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Requirements for Air Traffic Management in the En-Route Environment

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Abstract—Future aviation traffic is expected to continue to increase at 2% or more annually for the foreseeable future, unless the aviation system capacity acts to constrain this growth. To remove long-term airspace capacity limitations, new methods of air traffic management must be implemented. These new methods will necessarily require significant increases in the flow of information between air traffic management entities both on the ground and in the air. To support increased information flow, new aviation communications architectures are being investigated. One architecture gaining advocacy uses satellite communications for aircraft-ground and aircraft-aircraft communications while aircraft are flying in the en-route phase of flight. The purpose of this paper is to investigate the communications requirements for the en-route part of such an architecture. In particular, we will derive the instantaneous aircraft volume in the en-route environment by examining current air traffic statistics, as well as projections for future traffic. We also analyze the volume of data flow that might occur between aircraft in the en-route environment and air traffic management entities on the ground and examine the implications of these results on the design of satellite communications links that would serve the en-route communications requirements in the future.

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INTRODUCTION

Despite recent economic and terrorism-related setbacks for the global aviation industry, long-term air traffic growth is expected and considered essential for economic growth in every part of the world. In recent months, the first use of digital communications for air traffic control applications has been successfully implemented in a portion of US airspace in the Controller-Pilot Data Link Communications (CPDLC) Program. As the VHF frequency channels assigned to aviation become more congested with analog voice traffic, the use of digital communications is necessary to retain sufficient communications capability between aircraft and ground controllers.

But this is a short term solution. As aviation traffic continues to increase, current air traffic management (ATM) methods will be unable to cope because the fundamental limitation is the ability of a human air traffic controller to manage a maximum number of aircraft in a minimum sized portion of airspace. Hence, to enable long-term air traffic growth, new methods of ATM that provide air traffic controllers the necessary capabilities to manage airspace, rather than control individual aircraft, must be implemented.

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A primary feature of every new ATM method being developed, considered or researched is a significant increase in the flow of information between air traffic management entities on the ground and in the air.

The limited VHF spectrum available for aviation use is insufficient to provide the needed future information flow. Therefore, new aviation communications architectures are being investigated. The use of satellite communications for aviation has several advantages: the capability of covering oceanic and geographically remote regions; the ability to broadcast to many users with a single communications channel; the availability of bandwidth at higher satellite frequency bands; and reduced ground infrastructure needed to support a national and global communications network. These advantages apply especially to aircraft operating in the en-route environment – that is, aircraft that have completed their takeoff and departure phase of flight and have not yet entered the arrival and landing phase of flight, and are therefore under the control of the Air Route Traffic Control Centers (ARTCCs). The advantages of satellite communications do not accrue as easily to aircraft operating in the terminal area, arriving at and departing from the airports, because the primary information needed is highly local and not economically provided by satellites which cover continental regions. Hence, aviation communications architectures have been proposed that consist of satellite communications for aircraft en-route and in oceanic and remote regions, and terrestrial-based wireless communications for aircraft in the terminal area.

In the following sections we will review the basics of an ATM communications architecture featuring satellite communications for en-route aircraft, give an overview of how en-route air traffic is partitioned for management, give detailed estimates of recent and projected air traffic volumes, derive an estimate of communications requirements, and briefly review satellite communications parameters for the en-route environment.

AIR TRAFFIC MANAGEMENT COMMUNICATIONS ARCHITECTURES

The National Aeronautics and Space Administration (NASA) has been performing research and development on future air traffic management concepts, methods, and technologies under the Advanced Air Transportation Technologies (AATT) Project. At NASA's Glenn Research Center, attention has been focused on the communications architectures and technologies necessary to support advanced ATM concepts. Several studies sponsored under this program concluded that a network-oriented hybrid of satellite and ground-based communications systems will provide the most logical and potentially most cost effective architecture to support future requirements.[1,2,3]

As concepts for future air traffic management emerge, a logical assignment of ATM functions and applications between the satellite and ground-based communications links can be proposed. As described in previous papers,[4,5] a hybrid approach enables the architecture to take advantage of the best attributes of each type of communication link. In general, communications requirements which apply to system-wide (i.e. national or international) needs are most suitably served by a satellite communications solution.

