Final Report

of the

Working Group

on

Oceanic and Sparse Area Communications

Air Traffic Services Subcommittee

FAA Research, Engineering, and Development Advisory Committee

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I - Introduction and Summary

The efficiency of aircraft operations in oceanic and sparse area airspace and the capacity of oceanic air routes are limited in part by the absence of rapid, highly reliable means of communication between the pilot and controller (or, more generally, between the aircraft and the controlling facility). While general communications capability has rapidly advanced in recent decades, oceanic operations[1] still depend, in most areas, on relayed voice radios operating in the high frequency band, unchanged for the past 50 years or more except for equipment improvements.

In oceanic airspace large inter-aircraft spacings are maintained, and aircraft deviations from preset flight plans are constrained, because of uncertainties in aircraft position and the reliability of air/ground communications. This limits both the efficiency and capacity of oceanic operations. Air traffic in oceanic and remote areas has lessened with the economic decline and the terrorist attack of September 11, 2001, and this has provided a respite from the aggressive growth rates in the late 1990s. However, the recent 2003 FAA Forecast predicts a return to more normal growth rates beginning in 2005. Even with the introduction of RVSM and improved navigational accuracy (better INS, GNSS), access to best weather routes and the ability to change flight paths once en route is still limited due to the lack of real-time surveillance and rapid, reliable communication.

A variety of new communication technologies are available to enhance communication between aircraft and control facilities. As a follow-on to an earlier study[2], the Air Traffic Services (ATS) Subcommittee of the FAA Research, Engineering, and Development Advisory Committee (REDAC) recommended that an additional study address, in more detail, the issues of oceanic and remote area communication. The FAA concurred in this recommendation, following which the REDAC ATS Subcommittee formed a Working Group to assess the need for improved communication and the technical options available, and to develop recommendations for actions, if any, which the FAA should undertake.

Study Process

The Working Group solicited inputs from all segments of the aviation community with a stake in oceanic operations. These included ATM service providers, communication service providers, aircraft operators, and R&D organizations with relevant activities:

[1] In this report, the term "oceanic operations" will be used to refer to aircraft operations in airspace beyond line-of-sight of ground-based communication and surveillance facilities, both over oceans and over sparsely populated and/or underdeveloped areas, e.g. much of Asia and Africa and polar regions. In some oceanic airspace both capacity and efficiency are issues; in the remainder safety and operating efficiency are the primary concerns.

[2] Kern, et al**;** Recommendations For Aviation Communications Research Investments; report of the Air Traffic Services Subcommittee Aviation Communication Research and Technology Subgroup; March 2003

ATM Service providers

FAA
Air Services Australia (via written communications)
Nav Canada (via written communications)
Eurocontrol

Communication Service Providers

ARINC – Satellite and HF
INMARSAT
Iridium
Boeing - CONNEXION

Aircraft Operators

Air Transport Association – for scheduled airlines
National Business Aircraft Association – for business aviation
FedEx – for cargo airlines
DoD

R&D Organizations

Mitre/CAASD
MIT Lincoln Laboratory
NASA Glenn Research Center
DoD

To the extent available, copies of the presentations by these organizations are included in the "Appendices" section of the enclosed CDROM.

In addition to these inputs, Working Group members contributed substantially from their own knowledge and experience.

Structure of the Report

This initial section of the report concludes with summaries of the principal findings and conclusions of the Working Group. It is followed by several sections that discuss in more detail oceanic operations and communication alternatives. Appendices include the Working Group Terms of Reference, its membership and meeting participants, meeting agendas, and a bibliography. The enclosed CDROM contains an electronic copy of this report, plus copies of all available presentations to the working group and copies of available reference material. These are included as an aid to readers who wish to understand in depth the basis for the Working Group conclusions and recommendations and to make readily available reference material to assist in subsequent studies in this area.

Findings

1. The efficiency and capacity of aircraft operations in oceanic and sparse area airspace are limited by a number of factors, one of which is the lack of a rapid, reliable means of communication between aircraft and control facilities. This results in significant economic penalties to aircraft operators by forcing many flights to use non-optimum routes, a situation that will worsen as traffic levels increase in the future.

2. The introduction of RVSM (reduced vertical separation minima) on oceanic routes has significantly alleviated the near-term capacity problem, allowing more aircraft to operate on optimum or nearly-optimum flight paths. However, in many regions aircraft are still limited in their ability to make non-preplanned changes in flight paths once en route, e.g. to perform en route climb or to avoid unforecast adverse winds or hazardous weather. In addition, as oceanic traffic grows, there will be increasing pressure to allow operation at reduced interaircraft spacings.

3. Most providers of oceanic ATS services are deploying new oceanic ATS automation systems that support ADS-A and CPDLC FANS-1/A satellite data link applications. These include:

Australia - TAAATS
New Zealand - OCS
Fiji - EASY
Canada – GAATS
UK - GAATS
US – ATOP

4. Using these new oceanic automation systems and based on new ICAO oceanic separation standards, aircraft equipped with approved ADS (automatic dependent surveillance), controller/pilot data link communication capability, and the appropriate RNP capability will be able to operate at reduced interaircraft spacing and to change flight paths to respond to varying flight conditions. To achieve maximum benefits, all users of the airspace must be equipped. The FAA/RTCA CONOPS[3] envisions that such equipage will be required in the mid- to far-term. To foster universal equipage, it is desirable that the cost of equipage to the aircraft operator be commensurate with the economic benefit resulting from more efficient operation.

5. Existing means of oceanic communication are either expensive or do not meet the requirements to support improved ATS services. These include:

HF voice – does not meet requirements for improved ATS services
FANS/INMARSAT – expensive to install and operate
(Current) HFDL (high frequency data link) – does not meet requirements for improved ATS services

[3] RTCA document DO-244 – Government/Industry Guidelines and Concept for National Airspace Analysis and Redesign

6. There are both existing and proposed communication systems that could provide part or all of the requisite communication capability if they can meet US and international requirements. These include[4]:

Enhanced TDMA over INMARSAT
Improved HFDL
Iridium
NexSAT

The principal attributes of the systems in Findings 5&6 are summarized in Table 1.

Comm Alternative	Coverage	Cost to Users	Cost to ATC	Voice	Data	Meets current rqmts.	Meets rqmts for ( ) sep 50/50	30/30	Comments
HF voice	Global	Low	Low	Y	N	Y	N	N	Moderate reliability
FANS/ INMARSAT	All longitudes, no polar	High	Low	Y	Y	Y	Y	Y	Commercial; only 2.5% income from aviation
Current HFDL	Global	Low	Low	N	Y	N	N	N	Commercial; not designed for ATC
Enhanced TDMA over INMARSAT	All longitudes, no polar	Low	Low	N	Y	?	?	N*	R&D concept; not yet realized
Improved HFDL	Global	Low	Low	N	Y	?	?	N*	Under development
Iridium	Global	Low	?	Y	Y	?	?	?	Commercial; long-term viability uncertain
NexSAT	Europe +?; no polar	?	High	Y	Y	Y	Y	Y	R&D program; not yet realized

* By itself, only provides data link, not voice

Table 1

7. A major element of the cost of equipping an aircraft for ADS and CPDLC is interfacing the communication system with the aircraft's navigation and flight control system, and providing the pilot interface. This problem is most severe on the older (legacy, classic) aircraft without modern flight control systems and CMU's (communication management units). To increase the economic viability of equipping such older aircraft, consideration should be given ways to reduce the cost of this interface.

8. While its long-term economic viability is uncertain, Iridium appears to be an attractive candidate for communication to support global ATM. (It is possible that the adoption of Iridium as an element of international ATS communications would itself enhance its economic viability.)

[4] Because of its limited coverage in oceanic regions, Globalstar is not considered to be a viable candidate.

9. It is likely that the required communication performance will be met not by a single very high reliability system but by a combination of subsystems that together meet the communication requirements.

Recommendations

The FAA should initiate an activity to develop standards for an oceanic communication system that can meet the needs of advanced oceanic operations. The system should initially meet the requirements for 30/30 separation (30 miles lateral, 30 miles longitudinal), but should have the potential for closer spacings when and if indicated by demand. The standards should be realizable by a system that is economical to install and operate for a broad class of aircraft.

The performance standards should be expressed as Required Communication Performance (RCP).

Specific activities should include:

1. Designate organizational responsibility within the FAA for the development of oceanic communication standards and systems
2. Assess the performance of Iridium, especially its short-message service, as a means of supporting ADS and CPDLC.
3. Assess the ability of upgraded HFDL to serve as a primary means of communications for oceanic operations.
4. Examine new approaches[5], e.g. TDMA over INMARSAT
5. Reexamine the minimum communication performance required to support reduced oceanic separation standards (initially 30/30, but ultimately lower)
6. Request RTCA to form a Special Committee on oceanic data link to encourage and provide a forum for industry involvement. An early task for this Special Committee would be defining a standard interface among aircraft flight control systems, CMU and pilots (see Finding 7 above).
7. Conduct a trade study that examines the user implementation costs and benefits for each of the proposed links and for a broad class of aircraft including cargo, business and military, over the next several decades.
8. Participate actively in the Eurocontrol NexSAT program.
9. Continue to work with ICAO and other relevant groups to ensure that new international standards for minimum communication performance are developed and adopted.
10. Investigate means of reducing FANS installation and/or message traffic costs.
11. If a potential new communication system emerges from these activities, identify a “lead carrier” oceanic airspace user to initiate the avionics certification process.

[5] In addition to the approaches discussed here, two additional approaches should be considered. The first is the Boeing Connexion system. While Connexion is primarily focused on large-aircraft passenger communication, it will be carried by many airline aircraft and could potentially be useful for ATC communication. The second is the Boeing/INMARSAT proposal for Aero-BGAN (Broadband Global Aero Network), which appears to have many of the desired attributes. Unfortunately the Working Group did not become aware of the details of this proposed system until after the completion of its data-gathering activities.

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II – Oceanic Operations

Growth Forecasts

The air traffic in oceanic and remote areas has lessened with the economic decline and the terrorist attack of September 11, 2001. While this has provided a respite from the aggressive growth rates in the late 1990s, the recent 2003 FAA Forecast predicts a return to higher rates beginning in 2005.

The FAA 2003 Forecast asserts the following key points:

- There will be a return to positive economic growth by 2005
    - Most growth expected in Latin America and Asia/Pacific
    - The U.S. economy will slightly lag the rest of the world
    - International passenger markets will grow faster than domestic U.S.

- Forecast passenger annual growth rates for 2005-2014
    - Domestic U.S. - 4.6%
    - All International - 4.2%
    - Latin America - 5%
    - Pacific - 4.9%

- Forecast cargo annual growth rates for 2005-2014
    - Domestic RTM - 4.4%
    - International RTM - 6.3%
    - One carrier expects a 12% growth rate

- The key forecast risks are
    - Overly optimistic Asian economic forecasts
    - Impact of terrorism and heightened security measures
    - Impact of increasing fuel costs

A recent AIAA paper[6] by Jiang, Ren, and Hansman noted that China's soaring economy – growing at 9.4% during 1978-2002 - was accompanied in 2002 by an international air cargo increase of 19.3%. It also suggests air cargo – domestic and international - growth rates will continue to be high through 2020.

The potential impact on oceanic air traffic will be an increased demand for the best, most economic routes that avoid bad weather. Since airlines have been recently emphasizing profitability over market share, they will have increased interest in the most economical flight paths in most oceanic/remote airspace. A recent study indicated time savings ranging between 4.9 minutes to 29 minutes for aircraft flying between LAX and Sidney, when flex tracks (user preferred) tracks were used.

[6] H. Jiang, L. Ren and R. Hansman; Market and Infrastructure Analysis of Future Air Cargo Demand in China; AIAA's 3rd Annual Aviation Technology, Integration, & Operations (ATIO) Forum; AIAA Paper 2003-6770; 2003

Present Oceanic ATM

The current oceanic ATC automation system differs significantly from the domestic ATC automation system because much of oceanic flight is beyond the range of radars and Very High Frequency (VHF) communications. Oceanic ATC operations are performed manually or with limited automation, and most air/ground voice communication is through a third party communications service provider via High Frequency (HF) radio. These system limitations force large separation standards and impact the ability of the controller to grant aircraft requests for changes to flight profiles. In the early 1990s, these problems were exacerbated by the explosive growth in oceanic traffic. In 1994, the Federal Aviation Administration (FAA) made a commitment to the international aviation community that the FAA would implement "the use of a global navigation satellite system, digital data communications, and advanced automation" to address inefficiencies and projected traffic growth in oceanic airspace.

Figure 1 depicts the worldwide allocation of airspace into Flight Information Regions (FIRs). The FAA has a requirement for an ATC modernization system for the oceanic Flight Information Regions (FIRs) assigned to the United States.

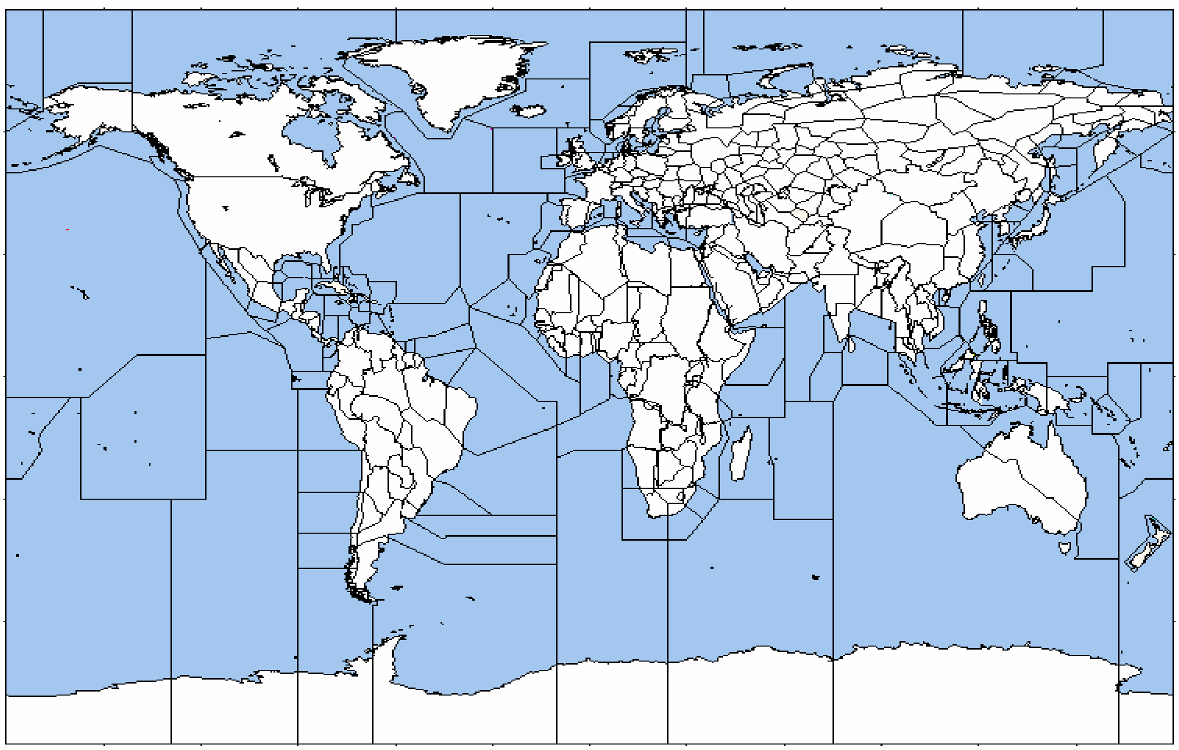

Figure 1. ICAO FIRs

The system also will be required to support radar services in transition sectors. The airlines that operate in this airspace have urged the FAA to provide automation that can reduce delays, support fuel-efficient routes, and manage growing international traffic loads, while maintaining current safety levels. In response, the FAA is acquiring automation capabilities to support requirements for modernized oceanic and transition operations at the Oakland, Anchorage, and New York Air Route Traffic Control Centers (ARTCCs). See Figure 2.

