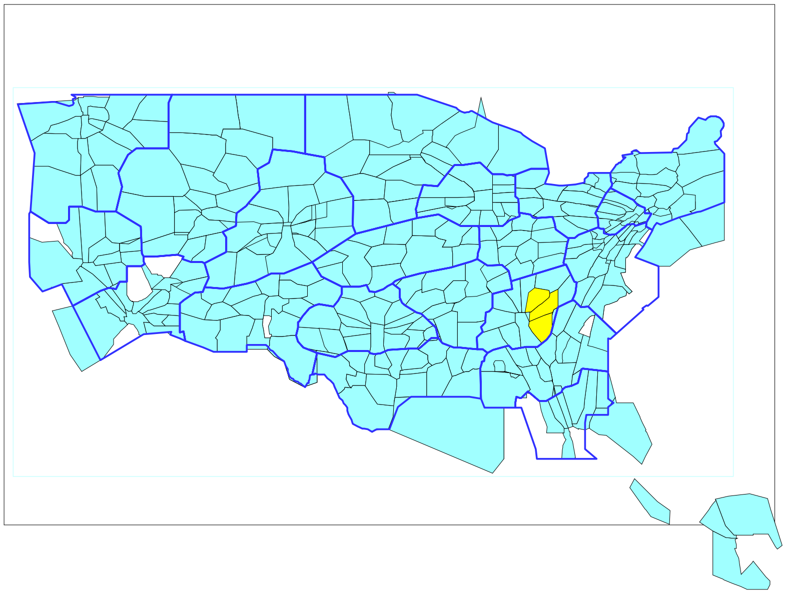


Figure 7-3: NAS En route Sectors

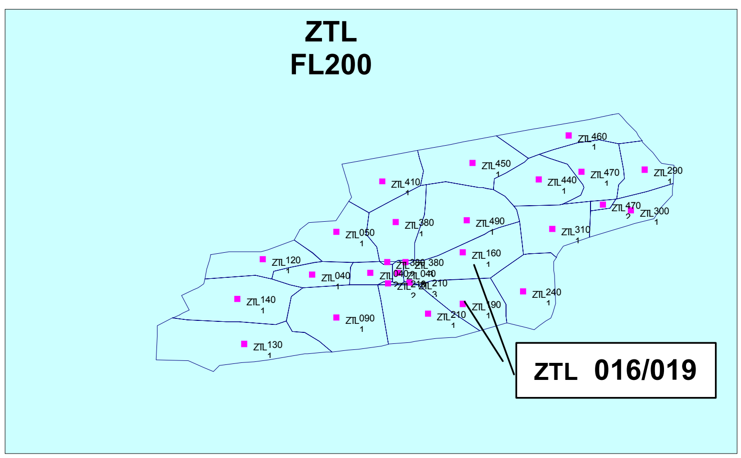


Figure 7-4: NAS 2005 En route Sectors ZTL 016 and 019

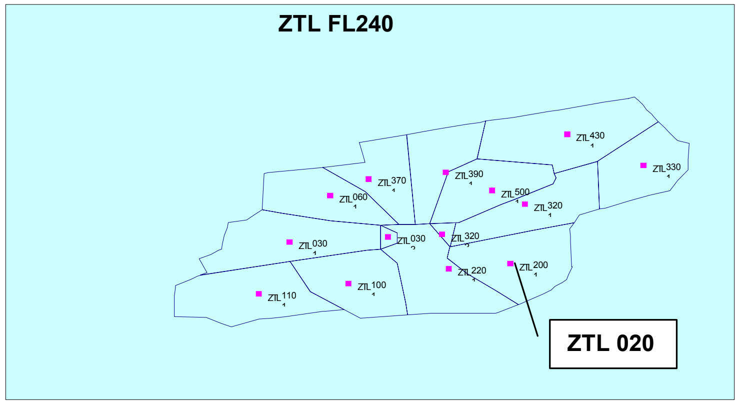


Figure 7-5: NAS 2005 En route Sector ZTL 020

8 Summary

8.1 Background

Communications are a critical component of air traffic management. Existing voice and data communications are becoming a systemic bottleneck, constraining capacity, security and safety improvements. Various proposals have been offered to address these communications-based constraints, but none has achieved global endorsement. The ICAO Aeronautical Communications Panel (ACP), as part of its work programme, is reviewing new communication technologies as potential future global solutions to the aviation communications issues. In support of the ACP work, EUROCONTROL and the FAA, with assistance from NASA, have established Cooperative Research and Development Action Plan 17, consisting of a three year study of future aviation communications. Objectives of this Future Communications Study include assessment of required capacity, development of realistic transition plans, definition of Air Traffic and Aeronautical Operational services, analysis of spectrum depletion and advanced avionics investigation.

This document, the Communications Operating Concept and Requirements (COCR), is a component of the Future Communications Study, and has three primary goals:

- to develop international understanding of air traffic management concepts and services which the future aviation communications system should support, based on future strategy documents,
- to document fundamental Future Radio System requirements, to facilitate subsequent FCS technology assessments
- to support ANSPs iterative process of operational service selection, by identifying the full range of services to choose from to begin safety, cost/benefit or other analyses

8.2 Process

To achieve the goals established for the COCR, a seven step process was employed. Initially, to determine the overall context for future communications, numerous Concepts of Operations, Vision Statements and Plans being developed and circulated by ANSPs around the world were reviewed. The first step was complete when a notional vision and universal operating concepts for air traffic management were developed. Identification and definition of Air Traffic Services and Aeronautical Operational Control services that would be necessary to achieve the vision comprised the second step. The operating environment, in which these services would be provided was then defined to ensure all implications of each service were addressed. Step four consisted of safety and security assessments for the air traffic services, which enabled step five's establishment of high-level requirements each service would have to meet (so that the specified outcome or benefit of the service could be achieved safely and efficiently) and allocation of those requirements to the Future Radio System. Next, the voice and data capacity the FRS would require in order to deliver the services was calculated. By walking through a few sample applications of the previous results, the seventh and final step attempted to put the COCR effort into perspective and facilitate future use.

8.2.1 Operational Concepts

A requirement driven approach was taken based on possible operational concepts in the 2020 to 2030 and beyond timeframe. This required the review of future concepts, some of which are immature. In some cases it was necessary to use expert opinion to define some ATS services and how they would be used. The associated communications operating concept and requirements, contained in this document, have been drawn from these concepts. Any change in the concepts will affect the results.

The scope of this document covers all air/ground and air/air communications services to support the operational ATS services including ASAS as well as future AOC services to the extent information was available.

Key points in the ATS concepts considered include:

- ASAS Operations are implemented in some airspace beginning in Phase 1, leading to Autonomous Operations in Phase 2.
- Larger sectors were assumed in Phase 2 and become more dynamic in managed airspace.
- Air Traffic Management begins using 4-D trajectory - based operations in managed airspace.
- Automation becomes available to both ground and air users enabling longer range conflict resolution. "Machine-to-Machine" information exchanges replace many Human-to-Human exchanges.
- The controller's role is transformed from a control to a management paradigm through various decision support tools.

8.2.2 Operational Services

The operating concept anticipates future ATM advancement occurring in two distinct phases. Phase 1 is near-term and characterised by step-wise enhancement of current air traffic control philosophy that would be enabled by ATS data communications. Longer-term Phase 2 represents the dawning of a new era, where many of the present constraints are overcome by technological and procedural advances. The different demands associated with airport, arrival/departure and continental/over-water cruise operations will ensure that the current distinction between airport, terminal, en route and oceanic domains remain important in definition of services and requirements.

Having defined the operational vision for each phase and domain, the ATS and AOC services necessary to achieve the vision were defined. The literature search revealed the ANSPs are anticipating a large number of services, and the definitions of many were well underway. The genesis of many of the ATS services can be traced to EUROCONTROL's rapid pace of data link trials and aggressive project timelines. Around 26 operational services were defined for full deployment under Phase 1, a number of which are expected to be effectively supported only by data. While most of the Phase 1 services remain available in Phase 2, instances of many of the 30 services in this phase are dramatically reduced as 4D trajectory negotiation via COTRAC and ‘Management by Exception’ becomes the rule.

Twenty two AOC data services are defined, but rather than sorting them into phases, it has been assumed all services would be available in each phase, with varying degrees of usage. Voice AOC services have been addressed superficially as it is considered that they will decline considerably over the next 10 to 20 years.

Key Points in the definition of the operational services include:

- Some services can only be effectively delivered by data, including those that have extensive or complicated data streams, such as 4-D trajectories, or would generate high workload due to repetition. In addition, elements of some services, such as tactical communications requiring near-immediate reaction, may only be effectively administered by voice. Many of the services, however, may be delivered by either means, such that workload or communications resource costs may be deciding factors.
- Use of services will vary over time: as new services emerge, use of some other services would diminish, or could be replaced altogether. Some services may require alternate means, and while infrequently used, their availability may be required nonetheless.
- While numerous services are described for each Phase, the entire set of services is not required, or even suggested, as necessary to achieve the objectives of either Phase depending on the regional or state requirements.
- Some services identified under Phase 1 are already being implemented in some regions of the world.

Given the complexity of some the services in Phase 2 it is anticipated that many states will initiate the transition to Phase 2 only after the capacity or efficiency gains engendered by Phase 1 services are insufficient. Therefore the timeframes associated with Phase 2 will be both uniquely associated with the circumstances of each state’s or region’s needs and are difficult to forecast. Given the typical investment cycles of commercial aviation, however, an FRS capable of supporting Phase 2 should be available in the 2020-2025 timeframe to support the most progressive early-adopters.

8.2.3 Operational Safety and Information Security

Safety and security requirements have an impact on the overall communications performance. To the maximum extent possible, these have been considered in compiling this document. Both safety and security were considered on an end-to-end basis. The relevant requirements were then allocated to the FRS.

Key Results of the Safety assessments include:

- The primary effect of the safety assessment was on parameters such as availability and integrity in the Phase 2 timeframe. In an environment where separation standards are reduced, ground and airborne systems must have the capability to detect conflicts, provide resolutions, and in rare cases implement the resolutions e.g. auto execution of the required manoeuvre by the aircraft, without human intervention. This places considerable demands on the communications systems. However work is required to complete detailed safety, security and performance analyses for each service and to refine the associated message sizes and/or sequences.

Safety requirements are extremely sensitive to the service definitions. Subtle changes in a service description can significantly alter safety assessment outcomes. Much of the safety assessment process relies upon subject matter expert judgement. As such, a full, complete and common understanding of a service and environment is required before safety-derived performance requirements can be verified and validated.

Misuse of information exchanged between ANSPs, aircraft, and users can have serious safety, efficiency and financial impact. Since keeping sensitive information out of the wrong hands, and preventing information from being misused, is especially critical to aviation, security analysis is an important source of FRS requirements. How sensitive the information is, what risks or threats are posed and how likely they are, and what damage could be inflicted, are compiled to characterise security objectives. Security requirements to be imposed on the communications system are derived from these objectives, as described in Section 4.3.

Key Findings of the Information Security analysis include:

- The security requirements were undertaken on an end-to-end basis and therefore many of the security requirements are beyond outside the scope of the FRS. One security requirement that is directly relevant to the FRS is the need for some level of deliberate RF interference resistance.
- The FRS should have the ability to use message security features, such as message authentication, as needed to ensure safe delivery of services that require high integrity messaging.

8.2.4 Operational Performance Requirements

The FRS technology selection, system design and implementation will, to a great degree, be driven by the performance requirements allocated to the FRS. Most significant of these performance requirements are availability, integrity and latency. In addition, as information security attributes are both difficult and expensive to implement as augmentations to a system, the ability of a technology to provide information security must also be addressed. For each data service, the severity of the worst-case operational hazard was determined under two cases: a data integrity failure, and a loss of service failure. These two assessments generated the Service Level Operational Hazard Severity classifications. In addition, the safety and business interest impact of the information associated with each service being intercepted, redirected, or replaced was evaluated to determine the Service Level Confidentiality classification. Finally, the largest latency (message delay) that could be tolerated during delivery of a service was derived.

