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Implementing FANS in the NASA 747-400 flight simulator for airspace operational research (Future Air Navigation System)

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We present the implementation effort for integrating the FANS-1 upgrade into the NASA-Ames 747-400 flight simulator. FANS is an advanced avionics system upgrade that will utilize global based satellite information and advanced technology to provide communications, navigation, surveillance and air traffic management for the 21st century. We describe the various upgrades and enhancements that were made to the NASA 747-400 simulator and how these changes will enable NASA to support important national research programs for capabilities provided by FANS, including modifications to the 747's advanced avionics systems, flight displays, warning system, and experimenter control stations. New features as a result of integrating FANS include a GPS simulation, an enhanced satellite based communications system, new ground based air traffic controller and airline operational communications features, as well as new tracking capabilities and functions. (Author)

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IMPLEMENTING FANS IN THE NASA 747-400 FLIGHT SIMULATOR FOR AIRSPACE OPERATIONAL RESEARCH

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ABSTRACT

This paper describes the implementation effort for integrating the FANS-1 upgrade into the NASA Ames Research Center's 747-400 flight simulator. FANS is an advanced avionics system upgrade that will utilize global based satellite information and advanced technology to provide communications, navigation, surveillance and air traffic management for the twenty-first century. This paper describes the various upgrades and enhancements that were made to the NASA 747-400 simulator and how these changes will enable NASA to support important national research programs that will further utilize these advanced features and capabilities provided by FANS. These changes include modifications to the 747's advanced avionics systems, flight displays, warning system, and experimenter control stations. New features as a result of integrating FANS include a Global Positioning System (GPS) simulation, an enhanced satellite based communications system, new ground based air traffic controller and airline operational communications features, as well as new tracking capabilities and functions. In addition, this paper describes some of the upcoming research programs and benefits that may be gained as a result of FANS.

INTRODUCTION

The current system for managing air traffic in the oceanic arena was developed and implemented many years ago, when air travel was substantially less congested than it is today. This system used procedural controls with air traffic control intervention via High Frequency (HF) radio communications. During that time, this system was very safe, reliable and efficient. Since then, technology has evolved and now high speed jet propelled aircraft fly along very congested and inefficient airways. In addition, current HF radio communications have become heavily congested resulting in a system that is more susceptible to potential operator errors due to problems interpreting information that is being transmitted via the radios.

Through the efforts of the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), and other air traffic service providers, a Future Air Navigation System (FANS) concept was developed to transition the current air navigation system to a more advanced, efficient and safer system utilizing global satellite based information for performing Communications, Navigation, Surveillance and Air Traffic Management (CNS/ATM) functions for all regions of the world for the twenty-first century.

The FANS concept will make extensive use of automation, satellites and data communications to provide the future air traffic services for the new CNS/ATM system. The aeronautical communications system in the new CNS/ATM will make use of digital communications to provide an efficient means of passing information. While the need for voice communications will remain, the introduction of data communications will enable fast exchange of information between all parties via a single network. The increasing use of data communications between aircraft and various ground systems will require a communications system that gives users close control over the routing of data, and allows different systems to communicate with each other without human intervention. This system will have to support two-way pilot-controller data communications in addition to the present day voice communications. The global inter-networking infrastructure that will be used to support the FANS concept is the Aeronautical Telecommunications Network (ATN). This virtual network is comprised of existing and planned telecommunications networks and will link the various air-ground and ground-ground data systems together. The ATN will operate globally, encompassing all aeronautical data communications associated with the international aviation environment.

The ATN is composed of three basic sub networks which include a ground network, an air-ground network and an airborne network. The ground network consists primarily of the Aeronautical Fixed Telecommunications Network/Common ICAO Data Interchange Network (AFTN/CIDIN) and airline industry private networks such as the ARINC Data Network Service (ADNS) and the SITA network. The air-ground network contains the satellite, Very High

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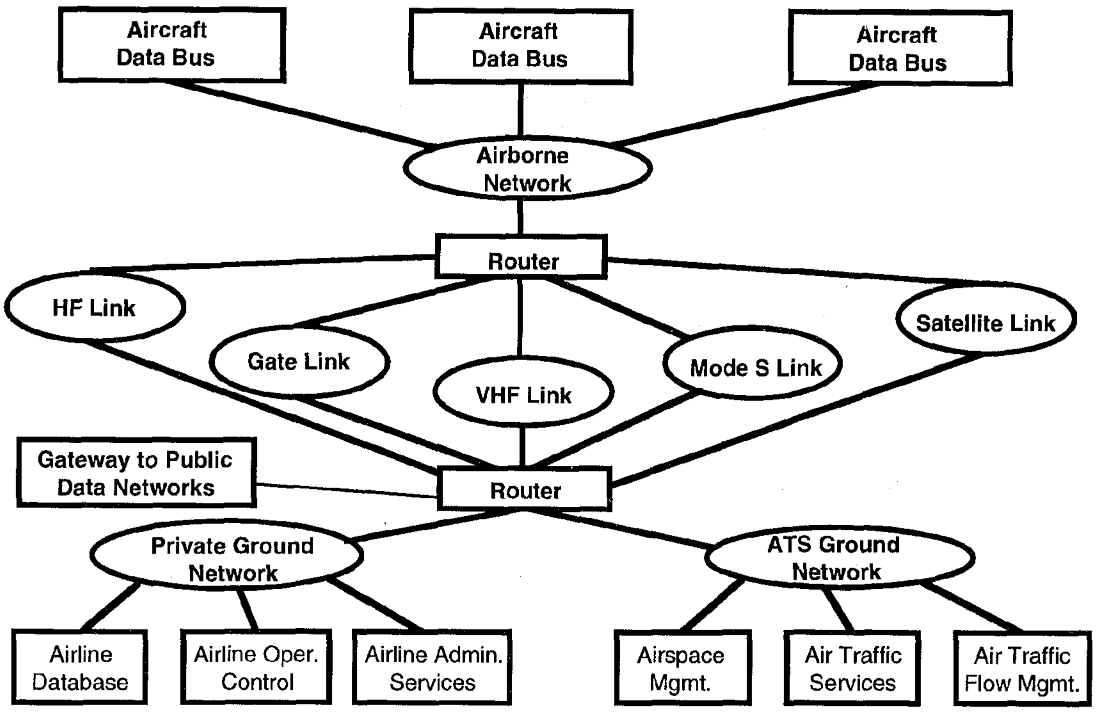

Figure 1 - Aeronautical Telecommunications Network (ATN)

Frequency (VHF), Mode S, HF and gatelink sub networks, while the airborne network consists of the airborne network router and the aircraft data busses. Figure 1 shows the various networks and how they are linked within the ATN.