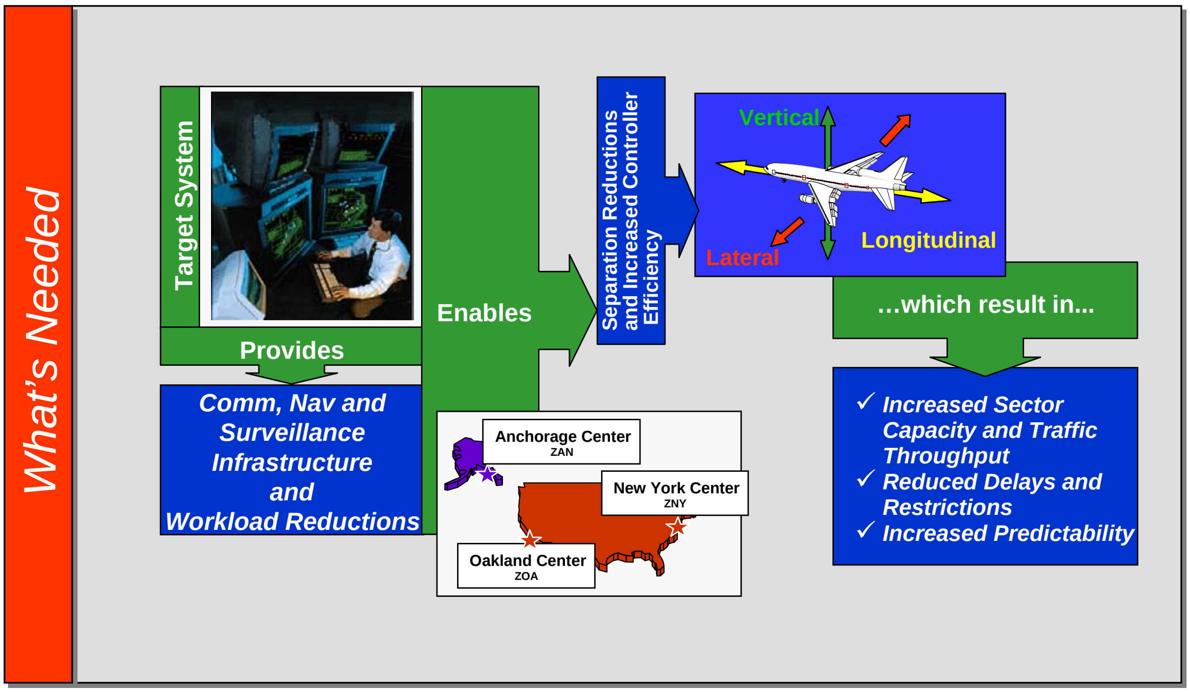

Figure 2. Oceanic Modernization Needs

Separation

Separation standards in a given airspace are a function of the communication, navigation, and surveillance capabilities available in a specific operating environment. Safety analysis and operational judgment consider factors such as: timeliness and reliability of controller-pilot communications, accuracy of aircraft navigation, the controller's ability to determine potential separation loss, aircraft traffic density, and procedures for contingencies such as engine failure and weather deviations.

The Required Navigation Performance (RNP) concept has been introduced into ATC operations to standardize navigation. For example, RNP-10 approved aircraft are equipped with navigation systems that can navigate within 10 nautical miles of desired position with 95% probability.

Currently in oceanic airspace, the minimum lateral separation applied by the FAA is 120 nm in Atlantic and Caribbean/South American airspace; 60 nm in North Atlantic minimum navigation performance specification airspace; 50 nm between RNP-10 approved aircraft in Pacific airspace except in the Central Pacific where, due to convective weather, 100 nm lateral is applied south of 30N.

The FAA standard for longitudinal separation is 10 minutes (approximately 80 nm).

Air Traffic Service Providers in New Zealand, Australia, Tahiti, and Fiji use FANS 1/A Automatic Dependent Surveillance-Address (ADS-A) systems in Pacific oceanic airspace. A 50 nm longitudinal separation standard is currently applied by South Pacific air traffic service providers having enhanced CNS/ATM systems to aircraft certified for RNP-10 and approved for direct controller-pilot communication via voice or data link.

The FAA and other civil aviation authorities have certified ADS-A, CPDLC[7], and RNP capabilities on aircraft such as the B-747-400, B-777 and the A-340.

Controller-pilot data link communication (CPDLC) allows digital communication between air traffic controllers and Future Air Navigation Systems (FANS-1) equipped aircraft. The system reduces voice communications by allowing pilots and controllers to transmit digital data messages directly between computers on the ground and on-board flight computers. Information such as altitude changes and altimeter settings can now be transmitted electronically, freeing up the voice communications bandwidth for urgent voice messages. Unlike ADS, CPDLC requires flight crew interaction. Pilots remain constantly aware of which air traffic service unit (ATSU) has the active connection, and they are also aware of the transfer of control taking place from one ATSU to another.

CPDLC has been a significant step in the FAA's modernization plans. The first use of FANS 1/A CPDLC was implemented at Oakland Center in 1995 and New York Center in 2003. CPDLC has been the primary means of communication over the Pacific for suitably equipped aircraft since early 1999. The system greatly reduces pilot and air traffic controller workloads, allowing for greater flexibility. One of the most significant aspects of this system is its reduction of crew-input errors. The crew can downlink a route clearance request, which the controller can review and return to the crew. This eliminates the errors that occur during manual input of data.

ICAO, FAA and other civil aviation authorities have also approved RVSM (Reduced Vertical Separation Minima) operations that permit a 1000-foot vertical separation standard to be applied to certified aircraft over the ocean. This has greatly alleviated the capacity constraints in the North Atlantic Oceanic FIRs.

Near-Future Oceanic ATM

ATOP (Advanced Technologies & Oceanic Procedures)

ATOP is FAA's advanced ATC automation system that is replacing oceanic ATC automation systems currently in use at the Oakland, New York, and Anchorage ARTCCs. Anchorage will retain its current automation platforms to support domestic operations. ATOP will be delivered in two increments, ATOP Builds 1 and 2. Build 1 replaces the current systems at Oakland and New York, providing ATC automation for non-radar procedural airspace. Build 2 adds a radar data and ADS-B processing capabilities for use

[7] When used in this report, the term CPDLC refers to generic controller-pilot data link, not the specific implementation using VDL-2.

in Anchorage, as well as the radar transition sectors in Oakland and New York currently utilizing Host/DSR equipment.

ATOP will provide a Flight Data Processing (FDP) capability fully integrated with Surveillance Data Processing (SDP). The SDP will be capable of processing primary and secondary radar, Automatic Dependent Surveillance (ADS), both Addressable (ADS-A) and Broadcast (ADS-B), Controller Pilot Data Link Communications (CPDLC) position reports, and relayed HF radio voice pilot position reports from an HF radio operator employed by a communications service provider under contract to the FAA.

ATOP will support radar and non-radar procedural separation, tracking clearances issued via CPDLC or messages through the HF radio service provider, conflict detection/prediction capabilities through the use of controller tools (Conflict Alert and Minimum Safe Altitude Warning for radar airspace and Conflict Probe for non-radar procedural separation applications), and fully automated coordination via Air Traffic Services Inter-facility Data Communications System (AIDCS) with adjacent AIDCS-equipped Flight Information Regions (FIRs).

The ATOP system is scheduled to become operational at Oakland in June 2004, in New York in March 2005, and in Anchorage in March 2006.

Separation

The ICAO Separation and Airspace Safety Panel has established standards for the implementation of 30 nm lateral and longitudinal separation that call for: direct controller-pilot communication via voice or data link, aircraft navigation accuracy to RNP-4 (4 nm/95% probability) and ADS-A capability in the aircraft and at the oceanic control center. The ATOP system will enable the application (to such suitably-equipped aircraft) of 30 nm lateral and longitudinal separation. These reduced separation standards will increase oceanic airspace capacity and aircraft time/fuel burn efficiency. ATOP will also improve the safety of oceanic operations by giving controllers enhanced tools to track aircraft progress and identify potential aircraft conflicts and problems. Initial FAA goals are to implement 30 nm lateral and longitudinal (30/30) separation in Oakland controlled South Pacific airspace by 2005. As ADS-A deployment progresses and as more aircraft become RNP-4 capable and approved, use of 30/30 separation will be expanded beyond the South Pacific. In the period 2006-2013 it is expected that 30/30 will be utilized throughout the Pacific and potentially in the North Atlantic airspace controlled by New York ARTCC. (Note that most North Atlantic airspace is controlled by Canada and the U.K., each of which are implementing similar oceanic automation systems.)

Future Oceanic ATM[8]

There are expanded capabilities available to all aircraft and in all airspace. User-preferred routes replace the track system. Increased airspace capacity is achieved through further reductions in separation minima.

[8] The following is adapted from the description of the operational improvements derived from the RTCA Concept of Operations and documented in the NAS Architecture as the Target System Description for Oceanic Operations.

The positions of all controlled aircraft are determined through automated means and are displayed to the service provider. Separation assurance is accomplished with the aid of Decision Support Systems (DSSs) and a visual display system similar to that used in domestic en route. Communications are seamless as data-link services become common in both environments. ATM services (including TFM planning and agreements), DSSs, and automation in assigned international oceanic airspace are harmonized with those of the domestic en route environment. User-preferred routings are available throughout the airspace. Advanced CNS and automation capabilities enable achievement of domestic-like separation services in the international oceanic environment.

Intelligent agents operating on behalf of the user and service provider monitor changes in the flight environment, and propose adjustments to the profile in response to changes in ATM system constraints. The proposed changes reflect the removal of constraints and permit the as-flown profile to more closely align with either the user's original preferred profile or a profile constructed based on known user preferences. Different users may have different operational responses and preferences to the same changes in ATM system conditions. These responses are similar to those experienced by flights operating in the domestic en route environment, with some adjustment for the differences in response times and traffic volume.

There will be increasing reliance on satellite technology for data communication and surveillance with a higher reporting rate, potentially enabling separation reduction beyond 30 lat/30 long. Situational awareness in the cockpit (CDTI) will allow for shared separation responsibility and enhanced safety during contingency events. User preferred trajectories will be utilized, rather than fixed or flexed tracks; improved sharing of information with AOCs, collaborative decision making, will allow for more efficient route/altitude profiles.

Automation

The use of ATOP is expanded to support conflict free 4-D flight profiles. Periodic position reports using either ADS or other means (Satellite or HF radio) are automatically processed by ATOP to ensure that the aircraft are adhering to their cleared 4-D profiles. Non-conformance to the cleared 4-D profile is noted to the controller for resolution. Clearances are issued to effect changes to an aircraft's profile and these are ensured to be conflict free before they are sent. The aircraft's cleared 4-D flight profile is automatically updated upon the acceptance of the clearance by the aircraft. The goal is to ensure that the 4-D cleared profile held by the ATOP system and that being executed by the aircraft is the same.

Communications

VDL Mode 3 voice along with DSB AM voice will be used for Air-Air communications in domestic US airspace. Satellite communication will be available for oceanic airspace, utilizing both voice and data capabilities, but data communication will be the primary capability. Both HF voice and HFDL data capabilities will be used as backup to the satellite capabilities. ATN will be the networking technology to provide data link interoperability across the various technologies. ATN will likely be enhanced with IP protocols due to user demand. Data security will be increased with all links being modified as necessary to minimize the risks and probabilities of deliberate interference.

Navigation

Satellite based navigation systems will become more accurate and will be available from a number of service providers. The availability of WAAS in oceanic transition areas will reduce the occurrence and duration of “holes” in GPS coverage. RNP capability (beyond RNP-10 which is currently required in Pacific oceanic airspace) will be required to use certain routes and gain the most efficiency.

Weather

Various products tailored for transoceanic flights such as convection, volcanic ash, in-flight icing, clear air turbulence (CAT), and convection-induced turbulence (CIT) will emerge from FAA-sponsored R&D. Better data link technology using ground- and satellite-based dissemination architectures speed delivery enabling common situation awareness (oceanic control, AOC dispatcher & flight deck) of the hazard along the flight path.

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III - Requirements to Support Reduced Separation

Given global improvements in the capabilities of CNS, ATM controllers can provide improved oceanic separation assurance (SA) by:

1) monitoring the progress of aircraft under their control,
2) estimating the future "trajectory " of each aircraft
3) intervening in a timely manner whenever any pair of aircraft are predicted to be "encountering" each other.

An "Intervention" is a controller instruction communicated to one or both pilots that changes the future trajectories such as to increase the minimum separation during the encounter. It must be understood and executed by pilots before the time of passage for the encounter, and controllers will monitor its execution, and also the remainder of the encounter until passage, to ensure the desired separation at passage is maintained.

