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Free Flight Simulation Infrastructure

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Abstract

Over the past twenty years, unprecedented demand for air travel has outpaced the design of the National Airspace System (NAS). Insufficient capacity, limited access, and excessive operating restrictions have led to significant increases in user costs and delays, and an overall decrease in efficiency for all users [RTCA95]. Furthermore, the market demand for air travel is expected to increase several-fold in the coming decade.

In an attempt to redesign the NAS to accommodate the expected rise in demand in air transportation, the Advanced Air Transportation Technologies (AATT) program of the National Aerospace and Space Administration (NASA) is working to realize a capability known broadly as "Free Flight". The transition from the existing air-traffic-management system to a pragmatic realization of Free Flight will involve significant developments in technology and procedures, both for air-traffic-control systems on the ground and in aircraft flight-deck systems.

This manual documents the software development and engineering effort to realize Phase 2 of a Free-Flight simulation (FFSIM) infrastructure that is intended to help NASA's AATT program test improved air-traffic-management concepts, and achieve increased NAS capacity, while maintaining or improving safety.

The primary objective of this FFSIM effort is to develop a comprehensive, distributed simulation infrastructure to evaluate the efficacy of critical free-flight technologies and concepts from an overall systems perspective. The FFSIM Infrastructure enables multiple researchers and other human subjects to participate in a real-time simulation of air-traffic control operations. Phase 2 focuses on the simulation of future versions of two major components of the National Airspace System (NAS): aircraft flight decks and air traffic control (ATC).

The FFSIM Phase 2 Infrastructure (whose latest software implementation is known as FFSIM Version 1.4) provides the capability to evaluate various distributed air-ground separation concepts, including conflict detection and resolution modules. Key communication, navigation, and surveillance (CNS) infrastructure components are modeled. A second important capability provided by the FFSIM Infrastructure is the ability to investigate overall ATM system performance as a function of specific parameters such as the accuracy, update rates and latencies for GPS position/velocity measurements, and automatic dependent surveillance – broadcast (ADS-B) messages. The impact on overall system performance of nominal operating ranges for transmitting and receiving equipment associated with ADS-B can also be investigated. A third capability provided by the FFSIM Infrastructure is the ability to conduct experiments with mixed aircraft-equipage scenarios, to examine not just the current state of ATM operations and mature-state free flight, but also the transitional period in-between.

The FFSIM Infrastructure is a distributed human-in-the-loop simulation comprised of several components. Aircraft flight-deck components include pilot stations, where one human controls a single aircraft modeled with "medium" fidelity; and pseudo-pilot stations, where one human controls up to a dozen aircraft with a lower level of fidelity. A central focus of this work is the modeling of current and envisioned CNS infrastructure components with appropriate fidelity. Air-to-air and air-to-ground ADS-B messages are exchanged among all equipped aircraft and/or ground. ADS-B messages include position and velocity measurements based on a stochastic model of GPS accuracy. Voice communications and digital controller-pilot data link communications (CPDLC) also exist between ATC and the aircraft flight decks.

The FFSIM Infrastructure leverages several mature, air-traffic-control simulation components developed by NASA and other organizations. The Center-TRACON Automation System (CTAS) is used to provide the key element of the ATC station. FastWin, a NASA-developed PC-based flight-management system model including cockpit displays, and a NASA Cockpit Display of Traffic Information (CDTI) system are used to represent the FFSIM Infrastructure's pilot station. The Pseudo-Aircraft Systems (PAS) software, developed by Logicon, is utilized to realize a pseudo-pilot station and to manage traffic scenarios.

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Symbols and Abbreviations

AATT	Advanced Air Transportation Technologies
ADS-B	Automatic Dependent Surveillance - Broadcast
AOC	Airline Operational Center
ARSR	Air Route Surveillance Radar
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCDST	Air Traffic Control Decision Support Tool
ATM	Air Traffic Management
CDU	Control Display Unit
CID	Computer Identification
CM	Communications Manager CTAS software process
CPDLC	Controller-Pilot Data Link Communications
CTAS	Center-TRACON Automation System
DFW	Dallas / Fort Worth Airport
DST	Decision Support Tool
ECP	EFIS Control Panel
EFIS	Electronic Flight Information System
ETA	Estimated Time of Arrival
FAST	Final-Approach Spacing Tool
FastWin	FMS/Autoflight Simulation Tools for Windows, NASA-developed FMS-modeling software
FFSIM	Free Flight Simulation
FIS	Flight Information Services
FMS	Flight Management System
GPS	Global Positioning System
IAS	Indicated Air Speed
ID	Identification
ISM	Input Source Manager CTAS software process
LAAS	Local-Area Augmentation System to the Global Positioning System
MCP	Mode Control Panel
METAR	Meteorological Terminal Aerodrome Forecast
MFD	Multi-function Display

NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NEXRAD	Next Generation Weather Radar
PAS	Pseudo Aircraft Systems
PFD	Primary Flight Display
PGUI	CTAS' Plan-view Graphical User Interface Display
p-FAST	Passive Final Approach Spacing Tool
PSR	Primary Surveillance Radar
PVD	Plan View Display
RA	Route Analyzer CTAS software process
RTA	Required Time of Arrival
SA	Selective Availability to the Global Positioning System
SID	Standard Instrument Departure
SSR	Secondary Surveillance Radar
STA	Scheduled Time of Arrival
STAR	Standard Instrument Arrival Route
TCP/IP	Transmission Control Protocol/Internet Protocol
TIS	Traffic Information Services
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control
TS	Trajectory Synthesizer CTAS software process
UAT	Universal Access Transceiver
VDL	Very High Frequency Digital Link
VHF	Very High Frequency
VOR	VHF Omni-directional Range
WAAS	Wide-Area Augmentation System to the Global Positioning System
ZFW	The Dallas / Fort Worth Air Route Traffic Control Center

1 Introduction

This report documents the software development and engineering effort to realize a Free-Flight simulation infrastructure for the Advanced Air Transportation Technologies (AATT) program of the National Aerospace and Space Administration (NASA).

This chapter provides a high-level overview of the continuing Free Flight Simulation (FFSIM) Infrastructure development, its motivation, capabilities, and numerous components. Included in this chapter is a discussion about capabilities realized and delivered in this phase, as well as those planned for future phases.

1.1 Motivation

In the past twenty years, increased demand for air travel has outpaced the design of the National Airspace System (NAS). Insufficient capacity, limited access, and excessive operating restrictions have led to significant increases in user costs and delays, and an overall decrease in efficiency for all users [RTCA95]. Furthermore, the market demand for air travel is expected to increase several-fold in the coming decade. Recent technological advances now provide the opportunity to redesign the NAS to substantially increase capacity and efficiency, while maintaining, and possibly improving, safety.

In an attempt to redesign the NAS to accommodate the expected rise in demand to air transportation, a broad concept known as "Free Flight" has been proposed. The primary difference between today's direct-route-clearance approach and Free Flight will be the pilot's ability to operate the flight without being required to follow specific route, speed, and altitude clearances. The transition from the existing ground-based air traffic management system to Free Flight will involve significant developments in technology and procedures, both for air traffic control systems on the ground and aircraft flight-deck systems. The realization of Free Flight will ultimately be a distributed system, comprised of a vast number of individual technologies and procedures.

In recent years, a great deal of attention has been given to some of the individual modules that will play a central role in Free Flight. For operations in air traffic control (ATC) facilities on the ground, researchers have been designing and field-testing the Center-TRACON Automation System (CTAS) [EDG93, DE95]. Commercial industry organizations have led the way in researching and developing airborne technology for the flight deck, such as advanced flight-management-system (FMS) avionics, conflict probes, and strategic flight planners.

In contrast to the individual ATC and airborne technologies, less attention has been given to date to the overall system implementation of free flight, and the essential underlying communication, navigation, and surveillance (CNS) components. It is the purpose of this work is to make a significant contribution to the air-traffic-management (ATM) research community by developing a research tool that models both current and envisioned CNS technologies and allows evaluation of Free Flight concepts in a systems context.

1.2 Capabilities

The primary objective of this effort is to develop a comprehensive, distributed simulation infrastructure to evaluate the efficacy of candidate free-flight technologies and concepts from an overall systems perspective. The simulation infrastructure enables multiple researchers and other human subjects to participate in a real-time simulation of air-traffic control operations. As depicted in Figure 1-1, all three major components of the ATM triad will be incorporated: aircraft flight decks, air traffic control (ATC), and airline operational control (AOC). Although the current scope of this work focuses on the ATC and aircraft flight deck aspects of ATM operations, the FFSIM Infrastructure is designed to facilitate the incorporation of a future AOC presence. The FFSIM Infrastructure allows participants to emulate the roles of pilots and pseudo-pilots, ground-based controllers, and, eventually, airline dispatchers.

The FFSIM Infrastructure is constructed to model a variety of technologies that are considered important to realize candidate Free Flight concepts. The technologies include various distributed air-ground separation concepts, as well as numerous CNS infrastructure components. Examples of distributed air-ground separation concepts include conflict detection, conflict resolution, and strategic flight [re]-planning modules. Examples of CNS infrastructure components that are, or will be, modeled include Automatic Dependent Surveillance – Broadcast (ADS-B) messaging, Flight Information Services (FIS), Wide-Area and Local-Area Augmentation Systems (WAAS and LAAS) to the Global Positioning System (GPS), and Controller-Pilot Data Link Communications (CPDLC).

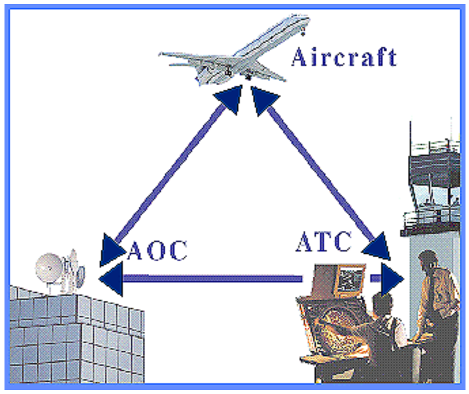

Figure 1-1 The air traffic management (ATM) triad

Another important capability provided by the FFSIM Infrastructure is the ability to investigate overall ATM system performance as a function of specific parameters such as the accuracy, update rates and latencies for GPS position and velocity measurements, ADS-B message types, wind and weather data. The impact on overall system performance of nominal operating ranges for transmitting and receiver equipment associated with ADS-B, FIS, and Traffic Information Services (TIS), can also be investigated.

A third capability provided by the FFSIM Infrastructure, is the ability to conduct experiments with mixed aircraft-equipage scenarios. For example, only a subset of the aircraft active in the simulation may be equipped with ADS-B transceivers. Likewise, a different subset of the aircraft may be equipped to receive FIS and/or TIS broadcasts. In this way, researchers will be able to investigate the impact of mixed aircraft equipage on overall ATM performance, as they examine not just the current state of ATM operations and mature-state Free-Flight operations, but also the transitional period.

2 Infrastructure Components

The FFSIM Infrastructure is a distributed simulation system comprised of many components. Figure 2-1 depicts the majority of these components in a single schematic. As shown in the figure, development emphasis to date has focused on the aircraft flight deck, ATC, ground infrastructure and communication components. A brief description of each of the FFSIM components is given in the following sections.

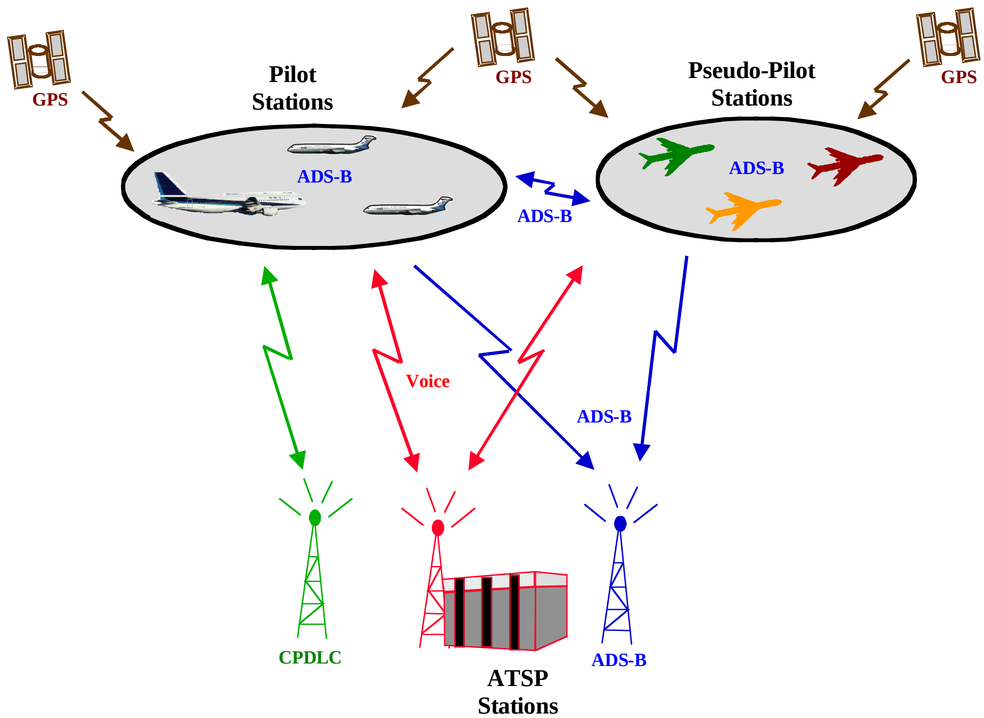

Figure 2-1 Major Free-Flight Simulation infrastructure components

2.1 Flight Decks

The airborne portion of the FFSIM Infrastructure is comprised of two types of flight decks: pilot stations and pseudo-pilot stations. Collectively, these two types of flight decks can be employed to realize traffic scenarios containing dozens or even hundreds of aircraft.

2.1.1 Pilot Stations

A pilot station is a component of the FFSIM Infrastructure where one human (i.e., pilot) can control, in real time, a single aircraft with an appropriate level of fidelity. The pilot station is comprised of a flight management system (FMS) model, a primary-flight display (PFD), a multi-function display (MFD), a central "radio rack," and, if sufficiently equipped, a cockpit display of traffic information (CDTI).

The pilot station FMS model is realized by leveraging the NASA-developed, FastWin software [PAW97]. The FastWin software includes both a PFD and a navigation display. The navigation display is being evolved into an integrated MFD that will include navigation, flight plan, traffic, weather, and other data, in a user-configurable, layered format.

The central "radio rack" contains a model of all the communication hardware required by the pilot station, including a voice receiver/transmitter for verbal communication with ATC (and eventually the AOC), a controller-pilot data link communications (CPDLC) transceiver for digital communication with ATC (and eventually the AOC), a GPS receiver, and an ADS-B transceiver.

Any pilot station may also contain a CDTI that is currently being developed by NASA [JBD97]. This CDTI provides automated conflict alerting and resolution suggestions.

2.1.2 Pseudo-Pilot Stations

A pseudo-pilot station is a component of the FFSIM Infrastructure where one human (i.e., pseudo-pilot) can control, in real time, multiple aircraft with a low level of fidelity. The pseudo-pilot capability enables FFSIM traffic scenarios to be populated with many aircraft, without requiring the same number of human operators to control each aircraft individually.

Similar to the pilot station, the pseudo-pilot station contains an auto-pilot capability (similar to an FMS), a central "radio rack", and possible instances of various DSTs. There are no individual cockpit displays such as the PFD and MFD included in the pseudo-pilot station, because the pseudo-pilot must control up to one dozen aircraft at any time.

The pseudo-pilot station auto-pilot and control interface is realized by leveraging the Pseudo-Aircraft Systems (PAS) software, developed by Logicon.

The pseudo-pilot "radio rack" is an almost exact duplicate of that employed by the pilot station, configured to represent multiple aircraft.

2.2 Air Traffic Service Providers

Figure 1-1 depicts ATM operations in terms of a simplified triad. A more comprehensive title for the entity in the lower right of this triad is "Air Traffic Service Providers". For the purpose of discussion, included in this definition of air traffic services providers are the various ATC facilities, as well as the following critical communication, navigation, and surveillance (CNS) infrastructure components: ADS-B, ground-based radar surveillance, TIS, FIS, CPDLC, and GPS.

2.2.1 Air Traffic Control

The FFSIM Infrastructure includes an air-traffic-control component that allows human subjects to regulate and separate air traffic according to both current and future (envisioned) operating procedures for air-traffic-management. The central ingredient of the FFSIM ATC component is the NASA-developed, Center-TRACON Automation System (CTAS) software.

Both voice and digital (e.g., CPDLC) communications between ATC and all appropriately equipped aircraft allow for simulation of current control procedures, as well as a wide range of future concepts.

In addition to decision-support tools (DSTs) provided by CTAS, the ATC component of the FFSIM Infrastructure is designed to incorporate additional future ground-based DSTs. Similar to those that can be integrated into the flight deck components, these DSTs include a recently-developed GBDST (ground-based DST) developed by NASA, in conjunction with Lockheed-Martin, Raytheon, and Computer Sciences Corporation.

2.2.2 Communication, Navigation and Surveillance (CNS) Components

Comprehensive modeling of the CNS components at an appropriate level of fidelity is included in FFSIM. Each of the CNS infrastructure components is now briefly described.

2.2.2.1 Automatic Dependent Surveillance – Broadcast (ADS-B)

Air-to-air and air-to-ground ADS-B messages are exchanged among all equipped aircraft, and between all equipped aircraft and the ground. Both the broadcast rate and the nominal operating range for ADS-B is variable and can be configured by the researcher using the FFSIM Infrastructure at the beginning of a simulation scenario. Typical ADS-B broadcast rates are 0.5 to 14 seconds, and typical nominal-operating ranges are 50 to 120 nautical miles [RTCA-242, OH94].