The Global Navigation Satellite System (GNSS), a key feature of FANS, will provide navigation coverage and accurate time referencing on a global basis. This system includes one or more satellite constellations, aircraft receivers, ground monitor stations and system integrity monitoring. GNSS provides users with the capability to perform on-board position determination referenced to a standard geodetic reference system, independently from its geographic location. The GNSS will make use of the United States' Global Positioning System (GPS) and the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS). Each of these systems comprises a constellation of satellites including spares. In the future, ground based augmentation is expected to extend GPS capabilities by providing the capability to conduct precision approaches. With the introduction of the GNSS, airplanes will be able to fly routes efficiently and accurately.

As part of the FANS concept, surveillance will be the basic method by which controllers will monitor aircraft separation, manage airspace efficiently, and assist pilots in navigating their aircraft safely. Three tools critical to surveillance under FANS include an Airborne Collision Avoidance System (ACAS), Automatic Dependent Surveillance (ADS), and Secondary Surveillance Radar Mode Select (SSR Mode S). ACAS will provide back-up to the air traffic services by alerting flight crews of potential collisions through an on-board alerting system that is independent of any ground based system (presently implemented in the U.S. as Traffic Alert and Collision Avoidance System - TCAS). ADS will support automatic surveillance of appropriately equipped aircraft independent of any pilot-controller communications. For oceanic surveillance/tracking, ADS will match land capability through the use of inertial navigation or GNSS to determine aircraft position. Satellite communications will automatically transmit aircraft position and other information in near real-time. Over land regions ATC Radar Beacon System (ATCRBS) and Secondary Surveillance Radar (SSR) will continue to be used for tracking/surveillance.

The main beneficiary of the new CNS system will be the future Air Traffic Management (ATM) System. New CNS systems will provide more and better information transfer between ground and aircraft systems during all phases of flight and between all Flight Information Regions (FIRS). Although the future ATM system will be more efficient and enhanced, its basic functions will remain the same. These functions include Air Traffic Flow Management (ATFM), Air Space Management (ASM) and Air Traffic Services (ATS) which encompasses flight information services, alerting services, and air traffic control. These systems will be optimized strategically and tactically to expedite and maintain a safe and orderly flow of traffic while giving due consideration to costs of implementation and system operation. In addition, they will enable aircraft operators to meet their planned times of departure and arrival and adhere to their preferred flight profiles with minimum constraints and without compromising agreed levels of safety.

Many of the FANS concepts are currently being implemented and tested in the aviation community. It is expected that it will take about fifteen to twenty years before it is fully implemented. As a result of this gradual implementation there will be many human factors and airspace operations issues that will need to be addressed.

At the NASA Ames Research Center, a unique national research facility is available to support the kinds of research issues that will result by implementing FANS. The NASA 747-400 Flight Simulator, located at the Crew-Vehicle Systems Research Facility (CVSRF), at Moffett Field, California is prepared to help address these issues. The NASA 747-400 Simulator is but one integral component of the CVSRF. This unique facility was built in the early 1980's, primarily to support aviation human factors research. Over the years, the CVSRF's role has also expanded to include studying issues pertaining to airspace operations, in an effort to try and find ways of improving aviation safety and increasing the efficiency of the national airspace system. Through the use of it's full-mission simulation capability the CVSRF has positioned itself to support such issues. In addition, the CVSRF includes an Air Traffic Control (ATC) simulator, which can be integrated with the 747 simulator, providing the air-ground communications and creating a "full-mission" environment with the ability to perform complex multi-aircraft full-mission scenarios to support human factors and airspace operations research.

This paper focuses on the development and integration effort involved with implementing FANS in the NASA 747-400 Simulator. It highlights the various new features introduced by FANS, as well as the numerous modifications made to the 747 simulator and it's related systems in support of this upgrade. In addition, it describes some of the upcoming research programs and benefits that may be gained as a result of implementing FANS.

OVERVIEW OF 747-400 SIMULATOR

The NASA 747-400 flight simulator is an exact replica of a United Airlines 747-400 airplane cockpit. It is modeled after aircraft number RT612 and was built by CAE Electronics Ltd. in St. Laurent, Canada. The simulator represents a state of the art current technology glass cockpit. The NASA 747-400 simulator is certified to both FAA Level D and the newly established International Qualification Standard Level II, as established by ICAO. It is equipped with a Flight Safety International VITAL VIIe visual system, a CAE series 600 digital control loading and motion system, and an IBM RISC 6000, Model 580 host computer. The simulator is also equipped with unique research capabilities which make it an ideal tool for conducting aviation human factors and airspace operations research. These capabilities include reprogrammable flight displays, cameras mounted throughout the cockpit to allow videotaping of pilots actions or images of the various flight displays or Multifunction Control Display Units (MCDUs) within the cockpit, and a separate IBM RISC 6000 Model 560 computer for data collection and reduction purposes. In addition, user friendly touch sensitive experimenter operator control stations are also included, as well as repeater monitors of each of the cockpit displays. The simulator is also integrated to the CVSRF's ATC simulator and is networked to other research facilities such as the FAA Technical Center's ATC simulation complex in Atlantic City, and the FAA's Aeronautical Test Facility in Oklahoma City. These specially adapted capabilities provides NASA with a unique research facility for examining operational and human factors issues pertaining to the implementation and utilization of FANS. The relative importance of integrating FANS in the NASA 747-400 simulator is that it enables the CVSRF to support important national research programs.

FANS FUNCTIONS

The FANS-1 upgrade is a partial realization of a futuristic CNS/ATM concept envisaged by ICAO. This implementation is better described in terms of FANS functions which are discussed here as a prelude to the airborne and ground based upgrades. Components belonging to a majority of these functions exist both in the airborne and ground based systems.

AIR-GROUND DATA-LINK COMMUNICATIONS

Digital data-link for air-ground communications is already in widespread use today. A discussion of the systems and the support infrastructure that currently exists is useful in understanding the ICAO proposed schemes for FANS data link.

The ARINC Communications Addressing and Reporting System (ACARS), which dates back to the late seventies was initially adopted by the major airlines as a logging system for flight phase times for their flights. Known as the OOOI (Out-Off-On-In), these reports transmitted the aircraft push-back, takeoff, landing and at-gate times to a central logging system at the airline operations center. Today, the airlines use the system for a number of other types of information gathering and reporting jobs.

The end-to-end systems in this setup consist of the ACARS Management Unit (AMU) on the airborne side connected via a network of VHF stations to the ground operations center. The VHF enroute coverage is available across the continental U.S. and several areas around the world. In addition, local coverage is available at most airports. For aircraft equipped with SATCOM, the coverage is available globally since at present, the network service providers also support ACARS communications via satellite. In a typical glass cockpit installation like the 747-400, the AMU may be connected to several aircraft systems which automatically collect data and send it to the appropriate ground station without imposing any additional workload on the flight crew. The Aircraft Condition Monitoring System (ACMS), for example, can collect engine data and send to the aircraft maintenance operations. The variety of information the current ACARS systems can provide includes information on weather, winds aloft, flight planning and position. Many airlines also use ACARS for Pre-Departure Clearances which helps reduce congestion over the voice channels.

