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MITRE TECHNICAL REPORT

Air/Ground Communications Traffic Modeling Capability for the Mid-Level Model (MLM)

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Center for Advanced Aviation System Development
McLean, Virginia

CAASD

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MITRE
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Abstract

The Mid-Level Model (MLM) simulates the flow of aircraft in the National Airspace System (NAS), and is used for capacity and delay analyses. Prior to the effort documented in this report, MLM did not account for the communications events that transpire, and the related communications messages that would ensue, as the simulated aircraft are moving through the NAS. In order to properly engineer current and future air/ground (A/G) communications systems, it is necessary to quantify the communications traffic that those systems are expected to serve. This document describes the capability added to MLM during fiscal year 2005 (FY05) to identify communications message triggering events, and to generate the appropriate voice or data communications messages.

Acknowledgments

Foremost we would like to thank Stephen Giles for sharing his expertise in data link with us, for directing us to the documentation needed, for pointing us in the right direction as this project was just beginning, for laying out a framework for us to follow, and for helping us along the way to completion. He also performed the technical review for this report.

We would also like to thank:

- Niamh Lowry for her guidance and for providing us with the operational expertise necessary to adding the communications capability correctly to MLM. She also helped us to obtain the voice tape transcription data that was used extensively in this modeling effort, and also spent a significant amount of time in helping to analyze the voice tape transcription data.
- Edward Brestle for allowing us to take advantage of his controller expertise that was invaluable to incorporating the communications capability into MLM.
- George W. Flathers for providing us the pilot's perspective in using air/ground communications systems.
- Brian Hung who did a thorough analysis of the voice tape transcription data, and whose results were used in this modeling effort.
- Melvin Zeltser for collaborating with us to generate the ideas upon which this task was built and for helping us obtain support for this task through the MITRE -+
- Brian Simmons for his support and patience and for providing us the opportunity to work on this MSR project.
- Ted Gobble for his expertise in preparing this document for publication.

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1 Introduction

In order to effectively plan an air/ground (A/G) communications system for the National Airspace System (NAS), it is important to have the capability to quantify the distribution of A/G communications transactions over different geographical locations over a typical day. This report describes the work to provide an existing fast-time simulation tool of the NAS, called the Mid-Level Model (MLM), the capability to trigger and quantify A/G communications transactions. This work does not address any ground/ground (G/G) communications that may result from or give rise to the A/G communications. Modeling ground/ground communications as a function of air traffic should be considered as a future enhancement to MLM, because it would enable quantification of ground/ground communications, which would be useful in the design of the ground/ground communications network. This work was facilitated through the MITRE Sponsored Research (MSR) Program of the MITRE Technology Program.

1.1 Background

MLM uses discrete event techniques to simulate the flow of aircraft in the NAS, and is used for capacity and delay analyses. Figure 1-1 shows a high-level diagram of MLM, with the new communications capability added during FY2005 highlighted with bold italics.

The inputs to MLM are data for items related to flights, such as aircraft characteristics, the airlines to which the flights belong, and the sectors, airports, and fixes that the aircraft encounter as they fly from origin to destination. MLM provides user options to customize routing, altitude, flights, sector and airport capacities, and other parameters affecting system performance.

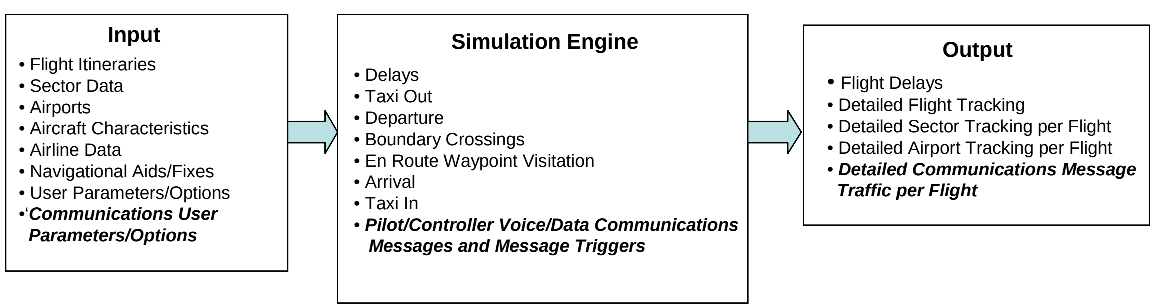

Figure 1-1. MLM High-Level Description

Prior to the research documented here, the A/G communications events that transpire and the related communications messages that would ensue, as the simulated aircraft are moving through the NAS, were not accounted for by MLM. In order to properly engineer current and future A/G communications systems, it is necessary to quantify the communications traffic that those systems are expected to serve. Figure 1-2 shows a high-level depiction of the use of MLM for the purpose of quantifying A/G communications. The desired end-state model would be able to quantify A/G communications transactions for any Air Traffic Control (ATC) paradigm and for any communications system (reflecting their application, network, and subnetwork characteristics).

This fiscal year (FY) 2005 MSR effort is an initial attempt along the way towards the end state, and will add to MLM the capability to identify communications message triggering events, and to generate basic voice and Controller-Pilot Data-Link Communications (CPDLC) data-link messages. Although there are different data-link protocols that can be considered, during this past fiscal year, only the Aeronautical Telecommunications Network (ATN) Open System Interconnect (OSI) protocol [1] was added in some detail to MLM.

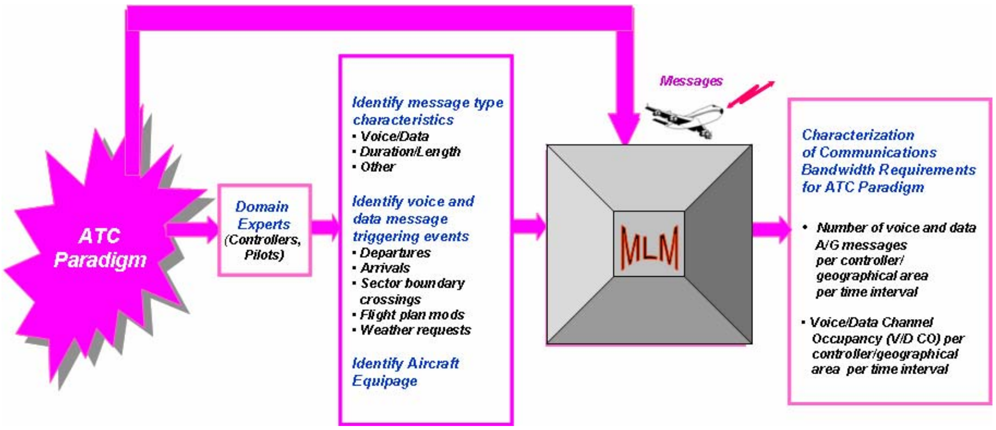

Figure 1-2. Proposed Use of Communications Capability for MLM

1.2 Approach

A/G communications between a controller and a pilot take place as a result of events that aircraft encounter from prior to departure from one airport to arrival at the gate of the destination airport. These events are called *communications message triggering events*.

This FY2005 MSR effort provided MLM with the capability to identify basic communications message triggering events and to generate the ensuing number of messages of the appropriate types and the communications load for different entities as, for example, a communications channel, a controller team, or some other entity. In order to determine communications loading, the size in bytes for data messages, and the channel occupancy for voice messages must be provided. Thus, two major efforts, in addition to other efforts described in this report, were required just to provide MLM with a basic communications message generation capability: developing the capability to identify communications message triggering events, and developing a basic set of messages associated with each triggering event.

Aircraft equipped for data link can generate both voice and data messages depending on the conditions under which the messages are sent. Unequipped aircraft can transmit only voice messages. Thus, MLM was provided with the capability to distinguish between equipped and unequipped aircraft and to generate communications messages as either voice or data, depending on equipage and certain conditions that are described later. Designation of a particular flight as voice-capable or voice and data-capable is done during scenario development.

De-identified transcriptions for voice recordings for Denver Center (ZDV), Fort Worth Center (ZFW), and Atlanta Center (ZTL) were available; they were used for determining voice message duration probability distributions, frequency of occurrence, and other statistics for different message types. An analysis was conducted as part of this MSR effort, and documented in reference [2]. A limited range of sectors in ZDV, ZFW, and ZTL are the only cases for which voice tape transcriptions were available at the time of the analysis, and thus the statistics documented in reference [2] will be used in MLM for the other sectors and centers. Ongoing research in The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) is concluding that variation in workload across sectors makes it hard to extrapolate from a limited sample set [3]. As the relationship between sector type and communication workload is better understood, application of the conclusions of the voice tape analysis across NAS sectors will be updated.

Several sources of information of data message sizes are available for both the ATN OSI [1] and the ARINC 622 protocols [4], although only those for ATN OSI were developed and incorporated during this year's effort. A mapping of message types from the various sources of information to communications triggering events was performed, and incorporated into MLM.

There are four basic methods used to identify communications message triggering events:

- Using MLM-generated events in a simulation such as push-backs, departures and arrivals.
- Identifying anticipated aircraft proximities in an MLM simulation such as: the proximity of an aircraft to a sector boundary, in which case communications for handoff is sent some time (entered as input to the model) prior to the sector boundary crossing; or the proximity of one aircraft to another, in which case a conflict resolution message (e.g., an altitude or heading clearance) is sent if the two aircraft are predicted to violate separation buffers.
- Identifying in a preprocessing step where clearances are given to aircraft based on Enhanced Traffic Management System (ETMS)-derived flight profile data. Clearances identified in this way are altitude and route clearances that have resulted in an update of the flight plan in the flight data processor. When an aircraft reaches the designated location during the simulation, the clearance is sent.
- Developing statistics in a preprocessing step performed using the voice tape transcription data on the various types of communications messages that were recorded at the sample sectors. These statistics are used in the simulation to determine the frequency of triggers for the various communications messages for each aircraft in a sector; the communication events are distributed throughout the time the aircraft occupies a given sector. If the aircraft are equipped for data link, some portion of these messages is designated as data messages. The message channel occupancy, in seconds, is also derived from the voice

tape transcription data, and used for voice messages. Triggers derived from the voice tape transcription data are used to supplement those obtained from the host amendment data.

For a proximity event (second bullet above), the communications message is sent at some predetermined time before the actual event. A capability, called a “look-ahead” or “headlight” function, was developed in order to trigger a communications message when the aircraft is with a certain time (e.g., 2 minutes) from reaching the sector boundary, or when two aircraft are within a certain distance of each other. This headlight function is also used to determine when a communications message derived from the voice tape transcription data is sent. In the latter case, a determination is made based on a draw of a random variable, referred to as random variable (RV) draw, as to the length of time from when the aircraft enters the sector to when a communications message triggering should occur. The look-ahead capability of the headlight function is used to make this determination.

1.3 Document Organization

Section 2 of this document describes the development of communications messages, their lengths (in bytes) if data, and their expected channel occupancy (in seconds) if voice. Section 3 discusses the identification of triggering events. Section 4 discusses equipage. Section 5 discusses the inputs needed and the outputs produced when MLM generates communications messages. Section 6 discusses future communications features, systems, and services that should be considered for modeling in future versions of MLM.

2 Communications Messages

The model will designate aircraft as either equipped with data link or not equipped based upon user input of percentages of aircraft equipped and random variable drawing. For the FY 2005 effort, the ATN OSI protocol [1] has been modeled; though other technologies (e.g., Future Air Navigation System [FANS]-1/A [4]) can be adapted as needed. Message sizes in bytes for most of the different types of ATN/OSI messages were obtained from reference [5]. The sizes for some of the message types were not documented, and in these cases, engineering judgment was used to determine message size. Message size estimates include protocol-specific factors such as message header and cyclic redundancy check data. Unequipped aircraft will transmit all messages as voice. Equipped aircraft will transmit most messages as data, but depending on conditions, could transmit voice messages as well. As mentioned previously, voice message channel occupancy, and other statistics have been obtained from voice tape transcriptions [2].

In addition to message lengths, the latency of the communication infrastructure (time to transmit the message from the ground to the air and from the air to the ground) must be accounted for. This time must include: the time to transmit the message through the various ground systems such as the display systems, automation systems, and the communications subnetworks; and the time for a human to respond for those messages that have a human in the loop. The latency values used are distributions reflecting the uncertainty of the latency contributions of various elements of the end-to-end chain of contributors.