Table 1 – Division of Applications Between Satellite and Ground-based Communications

		Satellite-based Applications	Ground-based Applications
ATM Communications	Air Traffic Control (ATC) Communications	En-Route ATC Data Controller-Pilot Data-Link Communications (CPDLC)	Terminal Area and Surface ATC (CPDLC)
		En-Route Automatic Dependent Surveillance (ADS)	Terminal Area and Surface ADS
		En Route (National) Traffic Information Service (TIS)	Terminal Area (Local) TIS
	Advisory Services	Weather Sensor Data Downlink	
		En-Route (National) Flight Information Service (FIS)	Terminal Area FIS
	Airline Operation Communications	En-Route Airline Dispatch and Administration	Terminal Area Airline Administration
Other Non-passenger Communications		En-Route Aircraft Health/Maintenance	Surface and Terminal Area Health/Maintenance
		En-Route Security, Surveillance "Black Box"	Terminal Area Security, Surveillance "Black Box"

These are the communications requirements that correspond to the en-route phase of flight. Oceanic and remote regions, where the installation of ground-based facilities is impossible or unfeasible, can also be served using satellite communications, although extreme latitudes would require non-geostationary satellites. The ATM applications in these regions are very similar to continental en-route applications. Requirements that serve the terminal area – the arrival, departure, surface and pre-flight planning phases of flight – are most suitable for a ground-based solution. The localized nature of the data being communicated in the terminal area environment is not efficiently disseminated through a satellite-based link which covers a large geographic area. In addition, weather-induced degradations which affect high-frequency satellite communications links are not a factor for en-route communications where aircraft are primarily operating above the weather. But they may be intolerable for aircraft ascending and descending through weather in terminal areas. Hence, ground-based communications links operating at frequencies not impaired by weather are more practical for terminal area communications. Table 1 summarizes the types of applications needed in the en-route and terminal area phases of flight.

Such a hybrid communications architecture also has global implications. Satellite communications can be implemented between continents, potentially providing continuous communications coverage for trans-oceanic flights. Satellites can also potentially provide modern infrastructure for less developed regions where establishment of the types of vast ground infrastructures currently in existence in many countries is prohibitively costly. Since several international entities are also studying future ATM communications architectures, global coordination of these efforts is necessary.

EN-ROUTE AIR TRAFFIC MANAGEMENT STRUCTURE

In the airspace system of the United States, air traffic management for the en-route phase of flight is handled by Air Route Traffic Control Centers (ARTCCs). The 20 ARTCCs covering the continental United States (CONUS) are shown in Figure 1. Each ARTCC controls air en-route air traffic within its geographic area. For the purposes of estimating future en-route communications requirements, we assume that ARTCC's will still maintain air traffic management responsibility in the future, so that air traffic for each ARTCC can be estimated. In terms of communications architectures, this structure could be used for designing the satellite communications link portion. For example, a satellite ground terminal located at each ARTCC could handle communications with aircraft within its region. This enables a reasonable sizing of most ground terminals, which would need to handle at most the communications traffic associated with aircraft under its control and perhaps neighboring ARTCCs. Since ARTCCs are already connected by land line communications links, site diversity to combat rain attenuation is built into such an architecture. One or more large ground stations could be configured to receive data from all aircraft in all ARTCCs in order to analyze national traffic flow and create a national traffic view. These large ground stations could also be configured to provide the required uplink to the satellite provide a broadcast-type ground-to-air link. Redundant ground terminals, emergency backup data links, and network security techniques (i.e. encryption and authentication) would be required to secure these critical communications links.