As the quality of both the surveillance and communication is improved, the procedures for SA can be improved and the separation criteria used to define an "encounter" and a "safe separation at passage" can be reduced. It is necessary to understand the relationship between the degree of improvement in surveillance and communication and the corresponding improvements in SA if we are to make the tradeoffs necessary to find cost efficient improvements in oceanic ATM for all classes of users. This section discusses the particular qualities of surveillance and communication that are needed to allow improvements in oceanic procedures.

Separation Assurance

Separation assurance is the primary service provided by ATM. The procedures used for separation assurance in various operational situations (along with their corresponding minimum separation criteria) are strongly dependent on the performance of <u>all</u> of the redundant systems that are available for CNS (communications, <u>and</u> navigation, <u>and</u> surveillance). Through ICAO, using guidance manuals such as Reference X, ATM managers from many countries will develop safe new oceanic SA procedures.

We will briefly provide a common understanding of separation assurance and its issues before discussing how improved CNS capabilities lead to SA improvements and reduced aircraft separations.

Measuring the Quality of CNS Performance

Measures for the quality of operational performance for communication systems (both voice and data) are transfer-delay, availability, reliability, continuity, integrity, priority, preemption, and precedence.

Measures for quality of operational performance for surveillance systems are position accuracy, position data rate, independence/dependence from aircraft navcom systems, availability, reliability, continuity, and integrity.

Measures for the quality of operational performance for navigation systems are position accuracy, position update rate, availability, reliability, continuity, and integrity.

In determining safe separations, average values for these measures of performance are not as important as the 95 or 99% level of performance. An acceptable operational procedure to provide separation assurance must have a probability of failure of the order of one in a million.

Dealing with Uncertainty in SAS Information

In providing SA, controllers use information about the actual, intended, and the probable future 4-D trajectories that extend ahead of each aircraft. A trajectory consists of the projected horizontal and vertical paths, and the rates of progress along those paths – e.g., intended and future ground speeds and vertical rates, and consequently the expected, or estimated, times of arrival at various waypoints/altitudes. This is uncertain information, and the degree of uncertainty in future positions (and the increase in levels of uncertainty with the projected time until an encounter) strongly influences the procedures and criteria used to provide SAS.

Types of ATC Separation

There are three types of separation provided by ATC: vertical, lateral, and longitudinal.

1) Vertical Separation - When using vertical separation, controllers assign aircraft to different pressure altitudes that differ by 1000 or 2000 feet, and then rely on pilots/autopilots to maintain "conformance" to their assigned levels. Because of the accuracy of height measurement, and also the quality of manual and automatic height-keeping systems onboard current aircraft, the average quality of vertical conformance is exceptionally good (average deviations are 100 feet or less), so that these small separations are operationally acceptable as being "safe").

   Controllers monitor for "Gross Altitude Deviations" by manually (in the case of voice position reports) or automatically (in the case of data-linked position reports) comparing reported altitude with assigned altitude. Monitoring altitude separation and handling gross altitude deviations requires good performance from both surveillance and communication systems.

2) Lateral Separation – In applying Lateral Separation on well-defined parallel tracks for aircraft at the same altitude, in a manner similar to providing vertical separation, controllers will assign aircraft to tracks nominally separated by certain distances and then monitor their conformance to those tracks. The track separations used depends on the operational situation (for oceanic parallel tracks, the current separations are roughly 50 nm. i.e., 30,000 feet). (Note that RNP-10 tracks are generated 1 degree apart which is approximately 60 miles. Applied separation is 50 nm). This increase of three hundred times over the vertical separation is due to the relatively poor quality of lateral conformance due to the historical quality of position information from aircraft navigation systems, and also the track-keeping performance of

their manual or automatic guidance systems. The introduction thirty years ago of digital autopilots (now called Flight Management Systems) in larger aircraft and the newer availability of good position information from GPS create the potential for a significant reductions in lateral track separation whenever all (or most) aircraft flying the parallel tracks are using such systems.

But the “Gross Lateral Deviation” problem must still be handled in some way. This requires recurrent position information (i.e., primary and backup modes of surveillance of some form) to monitor aircraft lateral deviations, and also requires the ability to communicate reliably and with little delay to provide aircraft with a resolution.

3) Longitudinal Separation - For aircraft at the same altitude, when using longitudinal separation for aircraft on the same track (or lateral separation for aircraft on crossing tracks) ATC controllers will use time or distance separation. Typical time separations for oceanic operations are 10-15 minutes, but it depends on the operational situations and the expected speeds of successive in-trail aircraft. At cruising speeds for jet subsonic transport aircraft of roughly 8 miles per minute, 15 minutes separation translates to 120 nm, or 720 times the vertical separation used by ATC. The required initial longitudinal separation applied to successive aircraft on the same track depends on the expected speeds and the length of time between reporting waypoints. If the following aircraft adopts the same airspeed as the prior aircraft, initial separation may be reduced (e.g., 10 minutes on the North Atlantic Track System), and conversely, if the first aircraft is expected to be significantly faster, the initial longitudinal separation may be reduced to 5 minutes..

Having assigned the track and altitude and an initial longitudinal separation, ATC does not currently assign and continuously monitor groundspeed, nor assign a RTA (Required Time of Arrival) at waypoints along the track. Instead, it assumes that constant airspeeds will be maintained, and monitors using ETAs (Estimated Time of Arrival) and ATAs (Actual Time of Arrival) at waypoints at specified intervals along the track. Today in the oceanic environment this information is usually provided rather infrequently by each aircraft via an occasionally unreliable HF voice communication system. Uncertainty is introduced into the ATA by short-term variations in the actual winds as well as the errors in expected average winds obtained from different forecast sources, using forecasts that are created and updated at different times.

ATC performs conformance monitoring by examining the difference in ATAs reported by successive aircraft at each waypoint. If the difference violates longitudinal separation criteria, then oceanic ATC will intervene to change airspeeds or assign different altitudes. This “after–the-fact” conformance monitoring and resolution causes the use of larger longitudinal separations since there must be some extra margin to allow time for safe resolution. Alternatively, it may be possible to use the “closure trend” from successive and more frequent waypoints to intervene early - although uncertainties from wind variations might mean that such interventions were actually unnecessary.

The ability to specify the frequency of position reports during a closure/crossing situation, and to communicate a resolution quickly and reliably, would allow longitudinal and lateral crossing separation criteria to be reduced in oceanic/remote regions. This would require future improvements in surveillance and communications in the oceanic/remote area environment.

Component Sub-functions of SAS

There are three sub-functions imbedded in separation assurance: Flight Plan Management (FPM), Conformance Management (CM), and Conflict/Encounter Management (CNM/ENM).

1) Flight Plan Management - FPM provides information about the intended "flight path", and while available before a flight starts, this information is continuously updated and revised during each flight using air/ground communications. There should be agreement at all times between the information existing on the ground and in the cockpit concerning intended flight paths. That information may be incomplete for some future portion of the path (e.g., altitude, ETAs), but it will be mutually understood by the pilot and controller that it will be extended/updated at an appropriate time to cover the future portions of the flight. This updating requires good air-ground communications.

There are meteorological and aircraft state variables that limit the performance of each aircraft in terms of achievable groundspeeds and vertical rates, and these may be unknown to controllers, and uncertain in the minds of pilots and dispatchers. For example, long haul oceanic aircraft may not be able to climb initially to their desired cruising altitude because of their heavy fuel load and air temperatures at cruising altitudes affecting engine performance. While the pilot may have a general idea of where and when he is usually able to climb on this trip, it depends on the diminishing fuel load and the actual temperatures as they are encountered. It is possible to climb to a better cruising altitude earlier in the flight if ATC can accommodate the slower climb rates that result in longer and uncertain times to report being safely established at the new altitude. Otherwise, ATC normally prefers to wait until the step climb can be accomplished promptly and its completion reported promptly. As these uncertainties resolve themselves, better trajectory predictions can be made to improve the flight plan and support SAS.

2) Conformance Management – As described above, CM consists of monitoring the actual progress of all aircraft along their intended trajectories, and resolution, where the controller may intervene from time to time to eliminate any undesirable deviations.

Monitoring is accomplished using surveillance information on the recent position/altitude of each aircraft to compare it with the expected position/altitude at those times. There are conformance limits on the deviations that will be tolerated by a controller. These limits depend on the traffic situation, (e.g., an imminent encounter with another aircraft, an apparent failure to initiate an expected turn or level-off, or an expected change of altitude). As well as the accuracy of the position reported by surveillance, the time between surveillance position reports is important to monitoring. A number of consecutive reports are required to establish that the aircraft is truly deviating from its intended path/altitude, and will not be correcting the deviation on its own. Notice that when CM uses dependent surveillance, where communication of each aircraft's position derived from its onboard navigation systems is substituted for direct and "independent" ground surveillance, an error in navigation data onboard the aircraft denies redundant, independent conformance monitoring – both pilot and controller will think the aircraft is following the intended path/altitude. A second independent source of position/altitude data onboard the aircraft is required to allow the pilot to detect non-conformance. Such second, independent, backup CNS systems are very desirable in ATC to ensure safety. Loran C is being considered currently to provide such backup to GPS. During Oceanic operations, this is accomplished with redundant IRS systems and, recently, GNSS.

Resolution of any altitude/path deviation requires good communications performance since an intervention will be initiated by the controller to advise the pilot of the deviation and suggest a correction. The pilot will not be expecting this communication, and may or may not be aware of the deviation, and may or may not agree that there is a deviation. It may take some longer period of time for the pilot to respond and understand the deviation, and to concur with a suggested resolution, or perhaps try to negotiate another correction, and then to report initiation of the agreed correction. These operational, not technical, time delays, and the reliability and continuity of expected communications needed to carry them out, affect the ability of ATC to introduce reduced separations dependent on real-time intervention and resolution.

Conformance Management of the longitudinal progress along the trajectory is performed quite differently due to continuously varying winds. Progress along the path is monitored and expected times of arrival at varying waypoints are revised on the ground by ATC rather than intervening to change the airspeed (and hence the groundspeed) to try to maintain a desired time of arrival. Where independent surveillance is available, longitudinal conformance can be achieved with no requirement for air/ground communication by revising the future estimated time of arrival on the ground, i.e., the expected future flight path is modified, not the airspeed of the aircraft. With dependent surveillance, there will be frequent communication of the aircraft's position, and also, perhaps, its own estimated times of arrival at the next one or two waypoints, or at additional waypoints as requested by ATC. It may be possible to reduce oceanic separation criteria if such automated capabilities can be reliably introduced. It requires good communications performance – but it need not be voice communication.

Conflict/Encounter Management – CNM/ENM

There is a spectrum of methods that provide separation assurance to aircraft by intervening to modify future flight paths and trajectories. These can be classified as conflict management for longer-term path probes (say 15 to 60 minutes), encounter management for intermediate terms (say 2 to 15 minutes), and collision avoidance for a very short term (less than 2 minutes) response to imminent, unexpected potential collisions. We are interested in the first two classes of methods in examining the possibilities for improving oceanic ATC. We are not limiting ourselves to incremental improvements of existing oceanic SA procedures.

Conflict Management - The first class of methods predates the introduction of radar surveillance to ATC. It does not use surveillance, but depends strongly on communication performance. It must be accompanied by some degree of conformance management. The basic approach is to create and maintain longer term, conflict-free flight plans. It is still in use in oceanic areas, and consists of two sub-processes; conflict monitoring and conflict resolution.

The conflict monitoring sub-process (whether human or automated) examines flight plans for all aircraft when they are introduced and also as they are continuously updated during the flight to detect a "conflict" between any pair of flight plans, i.e., a potential violation of the standards for required separation. Upon detection of a potential conflict, a conflict resolution sub-process then modifies one or both of the flight plans of the conflict pair appropriately to provide the required separation, transmits the desired changes to each pilot at an appropriate time, and awaits a report of their execution. CNM operates closely with conformance management since the update of flight plans and particularly the monitoring of longitudinal progress is a major input to conflict detection.

Encounter Management – The second class of methods are relatively undeveloped at the present time. They use real-time, surveillance information about the current position, ground speed and direction, and vertical rate of each aircraft, plus good knowledge of its near-term planned path. The basic approach is to create and maintain for every aircraft, a set of continuously updated, shorter term (15 minutes or less), 4-D trajectories that are encounter-free. The prime example occurs in "radar control" where flight plans are not modified, but instead, only the immediate trajectory of one or both aircraft is temporarily changed. These methods also have two sub-processes: encounter monitoring and encounter resolution.

The encounter monitoring sub-process creates continuously updated predictions of the probable trajectory of every aircraft for some probe time like the next 15 minutes or less. These 4-D trajectories are then monitored to detect an "intrusion" event where the minimum separation between two trajectories is expected to violate some defined separation criteria. Encounter resolution then modifies either one or both trajectories to eliminate the Intrusion, and then to restore conformance to the original flight plans.

ANALYSIS OF A CONTROLLER'S DECISION TO INTERVENE – EXAMPLE

To illustrate the role of CNS in providing information to controllers when they are providing SA with intervention, consider an example of two aircraft approaching a crossing encounter in mid-ocean at the same altitude. We shall describe the elements of the controller's problem of deciding whether, and when, to intervene.

Although the original flight plans indicated that the aircraft should have sufficient separation at the crossing point, at some large "time-to-passage" the controller monitoring the progress of both aircraft becomes aware that there is some probability of violating the required "separation-at-passage". But because the time-to-passage is large, there is still a high degree of uncertainty in both trajectory predictions and consequently the estimated separation-at-passage. Since the probability of an actual violation is not high at this point, and there is a desire to avoid intervening with an unnecessary change of altitude or direction, the controller may decide to defer the intervention. To defer, the CNS must have a high probability of allowing the controller to intervene later, and also must have good surveillance information over the period of the deferral.

Upon deferral, the controller will decide to improve the quality of conformance monitoring and trajectory prediction by asking (via some communication link) for more frequent position reports. This will reduce the uncertainties in trajectory prediction and improve the estimated separation. The improvement in uncertainty avoids unnecessary interventions, and can also allow the use of smaller crossing separation.

There is a minimum time-to-passage to allow the execution of an intervention. It is determined not by the speed to transmit a message, but rather by the time it takes to gain the pilot's attention, get agreement on the execution of the intervention, and get it completed. The reliability of the communication link and in particular the continuity of maintaining "contact" is also important, but it is swamped by this longer time in setting the "critical time-to-go". If there is any question about maintaining contact, a backup communication system will be required by ATC procedures, but this increases the critical time-to-passage, and thus the crossing separation criteria.