The ACARS data-link communications are based on a fixed length character based message block, as per the ARINC 618 protocol. Each character byte is made up of a 7-bit ISO-5 character with the 8th bit providing odd parity. The 256 character message block is made up of a header and text components. The information in the header includes the aircraft identification while the 220 character text portion is used to transmit the message data. The end of the message is appended with a 16 bit checksum. Multiple blocks may be utilized to transmit messages that do not fit into a single 220 character text portion. A special end of the message block bit is used to inform whether additional blocks follow.

FANS DATA-LINK APPLICATIONS

Under the ICAO FANS concept, all data-link communications are expected to be transitioned to a digital network based on the International Standards organization (ISO) Open Systems Interconnect (OSI) standards. Known as the Aeronautical Telecommunications Network (ATN), this will encompass all air-ground and ground-ground aviation data communications. The VHF, SATCOM, Mode S and possibly a future HF data network will be sub-networks under the ATN. The ATN compliant applications will, however, need to be based on bit-oriented, data transparent message based protocols. Unfortunately, the current ACARS data is character oriented and incompatible with ATN. Since the ACARS system is expected to be in use for some time, the aviation industry has come up with an interim solution which allows bit-oriented applications to communicate over the ACARS network. This standard, called ARINC 622, defines the ACARS Convergence Function (ACF) which performs the bit-to-character and character-to-bit conversions required in order for bit-oriented applications to be able to use the character oriented ACARS network. The ADS and the ATC DL under FANS have been defined as bit oriented applications and already take advantage of this interim standard.

AIR TRAFFIC SERVICES FACILITIES NOTIFICATION (AFN)

An Air Traffic Services (ATS) facility becomes aware of a FANS data-link equipped aircraft by means of the AFN data-link function. As is the case with the other data-link applications, there are airborne and ground ends to the AFN, with the airborne side residing in the flight management computer (FMC).

The AFN Initial Notification data transaction is normally initiated from the aircraft with the aircrew member entering a ground ATS facility identification through a logon page on the MCDU. A downlink contact message is then sent to the ground facility where it is acknowledged by sending an appropriate uplink response. These two messages exchange all the addressing information that will be required for the air and ground application counterparts of the ADS and ATC DL applications to establish their respective communication links.

When the aircraft moves from one region to the next, the addressing information is exchanged by the controlling facilities through ground-ground links. As an alternative, a ground facility may utilize the aircraft AFN to pass on the information to the next facility. An additional 3 data-link messages, constituting the Contact Advisory transaction are provided for this purpose.

AIR TRAFFIC CONTROL DATA-LINK

Once an AFN Initial Notification transaction is successfully completed, a ground ATS facility may establish a data-link connection between the ground based and airborne elements of the ATC DL application. The ATC DL, also known as the Controller Pilot Data-Link Communications (CPDLC), consists of a set of uplink and downlink messages used for controller-pilot dialogue. The message set, specified by RTCA DO-219 is based on phraseology currently in use for voice communications. A typical ATC DL message consists of a fixed message portion and one or several variable fields. For example, in the vertical clearance CLIMB TO AND MAINTAIN FL330, altitude is the input variable. The various types of input variables include time, speed, altitude, position, vertical rate, direction, distance, facility identifications, frequencies and route clearances. The messages are grouped into the functional categories as follows:

Uplink Message Groups:
- Responses / Acknowledgments
- Vertical Clearances
- Crossing Constraints
- Lateral Offsets
- Route Modifications
- Speed Changes
- Contact / Monitor / Surveillance Requests
- Report / Confirmation Requests
- Negotiation Requests
- Air Traffic Advisories
- System Management Messages
- Additional Messages

Downlink Message Groups:
- Responses
- Vertical Requests
- Lateral Offset Requests
- Speed Requests
- Route Modification Requests
- Negotiation Requests
- Emergency Messages
- System Management Messages
- Additional Messages

ATC DL application sends and receives only bit oriented messages. The ACF, defined by ARINC 622, is currently included at each end to accomplish the conversion to and restoration from the character based ACARS format in which the actual message is transmitted.

AIRLINE OPERATIONS COMMUNICATIONS DATA-LINK

A separate data-link function dedicated to airline communications is provided by FANS. The AOC DL, as it is called, in a sense is an extension to the functions currently supported via the AMU. The airborne side of the AOC DL application, however, resides in the FMC. Some of the new features in AOC DL include the ability to uplink a flight plan which can be automatically loaded by the flight crew. Similarly, enroute and descent forecast winds can be separately uplinked. A flight crew can also send a request for the above data via a downlink to ground operations. Other features supported in AOC DL include automatic triggering of position reports and winds aloft without any flight crew input. The AOC DL application currently utilizes character based messages.

AUTOMATIC DEPENDENT SURVEILLANCE

Automatic Dependent Surveillance (ADS) provides aircraft current position, intent and other information derived from various on-board avionics systems via an air-ground data-link, typically to a requesting ATS facility. A contract initiates and establishes the type of information to be transmitted. The airborne ADS function, resident in the FMC, assembles and delivers the required information in response to the contract received from its ground-based counterpart. The contract uplink and the associated downlink report transaction takes place without any flight crew intervention. The ADS is expected to fulfill a very important role in the future as an automatic surveillance mechanism, especially in the oceanic environment where there is no radar coverage.

Information supplied by the ADS can be periodic, on-demand, or event driven. In a periodic contract, the requested data is updated at the interval specified in the contract uplink. For on-demand contracts, the requested report is sent once, while in the event contract the reports are generated when any of a set of pre-defined events takes place. The ADS reports are divided into groups of data and include:

- Basic - latitude, longitude, altitude, time, position fixing accuracy, navigation redundancy.
- Flight Identification
- Earth Reference - true track, ground speed, vertical rate.
- Air Reference - true heading, mach speed, vertical rate
- Meteorological - wind speed, direction, temperature
- Predicted Route - latitude, longitude, altitude at the next and next+1 waypoints in the active flight plan and estimated time of arrival at the next waypoint.
- Intermediate Projected Intent - up to 10 waypoints in the active flight plan, specified as along-track distance, track, altitude and time where a change to the target altitude, speed or course is expected.
- Fixed Intent - projected waypoint in the active waypoint specified as latitude, longitude, altitude, given a projected time.

A contract may request a report for a single group or a combination of groups, either on a periodic or on-demand basis. For an Event contract, the airborne ADS reports on any of the following occurrences:

- Waypoint Sequence - Basic and Predicted Route group data is supplied anytime a waypoint is sequenced.
- Altitude Range - Basic group data is supplied when the aircraft violates the specified altitude range.
- Vertical Rate - Basic and Earth Reference group data is supplied when the specified vertical rate threshold is exceeded.
- Lateral Deviation - Basic group data is supplied when the lateral deviation exceeds the specified threshold.