2.1 Message Uplink/Downlink Transmission Time

In addition to the message lengths, the time to transmit the messages through the data-link equipment (ground and air) and the ground telecommunications systems, including the Federal Aviation Administration (FAA) Telecommunications Infrastructure (FTI), is accounted for in a generic manner in MLM. Figure 2-1 shows the various components of the path through which the message must traverse. For cases in which a human response is required, Figure 2-1[1] shows the human response time. The CPDLC Specification, Version 2.0, Section 3.4.4.1.3 [6] provides specifications for end-to-end delays. Only the overall means for the total transit delay of 7.3 seconds (s) and the human response time of 25 s were used in MLM. For the current version of MLM, a uniform distribution is used for both transit time and human response time. The standard deviations are not readily available for the transit time and for the human response time so that distributions such as the normal or lognormal distribution could be used. Thus, for the transit time a uniform distribution is applied to the interval [5.3 s, 9.3 s], i.e., 2 s around the mean of 7.3 s; and for the human response time, it is applied to the interval [15 s, 35 s], i.e., 10 s around the mean of 25 s. Although a uniform distribution is currently used, it is not difficult to change this in MLM to some other distribution such as the normal or lognormal distribution when the standard deviations are known.

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[1] Figure developed by Stephen Giles, The MITRE Corporation.

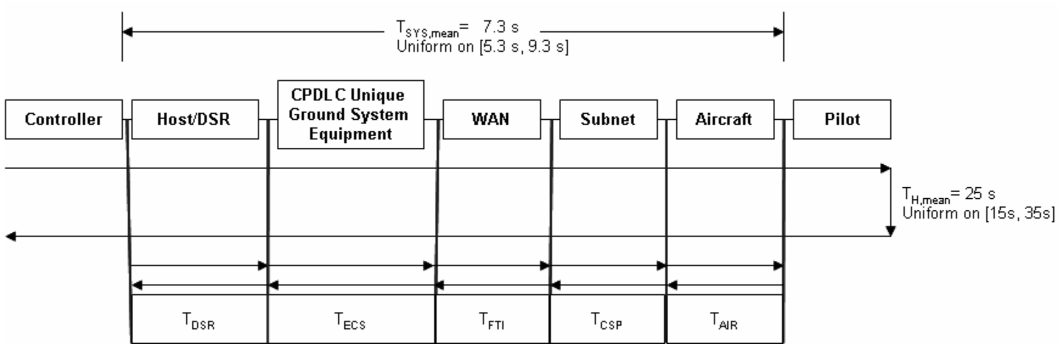

Figure 2-1. Message Uplink/Downlink Path

2.2 Data-Link Messages

For ATN/OSI equipped aircraft, there are a series of tables from RTCA DO-280 [1] that characterize the uplink and downlink communications between a controller and pilot for different dialogue types. Only the basic elements from the various tables have been incorporated into MLM. The various timers used to put upper limits on the time to receive a message, causing retransmission if a message has not been received within the time limit, have not been incorporated, for example. This is something that can be done in a later stage of development of MLM if desired.

2.2.1 Data Link Initiation Capability (DLIC)

For ATN/OSI-equipped aircraft the sequence of messages shown in Table 2-1 is used. This sequence of uplink and downlink messages can be found in reference [5]. The message sizes in bytes were obtained from reference [5]. "D" refers to downlink from pilot to controller, and "U" to uplink from controller to pilot. The DLIC timing diagram in Figure 2-2 is a portion of Figure 4-1 of RTCA DO-280 [1]. The timing diagram indicates the sender and receiver of each message by arrow direction. Increasing time is in the downward direction. Thus, a line slanted downward according to arrow direction in the communications portion of the timing diagram means that some time must transpire to transmit the message.

Table 2-1. ATN/OSI DLIC Message

Message Type	Direction	Number of Bytes
CPDLC Logon Request	D	168
CPDLC Logon Response	U	105
Total		273

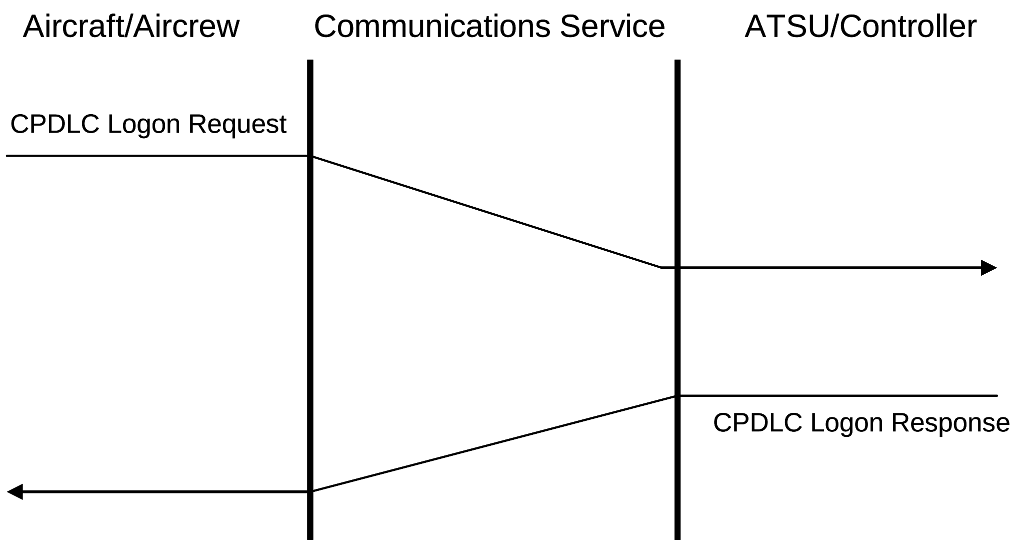

Figure 2-2. ATN/OSI DLIC Logon/Contact Timing Diagram

2.2.2 TRACON-to-Center Communications

Table 2-2, based on Table 4-4 of reference [1], shows the sequence of messages, transmitted both uplink and downlink for transfer of communications (TOC) and initial contact (IC), at a parameter time (see Section 5.1), supplied as input to MLM, prior to an aircraft transitioning from terminal airspace to en route airspace. Use of this dynamic behavior is based on the assumption that CPDLC is available only in en route airspace, so voice must be used for transactions not otherwise supported by CPDLC. Figure 2-3 shows the corresponding timing diagram, which is a modification of Figure 4-4 of reference [1]. Since the underlying assumption is that CPDLC is used only in en route airspace, the Terminal Radar Approach Control (TRACON)-to-Center scenario is referred to as transferring-air traffic service unit (T-ATSU) not using CPDLC to receiving-ATSU (R-ATSU) using CPDLC. Note that the aircraft must log onto CPDLC prior to entering the center's airspace. Message sizes were obtained from reference [5].

Table 2-2. ATN OSI TOC for TRACON-to-Center Communications

Segment	Message Type	Direction	Number of Bytes	Duration (seconds)
1.	CPDLC Start Request	U	98	
2.	CPDLC Start Response	D	83	
3.	Current Data Authority (CDA)	D (DM99)	83	
4.	LACK	U (UM227)	83	
5.	Voice Contact Instruction** (includes handoff, handoff acknowledgment, and intervening response time)	U	N/A	7.44*
6.	Voice Mode-C Contact*** (includes initial call, initial call acknowledgment, and intervening response time)	D	N/A	7.30*
	Total		347	

*average over ZFW, ZTL, ZDV from voice tape transcription data [2] – also see Table 2-10 for details regarding a further breakdown of this message with means, standard deviations, and response times

** implemented in MLM as occurring simultaneously with segment 1, whereas in fact segments 1 and 5 occur independently of each other[2]

*** assumption - occurs 30 seconds after the end of segment 5, and is supported by another communication asset

[2] Edward Brestle, The MITRE Corporation

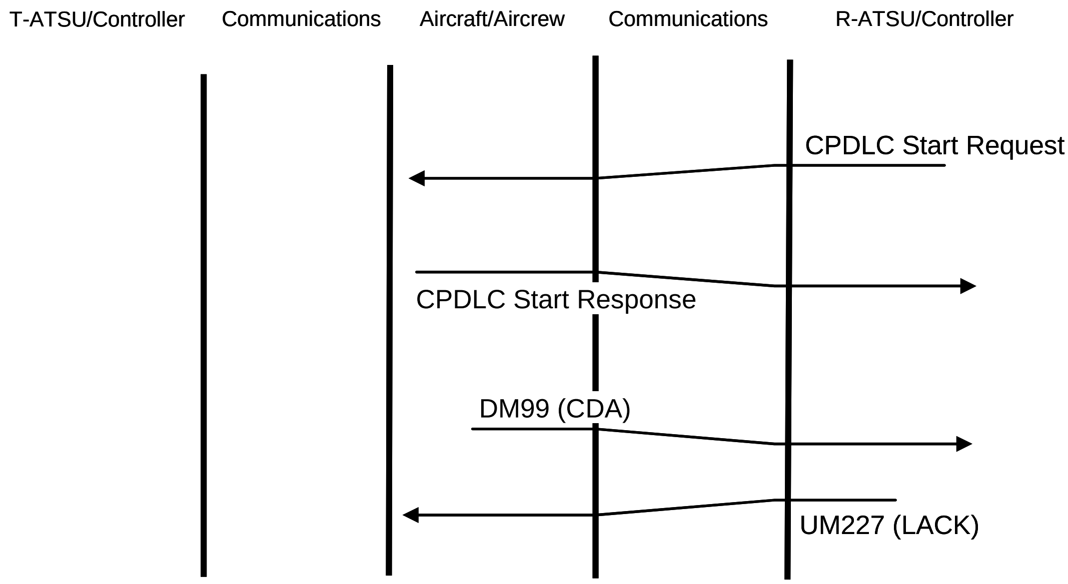

Figure 2-3. TRACON-to-Center Communications Timing Diagram

2.2.3 Center-to-Center Communications

Table 2-3 shows the sequence of messages, and their sizes, that are transmitted at a parameter time (see Section 5.1), supplied as input to MLM, prior to an aircraft crossing center boundaries. Table 2-3 is based on Table 4-3 of reference [1] for T-ATSU using CPDLC and R-ATSU using CPDLC. Figure 2-4 shows the corresponding timing diagram, and is a modification of Figure 4-2 of reference [1]. Note that when transferring from one center to another, the aircraft must log off from the current center and log on to the next center into which the aircraft will travel. Message sizes were obtained from reference [5].

Table 2-3. ATN/OSI TOC for Center-to-Center Communications

Segment	Message Type	Direction	Number of Bytes	Duration (seconds)
1.	Next Data Authority (NDA)	U (UM160)	88	
2.	LACK	D (DM100)	83	
3.	CPDLC Start Request	U	98	
4.	CPDLC Start Response	D	83	
5.	Contact/CPDLC End Request	U (UM117/UM CPDLC End	123 + 98 = 221	
6.	LACK	D (DM100)	83	
7.	WILCO/CPDLC End Response*	D (DM0/DM CPDLC End)	83 + 83 = 166	
8.	Current Data Authority (CDA)	D (DM99)	83	
9.	Voice Mode-C Contact** (includes initial call, initial call acknowledgment, and intervening response time)	D	N/A	7.3***
10.	LACK	U (UM227)	83	
	Total		988	

* occurs at the start of segment 6 at a time drawn randomly in the interval [15 s, 35 s]

** occurs 30 seconds after segment 7

*** Average over ZFW, ZTL, ZDV from voice tape transcription data [2] – also see Table 2-10 for details regarding a further breakdown of this message with means, standard deviations, and response times