The controller may decide to make the pilots aware of the potential crossing problem at some appropriate time before the critical time-to-passage just to test any voice link, and to improve the alertness and awareness of the pilots. The use of dependent surveillance in reporting aircraft position at specified times inherently provides a frequent test of its data link to the aircraft. Procedures for oceanic SA can be developed to rely on this data link as the primary means of intervening. The simple awareness by pilots of the location and time of a potential upcoming encounter enlists TCAS as a safety backup for such procedures in the event of a sudden and unexpected failure of communications.

It is pertinent to note that the critical case in making the intervention decision occurs when the estimated actual separations have values near the required crossing separation, not when they are near zero. The controller is trying to avoid a "violation" of the crossing separation criteria, not trying to avoid a mid-air collision. If the estimated separations begin to indicate that the actual separation will be near zero, the probability that an intervention will be needed will much higher, and the decision to intervene becomes obvious much earlier. Since we are dealing with a possible violation, not a mid-air collision, if there is a sudden, unexpected failure of communications or surveillance as the critical time-to-passage is approached, it will lead to a violation that still has a very small probability of a mid-air collision, even without the backup of TCAS. It is this rare failure situation that determines the allowable reduction in separation.

It will require further study to develop oceanic SA procedures based on various levels of expected performance of CNS systems in order to perform benefit–cost tradeoffs. But almost any CNS improvement can lead to some degree of ATC improvement. It is a mistake to insist on "gold-plated" requirements for excellent voice and data communications before examining what can be done with lesser performance - and cost - CNS, since such systems might be much more acceptable to aircraft operators and lead to earlier and wider equipage, and thus earlier reductions in separation criteria.

New CNS Capabilities To Improve Oceanic SAS

We now turn to examining characteristics of newer forms of CNS that would be valuable in creating new operating procedures for ATC (and particularly improved separation assurance) for low density traffic areas with a high proportion of level cruising flight such as typically found in oceanic/remote regions, but also at higher flight levels everywhere.

Navigation

We can assume that dual redundant and independent GPS/Galileo navigation systems will become available in all aircraft over the next 15 years. That means that there will be accurate digital data available from every aircraft for determination of position, ground speed, and direction, with global signal coverage and high continuity, reliability, and integrity. It is this digital data that we wish to make available to ATC using a global satellite data communication system to match the characteristics of GPS/Galileo.

It is likely that there will also be an increasing equipage of most aircraft to make digital information available on many more items of flight data, such as next waypoints, airspeed, wind speed, vertical rates, aircraft weight, outside air temperature, guidance mode, etc. This has been called extended or enhanced surveillance.

The ICAO Surveillance and Conflict Resolution Systems Panel (SCRSP) has defined several levels of enhanced surveillance reporting in response to states concerns about altitude violations and the need for conflict detection. For example, the UK has mandated the reporting of selected altitude by Mode S in the 2005-6 time frame; France and Germany are taking similar actions in the future, to insure that flight crews select the correct assigned altitude and to monitor their compliance. It is likely that similar requirements will exist in oceanic and remote areas. However, because of the cost of installing the required systems (usually called FMS on the larger aircraft), we cannot assume a single common type of equipage, nor can we assume that at some future time civil aviation authorities will mandate a minimal performance of such digital flight systems for all aircraft operations in all areas.

Surveillance

Using the onboard position/groundspeed/direction data from each aircraft means that ATC becomes dependent on each aircraft's navigation and data communication capabilities. If we are to rely on this data for separation assurance at reduced separations, then as well as dual independent onboard navigation systems, we also need dual independent onboard data communication systems, and perhaps an alternate means of communication to advise the aircraft that surveillance data is no longer arriving at the ground. These alternate means may also necessary to be able to intervene quickly and reliably to apply larger reversionary separations (e.g., altitude change) to resolve any imminent encounter if both aircraft have lost data contact due to satcom system failure.

The probability of loss of continuity (i.e., loss of data over the next period of time given that it is working now) must be kept small, especially as ATC separations become smaller, and consequently ATC intervention times must get smaller. ATC procedures for handling an encounter will confirm communication contact with both aircraft at some point before passage, and it is desirable that the probability of losing contact between that point and commitment to passage at reduced separation be very small.

Communication

The following briefly summarizes desirable characteristics of a new satellite-based oceanic communication system

1) Efficiently handle frequent transmission of short position data messages from multiple aircraft to one or more ground facilities.

2) Capability of the ground to vary the reporting intervals of the short position messages for each airborne aircraft, i.e., re-arrange contracts for position reporting as a function of the traffic situation.

3) Availability of reliable longer-message data links between controller/pilot for requesting revisions of trajectories and flight plans (due to weather or desired altitude change), accepting revisions, confirming completion of a revision, transmitting weather and traffic advisories by the controller, performing handoffs of each aircraft to the next oceanic facility, and announcing emergencies (e.g., engine failures or loss of pressurization that require rapid and unexpected descents, or cargo fires or passenger sickness requiring diversion to nearest airport

4) Provision of independent, backup voice or data communication in case of failure of the primary data link.

With the exception of (1), these capabilities are all provided by FANS-1/A; FANS-1/A is not efficient (in terms of channel usage) in transmitting short data messages such as position reports.

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IV - Communication Requirements to Support Oceanic Weather Data Exchange

Flights in oceanic and remote areas must contend with the risks of bad weather and volcanic dust. Accordingly, the FAA Aviation Weather Research Program has formed an Oceanic Weather Product Development Team (OWPDT). The OWPDT is tasked to develop near-term, 0-6 hour forecasts of convection, turbulence, high-resolution winds, volcanic ash, and in-flight icing, and to develop data dissemination methods.

A major challenge to this effort is the lack of meteorological data in oceanic and remote areas. Presently meteorological data is sent each 15 minutes from equipped aircraft, but there is interest in higher update rates. The OWPDT is addressing this issue, by seeking additional data and by developing better methods to use existing data to provide more accurate and timely forecasts. As the value of additional data is understood, it is likely that additional communications bandwidth will be sought to enable this capability. This relatively modest need should be accounted for as improved oceanic and remote communications links are developed.

In considering the potential burden of weather reporting on a future oceanic/remote area data link, the Tropospheric Airborne Meteorological Data Reporting (system), TAMDAR, being developed by the NASA Aviation Safety Program, may be a useful design example[9]. TAMDAR is addressing the current lack of atmospheric data in the lower atmosphere. It will sense and report moisture, temperature, winds, turbulence, and ice for use by forecast modelers, weather breifers, controllers, and other aircraft

The TAMDAR 250 bit message consists of the 208 data bits shown in Table 2 below, plus a 20% overhead added to account for framing, error detection, and reserve. NASA has estimated the frequency of message transmissions for TAMDAR, using DO-237, which provides different rates of transmission for different phases of flight. The lower portion of the atmosphere is of greatest interest, requiring more frequent transmissions for flights in that domain.

[9] TAMDAR information received from Tom Tanger, courtesy of Konstantinos Martzaklis at NASA Glen Research Center, via email on 26 August 2003.

Table 2. TAMDAR Data Message

Element	Bits
I.D.	16
A/C Type	8
Date/Time	
Date	16
Time	20
Location	
Latitude	20
Longitude	20
Pressure Altitude	16
Weather Elements	
Wind	
Speed	8
Direction	8
Temperature	12
Moisture	
Humidity	8
Water Vapor Mixing Ratio	8
Peak Liquid Water Content	8
Average Liquid Water Content	8
Super Cooled Large Droplet	4
Turbulence	
Average	8
Peak	8
Icing	4
Roll Angle	4
Phase of Flight	4
Total	208

The proposed message transmission rates are as follows:

Takeoff and landing	1 report per 6 seconds
Climb and descent	1 report per 20 seconds
Cruise	1 report per 15 minutes

NASA also states that the maximum latency for these transmissions should be less than 1 minute, where latency is defined as the time from message creation at the source until receipt at the destination.

As the FAA oceanic research activity advances its understanding of weather in the oceanic domain, and TAMDAR is field tested, these proposed requirements will be refined. Additionally, trade studies will be conducted to determine the how safety and efficiency are improved through better oceanic meteorological sensing and forecasting. In any case, it is clear that oceanic and remote area operations will need to consider metrological data reporting in the coming years.

V - Oceanic Communication Alternatives
Present and (Near) Future

HF Voice

Single-sideband voice communication operating in the high frequency band (3 – 30 MHz) is the primary means of communication for aircraft operating beyond line-of-sight of VHF ground facilities. The performance capability of HF voice communication is a primary limiting factor in oceanic procedures and separation standards.

In most oceanic airspace HF voice communication is not directly between pilot and controller; rather it is between the pilot and a radio operator of a communication service provider (ARINC, SITA). The radio operator in turn relays the content of the communication to/from the controller, generally as a text message.

Except for some hardware improvements, this is basically the same technology/system used for long-range communication since the 1940's. The major change has been the switch from Morse code to voice, with the concomitant elimination of an aircraft radio operator, and the later change from DSB (double-sideband) to SSB (single-sideband) modulation.

HF voice communication is subject to disruption by interference and ionospheric disturbances. Both effects can reduce intelligibility or completely preclude communication. Therefore oceanic procedures and separation standards have been designed to accommodate long periods of communication outage (possibly as long as the entire beyond line-of-sight part of the flight) without compromising safety.

Typically aircraft report position roughly every hour or 10 degrees of longitude on North Atlantic tracks. The length of time it takes to make a report, especially under degraded communication conditions, limits the number of aircraft which can be accommodated on the available frequencies

HF Data Link

The use of digital communication on HF overcomes many of the problems of HF voice, while retaining its long-range, over-the-horizon capability. As part of its GLOBALink service, ARINC provides HFDL air-ground service from a worldwide network of 13 ground stations (with one more planned). To make use of this service, the aircraft must be fitted with a data-link-capable HF radio. Most modern HF aircraft radios have this capability built-in. Many older radios can be retrofit. For aircraft already fitted with HF radios (required for all aircraft used on oceanic routes), the addition of HFDL capability is significantly less expensive than installing current satellite communications systems.

Although data transmission on HF frequencies has a long history (the earliest HF communication using Morse code was a form of data link, and the military services developed and tested sophisticated HFDL systems in the 1950's), modern HFDL for civil aviation is a recently introduced and still evolving service.

As of the beginning of 2003, more than 300 aircraft were HFDL-equipped, with that number increasing by approximately 8 per month

HFDL message traffic has grown from approximately 50K messages per month at the beginning of 2000 to over 300K messages per month in December 2002.

Overall message success rate has increased to over 97%

On the North Atlantic, 95% of position reports were received in 2 minutes or less (the goal was 95% in 5 minutes or less)

For aircraft equipped with SATCOM data link, HFDL is a useful backup in the event of a SATCOM outage. For other aircraft, especially cargo and military, it is a relatively low-cost means of providing long range, over-the-horizon data communication. However, HFDL is currently certified only for AOC communications, not for ATC. It has not yet been established whether HFDL alone can meet the communication requirements to support 30/30 oceanic separation.

INMARSAT

INMARSAT was formed as a maritime-focused intergovernmental organization over 20 years ago. It has been a limited company since 1999, serving a broad range of markets. Starting with a user base of 900 ships in the early 1980s, it now supports links for phone, fax and data communications at up to 64kbit/s to more than 250,000 ship, vehicle, aircraft and portable terminals. That number is growing at several thousand a month.

INMARSAT operates a constellation of geostationary satellites designed to extend phone, fax and data communications all over the world. The constellation comprises five third-generation satellites backed up by four earlier spacecraft[10]. INMARSAT also operates a worldwide network of ground stations to deliver its services.

The overall architecture of the INMARSAT system, as seen by the user, is shown in Figure 3..

The satellites are controlled from the Satellite Control Centre (SCC) at the INMARSAT HQ in London. The control teams there are responsible for keeping the satellites in position above the Equator, and for ensuring that the onboard systems are fully functional at all times. Data on the status of the nine INMARSAT satellites is supplied to the SCC by four tracking, telemetry and control (TT&C) stations located at Fucino, Italy; Beijing in China; Lake Cowichan, western Canada; and Pennant Point, eastern Canada. There is also a back-up station at Eik in Norway.

The flow of communications traffic through the INMARSAT network is monitored and managed by the Network Operations Centre (NOC) at INMARSAT HQ. The NOC is supported by network co-ordination stations (NCSs). Their primary role is to help set up

[10] www.INMARSAT.com

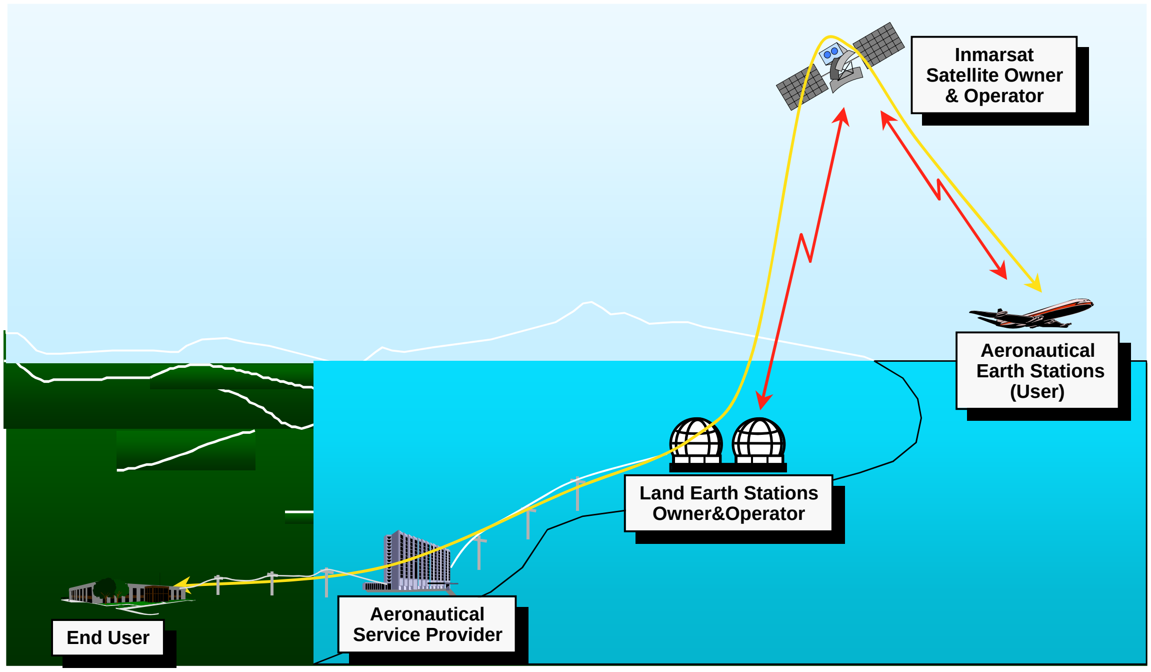


Figure 3. INMARSAT System Architecture

each call by assigning a channel to the Aeronautical Earth Station (AES) and the appropriate Land Earth Station (LES). There is one NCS for each ocean region and for each INMARSAT system (INMARSAT A, B, C, etc). Each NCS communicates with all the land earth station operators in its ocean region, the other NCS and the NOC, making it possible to distribute operational information throughout the system.