Since the Service Level Operational Hazard and Confidentiality classifications and the Service Latencies are determined by examining the conduct and delivery of the service, they establish how strong the whole chain of components in the service delivery thread has to be. The FRS is but one link in the chain, which would include automation, other ground systems and networks, other airborne systems and networks, etc. So, the next step was to decide what portions of these Service Level requirements would have to be met by the FRS. Allocated latency, integrity and availability requirements were derived using assumptions described in Section 5.4. Finally, classes of communications services were established to group together services that shared similar allocated performance requirements.

Performance requirements for Voice services were developed with a more direct approach. Since the Operating Concept envisioned the voice function would support the same types of services presently offered (but perhaps in lesser quantities), the performance requirements (call establishment, latency, availability and confidentiality) were derived from existing voice system requirements documents.

The most stringent FRS Allocated data requirements are highlighted in Table 8-1 below.

Service & Phase	Service Type	Confidentiality	Latency (sec)					Integrity FRS	Availability Of Provision FRS
			APT	TMA	ENR	ORP	AOA		
ATS Phase 1	Broadcast	Medium	0.8	4.8	9.6	9.6	-	5E-06	0.9965
	Addressed	Medium	3.8	3.8	3.8	26.5	-	5E-06	0.9965
ATS Phase 2	Broadcast	Medium	0.8	2.4	2.4	2.4	2.4	1E-06	1-(5.0E-6)
	Addressed	Medium	1.4	0.74	0.74	0.74	1.4	5E-10	1-(5.0E-8)
AOC 1+2	-	Medium	13.60	13.60	13.60	26.50	26.5	5.0E-8	1-(5.0E-5)

Table 8-1 Most stringent FRS Allocated data requirements

ATS services that generate stringent requirements, which might merit further consideration, include:

- D-ALERT drives ATS Phase 1 confidentiality
- A-EXEC drives ATS Phase 2 integrity and availability
- PAIRAPP and A-EXEC drive ATS Phase 2 latency
- ADS-B and TIS-B drive broadcast performance requirements

The FRS Voice requirements identified are shown in Table 8-2 below.

Service Type	Party-line								Broadcast
Domain	APT		TMA		ENR		ORP		ALL
Density	HD	LD	HD	LD	HD	LD	HD	LD	ALL
Call Establishment Delay	50 ms	100 ms	50 ms	100 ms	50 ms	200 ms	200 ms	20 s	20 s
Voice Latency	250 ms	350 ms	250 ms	350 ms	250 ms	485 ms	485 ms	485 ms	485 ms
A_P	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.99999	0.999
A_U	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.99998	0.998

Table 8-2: Voice Performance Requirements (ATS) – Phase 1 & 2

Some considerations to take into account when evaluating these operational requirements include:

- Assumptions of the role the FRS plays in the whole service ‘chain’ have a significant impact on the calculation of allocated requirements.
- The performance requirements are, to the extent possible, independent of any specific technology. In addition, every effort was made to constrain the performance requirements to the operational context. However, it may prove impossible to develop performance requirements that are both useful and completely without technological footing. The operational performance requirements documented herein should form the basis of performance requirements that are appropriate and tailored for the technologies to be considered.
- Similarly, the performance requirements reflect the current understanding of the services, and one perspective on the most basic of architectural (non-technological) assumptions. For example, the availability requirements allocated to the FRS for each service take into account the role data plays in delivering that service. For services where the hazard associated with loss of data connectivity can be mitigated by voice connectivity (e.g. for some of Phase 1 services), the FRS data availability allocation was determined assuming voice redundancy. This is valid as long as voice availability is not linked to data availability, as would be the case with an FRS that employed separate voice and data systems. If the linkage between voice and data availability were not independent, the FRS data availability allocation would necessarily be different (e.g. more stringent). This is reflected in some of the quality of service requirements under Phase 2.
- Phase 2 includes that set of services that enable the paradigm shift to 4D trajectory management as well as management by exception. Since this paradigm shift may not happen simultaneously throughout the airspace, Phase 1 services will probably co-exist with Phase 2 for an extended period of time. While Phase 2 services may be offered by an ANSP, other airspace may never merit introduction of more than a select set of Phase 1 services. For these reasons, an FRS that supports Phase 2 requirements must also support Phase 1 requirements.

8.2.5 Communications Loading and Capacity Requirements

Three distinct processes were employed to determine the communications loading, and thus the required capacities, of the FRS and are summarised in the following sections.

8.2.5.1 Air/Ground Data Capacity Requirements

The capacity required to support air/ground data communications was calculated for each Phase and Service Volume using the following process:

- Service Volumes were defined for each operational domain.
- Instances of messaging needed to deliver each service were estimated by domain, accounting for the number & type of aircraft served, data equipage and usage rates, flight durations, message interactions and flows, and other factors.
- Message sizes were estimated.
- Peak instantaneous aircraft counts (PIACs) for each service volume were determined using models for anticipated traffic growth.
- A queuing model was developed to estimate channel capacity (in kbps) required to ensure messages were delivered to all aircraft in accordance with each service's latency requirements.

Using the queuing model discussed above the resulting communication capacities to meet the requirements with the volume of traffic generated for Phase 1 and Phase 2 are shown in Table 8-3 and Table 8-4 below.

PHASE 1		**APT SV**		**TMA SV**		**ENR SV**			**ORP SV**	
		HD	**LD**	**HD**	**LD**	**HD EU**	**HD US**	**LD**	**HD**	**LD**
Separate ATS	**UL**	4.0	1.2	2.3	2.2	1.2	1.5	1.2	0.3	0.3
	DL	4.3	1.9	4.1	3.9	3.7	4.9	3.7	2.7	2.2
	UL&DL	7.4	2.0	5.3	5.0	4.1	5.6	4.1	2.8	2.2
Separate AOC	**UL**	15.6	2.7	0.3	0.3	8.6	11.9	8.6	3.3	2.8
	DL	3.5	0.7	0.8	0.8	0.8	1.3	0.8	0.4	0.3
	UL&DL	19.9	2.9	0.8	0.8	9.1	13.8	9.1	3.3	2.8
Combined ATS&AOC	**UL**	18.4	2.9	2.3	2.2	9.0	12.7	8.9	3.3	2.8
	DL	6.7	2.0	4.3	4.1	3.8	5.2	3.8	2.7	2.2
	UL&DL	25.5	3.3	5.6	5.3	11.4	17.7	11.3	4.5	3.4

Table 8-3: Air/Ground Capacity Requirements (kbps) – Phase 1

PHASE 2		APT SV		TMA SV		ENR SV			ORP SV		AOA
		HD	LD	HD	LD	HD EU	HD US	LD	HD	LD	
Separate ATS	UL	12.8	7.1	22.0	22.2	20.9	22.4	21.0	19.8	19.6	7.1
	DL	11.3	5.2	10.3	10.7	9.8	13.5	10.5	8.9	8.7	13.3
	UL&DL	19.6	7.3	24.5	25.1	23.5	27.0	24.0	20.3	19.9	13.6
Separate AOC	UL	113.0	14.1	0.3	0.2	52.4	96.1	64.1	24.0	18.2	56.2
	DL	6.7	1.2	2.4	2.2	1.4	2.7	1.8	0.6	0.4	1.1
	UL&DL	131.2	14.1	2.6	2.3	58.6	106.9	72.6	24.4	18.2	62.8
Combined ATS&AOC	UL	120.0	24.6	22.0	22.2	119.1	168.3	134.8	82.1	62.8	76.7
	DL	13.4	5.4	11.1	11.8	10.2	13.9	10.9	9.0	8.8	13.4
	UL&DL	144.3	24.8	25.2	25.8	119.4	168.9	135.2	82.2	62.9	80.5

Table 8-4: Air/Ground Capacity Requirements (kbps) – Phase 2

Table 8-5 and Table 8-6 provide the estimated Phase 1 and Phase 2 capacity requirements for each aircraft using a dedicated queue.

PHASE 1		APT SV Dep	APT SV Arr	TMA SV Dep	TMA SV Arr	ENR SV	ORP SV
Separate ATS	UL	1.1	0.7	0.6	1.5	0.9	0.3
	DL	1.8	0.7	1.9	0.8	2.4	1.7
	UL&DL	1.8	0.7	2.0	1.5	2.5	1.7
Separate AOC	UL	2.4	0.2	0.2	0.2	4.3	2.4
	DL	0.3	0.3	0.3	0.3	0.3	0.3
	UL&DL	2.4	0.3	0.3	0.3	4.3	2.4
Combined ATS&AOC	UL	2.4	0.7	0.6	1.5	4.3	2.4
	DL	1.8	0.7	1.9	0.8	2.5	1.7
	UL&DL	2.4	0.7	2.0	1.5	4.3	2.5

Table 8-5 Air/Ground Capacity Requirements (kbps) for Each Aircraft using a separate 'channel' – Phase 1

PHASE 2		APT SV Dep	APT SV Arr	TMA SV Dep	TMA SV Arr	ENR SV	ORP SV	AOA
Separate ATS	UL	6.9	1.8	19.5	19.5	19.5	19.4	6.7
	DL	6.2	1.9	6.8	3.3	6.7	8.5	12.5
	UL&DL	6.9	1.9	19.7	19.5	19.5	19.5	12.5
Separate AOC	UL	9.2	0.2	0.2	0.2	20.4	12.1	12.6
	DL	0.3	0.3	0.4	0.4	0.3	0.3	0.3
	UL&DL	9.2	0.3	0.4	0.4	20.4	12.1	12.6
Combined ATS&AOC	UL	9.2	1.8	19.5	19.5	28.6	25.4	12.7
	DL	6.2	1.9	6.8	3.4	6.7	8.5	12.5
	UL&DL	9.5	1.9	19.8	19.5	28.7	25.4	17.0

Table 8-6 Air/Ground Capacity Requirements (kbps) for each aircraft using a separate 'Channel' – Phase 2

Many emerging ATS data link services were included in Phase 1. This resulted in an increased requirement for bandwidth to support the new services. The highest ATS requirements for Phase 1 occur in the TMA.

In Phase 2 for the en route and Oceanic/Remote service volumes, the A-EXEC service generated the most demanding requirements. If the service were not implemented, capacity required would be reduced. Similar reductions in Phase 1 required capacity would be achieved by reducing the repetition rates of the SAP service and the message sizes for Graphical Weather.

The increase in capacity requirements in Phase 2 for the Airport Domain can be attributed in part to increased message sizes and reduced latencies.

Little information was available on future AOC requirements and therefore many services considered were extensions of those used currently. More intense use of AOC data services will impact the results.

Some sensitivity analysis was carried out on the results and it was noted that the capacity requirements do not increase linearly with aircraft density. In some cases, the latency had the greatest effect on capacity. Under these conditions not all the capacity was used therefore doubling the aircraft to be supported did not double the capacity requirements.

8.2.5.2 Air/Air Data Capacity Requirements

An analysis of the requirements to support broadcast services such as ADS-B/TIS-B and addressed air/air communication services such as PAIRAPP and AIRSEP was carried out. The information transfer rate, in kilobits per second, associated with air-to-air data communications was calculated using the following process:

- Transmission Volumes were derived from the operational service definitions.
- PIACs for the transmission volumes were established.
- Message rates were estimated, accounting for the number and type of aircraft within the volume, equipage rates and service requirements.
- Basic assumptions about the FRS architecture were developed.
- The information transfer rate (kbps) was calculated by multiplying message rates, message sizes and PIACs.

The following table - Table 8-7 - summarizes the air-to-air capacity requirements:

Information Transfer Rate (kbps)	APT	TMA	ENR	ORP	AOA
Phase 1	170	85	71	0.161	0
Phase 2	232	288	363	3	15

Table 8-7 Summary of air to air capacity requirements (kbps)

As the COCR is technology independent, consideration was not given to transmission collision, media access delays and/or scheduling overhead.

8.2.5.3 Voice Capacity Requirements

A different approach to reviewing the data requirements was adopted for voice. Voice was considered necessary in both Phase 1 and Phase 2 but with decreasing use in Phase 2. However when voice was required it was considered to have similar requirements to current VHF radio usage. For air/ground voice communications requirements, the number of seconds of voice transmissions per hour was calculated for each domain using the following process:

- The average number and duration of voice transmissions per aircraft flight hour were estimated from existing research
- Aircraft counts and flight durations per domain, as developed for A/G data calculations, were carried over
- The extent to which voice transmissions would be reduced by data communications was estimated using equipage estimates and existing literature
- The seconds of voice per hour (by domain) was then computed by multiplication

The voice capacity requirements, in seconds of voice communications per hour, are summarized in Table 8-8 below. It should be noted that for comparison in en route high density airspace two values have been calculated; one for Europe and one for the U.S.