The existing ADS-B messaging provides information that primarily follows aviation industry standards [RTCA-242] (i.e., includes: computer-id, timestamp, aircraft type, position source, latitude, longitude, altitude source, altitude, ground speed, ground-track direction, vertical speed, and next waypoint(s)), but has additional information such as last-passed waypoint and future waypoints greater than Next+1. A detailed description of the ADS-B message content is included in B.4.

The implementation of ADS-B includes a range model that computes the probability of a successful message reception as a function of range and altitude. This problem is decomposed into a series of two steps. The first step determines whether the curvature of the Earth will prevent the direct line-of-sight reception of a signal between a transmitting and a receiving entity. Empirical data has shown that the Earth's atmosphere has a tendency to deflect downward radio signals, increasing the effective visible range [OH94]. Given that a signal reception is not prevented by the Earth's curvature, the second step determines the probability of signal reception based solely on range. For this step a simple probability density function is used that compares actual range to the nominal operating range of the transmitter/receiver. The FFSIM Infrastructure supports a variety of antenna types with a spectrum of nominal operating ranges. The simulation user (i.e., the researcher) is able to select the antenna types (and hence, the operating range) for equipment at the beginning of a simulation scenario. For more information on the ADS-B range modeling, refer to B.6.

2.2.2.2 Controller-Pilot Data Link Communications (CPDLC)

Controller-pilot data link communications allow for digital communications between ATC on the ground and the pilot-station and pseudo-pilot-station aircraft. A simple graphical / textual interface is realized at both the pilot and controller end to facilitate the use of CPDLC [RTCA-219].

CPDLC is envisioned for many applications in current and future ATM operations, including the up-link of clearances, route deviations, and new flight plans from ATC to the pilot. Pilots will use CPDLC to respond to ATC instructions, and request changes to the current flight trajectory.

In FFSIM Phase 2, ATC can uplink a 4D-trajectory clearance message to a specified pilot and the pilot can downlink an accept/reject response. A detailed description of the CPDLC message content is included in C.3.

2.2.2.3 Global Positioning System (GPS)

The position and velocity data contained in each ADS-B message is provided by GPS satellite navigation. The FFSIM Infrastructure includes a stochastic error model of selective availability (SA) for the basic navigation signal. A 2^{nd} order Gauss-Markov process is used to represent the SA error model [AIAA-GPS, DOD-GPS]. The researcher can select the GPS update rate and one-sigma error values for position and velocity in three dimensions at the beginning of a simulation scenario.

3 Software Implementation

This section describes the software implementation of the FFSIM Infrastructure Version 1.4 developed and delivered at the end of Fiscal Year 1999 during this contract. This FFSIM functionality can be classified into pilot stations, pseudo-pilot stations, controller stations, ATSP infrastructure, and simulation infrastructure. The top-level software layout for FFSIM is shown in Figure 3-1.

Th standard configuration contains three pilot stations, three pseudo-pilot stations, two controller stations, and additional stations for ATSP and simulation infrastructure. Figure 3-1 shows this configuration and the various applications that comprise FFSIM along with the inter-application communication. Inter-process communication is handled with a combination of TCP/IP and CORBA protocols. All of the applications are written in C or C++.

3.1 Pilot Station

The software for each Pilot Station consists of three major applications, FastWin, CDTI, and Infrastructure. These applications, the individual processes, and the inter-process communication are shown in Figure 3-2.

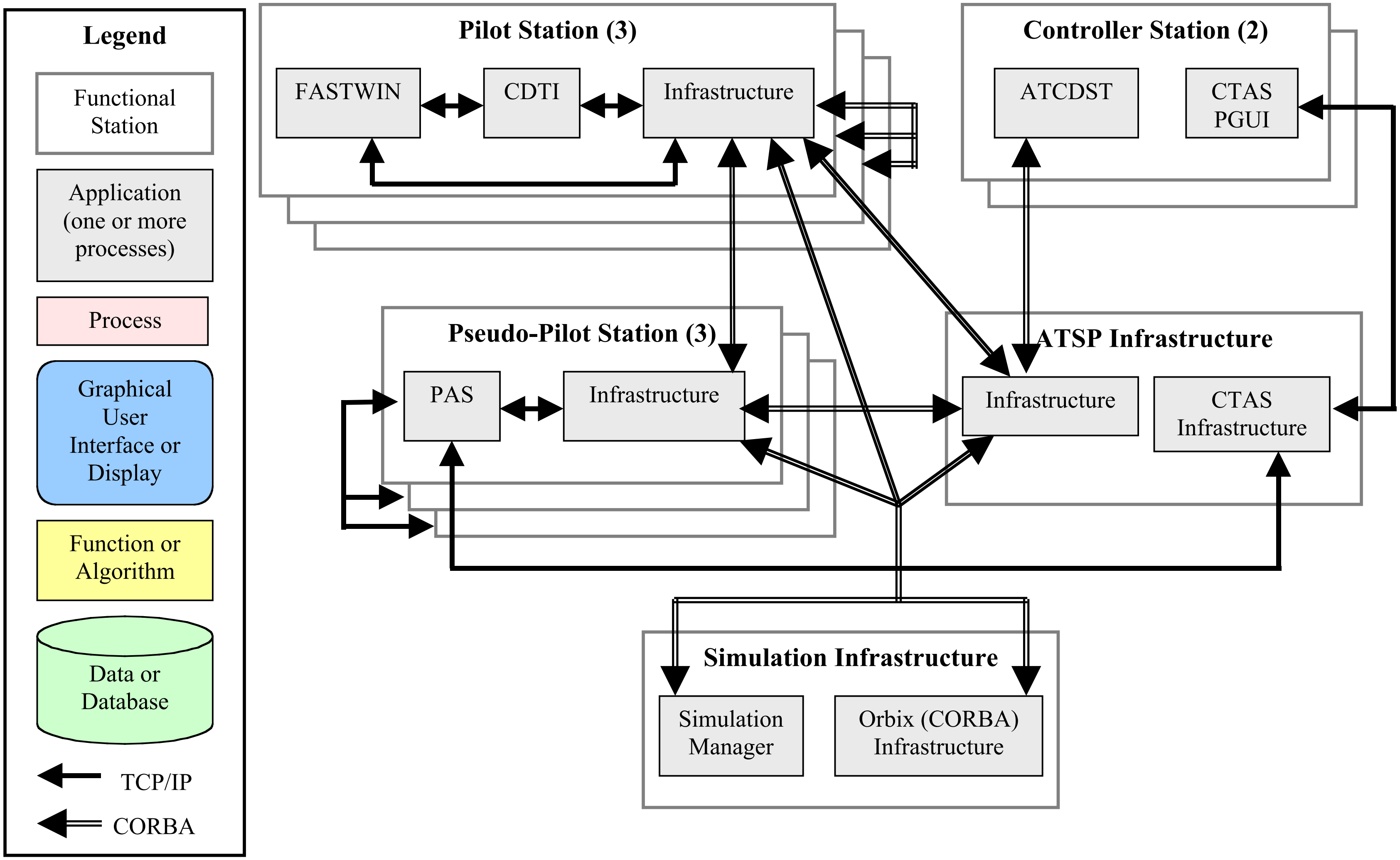

Figure 3-1 FFSIM top-level software layout

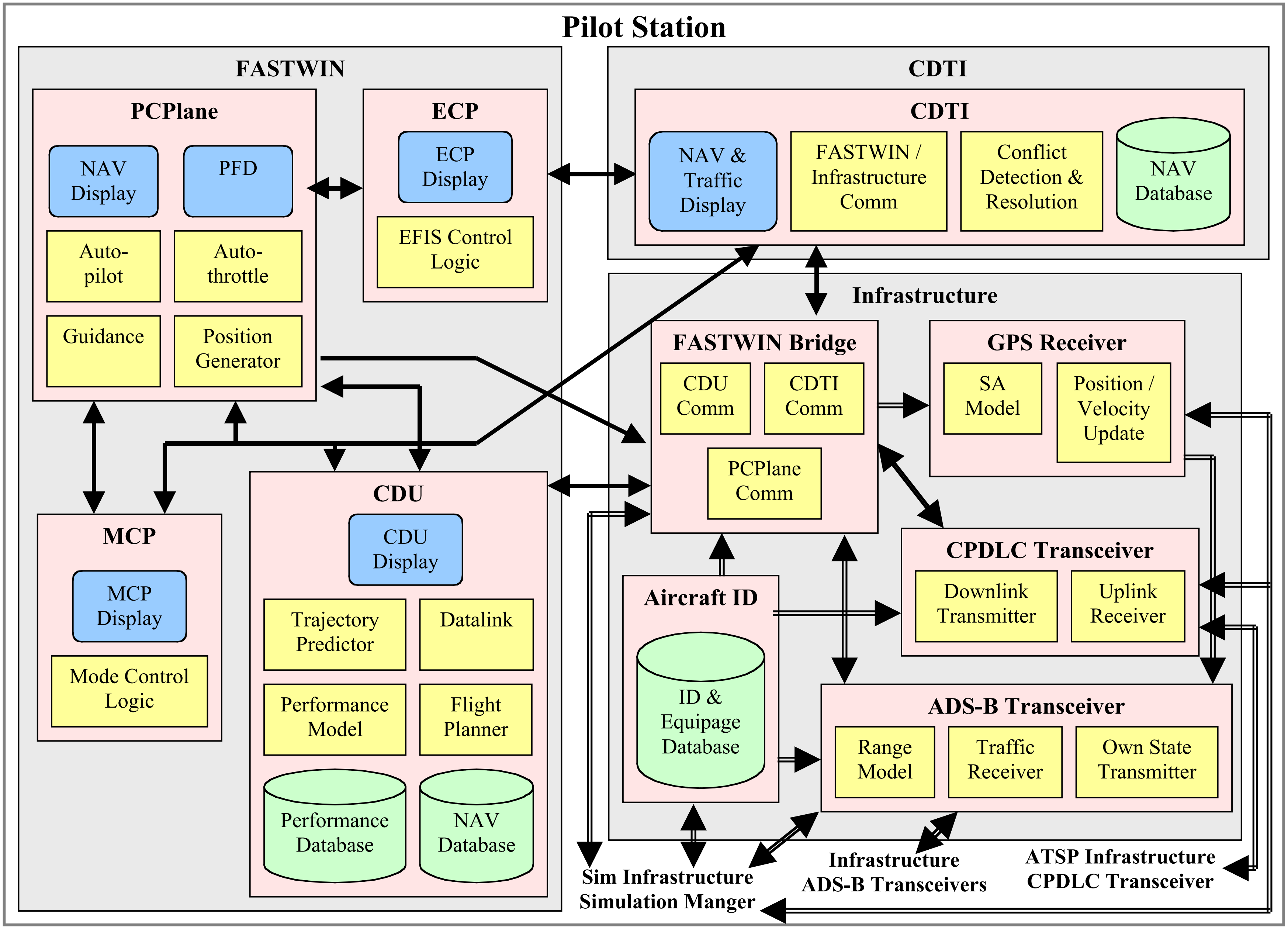

Figure 3-2 Pilot station software functonality

3.1.1 FastWin

The FastWin software developed by NASA Langley Research Center was modified for use on the FFSIM Pilot Station. This version of FastWin consists of four executables, PCPlane, MCP, ECP, and CDU.

3.1.1.1 PCPlane

PCPlane contains a Primary Flight Display (PFD) and a Navigation Display (ND), Figure 3-3. PCPlane contains a Boeing 757 aircraft dynamics model and is responsible for generating the aircraft's trajectory. PCPlane also contains auto-pilot and auto-throttle capabilities.

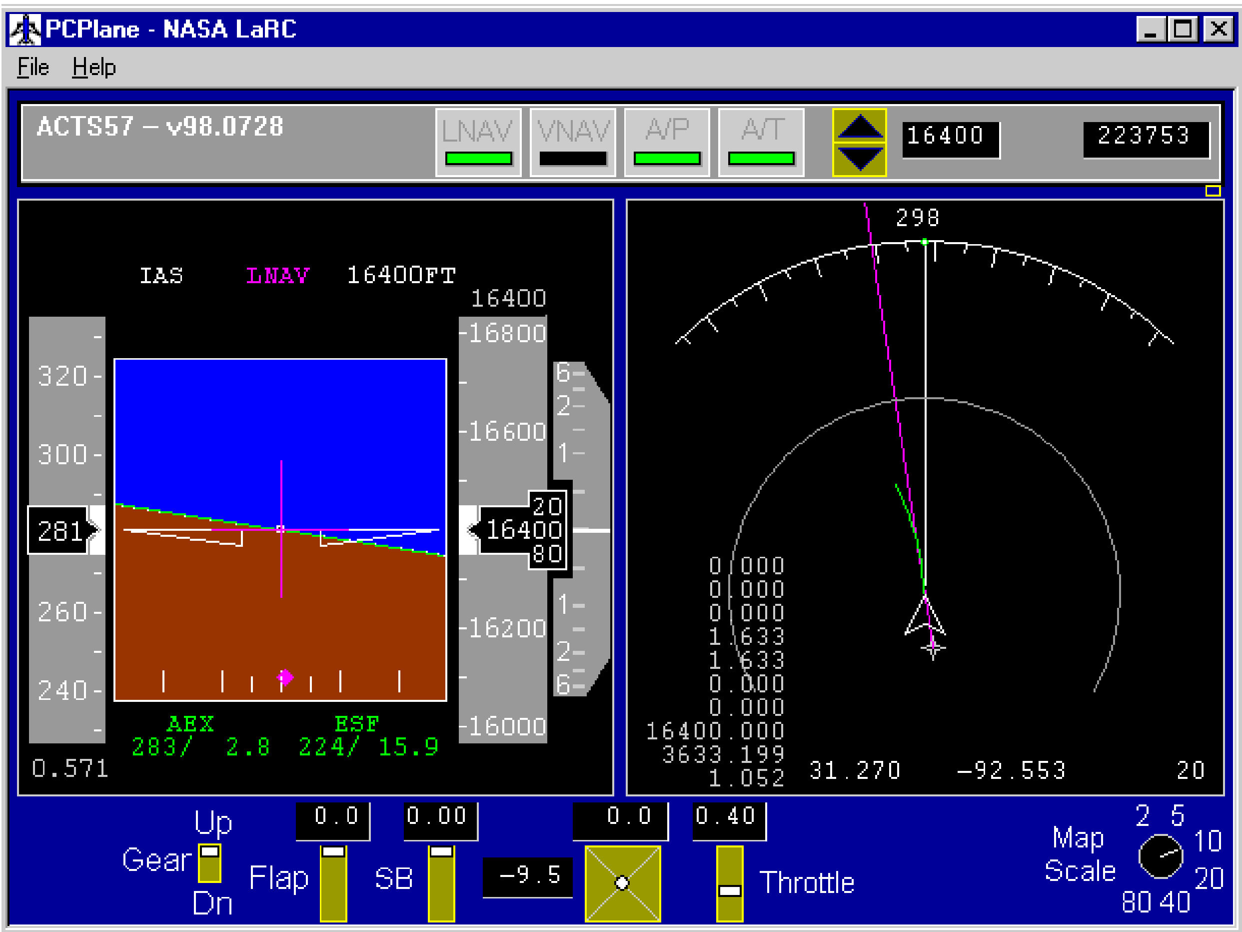

Figure 3-3 The FastWin PFD and Navigation Display

PCPlane communicates via TCP/IP sockets with each of the other FastWin processes: ECP, CDU, and MCP. In addition PCPlane has a socket connection with CDTI and the FastWin Bridge.

3.1.1.2 MCP

The FastWin Mode Control Panel (MCP) is used to model some of the dials, buttons, and gauges that control the mode of the aircraft. The MCP also allows the operator access to the auto-pilot and control the aircraft being "flown" by PCPlane. The MCP for the Boeing 757 is shown in Figure 3-4.

The MCP communicates to PCPlane via a TCP/IP socket. MCP initialization is done through a socket connection to CDTI.

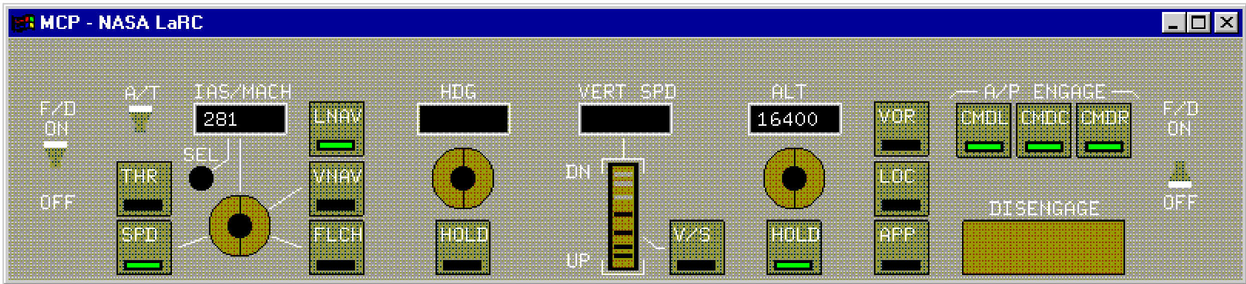

Figure 3-4 The FastWin Boeing 757 Mode Control Panel

3.1.1.3 ECP

The FastWin Electronic Flight Information System (EFIS) Control Panel (ECP) provides additional display and controls that are present in a real cockpit. The ECP for the Boeing 757 is shown in Figure 3-5.

Figure 3-5 The FastWin Boeing 757 EFIS Control Panel

The ECP communicates with PCPlane via a TCP/IP socket. ECP initialization is done through a socket connection with CDTI.

3.1.1.4 CDU

FastWin contains a Flight Management System (FMS). The interface to the FMS is the Control Display Unit (CDU), shown in Figure 3-6. The CDU contains trajectory prediction routines, flight planning, and datalink routines and interfaces. The CDU provides access to FMS navigation databases including U.S.-wide information on VORs, low- and high-altitude airway structures, airports, and runway configurations. Databases are also included for specific SIDs, STARs, and approaches for a limited number of selected airports [PAW97]. The CDU also contains an aircraft performance database.