Traffic from a user terminal passes via a satellite and then down to a land earth station (LES), which acts as a gateway into the terrestrial telecom networks and to applications providers. There are about 40 LESs, located in 30 countries. The LESs are owned and operated by LES Operators (LESOs), who contract with INMARSAT to provide the transmission capabilities. Eight of the LESs are equipped to support the current aeronautical services offered by INMARSAT.

The aeronautical service provider (e.g., ARINC, SITA) contracts with the LES Operators for transmission access, and to provide transmission services out to the end users.

The data and voice communications architecture for the INMARSAT system is shown in Figure 4..

INMARSAT aeronautical services require one of six available airborne terminal configurations (known as Aeronautical or Aircraft Earth Stations (AESs)) to be installed in the aircraft. These configurations currently provide different maximum data rates under different coverage areas, as summarized in Table 3.

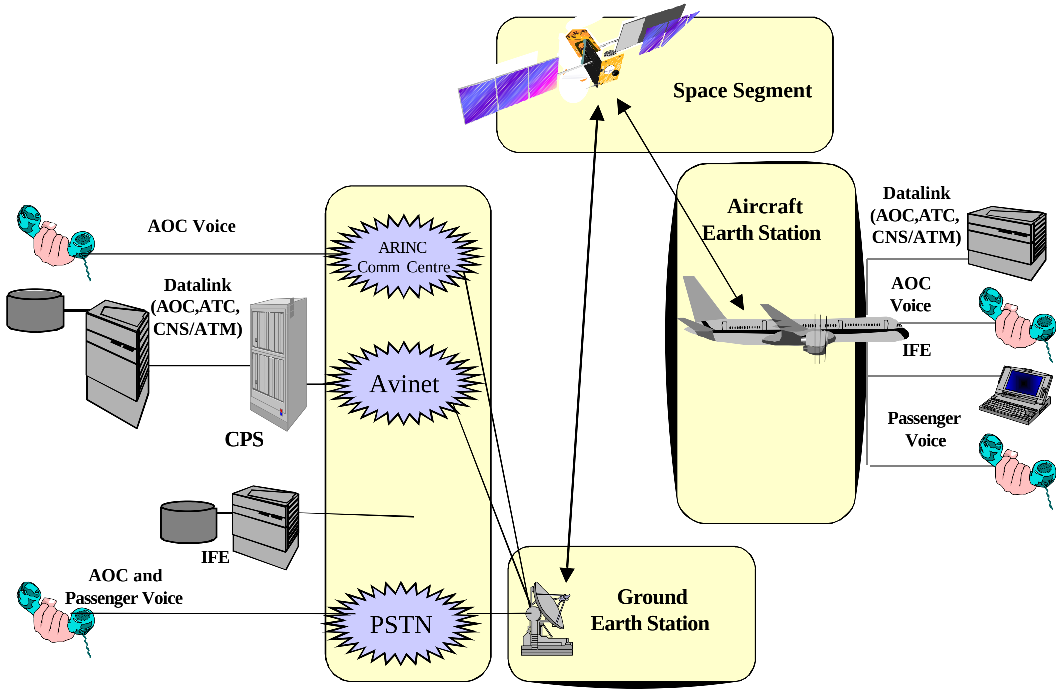


Figure 4. General User Communications Architecture of INMARSAT

Terminal/Service	Aero H	Aero H+	Aero I	Aero L	Aero M	Aero C
General Description	Global Beam Voice & Data	Global & Spot Beam Voice & Data	Spot beam voice. Global Beam data.	Packet Mode Data	Spot Beam Voice & Data	Store & Forward Packet Mode
Global Beam						
Voice (bps)	9600	9600				
Packet Data (bps)	Š 10,500	Š 10,500	Š 4800	600/1200		600
Circuit Data (bps)	4800/9600	4800/9600	2400/4800			
Spot Beam						
Voice (bps)		4800	4800		4800	
Packet Data (bps)		Š 10500				
Circuit Data (bps)		4800/9600			2400/4800	
High Speed Data (kbps)	64/128	64/128				
Channels	1 to 11	1 to 11	1 to 7	1	1	1
Services						
ICAO SARPS Safety	Yes	Yes	Yes	Yes	No	No
Passenger	Yes	Yes	Yes	No	Yes	No
Antenna						
Gain	12 dBiC	12 dBiC	6 dBiC	0 dBiC	6 dBiC	0 dBiC
Typical Size (inches)	18x18x8	18x18x8	18x9x8	10x8x5	18x9x8	10x8x5
Weight (typ) with Antenna	220 lbs	220 lbs	40 lbs	11 lbs	20 lbs	11 lbs

Table 3. INMARSAT Aeronautical Terminals/Services

The associated coverages, determined by the satellite resources and the installed GES equipment, are shown in Figure 5.

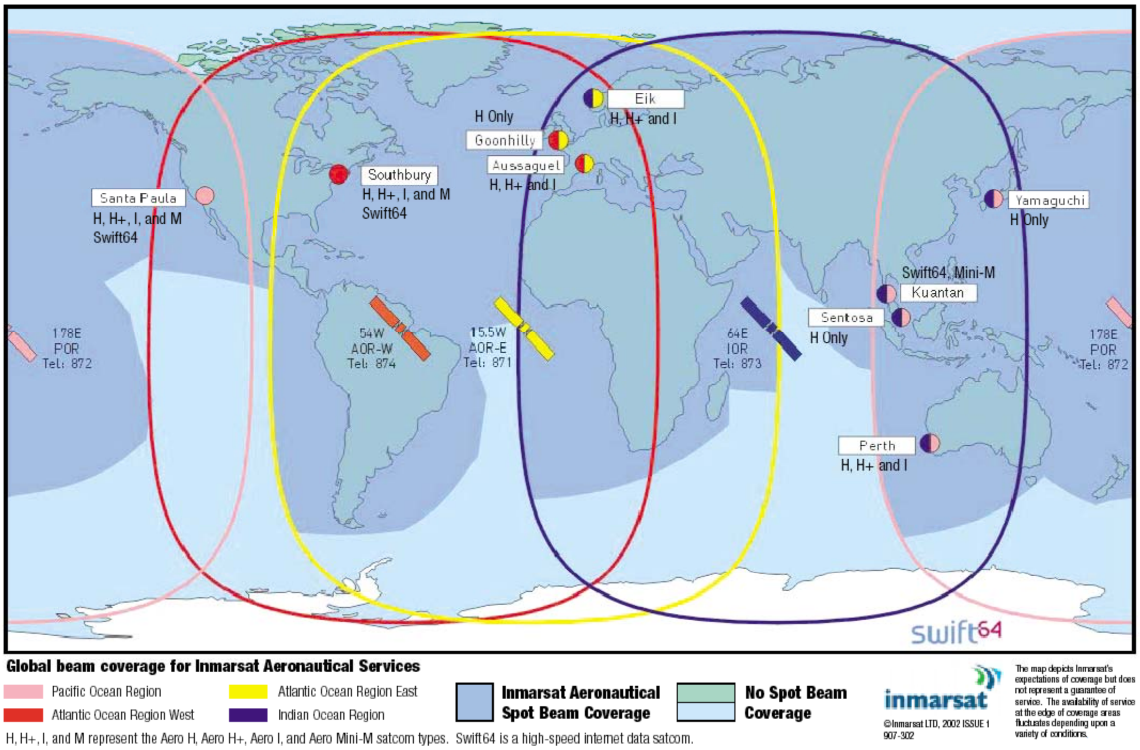


Figure 5. INMARSAT Coverage Areas for Aeronautical Services

The Aeronautical Services include:

- Aero C - store and forward packets worldwide
- Aero H/H+ - up to 10 kbps in Global Beam, requires 12 dB G_{ant}
- Aero I[11] - up to 4.8 kbps in Global Beam, requires 6 dB G_{ant}
- Aero L[12] - 600bps/1200bps Airline ATC
- Aero Mini-M - upgradeable to Aero I
- Aero HSD – up to 128 kbps under spot beams

The next generation of satellites, known as INMARSAT-4, will expand the High Speed Data (HDS) to global beam coverage, and enable data rates greater than the 64/128 kbps in the spot beams. The INMARSAT-4 satellites are scheduled to enter service in 2005.

The estimated equipage for 2004 is:

- 1700 airliners
- 1200 corporate and government aircraft
- 1200 helicopters and military transports (Aero-C)

[11] Complies with SARPS for AMSS, can be used as part of CNS/ATM
[12] Complies with SARPS for AMSS, can be used as part of CNS/ATM

The underlying access of the satellite channel is by demand assignment. That is, an AES sends a request for service to the NCS via the associated LES in a random access channel, and a TDMA slot assignment for subsequent communications is provided back to the requesting LES. This general service paradigm is analogous to circuit switching in the Plain Old Telephone System. Digital voice and data can be transmitted over the assigned channel(s). Short data messages can be sent in the random access channel. This set of protocols is well suited to low-density traffic such as individual telephone-like calls, but is not efficient for large numbers of users such as aeronautical who need to communicate with the same ground node.

The satellite link supports several types of channels:

> **P-channel:** A Packet-mode time division multiplex (TDM) channel, used in the forward direction (ground-to-air) to carry signaling and packet-mode data. The transmission is continuous from each GES in the satellite network. A P-channel being used for System Management functions is designated Psmc, while a P-channel being used for other functions is designated Pd. The functional designations Psmc and Pd do not necessarily apply to separate physical channels.
>
> **R-channel:** A Random access (slotted Aloha) channel, used in the return direction (aircraft-to-ground) to carry signaling and packet-mode data, specifically the initial signals of a transaction, typically request signals. An R-channel being used for System Management functions is designated Rsmc, while an R-channel being used for other functions is designated Rd. The functional designations Rsmc and Rd do not necessarily apply to separate physical channels.
>
> **T-channel:** A Reservation Time Division Multiple Access (TDMA) channel, used in the return direction only. The receiving GES reserves time slots for transmissions requested by AESs, according to length. The sending AES transmits the messages in the reserved time slots according to priority.
>
> **C-channel:** A Circuit-mode single channel per carrier (SCPC) channel, used in both forward and return directions to carry digital voice or data/facsimile traffic. The use of the channel is controlled by assignment and release signaling at the start and end of each call.

The modulation for the 600 bps to 2400bps modes is A-BPSK, a form of BPSK with particular pulse shaping for spectral containment. The modulation for rates above 2400 bps is A-QPSK, a form of QPSK with particular pulse shaping for spectral containment. Offset QPSK is used for some of the higher rates. Interleaving and standard convolutional coding with Viterbi decoding is specified for the P and R channels described above.

The aeronautical services provide relatively little revenue to INMARSAT: $12M out of total revenue of $442M in 2001[13]. INMARSAT does not anticipate saturation of the aeronautical capability for the foreseeable future. As capacity demand increases, the NCS just assigns more channels until the total system begins to saturate. The market is so small that negligible investment in increased capability is anticipated in the near term.

[13] INMARSAT Annual Report for 2001.

The Defense Information Services Agency[14] has entered into a series of contracts for INMARSAT services that could extend until 2012. Under that set of bulk contracts, budgetary pricing for some services is given in Table 4.

Service		Cost	Units
Inmarsat C			
	X.25, Polled, FAX, Telex	$0.13 to $0.30	per 256 bits
	Small Data Report	$0.03	up to 8 bytes
	Medium Data Report	$0.06	up to 20 bytes
	Large Data Report	$0.09	up to 32 bytes
Aero H+, Aero I			
	AES <-> AES	$10.26	per minute
	AES -> PSTN	$5.39	per minute
	PSTN -> AES	$7.35	per minute
Bandwidth Lease			
	100 kHz	$29,692	per month

Table 4. Budgetary Pricing for INMARSAT Services under DISA Contract

From a continuing cost standpoint, usually the most economic way to utilize a satellite repeater is to lease the bandwidth (and power) over the desired coverage area, and to lease space in the associated GES to provide tailored processing. In the specific case of INMARSAT, suppose only 100 kHz were leased, and the bandwidth were utilized only 8 hours/day. With a total of 14,400 minutes in a 30-day month, the cost of the lease averaged over the 8 hours/day would be under $2/minute. While this is not a design, it seems likely that the 100 kHz bandwidth would provide more than enough capacity for Oceanic CNS.

FANS

History of FANS and FMS Development

The Future Air Navigation System (FANS) Study conducted by ICAO during the 1980's focused on the possible use of satellites for global air navigation/ATC. As the FANS concept was further developed for new forms of management of ATC, it became known as CNS/ATM (Communication, Navigation, and Surveillance/Air Traffic Management). There is now an ICAO Global Plan for ATM Development based on CNS/ATM that contains a Global Concept for Future ATM.

Boeing and Honeywell, hoping to stimulate the introduction of FANS and CNS/ATM, committed to introducing a first version of the necessary aircraft equipment (called FANS-1) for the new B747-400, and certified it in 1995. A similar FANS-1 system, with a different pilot interface, has been built later for the B-777, and another version is apparently available for the Boeing Business Jet (BBJ). Airbus started a similar project that was initially called AIM-FANS (Airbus Interoperable Modular-FANS, but shortened

[14] http://www.disa.mil/acq/contracts/INMARSAT/contract/pdf/INMARSAT_pricing.pdf

to FANS-A in its first implementation) that provided equipment that became available after 1997 for the later production of the Airbus 330/340 fleets. Approximately 1500 aircraft have these two initial versions of FANS equipment, but very few of other aircraft currently used on oceanic routes have been retrofitted (e.g., DC-10, MD-11, older B-747, B-767, B757, B-737Adv, older A300/340)

Because of the uncertainties in adopting a new global system for ATM, both these initial versions claim to have been designed in a modular fashion as the first steps of an evolution towards the ultimate CNS/ATM system, particularly with regard to accommodating various future forms of data link communication. That explains the original descriptive name given by Airbus to emphasize its interoperability and modularity. They can accommodate any form of future satcom or data link. There will be many future implementations of FMS equipment for all types of aircraft, and hopefully most will be based on newer and cheaper forms of satellite data link.