Voice Communications secs/hr/position	APT		TMA		ENR			ORP	
	HD	LD	HD	LD	HD-NAS	HD-ECAC	LD	HD	LD
Phase 1	3154	1109	2302	1294	3493	2044	1533	34	17
Phase 1 occupancy	88%	31%	64%	36%	97%	57%	43%	1%	0%
Phase 2	1819	659	3140	1788	505	239	251	3	2
Phase 2 occupancy	51%	18%	87%	50%	14%	7%	7%	0%	0%

Table 8-8 Voice Capacity Requirements

The occupancy rows indicate what percentage of today's voice channel would be used by controller or pilot communications. This analysis indicates that the capacity of current technologies would prove adequate provided that data link equipage levels meet the stated expectations especially in the APT and TMA domains. The required voice capacities in the ENR and ORP domains are significantly reduced with the expected data link equipage rates.

8.3 Other Considerations

8.3.1 Air Traffic Growth

An important factor in the analysis of communication requirements was the density of aircraft. Airspace models for Europe and the U.S. traffic growth were used to determine numbers of aircraft over the period under consideration. Two models were used 1) EUROCONTROL SAAM and 2) the U.S. MLM. In reviewing the outputs from these models it highlighted the basic assumptions behind them. For example, it is believed that SAAM traffic growth, based on STATFOR predictions, is constrained by airport capacity and that traffic is spread over the day to handle the growth. The result is that traffic density does not grow at the rate of traffic growth.

The MLM originally took a similar approach for en-route airspace however it was modified to enable unconstrained growth of traffic. New satellite airports were included to cope with the expected traffic resulting from the NGAT concept which anticipates the introduction of thousands of microjets and UAVs into the airspace.

These two approaches resulted in two sets of complementary results with the U.S. having higher densities in Phase 2 en route airspace.

8.3.2 Queuing Model

A model was developed to determine the required capacity of the FRS to handle the traffic generated by the ATS and AOC services. A number of options for the queuing model were considered and the final option implemented used a single non-pre-emptive queue supporting ATS and AOC. ATS and AOC requirements were also determined independently. Other ways of using the raw data identified in this document can be envisaged and may be useful when reviewing specific technologies as part of the assessment process.

8.3.3 Overall

In terms of capacity, the results appear to indicate that requirements for future ATS air/ground data are relatively modest, especially when compared to the high capacities promised by future technologies. However, this problem has more than one dimension, as delivery of air traffic services requires simultaneous achievement of many, often challenging, requirements. This safety-driven combination of capacity, integrity, reliability, latency and coverage requirements have typically dictated unique solutions for aviation. Current system capabilities must be assessed to determine under what conditions Phase 1 requirements could be met, or if enhancements would be necessary. While Phase 2 requirements appear to be beyond the capabilities of systems currently deployed, numerous advanced technologies, as well as options for further evolution of today’s most capable systems, should meet all but the most demanding needs. To implement this two-phased vision affordably, careful examination of the services, especially those that drive requirements, will be necessary to balance costs and benefits.

There are a number of considerations to take into account when attempting to interpret or employ these results. These include:

- The communications loading analysis and capacity results represent the product of one set of assumptions, and while intended to be representative, should not be interpreted as the only method of determining the required throughput.
- This analysis is sensitive to a number of assumptions, and slight changes to any of several assumptions would dramatically alter the results.
- The analysis results are largely driven by the FRS allocations derived from service-based performance requirements. If subsequent safety analyses update the Service Level hazard-based requirements, the FRS allocations would require revision, and the loading results would change.
- There may be implications of the operational concepts and services that could impact communications loading. For example, sector sizes are expected to grow as the operational focus shifts from tactical control to strategic planning. Sector size growth may necessitate more dynamic sector boundaries and/or longer range communications. All of these factors could impact on these capacity results.
- Operating concepts and service definitions are not the only source of requirements for the FRS. Many other considerations will yield constraints on the FRS. For example, an institutional interest to allow air traffic management facilities to operate at greater distances from the air traffic may generate additional requirements on the FRS.

APPENDICES

APPENDIX 1.STATFOR AND SAAM OVERVIEW

A.1.1 Description of the Air Traffic Statistics and Forecast Service

The Air Traffic Statistics and Forecast (STATFOR) service was established by the EUROCONTROL Agency and has been active since 1967. The objective of the STATFOR service is to provide statistics and forecasts on air traffic in Europe and to monitor and analyse the evolution of the Air Transport Industry.

The STATFOR service of statistics and forecasts is discussed and reviewed by the STATFOR User Group, a body of European forecasting and statistics experts that meets regularly. The terms of reference of the User Group include methodological and practical aspects of statistics and forecasting as well as an exchange of views and information on the current and possible future situation of air traffic, and on activities in National Administrations, International Organizations and elsewhere in the field of statistics and forecasting.

Currently, STATFOR's two main products are monthly statistics, and an annual medium-term forecast.

A.1.2 Description of the System for Traffic Assignment and Analysis at a Macroscopic Level (SAAM)

SAAM is an integrated system for wide or local design evaluation, analysis, and presentation of Air Traffic Airspace/TMA scenarios.

Background

EUROCONTROL develops and operates a set of tools in order to assess quantitative information in support of development at Europe's airports, on air routes and the airspace system. SAAM is being used in the context of Airspace Management and Navigation activities to perform strategic traffic flow organisation, route network and airspace optimisation, analysis and presentation. These features support the development of the EUROCONTROL Airspace Strategy for the ECAC states.

SAAM can operate on an area the size of ECAC or at the detailed level of an airport, and is able to process a large quantity of data: hundreds of sectors, millions of cells, several days of traffic. It can be used for preliminary surveys, for testing and analysing various options and for preparing a scenario that can be exported to fast-time or realtime simulators. Its powerful "what if" functions associated with presentational capabilities make SAAM an ideal tool for understanding, experimenting, evaluating and presenting European Airspace proposals and future ATC concepts.

Modelling

Airspace structure design and the processing of traffic trajectories are fully mastered and linked together in SAAM. Users can create/change/design both air traffic route networks and airspace volumes. At any time full 4-D trajectories can be generated (based on traffic demand, route network, aircraft performance) and intersected with airspace volumes. By default, SAAM will choose the best trajectory option (shortest path and optimal profile performance), but operational rules can be applied such as flight level constraints (arrival, departure, cruising) and/or reserved or restricted route network segments.

In order to help optimise airspace structures, the user can request the traffic demand be optimally and automatically distributed on the structure at the lowest cost, while respecting operational rules, thus revealing structural weaknesses of airspace areas. This function makes use of advanced linear programming techniques, embedded in the SOP model and developed in the EUROCONTROL AMN Unit. SIDs and STARs can be portrayed for different cases, possibly with terrain data to help understand and improve TMA organisation.

Analysis

Different sources of data can be selected for analysis and comparisons: CFMU flight plan, imported radar data, or simply the data coming out from the SAAM modelling tools.

Many queries can be combined and applied on the 4-D traffic trajectories. For instance, the user can request flight trajectories based on departures, arrivals, route points, companies, sectors crossed, aircraft type, etc.

Various analyses can be performed on loaded airspace structures. The number of flights on route network points, route network segments, airspace volume and 3D density cells can be filtered and displayed accordingly. Graphs showing variations and comparisons of airspace load, entry rate, and conflict, for each hour of the day are easily produced. In the same manner, Controller workload graphs can be provided rapidly using a validated analytical formula. Capacity figures for newly designed sectors can be advantageously derived using the analytical formulas.

Route length extension, fuel consumption, delays, route charges, etc., can be launched independently, and results can be summarised and mixed to give a global economic indicator of a scenario.

Visualization/Presentation

The importance of visually pinpointing problems and graphically presenting possible solutions was recognised from the beginning. Therefore, SAAM is entirely built on a 2D/3D/4-D Geographical Information System (GIS) with the possibility of generating time-based animations. To add more realism, SAAM can also manage and generate stereo information (with specific hardware-like stereo glasses).

All modelling and analysis activities are integrated in this GIS platform and fully benefit from the 3D visualisation, animation and stereo. For instance a user can design a specific airspace of interest in 3D to check interaction while aircraft are flying on their 3D trajectories. Images/animations are interactively panned, zoomed, and rotated with the mouse. The camera location and/or "look at" point can be moved or linked to a flying object.

Objects such as aircraft, airspace volumes, points or lines, can be moved, set on/off, or have their graphical attributes (e.g., colour or size) smoothly changed based on time events managed through the animations. For example, this feature is commonly used to demonstrate the benefits of Flexible Use of Airspace project (FUA). Several 3D aircraft models are available and can be imported from the classical “3ds” format.

Users can add titles and bitmaps to their design. Pictures/animations can be grouped into a SAAM presentation file that can be run manually or in standalone mode. If preferred, a SAAM presentation can be recorded in a standard “avi” movie file.

APPENDIX 2.MID LEVEL MODEL DESCRIPTION

A.2.1 Introduction

Modelling is the technique of building an imitative representation of the functioning of a real or proposed system by means of the functioning of another. The key power of modelling is the ability to model the behaviour of the real system as time progresses, and study the results to gain insights into its behaviour.

Computer modelling involves the need for some sort of software to represent the proposed system. The Mid-Level-Model (MLM) is a software model of the national airspace system (NAS), developed by MITRE Corporation's Centre for Advanced Aviation systems Development (CAASD), to study system-wide effects to the NAS for specific scenarios. MLM software is data driven; the model is specified based on user-defined and default data items.

A.2.2 Discrete Event Simulation

MLM is built around the principles of discrete event simulation. Discrete event simulation requires the presence of two key factors:

- Model Software
- Mechanisms for time advance

Model Software: Model software is made up of entities. Entities are tangible elements found in the real world with respect to the system being modelled. Each identified entity exhibits a very specific functional behaviour of the system that is being modelled and plays a very specific role within the system. The aggregation of the functional behaviour of the individual entities represents the functional capability of the system as a whole.

There are two types of entities. They are:-

- Input Entity
- Permanent Entity

Input Entity: These are inputs to the modelled system and in the modelling world better referred to as "temporary entities". Input entities get very often confused with user customizable system configurable parameters (discussed below). The easiest way to recognize the input entity(ies) to a system is to identify the entity(ies) whose absence from the system will produce no insights to the working of the system. Input entities are temporary as they exist only for short durations and are only created on an as need basis and at very specific times. They cause fluctuations in the system output, especially when the system or components within the system are subject to different boundary conditions. These entities could also exhibit different types of functionality in which case the fluctuations to the system can be studied for different kinds of input.

Permanent Entity: Permanent entities exhibit specific functional behaviour within the system being modelled. They typically exist through the entire simulation run time and are created when the system comes up and are destroyed only when the system itself shuts down or at the exhaustion of the inputs. They have the unique quality of being able to facilitate or inhibit the flow of a temporary entity as the temporary entity traverses the system. To study the behaviour of a system, either permanent entities are calibrated for varying boundary conditions while maintaining constant input or permanent entities are maintained at constant values while changing the input characteristics.

System Configurable Parameters: These are parameters that are user configurable and are used to alter the default functionality or threshold of the individual entities or the system as a whole. If the software provides it, users use this capability to configure the system for different scenarios to study the similarities or fluctuations in the system output, due to the effect of the interaction between input entities and permanent entities.

In the NAS world the input entities are flights, and the permanent entities are airports, sectors, air traffic controllers (ATCs), and communications, navigation, and surveillance systems (CNS). The flights, airports, sectors, ATCs, and CNS together form the NAS system. The flight entities enter the NAS and requests the services from the permanent entities to complete the flight. Routing, weather, and traffic flow management (TFM) are functional components that affect the performance of the system as a whole by imposing specific kinds of boundary conditions on the system entities.