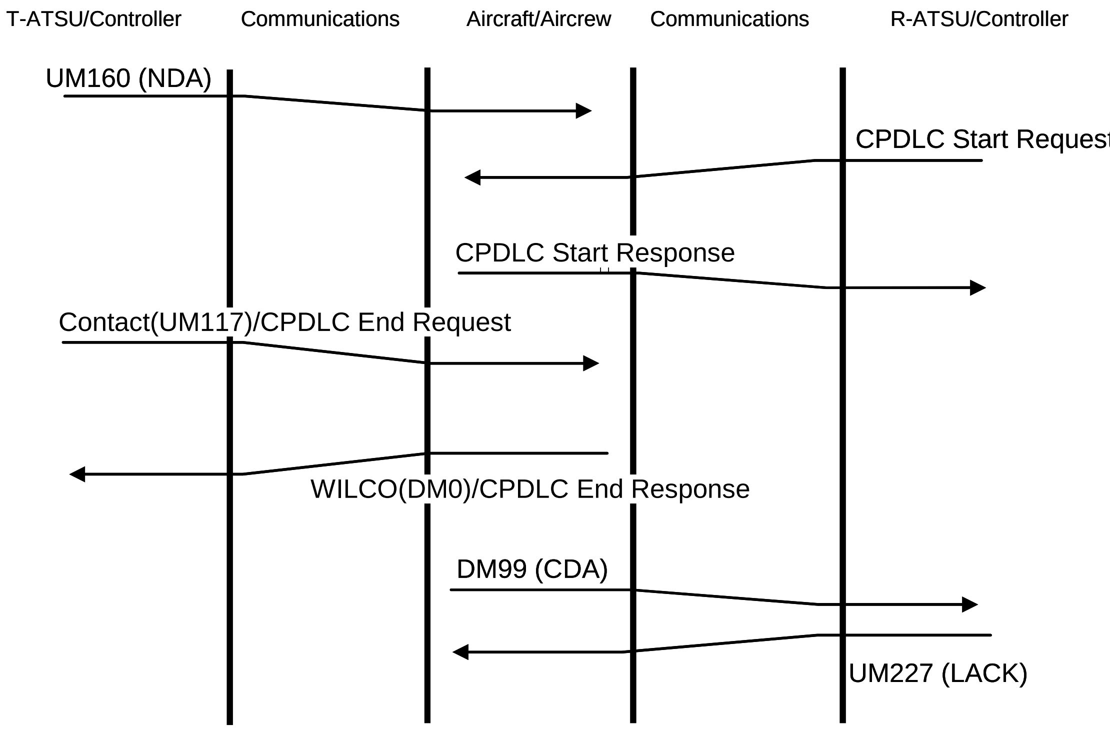

Figure 2-4. Center-to-Center Communications Timing Diagram

2.2.4 Within Center Sector Boundary Crossing Communications

Table 2-4 shows the sequence of messages, and their sizes, that are transmitted at a parameter time (see Section 5.1), specified as input to MLM, prior to an aircraft crossing sector boundaries within the same center. Table 2-4 is based on Table 4-6 of reference [1] for transfers or change of frequency using CPDLC with no change of CDPLC connection, and where the T-ATSU and R-ATSU both use CPDLC. Currently, all sectors in en route airspace are assumed to be CPDLC-capable, although there could be situations where there are some sectors not using CPDLC as, for example, during the transition to CPDLC. This latter scenario is accounted for in reference [1]; however, it has not been modeled in MLM. Figure 2-5 shows the corresponding timing diagram for the scenario modeled, and is a modification of Figure 4-9 of reference [1]. Note that when transferring from one sector to another within the same center, there is no need for the aircraft to log off from CPDLC. Messages sizes were obtained from reference [5].

Table 2-4. ATN OSI TOC for Within Center Sector Boundary Crossing Communications

Segment	Message Type	Direction	Number of Bytes
1.	Monitor/Confirm Assigned Level	U (UM120/UM135)	121 + 83**
2.	LACK	D (DM100)	83
3.	WILCO/Assigned Level*	D (DM0/DM32)	83 + 83**
4.	LACK	U (UM227)	83
	Total		536

*occurs at the start of segment 2 at a time drawn randomly in the interval [15 s, 35 s]

**assumption

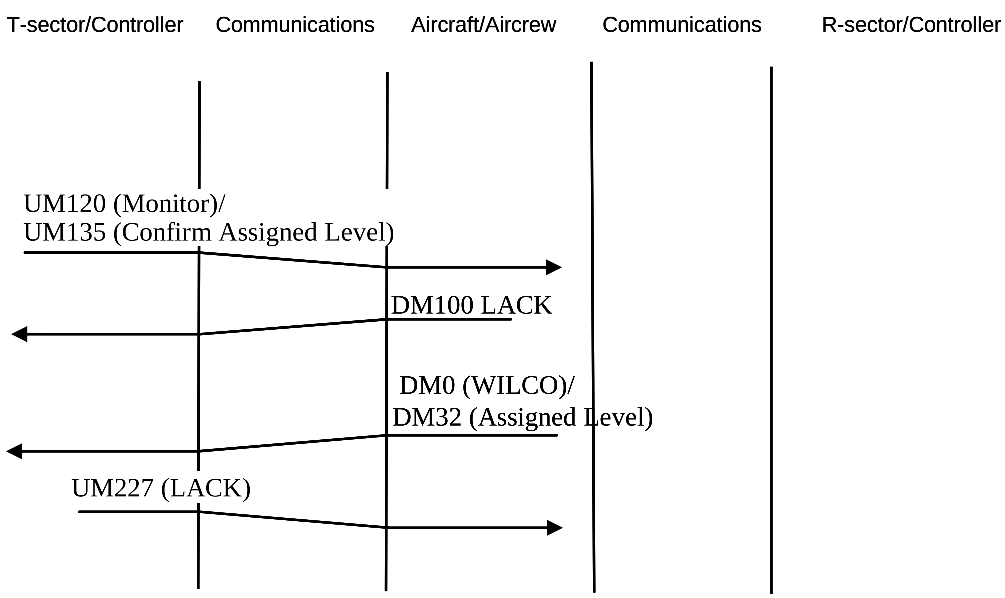

Figure 2-5. Within Center Sector Boundary Crossing Communications Timing Diagram

2.2.5 Center-to-TRACON Communications

Table 2-5 shows the sequence of messages, and their sizes, that are transmitted at a parameter time (see Section 5.1), supplied as input to MLM, prior to the aircraft crossing from en route airspace where CPDLC is used to terminal airspace where it is not used. Table 2-5 is based on Table 4-3 of reference [1] for T-ATSU using CPDLC and R-ATSU not using CPDLC.

Figure 2-6 shows the corresponding timing diagram, and is a modification of Figure 4-2 of reference [1]. Note that when transferring from a center to terminal airspace, the aircraft must log off from CPDLC. Message sizes were obtained from reference [5].

Table 2-5. ATN OSI TOC for Center-to-TRACON Communications

Segment	Message Type	Direction	Number of Bytes	Duration (seconds)
1.	Next Data Authority (NDA)	U (UM160)	88	
2.	LACK	D (DM100)	83	
3.	Contact/CPDLC End Request	U (UM117/UM CPDLC End)	123 + 98 = 221	
4.	LACK	D (DM100)	83	
5.	WILCO/CPDLC End Response*	D (DM0/DM CPDLC End)	83 + 83 = 166	
6.	Voice Mode-C Contact** (includes initial call, initial call acknowledgment, and intervening response time)	D	N/A	7.3***
	Total		641	

* occurs at the start of segment 4 at a time drawn randomly in the interval [15 s, 35 s]

** occurs 30 seconds after segment 5

***Average over ZFW, ZTL, ZDV from voice tape transcription data [2] – also see Table 2-10 for details regarding a further breakdown of this message with means, standard deviations, and response times

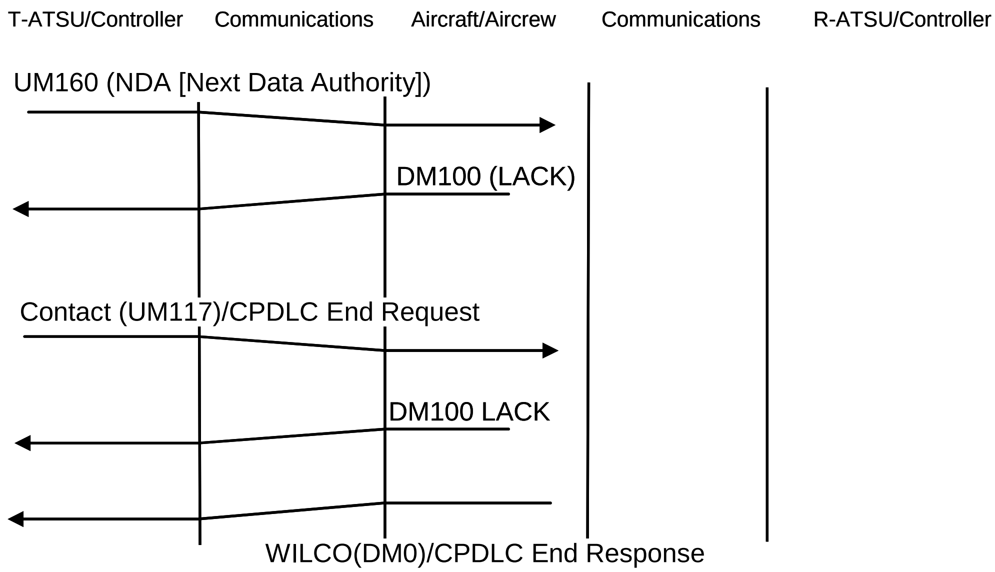

Figure 2-6. Center-to-TRACON Communications Timing Diagram

2.2.6 Top-of-Descent Communications

Table 2-6 shows the sequence of message segments, and their sizes, that are transmitted as an equipped aircraft is a parameter time (see Section 5.1), supplied as input to MLM, before leaving the last en route sector. Table 2-6 is based on Table 4-12 of reference [1]. Figure 2-6 shows the corresponding timing diagram, and is a modification of Figure 4-2 of reference [1]. The designations downlink message (DM) 109 and uplink message (UM) 83 for preferred start and position/route clearance, respectively, are provided in reference [1]. Sizes for these message segments were not available, and thus the values shown in the table are assumed values.

Table 2-6. ATN OSI Top-of-Descent Communications

Segment	Message Type	Direction	Number of Bytes
1.	Top-of-Descent (preferred start)	D (DM109)	84*
2.	At (position) Cleared (route clearance)**	U (UM83)	93*
3.	LACK	D (DM100)	83
4.	WILCO***	D (DM0)	82
5.	LACK	U (UM227)	83
	Total		425

* assumption

** occurs at the end of segment 1 at a time drawn randomly in the interval [15 s, 35 s]

*** occurs at the start of segment 3 at a time drawn randomly in the interval [15 s, 35 s]

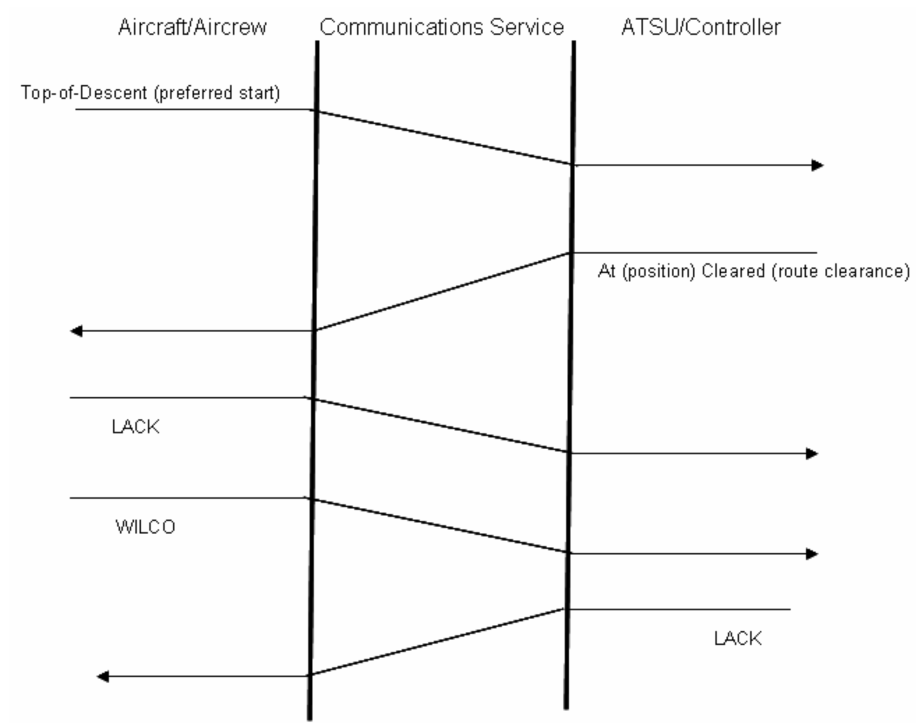

Figure 2-7. Timing Diagram for ATN OSI Top-of-Descent Communications

2.2.7 Controller-Initiated Status/Advisory Communications

Table 2-7, based on Table 4-13 of reference [1], shows the sequence of messages transmitted for the following controller-initiated exchanges: altimeter setting instruction, beacon code setting instruction, weather advisories, and traffic advisories. Reference [1] provides UM123 and UM213 as the designations for beacon code setting and altimeter setting instructions, respectively. No designations were provided for weather and traffic advisories in reference [1]. Also, the sizes of the advisory/status messages were not provided, therefore, currently, an assumption of 84 bytes is used. "WILCO" is used in Table 2-7 for the pilot's response to the controller's status or advisory message. Other responses are possible such as "no response required" or "ROGER", depending on the response attribute of the uplink. Future enhancements of MLM could possibly take this into account if it is deemed that the difference in the pilot's response makes a significant difference in the results of the model. Figure 2-8 shows the corresponding timing diagram, and is a modification of Figure 4-21 of reference [1].