Today, other manufacturers of FMS systems for business aviation and other aircraft, such as Canadian Marconi, Universal Avionics, and Rockwell Collins are capable of modifying their installed (and new installations) of their FMS on various different aircraft to provide some (or all) of the CNS/ATM functionalities. They need sufficient demand from prospective and current customers to commit to certification costs. Canadian Marconi is teaming with Boeing to retrofit the older B-747s of Japan Airlines. The USAF is considering modifying the current FMS to retrofit some of its fleets (e.g., KC-10, C-17, C-5, and perhaps the leased tanker versions of B-767) to gain certain CNS/ATM functions.

CNS/ATM Functions for the FMS

FMS is the name used for a digital flight management system that automates and integrates some of the various cockpit functions involved in managing the flight operation of a modern aircraft in an air traffic environment. The CNS/ATM functions it handles can be organized as: 1) navigation management; 2) guidance; 3) flight control; 4) flight planning/aircraft performance; 5) dependent surveillance management; and 6) communications management. These functions will be briefly described below to provide an idea of what the current FANS implementations can do, but also what might be done in the future. As yet, there is no requirement that some of the CNS/ATM functions be implemented to fly in any airspace, but there have been some introduction of use of the initial versions of FANS for Oceanic ATM in very low traffic density areas.

1. Navigation Management

    The FMS provides optimal area navigation (RNAV) by selective use of the multiple redundant navigation sensors available onboard the aircraft (e.g., INS, GPS, and in the future - Galileo, WAAS, LAAS, and perhaps even Loran-C if it is adopted as the backup for GPS). It estimates and monitors the continuous operation and accuracy of each of the various navigation systems onboard the aircraft during the flight, and provides an ongoing assessment of the aircraft's actual overall navigation performance. If a value is inserted into the FMS for Required Navigation Performance (RNP), it will provide alerts to the pilots if the current aircraft navigation performance falls below the desired value.

2. Guidance

The FMS is a full digital autopilot capable of automatically flying and maintaining vertical and lateral conformance to any flight-planned route (or ATC clearance). The route is usually described by a series of waypoints with desired altitudes. It can monitor its own conformance to this inserted flight plan with automatic alerts of non-conformance to the pilots for either lateral or vertical deviations beyond some specified value. Some FMS installations provide RTA (Required Time of Arrival) capability, changing the airspeed as winds vary, to maintain groundspeed and try to arrive at some future waypoint at a desired time. It will then provide alerts to the pilots if the aircraft is not going to be capable of conforming to this RTA due to airspeed limitations of the aircraft.

There should be a means for ATC to check that the flight plan (or ATC clearance) that the aircraft's Guidance function is currently using to maintain conformance is identical to that currently being used by ATC. FANS originally specified data link waypoint reports that provide next (and next+1) waypoints from the FMS. If there is not agreement, then ATC needs time to communicate and confirm a mutual understanding of the intended flight path. If the Guidance function is working correctly, it is difficult to see why there should be any deviation unless the pilots have accidentally or deliberately disengaged it for a temporary deviation from the intended path.

3. Flight Control

The FMS is a digital autopilot capable of smooth, stable automatic maneuvering required to capture and maintain the dynamic values of heading, or track over the ground, or altitude that are specified by the Guidance function. It is this function that makes the FMS software "flight critical" in safety certification terms, and seems to cause the expensive need that FMS software, and any changes, be fully tested for correct and reliable operation. It should be possible to create modular FMS software and/or separate hardware to isolate the inevitable evolutionary changes in non-flight critical functions of the FMS after it is installed, and thereby avoid rigorous re-certification for every minor revision of FMS software as it evolves.

4. Flight Planning/Aircraft Performance

Given information about future winds and temperatures at various altitudes, and knowing the current aircraft weight as fuel burn makes it lighter, and using a idealized model of aircraft and engine performance, the FMS can provide the pilots with a variety of estimates for current and future aircraft performance that may enable onboard flight planning in the event of an emergency diversion. For example, it can estimate desired future or current en route speeds and altitudes for best time and fuel burn, current and future altitude and airspeed capabilities (with an engine failure), time required to climb to some altitude, the future position of Top of Climb and Top of Descent, landing and takeoff airspeeds and distances, onboard fuel at arrival, landing weight, etc. If good digital communications exist with the current ATC facility, the pilots may create a new flight plan and send it as a request to ATC directly from the FMS.

If there is also good data link communication with the AOC (Airline Operations Center, or a commercial Flight Planning Service used by other oceanic traffic), a dispatcher may initiate and perform this re-planning and can send one or more flight plans (named as A, B, C, etc.) in digital form directly to the FMS. Upon acceptance of one new plan by the pilots (digital or voice), the pilot or dispatcher may then send the requested new flight plan directly to the appropriate ATC facility. If it is not acceptable to ATC because of other traffic, the dispatcher may negotiate directly with ATC to find the best acceptable flight plan, and then send this negotiated plan to the FMS for pilot concurrence. Remember that there may be more than one ATC facility interested in the revision to the flight plan. It may take some while to negotiate, and a good communication link between ATC facilities on different continents may also be necessary to gain acceptance of the proposed revision. AIDC (Automatic Inter-facility Data link Communications) may be available in the future to speed up this negotiation across oceans and between countries. The pilots may prefer to negotiate their own updated flight plan if they have satellite data links with pertinent ATC facilities, especially if ATC has current reports of turbulence at various altitudes along the route.

There will be various forms of this dynamic re-planning in the future as good oceanic data links and AIDC become available. The current example is DARP (Dynamic Airborne Reroute Procedure) by the Oakland Oceanic Center on the South Pacific routes where given new weather and their calculation of better routes (using their model of B747-400 performance and their definition of "better"). If there is a significant improvement, Oakland facility informs (or initiates negotiations) with other Oceanic facilities, and then updates the South Pacific track system for all B747-400 aircraft, including those already airborne via data link. A second proposal under study by Oakland is called DUPR (Dynamic User-Preferred Rerouting) where each airline's dispatcher calculates a revised flight plan and initiates negotiations with ATC to gain its acceptance in competition with other revisions (either already submitted or about to be re-submitted). It will not be easy to find a larger set of compatible revisions for oceanic areas when there is a higher traffic density and a variety of different types of aircraft requesting changes. It requires good data communications to gain the benefits of dynamic re-planning of flights.

5. Dependent Surveillance Management

Since the FMS has digital information at all times about the current and intended positions of the aircraft, it plays a key role in providing Automatic Dependent Surveillance (ADS). The FANS Study called for ATC controllers, using their automation and the aircraft's FMS, to be able to establish and modify Periodic, Event-based, and On-Demand Contracts for position reporting with aircraft. Periodic reports confirm that data link communication is being maintained as well as monitoring longitudinal progress. Event reports provide a timely alert to ATC that certain events have now occurred (e.g., a waypoint or crossing point has been reached, or a non-conformance has occurred), and may also provide a check on the current value of the next two intended waypoints. On-Demand reports will be needed when unexpected non-conformance events are occurring in the area, or revised flight plans have been requested. These ADS contracts are automatically managed by the FMS with oversight and agreement of pilots and controllers.

There may be a coordinated contract to report simultaneously certain weather data to support and improve weather forecasting and planning activities of ATC and AOCs. They create a random occurrence of short data messages from many aircraft to one (or more) ATC/AOC facilities. There is a growing set of developments by the GPS industry for the "tracking" of terrestrial vehicles using satellite data communications.

6. Communication Management

Modern aircraft now have a number of ways to communicate by voice (VHF, UHF, SATCOM, HF), and all aircraft will be adopting data link or CPDL in future years using different media (SATCOM, HFDL, Mode S, VDL-X, ATN). The FMS usually provides some degree of Communications Management (isolated to some degree from the flight-critical FMS functions) for these various means of communication, particularly for data messages that need integration with the FMS and should have similarity in their handling/management by pilots that is independent of the media used for communication.

Summary

The current implementations of FANS (FANS-1, FANS-A) have adopted INMARSAT Service H since it was available at the time and simultaneously provided voice, fax, and data communications to meet the needs of both passengers and AOCs. This multiple requirement led to the use of steerable satellite antennas with their large size and expensive installation, and costly message fees (e.g., $7.50/minute). To get FANS working in the 1995 period, the existing ACARS ground network was used as the ground link, necessitating in an inefficient conversion of bit-oriented messages to allow their transmission over the ACARS character-oriented format. This was considered an interim implementation since it was expected that ATN and other aviation data link media would eventually appear to allow more efficient communications. This evolution has been delayed, and FANS continues to use this "temporary" system.

FANS is the only existing system that meets the oceanic system requirements for ADS and CPDLC. However, installation and operating costs, and the physical size of the antenna system, limit the class of aircraft on which FANS can be used. This in turn will limit access to airspace in which these capabilities are required. We encourage the FAA and the aviation industry to build on the operationally useful portions of FANS, and develop a newer-technology, less expensive implementation in order to encourage increased equipage and open the airspace to all users.

Enhanced TDMA over INMARSAT

As noted above, the set of TDMA protocols used in INMARSAT is well suited to low density traffic such as individual telephone-like calls, but is not efficient for large numbers of users who need to communicate with the same ground node. The amount of satellite transponder power and bandwidth utilized for a given service strongly drives the cost of INMARSAT transmission. Thus, more efficient use of the satellite transponder bandwidth and power has the potential to reduce the cost of a service.

In a previous study[15], representative cost for reporting a 150-bit aircraft position report message every 30 seconds using offered services (and the existing protocols) was estimated to be $45 for a 5-hour flight based on $0.50/kbit service charge. Supporting 500 such aircraft over a single 100 kHz leased INMARSAT channel could be done with a more efficient slotted TDMA scheme. Leasing the channel at $30k/month (based on the DISA lease rates given above) would cost an average $2 per aircraft per day. Total service costs might be twice this. In any event, the potential economic advantage for using an efficient TDMA protocol is substantial and worth further investigation.

Iridium[16]

The Iridium System is a satellite-based, wireless communications network providing a robust suite of voice and data services to virtually any destination anywhere on earth. The Iridium system comprises three principal components: the satellite network, the ground network and the Iridium subscriber products including phones and pagers. The design of the Iridium network allows voice and data to be routed virtually anywhere in the world. Calls are relayed from one satellite to another until they reach the satellite above the Iridium Subscriber Unit and the signal is relayed back to Earth.

The on-orbit Iridium constellation consists of 66 operational satellites and 14 spares in a constellation of six polar planes. Each plane has 11 mission satellites performing as nodes in the telephony network. The 14 additional satellites orbit as spares ready to replace any unserviceable satellite. This constellation ensures that every region on the globe is covered by at least one satellite at all times. The satellites are in a near-polar orbit at an altitude of 485 miles (780 km). They circle the earth once every 100 minutes traveling at a rate of 16,832 miles per hour. Each satellite is cross-linked to four other satellites; two satellites in the same orbital plane and two in an adjacent plane. The satellite constellation is expected to provide continuous global coverage until 2014.

The ground network is comprised of the System Control Segment and gateways used to connect into the terrestrial voice and data networks. The System Control Segment is the central management for the Iridium system. It provides global operational support and control services for the satellite constellation and delivers satellite-tracking data to the

[15] Goblick, "Advanced Satellite Communication Technology for Oceanic Air Traffic Control," MIT Lincoln Laboratory Advanced Concepts Committee Project #262 Final Report, September 1998

[16] Adapted from: www.iridium.com

gateways. The System Control Segment consists of three main components: Four Telemetry Tracking and Control sites, the Operational Support Network, and the Satellite Network Operation Center. The primary linkage between the System Control Segment, the satellites, and the gateways is via K-Band feeder links and cross-links throughout the satellite constellation.

Gateways are the terrestrial infrastructure that provides interconnection to the terrestrial voice and data networks. Gateways also provide network management functions for their own network elements and links.

The Iridium system was designed to provide cellular-like voice services anywhere on earth. The common subscriber equipment is a cellphone-like handset with a data port, available for around $1400 retail[17]. Calls are set up very much like a cellphone: dialing a number results in a transmission to the cognizant gateway (generally via crosslink) requesting a channel. The gateway assigns the channel and sets up the communications path, and manages handovers among satellites as individual satellites rise and set. (Individual satellites will only remain within view of a given location for less than 15 minutes.)

In December 2000, Iridium Satellite LLC acquired the operating assets of Iridium LLC including the satellite constellation, the terrestrial network, and Iridium real property and intellectual capital. Headed by aviation industry veteran Dan Colussy, and funded by a group of private investors, Iridium Satellite LLC has essentially no debt and monthly operating charges that are one-tenth the cost of the previous Iridium. Through its own gateway in Hawaii, the U.S. Department of Defense (DoD) utilizes Iridium for global communications capabilities. Services to other U.S. government entities are available through the DoD contract.

Iridium Satellite began service to the U.S. Government in December 2000. On March 28, 2001, commercial satellite communications services were launched to heavy industry and other government customers. The marketing strategy is to focus on industrial clients whose operations require reliable communications to and from remote areas of the globe where terrestrial systems are not available. Specifically, the company will pursue industrial segments including aviation, maritime, oil & gas, mining, heavy construction, forestry, emergency services, and the leisure market.

Iridium Satellite has contracted with the Boeing Company to operate and maintain the satellite constellation, and Motorola has agreed to provide subscriber equipment.

At the 2003 Paris Air Show, Iridium announced four new aviation-based efforts firmly establishing Iridium's ever-growing reach into the aviation sector. Those announcements included; a contract to supply Iridium communications on the Federal Aviation Administration's fleet of aircraft; a contract with the U.S. State Department to equip an initial 80 aircraft in support of drug enforcement programs in South America; a contract with the U.S. Department of Agriculture, Forest Services to provide tracking capabilities for their large fleet of aircraft and ground support equipment for mission support of Wild land Fire Suppression and an additional announcement of Iridium communication

[17] Web posting by SatPhoneStore at http://www.satphonestore.com/servprod/iridium/AirTime.htm

services being utilized by the Russian space firm, Space Flight Operations Company to provide ground, recovery aircraft and spacecraft communications. Iridium is currently working on trial applications with several commercial airlines and foresees a strong continual growth for its voice and data capabilities within this industry.