The CDU communicates to PCPlane, CDTI, and FastWin Bridge via TCP/IP sockets. The CDU receives initialization commands, route changes, and datalink messages from the CDTI. The CDU sends trajectory information to the FastWin Bridge. In addition, the FastWin Bridge can serve as an alternate source of datalink and route messages.

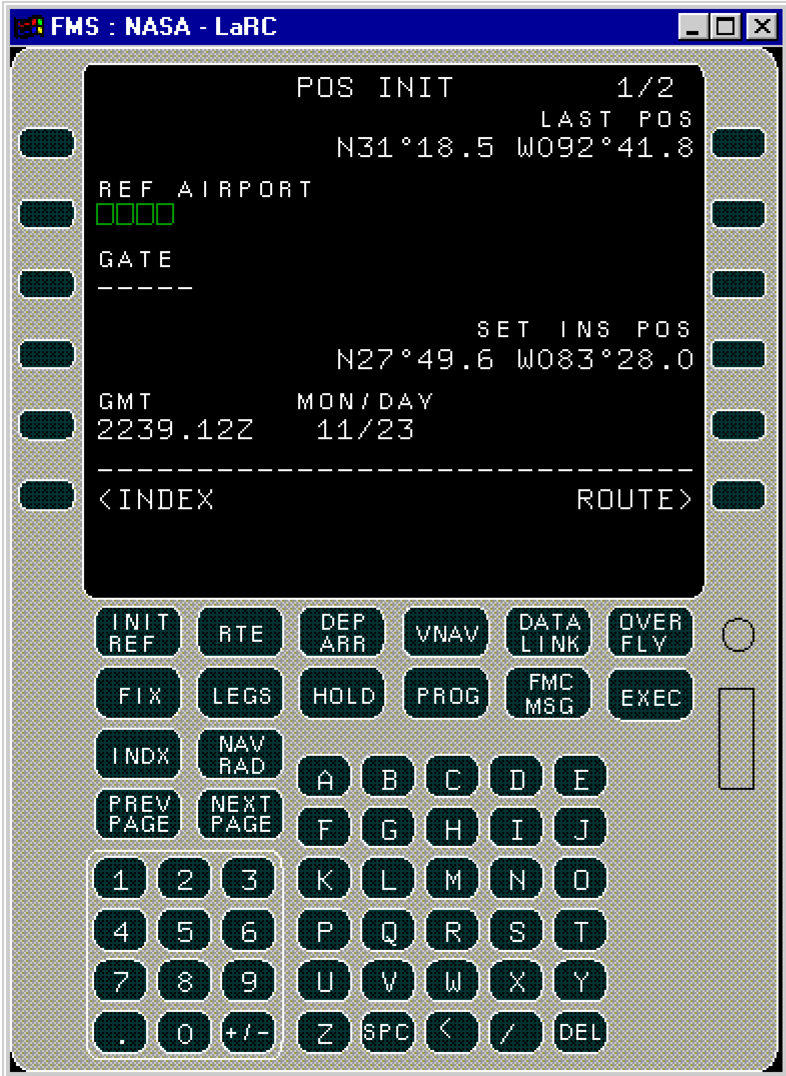

Figure 3-6 The FastWin FMS CDU

3.1.2 CDTI

The NASA-Ames Research Center Cockpit Display of Traffic Information (CDTI) provides a graphical interface that combines a navigation display with automated conflict detection and resolution capabilities, a CPDLC proposed trajectory accept/reject interface, and the ability to display 4D aircraft intent. The interface to the pilot is the display shown in Figure 3-7. Both Dependent and Independent equipped aircraft use the CDTI display. However, only the Independent aircraft are equipped with the CD&R logic.

CDTI communicates with all four of the FastWin processes and with the FastWin Bridge via TCP/IP sockets.

Figure 3-7 The CDTI display

3.1.3 Infrastructure

The Pilot Station Infrastructure consists of five processes, Aircraft ID, ADS-B Transceiver, CPDLC Transceiver, GPS Receiver, and FastWin Bridge. The infrastructure handles the Pilot Station communication with other Pilot stations, pseudo-pilot stations and the ATSP stations. Communication between the infrastructure processes is done with CORBA. Communication with other Pilot Station applications is done with TCP/IP and handled through the FastWin Bridge.

3.1.3.1 Aircraft ID

Each aircraft in the simulation has a unique identification (ID). The ID for the aircraft represented by a Pilot Station, is maintained by the Aircraft ID Server. The ID of the aircraft consists of:

Computer ID (CID)
Call Sign
Beacon Code
Aircraft Type/Model
Equipage Level

Clients communicate with the Aircraft ID Server via CORBA.

3.1.3.2 ADS-B Transceiver

The Pilot Station ADS-B Transceiver broadcasts and receives ADS-B traffic information. The ADS-B Transceiver transmits own-state information at the configured interval. The configurable interval range is 0.5 seconds to 5.0 seconds. The ADS-B Transceiver obtains position and velocity information from the GPS Receiver, intent information from the FMS/CDU via the FastWin Bridge, and identification and equipage from the Aircraft ID. The traffic information is packaged into an ADS-B message which is then broadcast to every other ADS-B Transceiver and ADS-B Receiver in the simulation.

The ADS-B Transceiver receives all traffic messages broadcast by other ADS-B Transceivers in the simulation. Receiver side filtering is done to determine which messages are received and which are dropped. Current filtering models the effect that distance between the transmitter and receiver has on transmission success. See B.6 for specifics regarding the range model. Messages that are determined to be out of range are logged and subsequently removed from the reception list. Messages that pass the filtering step are then available to other CORBA clients.

3.1.3.3 CPDLC Transceiver

The Pilot Station Controller-Pilot Datalink Communications (CPDLC) Transceiver receives messages from and broadcasts messages to, the ATSP Infrastructure CPDLC Transceiver. Unlike the ADS-B Transceiver, CPDLC is a point to point communication. Messages received from the Controller CPDLC Transceiver are passed along to the FastWin Bridge where they are then sent to the CDTI or CDU, depending on the configuration. Pilot generated messages and responses come to the Pilot Station CPDLC Transceiver from the CDU via the FastWin Bridge and are then sent to the ATSP Infrastructure CPDLC Transceiver. The Pilot Station CPDLC Transceiver uses CORBA for communication.

3.1.3.4 GPS Receiver

Each Pilot Station is capable of having a Global Positioning System (GPS) Receiver. The GPS Receiver provides GPS modeled navigation data (position and velocity) to other Pilot Station processes. The GPS Receiver obtains the navigation data from the generating source (i.e., PCPlane via the FastWin Bridge), adds GPS errors, and makes the error-modeled data available to clients. The update rate for the GPS Receiver is currently one Hertz. The GPS Receiver communicates with other processes using CORBA.

3.1.3.5 FastWin Bridge

The FastWin Bridge is a communication bridge between the two protocols used on the Pilot Station, TCP/IP and CORBA. The FastWin Bridge uses TCP/IP to communicate with the FastWin CDU and PCPlane processes. The FastWin Bridge also communicates with the CDTI via TCP/IP. The FastWin Bridge uses CORBA to communicate with the Pilot Station Infrastructure.

3.2 Pseudo Pilot Station

The pseudo-pilot capability was implemented with the Pseudo-Aircraft Systems (PAS) software [PAS97]. PAS is a multi-aircraft target-generating tool that simulates the flight dynamics of aircraft in an air traffic controlled area. PAS also provides a communication link to CTAS. Modifications were made to PAS so that is could accept Pilot Station aircraft and pass them along to CTAS. Additional modifications allow the PAS to provide pseudo-aircraft information (including future waypoint ETA intent) for the simulation.

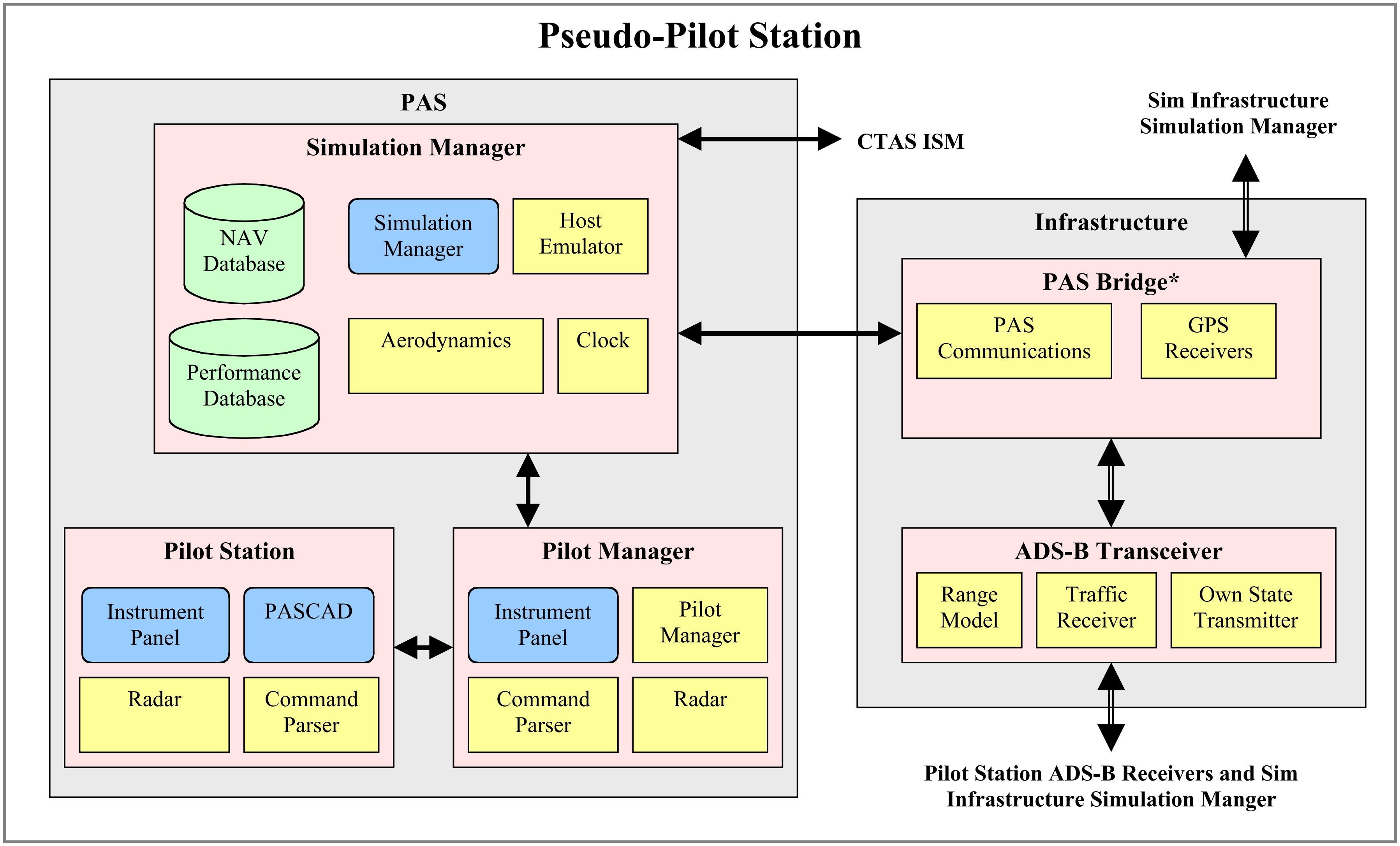

Figure 3-8 Pseudo-Pilot station software functionality

3.2.1 PAS

The Pseudo-Aircraft Systems (PAS) software is furnished and maintained by Logicon Corporation located at the NASA Ames Research Center.

3.2.1.1 Simulation Manager

The PAS Simulation Manager module controls the pseudo-aircraft portion of the simulation. The PAS Simulation Manager contains the aircraft performance and aerodynamic models. The PAS Simulation Manager also handles the communication links to the Free Flight Simulation (i.e., the PAS Bridge) and CTAS (i.e., the CM).

3.2.1.2 Pilot Manager

A single Pilot Manager manages all of the PAS Pseudo-Pilot stations. The Pilot Manager handles communication between the PAS Simulation Manager and the PAS (Pseudo) Pilot Station.

3.2.1.3 Pilot Station

The PAS Pilot Station is really a Pseudo-Pilot Station and should not to be confused with the FFSIM concept of a Pilot Station, which is a representation of a single flight deck. The PAS Pilot Station allows a pseudo-pilot to control a number of PAS-generated pseudo-aircraft. The pseudo-pilot controls the pseudo-aircraft by issuing pre-defined commands strings through the Instrument Panel, shown in Figure 3-9.

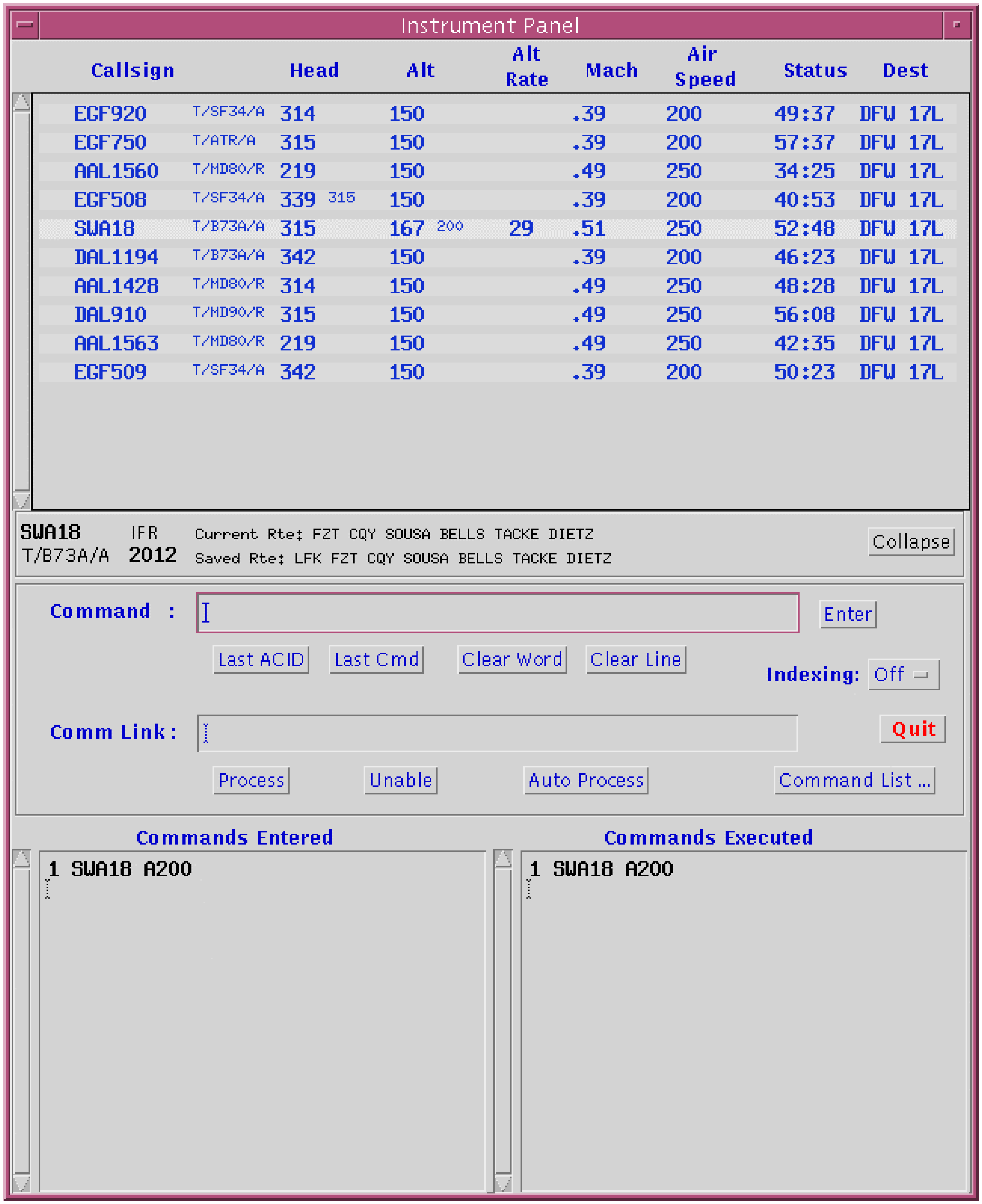

Figure 3-9 The PAS Pseudo-Pilot Station Instrument Panel

3.2.2 Infrastructure

The Pseudo-Pilot Infrastructure consists of the PAS Bridge and an ADS-B Transceiver.

3.2.2.1 PAS Bridge

The PAS Bridge is a communication bridge between the CORBA infrastructure and the PAS Simulation Manager. The PAS Bridge is conceptually part of the Pseudo-Pilot Station Infrastructure as well as the ATSP Infrastructure. Only the Pseudo-Pilot Infrastructure is presented in this section. See Section 3.3.2.3 for a description of the PAS Bridge's role in the ATSP Infrastructure.

The PAS Bridge uses an ADS-B Transceiver to transmit PAS generated traffic information to the Pilot Station ADS-B Transceivers. The PAS traffic is first processed through a local GPS Receiver module to introduce GPS errors into the traffic data. Unlike the Pilot Station GPS Receiver, this is not a separate process, although the software is the same.

3.2.2.2 ADS-B Transceiver

Like the PAS Bridge, the ADS-B Transceiver plays a role in the Pseudo-Pilot Station Infrastructure as well as the ATSP Infrastructure. Only the Pseudo-Pilot Infrastructure is presented in this section. See 3.3.2.1 for a description of the ADS-B Transceiver's role in the ATSP Infrastructure.

The Pseudo-Pilot Station Infrastructure ADS-B Transceiver is also used to send traffic messages from the pseudo-aircraft generated by the PAS. For, efficiency, a single ADS-B Transceiver handles this responsibility for all pseudo-aircraft. The ADS-B Transceiver also receives ADS-B messages from the Pilot Station ADS-B Transceivers.