Table 2-7. ATN OSI Status/Advisory Communications

Segment	Message Type	Direction	Number of Bytes
1.	Status or Advisory	U (UMxxx)	84*
2.	LACK	D (DM100)	83
3.	WILCO**	D (DM0)	82
4.	LACK	U (UM227)	83
	Total		332

*assumption

**occurs at the start of segment 2 at a time drawn randomly in the interval [15 s, 35 s]

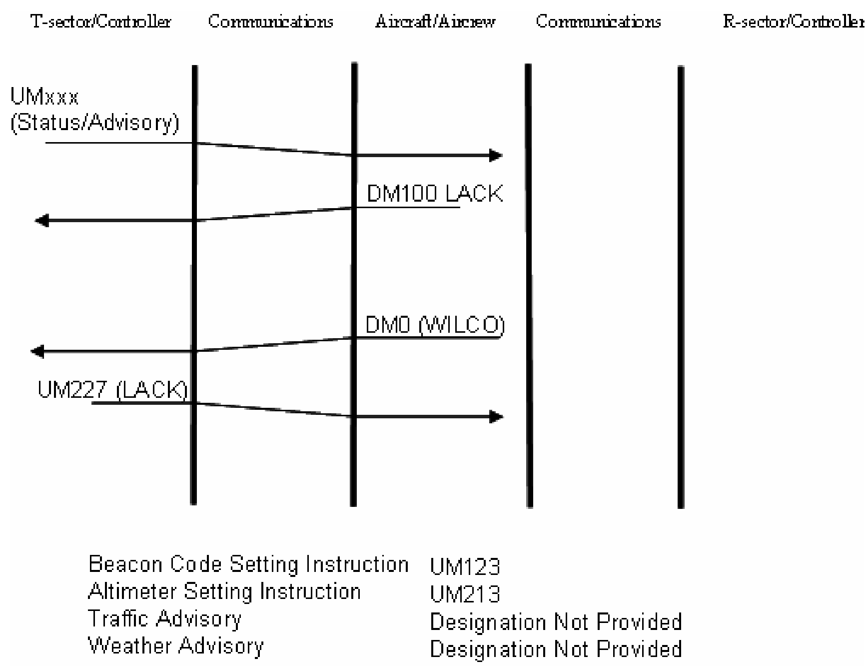

Figure 2-8. Controller-Initiated Status/Advisory Communications Timing Diagram

2.2.8 Pilot-Initiated Clearance Request Communications

The pilot requests for clearances that have been incorporated into MLM are requests for altitude and route clearances. Table 2-8, based on Table 4-12 of reference [1], shows the sequence of messages transmitted. Figure 2-9 shows the timing diagram used for these clearance requests, and is based on Figure 4-20 of reference [1]. The designations DM9 and DM24 have been provided in reference [1] for altitude and route changes, respectively. Reference [5] provides

84 bytes for altitude and 93 bytes for route clearance requests. Various messages can be provided for the controller response to the clearance requests. For an assigned altitude provided in response to the altitude clearance request, UM20, UM28, or UM171, each of 83 bytes [2] can be provided. For assigned route, UM83 is assumed to be 84 bytes.

Table 2-8. ATN OSI Pilot-Initiated Clearance Request Communications

Segment	Message Type	Direction	Number of Bytes
1.	Clearance Request	D (DMxxx)	A: 84, R: 93
2.	LACK	U (UM227)	83
3.	Standby**	U (UM1)	82*
4.	LACK	D (DM100)	83
5.	Clearance ***	U (UMxxx)	A: 83, R: 84
6.	LACK	D (DM100)	83
	Total		A: 498, R: 508

*assumed same size as downlink "standby (DM2)"

**occurs at the start of segment 2 at a time drawn randomly from the interval [15 s, 35 s]

***occurs 30 seconds after segment 3[3]

[3] Edward Brestle, The MITRE Corporation.

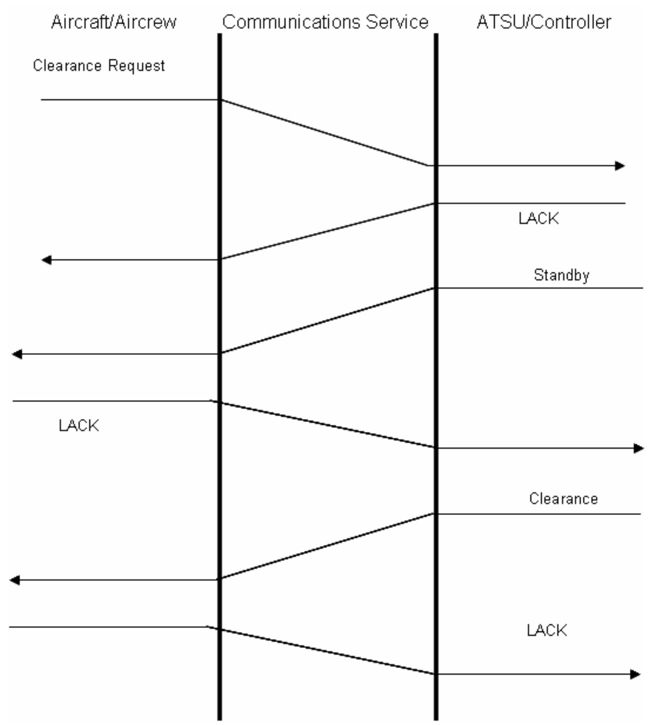

Figure 2-9. Pilot-Initiated Clearance Request Communications Timing Diagram

2.2.9 Controller-Initiated Clearance Communications

The controller-initiated clearances that have been incorporated into MLM are: heading, altitude, route, speed, and crossing constraints. Table 2-9, based on Table 4-13 of reference [1], shows the sequence of messages transmitted. Figure 2-10 shows the timing diagram used for these controller-initiated clearances, and is based on Figure 4-22 of reference [1]. The designations UM20/UM28/UM171, UM215, UM55, and UM83 have been provided in reference [1] for altitude (A), heading (H), speed (S), route changes (R) and crossing constraints (C), respectively. Reference [5] provides 84 bytes for altitude, 84 bytes for heading clearances, 94 bytes for speed clearances, and 95 bytes for crossing constraints. An assumption of 84 bytes was made for route clearances.

Table 2-9. ATN OSI Controller-Initiated Clearance Communications

Segment	Message Type	Direction	Number of Bytes
1.	Clearance	U (UMxxx)	A/H/R*: 84, S: 94, C: 95
2.	LACK	D (DM100)	83
3.	WILCO**	D (DM0)	82
4.	LACK	U (UM227)	83
	Total		A/H/R: 332, S: 342, C: 343

*assumption for R

**occurs at the start of segment 2 at a time drawn randomly from the interval [15 s, 35 s]

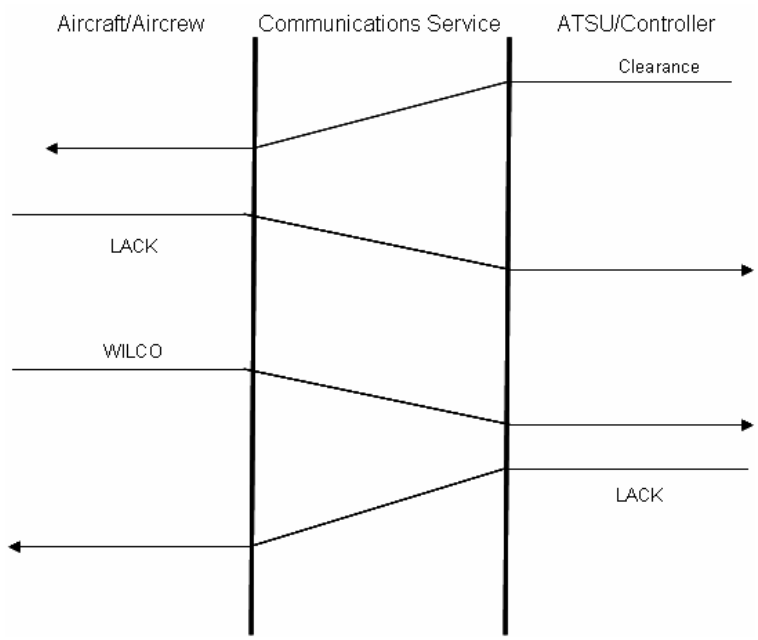

Figure 2-10. Timing Diagram for Controller-Initiated Clearance Communications

2.3 Voice Messages

Voice messages are transmitted for aircraft designated as unequipped and even for equipped aircraft depending on the conditions under which the message is sent. The following sections show all of the voice messages that have been implemented thus far in MLM.

2.3.1 Voice Handoff and Initial Call Communications

Table 2-10 shows the sequence of messages that are transmitted, and Figure 2-11 shows the timing diagram for voice handoff and initial call messages. Transfer of communications or handoffs and initial contact messages are transmitted using voice for unequipped aircraft for arrival (Airport Traffic Control Tower [ATCT]-to-TRACON), TRACON-to-center, sector-to-sector within the same center, center-to-TRACON, and departure (TRACON-to-ATCT). In addition, because the terminal area is assumed not to be data-link capable, handoffs and initial contact messages for equipped aircraft are transmitted using voice for ATCT-to-TRACON and TRACON-to-Center (message segments 5 and 6 of Table 2-2). The initial call message portion of the message sequence for equipped aircraft for center-to-center (see Table 2-3) and center-to-TRACON (see Table 2-5) is transmitted as a voice message for equipped aircraft.

The handoff and initial call message duration means and standard deviations as shown in Table 2-10 were obtained from reference [2], and are applicable to en route airspace. Since no data on voice transactions was available for the terminal area, handoffs and initial calls are the only voice messages implemented there. There is other voice dialogue that takes place in the terminal areas, and should be included in future versions of MLM when data regarding that voice dialogue becomes known. During an MLM simulation, the message durations are drawn from a normal distribution with means and standard deviations as shown in Table 2-10. The response times are assumed to be constant.

Table 2-10. Voice Handoff and Initial Call Communications

Segment	Message Type	Direction	Duration Mean/SD (seconds)	Response Time (seconds)
1.	Handoff	U	4.1/0.98	
				Pilot: 0.87
2.	Handoff Acknowledgment	D	2.47/0.69	
	Total Handoff**		7.44	
3.	Initial Call*	D	3.6/1.08	
				Controller: 1.1
4.	Initial Call Acknowledgment	U	2.6/1.57	
	Total Initial Call**		7.3	

*segment 3 occurs 30 seconds after segment 2

**includes response time

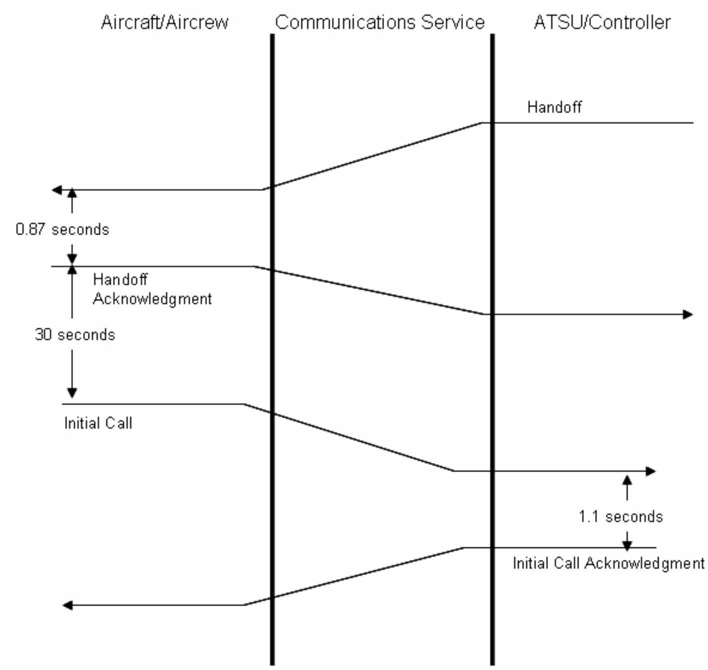

Figure 2-11. Timing Diagram for Voice Handoffs and Initial Call Communication

2.3.2 Controller-Initiated Status/Advisory Voice Communications

Table 2-11 shows the sequence of voice messages transmitted for the following controller-initiated exchanges: altimeter setting instruction, beacon code setting instruction, weather advisories, and traffic advisories. During an MLM simulation, the message durations are drawn from a normal distribution with means and standard deviations as shown in Table 2-11 that were derived from the voice tape transcription analysis [2]. The response times are assumed to be constant. Figure 2-12 shows the corresponding timing diagram.