The projected lifetime of the satellites has been evaluated based on on-orbit experience, and the initial constellation is estimated to provide service into 2014. Nonetheless, the bankruptcy of the original Iridium naturally raises questions about the long-term economic viability of Iridium Satellite LLC. The DoD contract, at $36M/year for up to 20,000 users, provides a substantial initial business base. The new Iridium, unlike the original one that needed 1 million subscribers to break even, only needs 60,000 subscribers to cover costs[18]. However, Iridium will need a larger business base to finance a follow-on generation of satellites. Assuming a seven-year lead-time for the next generation, Iridium has until about 2007 to achieve the larger business base.

General Dynamics is presently developing a method to support a "party-line" permitting multiple voice users to share a single channel. This system is to be demonstrated in 2004 for the USMC, where all the terminals are within the order of 100 miles of one another. General Dynamics suggested that this Netted Voice method might be extended to provide Aviation Netted Voice. The estimated capacity, assuming each aircraft generates 3 voice messages of 10 seconds duration, and 5 data messages of 100 bytes each, every hour, is about 120 aircraft per Iridium channel with 40% loading.

In addition to voice services, Iridium has developed a large number of data services[19] with different characteristics, as summarized in Table 5. Also, Iridium developed and has made available a data transceiver for embedding into applications. The Motorola Satellite Series 9522 L-Band Transceiver (LBT) is intended for incorporation into an data solution

or product. The LBT is simply the core modem that is required in order to communicate over the Iridium network. Additional components are required such as power supply, antenna, environmental protection and the serial based interface between the LBT and the customer's application. At least AirCell, Blue Sky, Honeywell and Icarus are offering Iridium Terminals to the aviation community. For example, the Icarus Satphone II recently listed at $4495.[20]

Of the available Iridium data services, the Short Burst Data (SBD) Service and Short Messaging Service (SMS) seem of most interest for Oceanic CNS.

Iridium Short Burst Data (SBD) Service

Iridium Short Burst Data (SBD) Service is an efficient network protocol designed for shorter sized data messages than can be economically sent via Iridium Circuit Switched Data Services. SBD uses a proprietary network protocol to transfer data messages to and

[18] Quote attributed to Dan Colussy in 2001, see: http://uk.gsmbox.com/news/mobile_news/all/35771.gsmbox
[19] Iridium Satellite Data Services White Paper, Version 1.0, June 2nd, 2003.
[20] E.g., see SatPhoneStore web site at http://www.satphonestore.com

from the remote terminal. Example applications include flight following for aircraft and helicopters.

It is possible to originate and receive messages at the subscriber terminal. Message size for inbound SBD messages from the subscriber is between 1 and 1960 bytes. (0 byte messages are referred to as "mailbox checks.") Message size for outbound messages to the subscriber is between 1 and 1890 bytes. All messages are acknowledged.

The target vertical markets for SBD are Oil, Gas, Rail, Maritime, Aeronautical, and Utility industries as well as applications in the Government and Military sectors. Iridium itself does not provide complete end-to end solutions. However, it looks to selectively partner with skilled Value Added Resellers (VARs) to integrate the required hardware, software, and SBD service that ultimately forms the complete packaged solution for the end customer.

Service Name	Typical Use	Transfer Type
Direct Internet	Remote access to Internet based personal email service using a Windows based computer	Human to Machine
Dial-Up Data	Remote access to a corporate email service not connected to the Internet	Human to Machine
PPP Service	Access to the Internet by a computer without a Windows Operating System	Human to Machine
RUDICS Short Burst Data	Large scale monitoring of fixed or mobile assets beyond typical terrestrial coverage	Machine to Machine
Direct Internet Dial-Up Data RUDICS	File transfers that typically are 500 bytes or more per transfer	Machine to Machine
Short Burst Data	File transfers that typically are less than 500 bytes per transfer	Machine to Machine
Short Burst Data	Frequent short file transfers [Less than 500 bytes]	Machine to Machine
RUDICS Short Burst Data	Integrated data applications	Machine to Machine
Direct Internet Dial-Up Data PPP	General ad-hoc file transfer [Human to Machine]	Human to Machine
Short Message Service	Send or receive short email (text message)	Human to Human

Table 5. Iridium Data Services

Remote Applications send data messages via an Iridium 9522 L-Band Transceiver ("LBT"). The application microcontroller or microprocessor communicates with the LBT using AT commands over an RS232 serial port. The application loads the data message into the LBT and instructs it to send the data message. The data message is transmitted across the Iridium satellite network utilizing inter-satellite links to reach the Iridium

Gateway. From there the data message is transferred via e-mail to the VARs host computer system. Here the message is stored in a database for further data processing.

Outbound messages to the remote terminal are sent to the Iridium Gateway via e-mail from the VAR's host computer system. Data messages are delivered to the LBT following a "mailbox check" initiated by the remote application. Global network transmit latency for delivery of messages ranges from approximately 5 seconds for short messages to approximately 20 seconds for maximum length messages. This latency is the elapsed time before the Iridium SBD system sends the SBD message to its email destination. Additional latency introduced by the Internet or the customer's host system is not in Iridium's control.

Iridium Short Message Service (SMS)

Short Message Service (SMS) is a Global System for Mobile Communications (GSM) based system capability designed for both mobile origination and reception of short text messages. There are numerous GSM-SMS applications developed for terrestrial GSM networks. It should be possible to adapt existing terrestrial based applications and also to develop new applications using the Iridium SMS service.

The Iridium SMS service offers the following capabilities:
- Two-way global text messaging.
- Send to and receive from other Iridium SMS subscribers.
- Send to and receive from email addresses. Iridium subscribers are able to receive SMS messages via <MSISDN>@msg.iridium.com, where <MSISDN> is the Iridium phone number.
- Send to and receive from cellular subscribers (when available.)
- 160 characters per message.
- Messages will be stored until delivered (up to 8 days.)
- Supported on 9505 handsets and 9522 LBTs with SMS capable firmware.
- SMS messages can be entered into the phone in one of two ways:
    - via the phone's keypad
    - via the phone's data port, using standard AT commands

The Iridium SMS Service can be used to serve a range of applications that can send useful information within the 160-character limit of each message. Specific applications may include: weather information & alerts, schedule information, personal messaging, basic email messaging, and monitoring of remote applications.

A major advantage of Iridium is that its current cost structure is very low. An illustrative cost comparison provided by an Iridium aviation service and equipment supplier is given in Table 6.

Current Aviation Usage of Iridium

Under contract with General Dynamics, the FAA currently experimenting with the use of Iridium for air-ground communications in support of the Capstone program in Alaska.

Iridium will be used to extend Capstone services to regions that do not have conventional VHF air-ground communication coverage.

In addition, several service providers, including ARINC, are providing Iridium service to aircraft. To date, this service is for personal and company communications, not for air traffic control.

	Blue Sky Network C-1000 Fixed Console	Trane/Trane Resellers AERO MINI M
Network Foundation	SATELLITE GROUND STATIONS/TOWERS	SATELLITE
System Operator	IRIDIUM	INMARSAT
Coverage Area	WORLDWIDE	WORLDWIDE/NON POLAR AREAS
Satellite Type	LOW EARTH ORBITING	GEOSYNCRONOUS
Altitude Requirement Before Use	NO	NO
FAA Certified	YES	YES
Installation Required	YES	YES
Distribution Method	DIRECT OR DEALER	DEALER ONLY
Equipment Costs with TSO'D Antenna	$6,995	$40,000
Handset Included in Basic Kit	YES	YES
Data Capable (Incl Internet/Email)	YES	YES
Free Short Text Message Service Available	YES	NO
Service Plan Elements		
Activation Fee	YES	YES
Monthly Fee	YES (a)	YES
$100 Plan (Closest) Minutes Included	60	30-35
Cost Per Extra Minute	$1.45	$3.05

Table 6. Example Cost Comparison between Iridium and INMARSAT

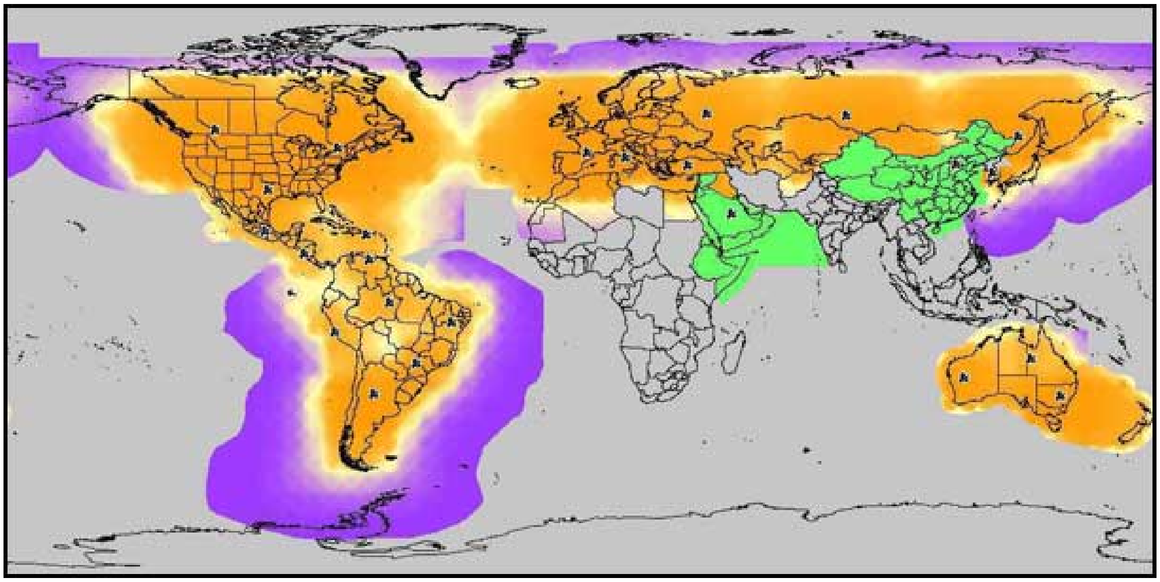
Globalstar[21]

Globalstar currently offers service from virtually anywhere across over 100 countries, as well as from most territorial waters and several mid-ocean regions. Signals from a Globalstar phone or modem are received by the company's constellation of 48 Low Earth Orbiting (LEO) satellites and relayed to ground-based gateways, which then pass the call on to the terrestrial telephone network. The satellites act as "bent-pipe" relays to the gateways.

Gateways process calls, then distribute them to existing fixed and cellular local networks. Terrestrial gateways are an important part of Globalstar's strategy to keep key technology

[21] Adapted in part from www.globalstar.com

and equipment easily accessible and to integrate services as closely as possible with existing local telephony networks. This makes the Globalstar system and its services simple to manage, expand and improve. Since only satellites within view of gateways provide service, coverage is correspondingly limited by the gateway deployments. From the above figure, it appears that Globalstar primary coverage is not sufficient for Oceanic CNS.



Primary Globalstar Service Area

Extended Globalstar Service Area (Customers may occasionally experience lower signal availability)

Fringe Globalstar Service Area (Customers may experience intermittent signals)

Figure 6. Current GLOBALSTAR coverage

In addition to normal voice communications, Globalstar services include: Internet and private data network connectivity, position location, SMS (short messaging service), and call forwarding. These services are supported by a growing range of products and accessories designed to make Globalstar service productive and easy-to-use in almost any situation or environment, including aviation and maritime applications. The company's data modem products can also be used for asset tracking and environmental telemetry applications.

Globalstar L. P. was established in 1991 and began commercial service in late 1999. In February 2002 it reached agreement with several of its major creditors to restructure the company's debt and, in order to facilitate the timely completion of the restructuring, filed a voluntary petition under Chapter 11 of the U.S. Bankruptcy Code in the U.S.

Bankruptcy Court in Delaware. The court approved transfer of substantially all of Globalstar L.P.'s assets to a newly created Delaware corporation in exchange for a minority interest in the new corporation. Under the agreement, ICO Global Communications (Holdings) Limited was to acquire a majority interest in the new corporation in exchange for an investment of $55 million. However, that contemplated restructuring did not occur. Instead, a new Globalstar company, 81.25% owned by Thermo Capital Partners LLC for an investment of up to $43 million in cash, has entered into an acquisition agreement for Globalstar's business asset. The acquisition will be completed upon receipt of U.S. regulatory approval, expected the first quarter of 2004[22].

As of June 30, 2003, Globalstar had approximately 93,000 subscribers worldwide, an increase of 11% over the previous quarter.

Looking ahead, Globalstar intends to continue expanding its operations to provide service in the few remaining land areas not covered today, as well as across mid-ocean regions. Nonetheless, in view of the large investment for an individual gateway, and the relatively modest traffic opportunity afforded by the oceanic areas, it does not seem likely that gateways to provide primary coverage into the mid-Atlantic or mid-Pacific areas would be installed until the business base on the existing assets becomes a net cash generator.

Globalstar has announced several products supporting voice and data services for general aviation fixed wing and helicopter aircraft. Examples include

ARNAV RCOM-100 SatPhone and Accessories: A single line, multi-port Globalstar duplex transceiver, which uses a standard telephone interface for installation flexibility and easy connectivity to a phone handset, PC or cockpit Multi-Function Display. ARNAV also offers a number of accessories for the RCOM-100, including cordless and retractor-reel handsets as well as a dialer/adapter that allows calls to be made through the aircraft's audio panel for full headset operation.

Northern Airborne STX100 Satcom System: An airborne communications system, certified by Transport Canada and the U.S. Federal Aviation Administration, that combines a Globalstar-compatible system unit with Northern Airborne's PTA12 Dialer/Adapter, a full feature keypad that allows calls to be made through the aircraft's audio system for full headset operation. For cabin applications, a handset can be used in parallel with the PTA12 to provided independent access to the system. Optional accessories include the LMC01 geo-location system, which can be used to provide flight-following capability.

All Globalstar aviation products take advantage of Globalstar's very-low- profile, omni-directional antenna technology, which eliminates the need for expensive, bulky antennas used in earlier-generation satellite systems. Globalstar antennas require no aiming or calibration, and their small size results in extremely low aerodynamic drag.

Airtime for all Globalstar aviation products is available through three aircraft service pricing plans, specifically designed for low, medium and high minute-of-use requirements. Service plans start as low as $39.95 per month.

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[22] "Thermo Capital Partners Complete Take Over of Globalstar", Space Daily News, Dec 09, 2003.