In addition to the ADS contracts discussed above which are generally initiated by a ATS facility, the flight crew may also initiate an emergency periodic report which transmits the Basic group and other data at pre-determined intervals. A complete definition of ADS is available in ARINC 745-2 and RTCA DO-212.

REQUIRED NAVIGATION PERFORMANCE

The advent of highly accurate satellite navigation systems has resulted in the development of new concepts to better utilize the available airspace with increasing levels of traffic. Required Navigation Performance (RNP) is one such concept.

Although RNP affects both the aircraft and the airspace in which it is operating, it is essentially a parameter specifying the navigation performance requirements that the aircraft must satisfy in order to operate in that airspace. The airspace in this context can be a segment of an airspace, a navigation flight phase or a procedure. A rigorous definition of RNP is beyond the scope of this paper and the interested reader is referred to reference [8]. For the current discussion, it is sufficient to say the RNP type may be thought of as a containment surface within which the aircraft is expected to stay with a probability of 95%. As an example, an aircraft operating in a RNP 12.0 airspace is expected to stay within a 12 nautical mile radius 95% of the time. By extending this containment surface along an approach segment, an operational envelope of airspace or "tunnel in the sky" is defined for flying the approach. In the geometry of this tunnel, individual requirements such as obstacle clearance or terrain separation can also be factored in. The RNP function contained in the FMC includes a set of default values for the various operational flight phases. The default values can be overridden by manual input on the Multi-function Control Display Unit (MCDU).

REQUIRED TIME OF ARRIVAL

The Required Time of Arrival (RTA) function in the FMC allows for placement of a time constraint at a single enroute waypoint. Time based, or 4-D guidance to the waypoint is then attempted by varying the enroute speed between minimum and maximum speed limits within the performance envelope. The FMC alerts the crew via a MCDU message when it cannot meet the time requirement.

The ability of an aircraft to control its arrival times at metering points enhances the effectiveness of ATC flow control. Utilizing the FANS data-link features, the controller may uplink required crossing times. This new capability allows aircraft to cross other routes, thus allowing access to airspace that would be otherwise restricted.

SIMULATED AIRBORNE ENVIRONMENT

On the Boeing 747-400 aircraft, the navigation system, the Flight Management System (FMS), the communications system, and the display system are affected by FANS. The navigation system is augmented by the addition of dual Global Positioning System (GPS) sensor units. The FMS has added capabilities such as using the GPS inputs to improve navigation performance, and to provide extensive two-way aircraft/air traffic controller and aircraft/airline operations communications. To support the additional communication features of the FMS, the communications system is improved by upgrading the ARINC Communications, Addressing, and Reporting System (ACARS) and adding a Satellite Communications System (SATCOM). The display system is upgraded to reflect the additions and improvements in the aforementioned systems.

GLOBAL POSITIONING SYSTEM

The Global Navigation Satellite System (GNSS) is currently composed of a constellation of GPS satellites that circle the earth continuously transmitting signals to sensor units on or close to the surface. The GPS satellites transmit accurate timing signals such as the Universal Time Clock (UTC) and other data pertaining to their exact location. The sensor units can accurately determine their position by comparing the timing of different GPS satellites. The accuracy of the position fix is dependent primarily on the Dilution of Precision (DOP) and the User Range Error (URE). The DOP accounts for the number of satellites in sight and their spatial distribution relative to the sensor. The URE reflects several factors that affect the satellite range measurement. The GPS sensor unit is equipped with a Receiver Autonomous Integrity Monitor (RAIM). The GPS RAIM monitors the integrity of the GPS satellites and eliminates any non-tolerant satellite source signal from the position calculation. The FANS-1 equipped 747-400 aircraft has two GPS sensor units which are directly connected to the two FMCs. The aircraft FMS uses the Inertial Reference System (IRS) as the primary source for navigation. Various external sources including radio signals such as Distance Measurement Equipment (DME) and localizers are used to update the IRS calculated position. With FANS, GPS becomes the main source for FMS position updating. Through the MCDU, the flight crew can interface with the GPS units. The latitude, longitude, and ground speed from both GPS units are displayed along with the active position update mode, UTC time, the current Actual Navigation Performance (ANP), and the RNP. The flight crew also has the ability to inhibit GPS updating altogether. The FMS RNP function provides display of ANP and RNP to the crew, and triggers alerts if the RNP is exceeded. The ANP is the radius that the current FMC position update mode can guarantee to within 95%. With GPS updating, a vastly improved ANP is obtained. The default RNP values range from twelve nautical miles in the oceanic environment down to 0.5 nautical mile in the approach phase. With ANP values below 0.5, FMS/GPS arrival procedures are therefore possible. FMS/GPS can be used as an additional method to guide the aircraft to any airport runway for nonprecision approaches. On oceanic routes, FMS/GPS navigation can reduce lateral and longitudinal separation as a result of the increased position and time accuracy.

The GPS simulation in NASA's B747-400 simulator is based on the Honeywell HG2021 Global Navigation Satellite Sensor Unit (GNSSU) for the B747-400 aircraft. The model simulates a dual-sensor system with each sensor sending data to both FMCs. GPS computed data are simulated by taking the simulator computed navigational data with random errors superimposed. If the GNSSUs have just been powered up, a system self-test and satellite acquisition delays are modeled. The state of the electrical busses and experimenter operator station (EOS) control variables are also used to determine whether the sensors are operational. Simulator interface modifications were required to model the circuit breaker for each unit. EOS control allows the user to effect the FMS ANP by imposing a sensor malfunction or a complete failure. If the GNSSUs are operational, appropriate outputs are computed in the host computer and sent to the FMCs once per second over a high speed ARINC 429 bus. ARINC 429 is based on a serial data communication protocol used to exchange data between different aircraft line replaceable units (LRUs). The outputs include latitude, longitude, ground speed, date and UTC, autonomous horizontal integrity limit, horizontal figure of merit, and GPS sensor status. These are the only sensor outputs that are utilized by the FMCs. The GPS simulation assumes a minimum required number of satellites are in view at all times.

AVIONICS SYSTEM UPGRADES

FANS modifications that apply to both the aircraft and the simulator include upgrades to the various installed avionics. Specifically, the 2 FMCs, the 3 MCDUs, the ACARS Management Unit (AMU), and the multi-input cockpit printer are affected by FANS.

The FMCs are the focal point for all the major airborne functions provided by FANS. The FMC upgrade is comprised of a memory expansion, new operational software and a new navigational database. FANS functions that are incorporated as a result of the upgrade are ADS, AFN, AOC DL, ATC DL, RNP, and RTA. Three program option select pins must be set to activate the FANS functions. For each FMC, they are the data-link enable, the ATS enable, and the GNSSU enable. Simulator interface modifications are also required to support the new GPS and program option select inputs.