Table 2-11. Controller-Initiated Voice Status/Advisory Voice Communications

Segment	1		2	
Message Type	**Status/Advisory (Uplink) Duration Mean/SD (seconds)**	**Status/Advisory Response Time Mean/SD (seconds)**	**Status/Advisory Acknowledgment (Downlink) Duration Mean/SD (seconds)**	**Total* (seconds)**
Altimeter Setting	2.04/0.34	0.78	1.68/0.54	4.50
Beacon Code Setting	3.45/0.62	0.80	2.24/0.63	6.49
Weather Advisory	3.58/2.1	1.88	2.34/1.52	7.80
Traffic Advisory	1.48/0.59	1.16	4.81/2.58	7.45

*includes response time

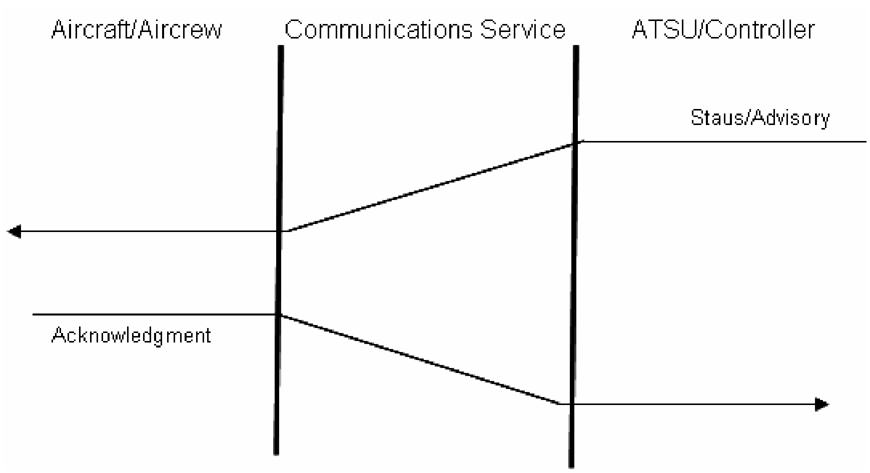

Figure 2-12. Timing Diagram for Controller-Initiated Status/Advisory Voice Communications

2.3.3 Pilot-Initiated Clearance Request and Top of Descent Voice Communications

The pilot requests for clearances using voice that have been incorporated into MLM are requests for altitude and route clearances, and these are shown in Table 2-12. Top of Descent for voice was modeled as a pilot request for altitude clearance, because there was no data available corresponding to Top of Descent in the voice tape transcription data. A Top of Descent message would in fact be more complex than an altitude clearance. The durations of the messages and the response times were derived from the voice tape transcription data. Reference [2] shows the durations and response times for pilot requests, a category in which pilot requests for altitude changes and route changes were combined. A separate analysis was performed to breakout altitude and route messages. Figure 2-13 shows the corresponding timing diagram. During an MLM simulation, the message durations are drawn from a normal distribution with means and standard deviations as shown in Table 2-12. The response times are assumed to be constant.

Table 2-12. Pilot-Initiated Clearance Request and Top of Descent Voice Communications

Segment	**1**		**2**	
Message Type	**Pilot Request (Downlink) Duration Mean/SD (seconds)**	**Response Time (seconds)**	**Clearance (Uplink) Duration Mean/SD (seconds)**	**Total* (seconds)**
Altitude **	3.48/1.31	2.27	3.50/1.68	9.25
Route	4.02/1.76	2.27	3.28/2.63	9.57

*includes response time

** used for Top of Descent

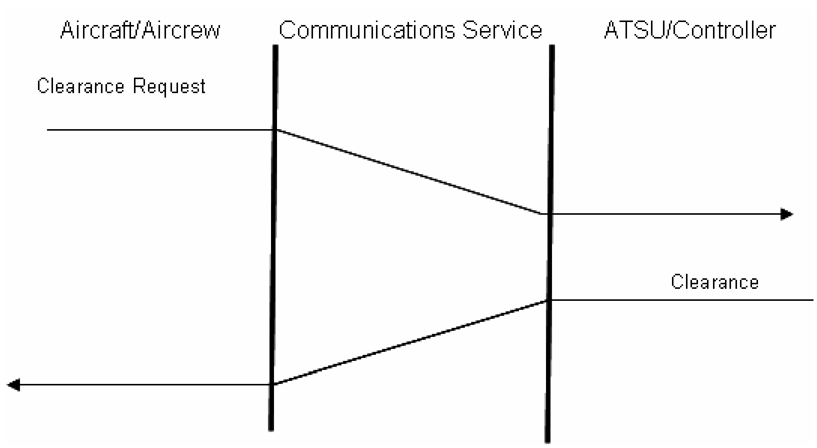

Figure 2-13. Timing Diagram for Pilot-Initiated Clearance Request and Top of Descent Voice Communications

2.3.4 Controller-Initiated Voice Clearance Communications

The controller-initiated voice clearances that have been incorporated into MLM are: heading, altitude, route, speed, and crossing constraints. Table 2-13 shows the sequence of voice messages transmitted with the corresponding duration means and standard deviations derived from the voice tape transcription analysis [2]. Figure 2-14 shows the timing diagram used for these controller-initiated clearances. During an MLM simulation, the message durations are drawn from a normal distribution with means and standard deviations as shown in Table 2-13. The response times are assumed to be constant.

Table 2-13. Controller-Initiated Voice Clearance Communications

Segment	1		2	
Message Type	**Clearance (Uplink) Duration Mean/SD (seconds)**	**Clearance Response Time Mean/SD (seconds)**	**Clearance Acknowledgment (Downlink) Duration Mean/SD (seconds)**	**Total* (seconds)**
Heading	4.67/2.13	0.77	3.03/1.3	8.47
Altitude	4.2/1.63	0.73	3.03/1.1	7.96
Route	3.23/1.24	1.0	2.37/0.87	6.60
Crossing Constraint	3.34/0.69	1.13	4.76/0.55	9.23
Speed	4.53/1.32	0.60	2.80/0.79	7.93

*includes response time

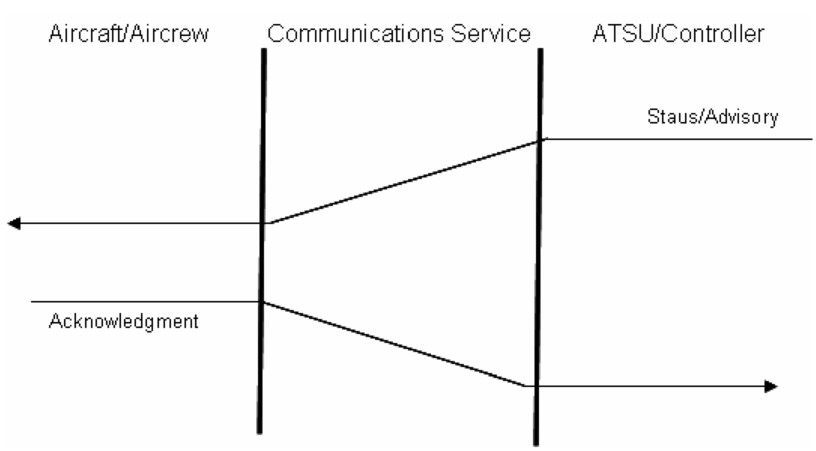

Figure 2-14. Timing Diagram for Controller-Initiated Voice Clearance Communications

3 Communications Message Triggering Events

This section describes the methodology used to identify communications message triggering events, and the mapping of the communications messages described in Section 2 to those triggering events. There are four basic methods used to identify communications message triggering events:

- MLM-generated events such as pushback, departure, and arrival trigger DLIC logon, departure clearance, and arrival clearance messages, respectively.
- Proximity events where aircraft that are within a certain distance of a sector boundary or of another aircraft would trigger a communications message to be sent.
- The host amendment field in the ETMS data contains any changes to the flight plan entered by controllers (not all are entered) as a result of altitude or route (fix) clearances. For each of these amendments found, it is assumed in MLM that some communications transpired between the controller and pilot. These clearances are simply referred to in this document as miscellaneous clearances. The location of where these clearances were given can be derived from the ETMS data, and used as a trigger for the simulation to send these messages when the aircraft arrives at this location during a simulation run.
- The voice tape transcription data are used to supplement the miscellaneous clearances in the host amendment data, since it is known that not all communications are recorded in the host amendment data. The frequency of occurrence of these messages are determined based on a statistical analysis of the voice tape transcription data, and those frequencies of occurrence are used to randomly generate triggers for the different types of messages found in the voice tape transcription data.

Figure 3-1 summarizes the different methods of generating triggers during a simulation run. The following sections discuss each of these methods.

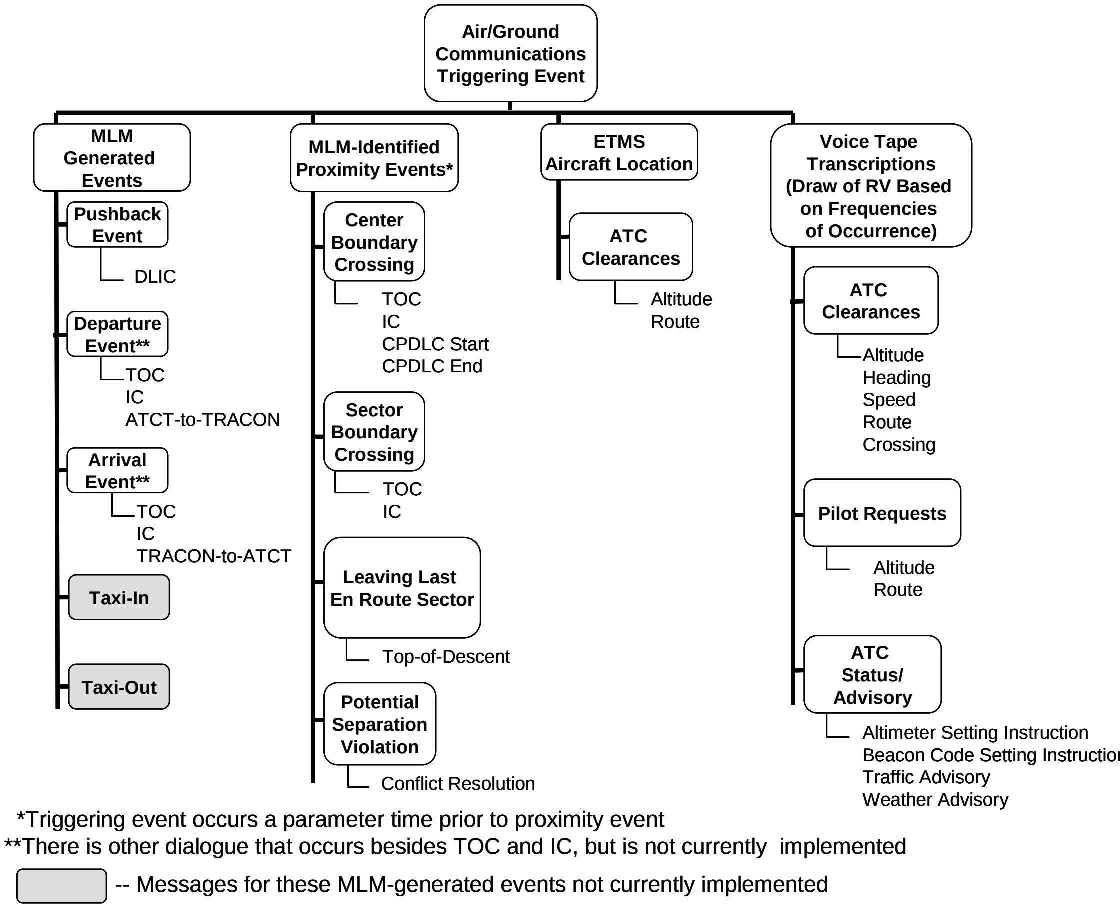

Figure 3-1. Communications Message Triggering Methods

3.1 MLM-Generated Communications Message Triggers

Figure 3-2 shows the MLM-generated events that trigger DLIC, departure clearance, and arrival clearance messages to be sent.