3.3 ATSP Infrastructure

The Air Traffic Service Provider (ATSP) Infrastructure consists of portions of the Center-TRACON Automation System (CTAS) and Infrastructure applications as shown in Figure 3-10.

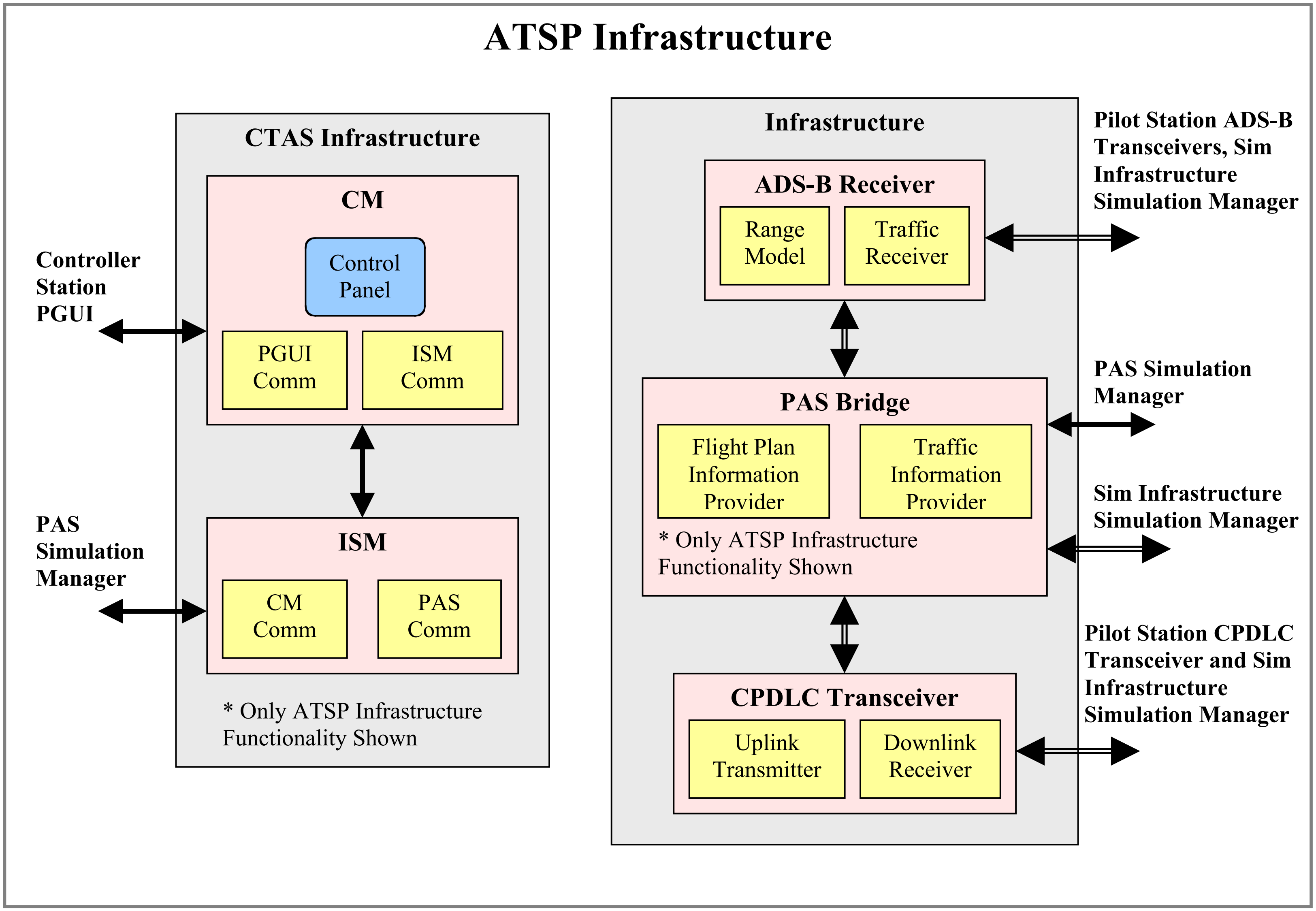

Figure 3-10 ATSP infrastructure software functionality

3.3.1 CTAS

The CTAS processes currently used in the ATSP Infrastructure are the ISM and the CM. CTAS communication is done through a combination of TCP/IP and shared memory.

3.3.1.1 CM

The Communications Manager (CM) handles communication between the various CTAS processes. In the FFSIM configuration the CM handles communication between the ISM and the Controller Station PGUI. The CM user interface is shown in Figure 3-11.

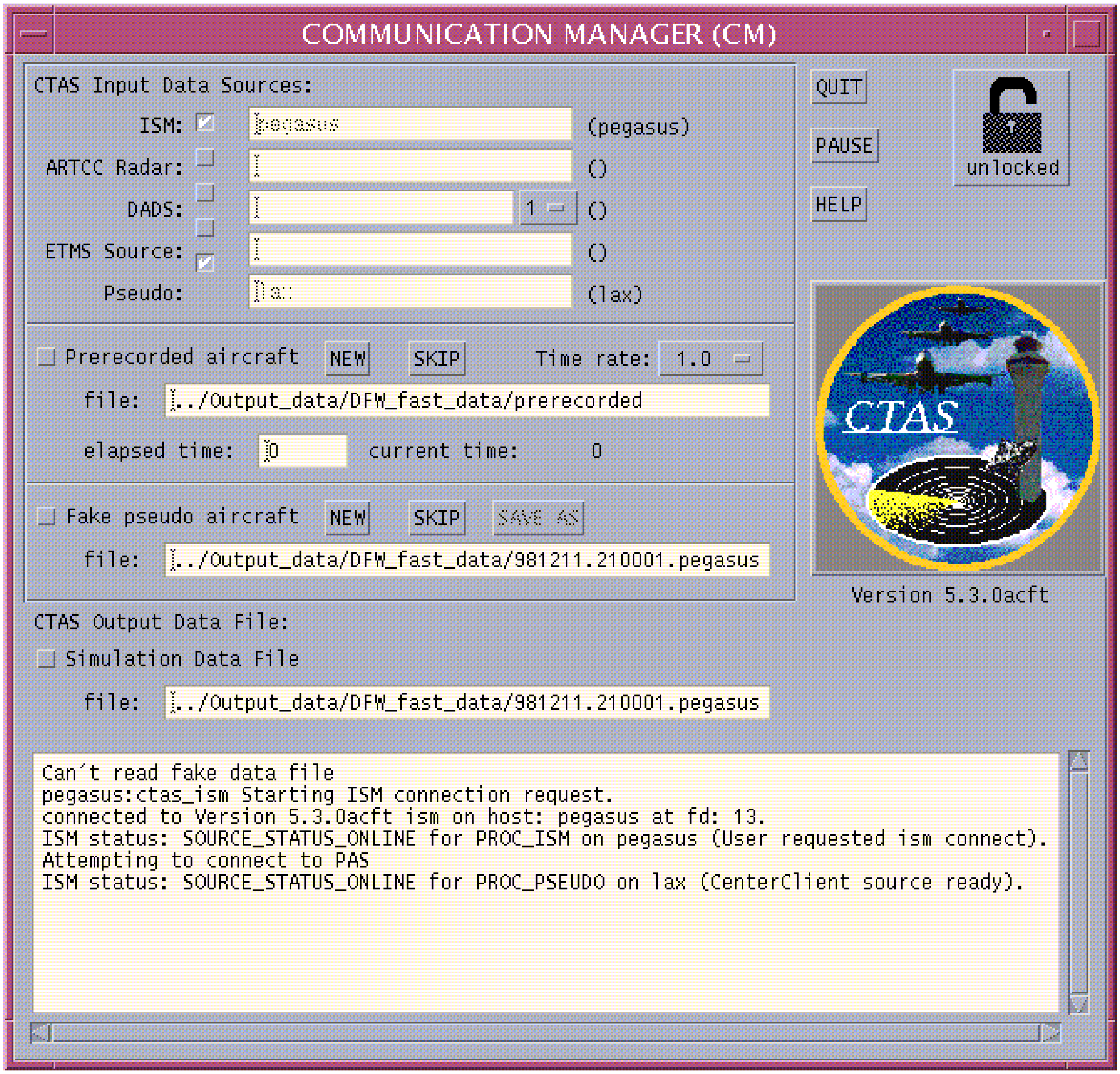

Figure 3-11 The CTAS CM user interface

3.3.1.2 ISM

The Input Source Manager (ISM) handles communication with applications external to CTAS. In the case of FFSIM this is the PAS Simulation Manager. PAS provides CTAS with traffic information (flight plans and position reports). The traffic information is sent to the CM.

3.3.2 Infrastructure

3.3.2.1 ADS-B Receiver

The ADS-B Receiver in Figure 3-10 represents the ADS-B Receiver used by the ATSP. Since the ATSP cannot broadcast ADS-B message it is only equipped with a receiver and not a transceiver. In the FFSIM implementation the ATSP ADS-B Receiver is the same as the Pseudo-Pilot Station ADS-B Transceiver, described in Section 3.2.2.2. The reason for the two being combined is because of efficiency. The ATSP ADS-B Receiver is used for providing traffic information to ATSP traffic displays and decision support tools. The ADS-B Receiver communicates using CORBA.

3.3.2.2 CPDLC Transceiver

The ATSP Infrastructure Controller-Pilot Datalink Communications (CPDLC) Transceiver receives messages from and broadcasts messages to the CPDLC Transceiver for each Pilot Station. The GBDST is the controller application that generates and receives datalink messages. Messages are routed to and from the GBDST via the GSI process. The ATSP Infrastructure CPDLC Transceiver uses CORBA for communication.

3.3.2.3 PAS Bridge

The PAS Bridge is a communication bridge between the CORBA infrastructure and the PAS Simulation Manager. The PAS Bridge is conceptually part of the Pseudo-Pilot Station Infrastructure as well as the ATSP Infrastructure. Only the ATSP Infrastructure is presented in this section. See Section 3.2.2.1 for a description of the PAS Bridge's role in the Pseudo-Pilot Station.

The PAS Bridge functions as the ATSP traffic server. Traffic data being received from the Pilot Stations as well as PAS are merged and made available to ATSP applications, e.g., GBDST. The PAS Bridge also maintains the flight plan information for all of the aircraft in the simulation.

3.4 Controller Station

The Air Traffic Controller Station is implemented with the Center-TRACON Automation System (CTAS) and an Air Traffic Control Decision Support Tool (ATCDST) as shown in Figure 3-12.

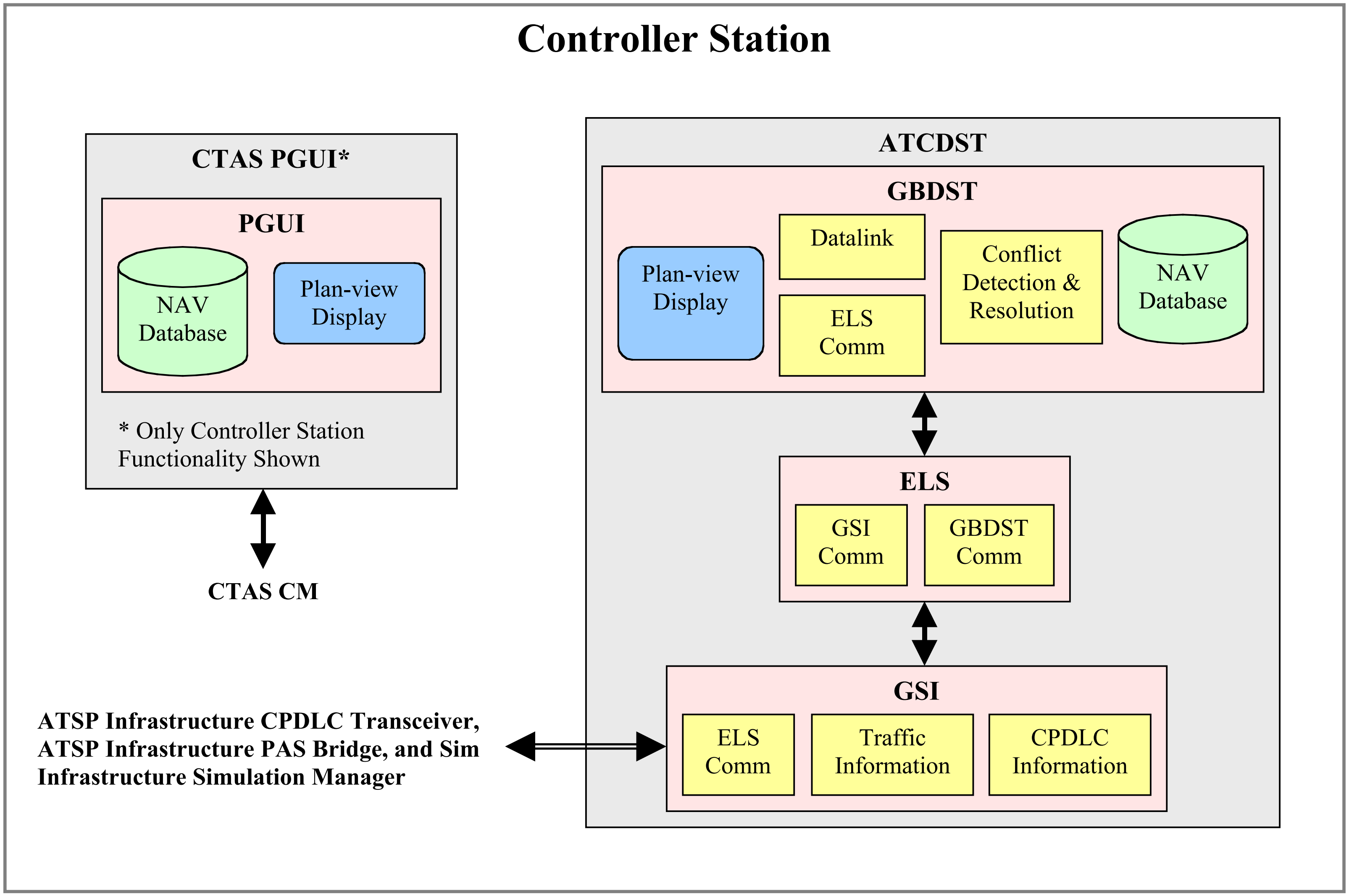

Figure 3-12 Air traffic controller station software functionality

3.4.1 CTAS PGUI

The CTAS portion of the Controller Station is comprised of the Plan-view Graphical User Interface (PGUI).

3.4.1.1 PGUI

The PGUI provides a CTAS plan view display (PVD) for the Controller Station, as shown in Figure 3-13. The PGUI receives aircraft flight plan and track data from the CM. The PGUI is also capable of receiving Estimated Times of Arrival (ETA's), Scheduled Times of Arrival (STA's), runway assignments, descent advisories, and responses to user requests and limited weather information.

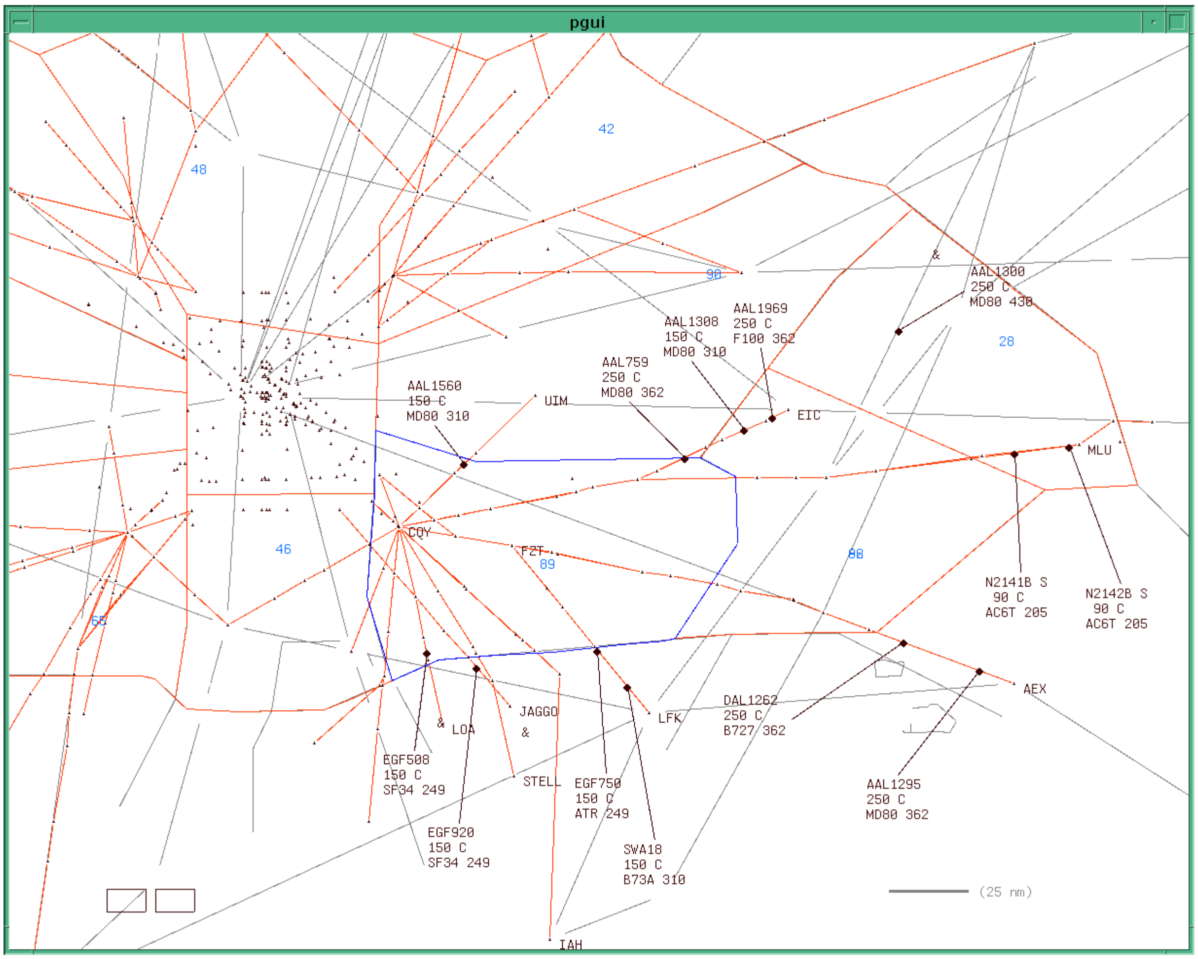

Figure 3-13 The CTAS PGUI controller display for ZFW

3.4.2 ATCDST

The Air Traffic Control Decision Support Tool (ATCDST) is comprised of three processes, GBDST, ELS, and GSI.