The FANS upgrade to the MCDUs consist of incorporating two new function keys, ATC and FMC COMM. The ATC key allows the crew to access the new ATC data-link page directly. The FMC COMM button allows access to the new AOC data-link page.

The AMU upgrade consists of a revised EPROM to support the new FANS functions in the FMS.

The Multi-input cockpit printer is upgraded and connected to the FMCs, allowing the crew to print out data-link messages such as clearances and route information.

SATELLITE COMMUNICATIONS SYSTEM

The SATCOM system is a communications system that uses satellites as relay stations. The system consists of three components, the satellite, the Aircraft Earth Stations (AES), and the Ground Earth Stations (GES). The satellite relays radio signals between AES and the GES. The AES on the aircraft interfaces with various on-board avionics systems. The GES is a fixed radio station that interfaces with ground based communication networks. The SATCOM network provides data, voice, and passenger communications for aircraft worldwide. The Collins SAT-906 system has been installed on many of United's 747-400 aircraft. This system consists of a Satellite Data Unit (SDU), two High Power Amplifier (HPAs), a Radio Frequency Unit (RFU), a low gain antenna (LGA), a high gain antenna (HGA), and a beam steering unit (BSU). The SDU manages the satellite communication protocols and the interface to all other aircraft systems. The SDU provides up to six channels for cockpit data communications as well as both cockpit and cabin voice communications simultaneously. One channel is always reserved for cockpit data communications to ensure data-link reliability. The SDU is connected to the cockpit MCDUs via an ARINC 739 serial communications interface. The MCDU provides the crew control interface to SATCOM allowing manual access to items such as telephone directories, owner requirements tables, and maintenance functions. Although, three MCDUs are connected to the SDU, the SDU can only be actively controlled by one MCDU at a time. The SDU is also connected to the flight crew's audio control panels (ACP) for the placement of voice calls. The AMU handles the aircraft data-link functions either through VHF radio or SATCOM. Message data is exchanged with the AMU on a low speed ARINC 429 bus using a bit oriented communications protocol specified by ARINC 429.

The SATCOM implementation on the NASA B747-400 simulator is composed of the host based AES simulation, the GES simulation on the EOS, the ARINC 739 interface with the MCDUs, and the ARINC 429 Williamsburg interface with the AMU. The AES model generates all the SATCOM MCDU pages available to the crew and simulates their functionality except for the maintenance functions. The ACP operations and system malfunctions are also handled by this model. The simulation of the ground station is two-fold, comprising of audio control and data-link control via the EOS.

INTEGRATED DISPLAY SYSTEM UPGRADES

The Integrated Display System (IDS) is composed of the Electronic Flight Instrument System (EFIS) and the Engine Indication and Crew Alerting System (EICAS). The EFIS portion of the IDS is composed of the Primary Flight Display (PFD) and the Navigation Display (ND) for both the Captain and First Officer. The PFD displays attitude/direction/altitude/airspeed information, while navigation, performance, and weather radar information is displayed on the ND. The EICAS displays engine data, caution and warning messages, and subsystem data and faults. On the B747-400 simulator, the IDS is programmable to support the development of new or revised flight displays and/or system synoptics for aviation safety research. The actual aircraft IDS is normally comprised of six integrated display units (IDUs), and three Electronic Interface Units (EIUs). On the simulator, the IDUs are simulated through the use of six commercial, raster-based CRT displays which are driven by High Resolution Graphics Cards (HRGCs). When the simulator is loaded, the HRGCs contain down load files which include all the EFIS and EICAS display information. The down load files are programmable in order to create or modify existing IDS display pages. The IDS simulation model, resident on the host computer, provides the EFIS and EICAS system logic to drive, in real-time, the HRGC graphics software on the IDS pages. The software also provides for EIU functions, including data processing and formatting for EICAS message generation, and interfacing with other simulator hardware and software systems.

The addition of two new systems, GPS and SATCOM, and the upgrade of the FMS, introduced the need for specific EICAS messages and EFIS modifications. The new EICAS messages warn the flight crew of GPS sensor and SATCOM faults. Advisories and cautions are also generated for RNP inadequacies and data-link status. Changes to the host computer software were made to incorporate these new EICAS messages. The EFIS was modified to add a unique symbol to indicate the GPS position on the ND. This symbol required the modification of the ND HRGC down-load files and the IDS simulation. For both the EICAS messages and the ND modifications, new FMC outputs had to be accessed and made available to the host software in order to drive the new elements.

Another component of the B747-400 aircraft warning system is the Modular Avionics and Warning Electronics Assembly (MAWEA). The MAWEA handles data/configuration management, fault management, crew control/indication, and guidance. As part of the FANS upgrade, the crew alerting module was modified to activate the low level chime upon receipt of an ATC uplink and an aural alert if the RNP is exceeded in the approach phase. Modifications were also made to the host based MAWEA model and other associated software in order to monitor specific FMC outputs that trigger aural alerts.

Figure 2 shows the various modifications as part of the FANS upgrade on the NASA 747 simulator, depicting changes to the simulated systems and affected aircraft avionics.

SIMULATED GROUND-BASED ENVIRONMENT

The ADS and CPDLC functions are generally hosted on controller workstations with graphical user interfaces for selecting or displaying the data-link information for the airplanes flying in the airspace in the controller's jurisdiction. The simulated environment for the current FANS upgrade is supported via specially designed control pages on the 747-400 simulator's EOS. Each of the FANS data-link applications has a ground-based counterpart that must process each message sent to or received from the data link avionics. Providing the ground support functions constituted the bulk of the