NexSAT[23]

In Europe air traffic growth is expected to outstrip communication resources in the VHF band despite introduction of 8.33kHz spacing. There is a predicted lack of capacity to handle expected communications traffic in the future. Therefore other technologies are being considered in the timeframe of 2010-2015 to complement VHF systems and Eurocontrol is currently pursuing two options in line with its Communications Strategy -

1. Terrestrial-based using UMTS-type technology
2. Satellite-based using enhancement of existing AMSS as a Next Generation Satellite System (NGSS) that would be useable in Europe and the rest of the world.

The timescale is for the system(s) to be operational by 2010 to 2015 to meet the communication shortfall predicted at that time.

Satellite communications could be a potential candidate technology but only with improved performance over current AMSS and at lower cost. Although consideration was being given to benefits in Europe, NGSS is envisioned as a global system with the ability to complement terrestrial systems to meet regional needs. The basic NGSS would have many benefits in other parts of the world particularly low-density areas.

Accordingly, the EUROCONTROL Next Generation Satellite System Steering Group (NexSAT SG) was formed to address NGSS to meet future aeronautical communication requirements. EUROCONTROL has contracted with QinetQ to support NexSAT activities. The first meeting of the NexSAT SG was in November 2002.

The point of departure for this community is that some of the limitations of the current Aeronautical Mobile Satellite Service (AMSS), as defined in ICAO standards, resulted from its design goal to support the full range of aeronautical users. This led to a more complex system design. Safety-related communications were only a small fraction of the total communication traffic, and although they had priority over the use of the spectrum, the business case was mainly driven by the non-safety traffic. The cost of aircraft installation and avionics was high; large GESs were needed and quality of communication service not adequate for medium or high-density region usage. In addition the resulting shared use of spectrum between safety and non-safety services made it difficult to defend the need for exclusive spectrum.

Although new satellite based communication systems are being considered (e.g. Swift64, Connexion) these are primarily aimed at non-safety communications such as Internet access for passengers and they would be subject to similar commercial issues as AMSS. There was currently no system dedicated to support safety-related communications (i.e. AMS(R)S)

[23] This discussion is based primarily on presentations by Phil Platt and Philippe Renaud of NexSAT at the Working Group meeting on 26 November 2002.

Despite limitations with existing AMSS its current use to support ATM in various parts of the world had enabled a good infrastructure to be built up which could be re-used for a NGSS. These elements include -

- GEO Satellites
- GESs
- Spectrum in L-band
- Terrestrial networks
- Institutional arrangements

The NGSS could reuse this infrastructure and on it overlay improved technology and techniques with the following features -

- Lower cost AESs by tailoring the system to meet safety and regularity of flight communications only
- Use of modern techniques, e.g. CDMA, to improve multiple access and overall efficiency
- Providing two levels of service - global (low rate) and regional (higher rate)
- Options to allow use of Ku-band feeder links enabling small GESs
- Design in high levels of availability, reliability and continuity required for safety and regularity of flight communications

A possible initial deployment in Europe was shown based on the existing AMSS infrastructure; an extension of this was also illustrated using regional beam coverage to provide enhanced capability.

The design of the NGSS would be requirements driven, based on supporting ATS and AOC applications. By analysis of advanced ATM concepts emerging from Eurocontrol strategies, the communication requirements appear to require modest instantaneous throughputs - these can be met by a medium rate highly reliable communication system. Aggregated ATM data link based concepts seemed to be able to be supported by a throughput of around 1 kb/s per aircraft[24]. In addition, voice services would be supported too for non-routine or emergency situations. Using a 4.8Kbps vocoder plus error detecting/correcting this requirement could be accommodated in a channel operating at around 7 kb/s per aircraft. It may be possible to increase this basic rate to around 30kbps in a regional beam e.g. over Europe.

Based on work undertaken by ESA it seems there is an opportunity to define a NGSS that could meet these requirements by overcoming some of the limitations of the current AMSS.

The technical specification for such a NGSS would have to be refined and be introduced into the ICAO AMCP work programme. Some papers have already presented that have presented some high level considerations. The high level SARPS for a generic NGSS already exist and the draft ICAO Communications Roadmap Document for presentation at the 11th Air Navigation Conference is expected to explicitly include NGSS.

Eurocontrol has visited the Japanese Civil Aviation Bureau (JCAB). JCAB uses AMSS and is generally concerned about the quality of the communication service (mainly

[24] Eurocontrol Report ‘Operating Concept for the Future Mobile Communication Infrastructure - D2’

availability). However it is about to launch its own satellite (MTSAT) for supporting the current AMS(R)S services. A second co-located satellite will follow this the following year and two hot redundant GESs have been built. JCAB are interested in enhancing the current system and are also interested in co-operating with activity underway in Europe and other parts of the world on the system definition for a NGSS, a common approach for spectrum availability, and participating in technical tasks.

A NexSAT priority is the development of a more descriptive document of the proposed NGSS as mentioned above that could become an ICAO Circular.

Aviation lost its exclusive AMS(R)S spectrum at L-band as a result of WRC 97. However, the ITU recognizes aviation as “priority” users of the band pending on supporting services in the 1 - 6 priority levels (according to ITU definition) - ITU footnote S5.357A. At Eurocontrol’s request, CEPT CPG has confirmed that, when aviation is ready to operate the service, National Radio Administrations will have to ensure access to the frequency in the former AMS(R)S sub-band.

An Agreement for Co-operation has been signed between EUROCONTROL and ESA. One task is to progress the definition of a Next Generation Satellite System. For many years, ESA has been investigating the concept of new mobile satellite communication services with tailored applications in a private network environment. The Satellite Data Link System (SDLS) was conceived with a view to meeting the highly demanding requirements of safety and regularity of flight communications. The “MSBN” prototype system for Land Mobile Service application developed by ESA has served as a basis for the SDLS concept.

The main design goals of SDLS are to improve on the major identified limitations of the existing AMSS such as –

- AES complexity and cost
- Limitation of number of accessing GESs and need for a Network Control System
- Slow service recovery following a GES outage
- Very slow service recovery following a satellite outage
- Large usage of capacity hungry random access transmissions
- Voice service limited to a mobile extension of the Public Switched Telephone Network supported telephony service

A demonstrator had now been built with the aim of showing some of the key features of SDLS to -

- Illustrate the capacity of modern techniques in mobile communication systems to efficiently support some important ATM applications beyond the capability of the existing AMSS
- Demonstrate the party line functionality in the voice service
- Prove that guaranteed transmission delay for time-critical aircraft data (e.g. ADS) can be achieved

ESA intended to fund future industrial activities to develop an SDLS detailed system definition, starting in December 2002. This would be complementary to the Eurocontrol NGSS activities. SDLS Full system development of SDLS may start in 2004. In the meantime ESA would help industry support to Demonstrations/Evaluations of SDLS in co-operation with EUROCONTROL It is hoped that the ‘tool-box’ of good ideas from the SDLS work would be a major contribution to the definition of the NGSS.

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Appendix A

Terms of Reference

Study of Cost-Effective Aircraft-Controller Communications to Support Enhanced Oceanic ATC

Short title: Oceanic Comm Study

Background and Objectives

Air traffic in oceanic areas, the Polar Regions, and the Gulf of Mexico has been growing steadily in recent years. The March 2002 FAA Forecast predicts that international passenger traffic will grow through 2013 at an annual rate of 4% in the Atlantic, 4.9% in the Pacific, and 6% in the Latin American and Pacific markets. In response, civil aviation authorities are introducing new technologies and procedures to increase capacity and improve efficiency and predictability. These include Reduced Vertical Separation Minima (RVSM), Required Navigation Performance (RNP), and new automation systems for the control of oceanic traffic.

To achieve maximum benefit of the new automation systems requires that the aircraft make frequent GNSS-based position reports (ADS) and have a rapid, reliable data communication link between aircraft and controller (CPDLC). The FANS program has defined the requisite message formats and operational protocols. However, the high cost of current air-ground satellite communications, both in terms of avionics and training costs and communication link charges, may limit the rate of aircraft equipage. Only when these costs have been reduced to the point that they are affordable to essentially all oceanic operators will it be possible to require equipage for operation in "prime" oceanic airspace (as has been done in the case of RVSM)), and thereby achieve the full potential operational benefits. (In addition, these techniques can provide the basis for enhanced ATC in sparse-traffic areas where increased safety, rather than capacity and efficiency, is the principal driver.)

This study will examine the various technical alternatives for providing a high integrity communication link between the aircraft and control facility which can support the FANS-defined ADS and CPDLC, make an assessment of their economic viability, and provide its conclusions and a recommended course of action to the FAA via the REDAC.

Specific Study Tasks

1. Assess and summarize projections of the growth in demand for oceanic operations.

2. Based on existing studies, summarize the economic benefits of enhancing the capacity and efficiency of oceanic ATC. Determine what level of equipage is needed to obtain benefits and what are the current plans for oceanic operators to equip.

3. Examine technical alternatives for providing a high integrity communication link between the aircraft and control facility which can support the FANS-defined ADS and CPDLC. Estimate costs of viable alternatives.

4. Examine plausible strategies for transition to a more affordable oceanic ATC communications architecture.

5. Prepare conclusions and recommendations for forwarding to the FAA via the ATS Subcommittee and the REDAC.

Study Structure

The study will be performed by an ad hoc working group of the REDAC ATS subcommittee. This working group will comprise 10-12 subject matter experts drawn from the ATS subcommittee and other organizations.

The output of the working group will be a final report to the ATS subcommittee, with the recommendation that the report be forwarded in turn to the REDAC and, with REDAC endorsement, to the FAA.

Study Schedule

It is expected that the study will be carried out over an approximately six-month period, with five to seven meetings of the working group during that period.

February 10, 2003

Appendix B

Study Participants

Working Group Members[25]

Drouilhet, Paul – Chairman	MIT Lincoln Laboratory (Retired)
Parra, Ricardo – Designated Federal Official	FAA
Dundermann, Gloria – FAA Logistics Support	FAA
Fielding, John	Raytheon (Retired)
Kerczewski, Robert	NASA Glenn Research Center
LaFrey, Raymond	MIT Lincoln Laboratory
Perie, Michael	Air Traffic Control Association
Poritzky, Siegbert	Consultant
Seay, Thomas	Consultant
Simpson, Robert	MIT Flight Transportation Laboratory (Retired)

Other Study Participants

Anderson, Teresa	
Anton, Terri	ARINC
Bonard, Michael	
Bradford, Steve	FAA
Brown, John	Boeing
Budinger, James	NASA/FAA
Burton, C. Ross	CSSI
Chamness, Kevin	FAA AUA-600
Colamosca, Brian	FAA
Dieudonne, James	Mitre/CAASD
Feldman, Ellis	
Flax, Bennett	
Ford, David	FAA AUA-600
Gelinas, Michel	General Dynamics
Grappel, Robert	MIT Lincoln Laboratory
Greenfeld, Israel	
Grimm, Kevin	FAA
Gross, Amy	Mitre/CAASD
Hassan-Miller, Angel	Mitre/CAASD
Heinke, Ann	USAF
Leftwich, Roberta	FAA
Lindholm, Tenny	NCAR
Livingston, Dave	

[25] Mitre/CAASD was invited to have a member of its staff on the working group, but had to decline because of workload considerations. However, Mitre personnel made several presentations to the working group, and reviewed and made a number of useful suggestions to the final report.

Manning, Robert	USAF
McCarron, John	FAA AUA-600
Mittelman, Jeff	
Moulton, Jim	
Oishi, Roy	ARINC
Platt, Phil	Eurocontrol
Renaud, Philippe	Eurocontrol
Sears, Bill	Air Transport Association
Stine, Bill	National Business Aircraft Assn.
Storm, Allan	USAF
Terri Anton,	ARINC
Thoma, Don	
Zelenka, Rick	Boeing

Appendix C

Presentations to the Working Group

(* indicates presentation is included on CDROM)

Date	Subject	Presenter(s)
11 Dec 02		
	CNS/ATM initiatives in the oceanic environment	Kevin Chamness, FAA/AUA-600
	Benefits of Enhanced Oceanic Ops	Ellis Feldman, Ricardo Parra
8/9 Jan 03		
	Potential Benefits of More Efficient Oceanic Operations	Amy Gross, Mitre/CAASD
	Cost/Benefit Analysis of Oceanic Operations	Ross Burton, CSSI
	Australia ADS-B Initiative *FANS Implementation in Australia *CNS-ATM in the Australia FIR	Michael Perie
	*FANS 1	John Brown, Patrick Harper, Rick Zelenka, Boeing
	*Globalink/HF Data Link	Terri Anton, ARINC Inc.
6/7 Feb 03		
	ATOP 30/30 Implementation	Kevin Chamness, FAA/AUA-600
	*Thoughts on Communication Requirements	Tom Seay
	*On Satellite Communications for Oceanic CNS	Tom Seay
	*TACC Mobility 2000	Allan Storm, Bob Manning, Anne Heinke, DoD/USAF Flight Standards
	*Globalink/Satellite Tutorial	Roy Oishi, ARINC
	*Separation and Airspace Safety Panel (SASP) 30/30 Activities	Robbie Leftwich
	*CNS-ATM Oceanic (Federal Express Perspective on Oceanic Operations)	Steve Vail
6 Mar 03		
	ATOPS Update and Tour	Angel Hassan-Miller, Mitre/CAASD
	Requirements for 30/30 Separation	Brian Colamosca
	ATA Perspective on Oceanic Operations	Bill Sears, ATA
	NBAA Perspective on Oceanic Operations	Bill Stine, NBAA
3/4 Apr 03		
	FANS/AMSS	Kevin Grimm, FAA
	Eurocontrol's Outlook on ATC Comm	Philippe Renaud, Eurocontrol
	*NextSAT – Satellite communication services dedicated to ATM	Phil Platt, Eurocontrol

INMARSAT	Michael Bonard, Telenor
Oceanic Aviation Weather	Tenny Lindholm, NCAR
Iridium	Don Thoma, Iridium
*Capstone Satellite Feasibility Study	Jeff Mittelman, Mitre/CAASD
*Netted Radio – A Cost-Effective Iridium Communications Link for Oceanic CNS	Michel Gelinas, General Dynamics,

1/2 May 03

FAA Target System Description	Robbie Leftwich & Steve Bradford
Oceanic Benefits Analysis	Ellis Feldman, FAA
*Open System Protocols for Aviation Data Link Applications	Bob Grappel, Lincoln Laboratory
Comparison of ATN and TCP/IP	Jim Moulton

5 Jun 03

*GCNSS Demonstration and Simulations	Jim Dieudonne, Mitre/CAASD

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