3.4.2.1 GBDST

The Ground-based Decision Support Tool (GBDST) provides automated conflict detection and resolution and CPDLC-based datalink capabilities. The GBDST has been designed to have conflict detection and resolution algorithms that are compatible with those in the airborne CDTI and to allow the air traffic service provider to manually initiate a specified 4D-trajectory clearance uplink to a specified Pilot Station in order to resolve an existing conflict. The existing plan-view GBDST display is shown in Figure 3-14.

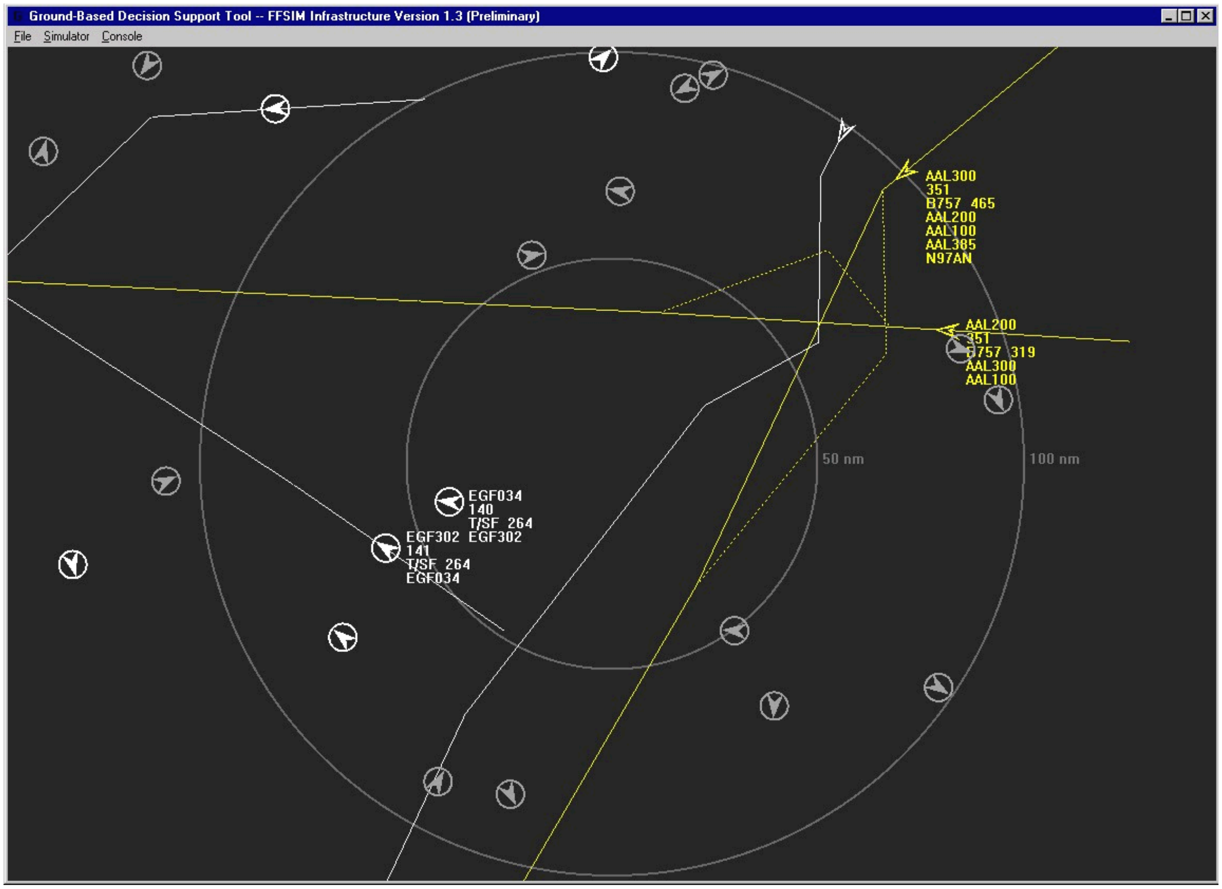

Figure 3-14 The GBDST plan-view display

3.4.2.2 ELS

The Electronic Library System (ELS) is a process that handles communication between the GBDST and GSI.

3.4.2.3 GSI

The Generic Simulation Interface (GSI) is a communications bridge between GBDST/ELS and the Controller Infrastructure. The GSI uses TCP/IP to communicate with ELS and CORBA to communicate with the ATSP Infrastructure CPDLC Transceiver and PAS Bridge. The PAS Bridge supplies all traffic information needed by the ATCDST.

3.5 Simulation Infrastructure

The Simulation Infrastructure consists of a Simulation Manager and the CORBA infrastructure, Orbix as shown in Figure 3-15.

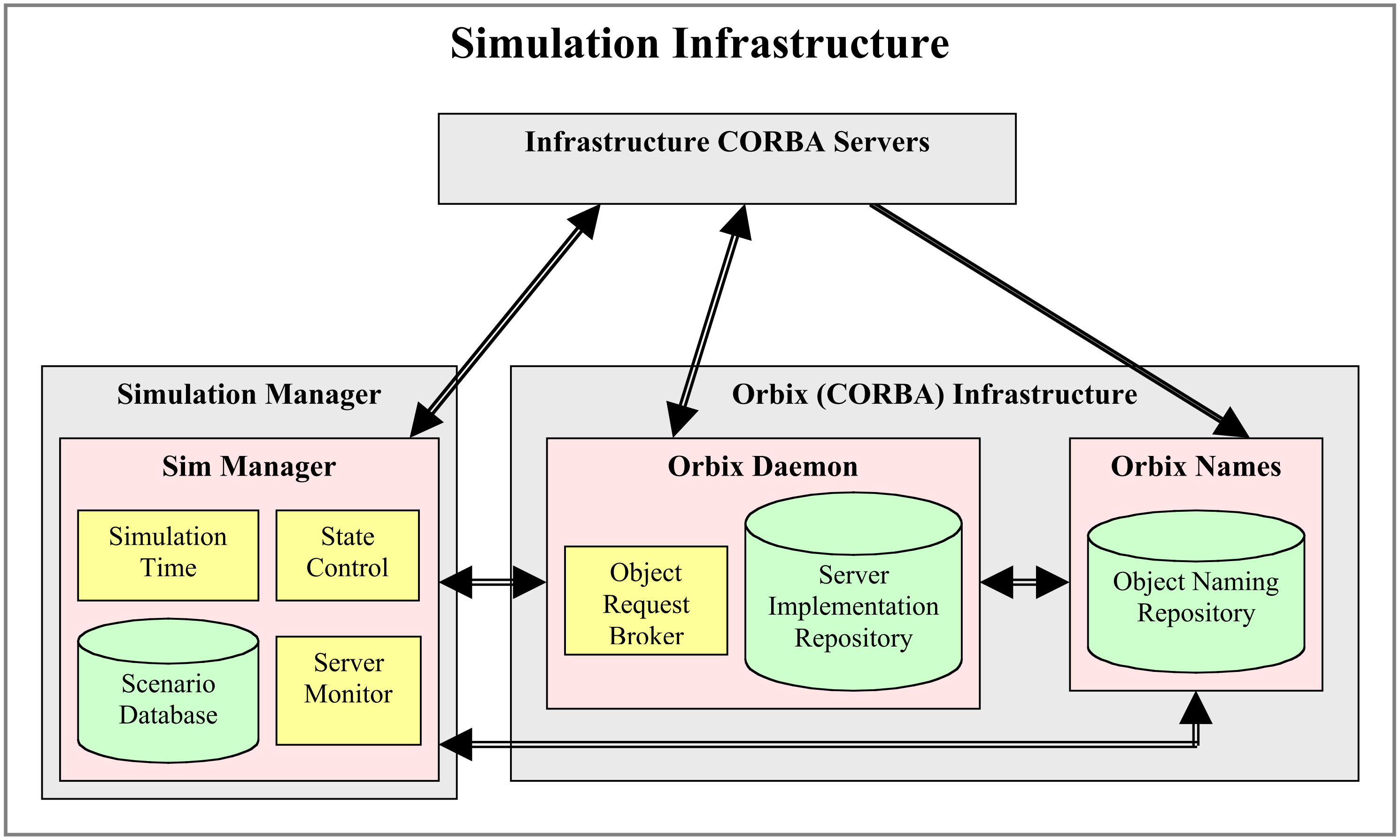

Figure 3-15 Simulation infrastructure software functionality

3.5.1 Simulation Manager

The Simulation Manager is the process that allows the researcher to run scenarios. Through the Simulation Manager, the researcher loads in a scenario and then initializes, starts, stops, and shutdowns the simulation. The Simulation Manager is a command driven application.

The Simulation Manager directly communicates with all of the Infrastructure processes that use CORBA. In addition it communicates with FastWin and CDTI through the FastWin Bridge, with GBDST through GSI, and with PAS and CTAS through the PAS Bridge. Each of the applications responds to initialize, start, and stop commands issued from the Simulation Manager.

3.5.2 Orbix Infrastructure

Orbix is Iona Technologies' implementation of the Common Object Request Broker Architecture (CORBA). Orbix is used to handle the inter-process communication between the FFSIM Infrastructure.

3.5.2.1 Orbix Daemon

The Orbix Daemon is the Object Request Broker (ORB). The ORB acts like an executive and facilitates communication among the CORBA servers and clients.

3.5.2.2 Orbix Names

Orbix Names is Iona's implementation of the CORBA Naming Service. The Naming Service stores references to CORBA objects. The Naming Service is used to store object information about the CORBA servers that is needed by the Simulation Manager. In addition servers such as the ADS-B Transceiver need to know about other ADS-B Transceivers. They do this through the Naming Service.

4 Software Deployment

The Free-Flight Simulation infrastructure is capable of supporting a minimum of three pilot stations, three pseudo-pilot stations, and two controller stations. However, in order to support NASA-Langley's FY99 demonstration requirements (specified in Appendix A), a hardware configuration to support three pilot stations (two Independent and one Dependent), one Pseudo-Pilot Station, and one controller station was needed. The hardware that is required for this configuration is seven Windows NT workstations and three Solaris workstations, as shown in Figure 4-1.

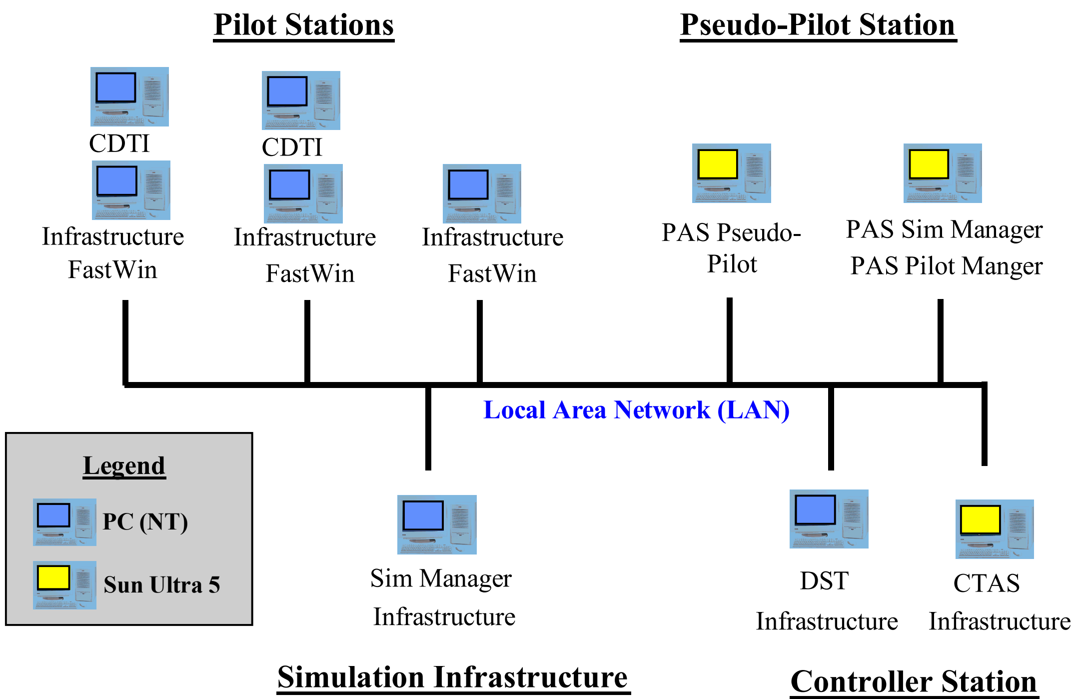

Figure 4-1 FY99 FFSIM Version 1.4 software deployment

4.1 Pilot Station

A single Pilot Station is deployed on one or two Windows NT PCs, depending on whether a Pilot Station is equipped with CDTI. The primary Pilot Station PC contains FastWin and the Pilot Station Infrastructure processes. If CDTI is used, it is deployed on a secondary PC. The current minimum requirements for the primary PC are a 200 MHz Pentium with 64 MB of RAM running Windows NT 4.0. For the secondary PC (CDTI) minimum requirements are a dual 400 MHz Pentium II with 256 MB of RAM running Windows NT 4.0 and Microsoft Access 97 database software.

4.2 Simulation Infrastructure

The Simulation Manager and Orbix Names are deployed on the Simulation Infrastructure PC. The minimum requirements are a 400 MHz Pentium with 256 MB of RAM running Windows NT 4.0.

4.3 Pseudo-Pilot Station

The PAS software is deployed on two Sun Ultra 5 workstations (the PAS Server and the single Pseudo-Pilot Station). The Simulation Manager is located on the PAS Server workstation. Each Pseudo-Pilot workstation contains an instance of the PAS Pilot Station module. A single Pilot Manager, located on the PAS Server workstation, manages all of the Pseudo-Pilot instances.

4.4 Controller Station

The CTAS software is deployed on one Sun Ultra 5 workstation. The DST is deployed on a Windows NT PC. The minimum requirements for the PC are a 400 MHz Pentium with 256 MB of RAM.

4.5 ATSP Infrastructure

The ATSP Infrastructure is deployed on the Controller Station Sun Ultra 5 and the Simulation Infrastructure PC. The CTAS ISM and CM are on the Sun Ultra 5 and the PAS Bridge, CPDLC Transceiver, and ADS-B Transceiver are on the Simulation Infrastructure PC.

5 Future Development

5.1 Conclusions

Development of the FFSIM Infrastructure software during FY99 was very ambitious and presented numerous integration challenges, but was ultimately successful. It involved a number of evolving constraints and required significant collaboration among a number of government and industry organizations.

The software design is object-oriented, flexible and modular. An object-oriented design allows for higher code reuse and faster development time. Software modularity allows for customization and integration of specific concept solutions. The CORBA standard is being leveraged for inter-process communication. This provides for increased flexibility, decreased development time, and increased longevity of the interfaces and components.

The FY99 FFSIM delivery included numerous enhancements to the core flight deck, ATC, and CNS infrastructure components delivered at the conclusion of FY98. The ADS-B message set was augmented to support conflict detection and resolution. A CPDLC message set was incorporated into the FFSIM. Substantial work was performed to improve the flight plans used by both the pilot-station and pseudo-pilot-station aircraft, and how those flight plans are distributed among and used by the other components of the FFSIM. A distributed conflict-detection and resolution module (provided by Lockheed Martin) was integrated (largely by CSC with support from Seagull) into the pilot stations and the ground ATC station. This CD&R capability includes a cockpit display of traffic information (CDTI) that was integrated into the pilot station's FastWin software by NASA Ames and Raytheon contractors (with support by Seagull). Significant improvements in FFSIM initialization, start-up, and shutdown were achieved through the addition of an FFSIM Simulation Manager executive. This involved significant modifications to the PAS software by Logicon as guided by Seagull.

Also, improved traffic scenarios developed by SRC were tested and run on FFSIM Version 1.4.

5.2 Recommendations for Future Work

There are numerous areas in the FFSIM Infrastructure where future work is needed to enhance desired functionality. In this section, recommended tasks are separated into three categories indicating the order in which thee tasks should be completed: the "imminent" tasks are to be completed first; the "near-term" tasks are to be completed next; and the "other remaining" tasks are suggested for completion following the first two categories. This breakdown of tasks does not indicate the relative importance of the tasks, but the sensible order in which they should be completed from a software-development and system-functionality perspective. This "suggested" list of tasks and their priorities is subject to change based on continual discussions with NASA.

5.2.1 Imminent Tasks

5.2.1.1 Continued Simulation Infrastructure Support

Some level of support will be required to support the presence of the FFSIM Infrastructure at NASA Langley Research Center. This task includes cooperative software functional verification, identification and resolution of errors, and a timely response to any unforeseen problems with the software.

5.2.1.2 Continued Upgrade of User Interfaces and Simulation Control Features

This task includes responding to NASA's suggestions regarding desired improvements in simulation control, scenario generation, data logging, or other simulation functions.

5.2.1.3 Continued Enhancement of Error-Handling Capabilities

Enhancement of the FFSIM Infrastructure's error-handling capabilities is considered an important task that will increase usability and reliability of the infrastructure over the long term.