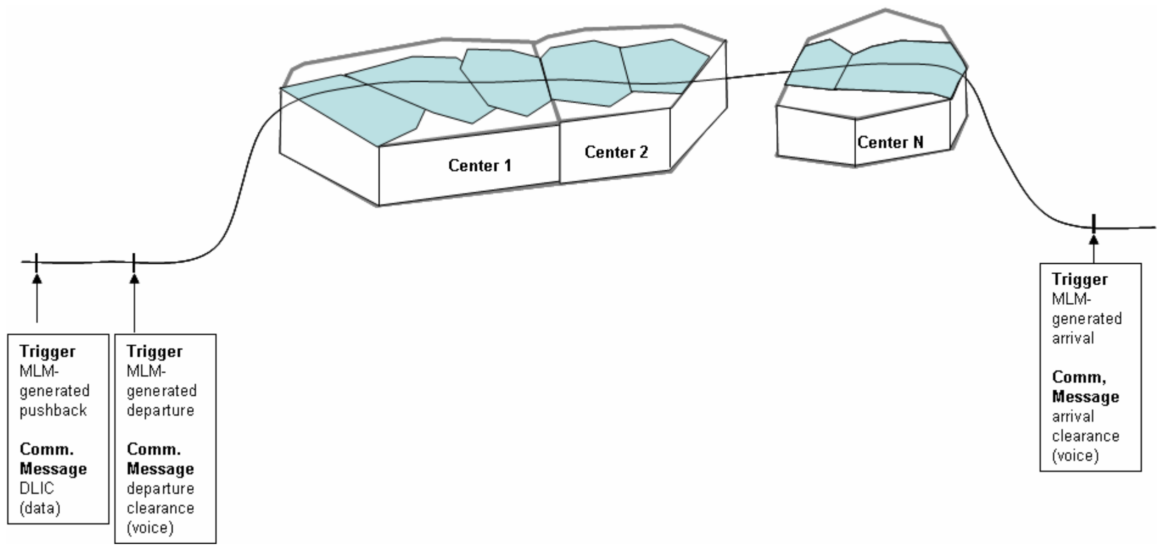

Figure 3-2. Communications Message Triggering Events Based on MLM-Generated Events

3.2 Communications Message Triggers from Proximity Events

Center and sector boundary crossings are events that would give rise to such communications messages as handoffs and initial contacts. Center crossings, in addition, give rise to CPDLC start and end messages. These crossings can be detected by MLM by using sector boundary data, which is available to MLM. A corresponding trigger for any one of these events occurs at a user-specified time (see Section 5.1) prior to an aircraft's reaching the center or sector boundary. This capability to look ahead is referred to as a "headlight function." Currently, the times used are not drawn from a probability distribution function, but are fixed values. It would be relatively easy to upgrade MLM so that a probability distribution function is used.

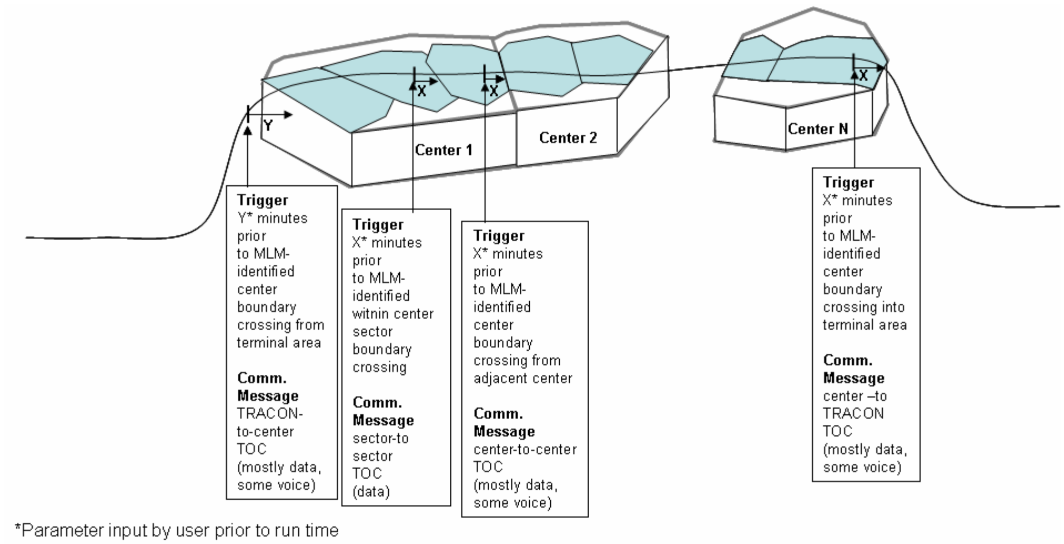

Figure 3-3. Triggering Events from Center and Sector Boundary Crossings

Proximity events where aircraft violate a separation buffer, thereby triggering a conflict resolution message from the controller to the pilot are shown in Figures 3-4 and 3-5. When an aircraft enters a sector, a check is made to determine whether there will be a 5 nmi lateral separation violation, and a 1000 ft. vertical separation violation between it and any other aircraft in the sector. If it is determined that there will be a separation encroachment, then a conflict resolution message is sent to the entering aircraft of the pair x minutes prior to when the conflict is predicted to occur, where x is supplied by the user as input (see Section 5.1). Figure 3-4 depicts the case where the user has specified x = 3 minutes. If the time to separation violation is less than 4 minutes, the conflict resolution message is sent as voice to equipped aircraft, and if the time to separation violation is greater than 4 minutes, then the message is sent as data to equipped aircraft, as shown in Figure 3-5. In MLM, conflict resolution messages are sent either as a heading clearance or an altitude clearance where 80% are heading clearances and 20% are altitude clearances.[4]

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[4] Edward Brestle, The MITRE Corporation.

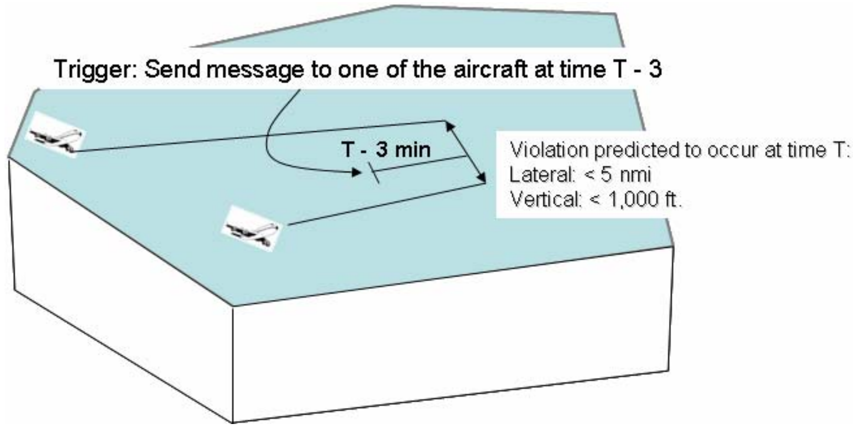

Figure 3-4. Determining Conflict Resolution Message Triggering Time for Equipped and Unequipped Aircraft

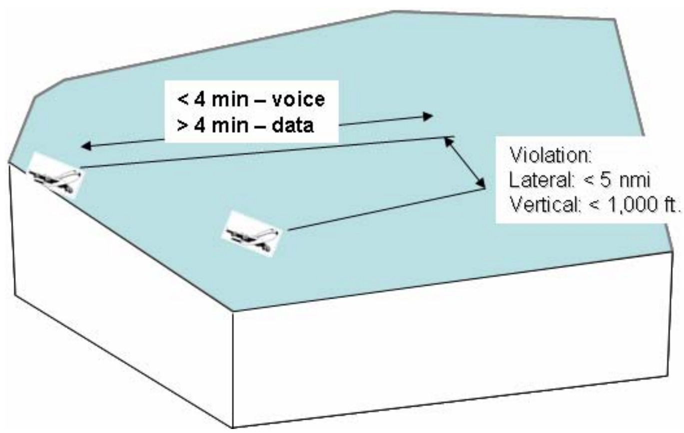

Figure 3-5. Determining Conflict Resolution Message Type as Voice or Data for Equipped Aircraft

3.3 Communications Message Triggers from ETMS Host Amendments

Communications messages (refer to Figure 3-1) besides those triggered by MLM-generated events and those triggered by proximities are referred to as miscellaneous clearances, and include heading, altitude, route, speed, and crossing clearances, pilot requests for clearances, and status and advisory messages. In the host amendment field of the ETMS data the miscellaneous messages that can be partially accounted for are altitude and route clearances. Times of occurrence are provided for these communications messages in the host amendment field; however, these times are not useful to MLM, because the time/location association for each aircraft as determined during a simulation would differ somewhat from the actual ETMS data. It was determined that the location (instead of the time) given in the ETMS data where a miscellaneous clearance was sent, would be matched to the location where that message would be sent in the simulation. Only for the route clearance message is the latitude and longitude of the location of the aircraft provided. A pre-processing step was used (see Section 5.1.1) for the altitude clearances to correlate TZ messages, which contain latitude and longitude and time for each location along the track of the aircraft, with the time provided in the host amendment data for those clearances in order to estimate the location of the aircraft where the related communications message was transmitted.

3.4 Triggers Based on Statistics from Voice Tape Transcription Data

Since it is known that not all miscellaneous clearances are recorded in the host amendment field of the ETMS data, statistics on the occurrences of the various messages were determined from the voice tape transcription data, and used in generating miscellaneous clearances. These supplement in MLM the communications messages obtained from the host amendments.

Aircraft time in sector and number of miscellaneous clearances were averaged over nine sectors from three centers – ZFW, ZTL, ZDV, provided in the voice tape transcription data. The result showed that there were 3.3194 miscellaneous clearances per aircraft per sector, and the average time in sector for an aircraft was 8.83 minutes. This implies that there are, on average, 0.38 miscellaneous clearances per aircraft per minute per sector. Based on operational expertise, the number of miscellaneous clearances for any aircraft was capped at three per sector. Thus, the following equation was used to determine the number of miscellaneous messages for any aircraft per sector, where 0.5 is used for rounding-up to the next highest integer:

Equation 1

Number of Misc. Clearances per Aircraft= Min[3, int(0.38 X time in sector + 0.5)]

Table 3-1 shows the percentage of occurrence of the different types of miscellaneous clearances. These percentages are averages across the nine sectors provided in the voice tape transcription data of ZFW, ZTL, and ZDV. The average voice channel occupancy in seconds of the messages is also provided in the table, and includes the response times of the controller or pilot.

Table 3-1. Miscellaneous Clearance Messages

Message Type	Percentage of Occurrence	Average Length Including Response Time (seconds)*
Altitude Request	3.62	9.25
Route Request	8.33	9.57
Heading Clearance	6.62	8.47
Altitude Clearance	37.26	7.96
Fix Clearance (Route Change)	21.38	6.6
Speed Clearance	8.43	7.93
Crossing Constraint	3.67	9.23
Altimeter Setting Instruction	4.02	4.50
Beacon Code Setting Instruction	1.58	6.49
Weather Advisories	2.09	7.80
Traffic Advisories	3.00	7.45

*Includes controller or pilot response time

For an aircraft in a sector, there are times during the simulation when additional miscellaneous clearances are required to supplement those from the host amendments because the number of miscellaneous clearances from the host amendments does not add up to the number derived from Equation 1 above. The manner in which an additional miscellaneous clearance is selected is depicted in Figures 3-5 and 3-6. A uniformly distributed random number between zero and one is generated by MLM. The interval in which it falls determines which additional miscellaneous clearance is sent. If the miscellaneous clearance that is selected happens to be the same as one of the host amendments (if any) that has been generated for that sector, then the recently selected miscellaneous clearance is discarded. Another selection is then made. Selections of miscellaneous clearances are made using the bins until the number of miscellaneous clearances (those in amendments + additional) is equal to the number derived from Equation 1.