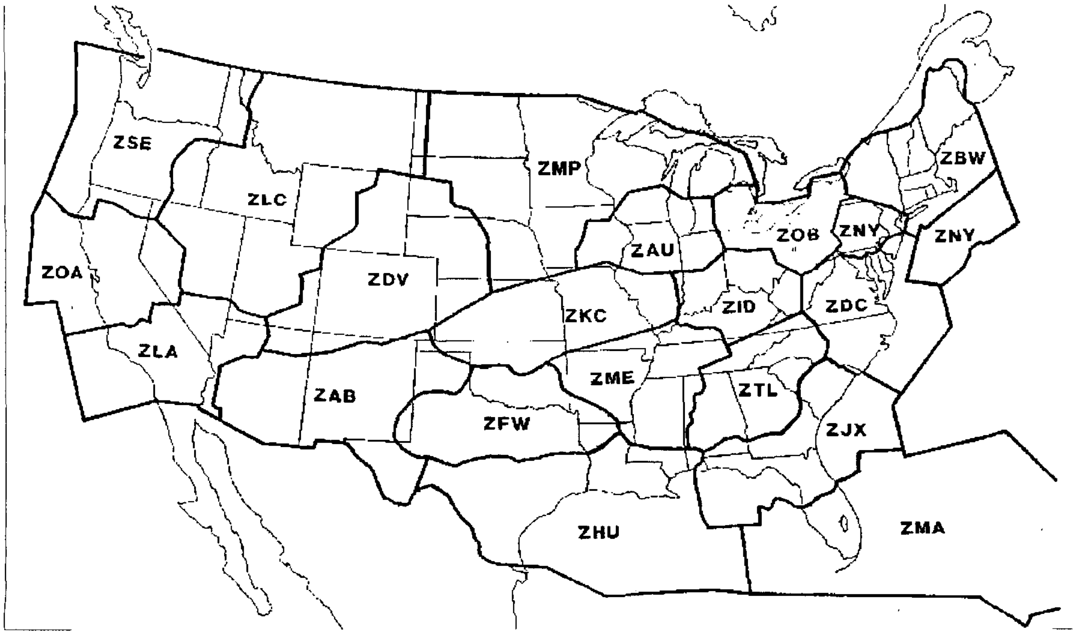

Figure 1 – Air Route Traffic Control Center distribution in the continental United States

TABLE 2 - Maximum Aircraft Handled at Air Route Traffic Control Centers Forecast

Center	Location Identifier	Peak # 11/22/2000	Time (UTC)	Forecast Peak FY 2013	Average Annual Percent Growth 2000 - 2013	Forecast Peak FY 2025	Average Annual Percent Growth 2013 - 2025
INDIANAPOLIS	ZID	425	20:00	564	2.2	758	2.5
KANSAS CITY	ZKC	379	22:00	497	2.1	668	2.5
ATLANTA	ZTL	515	20:45	666	2	895	2.5
MIAMI	ZMA	325	22:15	420	2	565	2.5
CHICAGO	ZAU	447	19:45	578	2	777	2.5
CLEVELAND	ZOB	501	20:15	639	1.9	860	2.5
DENVER	ZDV	407	17:00	519	1.9	699	2.5
OAKLAND	ZOA	266	22:45	335	1.8	451	2.5
MINNEAPOLIS	ZMP	370	22:45	466	1.8	627	2.5
SALT LAKE	ZLC	257	17:30	324	1.8	435	2.5
LOS ANGELES	ZLA	351	19:45	442	1.8	595	2.5
JACKSONVILLE	ZJX	466	18:15	587	1.8	790	2.5
HOUSTON	ZHU	359	19:45	452	1.8	608	2.5
LEESBURG	ZDC	538	21:00	678	1.8	912	2.5
ALBUQUERQUE	ZAB	347	16:15	437	1.8	588	2.5
FORT WORTH	ZFW	375	17:00	466	1.7	627	2.5
NASHUA	ZBW	291	0:45	362	1.7	487	2.5
MEMPHIS	ZME	393	19:30	483	1.6	649	2.5
NEW YORK	ZNY	326	21:15	395	1.5	532	2.5
SEATTLE	ZSE	191	20:45	223	1.2	299	2.5

- Statistics information for period covering FY 2001 – 2013 was obtained form: Statistics and Forecast Branch Office of Aviation Policy and Plans May 2002.
- Statistics information for period covering FY 2013 – 2025 was obtained form: FAA Long Range Aerospace Forecasts Fiscal Years 2015, 2020, 2025. Office of Aviation Policy and Plans.
- Forecast include only Continental US centers.