5.2.2 Near-Term Tasks

5.2.2.1 Model FIS

Provision of FIS is a necessary component of Free Flight and must be modeled with appropriate fidelity and incorporated into the FFSIM Infrastructure.

5.2.2.2 Model Ground-Based Radar

Ground-based radar includes primary and secondary surveillance radar. This task is necessary to realistically model and incorporate TIS into the simulation.

5.2.2.3 Utilize the CTAS ISM to Send Aircraft State Data to CTAS

PAS currently communicates aircraft state data directly to the CTAS. While this feature facilitated development and accelerated overall infrastructure functionality up to this point, it does not provide a means to model the error introduced by ground-based radar. In order to model TIS with an appropriate level of fidelity, this task must be performed in conjunction with that of modeling TIS.

5.2.2.4 Model TIS

Provision of TIS is a necessary component of Free Flight and must be modeled with appropriate fidelity and incorporated into the FFSIM Infrastructure.

5.2.2.5 Integrate Airborne Conflict-Detection-and-Resolution DST into the Pseudo-Pilot Station.

This task is necessary to investigate mature Free-Flight operations, where all aircraft have full equipage of DSTs.

5.2.2.6 Automate the Execution of DST-Proposed Trajectory Modifications into the Pseudo-Pilot Station.

This task is necessary to run simulation cases without low-level, human participation.

5.2.2.7 Continued Improvement of Communication Model Fidelity.

This task will involve working closely with NASA Glenn to improve the fidelity of the FFSIM CNS components and include realistic characteristics of communication mechanisms including Mode S, Universal Access Transceiver (UAT), VDL Mode 2, 3 and 4, and satellite communications.

5.2.2.8 Continued Development of Software Architecture for Advanced Flight Planner.

This task will involve working closely with NASA and the engineering and software teams of RTOs 29, 30, and 31.

5.2.3 Other Remaining Tasks

5.2.3.1 Model Equipment Failures

It is desired to investigate the impact equipment failures may have on overall system performance.

5.2.3.2 Integrate CTAS TMA-Build-2 for RTA Generation

Generation of required time-of-arrival (RTA) values is an important feature of future air-traffic management schemes. The CTAS Traffic Management Advisor (TMA), build-2, provides a realistic means to achieve this capability.

5.2.3.3 Refine GPS Model

Refinements to the current GPS model to include a colored-noise component to the error term have been considered. Also, modeling of WAAS and LAAS accuracy is desired.

5.2.3.4 Refine ADS-B Model

Additional versions of the ADS-B model and message set may be desired to allow for investigation of additional DST concepts and ADS-B strategies. Included in these refinements is the modeling of message collisions.

5.2.3.5 Develop a Centralized and Open Aircraft-Performance Database

It is desired to develop a centralized aircraft-performance database for all modules of the FFSIM Infrastructure to access.

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[PAS97] *Pseudo-Aircraft Systems (PAS) Users's Manual*, Revision 4.2, Logicon/Syscon/Syre, November, 1997.

Appendix A FY99 Demo Requirements

This document exists to specify the functional requirements for the FY99 Free Flight Simulation (FFSim) demonstration to the AATT Executive Steering Committee (ESC) at NASA-Langley Research Center in September 1999. This document will serve the purpose of scenario requirements coordination between the simulation participants from NASA-Langley, NASA-Ames, CSC, Seagull Technology, Raytheon, SRC, and ATAC.

Scenarios that will be shown during the demo have been grouped into two main classes:

I. Air-to-Air Free Flight
II. Distributed Air-Ground Traffic Separation

All scenarios within a class will have the same functional requirements. These requirements, in addition to events for several sample scenarios are described below.

A.1 Scenario Class I: Air-to-Air Free Flight

A.1.1 Objective

- To showcase the FFSim's capability to simulate future air-to-air free flight separation assurance concepts without air traffic controller involvement.

A.1.2 Functional Requirements

- 3 Independent-Equipped Pilot Stations with FastWin FMS, CDTI, CD&R DST.
- Crew display interface through Walt Johnson CDTI should include an accept/reject proposed conflict resolution maneuver button.
- ADS-B Transmissions implemented by pilot station ADS-B Tx, pseudo-pilot station ADS-B Tx
- Low-density background basic aircraft supported by the PAS Pilot Manager.
- Scenario management through PAS Simulation Manager.
- Scenario Initialization through FFSim Scenario Manager.
- Conflict resolution should maintain existing RTA's provided new route contains original waypoint having RTA.
- ATSP passive monitoring of air-to-air CD&R process through watching the CTAS PGUI or Ground LDAPS displays; ATSP ADS-B Rx

A.1.3 Planned Scenario Events

- Scenario Startup
- ~30 sec to 1 min lag time
- Conflict detected on 3 CD&R DSTs between the 3 Independent piloted aircraft
- Primary piloted aircraft has conflict with 2 other piloted aircraft.
- Primary aircraft accepts route modification to resolve both conflicts, speeds up to meet RTA.
- Two other piloted aircraft maintain original flight profiles.
- Resolved conflicts lose their "detected" status and the CD&R DSTs show no current conflicts on their displays.
- Scenario Stop

A.1.4 Other Relevant Information

- Independent (Level 3) Airborne Equipage = CDTI, CD&R DST, ADS-B, CPDLC, FMS, GPS, RNAV
- Viewgraph discussion of this scenario should include a description of future research regarding CD&R DST-TCAS integration.

- Different aircraft dynamics models (in FastWin, CDTI, Ground LDAPS, PAS, and Airborne LDAPS) will cause technical inconsistencies if altitude changes are the mode of conflict resolution. Therefore it is required that a horizontal conflict resolution maneuver is performed in this scenario.

A.2 Scenario Class II: Distributed Air-Ground Traffic Separation

A.1.5 Objective

- To showcase the FFSim's capability to simulate future distributed air-ground traffic separation assurance concepts involving interaction between Independent and Dependent aircraft. The safety benefit provided by the redundancy of this integrated system will be demonstrated.

A.2.1 Minimum Simulation Functional Requirements

- 1 Independent-Equipped Pilot Station with ADS-B Tx, FastWin FMS, CDTI, CD&R DST
- Independent aircraft crew display interface through Walt Johnson CDTI should include an accept/reject proposed conflict resolution maneuver button.
- 1 Dependent-Equipped Pilot Station with CPDLC Tx, ADS-B Tx, and FastWin FMS, CDTI (no CD&R DST).
- The Dependent aircraft crew's CDTI needs to have the ability to display datalinked routes and to accept and initiate the accepted route modification.
- 1 ATSP Station with CPDLC Tx and Ground LDAPS displays
- The Ground LDAPS display needs to have the ability for the controller to select an aircraft and send it a new route clearance through CPDLC.
- ADS-B Transmissions implemented by pilot station ADS-B Tx, pseudopilot station ADS-B Tx, ATSP ADS-B Rx
- CPDLC Transmissions implemented by pilot station CPDLC Tx, ATSP CPDLC Tx
- Low-density background basic aircraft supported by the PAS Pilot Manager
- Scenario management through PAS Simulation Manager
- Scenario Initialization through FFSim Scenario Manager

A.2.2 Planned Scenario Events

- Scenario Startup
- ~30 sec to 1 min lag time
- Conflict detected on the Independent pilot station's CD&R DST and on the ATSP's Ground LDAPS display between the Independent and Dependent piloted aircraft.
- The pilot station's CD&R DST and the ATSP's Ground LDAPS display propose conflict resolution maneuvers for the involved aircraft
- Various scenarios could emphasize different events depending on flight procedures and situations:
    - The controller at the ATSP station could accept the Ground LDAPS-proposed conflict resolution maneuver and send the new route clearance to the Dependent pilot station through CPDLC.
        - The Dependent pilot notices an alert that a new route clearance has been sent by the controller.
        - The Dependent pilot views the new route clearance on his CDTI/nav display and accepts the route clearance.
        - The controller receives a "new route accept" message from the Dependent pilot.
        - The Dependent pilot initiates its conflict resolution maneuver.
    - The pilot at the Independent pilot station could accept the proposed conflict resolution maneuver.
- Resolved conflicts lose their "detected" status and the Independent aircraft's CD&R DST and the ATSP's Ground LDAPS display show no current conflicts on their displays.
- Scenario Stop

A.2.3 Other Relevant Information

- Dependent (Level 2) Airborne Equipage = ADS-B, CPDLC, FMS, CDTI/Nav Display with Proposed Routes, GPS, RNAV

- The substitution of aircraft with Basic (Level 1= ADS-B, GPS, RNAV) airborne equipage for the Dependent aircraft could involve the difficult issue of lack of updated intent information when the aircraft is being vectored.
- Different aircraft dynamics models (in FastWin, CDTI, Ground LDAPS, PAS, and Airborne LDAPS) will cause technical inconsistencies if altitude changes are the mode of conflict resolution. Therefore it is required that a horizontal conflict resolution maneuver is performed in this scenario.

A.3 Additional Functional Requirement

- Intercom system connecting all pilot and controller stations. (Depending on the scenario, we may want to coordinate clearances and failure notifications by voice.)

Appendix B FFSIM Phase 2 ADS-B Modeling Requirements

B.1 Purpose

The purpose of this appendix is to describe the message content and communication modeling of the Automatic Dependent Surveillance-Broadcast (ADS-B) message to be used in Phase 2 of NASA Langley Research Center's Free-Flight Simulation Infrastructure (FFSIM). The message content and communication modeling are based on the original ADS-B modeling developed in [1] during previous FFSIM work by Seagull Technology. The message content reported here is extended to include intent information in-line with NASA-Langley's evolving ADS-B message content being developed for NASA's Terminal Area Productivity (TAP) program [2].

B.2 Appendix Organization

This appendix is organized in 7 sections:

1. Section 1 describes the purpose of the appendix,
2. Section 2 describes the organization of the appendix,
3. Section 3 describes the FFSIM ADS-B message set,
4. Section 4 describes the RTCA Special-Committee 186 (SC-186) definitions for ADS-B, ADS-B reports, and ADS-B messages,
5. Section 5 compares the FFSIM ADS-B message set to RTCA ADS-B standards,
6. Section 6 provides information on the ADS-B communications modeling,
7. Section 7 provides references.

B.3 FFSIM Phase 2 ADS-B Message

B.3.1 ADS-B Message Content

The FFSIM Phase 2 ADS-B message set consists of the following information:

Table B - 1 FFSIM Phase 2 ADS-B Message Set

Item	Data Name*	Data Type*	Example	Comments
Simulation ID	simulation_id	long	125	Unique computer id (CID) for the aircraft
Latitude	latitude	double	25.1223	The aircraft's North geodetic (not geocentric) latitude in degrees referenced to the WGS-84 ellipsoid.
Longitude	longitude	double	-125.1583	The aircraft's East geodetic longitude in degrees referenced to the WGS-84 ellipsoid.
Altitude, Geometric	altitude_geometric	float	25000.0	The aircraft's altitude above mean sea level relative to the WGS-84 reference ellipsoid surface in feet
Altitude, Barometric	altitude_barometric	float	25000.0	The altitude in the standard atmosphere above 29.92 in Hg pressure level at which the pressure equals that at the current aircraft altitude
Geometric Altitude Rate	climb_rate_geometric	float	1200.0	The aircraft's vertical speed in geometric altitude feet per minute. A positive value indicates that the aircraft is climbing in altitude
Barometric Altitude Rate	climb_rate_barometric	float	1200.0	The aircraft's vertical speed in barometric altitude feet per minute

Airspeed Flag	airspeed_flag	char	T	An indication of the given airspeed as either being indicated (I) or true (T) airspeed
Airspeed	airspeed	float	250.0	The aircraft's airspeed in knots
Ground Speed	ground_speed	float	250.0	The aircraft's ground speed in knots
True Ground Track Angle	true_ground_track	float	20.0	The angle of the horizontal velocity vector from true north in degrees (positive rotation is clockwise)
Magnetic Ground Track Angle	magnetic_ground_track	float	20.0	The angle of the horizontal velocity vector from magnetic north in degrees (positive rotation is clockwise)
Time Stamp: Hour	hour	short	18	The hour of the time stamp in UTC/Greenwich Mean Time
Time Stamp: Minute	minute	short	58	The minute of the time stamp
Time Stamp: Second	second	short	22	The second of the time stamp
Call Sign	call_sign	long	AAL100	The aircraft call sign used in communication between the aircraft and air traffic control
Beacon Code	beacon_code	short	7700	Specified in PAS aircraft identifications, but not currently used; Could be used in the future to identify aircraft flying VFR or experiencing emergencies
Aircraft Type	type	string	B757	Refers to the aircraft model
Equipage Type	equipage	long	101	Refers to the DAG identification of aircraft as being basic (100), Dependent (101), or Independent (102); Is equivalent to the RTCA/DO-242 "Class Code".
Number of Trajectory Change Points	tcp_number	short	2	0 to N; Will identify the number of following sets of: TCP Type, Name, Latitude, Longitude, Geometric Altitude, Barometric Altitude, ETA; The first waypoint will be the "last-passed" waypoint and all others will be future waypoints.
Trajectory Change Point (TCP) Type	tcp_type	string	WP	WP: Waypoint; In the future, this will be expanded to cover other point types similar to those defined by the TAP program (i.e., TC: TOC; TD: TOD; transition altitude, reporting point)
TCP Name	tcp_name	string	SEAGUL or N25W125	Consists of an identifiable waypoint name or a latitude/longitude name (in the case of a waypoint constructed by the CD&R system). The lat/long name will be specified by the CD&R specialists (i.e., Downs & Barhydt) and will likely take the format of axxbxxx, where a is either an "N" for North or "S" for South of the Equator, b is either "W" for West or "E" for East of Greenwich, and the x's are truncated degrees

TCP Latitude	tcp_latitude	double	25.1223	The North geodetic latitude in degrees, referenced to the WGS-84 ellipsoid, of the nth TCP.
TCP Longitude	tcp_longitude	double	25.1223	The East geodetic longitude in degrees, referenced to the WGS-84 ellipsoid, of the nth TCP.
TCP Geometric Altitude	tcp_altitude_geometric	float	25000.0	The altitude above mean sea level relative to the WGS-84 reference ellipsoid surface in feet of the nth TCP
TCP Barometric Altitude	tcp_altitude_barometric	float	25000.0	The altitude in the standard atmosphere above 29.92 in Hg pressure level at which the pressure equals that at the altitude of the nth TCP
TCP Estimated Time of Arrival:Hour	tcp_eta_hour	short	18	The hour of the estimated time of arrival at the nth TCP in UTC/Greenwich Mean Time
TCP Estimated Time of Arrival:Minute	tcp_eta_minute	short	58	The minute of the estimated time of arrival at the nth TCP in UTC/Greenwich Mean Time
TCP Estimated Time of Arrival:Second	tcp_eta_second	short	22	The second of the estimated time of arrival at the nth TCP in UTC/Greenwich Mean Time

* The data names and data types are representative of the actual types that may be used. Interfaces between specific components may have slight deviations from these names and types. For example the *string* data type represents a dynamic character array, but a specific interface may implement it as a fixed sized array.

The above message is a compilation of information that would, according to RTCA SC-186 standards [3], go out in three possible messages: a State Vector Report, a Mode-Status Report, and an On-Condition Report (see Section 4 for more details).

B.3.2 Other Possible Message Content

In the future, the FFSIM ADS-B message set will most likely migrate into one that integrates more guidance from RTCA/DO-242 [3] and TAP ADS-B message definitions [2]. Likely additions include:

1. Navigational Uncertainty Category-Position
2. Navigational Uncertainty Category-Velocity
3. North Velocity
4. East Velocity
5. Turn Indication
6. Participant Category
7. Surveillance Support Code
8. Emergency/Priority Status (which could supercede Beacon Code)
9. Class Code (which could be merged with Equipage)
10. New Trajectory Change Point Types (TC, TD, etc.) a la TAP
11. TCP Restrictions (altitude, time, and speed)

B.4 RTCA SC-186 Standard ADS-B Message

RTCA Special Committee 186 has recently developed Minimum Aviation System Performance Standards (MASPS) for ADS-B that include recommendations on ADS-B applications, message content, update rate, and system and subsystem requirements [3]. The rest of this section provides details on the RTCA SC-186 recommendations on the content of ADS-B messages.

B.4.1 Definition of Terms

The ADS-B Minimum Aviation System Performance Standards (MASPS) created by the RTCA [3] defines several terms relevant to this document:

ADS-B: ADS-B is a function on an aircraft or a surface vehicle operating within the surface movement area that periodically broadcasts its state vector and other information. ADS-B 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 broadcast transmission systems to provide surveillance information to other users. The aircraft or vehicle originating the broadcast may or may not have knowledge of which users are receiving its broadcast; any user, either aircraft or ground-based, within range of this broadcast, may choose to receive and process ADS-B surveillance information.

ADS-B Message: An ADS-B message is a packet of formatted data that convey information used in the development of ADS-B reports. Message contents and formats are specific to the ADS-B data link; the MASPS does not address message definitions and structures.

ADS-B Report: An ADS-B report is information provided by ADS-B messages received from a transmitting participant. These information elements are available for use by applications external to the ADS-B system.

CDTI: The Cockpit Display of Traffic Information (CDTI) is a generic display that provides the crew with surveillance information about other aircraft, including their position.

Note that ADS-B reports are assembled from ADS-B messages. Different ADS-B technology applications may use different ADS-B reports. Some ADS-B reports may be comprised of a single ADS-B message, while others may take multiple ADS-B messages to assemble an ADS-B report, depending on the application.

B.4.2 ADS-B Reports

There are three ADS-B reports currently specified in the ADS-B MASPS [3]. These are:

- Surveillance State Vector Report (SV)
- Mode/Status Report (MS)
- On-Condition Report (OC)

These ADS-B reports are further defined by Tables 1, 2, and 3 (from [3]).