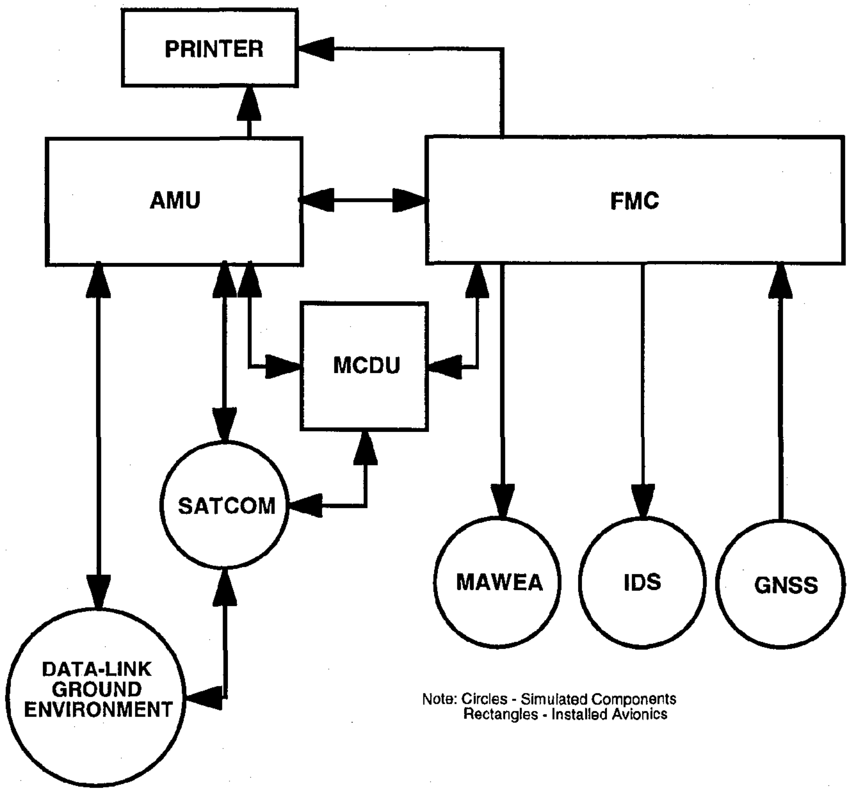

Figure 2 - Simulated Systems & Affected Avionics

software development effort for the FANS upgrade. This is also an area, unlike the airborne upgrades, where functionality and level of fidelity had to be designed for a phased development approach commensurate with near term research needs.

EOS GROUND STATION INTERFACE

The EOS is the primary interface from which the simulator set-up and control operations are performed. At the CVSRF, this state of the art system has been enhanced to also serve as the main experimenter control station.

An on-board station located in the aft of the simulator cab, and an off-board station located in the Experiment Lab, each consists of two interactive CRT displays driven by SGI Indigo graphics workstations. The EOS has a customized graphical user interface consisting of input buttons, pop-up menus, display windows, etc. The interface is user friendly and intuitive to use. Display page items are easy to program and utilize a script which is interpreted by a graphics rendering system.

The EOS is a logical choice as a user interface for the ground-based FANS data-link applications. The EOS already has pages to support ground based ACARS functions. In this FANS upgrade, additional pages are defined for FANS data-link applications. All data-link pages including the existing ACARS pages have been consolidated under a Datalink menu accessible from the EOS Main menu.

MESSAGE PROCESSING ARCHITECTURE

As mentioned earlier, ACARS functions commonly used in airline operations are included in the basic simulator capabilities. Simulation support for ground based ACARS functions consists of a set of ACARS message processing modules resident on the simulator's host computer. These modules interface to the AMU via a VHF data link. The ground user interface is provided on the EOS. The uplink messages sent to, and downlink messages received from the AMU, are all in the standard ACARS message format previously discussed.

In the FANS upgrade, a SATCOM data-link interface to AMU has been added. This will provide a data communications link where VHF coverage is not available. Additional software modules have also been added to support the special processing of the ADS, ATC and AOC data-link messages. Figure 3 is a generalized block diagram of the data-link ground based message processing components. The ADS and ATC DL messages are in bit-oriented format and therefore require the ACF to make conversions necessary to ACARS character format. In addition, all three message types include a Cyclical Redundancy Check (CRC) to ensure end-to-end integrity. Messages belonging to the bit-oriented category also utilize special encoding rules to translate message data, obtained from user selections on the appropriate EOS data-link page, into a binary stream. The encoding rules are defined in RTCA DO-212, 219 for the ADS and ATC DL respectively. Each 4-bit nibble in this binary stream is then replaced with the corresponding ISO-5 character as per the ACF. The resulting ACARS compatible characters are then encapsulated in a standard ACARS message format before transmission. These are the typical steps involved in the processing of a bit-oriented uplink message. The steps are reversed in the case of a downlink. Figure 4 shows schematically, the steps involved in a typical ATC DL uplink message processing.

The AOC DL messages utilize character-oriented messages and therefore can skip several of the message processing steps that apply to bit-oriented messages. However, the data in these messages are specified in a special syntax as per ARINC 702. Figure 5 is an example of a typical AOC DL uplink message.

GROUND BASED ADS

The ADS ground user interface page is accessible from the Datalink menu under the EOS main page. Three different contracts and their associated report processing are currently supported. The following are some specifics relating to the ADS implementation:

- Periodic - ADS Basic, Fixed Intent and Event contracts.
- Contracts initiated via dedicated buttons for each type. User selected parameters like the reporting rate, fixed intent time, altitude range, lateral deviation, etc., are input via dialog boxes.
- Display windows for each report.
- Button to terminate all contracts.

GROUND BASED AFN

Three downlink messages and two uplink messages comprising the Initial Notification and Contact Advisory are supported. AFN functions are combined on a single page accessible from the Datalink menu.

- Buttons representing three different ATC oceanic centers are used to acknowledge a contact initiated from the aircraft. A contact received status is indicated by changing the button color to red. On acknowledgment the status changes to green. An auto response button, when selected, automates the Initial Notification transaction by automatically sending an acknowledge response to a Contact downlink.
- Contact Advisory transaction may be initiated by first selecting a separate button provided.

GROUND BASED ATC DL

A considerable development effort was spent providing the ground support functions for ATC DL. As a result, nearly all downlink messages and a majority of the uplink messages comprising the total message set is now functional. The ground user interface is graphical and interactive as in the real world CPDLC workstations. It was designed in a flexible manner to support future enhancements. The ground support functions have been modularized in such a way the interface is separate enough from the message processing architecture so as to be easily modified without affecting the other components. Following are some of the salient features of the ATC DL user interface design:

- Separate pages provided for uplink and downlink operations. Both uplink and downlink pages are accessible from the Data Link menu. In addition uplinks can be reached from the downlink page and vice versa.
- Separate buttons provide access to the various functional message groups for uplink message selection. User selected parameters are input via pop-up dialog boxes. The solicited data values for these inputs are automatically limited to allowed ranges.
- Once the message and all associated data are selected, the composed uplink is shown in a preview window. The controller may then opt to either send or delete this preview buffer.
- A separate window is provided on both the uplink and downlink pages for logging a record of the transacted messages. Each message is shown with the data authority with which the transaction has taken place, time stamp, a unique message identification number, a message reference number and a status of the message. The message reference number is used as a reference number for all response type messages.
- ATC Data authority connect and transfer operations are provided on a separate page accessible from the Data Link menu. Three types of uplinks supporting connecting, ending and assigning a next oceanic center for data service are available.