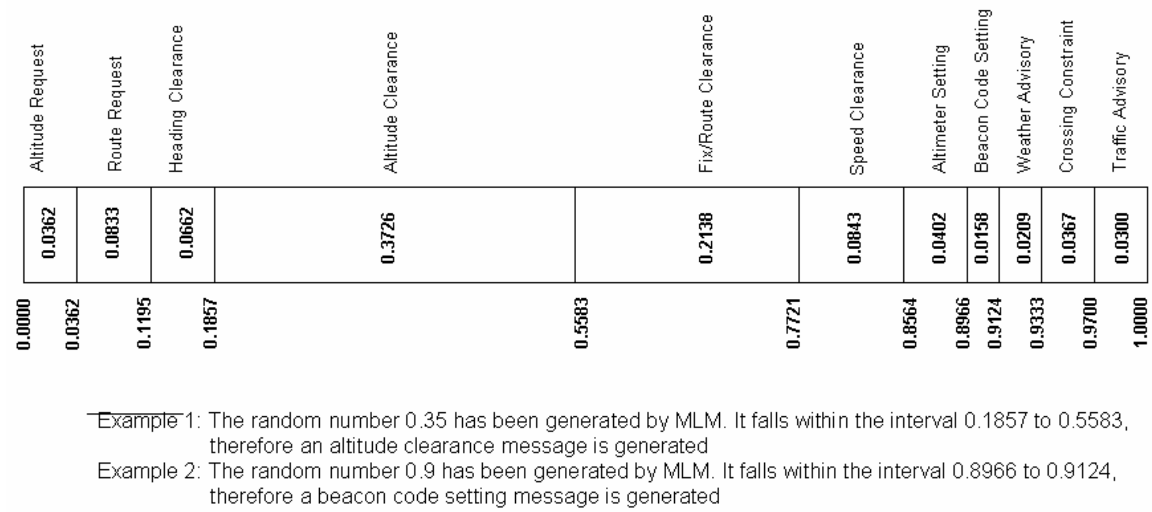

Figure 3-6. Selection of Supplemental Clearances Through Use of Bin

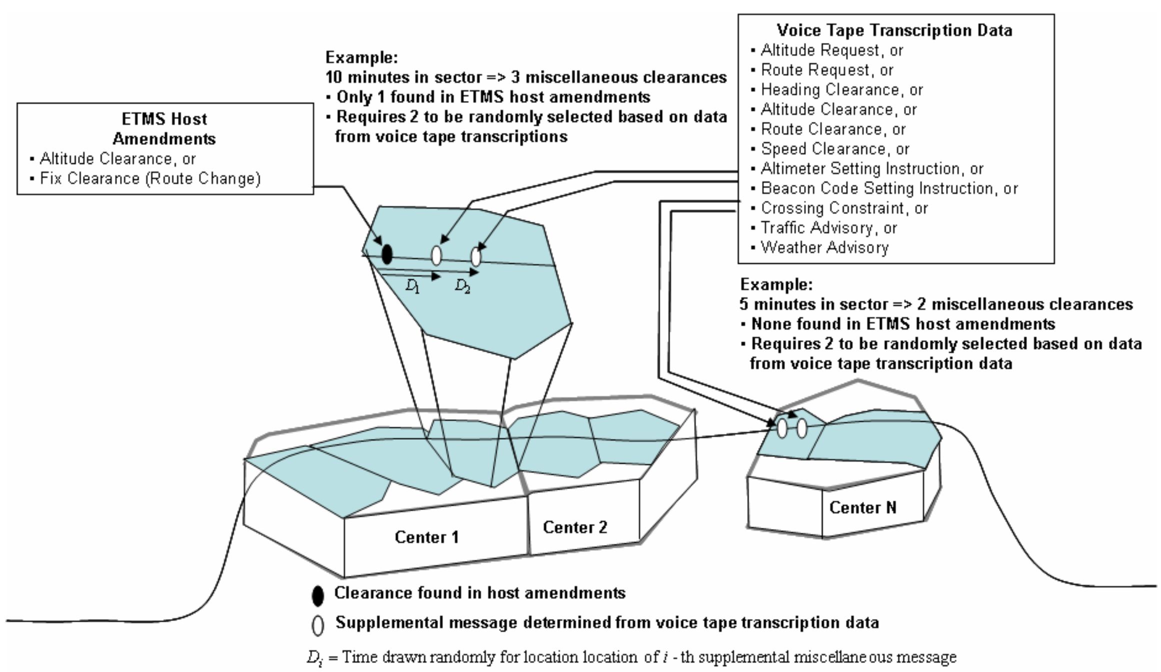

Figure 3-7. Triggering Events for Miscellaneous Clearances

Table 3-2 shows the triggering events, the mapping of communications messages to the triggering events, the references for the structures of the communications messages, the corresponding data message sizes and voice message durations, and either the frequency of the message or the manner in which the frequency was determined.

Table 3-2. Summary Information on Triggering Events and Corresponding Messages

Triggering Event	Data Message	Voice Message	Size – Data (bytes†)	Size – Voice (seconds)	Frequency per Flight
MLM –Generated Push Back	CPDLC Logon Table 2-1, Figure 2-2	NA	273	NA	1
MLM--generated departure ATCT-to-TRACON	NA	Handoff/ Initial Call	NA	7.44/ 7.3*	1
TRACON-to-Center Boundary Crossing – 2 min.	TOC/IC for Unequipped ATSU to Equipped ATSU Table 2-2, Figure 2-3	Handoff/ Initial Call	347	7.44/ 7.3*	1
Center-to-Center Boundary Crossing – 2 min.	TOC/IC for Equipped ATSU to Equipped ATSU Table 2-3, Figure 2-4	Handoff/ Initial Call	988	7.44/ 7.3*	Number of centers traversed
Sector-to-Sector Boundary Crossing – 2 min.	TOC/IC for Equipped Sector to Equipped Sector Table 2-4, Figure 2-5	Handoff /Initial Call	536	7.44/ 7.3*	Number of sectors traversed
Center-to-TRACON Boundary Crossing – 2 min.	TOC/IC for Equipped ATSU to Unequipped ATSU Table 2-5, Figure 2-6	Handoff/ Initial Call	641	7.44/ 7.3*	1
RV draw or Host Amendment	Fix Clearance (Route Change) Table2-9, Figure 2-10	Fix Clearance (Route Change)	332	6.6**	Host Amendment or Based on Equation 1 for each sector
RV draw or Host Amendment	Altitude Clearance Table 2-9, Figure 2-10	Altitude Clearance	332	7.96**	Host Amendment or Based on Equation 1 for each sector
RV draw	Requested Altitude Change Table 2-8, Figure 2-9	Requested Altitude Change	498	9.25**	Based on Equation 1 for each sector
RV draw	Requested Route Change Table 2-8, Figure 2-9	Requested Route Change	508	9.57**	Based on Equation 1 for each sector
RV draw	Heading Clearance Table 2-9, Figure 2-10	Heading Clearance	332	8.47**	Based on Equation 1 for each sector
RV draw	Speed Clearance [4] Table 2-9, Figure 2-10	Speed Clearance	342	7.93**	Based on Equation 1 for each sector

Triggering Event	Data Message	Voice Message	Size – Data (bytes†)	Size – Voice (seconds)	Frequency per Flight
MLM-generated Last sector boundary crossing prior to terminal area - 20 min.	Top of Descent [4] Table 2-6, Figure 2-7	Top of Descent	425	9.23**	1
RV draw	Crossing Constraint Table 2-9, Figure 2-10	Crossing	343	9.23**	Based on Equation 1 for each sector
RV draw	Altimeter Setting Table 2-7, Figure 2-8	Altimeter Setting	332	4.50**	Based on Equation 1 for each sector
RV draw	Beacon Code Setting Table 2-7, Figure 2-8	Beacon Code Setting	332	6.49**	Based on Equation 1 for each sector
RV draw	Traffic Advisory Table 2-7, Figure 2-8	Traffic Advisory	332	7.45**	Based on Equation 1 for each sector
RV draw	Weather Advisory Table 2-7, Figure 2-8	Weather Advisory	332	7.80**	Based on Equation 1 for each sector
Conflict Resolution/Altitude	Conflict Resolution Table 2-9, Figure 2-10	Altitude Clearance	332	7.96**	Number of Separation Violations
Conflict Resolution/Heading	Conflict Resolution Table 2-9, Figure 2-10	Heading Clearance	332	8.47**	Number of Separation Violations
MLM-generated arrival TRACON-to-ATCT	NA	Handoff/ Initial Call	NA	7.44/ 7.3*	1

* handoff (7.44 sec.)/initial call (7.3 sec.) with 30 seconds in-between – see Table 2-10, Figure 2-11

** voice message size from Table 3-1

4 Data-Link Equipage

Communications will be transmitted as voice or data depending on the aircraft equipage, and also on the capabilities of the ground infrastructure providing service to a volume of airspace. The assumption currently implemented in MLM is that the ground infrastructure for en route airspace has the capability to provide data-link service for equipped aircraft. The model also currently assumes that terminal airspace does not provide data-link service.

4.1 Aircraft Equipage

MLM has been provided with the capability for the user to set the equipage rates for commercial and General Aviation (GA) aircraft (see Section 5.1). Table 4-1 shows an example of annual estimates of data-link equipage that the user can provide as input to MLM.

Table 4-1. Aircraft Equipage Rates*

Year	Commercial	GA
2006	0.00	0.00
2007	0.00	0.00
2008	0.00	0.00
2009	0.00	0.00
2010	0.00	0.00
2011	0.10	0.01
2012	0.15	0.02
2013	0.20	0.03
2014	0.30	0.04
2015	0.40	0.06
2016	0.50	0.07
2017	0.60	0.10
2018	0.70	0.11
2019	0.75	0.12
2020	0.80	0.13
2021	0.80	0.15
2022	0.80	0.16
2023	0.82	0.17
2024	0.83	0.18
2025	0.85	0.20

*Estimates based on engineering judgment (Frank Buck, The MITRE Corporation).

4.2 Ground Equipage

Although the model currently assumes that all en route sectors can support data-link service, it is possible to assign each sector as equipped or not equipped for data link, based on the characteristics of the ground radio supporting the sector, in future evolutions of MLM. In this case all aircraft, equipped or not equipped, entering sectors not supporting data link would communicate using voice only.

5 Model Input/Output

To run MLM and generate communications messages, the user must provide the inputs required by MLM [7] plus an input file of mainly headlight parameters. The user must also provide for a file for output of the communications messages generated. In addition, if the user wants to include ETMS host amendment data, that data needs to be generated when the itinerary file of flights is produced for input to MLM. A flag should also be set in the configuration file input to MLM so MLM will perform conflict detection and generate conflict resolution messages. Details are given below.

5.1 Inputs

The input file needed in order to generate communications messages is identified to MLM by an entry having the following format in the configuration file input to MLM:

CNS_MESSAGES_INPUT<space>Headlight.txt

The different parameters that the user can provide as input are shown in Table 5-1, which also shows sample values for the parameters. Headlights.txt is a sample name for the file. It contains the following parameters, all of which are floating point numbers:

Table 5-1. MLM Input Parameters

Entry	Description	Sample Values
TC (Float)	The number of minutes prior to crossing from the TRACON to the first en route sector when a TRACON-to-center message is sent.	3.0
SC (Float)	The number of minutes prior to crossing from one sector to another within the same center when a sector crossing message is sent.	2.0
CC (Float)	The number of minutes prior to crossing from one center to another when a center crossing message is sent.	3.0
TD (Float)	The number of minutes prior to leaving the last en route sector when a top of descent message is sent.	20.0
CT (Float)	The number of minutes prior to crossing from the last en route sector to the TRACON when a center-to-TRACON message is sent.	3.0

Entry	Description	Sample Values
PX (Float)	The number of minutes prior to a separation violation between two aircraft when a pairwise conflict resolution message is sent.	3.0
PE (Float)	The percentage of commercial aircraft that are data-link equipped.	20.0
PG (Float)	The percentage of GA aircraft that are data-link equipped.*	0.03

*GA aircraft are identified by one of the following airline codes in the itinerary file input to MLM: “OOO”, “OPT”, “EJA”, “LXJ”, “FLX”, “AJI”, or “TAG.’