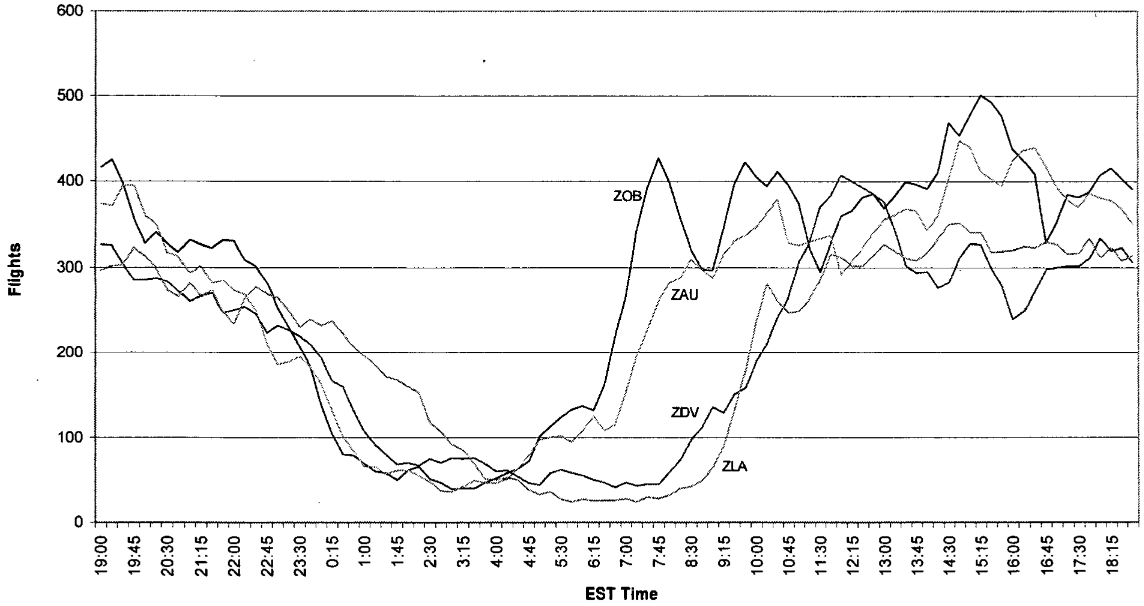

Figure 2 - Air traffic pattern for four ARTCCs, ZOB, ZAU, ZDV, ZLA, located in the Eastern, Central, Mountain and Pacific time zones, respectively.

Table 3 - Total IFR Aircraft Handled at Air Route Traffic Control Centers

Center	Location Identifier	Actual FY 2001	Forecast FY 2013	Average Annual Percent Growth 2000 - 2013	Forecast FY 2025	Average Annual Percent Growth 2013 - 2025
INDIANAPOLIS	ZID	2,599,679	3,376,001	2.2	4,540,346	2.5
KANSAS CITY	ZKC	2,165,811	2,783,891	2.1	3,744,024	2.5
ATLANTA	ZTL	2,933,710	3,735,602	2	5,023,969	2.5
MIAMI	ZMA	2,217,625	2,798,286	2	3,763,384	2.5
CHICAGO	ZAU	2,861,534	3,611,847	2	4,857,533	2.5
CLEVELAND	ZOB	3,130,917	3,926,201	1.9	5,280,304	2.5
DENVER	ZDV	1,718,521	2,164,840	1.9	2,911,469	2.5
OAKLAND	ZOA	1,677,791	2,074,030	1.8	2,789,340	2.5
MINNEAPOLIS	ZMP	2,103,143	2,613,549	1.8	3,514,933	2.5
SALT LAKE CITY	ZLC	1,542,667	1,901,831	1.8	2,557,751	2.5
LOS ANGELES	ZLA	2,145,804	2,647,012	1.8	3,559,937	2.5
JACKSONVILLE	ZJX	2,207,700	2,720,898	1.8	3,659,305	2.5
HOUSTON	ZHU	2,061,387	2,543,125	1.8	3,420,220	2.5
LEESBURG	ZDC	2,758,879	3,431,065	1.8	4,614,401	2.5
ALBUQUERQUE	ZAB	1,804,069	2,243,043	1.8	3,016,643	2.5
FORT WORTH	ZFW	2,173,752	2,646,601	1.7	3,559,384	2.5
NASHUA	ZBW	1,905,579	2,334,156	1.7	3,139,180	2.5
MEMPHIS	ZME	2,200,073	2,669,174	1.6	3,589,742	2.5
NEW YORK	ZNY	2,887,311	3,465,137	1.5	4,660,224	2.5
SEATTLE	ZSE	1,410,978	1,619,943	1.2	2,178,643	2.5