MLM, which models the NAS, has one input entity, the Flight entity. Flight entities have the capability to change its functional behaviour based on the type of the aircraft for the specific flight. The number of flights into MLM can also be varied. MLM implements Airport and Sector as permanent entities. Their services are requested by the flight object to complete a simulated flight. MLM provides system configuration parameters to customize routing, weather, and TFM functionality that can be used by the analyst to modify the boundary conditions of the flights, airports and sector entities for specific studies.

Time Advancing and Modelling tool: The “mechanism for time advance” is provided by the SLX environment. Time is advanced based on the next event and not based on time slicing. With the next event, the model is advanced to the time of the next significant event. Hence if nothing is going to happen in the next few minutes, SLX will move the model forward by few minutes in one go and run the first event that is scheduled for that time. Advancing time in this fashion is efficient and allows for speedy evaluations. SLX is also the modelling tool which provides a language definition and compiler capability to develop the model.

A.2.3 MLM High Level Software Architecture:

The Mid-Level-Model software architecture is an actor-based model. An actor is an entity (input or permanent) that models a very specific functional behaviour of the system. In actor-based model architecture, each actor is driven by user-supplied scripts/data that controls the behaviour of the actor. In the absence of a script or user data, the actor follows a default approach. There are three types of actors:

- Requesting Actors
- Authority Actors

- Passive Actors

Requesting Actors: These actors asks for clearance from the authority actor to execute the next executable source code step.

Authority Actors: These actors typically hold resources that need to be acquired by the requesting actor. If the resource is unavailable the requesting actor is made to wait till the resource is available. Authority actors from time to time may switch roles and become requesting actors especially if they need to obtain the resources from other actors.

Passive Actors: These actors do not hold any resources that a requesting actor or authority actor uses and is not called upon by any of the other actors to complete a instance. These actors are called by the system on a periodic basis. They are used merely for monitoring purposes and for modifying configurations when thresholds are met and for user input detection.

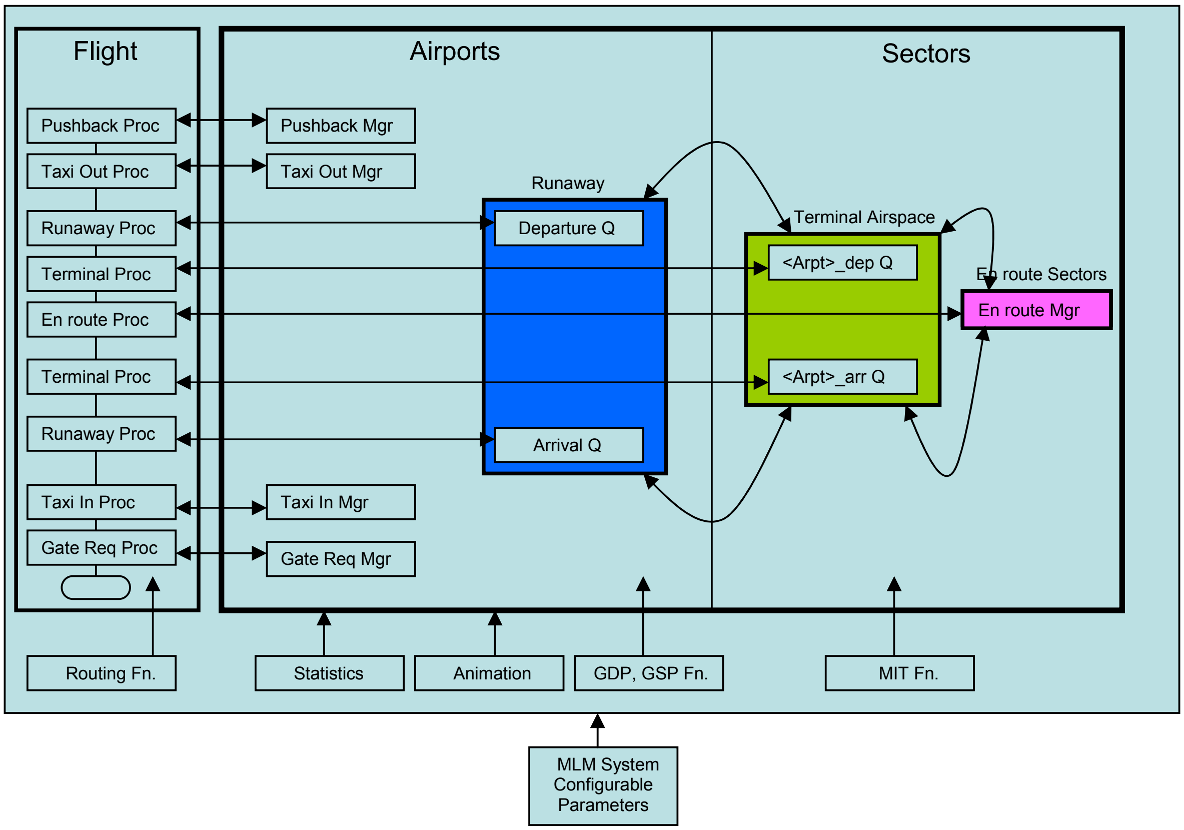
The predominant MLM actors are:

- Flight Actor – This actor is designed as a *requesting actor* and is the input entity into the system. There exists one flight actor for every flight entering the system. Sub-functionality provided by the flight actor is pushback-times and taxi-out-time.
- Airport Actor – This actor is designed as an *authority actor* and holds several key resources before a flight can traverse the system. The resources being modelled by Airport are
    - Push Back
    - Taxi Out
    - Departure Queue (Runaway)
    - Arrival Queue (Runaway)
    - Taxi In
    - Gate Clearance
- Sector Actor – This actor is designed as an *authority actor*. This actor provides clearance delivery as a flight traverses from one sector to another. There is one such actor for every defined sector in the NAS. This actor also models the following:
    - <Airport>_dep (queue modelling the departure terminal airspace for every modelled airport)
    - <Airport>_arr (queue modelling the arrival terminal airspace for every modelled airport)
- Statistics Actor – The statistics actor is a *passive actor* and its role is to collect metrics of interest as the simulation unfolds.
- Animation Actor – The animation actor is a *passive actor* and its role is to generate output for the Proof software (an external animation package) on a periodic basis with data from the model.

Figure A3-1 is an illustration of the relationship between the various actors within the MLM system as well as the functionality. As mentioned earlier, each actor can be controlled through various user supplied parameters. The box identified as “MLM

System Configuration Parameters" is ***not an actor***, but is merely a file which is read in by MLM and sets the input and output specifications.

Figure A3-1 - MLM High Level Software Architecture



A.2.4 MLM Applied to the COCR

The role of MLM in development of the COCR is two-fold:

a. Provide a crosscheck of Peak Instantaneous Aircraft Counts (PIACs) as derived by the Eurocontrol SAAM Model.
b. Provide PIACs for the U. S. NAS for specific milestones in the 2004-2030 timeframe.

The process followed mirrors that of the SAAM tool, however, the goal was primarily to obtain PIACs only for en route, as Oceanic, Terminal and Surface results will require MLM adaptation beyond the scope of expected work on COCR v1.0.

We asked the MLM modellers to perform runs of existing scenarios for 2004, 2013, 2020 and then to use regression analysis for 2030 PIACs. What was achieved was a distribution of en route PIACs for all NAS sectors, from which a maximum sector PIAC could be identified. While doing so, it became apparent that, in the longer term, the primary European concept to dealing with increased demand was to spread the additional traffic out across the day. In the U. S., the concept is to move the additional traffic to satellite airports. This is consistent with the Joint Program Development Office Next Generation Air Transportation System (NGATS) vision.

U. S. concepts also include the addition of thousands of Micro jets and Unmanned Aerial Systems.
NAS sectors are based upon strict geographic control principles. It is expected that PIACs obtained through this process would become the basis for determining capacity of future, larger sized sectors.

MLM Results were consistent with SAAM results in the en route service domain through 2020, but differ significantly after 2020. It was therefore felt that the COCR should reflect both sets of results.

APPENDIX 3. QUEUING MODEL DESCRIPTION

A.3.1 INTRODUCTION

This appendix describes the priority queuing analysis used to calculate the required channel capacities for the Future Radio System (FRS) based on the end-to-end delay requirements defined in the Future Communications Study (FCS) Communications Operating Concepts and Requirements (COCR) document.

The priority queuing analysis is a technique for estimating channel capacity to meet the end-to-end delay requirements for a given message and aircraft traffic loads. Priority queuing analysis may not take into account the details of the network protocols and the technical implementations of the FRS. The accuracy of the results depends on the assumptions built into the model and the inputs to the model.

This appendix is organized as follows:

- Section A3.1 Introduction
- Section A3.2 Data Channel Capacity Requirement Analysis Process and Inputs: This section describes data channel capacity requirement analysis process, inputs, and some assumptions made in the analysis.
- Section A3.3 Data Channel Capacity Priority Queuing Analysis: This section describes the priority queuing models and the analysis process.
- Section A3.4 Priority Queuing Analysis Basics: This section presents the basics of priority queuing analysis.

A.3.2 DATA CHANNEL CAPACITY REQUIREMENT ANALYSIS PROCESS AND INPUTS

Overview

Figure A3.2-1 gives an overview of the service volume data channel capacity requirement analysis process. It consists of inputs that define the problem, a process for solving the problem, and the desired output.

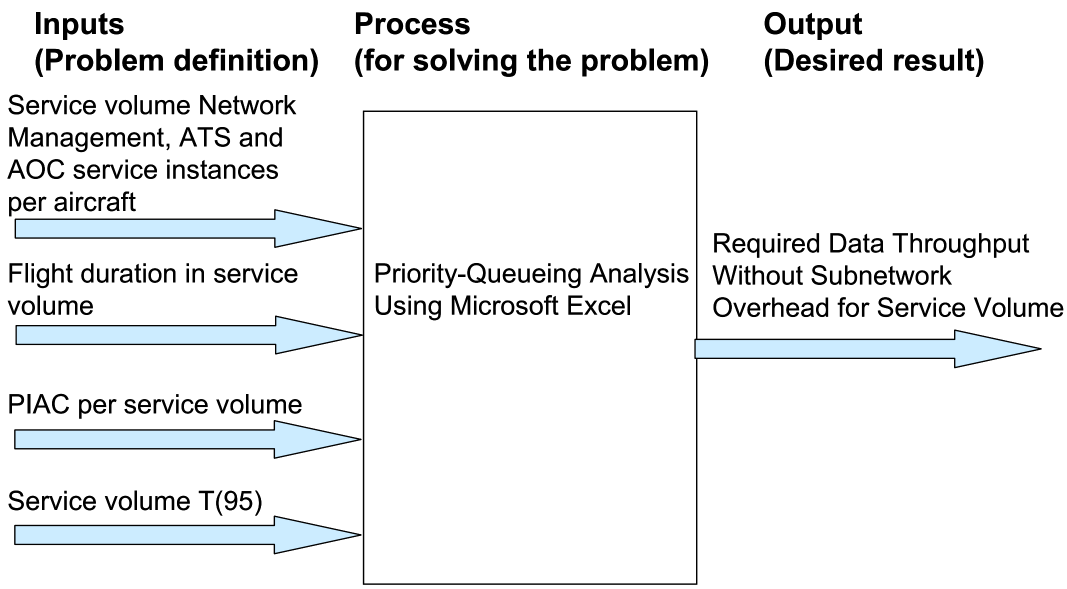


Figure A3.2-1. An Overview of Service Volume Data Channel Requirement Analysis Process

As seen in Figure A3.2-1, there are 4 inputs that define the problem:

1. The service volume Air Traffic Service (ATS) and Aeronautical Operational Communications (AOC) message traffic between each pair of aircraft and ground systems
2. Average flight duration in service volume
3. Peak Instantaneous Aircraft Count (PIAC) in each service volume
4. The Required Communications Technical Performance (RCTP) for the messages, i.e., 95^{th} percentile FRS end-to-end delay TT(95)

A3.2.1 ATS and AOC Traffic

The ATS and AOC traffic describe the statistics for each application service in a service volume including uplink and downlink message sizes and service instances.

A3.2.2 Flight Duration in Each Position/Sector

Flight durations apply to both low and high-density positions/sectors and to arrival and departure phases of flight. Flights durations are used with service instances to derive the message arrival rates that are used in the requirement analysis.