Table B - 2 ADS-B State Vector Report Definition.

Element	Contents
1	Participant Address
2	Latitude
3	Longitude
4	Geometric Altitude
5	Navigation Uncertainty Category NUC_P – Position
6	Geometric Position Valid (Horizontal/Vertical)
7	*North Velocity
8	*East Velocity
9	*Geometric Vertical Rate
10	Navigation Uncertainty Category NUC_R – Velocity
11	Barometric Altitude (Pressure Altitude)
12	* Barometric Altitude Rate
13	* Air Speed (True/IAS)
14	* Ground Speed, Ground Track (True/Mag Heading)
15	* Turn Indication
16	Time of Applicability
17	Report Mode (Acquisition, Track, Default)

* An indication that no data is available should be provided if appropriate

Table B - 3 ADS-B Mode-Status Report Definition.

Element	Contents
1	*Participant Address
2	*Call Sign
3	*Participant Category
4	*Surveillance Support Code
5	*Emergency/Priority Status
6	*Class Codes
7	TCP Latitude
8	TCP Longitude
9	TCP Altitude (Baro Alt/FL)
10	Time-To-Go TTG
11	Operational Mode Specific Data
12	Flight Mode Specific Data
13	Time of Applicability

* Elements 1-6 comprise a Partial Mode-Status Report.

Table B - 4 ADS-B TCP+1 On-Condition Report Definition.

Element	Contents
1	Participant Address
2	TCP+1 Latitude
3	TCP+1 Longitude
4	TCP+1 Altitude (Baro/FL)
5	TCP+1 Time-To-Go TTG
6	Time of Applicability

B.4.3 ADS-B Information Content

There are many elements within the ADS-B messages, and in this section, the standard information content of these elements are defined. These elements are listed in alphabetical order.

B.4.3.1 Airspeed

True or IAS airspeed may be provided as backup surveillance information to the geometric based state information.

B.4.3.2 Barometric Altitude

Barometric pressure altitude shall be reported, if available, within a range:

-1000 ft < altitude < 100,000 ft.

Barometric pressure altitude shall be reported referenced to standard temperature and pressure.

B.4.3.3 Barometric Altitude Rate

The altitude rate shall be designated as climbing or descending and shall be reported in the range:

| rate | < 32,000 fpm

Barometric altitude rate is defined as the rate of changes of barometric altitude. For $NUC_P = 8$ and $NUC_P = 9$, geometric altitude rate shall be reported, otherwise, barometric altitude rate or inertially augmented barometric altitude rate shall be reported.

B.4.3.4 Call Sign

The call sign provides a field up to 7 alphanumeric characters in length. The call sign is not required for aircraft and vehicles not receiving ATS services and for military aircraft.

B.4.3.5 Class Code

A class code indicates the capability of the aircraft or vehicle to support engagement of specific operations, including but not limited to:

1. No Application Capability (e.g., broadcast only)
2. CDTI-Based Traffic Display Capability
3. Collision Avoidance Capability
4. Terminal Station Keeping Capability
5. Free Flight / Cooperative Separation in Overflight Capability
6. Oceanic Cooperative Separation Capability
7. Simultaneous Approaches Capability
8. Blind Taxi Capability

B.4.3.6 Emergency/Priority Status

The aircraft or vehicle transmitting the ADS-B message can transmit an emergency or priority status as follows:

1. No Emergency / Not Reporting
2. General Emergency
3. Lifeguard/Medical
4. Minimum Fuel
5. No Communications
6. Unlawful Interference
7. Spare
8. Spare

B.4.3.7 Flight Mode Specific Data

The flight mode specific data will be specified by the RTCA at a later date.

B.4.3.8 Geometric Altitude

Geometric height altitude shall be reported, if available, within a range:

-1000 ft < altitude < 100,000 ft.

Geometric height altitude is defined as the minimum altitude above or below a plane tangent to the earth's ellipsoid as defined by WGS-87.

B.4.3.9 Geometric Position Valid

The geometric based state vector is either valid or invalid, indicated by this element of the report. When the geometric based state information is invalid, other state vector information may provide backup information including: barometric pressure altitude, barometric altitude rate, ground speed and ground track and airspeed.

B.4.3.10 Geometric Vertical Rate

The altitude rate shall be designated as climbing or descending and shall be reported in the range:

| rate | < 32,000 fpm.

The geometric altitude rate of the state vector is measured along the line from the origin of the GGS-84 reference system to the current position of the aircraft or vehicle. For $NUC_P = 8$ and $NUC_P = 9$, geometric altitude rate shall be reported, otherwise, barometric altitude rate or inertially augmented barometric altutde rate shall be reported.

B.4.3.11 Ground Speed, Ground Track

Ground speed and ground track may be provided as backup surveillance information to the geometric based state information.

B.4.3.12 Latitude

Horizontal latitude position shall be reported as a geometric position referenced to the WGS-84 ellipsoid [4].

B.4.3.13 Longitude

Horizontal longitude position shall be reported as a geometric position referenced to the WGS-84 ellipsoid [4].

B.4.3.14 Navigation Uncertainty Category – Position (NUC_P)

Currently, there are 9 levels defined for Navigation Uncertainty Category - Position, some of which correspond to Required Navigation Performance (RNP) levels:

0. No Integrity
1. < 20 nmi (RNP-10)
2. < 10 nmi (RNP-5)
3. < 2 nmi (RNP-1)
4. < 1 nmi (RNP-0.5)
5. < 0.5 nmi
6. < 0.2 nmi
7. < 0.1 nmi
8. TBD
9. TBD

B.4.3.15 Navigation Uncertainty Category – Velocity (NUC_R)

Currently, there are 4 levels defined for Navigation Uncertainty Category – Velocity, defined relative to horizontal velocity error (95%) or vertical velocity error (95%):

0.	Unknown	Horizontal Velocity Error	Unknown	Vertical Velocity Error
1.	< 20 m/s	Horizontal Velocity Error	< 50 fps	Vertical Velocity Error
2.	< 3 m/s	Horizontal Velocity Error	< 15 fps	Vertical Velocity Error
3.	< 1 m/s	Horizontal Velocity Error	< 5 fps	Vertical Velocity Error
4.	< 0.3 m/s	Horizontal Velocity Error	< 1.5 fps	Vertical Velocity Error

B.4.3.16 North/East Velocity Vector

The geometric velocity information shall be referenced to WGS-84. The horizontal velocity vector components are defined as the North-South and East-West velocity relative to the WGS-84 ellipsoid. Reported ranges are

0 < velocity < 250 kts on the surface
0 < velocity < 4000 kts airborne.

B.4.3.17 Operational Mode Specific Data

The operational mode specific data include but are not limited to: speed target, Mag/True Track, IAS/TAS. These data are dependent on the application of the ADS-B system.

B.4.3.18 Participant Address

A unique address correlates all ADS-B messages transmitted from a particular aircraft or vehicle and differentiates the message from other messages in the operational domain.

B.4.3.19 Participant Category

The aircraft or vehicle transmitting the ADS-B message has a category, as defined by ICAO, to be one of the following:

1. Light Aircraft – weight < 15,500 lbs
2. Reserved
3. Medium Aircraft – 15,000 lbs < weight < 300,000 lbs
4. Reserved
5. Heavy Aircraft – weight > 300,000 lbs
6. High Maneuverable Aircraft (>5g acceleration capability) and High Speed Aircraft (>400 kts cruise)
7. Reserved
8. Reserved
9. Reserved
10. Rotorcraft
11. Glider/Sailplane
12. Lighter-than-Air
13. Unmanned Aerial Vehicle
14. Space/Transatmospheric vehicle
15. Ultralight/Hangglider/Paraglider
16. Parachutist/Skydiver
17. Reserved
18. Reserved
19. Reserved
20. Surface Vehicle – Emergency Vehicle
21. Surface Vehicle – Service Vehicle
22. Fixed Ground or Tethered Obstruction
23. Reserved
24. Reserved

B.4.3.20 Report Mode

The report mode provides a positive indication when acquisition is complete and all applicable data sets and modal capabilities have been determined for the participant or that a default condition is determined by the report generator function.

B.4.3.21 Surveillance Support Code

The surveillance support code indicates:
Normal – all data is reliable for the stated class code
Default – transmitter advises that some transmitted data is not reliable or unavailable.

B.4.3.22 Time of Applicability

The time of applicability shall be provided in all reports, indicating the time at which the reported values were valid.

B.4.3.23 Time-To-Go (TTG)

The Time-To-Go (TTG) indicates the amount of flight time to go to the TCP.

B.4.3.24 Trajectory Change Point (TCP and TCP+1)

The TCP is the point in three dimensional space where the current trajectory is planned to change, and an estimation for the remaining flight Time-To-Go (TTG) to this point. The current TCP may be followed by another TCP, which is referred to as the TCP+1. Upon initiation of a flight path change, the TCP+1 will become the TCP.

B.4.3.25 Turn Indication

The aircraft or vehicle turn rate shall be transmitted as turning right, left, or not turning.

B.5 Comparison of FFSIM ADS-B message with RTCA SC-186 Standards

In general, the FFSIM Phase 2 ADS-B message set was designed to reflect the stated aviation industry requirements for strategic conflict detection and resolution applications (i.e., the "Flight Plan Deconfliction" application in [3]). However, important differences exist. (Note: within [3] itself, differences exist. For example in Section 2.1.2 of [3], no need is mentioned for an ADS-B transmission of airspeed (true or indicated). However, airspeed is later mentioned as a requirement in Section 3.4.3.1.). These differences are described below.

First of all, there are a number of ADS-B message items mentioned by the aviation industry standards, but are not included in the FFSIM Phase 2 ADS-B message content. These aviation industry standard items not being used include: Navigation Uncertainty Categories (Position and Velocity), Turn Indication, Report Mode, Surveillance Support Code, and any Flight Mode Specific Data

Next, there are a number of FFSIM Phase 2 ADS-B message items that are not mentioned by the aviation industry standards. These include the last-passed waypoint and future trajectory change points greater than Next + 1. In the FFSIM Phase 2 ADS-B messages, the last-passed waypoint is used in order to provide the airborne and ground conflict detection and resolution systems information on whether the current aircraft position is on its flight plan or not. Also, trajectory change points beyond the Next and Next+1 mentioned in [3] are used in order to maximize the possible intent information being transferred.

Then, for a number of the ADS-B message items, their use in FFSIM Phase 2 is roughly, but not exactly, equivalent to the convention in [3]. This holds true for the following FFSIM Phase 2 items: simulation ID, equipage type, aircraft type, beacon code, horizontal velocity, ground track angles, and trajectory change points. In the case of FFSIM Phase 2, a unique computer id for each aircraft is reflected in a 3 digit simulation ID and not a 24 bit "participant address", as stated in [3]. Next, the "equipage type" convention is specific to FFSIM, but reflective of the content of [3]'s "class code". FFSIM Phase 2's "aircraft type" is more specific than [3]'s requirement to broadcast ICAO aircraft/vehicle category (e.g., "B757" versus "Heavy aircraft"), and its "beacon code" is roughly equivalent to [3]'s "emergency/priority status". In the case of uniquely defining horizontal velocity, FFSIM Phase 2 uses the definition of a ground speed and ground track angle. However, the aviation industry standards suggest that both that definition as well as North Velocity and East Velocity be used. Unlike [3]'s requirement for either true or magnetic ground track angle, the FFSIM Phase 2 sends both values in order to provide the CDTI magnetic variance information. Finally, the FFSIM Phase 2's definition of the trajectory change points is different. FFSIM's value for the expected time at the TCP is in UTC time and not in "time-to-go", and it adds both geometric altitude and a TCP name, the latter of which allows for different types of TCPs in-line with the convention used in NASA's TAP program [2].

Finally, the FFSIM ADS-B message gets sent in one report as opposed to 3 separate ADS-B reports (State Vector, Mode-Status, and On-Condition) as recommended by the RTCA SC-186.

B.6 ADS-B Communications Modeling

Within FFSIM Phase 2, the capability to model some basic communication system behavior has also been incorporated. The existing ADS-B communications modeling includes the ability to model:

1. user-specified ADS-B transceiver range,
2. user-specified ADS-B broadcast rate,
3. a probabilistic degradation of ADS-B signal with range, and
4. ADS-B line-of-sight range constraints.

The last two ADS-B communications models mentioned above are now described.

B.6.1 Probabilistic ADS-B Signal Degradation with Range

The ADS-B signal degradation model consists of a piecewise linear relationship between the probability of signal reception versus the range of a receiving antenna over the antenna nominal operating range as shown in Figure B - 1. This characteristic consists of 3 important break points:

1. At a non-dimensional range of 0, the probability of correct reception is 0.995.
2. At a non-dimensional range of 0.9, the probability of correct reception is 0.9.
3. At a non-dimensional range of 1.1, the probability of correct reception is 0.0.

These break points lead to a probability of correct reception at the nominal antenna operating range of 0.5.

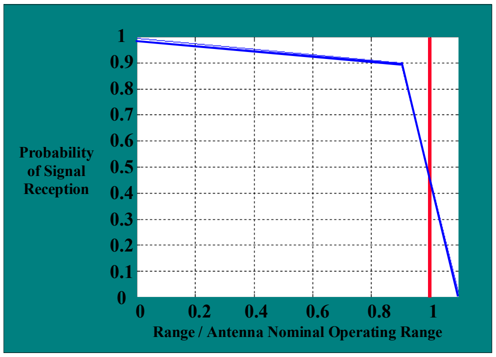

Figure B - 1 ADS-B Signal Range Attenuation

B.6.2 ADS-B Line-of-Sight Constraints

Two aircraft broadcasting ADS-B messages using Mode S communication will be limited in their range by line-of-sight problems with blockage due to the Earth being in the way. It can be shown that, from geometric considerations [5], message blocking due to a spherical Earth will limit the ADS-B range (without atmospheric bending effects) to:

$$\text{Max range (in nmi)} = R_E\left(\tan\left(\frac{\pi}{2}-\sin^{-1}\left(\frac{R_E}{R_E+h_1}\right)\right)+\tan\left(\frac{\pi}{2}-\sin^{-1}\left(\frac{R_E}{R_E+h_2}\right)\right)\right)$$

where

R_E = radius of the Earth (in nmi),

h_1 = geometric altitude (in nmi) of the first aircraft, and

h_2 = geometric altitude (in nmi) of the second aircraft.

However, the downward bending of radio waves due to the atmosphere serves to increase the maximum line-of-sight range with an effect equivalent to that of an Earth with a radius equal to 4/3 times its normal radius. Shown in Figure B - 2 this effect is approximated for the line-of-sight constraint from an aircraft to a given ground station by [6]:

$$\text{Max range (in nmi)} = \left(\frac{h}{0.662}\right)^{0.5}$$

where

h = geometric altitude (in feet) of the aircraft.

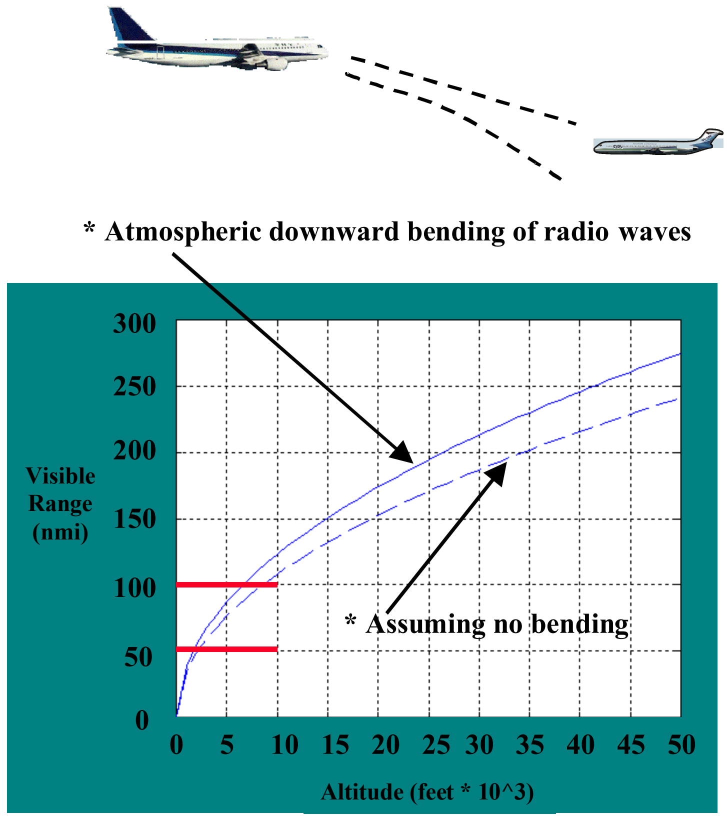

Figure B - 2 Maximum ADS-B Range to a Ground Station vs. Altitude

Due to the effect of this atmospheric bending, a good approximation of line-of-sight range constraints for two aircraft is derived by the equation:

$$\text{Max range (in nmi)} = \left(\frac{h_1}{0.662}\right)^{0.5} + \left(\frac{h_2}{0.662}\right)^{0.5}$$

where

h_1 = geometric altitude (in feet) of the first aircraft, and

h_2 = geometric altitude (in feet) of the second aircraft.

B.7 References

[1] Bjorkman, W.S., et al., "Development of a Free-Flight Simulation Infrastructure," NASA Contract No. NAS2-98001, TR 98175.3-01, Seagull Technology, Inc., Los Gatos, CA, December, 1998.
[2] "Data Link Messages for TAP CTAS/FMS Experiment," Updated June 25, 1999.
[3] RTCA SC-186, "Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)," Document No. RTCA/DO-242, February 19, 1998.
[4] Dept. of Defense, "World Geodetic System 1984: Its definition and relationships with local geodetic systems", Tech. Report TR-8350.2, Defense Mapping Agency, Fairfax, VI, September, 1991.
[5] Schleicher, David, "ADS-B Line of Sight Geometry Problem" notes, August 16, 1999.
[6] Orlando, V. A., and Harman, W. H., "GPS-Squitter Capacity Analysis," MIT Lincoln Laboratory Project Report ATC-214, Lexington, Massachusetts, May 20, 1994.