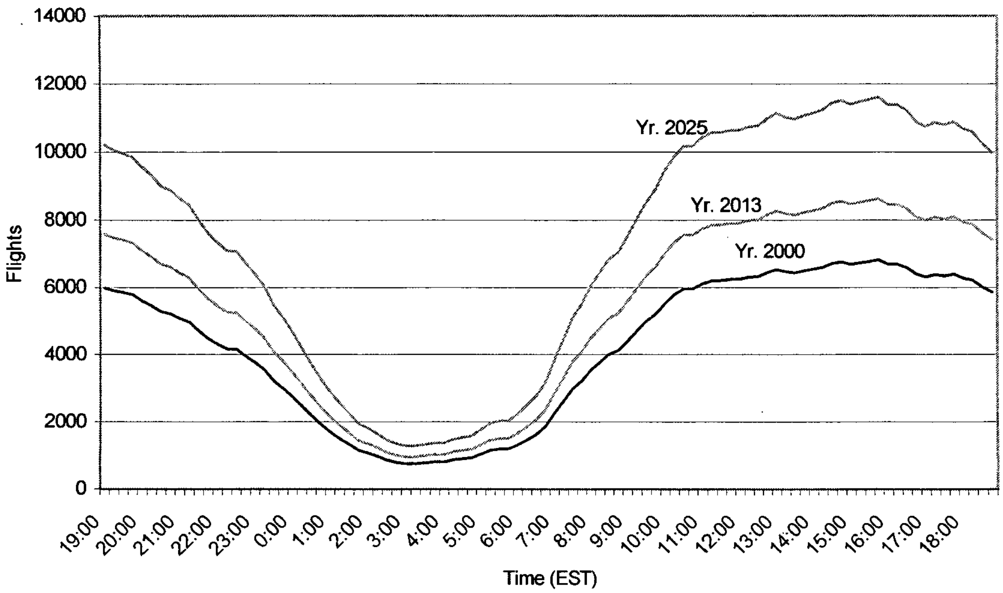

Figure 3 – Total number of fights controlled by ARTCCs in the US versus time for a high volume day for years 2000, 2013 and 2025.

AIR TRAFFIC STATISTICS AND PROJECTIONS

The airspace system in the United States prior to 11 September, 2001 was operating at or near capacity. After the events of 11 September there has been a decrease in traffic count that has been manifested across all 20 CONUS ARTCCs. To enable analysis of future aircraft traffic, flight information was obtained from the Enhanced Traffic Management System (ETMS). ETMS provided traffic count information for all ARTCCs in the CONUS. Flight count information was gathered in 15 minute increments for a full 24 hours starting at 0:00 UTC and ending at 24:00 UTC. ETMS is a subset of the Traffic Management System and is designed to support Air Traffic managers in measuring traffic demand by providing traffic surges, gaps, and volume. Added ETMS functionality includes monitoring, modeling, displaying and communicating traffic data in a variety of forms. ETMS relies on radar target information obtained from Long Range Radar Systems. Radar target information is forwarded to the ARTCC for processing and then it is sent to the ETMS. Flight information along with estimated air traffic growth figures were used to determine the estimated forecasted peak number of flights. The following formula was used to forecast growth: $G = X\left[1+\frac{P}{100}\right]^n$ where G is estimated growth, X is the initial aircraft number, P is the percent annual growth, and N is number of projected years.

Table 2 shows air traffic peak counts and the time of day at which they occur for all 20 CONUS ARTCCs. Information in table 2 has been captured to reflect a particularly busy date in the National Airspace system (NAS)[6]. The date selected, 22 November, 2000, is the day before the Thanksgiving holiday. Using expected growth analysis information,[7,8] Table 2 projects peak traffic increases for all ARTCCs at the point of maximum Air Traffic activity. This information shows Cleveland Center (ZOB), one of the busiest ARTCCs, handling a traffic load of 501 Instrument Flight Rules (IFR) aircraft at 3:15 pm EST. For the year 2013, at its busiest period, ZOB is projected to handle 639 aircraft, increasing to 860 aircraft in the year 2025. As observed in Table 2, peak traffic for CONUS ARTCCs occurs at different times. The United States covers four time zones, thus traffic loads vary accordingly, increasing first in the Eastern time zone and progressing westward across the Central, Mountain, and Pacific zones. Figure 2 shows a graph of number of flights versus time for Cleveland, Chicago (ZAU), Denver (ZDV) and Los Angeles (ZLA), based on the data supporting Table 2. These ATRCCs are geographically located in four different time zones (Eastern, Central, Mountain, and Pacific, respectively.) Figure 2 reflects the geographic traffic volume shift through the 24 hours, showing ZOB traffic starting to increase at about 6:30 am EST. At about 7:00 am EST, one half hour after ZOB traffic starts increasing, ZAU traffic volume starts to increase. At about 8:15 am EST traffic at ZDV starts to increase with ZLA starting to increase at about 9:15 am EST. Figure 2 also illustrates the decrease in traffic volume as time approaches night hours. It is evident that at about 7:00 pm EST all traffic in the US starts to decrease. This variation will be significant in attempting to determine the real peak communications loads in the future, and the potential for using dynamic bandwidth allocation and geographic bandwidth allocation methods for optimizing system performance.