A3.2.3 PIACs

PIACs in each high and low-density service volume (position/sector) in each domain have been used in accordance with the selected values in the main document. PIACs are used with the per aircraft message traffic defined in the data loading tables to derive the total message traffic in a service volume.

A3.2.4 Data Link Equipage

The PIAC represents the maximum number of aircraft in a position/sector. Of this number, a percentage of aircraft is equipped for data link service. This percentage multiplied by the PIAC would represent the maximum number of aircraft that use the data link service in a position/sector.

A3.2.5 Percentage Departure

In the airport and TMA domains, a distinction is made between departing and arriving aircraft because they may use different data link services and have different service instances. In the analysis process, it is assumed that a certain percentage of data link equipped aircraft are departure aircraft and the remainder arriving aircraft. The mix of departing and arriving aircraft produces the aggregate data traffic for a position/sector.

A.3.3 DATA CHANNEL CAPACITY PRIORITY QUEUING ANALYSIS

A3.3.1 Definitions

The following are the definitions and descriptions of most of the symbols used in this section.

Symbol	**Definition/Description**
ATS	Air Traffic Service
AOC	Aeronautical Operational Control
λ_{AGi}	Message arrival rate Air-to-Ground for priority i
λ_{GAi}	Message arrival rate Ground-to-Air for priority i
λ_{GAAGi}	Message arrival rate Ground-to-Air and Air-to-Ground for priority i
ULD Msg	Departure-aircraft UpLink Message size for a given priority
ULD λ	Departure-aircraft UpLink message arrival rate per aircraft for a given priority
ULD λ_T	Departure-aircraft UpLink message arrival rate for a service volume (position/sector) for a given priority
DLD Msg	Departure-aircraft DownLink Message size for a given priority
DLD λ	Departure-aircraft DownLink message arrival rate per aircraft for a given priority
DLD λ_T	Departure-aircraft DownLink message arrival rate for a service volume (position/sector) for a given priority
ULA Msg	Arrival-aircraft UpLink Message size for a given priority
ULA λ	Arrival-aircraft UpLink message arrival rate per aircraft for a given priority
ULA λ_T	Arrival-aircraft UpLink message arrival rate for a service volume (position/sector) for a given priority
DLA Msg	Arrival-aircraft DownLink Message size for a given priority
DLA λ	Arrival-aircraft DownLink message arrival rate per aircraft for a given priority
DLA λ_T	Arrival-aircraft DownLink message arrival rate for a service volume (position/sector) for a given priority
S_iMsg	Service i Message size for a given priority
S_iI	Service i Instance for a given priority
Msg	Aggregate message size for a given priority

I	Aggregate instance for a given priority
λ	Message arrival rate for a given priority
UL Msg	UpLink Message size for mixed departure and arrival for a given priority
UL λ_T	UpLink message arrival rate for mixed departure and arrival for a service volume (position/sector) for a given priority
DL Msg	DownLink Message size for mixed departure and arrival for a given priority
DL λ_T	DownLink message arrival rate for mixed departure and arrival for a service volume (position/sector) for a given priority
Msg_T	Aggregate uplink and downlink Message size for mixed departure and arrival for a given priority
λ_T	Aggregate uplink and downlink message arrival rate for mixed departure and arrival for a service volume (position/sector) for a given priority

A3.3.2 Priority Queuing Analysis Models

This section presents the queuing analysis models used to obtain the results.

A3.3.2.1 ATS and AOC Traffic on the Same Channel

In this set of models, ATS and AOC traffic share 1 single queue. 2 separate models were developed ─ separate channels for uplink and downlink traffic and shared channel for uplink and downlink traffic. Figure A3.3-1 shows the first model that uses 2 separate channels for ATS and AOC traffic ─ 1 uplink and 1 downlink.

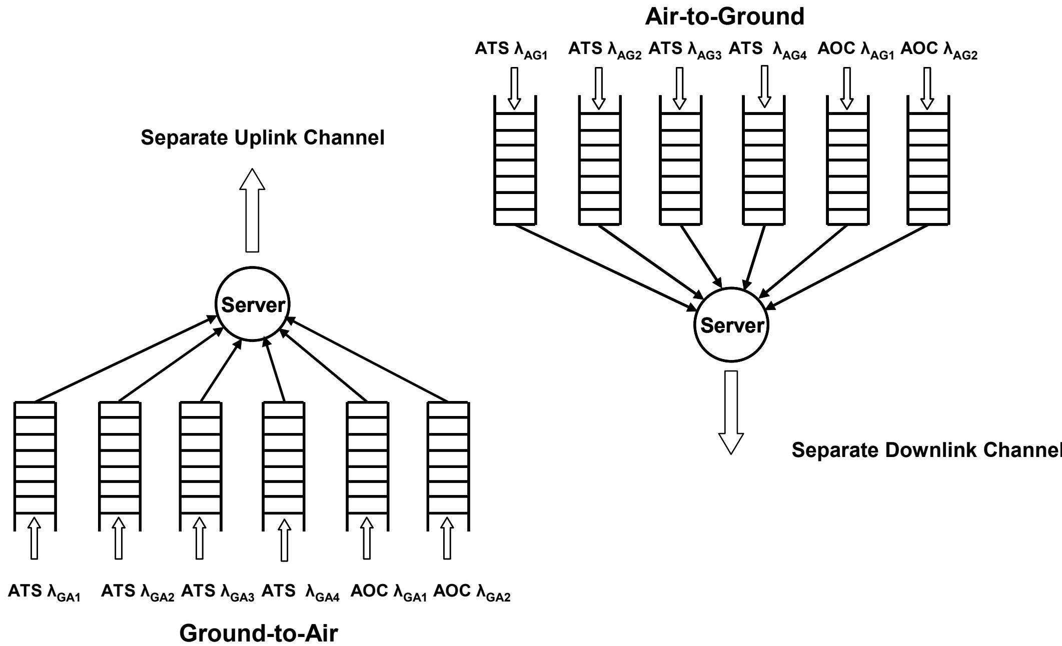


Figure A3.3-1. Combined ATS and AOC Traffic Separate Uplink and Downlink Channels

Figure A3.3-2 shows the second model that uses 1 channel for uplink and downlink ATS and AOC traffic.

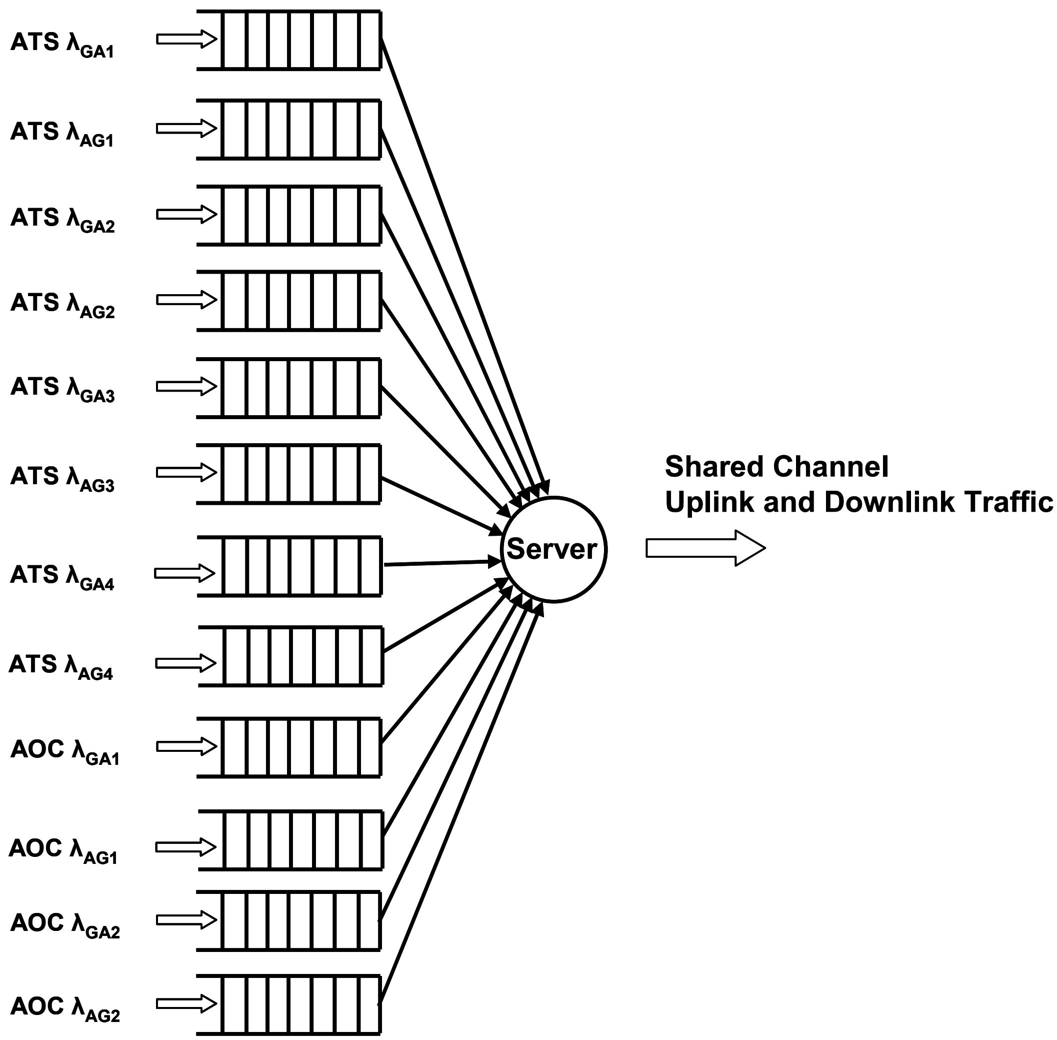


Figure A3.3-2. Shared Channel for ATS and AOC Uplink and Downlink Traffic

A3.3.2.2 Separate ATS and AOC Channels

In this set of models, ATS and AOC traffic use separate channels. 2 separate models were developed ─ separate channels for uplink and downlink traffic and combined channels for uplink and downlink traffic. Figure A3.3-3 shows the first model that uses 4 separate channels for ATS and AOC traffic ─ 1 ATS uplink, 1 AOC uplink, 1 ATS downlink, and 1 AOC downlink.

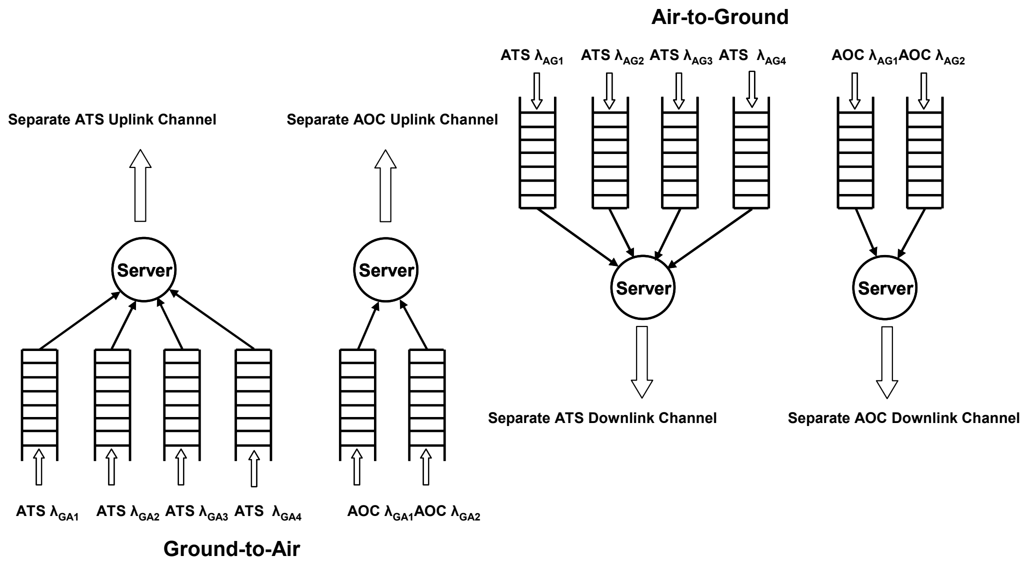


Figure A3.3-3. Separate ATS and AOC and Separate Uplink and Downlink Channels

Figure A3.3-4 shows the second model that uses 1 channel for uplink and downlink ATS traffic and 1 channel for uplink and downlink AOC traffic.