Appendix C FFSIM Phase 2 CPDLC Modeling Requirements

C.1 Purpose

The purpose of this appendix is to describe the message content of Controller-Pilot Data Link Communications (CPDLC) message to be used in Phase 2 of NASA Langley Research Center's Free-Flight Simulation Infrastructure (FFSIM). The message content reported here is designed to be compatible with current RTCA CPDLC standards [1] and with NASA-Langley's evolving datalink message content being developed for NASA's Terminal Area Productivity (TAP) program [2].

C.2 Appendix Organization

This appendix is organized in 6 sections:
1. Section 1 describes the purpose of the appendix,
2. Section 2 describes the organization of the appendix,
3. Section 3 describes the FFSIM CPDLC message set,
4. Section 4 describes the current CPDLC message standards,
5. Section 5 compares the FFSIM CPDLC message set to the current CPDLC message standards, and
6. Section 6 provides references.

C.3 FFSIM Phase 2 CPDLC Message

C.3.1 FFSIM CPDLC Message Content

The FFSIM Phase 2 CPDLC message set consists of: 1 4D Trajectory Clearance uplink message and 1 Clearance Response downlink message. Detailed content of the messages is shown in Table C - 1and Table C - 2.

Table C - 1 FFSIM Phase 2 CPDLC 4D Trajectory Clearance (Uplink) Message

Item	Data Name*	Data Type*	Example	Comments
Message Source	message_source	string	ZDV_33	The ATC sector identifier for the ATC controller who is sending the message.
Message Destination	message_destination	string	AAL100	The call sign for the aircraft which the message is being sent to.
Time Stamp: Hour	hour	short	18	The hour of the time stamp (when the message is created) in UTC/Greenwich Mean Time
Time Stamp: Minute	minute	short	58	The minute of the time stamp
Time Stamp: Second	second	short	22	The second of the time stamp
Message Identification Number	message_id_number	short	5175	A unique number assigned to each message
Response Required	response_req	short	1	0 = No, 1 = Yes
Number of Trajectory Change Points	tcp_number	short	2	0 to N; Will identify the number of following sets of: TCP Type, Name, Latitude, Longitude, Geometric Altitude, Barometric Altitude, ETA
Trajectory Change Point (TCP) Type	tcp_type	string	WP	WP: Waypoint; In the future, this will be expanded to cover other point types similar to those defined by the TAP program (i.e., TC: TOC; TD: TOD; transition altitude, reporting point)

TCP Name	tcp_name	string	SEAGUL or N25W125	Consists of an identifiable waypoint name or a latitude/longitude name (in the case of a waypoint constructed by the CD&R system). The lat/long name will be specified by the CD&R specialists (i.e., Downs & Barhydt) and will likely take the format of axxbxxx, where a is either an "N" for North or "S" for South of the Equator, b is either "W" for West or "E" for East of Greenwich, and the x's are truncated degrees
TCP Latitude	tcp_latitude	double	25.1223	The North geodetic latitude in degrees, referenced to the WGS-84 ellipsoid, of the nth TCP.
TCP Longitude	tcp_longitude	double	-125.1223	The East geodetic longitude in degrees, referenced to the WGS-84 ellipsoid, of the nth TCP.
TCP Geometric Altitude	tcp_altitude_geometric	float	25000.0	The altitude above mean sea level relative to the WGS-84 reference ellipsoid surface in feet of the nth TCP
TCP Barometric Altitude	tcp_altitude_barometric	float	25000.0	The altitude in the standard atmosphere above 29.92 in Hg pressure level at which the pressure equals that at the altitude of the nth TCP
TCP Required Time of Arrival:Hour	tcp_rta_hour	short	18	The hour of the required time of arrival at the nth TCP in UTC/Greenwich Mean Time
TCP Required Time of Arrival:Minute	tcp_rta_minute	short	58	The minute of the required time of arrival at the nth TCP in UTC/Greenwich Mean Time
TCP Required Time of Arrival:Second	tcp_rta_second	short	22	The second of the required time of arrival at the nth TCP in UTC/Greenwich Mean Time

Table C - 2 FFSIM Phase 2 CPDLC Clearance Response (Downlink) Message

Item	Data Name*	Data Type*	Example	Comments
Message Source	message_source	string	AAL100	The call sign for the aircraft which is sending the downlink message
Message Destination	message_destination	string	ZDV_33	The ATC sector identifier for the ATC controller who is sending the message.
Time Stamp: Hour	hour	short	18	The hour of the time stamp (when the message is created) in UTC/Greenwich Mean Time
Time Stamp: Minute	minute	short	58	The minute of the time stamp
Time Stamp: Second	second	short	22	The second of the time stamp
Message Identification Number	message_id_number	short	5175	A unique number assigned to each message

Message Reference Number	message_ref_number	short	5175	Used to uniquely associate a response with a previously received message.. The Message Identification Number of a previously-received message becomes the Message Reference Number of the response message
Pilot Response	pilot_response	string	WILCO	The downlinked pilot response to the uplinked CPDLC trajectory message; Options are WILCO or UNABLE

* The data names and data types are representative of the actual types that may be used. Interfaces between specific components may have slight deviations from these names and types. For example the *string* data type represents a dynamic character array, but a specific interface may implement it as a fixed sized array.

C.3.2 Other Possible Message Content

In the future, the FFSIM CPDLC message set will most likely migrate into one that integrates more guidance from RTCA SC-169 and TAP CPDLC message definitions. Possible additions include:

1. Message Precedence Levels (for prioritized message receipt)
2. Downlinked/Uplinked Free Text Messages
3. Downlinked AFFIRM/NEGATIVE Pilot Responses
4. Downlinked or Default CPDLC NOT ENABLED Message
5. Uplinked Vertical Clearances (e.g., CLIMB TO AND MAINTAIN [altitude]
6. Uplinked Crossing Constraints (e.g., CROSS [position] AT [altitude]
7. Uplinked Lateral Offsets (e.g., AT [time] OFFSET [distanceoffset][direction] OF ROUTE)
8. Uplinked Route Modifications (e.g., PROCEED DIRECT TO [position])
9. Uplinked Speed Changes (e.g., INCREASE SPEED TO [speed])
10. Uplinked Contact/Monitor/Surveillance Requests (e.g., AT [time] CONTACT [icaounitname][frequency])
11. Uplinked Report/Confirmation Requests (e.g., CONFIRM TIME OVER REPORTED WAYPOINT)
12. Uplinked Negotiation Requests (e.g., CAN YOU ACCEPT [altitude] AT [time])
13. Uplinked Air Traffic Advisories (e.g., RADAR CONTACT LOST)
14. Uplinked Additional Messages (e.g., FREE FLIGHT ENABLED/DISABLED)
15. Uplinked Descent Advisory Clearances (incl. cruise speed and clearance descent speed)
16. Uplinked Winds and Temperature Data
17. Downlinked Vertical Requests (e.g., REQUEST DESCENT TO [altitude])
18. Downlinked Lateral Offset Requests (e.g., AT [time] REQUEST OFFSET [distanceoffset][direction] OF ROUTE)
19. Downlinked Speed Requests (e.g., REQUEST [speed])
20. Downlinked Voice Contact Requests (e.g., REQUEST VOICE CONTACT)
21. Downlinked Route Modification Requests (e.g., REQUEST [routeclearance])
22. Downlinked Reports (e.g., DESCENDING TO [altitude])
23. Downlinked Negotiation Requests (e.g., WHEN CAN WE EXPECT HIGHER ALTITUDE)
24. Downlinked Emergency Messages (e.g., MAYDAY MAYDAY MAYDAY)
25. Downlinked User Preference Information (e.g., User Preferred Trajectory, Weight)

C.4 CPDLC Message Standards

C.4.1 RTCA Minimum Operational Performance Standards for ATC Two-Way Data Link Communications

RTCA Special Committee 169 has generated minimum operational performance standards for ATC two-way data link communications and documented them in [1]. This document defines the content and format of hundreds of potential pilot-controller datalink messages.

Currently, this document reflects the major US aviation industry standards work to date that is driving the specification of CPDLC messages. However, according to [3], in the near-future, a new document from RTCA SC-189/WG-53 is expected to be published which will supercede [1] and [4].

C.4.2 CPDLC Build I

Currently, the FAA is choosing a small subset of the datalink messages mentioned in [1] and designating them "CPDLC Build 1". The CPDLC Build 1 message set consists of four Aeronautical Telecommunication Network (ATN)-compliant messages [5]:

1. Transfer of Communication (TOC),
2. Initial Contact (IC),
3. An informational Free Text menu, and
4. Altimeter Setting Messages (ASM).

These messages will be transferred by a Very High Frequency Digital Link Mode 2 (VDL-2) air-ground communication network between data link-equipped aircraft and air traffic controllers.

Details on the CPDLC Build 1 messages [6] are shown in Table C - 3 through Table C - 10.

Table C - 3 Contact/Monitor/Surveillance Requests (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
117	Instruction that the ATS unit with the specified ATS unit name is to be contacted on the specified frequency.	CONTACT *(unit name) (frequency)*	N	M	W/U
120	Instruction that the ATS unit with the specified ATS unit name is to be monitored on the specified frequency.	MONITOR *(unit name) (frequency)*	N	M	W/U

Table C - 4 Report/Confirmation Requests (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
135	Instruction to confirm and acknowledge the currently assigned level.	CONFIRM ASSIGNED LEVEL	N	L	Y

Table C - 5 Air Traffic Advisories (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
213	ATS advisory that the specified altimeter setting relates to the specified facility.	*(facility designation)* ALTIMETER *(altimeter)*	N	L	R
157	Notification that a continuous transmission is detected on the specified frequency. Check the microphone button.	CHECK STUCK MICROPHONE *(frequency)*	U	M	N

Table C - 6 System Management Messages (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
159	A system generated message notifying that the ground system has detected an error.	ERROR *(error information)*	U	M	N
160	Notification to the avionics that the specified data authority is the Next Data Authority. If no data authority is specified, this indicates that any previously specified Next Data Authority is no longer valid.	NEXT DATA AUTHORITY *(facility)*	L	N	N

	Message Intent/Use	Message Element	URG	ALRT	RESP
162	Notification that the ground system does not support this message.	SERVICE UNAVAILABLE	L	L	N
227	Confirmation to the aircraft system that the ground system has received the message to which the logical acknowledgment refers and found it acceptable for display to the responsible person.	LOGICAL ACKNOWLEDGMENT	N	M	N
233	Notification to the pilot that messages sent requiring a logical acknowledgment will not be accepted by this ground system.	USE OF LOGICAL ACKNOWLEDGMENT PROHIBITED	N	M	N

Table C - 7 Additional Messages (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
183		*(free text)*	N	M	N
196		*(free text)*	N	M	W/U
203		*(free text)*	N	M	R
205		*(free text)*	N	M	A/N

Table C - 8 Responses (Downlink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
0	The instruction is understood and will be complied with.	WILCO	N	M	N
1	The instruction cannot be complied with.	UNABLE	N	M	N
2	Wait for a reply.	STANDBY	N	M	N
3	Message received and understood.	ROGER	N	M	N
4	Positive pilot response.	AFFIRM	N	M	N
5	Negative pilot response.	NEGATIVE	N	M	N

Table C - 9 Reports (Downlink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
38	Read-back of the assigned level.	ASSIGNED LEVEL *(level)*	N	M	N

Table C - 10 System Management Messages (Downlink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
62	A system generated message that the avionics has detected an error.	ERROR *(error information)*	U	L	N
63	A system generated denial to any CPDLC message sent from a ground facility that is not the current data authority.	NOT CURRENT DATA AUTHORITY	L	L	N
99	A system generated message to inform a ground facility that it is now the current data authority.	CURRENT DATA AUTHORITY	L	L	N

	Message Intent/Use	Message Element	URG	ALRT	RESP
107	A system generated message sent to a ground system that tries to connect to an aircraft when a current data authority has not designated the ground system as the NDA.	NOT AUTHORIZED NEXT DATA AUTHORITY	L	L	N
100	Confirmation to the ground system that the aircraft system has received the message to which the logical acknowledgment refers and found it acceptable for display to the responsible person.	LOGICAL ACKNOWLEDGMENT	N	M	N

Currently, the FAA plans to implement CPDLC Build 1 at the Miami ARTCC in 2002. Initial tests will be performed using B737-800 and B767-300ER owned by American Airlines [5].

C.4.3 CPDLC Build IA

After CPDLC Build I is deployed, the FAA plans to implement a follow-on CPDLC message set known as CPDLC Build IA. According to [5], Build IA will include the message set from Build I, but will add messages that will enable:

1. the assignment of speed clearances,
2. the assignment of heading clearances,
3. the assignment of altitude clearances,
4. the assignment of route clearances, and
5. pilot-initiated altitude requests.

In addition to the messages previously-specified in Table C - 3 through Table C - 10, CPDLC Build IA will provide the capability to transmit the messages described in Table C - 11 through Table C - 20 [6].

Table C - 11 Responses/Acknowledgments (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
0	Indicates that ATC cannot comply with the request.	UNABLE	N	M	N
1	Indicates that ATC has received the message and will respond.	STANDBY	N	L	N
3	Indicates that ATC has received and understood the message.	ROGER	N	L	N

Table C - 12 Vertical Clearances (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
19	Instruction to maintain the specified level.	MAINTAIN *(level)*	N	M	W/U
20	Instruction that a climb to a specified level is to commence and once reached the specified level is to be maintained.	CLIMB TO *(level)*	N	M	W/U
23	Instruction that a descent to a specified level is to commence and once reached the specified level is to be maintained.	DESCEND TO *(level)*	N	M	W/U

Note: Wherever the variable (level) is specified, the message can specify either a single level or a vertical range, i.e., block level.

Table C - 13 Route Modifications (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
74	Instruction to proceed directly from the present position to the specified position.	PROCEED DIRECT TO *(position)*	N	M	W/U
80	Instruction to proceed via the specified route.	CLEARED *(route clearance)*	N	M	W/U
190	Instruction to fly on the specified heading.	FLY HEADING (degrees)	N	M	W/U

Table C - 14 Speed Changes (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
106	Instruction that the specified speed is to be maintained.	MAINTAIN *(speed)*	N	M	W/U
108	Instruction that the specified speed or a greater speed is to be maintained.	MAINTAIN *(speed)* OR GREATER	N	M	W/U
109	Instruction that the specified speed or a lesser speed is to be maintained.	MAINTAIN *(speed)* OR LESS	N	M	W/U

Table C - 15 Report/Confirmation Requests (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
231	Instruction to indicate the pilot's preferred level.	STATE PREFERRED LEVEL	L	L	Y

Table C - 16 Additional Messages (Uplink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
165	Used to link two messages, indicating the proper order of execution of clearances/instructions.	THEN	L	N	N

Table C - 17 Vertical Requests (Downlink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
6	Request to fly at the specified level.	REQUEST *(level)*	N	L	Y
9	Request to climb to the specified level.	REQUEST CLIMB TO [level]	N	L	Y
10	Request to descend to the specified	REQUEST DESCENT TO [level]	N	L	Y

Table C - 18 Reports (Downlink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
106	Notification of the preferred level.	PREFERRED LEVEL *(level)*	L	L	N

Table C - 19 Crossing Constraints (Uplinks)

	Message Intent/Use	Message Element	URG	ALRT	RESP
46	The specified position is to be crossed at the specified level. This may require the aircraft to modify its climb or descent profile.	CROSS [position] AT [level]	N	M	W/U
51	The specified position is to be crossed at the specified time	CROSS [position] AT [time]	N	M	W/U
52	The specified position is to be crossed at or before the specified time.	CROSS [position] AT OR BEFORE [time]	N	M	W/U
53	The specified position is to be crossed at or after the specified time.	CROSS [position] AT OR AFTER [time]	N	M	W/U
55	The specified position is to be crossed at the specified speed and the specified speed is to be maintained until further advised.	CROSS [position] AT [speed]	N	M	W/U
61	Instruction that the specified position is to be crossed at the specified level and speed and the level and speed are to be maintained.	CROSS [position] AT AND MAINTAIN [level] AT [speed]	N	M	W/U

Table C - 20 Additional Messages (downlink)

	Message Intent/Use	Message Element	URG	ALRT	RESP
98	For use with dM62 – [Error]	[free text]	N	N	N

C.4.4 CPDLC Build II

Unlike CPDLC Builds I and IA, Build II is not specified yet. However, work is currently ongoing through RTCA Special Committee 194 (ATM Data Link Implementation), Working Group 2 (Flight Operations & ATM Integration) to define CPDLC Build II.

C.5 Comparison of FFSIM CPDLC message with RTCA SC-169 Standards

The FFSIM Phase 2 4D Trajectory Clearance and Clearance Response messages can be considered as a futuristic, 4D implementation of the CPDLC Build IA uplink route clearance (i.e., CLEARED *(route clearance)*) and downlink response (i.e., WILCO) messaging.

C.6 References

[1] RTCA SC-169, *Minimum Operational Performance Standards for ATC Two-Way Data Link Communications*, Document No. RTCA/DO-219, August 27, 1993.
[2] "Data Link Messages for TAP CTAS/FMS Experiment," Updated June 25, 1999.
[3] Communication with Michael Hawthorne/FAA, July 7, 1999.
[4] RTCA SC-170, *Minimum Operational Performance Standards for Airborne Automatic Dependent Surveillance (ADS) Equipment*, Document No. RTCA/DO212, October 26, 1992.
[5] Hawthorne, M., Skipper, S., and Hancock, T., "CPDLC: A Data Communications Evolution for ATM," *Journal of ATC*, pp. 16-19, April-June 1999.
[6] Communication with Steve Skipper/FAA, August 27, 1999.