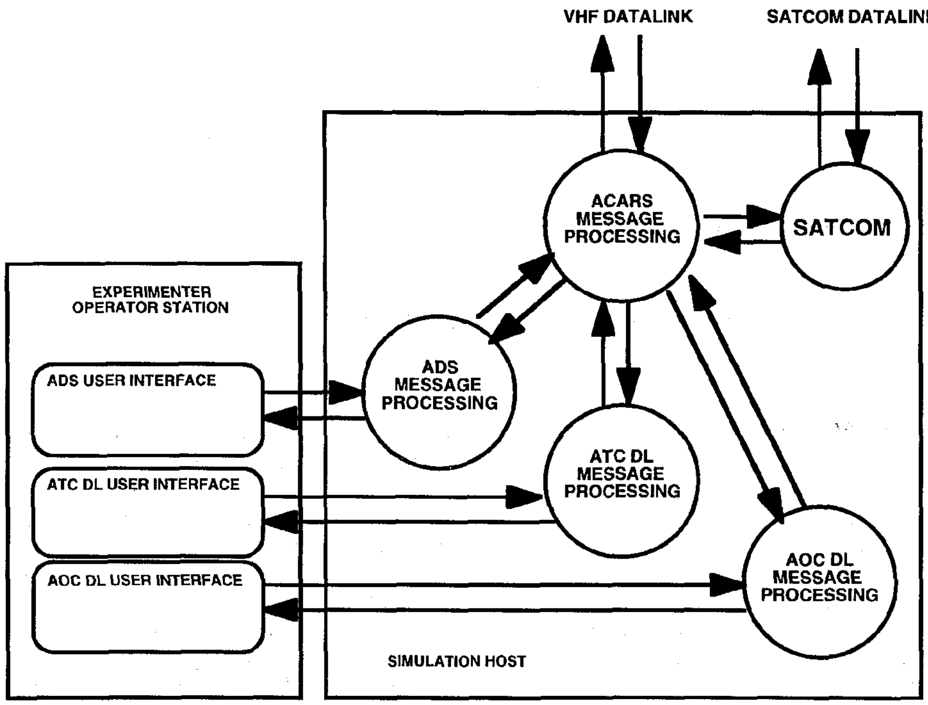

Figure 3 - Simulated Ground Based Data-Link Environment

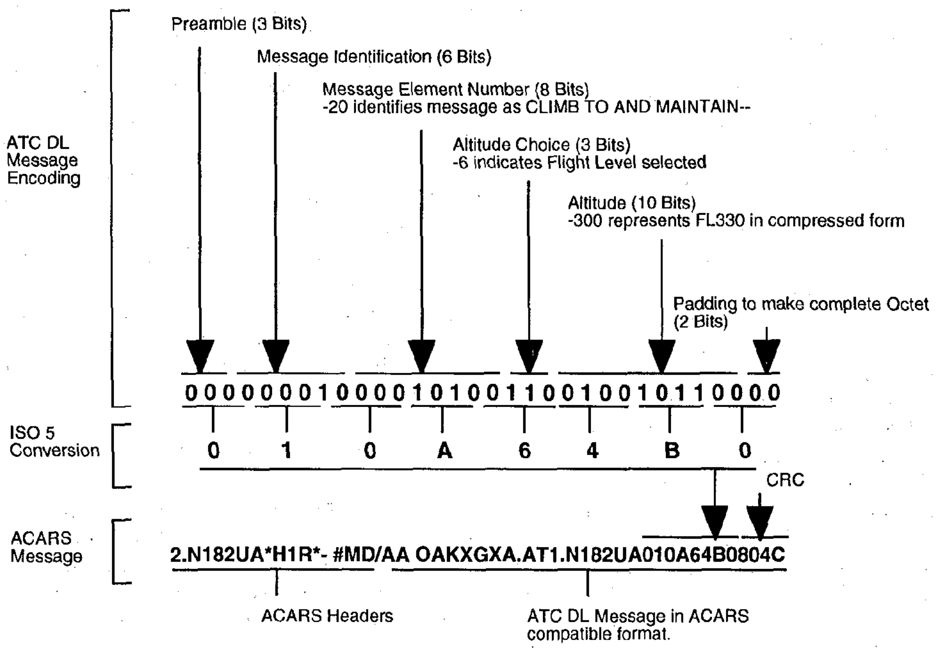

Figure 4 - Example of a typical ATC DL Message

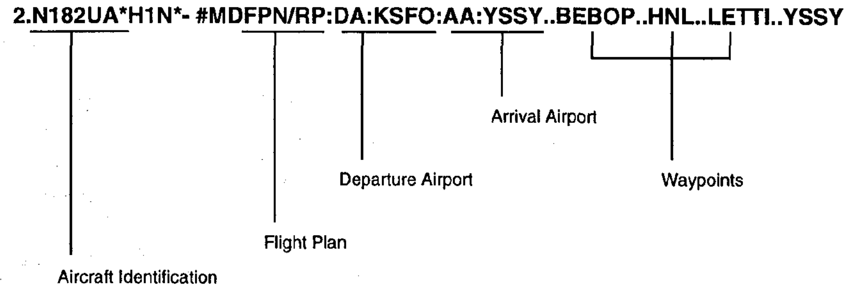

Figure 5 - Example of a typical AOC DL Message

GROUND BASED AOC DL

Flight plan and winds uplinks are currently supported under AOC DL. The ground operations page is accessed via the Datalink menu. Since the AOC DL messages are character based, they can be easily composed using an ASCII text editor using the syntax rules defined in ARINC 702A. For the current implementation, three flight plan uplinks and the associated winds data uplinks have been pre-defined.

- Flight plan and wind requests upon receipt are annunciated on the ground user interface.
- Buttons are provided to select any of the available flight plan or wind messages for uplink.

RESEARCH PROGRAMS

With the introduction of FANS in the NASA 747 simulator, a unique research capability is provided to the aviation community. Research programs dealing with issues such as the utilization of advanced digital information transfer between aircraft and ground-based functions can be examined or evaluated in a full-mission simulation environment. One of these programs already in progress is the Federal Aviation Administration's Dynamic Aircraft Route Planning (DARP) System Program. This program is concerned with the viability of sending rerouted flight plan information to aircraft over the ocean by exploiting the capabilities of emerging satellite-based communications and navigation systems, enhanced avionics capabilities, and advanced ground-based air traffic control systems. The DARP System requires four entities to participate and collaborate. These include the Traffic Management Unit (TMU) specialist, the Airlines Operations Center (AOC) flight dispatcher, the flight crew and air traffic control. In the DARP process the Traffic Management Unit (TMU) specialist is responsible for developing a new route based on the latest weather information. The Airlines Operations Center (AOC) flight dispatcher is responsible for developing a revised flight plan and then transmitting it to the aircraft. The flight crew's role is to review and accept the new flight plan and to request a new route clearance from ATC. ATC's role is to develop, coordinate, and issue the new route clearance. With the CVSRF's implementation of FANS on the 747-400 simulator, the ground-based functions are being emulated to support these air-ground digital communications, making it an ideal research tool for conducting studies regarding DARP operational and human factors issues. Other research programs that will benefit by the implementation of FANS include NASA's Advanced Air Traffic Technology (AATT) Program and the FAA's Free Flight Program. These studies will examine the impact of implementing advanced avionics and ground control systems on the current air traffic management system. Some of these programs will investigate new systems and capabilities that will evolve as a result of FANS. The introduction of new strategic collision detection systems making use of ADS information will also be examined, as well as the development and integration of advanced flight displays depicting enhanced traffic symbology, and reduced separation, vertical situation, and advanced ground taxi displays. Eventually, enhancements to existing GPS capabilities will provide the ability to conduct precision approaches. In addition, terminal area operations exploiting augmented GPS and RNP technologies will be evaluated for guiding aircraft along complex curved approaches.