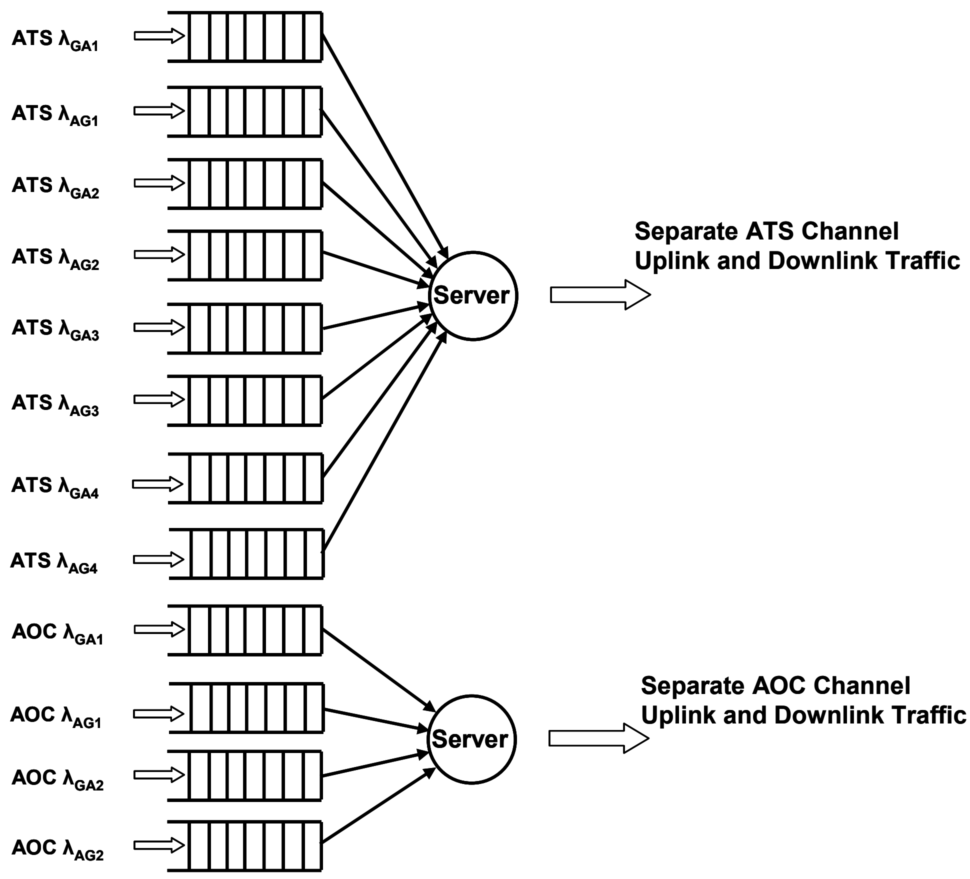


Figure A3.3-4. Separate ATS and AOC Channels with Combined Uplink and Downlink Traffic

A3.3.3 Traffic Model Development

Figure A3.3-5 shows the 2-phase priority queuing analysis process for a mixed aircraft arrival and departure environment in a service volume. The first phase is the traffic model development phase, and the second phase is the priority queuing analysis phase. The first phase which is discussed in more detail later includes developing traffic statistics for departure and arrival aircraft based on data loading tables. The queuing analysis which is also discussed in more detail later consists of analysis for separate uplink and downlink channels and shared uplink and downlink channel.

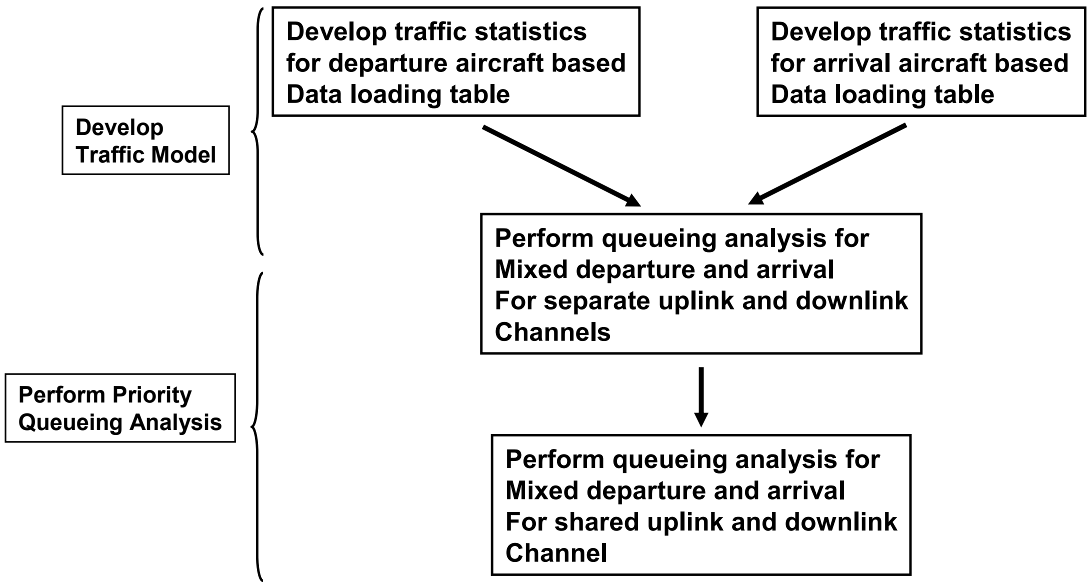


Figure A3.3-5. Priority Queuing Analysis Process for a Mixed Arrival and Departure Service volume

A3.3.3.1 Departure Aircraft

Figure A3.3-6 shows a 2 part traffic model development process for departure aircraft – per aircraft and per service volume.

Per Aircraft
Sort services into similar priorities
For each Priority
Develop departure uplink message statistics
- **Uplink average message size, ULD Msg**
- **Uplink message arrival rate, ULD λ**

Develop departure downlink message statistics
- **Downlink average message size, DLD Msg**
- **Downlink average arrival rate, DLD λ**

⇩

Per Control Volume
For each Priority
Develop departure uplink message statistics
- **Uplink average message size, ULD Msg**
- **Uplink message arrival rate, ULD λ_T = PIAC * Equipage * Percent Departure * ULD λ**

Develop departure downlink message statistics
- **Downlink average message size, DLD Msg**
- **Downlink average arrival rate, DLD λ_T = PIAC * Equipage * Percent Departure * DLD λ**

Figure A3.3-6. Departure Aircraft Traffic Statistics Development Process

The per aircraft process consists of developing departure and arrival aircraft message traffic based on departure and arrival message traffic in ATS and AOC data loading tables. The services in the data loading tables are sorted by priority. For each priority, departure uplink and downlink traffic statistics are developed. The departure uplink statistics consists of the following:

- Uplink average message size, ULD Msg
- Uplink message arrival rate, ULD λ

The departure downlink statistics consists of the following:

- Downlink average message size, DLD Msg
- Downlink message arrival rate, DLD λ

The per service volume traffic model is based on the per aircraft departure and arrival traffic, PIAC, equipage, and the departure and arrival mix. For each priority, departure uplink and downlink traffic statistics are developed. The departure uplink statistics consists of the following:

- Uplink average message size, ULD Msg
- Uplink message arrival rate, ULD λ_T = PIAC * Equipage * Percent Departure * ULD λ

The departure downlink statistics consists of the following:

- Downlink average message size, DLD Msg
- Downlink message arrival rate, DLD λ_T = PIAC * Equipage * Percent Departure * DLD λ

A3.3.3.1.1 Aggregate Message Size and Arrival Rate

Figure A3.3-7 shows the methods for calculating the aggregate message size, instance, and message arrival rate for each priority. The service message size and instance are represented by S_iMsg and S_iI respectively.

Calculate aggregate message size from service message sizes

$$Msg = \sum_{i=1}^{N}(S_i Msg * S_i I) / \sum_{i=1}^{N} S_i I$$

Calculate aggregate instance from service instances

$$I = \sum_{i=1}^{N} S_i I$$

Calculate average message arrival rate

λ = I/Flight Duration

Figure A3.3-7. Methods for Calculating Aggregate Message Size, Instance, and Arrival Rate for Each Priority

A3.3.3.2 Arrival Aircraft

Figure A3.3-8 shows a 2 part traffic model development process for arrival aircraft ─ per aircraft and per service volume.

Per Aircraft
Sort services into similar priorities
For each Priority
Develop arrival uplink message statistics
- ─ Uplink average message size, ULA Msg
- ─ Uplink message arrival rate, ULA λ

Develop arrival downlink message statistics
- ─ Downlink average message size, DLA Msg
- ─ Downlink average arrival rate, DLA λ

⇩

Per Control Volume
For each Priority
Develop arrival uplink message statistics
- ─ Uplink average message size, ULA Msg
- ─ Uplink message arrival rate, ULA λ_T = PIAC * Equipage * (100 - Percent Departure) * ULA λ

Develop arrival downlink message statistics
- ─ Downlink average message size, DLD Msg
- ─ Downlink average arrival rate, DLA λ_T = PIAC * Equipage * (100 - Percent Departure) * DLA λ

Figure A3.A3.3-8. Arrival Aircraft Traffic Statistics Development Process

A3.3.4 Queuing Analysis Process

A3.3.4.1 Mixed Departure and Arrival for Separate Uplink and Downlink Channels

Figure A3.3-9 shows the queuing analysis process for mixed departure and arrival service volume for separate uplink and downlink channels. The process consists of developing separate uplink and downlink traffic statistics and performing queuing analysis to calculate the required uplink and downlink channel capacities.

Develop uplink and downlink traffic statistics for mixed departure and arrival

⇓

Perform priority queueing analysis
- **Calculate required uplink channel capacity**
- **Calculate required downlink channel capacity**

FigureA3.3-9. Queuing Analysis Process for Mixed Departure and Arrival for Separate Uplink and Downlink Channels

A3.3.4.1.1 Traffic Statistics for Mixed Departure and Arrival Service volume

Figure A3.3-10 shows the procedure for calculating the uplink and downlink traffic statistics for mixed departure and arrival service volume.

Develop Uplink Statistics
- **Uplink message size**
  $\text{UL Msg} = (\text{ULD Msg} * \text{ULD } \lambda_T + \text{ULA Msg} * \text{ULA } \lambda_T)/(\text{ULD } \lambda_T + \text{ULA } \lambda_T)$
- **Uplink message arrival rate**
  $\text{UL } \lambda_T = \text{ULD } \lambda_T + \text{ULA } \lambda_T$

Develop Downlink Statistics
- **Downlink message size**
  $\text{DL Msg} = (\text{DLD Msg} * \text{DLD } \lambda_T + \text{DLA Msg} * \text{DLA } \lambda_T)/(\text{DLD } \lambda_T + \text{DLA } \lambda_T)$
- **Downlink message arrival rate**
  $\text{DL } \lambda_T = \text{DLD } \lambda_T + \text{DLA } \lambda_T$

Figure A3.3-10. Procedure for Calculating the Uplink and Downlink Traffic Statistics for a Mixed Departure and Arrival Service volume

A3.3.4.2 Mixed Departure and Arrival for Shared Uplink and Downlink Channel

Figure A3.3-11 shows the procedure for calculating the shared uplink and downlink channel capacity for mixed departure and arrival service volume. The process consists of using the previously developed uplink and downlink statistics in the analysis.