Air traffic in the United States is expected to grow at an average rate of 1.8% between the years of 2001 through 2013 annually.[7] Air traffic covering the time between 2013 through 2025 is expected to increase at a rate of 2.5% annually.[8] Table 3 shows the growth expected for all ARTCCs covering the CONUS. The table indicates that traffic for all ARTCCs increase by two-thirds from year 2001 to 2025. Figure 3 represents total IFR aircraft traffic in the CONUS for September 22, 2000 and projected volume for a corresponding date in the years 2013 and 2025.[6] The figure shows a projected maximum of 11607 airborne aircraft in 2025 occurring at about 3:45 pm EST, and a minimum of 1278 airborne aircraft occurring at 3:00 am EST. For 2013 the projected maximum and minimum are 8630 and 950, respectively.

Further refinement of these estimates is possible, but much more difficult. For example, the distribution of aircraft in time might be considerably altered as the number of flights increases. Economic factors and physical constraints of the system may reduce the actual peak volumes by spreading out flights over a more even distribution. An extensive study of the possible future flight distributions is required to analyze these potential effects.

EN-ROUTE COMMUNICATIONS REQUIREMENTS

For purposes of air traffic management, communications applications are currently divided between safety-of-flight, advisory, and airline operations services, as indicated in Table 1. These services are divided because safety critical communications have much more stringent quality, reliability, availability and integrity requirements. A similar division of services in the future might be avoided if a single communications system can be proven to economically meet the stringent requirements of safety criticality with sufficient bandwidth to provide for the other services. However, for the purposes to the present analysis, we limit the consideration of en-route communications to air traffic control communications and flight information service (FIS). We include FIS because future air traffic management concepts require the consideration of the presence of weather problems and other airspace restrictions that are delivered via FIS.

The communications load per aircraft on the air-to-ground link consists of the ADS message and the CPDLC message. The ADS message structure is being developed by the RTCA Special Committee 186. From the most recent draft document, a maximum ADS data rate (based on the ADS-broadcast specification, assuming the maximum state vector update rate of one second) can be estimated to be 423 bits per second (bps).[9] The average rate will be lower because certain information is updated only when it changes. From the analysis contained in [3], the average data rate for CPDLC-like ATC messaging is estimated at 153 bps. Adding these two requirements, and considering message overhead, encryption and authentication requirements, an air-to-ground data rate of one kbps per aircraft is a reasonable estimate. A wide variety of potential future ATM concepts are currently being studied, but there is no consensus expected in the near future as to which concepts will be eventually chosen for implementation in the 2025 time frame and beyond. Therefore, it is difficult to anticipate what additional air-ground communications requirements might accrue from information flow requirements needed to enable such concepts. However, given the basic parameters needed for understanding aircraft flight activities and intentions, it is not likely that the total communication requirements would be more than double our estimate derived here. A possible additional requirement is aircraft to aircraft communications. For example, aircraft performing self-separation activities envisioned in certain ATM concepts might negotiate trajectory changes far in advance of calculated potential conflicts without ground-based ATM involvement. However, these requirements are also speculative and may not have a major impact because only aircraft with potential conflicts would be engaged in such negotiations. But in designing a future system, expansion of requirements to account for needs not yet foreseen must be included because systems implemented for aviation often end up in service for 30 years or more due to the high cost of changing aircraft equipage and supporting ground systems.

The communications load for the ground-to-air link consists of the CPDLC messaging to the aircraft and the TIS and FIS broadcast. The CPDLC ground-to-air data rate is equivalent to the air-to-ground rate aggregated over the total number of aircraft operating. We use the peak aircraft counts developed in the previous section for the year 2025, i.e., 11607 aircraft, resulting in an estimate of 7.1 Mbps. The Traffic Information Service (TIS) broadcast data set size is difficult to estimate. Although TIS specifications are currently being developed, the methods to be used for processing ADS and other data required to create the TIS data set are not yet known. If an upper limit of all of the combined ADS messages was assumed, it would require, for the system peak load case, 4.91 Mbps. To consider the FIS data broadcast requirement, the primary data set being transmitted is textual and graphical weather. Although very-high-resolution, multi-dimensional graphical weather data may become a standard part of FIS in the future, requiring several Mbytes or more to be transmitted, updates of weather information are infrequent, ranging from 15 minutes to several hours. Hence, average data rates required for en-route FIS may be 50-100 kbps, yielding a combined total ground-to-air link requirement is 12.11 Mbps.