FUTURE UPGRADES

With the FANS-1 upgrade described in this paper, the CVSRF 747-400 simulator is up to date with the latest upgrade currently available to the airplane. As a simulator certified to the highest recognized standards, it can be expected to keep up with all the forthcoming avionics upgrades relating to the FANS airborne environment. These upgrades in the near term will likely include a revision to the FMC operational software and perhaps new data-link features. Any such upgrade to the installed avionics is easily supported. The ground-based support functions provided in the current upgrade fall in the realm of a single flight simulator environment. In order to support a futuristic CNS/ATM environment, the ADS and ATC DL should be part of a ground-based ATM dealing with a realistic airspace consisting of multiple FANS equipped and unequipped aircraft. This type of ground-based simulation environment currently exists at the FAA Technical Center. Researchers at Ames are also eager to explore FANS technologies, especially as they pertain to terminal area operations. A more extensive FANS ground environment, undertaken as part of the CVSRF's Air Traffic Control simulation facility is entirely justifiable in anticipation of future research.

SUMMARY

There are many benefits to be achieved by the implementation of FANS. These include an increase in safety and efficiency in flight operations, an improvement in service to passengers, and a reduction in airline operating costs. The increase in safety and efficiency improvements in flight operations will be made possible by the emergence of enhanced communications, navigation and surveillance capabilities. The airlines and ATS providers will have full access to the latest weather information, aircraft status and ATC facilities which will enable optimal use of the available resources. The ATS providers will have better planning tools and can sustain optimal routing with fewer delays. The ATM system will also be able to adapt quicker to changing conditions such as weather or system failures. Service improvements to passengers will be based on the increased communications capabilities introduced by data and satellite communications systems. This will introduce the ability to provide on-board reservations, access to various information services and enhanced passenger telephone networks. These benefits are likely to increase the number of passengers and provide additional revenue for the airlines as well. Efficiency improvements in flight operations should yield reductions in airline operating costs, resulting in higher payloads, improved aircraft utilization, reduced flight crew time, reduced maintenance costs and lower fuel costs.

Examples of direct benefits achieved by FANS will include the ability for pilots to automatically load up-linked flight plan changes into the FMC without having to manually type in the revised information. This provides a more efficient means of accepting clearances than what is used today. This will prevent typing errors or miscommunication errors, ensuring greater efficiency and enhanced safety. With the introduction of ADS, and the ability to up-link an optimal flight plan based on the latest weather information, reduced separation of aircraft for FANS equipped aircraft is also possible. With a smaller separation standard, the resulting improvement in airspace capacity will allow improvements in operating efficiencies for aircraft by reducing the required enroute fuel burn and contingency fuel. This will provide increased efficiency and savings in fuel costs for air carriers. In addition, ADS will enable ATC to detect the position of aircraft more accurately and allow safer and more efficient management of airspace. These features provided by FANS are the first step in transitioning the current air navigation system to a more efficient and safer air traffic management system. Incorporating FANS into the NASA 747-400 simulator will enable NASA to examine human factors and airspace operational issues regarding the automatic information transfer of flight plan changes or other ATC information, not just in the oceanic arena, but eventually in the terminal area as well, providing a safer overall flying environment.

ACKNOWLEDGMENTS

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LIST OF ACRONYMS

AATT	Advanced Air Traffic Technologies
ACARS	ARINC Communications, Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACF	ACARS Convergence Function
ACMS	Aircraft Condition Monitoring System
ACP	Audio Control Panel
ADNS	ARINC Data Network Service
ADS	Automatic Dependent Surveillance
AES	Aircraft Earth Station
AFN	ATS Facilities Notification
AFTN	Aeronautical Fixed Telecommunication Network
AMU	ACARS Management Unit
ANP	Actual Navigation Performance
AOC	Airline Operations (Operational) Communications
AOC DL	AOC Data-Link
ARINC	Aeronautical Radio Inc.
ASCII	American Standards Committee for Information Interchange
ASM	Air Space Management
ATC	Air Traffic Control
ATC DL	ATC Data-Link
ATCRBS	ATC Radar Beacon System
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
ATS	Air Traffic Services
BSU	Beam Steering Unit
CIDIN	Common ICAO Data Interchange Network
CPDLC	Controller Pilot Data-Link Communications
CNS	Communications, Navigation, Surveillance
CRC	Cyclical Redundancy Check
CRT	Cathode Ray Tube
CVSRF	Crew-Vehicle Systems Research Facility
DARP	Dynamic Aircraft Route Planning
DME	Distance Measurement Equipment
DOP	Dilution-of-Precision
EFIS	Electronic Flight Instrument System
EICAS	Engine Indication and Crew Alerting System
EIU	Electronic Interface Unit
EOS	Experimenter Operator Station
EPROM	Erasable Programmable Read Only Memory
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FIR	Flight Information Region
FMC	Flight Management Computer
FMS	Flight Management System
GES	Ground Earth Station
GPS	Global Positioning System
GLONASS	Russian Federation Global Navigating Orbiting Satellite System
GNSS	Global Navigation Satellite System
GNSSU	Global Navigation Satellite Sensor Unit
HF	High Frequency
HGA	High Gain Antenna
HRGC	High Resolution Graphics Card
HPA	High Power Amplifier
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IDS	Integrated Display System
IDU	Integrated Display Unit
IRS	Inertial Reference System
ISO	International Standards Organization
LGA	Low Gain Antenna
LRU	Line Replaceable Unit
MAWEA	Modular Avionics and Warning Electronics Assembly
MCDU	Multifunction Control Display Unit
NASA	National Aeronautics and Space Administration
ND	Navigation Display
OOOI	Out-Off-On-In
OSI	Open Systems Interconnect
PFD	Primary Flight Display
RAIM	Receiver Autonomous Integrity Monitoring
RFU	Radio Frequency Unit
RISC	Reduced Instruction Set Computer
RNP	Required Navigation Performance
RTA	Required Time of Arrival
SATCOM	Satellite Communications System
SDU	Satellite Data Unit
SGI	Silicon Graphics Inc.
SITA	Societe Internationale de Telecommunications Aeronautiques
SSR	Secondary Surveillance Radar
TCAS	Traffic Alert and Collision Avoidance System
TMU	Traffic Management Unit
URE	User Range Error
UTC	Universal Time Clock
VHF	Very High Frequency

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