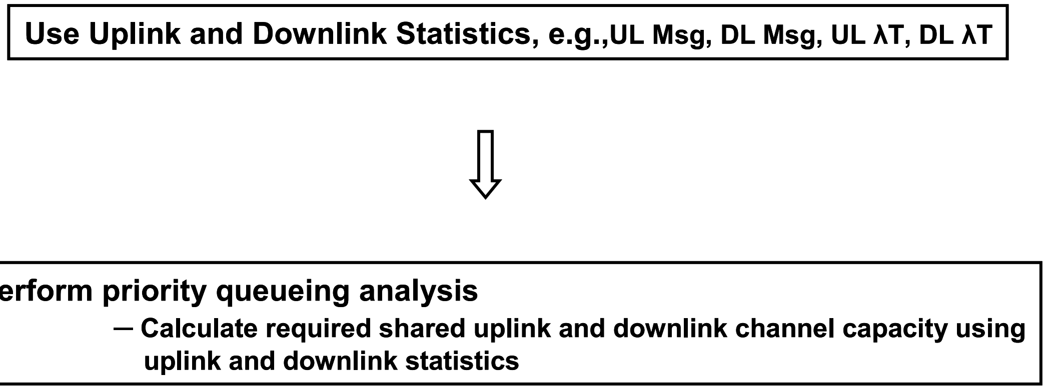


Figure A3.3-11. Procedure for Calculating Channel Capacity for Uplink and Downlink Traffic Sharing the Same Channel

A3.3.5 Priority Queuing Analysis Procedure

Figure A3.3-12 shows a priority queuing analysis procedure. It requires a traffic model and the required 95th percent end-to-end delay as inputs.

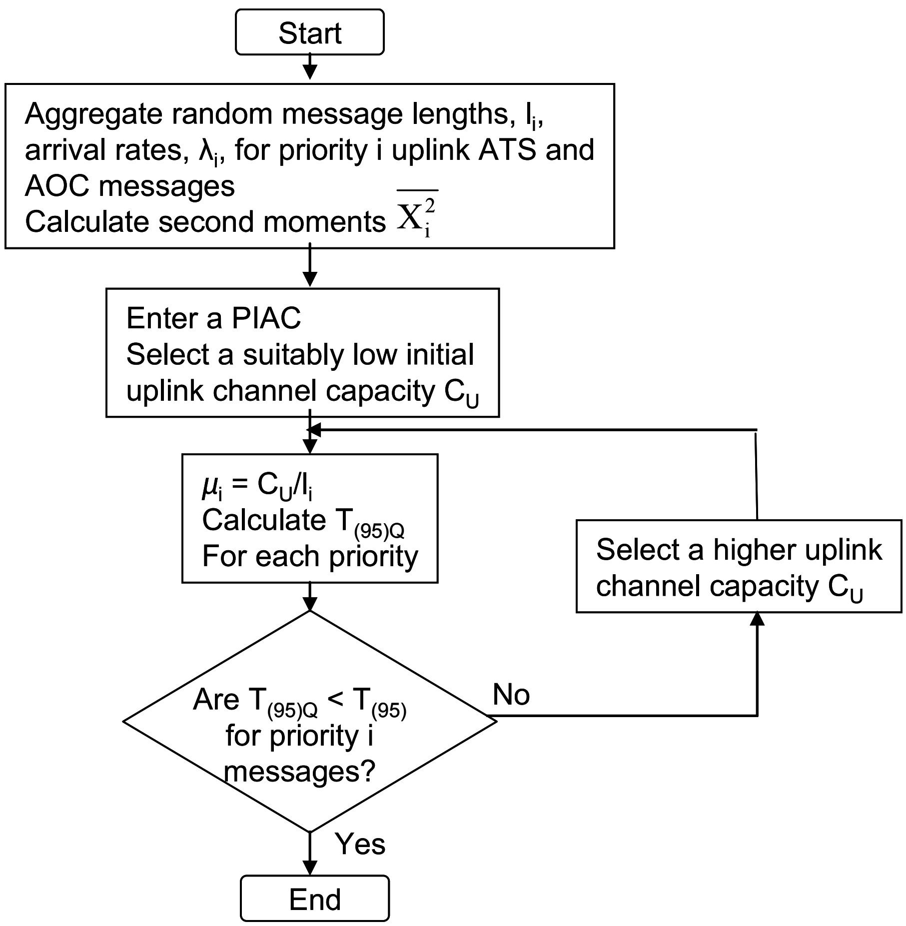


Figure A3.3-12. A Priority Queuing Analysis Procedure

A.3.4 PRIORITY QUEUING ANALYSIS BASICS

Figure A3.4-1 shows a priority queuing system with different classes of arrivals that have their own separate queues waiting for service by a single server. The different classes, A through K, have different arrival rates, λ_A through λ_K, and priorities, A being the highest and K the lowest. The messages in the higher priority queues are serviced ahead of those in the lower priority queues. The messages in each class are serviced at rates μ_A through μ_K. We assume a non-pre-emptive priority scheme where a message in service is allowed to complete its service even if a higher priority message is waiting.

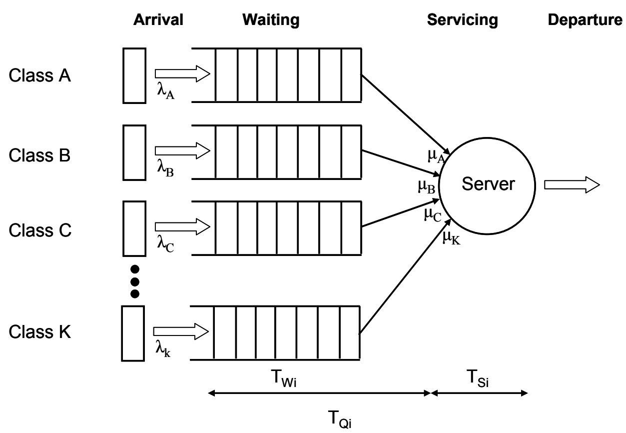


Figure A3.4-1. Delay Analysis by Priority Queuing Method

The following are the definitions used in this paper and depicted in Figure A3.4:

- Average class i message waiting time – T_{W_i}
- Average class i message service time – T_{S_i}
- Average class i message queuing delay –$T_{Q_i} = T_{W_i} + T_{S_i}$
- Class i utilisation – $\rho_i = \lambda_i / \mu_i$
- λ_i is the message arrival rate for class i messages
- μ_i is the message service rate for class i messages

Assuming a single-server M/G/1 queuing system, i.e., the arrivals are memory-less (Poisson) and service times have general distributions, the average waiting time, T_{W_i}, for the class i messages is [11]

$$T_{W_i} = \frac{\sum_{i=1}^{n} \lambda_i \overline{X_i^2}}{2(1-\rho_1-\ldots-\rho_{i-1})(1-\rho_1-\ldots-\rho_i)} \quad (1)$$

Where:

[11] D. Bertsekas and R. Gallager, *Data Networks*, Prentice-Hall, 1987.

$\overline{X_i^2}$ is the second moment of the service time T_{S_i}

The average queuing time, T_{Q_i}, for the ith priority message is

$$T_{Q_i} = \frac{1}{\mu_i} + T_{W_i} \quad (2)$$

From (1), the average waiting time for the highest priority message, T_{W_A}, is

$$T_{W_A} = \frac{\sum_{i=1}^{n} \lambda_i \overline{X_i^2}}{2(1-\rho_A)} \quad (3)$$

The average queuing time for the highest priority message, T_{Q_A} is

$$T_{Q_A} = \frac{1}{\mu_A} + T_{W_A} \quad (4)$$

The rth percentile of the queuing time, $T(r)_Q$, can be derived from the average queuing time T_Q as follows:

$$T(r)_Q = \ln\left(\frac{100}{100-r}\right) T_Q \quad (5)$$

For example, the 95th percentile of the queuing time, $T(95)_Q$ is

$$T(95)_Q = \ln\left(\frac{100}{100-95}\right) T_Q \quad (6)$$

The following are the equations for calculating the second moments for the exponential and constant distributions.

Exponential: $\overline{X^2} = \frac{2}{\mu^2}$ (7)

Constant: $\overline{X^2} = \frac{1}{\mu^2}$ (8)

APPENDIX 4.DEFINITIONS

The following terms are used in specifying the required communication performance in Section 6 of this document.

Air Traffic Control Sector	An airspace area of defined horizontal and vertical dimensions for which a Controller or group of Controllers (e.g. executive and planning Controller) has air traffic control responsibility. Source: 4VFR.COM
Air traffic management	The aggregation of the airborne functions and ground-based functions (air traffic services, airspace management and air traffic flow management) required to ensure the safe and efficient movement of aircraft during all phases of operations. (ICAO PANS-ATM)
Air traffic management system.	A system that provides ATM through the collaborative integration of humans, information, technology, facilities and services, supported by air, ground and/or space-based communications, navigation and surveillance.
Availability (inherent)	Probability that the equipment comprising the system is operational and conforms to specifications, excluding planned outages and logistics delays.
Availability of use (A_U)	Availability of use is the probability that the communication system between the two parties is in service when it is needed (DO-264). . The time a system is not available while repairs are underway (logistics delay, MTTR, etc) reduces availability of use.
Availability of provision (A_P)	Availability of provision is the probability that communication with all aircraft in the area is in service (DO-264).
Call Establishment Delay	The total time taken between the PTT action by the User and the time for the squelch to operate in the receiver (of the party being called). (EUROCAE WG67-1)
Continuity	Probability that a transaction will be completed having meet specified performance (assuming the system was available when the transaction is initiated). The value for the continuity parameter is based on the acceptable probability of detected anomalous behaviours of the communication transaction. Detected anomalous behaviors include, but are not limited to (ICAO RCP Manual Draft v4): • Late transactions; • Lost messages or transactions that cannot be recovered within the expiration time • Duplicate messages or transactions that are forwarded and/or used; and • Uncorrected detected message errors.
Integrity (I_{UCT})	Integrity is the acceptable rate of transactions that are completed with an undetected error (DO-264). Undetected errors include, but are not limited to (ICAO RCP Manual Draft v4): Undetected corruption of one or more messages within the

	transaction; Undetected misdirection of one or more messages within the transaction; Undetected delivery of message in an order that was not intended; Undetected delivery of a message after the communication transaction time; and Undetected loss of service or interruption in a communication transaction.
PIAC	Peak instantaneous aircraft count, the highest number of aircraft in a selected volume during the selected window of time
Push To Talk (PTT)	The physical action taken by the 'User' in operating his/her transmitter key. The general term 'User' refers to a pilot or Controller. The term 'key' is used to denote any type of device including buttons, levers, foot switches, computer mouse and LCD/plasma panel segments etc (EUROCAE WG67-1)
PTT Delay	This is the delay arising from the need to operate a transmitter remotely and would be nil if the User was actually physically located in the same place as the transmitter. (EUROCAE WG67-1)
Receiver Activation Delay	The total time taken for a receiver to have recognised the presence of a radio signal of designed minimum quality causing the squelch to operate. (EUROCAE WG67-1)
Reliability	See Availability (inherent)
Service Instance	A set of one or more messages and/or transactions associated with completing a objective. For example, a Flight Crew request followed by a Controller clearance followed by a Flight Crew acknowledgement would constitute a single service instance that contains three messages and two transactions..
Technical delay, one way	Time required by the system to deliver a message, beginning with user action to send the message, and ending upon notification of recipient of message receipt. Typically accounts for half of a transaction
Technical delay, two way	Time required by the system to deliver a message, beginning with user action to send the message, and ending upon notification by initiating user of reply receipt, excluding any user response time. Typically, that part of TT(95) allocated to system.
Transaction	A two-way operational communication process (e.g., controller and pilot, pilot and pilot, or controller and controller. It contains the outgoing request message, the controller or pilot response time and the incoming response message. Communications exchanges that have multiple responses, i.e., the STANDBY, followed by the operational response, are treated as two transactions. (DO-264)
Transaction Time (TT)	The transaction time is the time needed by a pilot and a controller to exchange a pair of messages. This time represents the sum of the delivery time of incoming and outgoing messages and the controller or pilot response time. (DO-264, Annex C.3.1.5.1)
Transmitter Activation Delay.	The total time taken between the PTT action by the User and the time that the transmitter has attained its designed operating power (EUROCAE WG67-1)
95% Transaction Time (TT95)	The time before which 95% of the transactions are completed. (DO-264)

TT(95)RCTP	96% of transactions are completed with a technical delay, two way with this time
TT(95)RCTP, one way	95% of transactions are completed with a technical delay, one way within this time
Voice Access Delay	The one-way user-to-user delay starting with the voice initiation event (e.g. PTT signal event) and ending with audio appearing at the remote end of the link, but excluding any human response times.
Voice Channel Setup Delay	Time needed for by the system to establish a path between users, prerequisite for voice access and communications.
Voice Latency	The one-way user-to-user voice delay between analogue system interfaces (HMIs) after the audio path has already been established.
User	A person who employs the services provided by the system. Typically a member of the aircraft cockpit crew, a member of the air traffic management team or flight operations personnel.