To summarize, an aeronautical satellite communications link for air traffic control communications over CONUS in 2025 would be required to handle up to 11,607 air-to-ground downlinks of 2 kbps (an aggregate total of 23.2 Mbps), and a ground-to-air uplink of 12.01 Mbps. Both the total communications load and the geographic distribution of the air-to-ground and ground-to-air non-broadcast (i.e., CPDLC) communications varies considerably with time.

SATELLITE COMMUNICATIONS FOR EN-ROUTE AIR TRAFFIC MANAGEMENT

In a previous study, a consideration of satellite communications links for en-route ATM indicated some rough bounds on the requirements of such a system[4]. Link budgets were developed for a hypothetical Ku-Band satellite communications system to provide ATM services similar to those described above, based on realistic satellite system parameters derived from existing systems. A similar link budget was developed at Ka Band. The following conclusions were found:

A satellite link scenario has been developed at both Ku-band and Ka-band consisting of CDMA air-to-ground satellite links capable of handling up to 10,000 simultaneous aircraft at 1 kbps using the equivalent of four 27 MHz transponders. The ground-to-air satellite link requires the equivalent of one transponder to broadcast the required information.

In the study being presented here, we have greatly refined the air traffic loading analysis from [4], so that a peak aircraft load of 11607 aircraft has been derived. The satellite link analysis from [4] would require a fifth 27 MHz transponder to provide the necessary air-to-ground capacity. If 2 kbps per aircraft for the air-to-ground link is required, as discussed in the previous section, then an additional 5 transponders would be necessary. This is easily accomplished in the Ku Band case because a single CONUS satellite antenna beam is used. However, in the case of a Ka Band system, the multi-spot-beam case analyzed would entail significant additional system design, which, although it enables dynamic reconfiguration of bandwidth corresponding to geographic time variation of communications traffic load, does not easily lend itself to significant additional communications capacity increase. Therefore anticipated capacity must be designed into the initial system. Hence, an accurate communications requirements analysis is critical.

CONCLUSIONS

Continued growth in aviation is both expected and desired to support global economic growth. But current air traffic management methods place constraints on growth that can only be removed by developing and implementing new air traffic management techniques. Such techniques will require a large increase in aviation system information flow. To accommodate greatly increased information flow, communications system architectures are being developed that include both space-based and ground-based communications links. One architecture being proposed assigns en-route communications between aircraft and ground to satellite communications links. To continue the process of developing and assessing competing architectures, accurate estimates of future communications requirements must be obtained. Two key components of air-ground communications requirements are the communications volume per aircraft and the peak number of aircraft in the en-route environment. This paper focuses on the latter item.

Aviation statistics and projections from the Federal Aviation Administration were analyzed to develop estimates of future peak aviation traffic. The following conclusions were reached. In 2025, the potential peak number of aircraft in the en-route phase of flight for a high volume day is estimated to be 11,607, occurring at 3:45 PM EST. The number of en-route aircraft in the airspace varies significantly with the time of day, the lowest count of 1278 occurring at 3:00 AM EST. The aircraft loading also varies geographically with time, with peak loads progressing from east to west during the morning hours. All of these conclusions have significant implications for design of the satellite communications system to serve en-route requirements.

The previous study of potential satellite communications solutions cited may have underestimated the future peak aircraft volume. However the basic parameters of the study and basic satellite link design still apply.

Additional efforts will be continued to develop and refine the analyses presented in this paper, as well as the following areas of satellite communications system design for en-route communications. Improved estimates of the per-aircraft data communications requirements; the performance requirements for safety-critical ATM communications and the translation of those requirements to specific satellite communications link performance parameters; further refinements of the satellite link analyses; and an accurate, objective economic (cost/benefit) analysis to justify the future development and implementation of an aeronautical satellite communications system for air traffic management.

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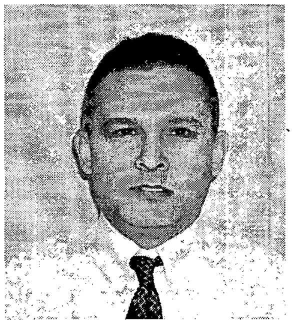

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