5.1.1 Conflict Detection

In order for MLM to perform conflict detection, the following entry must appear in the configuration file:

PERFORM_CONFLICT_DETECTION<space>TRUE

5.1.2 Incorporating Host Amendment Data as Input

The procedure for including ETMS host amendment data in the itinerary file is as follows. The data for the itinerary file is obtained from ETMS data bases by using SQL queries. Two new SQL queries have been developed to produce a table (**`aftable2`**) of altitude and route change flight plan amendment data.

- The first query produces a table (**`aftable`**) of flight plan amendments including the latitude and longitude from a TZ (track update) ETMS message within 30 seconds of the amendment time. There may be more than one such TZ message for a flight plan amendment, and a separate record is produced in **`aftable`** for each flight plan amendment and corresponding TZ message.

- The second query uses **`aftable`** and produces the table **`aftable2`**, which keeps one flight plan amendment and corresponding TZ message for each flight plan amendment. The latitude and longitude position is needed because altitude change amendments have a time but not a position. For route change amendments the latitude and longitude given in the amendment are used.

After **`aftable2`** is produced, another query is run using **`aftable2`** to produce the itinerary file in the format needed by MLM. The amendment data is included as two additional optional fields at the end of the record in the itinerary file for each flight. The first additional field is the number of amendments, which is zero when there are none. The second field lists data for each of the amendments. For each amendment it consists of the code for the amendment (06 for route change and 08 for altitude change), followed by an underscore, then the latitude and longitude where the amendment begins, and another underscore. The amendments are separated by commas.

5.2 Outputs

The file for output of communications messages generated is identified by placing the following entry in the configuration file:

CNS_MESSAGES_FILE<space>cns_messages.txt

The name cns_messages.txt is a sample name for the file. It contains the following fields shown in Table 5-2 for each message:

Table 5-2. Output Data Fields

Field	Contents
Message Type (String)	A two-character code which specifies the type of message (see Table 5-3)
Equipage (String)	"Equipped" if the aircraft is data link equipped and "Notequip" if the aircraft is not data link equipped.
Call Sign (String)	Airline code followed by the flight number
TAS (Float)	True air speed in knots.
Sending Facility (String)	Airport code or sector name from which the message is sent.
Receiving Facility (String)	Airport code or sector name in which the message is received.
Channel Speed (Integer)	Baud rate of message transmission.
Message Component ID (String) (two-character field)	Number of the component (an integer from 1 to 9) and a character indicating whether the component is data or voice. A "V" indicates voice and a "D" indicates data.
Component Start Time (Float)	Start time of this component of the message in days since 1/1/1900.
Component End Time (Float)	End time of this component of the message in days since 1/1/1900.
Time Before (Float)	Time in seconds before this component starts, referenced to the start or end of a previous component.

The last four fields (i.e., last four rows of Table 5-2) are repeated for each message component, except that there is no Time Before field following the last message component.

The codes used for *Message Type (String)* of the first entry in Table 5-2 are shown in Table 5-3.

Table 5-3. Message Codes and Messages

Message Code	Message
DL	DLIC logon data message.
DZ	Departure voice message
TC	Tracon to center data message.
UZ	Center crossing data message.
SC	Sector crossing data message.
CT	Center to tracon data message.
TD	Top of descent data or voice message.
HO	Handoff voice message.
IC	Initial call voice message.
H6	ETMS host amendment data or voice route change message.
H8	ETMS host amendment data or voice altitude change message.
PR	Pilot request route change data or voice message.
PA	Pilot request altitude change data or voice message.
HC	Heading clearance data or voice message.
AC	Altitude clearance data or voice message.
FC	Fix clearance data or voice message.
VC	Speed clearance data or voice message.
AT	Altimeter setting data or voice message.
BC	Beacon code setting data or voice message.
XH	Pairwise conflict resolution heading change data message.
XA	Pairwise conflict resolution altitude change data message.
XJ	Pairwise conflict resolution heading change voice message.
XB	Pairwise conflict resolution altitude change voice message.
CR	Crossing Constraint data or voice message.
WE	Weather advisory data or voice message.
TA	Traffic advisory data or voice message.

An example of a sector crossing message for an equipped aircraft is shown in Table 5-4: The entire contents of Table 5-4 would appear on the same line in the output file. Note that there are 4 message segments identified as 1D in row 8, 2D in row 12, 3D in row 16, and 4D in row 20. The 4 message components can be found in Table 2-4, along with their sizes in bytes.

Table 5-4. Example of Sector Crossing Message

Field	Field Name	Contents
1	Message Type	SC
2	Equipage	Equipped
3	Call Sign	AAL1036
4	TAS	338.6
5	Sending Facility	ZLA007
6	Receiving Facility	ZLA033
7	Channel Speed	9600
8	Message Component	1D
9	Component Start Time	38152.2468049
10	Component End Time	38152.2468061
11	Time Before	8.29
12	Message Component	2D
13	Component Start Time	38152.2469021
14	Component End Time	38152.2469029
15	Time Before	28.45
16	Message Component	3D
17	Component Start Time	38152.2472314
18	Component End Time	38152.2472322
19	Time Before	6.43
20	Message Component	4D
21	Component Start Time	38152.2473066
22	Component End Time	38152.2473074

An example of a handoff message for an unequipped aircraft is shown in Table 5-5: The entire contents of Table 5-5 would appear on the same line in the output file. Note that there are 2 voice message components identified as 1V (handoff) in row 8 and 2V (handoff acknowledgment) in row 12. These message components can be found in Table 2-10, which shows their durations in seconds, and the response of 0.87 seconds represented as "Time Before" in Table 5-5.

Table 5-5. Example of a Handoff Message

Field	Field Name	Contents
1	Message Type	HO
2	Equipage	Notequip
3	Call Sign	AAL1036
4	TAS	338.6
5	Sending Facility	ZLA007
6	Receiving Facility	ZLA033
7	Channel Speed	9600
8	Message Component	1V
9	Component Start Time	38152.2468049
10	Component End Time	38152.2468653
11	Time Before	0.87
12	Message Component	2V
13	Component Start Time	38152.2468754
14	Component End Time	38152.2469024

6 Future Communications Capabilities for MLM

At the outset of this project, there were a number of features that were considered for adding a communications capability to MLM. It was not possible to incorporate all of these features during this initial attempt at adding a communications capability to MLM; however, it is important to document the initial plans so that they can be considered for incorporation in some future evolution of MLM.

In addition, there are a number of future communications architectures and operational capabilities under consideration. It is important to determine the impact of these architectures and capabilities on bandwidth requirements and controller workload. MLM can possibly be enhanced to assess these new architectures and capabilities.

The following sections discuss providing MLM with additional communications modeling features to obtain a better understanding of the technical and operational implications of candidate architectures and capabilities to determine the impact of future communications on bandwidth and workload [8].

6.1 Features

6.1.1 Sector Categorization

Statistics estimated from the voice tape transcriptions from nine sectors at three centers were averaged together and used to determine frequencies of occurrences and voice channel utilization durations that were extrapolated to every en route sector across the NAS. The initial plan was to use a different set of statistics for each sector or group of sectors that would better characterize them. When voice tape transcription data or other indicators of communication workload become available for a larger sample of sectors, then it may be possible to identify unique characteristics for each sector or type of sector; and then to develop more appropriate set of statistics for each sector or type of sector to be used in a simulation. Reference [3] provides one way of characterizing sectors based on a newly developed concept of the "DNA" of a sector. The usage of "DNA" is meant to convey the notion that sectors with similar "behavior" can be identified through "DNA" samples, which could be representations of the different types of messages that are transmitted and received in the sectors over different time periods. This concept should be explored as a means of determining percentages of different types of messages that would be sent in a sector based on its "DNA."

In addition, the available voice tapes were sampled during certain times of the day. Therefore, the statistics obtained are valid with reasonable confidence for those times of the day in which they were collected. In the future, either data should be collected for each sector or group of sectors for different parts of the day, or some methodology should be developed to estimate statistics for other parts of the day from the available statistics.

6.1.2 Probability Distributions

The uniform distribution was assumed for response times, and times for data-link messages to transit the various systems. In addition, a normal distribution was assumed for voice message sizes. The original intent for the transit times was to use a lognormal distribution; however, MLM requires that a standard deviation be supplied as input. The standard deviation was not known at the time of the analysis. However, once the standard deviation is known, it is an easy task to change from the uniform distribution to a lognormal distribution in MLM.

Also, the voice message sizes may not be normally distributed. Again, once a distribution function is determined that would better represent voice message sizes, it would be an easy task to incorporate it into MLM.

6.1.3 Retransmissions

Currently all messages are successfully transmitted. In reality, there are many cases where messages must be retransmitted due to problems encountered along the transmission path. Some technique based on the probability of retransmission (once known) would be easy to incorporate into MLM. Reference [9] analyzed terminal and en route voice tapes, a different set from the set used in reference [2], to determine factors resulting in controller-pilot miscommunications of which communications equipment malfunction was one of the factors.

6.1.4 Voice Readbacks/Callbacks

Voice messages are sometimes not clearly understood by either the pilot or controller. Therefore, some voice messages require repeating, which would increase the bandwidth required. Statistics on readbacks and callbacks have been estimated from the voice tape transcription analysis [2], but only done for three centers. This has not yet been modeled. Again, with known rates at which this occurs, it would be an easy task to incorporate into MLM. Reference [9] also presents statistics on readbacks from an analysis of a different set of voice tapes than the ones used in reference [2].

6.1.5 Standby

For a certain percentage of messages, the controller or pilot cannot respond immediately and will send a standby message. In the current implementation of MLM "standby" has been left out of all but one of the messages (Table 2-8), and whenever that message is sent, "standby" is always transmitted. For a future enhancement of MLM, "standby" should be included a certain percentage of the time in the appropriate messages.

6.1.6 Timers

Reference [1] contains information regarding timers, which are functions that indicate when an expected response has not been received within a certain predetermined amount of time. A timer expiry results in additional messages being sent such as error and notification messages, resulting in more bandwidth being used; also, the original message, or one changed to reflect the changed operational circumstances, has to be sent to the pilot or controller. Using probabilities to model timer expiry can be incorporated into a future evolution of MLM.

6.1.7 Ground/Ground Communications

The work that was performed during FY2005 included only the A/G communications messages. There are ground/ground voice and, in the future, data communications that result from or give rise to A/G communications. Enhancing MLM to include ground/ground communications would provide a means of quantifying ground/ground communications in order to determine the connectivity and estimate the bandwidth required on the links of the ground/ground network supporting ATC communications.

6.2 Future Communications

6.2.1 Data Link Protocols

The current version of MLM reflects characteristics of the ATN OSI protocol for CPDLC, which is a future communication system under consideration. There are other data link protocols that can be included into MLM so that MLM can be used to facilitate a comparison of protocols, such as the comparison of the existing ARINC 622 (FANS-1/A) protocol with the ATN OSI protocol.

6.2.2 Future Communications Capabilities

Future communications capabilities such as Automatic Dependent Surveillance (ADS), ADS-Broadcast (ADS-B), Flight Plan Consistency (FLIPCY) service, System-Wide information Management (SWIM) system, and others will increase the amount of bandwidth required to support data link-based operations; but may decrease the amount of bandwidth required for voice communications. Modeling these capabilities in MLM can help determine the impact of their on bandwidth requirements and controller workload.

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Glossary

ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance-Broadcast
A/G	air/ground
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATCT	Airport Traffic Control Tower
ATN	Aeronautical Telecommunications Network
ATSU	Air Traffic Service Unit A general reference to centers or Air Route Traffic Control Centers (ARTCCs), TRACON facilities, ATCTs, and other air traffic control facilities to be applicable to the international community.
CAASD	Center for Aviation System Development
CDA	Current Data Authority
CPDLC	Controller-Pilot Data-Link Communications
DLIC	Data Link Initiation Capability
DM	downlink message
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FLIPCY	Flight Plan Consistency
FTI	FAA Telecommunications Administration
FY	fiscal year
GA	General Aviation
G/G	ground/ground
IC	initial contact
MLM	Mid-Level Model
MSR	MITRE Sponsored Research
NAS	National Airspace System
NDA	Next Data Authority
nmi	nautical mile
OSI	Open System Interconnect

R-ATSU	receiving-Air Traffic Service Unit
RTCA	RTCA, Incorporated, Washington, D.C.
RV	random variable
T-ATSU	transferring-Air Traffic Service Unit
TOC	transfer of communications
TRACON	Terminal Radar Approach Control
TZ	ETMS Track Update Message
UM	uplink message