APPENDIX 5.FRS LATENCY ALLOCATION

The COCR FRS technical latency allocation is intended to include the SNDCF processing latency, the radio processing latency (both air and ground), the RF-based transmission latency (this is the latency associated with the channel RF-bit transmission rate), and any RF-based media access delays. It is important to note that the FRS boundary has been chosen to be the SNDCF interface (a logical, stack-based boundary) rather than a physical interface. The FRS technical latency is allocated from the overall system RCTP transaction time, $TT_{95\text{-}RCTP}$.

A.5.1 Latency Allocation Methodology

The steps below describe the methodology for allocating the latency requirements to the FRS.

1. Start with the TT_{RCP} requirement.
2. Allocate the TT_{RCP} between the technical and human elements using an algebraic allocation, i.e., $TT_{95\text{-}RCP} = TT_{95\text{-}RCTP} + TT_{95\text{-}HUMAN}$.
3. Allocate the two-way $TT_{95\text{-}RCTP}$ into two one-way pieces, $TD_{95\text{-}RCTP}$ using the statistical allocation method described in Section 3.2 assuming that each one-way piece contributes equally to the two-way delay. Alternatively, an algebraic allocation could be made at this step.
4. Assuming estimated allocation percentages, statistically allocate the one-way delay among the ATSU, CSP, FRS, and External Airborne systems. Note: This step does not directly use the ground and airborne allocations of from prior work, since the FRS spans both the ground and airborne domains.
5. Evaluate the resultant statistically allocated figures for practically and reasonableness using a best effort attempt to equally distribute the difficulty in meeting the allocation. For example, it might be very difficult for FRS to met delays given the high likelihood of RF interference (a problem that the ATSU, CSP, and External Airborne equipment does not need to deal with). As another example, the processing requirements in the ATSU might be much greater (to authenticate security certificates) than the processing requirements in the FRS. The idea is to make a best effort at balancing the allocations such that a subsystem is not unfairly burdened.
6. As needed return to Step 3 above until a reasonable set of allocations is produced.

It is practical to develop the allocation percentages using the service with the most stringent TT_{RCP} requirement. The reasonableness test can then be applied for worst cast conditions. The resulting allocations can be applied to services with larger (less stringent) TT_{RCP} requirements with the assumption that the allocations will also be reasonable.

A.5.2 Statistical Allocation

A Poisson distribution is assumed for transaction times. Poisson distributions are commonly used to model message delays in queuing delay analyses. The allocation among system components is done using mean (average) delay values. The steps below describe the statistical allocation process:

1. Calculate the mean delay time using the 95% time and assuming a Poisson distribution.

   Note: A Poisson distribution calculator is available at:

   http://calculators.stat.ucla.edu/cdf/poisson/poissoncalc.php

2. Allocate the mean using the desired allocation percentages. If a component is allocated 10% of the mean, the component allocation is 0.1 times the system mean.

3. Calculate the 95% delay time for each of the components using the component mean delay value and assuming a Poisson distribution.

For example, assume a total 95% system delay of 10 seconds wherein the system consists of 3 components to be allocated 10%, 30% and 60% of the delay. First, you would obtain the mean system delay. Using the Poisson calculator (see link above), the system mean delay is 6.17 seconds. The mean delay allocations to the three components are 0.61, 1.85, and 4.31 seconds, respectively. Note: Values are truncated rather than rounded. Using the Poisson calculator and these mean values, the 95% delay values are 1.5, 3.8 and 7.4 seconds. Note: The sum of these three numbers are greater than 10 seconds, but the statistical allocation accounts for the fact that these three 95% delays do not happen at the same time. The system 95% delay is still 10 seconds.

A.5.3 Allocation Guidance

In reality, the allocation to the FRS should be based on what can reasonably be achieved. Annex E of DO-264 [43] provides guidance on allocation states:

> *Consideration should be given as to the reasonableness and practicability of the considerations and assumptions (be they procedural, functional, performance, environmental etc.). In particular, is the human component being unduly relied upon? A reasonableness check could be to relate the intended system architecture with the existing architecture, for example data-link* replacing voice communication path to ensure that the safety objectives of the *new technology are not significantly different from the existing technology, given similar mitigation and similar hazard category.*

To that end, it is useful to review a number of prior assessments and associated assumptions, limitations, and notes. Some of these assessments were presented in Section 2.0 of this document and some of the information is newly introduced below.

- Recent VDL-2 simulation studies conducted to evaluate European capacity requirements have assumed a VDL-2 round trip delay of 8 seconds, i.e. TT_{VDL2} = 8 seconds [46]. This represents a 50% algebraic allocation to the VDL-2 subnet. Note that this study has assumed a limited set of COCR-defined operational services and looked primarily at an en route deployment of VDL-2.

- A MITRE study [50] evaluated VDL-3 delays and estimated 95% uplink and downlink one-way delays of 0.8 and 5 seconds, respectively. This delay data assumes 18 aircraft and a defined Terminal Domain Message Traffic Model. NOTE: The traffic load in this model was significantly higher than that used in [46].

  - The system specification for US National Build 1.2 for CPDLC requires an automation 95% delay time of 5 seconds (delay between controller initiation and providing the message to the FAA Telecommunication Infrastructure, FTI, ground network).

These examples are technology specific; thus, should only be used to consider (not drive) FRS allocations.

A.5.4 FRS Latency Allocation

We start with step 3 in the proposed approach (see Section 3.1) given that the operational subject matter experts have already developed TD95 performance numbers for the end-to-end data link. For Phase 1, the most stringent requirement is for ACL/ACM, so will start the allocation process with a $TD_{95} = 8$. Using the Poisson calculator, the mean one-way delay time (TD_{MEAN}) is 4.695 seconds.

For the FRS, we will allocate this mean figure to the ATSU (e.g., automation), the CSP (e.g., network), the FRS, and the external aircraft (XAIR) equipment (e.g. FMS). The initial allocation percentage numbers for each component is **25%, 25%, 40%** and **10%**. These percentages are based on the following rationale:

- The FRS has the most restrictive transmission rate. Traditionally, the bit rates on the RF links are significantly less than that of the ground network. In addition, the RF link is subject to interference and is much more error prone than ground links, which will likely require the FRS system to retransmit many more messages than other components. Some reports have indicated that the present ACARS system looses on average 6% of the transmissions. Thus the FRS allocation is large in comparison to other components. The 40% allocation is similar to the 50% allocation assumed in [46]. . A slightly smaller allocation is assigned, since the future end systems will likely require additional processing (security certificate processing). In addition, a smaller allocation adds a degree of conservatism.

- The DO-290 algebraic allocation to the airborne domain resulted in $TD_{95\text{-}AIR}$ of 2 seconds. From Boeing [49], the external equipment (other than VDR and CMU), the delay was estimated as 0.5 seconds. This represents about 6% of the system delay. Given that the FRS boundary is within the CMU, the assumed initial allocation will be a bit larger to account for CMU processing. Thus, the initial allocation of 10%.

- The remaining delay is allocated equally between the ATSU and the CSP, i.e. 25% each.

Using these component allocations and a system mean delay of 4.695 seconds, the mean delays for the ATSU, CSP, FRS and XAIR are 1.17375, 1.17375, 1.878, and 0.4695 seconds respectively. Using the Poisson calculator and truncating to the nearest tenth of a second, the associated 95% delays are 2.6, 2.6, 3.8, and 1.2 seconds respectively. These allocations seem reasonable.

While it might be desirable to increase the FRS allocation, it would need to be at the expense of the other allocations. The ATSU delay is already about 50% faster than previously specified performance requirements for data link automation, i.e. 2.6 seconds versus 5.0 seconds.

APPENDIX 6. FULL DOCUMENT REFERENCE LIST

Ref no	Document Title
1	ICAO Global ATM Operational Concept
2	RTCA/EUROCAE - Safety and Performance Requirements Standard for Air Traffic Data Link Services in Continental Airspace – RTCA DO-290/EUROCAE ED-120
3	EUROCONTROL - Operational Requirements for Air/Ground Co-operative Air Traffic Services – AGC ORD-01
4	European Commission - Roadmap for the Implementation of Data Link Services in European Air Traffic Management (ATM: Non ATS Applications)
5	RTCA - Minimum Aviation System performance Standards for Automatic Dependent Surveillance – Broadcast –DO-242A
6	US Department of Transportation - Next Generation Air Transportation System Integrated Plan (NGATS), December 2004
7	RTCA - National Airspace System Concept of Operations and Vision for the Future of Aviation
8	EUROCONTROL ATM Operating Concept Volume 1, Concept of Operations, Year 2011
9	IATA - ATM Implementation Roadmap – Short and Medium Term – Release Version 1.0 – 15th October 2004
10	EUROCONTROL Air/ground data volumes in Europe – version 0.B – July 2000
11	EUROCONTROL/FAA. Security Analysis Supporting the Communications Operating Concept and Requirements for the Future Radio System. September 2005.
12	EUROCONTROL/FAA Principles of Operation for the Use of Airborne Separation Assurance Systems Version: 7.1 Date: 19 June 2001
13	RTCA/EUROCAE - Guidelines for Approval of the Provision and Use of Air Traffic Services Supported by Data Communication – RTCA DO-264/EUROCAE ED-78A
14	FAA Safety Management System (SMS) Manual
15	EUROCONTROL Safety Regulatory Requirement (ESARR 4) Set 1 Severity Indicators
16	COCR working paper AOC Transactions per Flight Domain, COCR-PSG-KD-09.
17	Buondonno, K. and Price, K, “Dallas/Fort Worth International Airport Perimeter Taxiway Demonstration”, DOT/FAA/CT-TN03/19, July 2003.
18	NASA Ames Research Centre, “Los Angeles International Airport Runway Incursion Studies, Phase I Baseline Simulation”, FFC-LAX-R001, May 9, 2001
19	FCS Operational Concept and Requirements Group: A Voice Study Survey Characterizing Voice Channel Access by Airspace Domain
20	Poject EMERTA WP2-NGSS Study Synthesis Report
21	PSG FRS Latency Allocation Proposal

22	PSG Node Analysis - Nodes and Operational Service Connectivity
23	PSG Large Airspace Volume Loading Proposal
24	PSG Queing and Loading Assumptions
25	PSG ATN Stack Message Traffic Estimate (Network Layer)
26	Voice Channel Impacts due to ASAS Application Usage
27	Next Generation Satellite Communication System - Mission Requirements
28	One Sky Global ATM V1 2005+ - A strategy for Future ATM
29	Time Required for Transmission of Time - Critical ATC Messages in an En-Route Environment
30	Communications Concepts - For FCOCR Meeting July 26th 2005
31	Operational Concepts of Required Communication Performance
32	ATN Project ATN Implementation Task Force DRAFT ATN Scenario Definition
33	Modelling the Other Half of the Flow
34	Data Link Benefits Study Team, "Benefits of Controller-Pilot Data Link ATC Communications in Terminal Airspace", DOT/FAA/CT-96/3, September 1996.
35	Graglia, L, "Etude Vocalise", CENA/ICS/R02-002, July 2002.
36	Hung, B, "MITRE-Sponsored Research: An Analysis of En Route Domain Air Traffic Control Voice Transcripts", April 2005.
37	PSG - AOC Message Volumes v0.2
38	PSG FIS Message Sizes v0.2
39	FRS Loading Associated with Security
40	ATS Message Sizes (UNICAST) v0.2
41	Centre Sectors - Harry Eberlin
42	NAS VHF Spectrum Survey Results: 20th September 2005
43	RTCA DO264 - Next Generation Air/Ground Communications System (NEXCOM) Safety and Performance Requirements (SPR)
44	ICAO Annex 10 – Volume 3
45	Terminal Radar Approach Control: Measures of Voice Communications System Performance - Prinzo & McClellan
46	EUROCONTROL VDLM2 Capacity Study
47	ICAO PAN-OPS Doc 4444
48	ICAO Annex 11
49	Boeing aircraft delays
50	A Simulation Study of the VDL Mode 3 Poll Scheduling Algorithm and Site Diversity", 22nd DASC, Indianapolis, IN, 14-16 October 2003. Brian T. Hung,