OPPORTUNITIES FOR THE USE OF HIGH PERFORMANCE INTERNET PROTOCOL SUITE (IPS) IN THE BRAZILIAN AIR TRAFFIC MANAGEMENT SCENARIO

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ABSTRACT

In 1983, the ICAO Council was tasked by its special committee on the Future Air Navigation System (FANS) to provide recommendations to the States with the objective to upgrade the communications, navigation and surveillance systems to cope with the growth of worldwide air traffic. The concept of FANS relies on digital communications (datalink) and aims at enhancing air space capacity, efficiency and safety. The datalink system that provides communication between aircraft and ground may be divided into two parts: applications (safety and non-safety services) and infrastructure (networks and subnetworks). In other words, datalink can be interpreted as *applications-over-infrastructure.*

Safety services applications included in the scope of Air Traffic Services (ATS), such as Automatic Dependent Surveillance – Contract (ADS-C) and Controller-Pilot Data Link Communications (CPDLC), employ network infrastructures such as Aircraft Communications Addressing and Reporting (ACARS) and Aeronautical Telecommunications Network (ATN). ACARS and ATN have several limitations (bandwidth, cost of infrastructure and operation) that challenge the implementation of next generation Air Traffic Management (ATM) concepts such as 4D Navigation (or Trajectory-Based Operations, TBO) since it requires high performance but low cost data exchanges between aircraft and ground systems.

Envisioning the means to address these limitations, the industry (Boeing, Honeywell, Inmarsat and SITA) are researching the potential use of a high performance Internet Protocol Suite (IPS) network in the eventual place of ACARS and ATN, and also the interoperability and compatibility of IPS with existing aircraft and ground systems. This research includes initial development of a more efficient and backward-compatible connectionless variant of the VHF Digital Link (VDL) Mode 2 subnetwork. In this paper, we will depict the FANS concept, the aforementioned research being conducted by these companies and the possibilities of implementation in Brazil.

Keywords: FANS, Datalink, Network infrastructures, CPDLC, IPS, ATN.

1. INTRODUCTION

This paper presents the Internet Protocol Suite (IPS), a network infrastructure envisioned to initially supplement and eventually replace ACARS (Aircraft Communications Addressing and Reporting System) and ATN (Aeronautical Telecommunications Network) aeronautical communication networks. IPS provides larger data transfer capacity and greater efficiency in order to overcome the current limitations that challenge the implementation of next generation Air Traffic Management (ATM) systems.

The Brazilian Air Navigation Service Provider (DECEA), by means of the Sirius Program, intends to implement an IP infrastructure in Brazilian territory in order to support ATM related services and applications, such as Automatic Dependent Surveillance (ADS) and continental Controller-Pilot Data Link Communications (CPDLC), indicating greater alignment with current technological trends.

This paper is organized as follows: Section 2 presents the applications for safety use and the current infrastructure (networks and subnetworks) for aeronautical communication; the capabilities of Boeing commercial airplane models are also mentioned. Section 3 presents the Internet Protocol Suite (IPS), the implementation of which is recognized as a strategic goal by Boeing and other stakeholders. Section 4 presents the conclusions and recommendations for implementations in Brazil.

2. APPLICATIONS AND INFRASTRUCTURE: DATALINK FRAMEWORK

In 1983, the ICAO Council tasked its special committee on the Future Air Navigation System (FANS) to provide recommendations to States with the objective to upgrade the communications, navigation and surveillance systems to cope with the growth of the worldwide air traffic. In 1991,

representatives from 85 nations and 13 international organizations endorsed the concept of FANS - also known as Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM).

Developed to improve the handling and transfer of information (datalink), extend surveillance using Automatic Dependent Surveillance (ADS) and navigational accuracy through Global Navigation Satellite Systems (GNSS), CNS/ATM systems involve a complex and interrelated set of technologies, dependent mainly on satellites. The use of CNS/ATM systems leads to safe reductions in separation between aircraft, allowing for an increase in airspace capacity and improved operational efficiency (Galotti Jr., 1997).

Datalink provides communication between aircraft and ground systems, ideally by integrating avionics and ground automation to enable beneficial capabilities that are not possible with voice communications, and also superseding voice communications when and where appropriate. Digital data is exchanged directly with the airborne Flight Management Computer (FMC) through communication networks.

Datalink systems may be divided into two parts: *applications* (safety and non-safety services) and *infrastructure* (networks and sub-networks). In other words, datalink can be interpreted as *applications-over-infrastructure*.

2.1. Types of services and infrastructure

Safety services comprise Air Traffic Services (ATS) and Aeronautical Operational Communications (AOC) applications. Non-safety services include Aeronautical Administrative Communications (AAC) and Aeronautical Passenger Communications (APC) applications. Table 1 describes each of these services and their main characteristics:

Table 1: Types of services and characteristics

Type of Service		Purposes
Safety Services	Air Traffic Services (**ATS**)	- Air traffic control and related purposes.
	Aeronautical Operational Communications (**AOC**)	- For safety-related communications by aircraft operator. For example, flight plans, weather reports and forecasts, weight and balance information, position and other reports, and free-text messages.
Non-safety Services	Aeronautical Administrative Communications (**AAC**)	- For non-safety-related communications by aircraft operator, for example, flight crew scheduling, wheelchair requests, and engine trend data.
	Aeronautical Passenger Communications (**APC**)	- For communications by passengers, for example, passenger e-mails.

Traditional datalink systems support ATS applications combined with AOC/AAC applications. The division between AOC and AAC is sometimes unclear. Controller-Pilot Data Link Communications (CPDLC) and Automatic Depended Surveillance – Contract (ADS-C), examples of ATS applications, are depicted in Table 2:

Table 2: ATS safety applications

	Applications	Purposes
Air Traffic Services (**ATS**)	ATS Facilities Notifications (**AFN**), or equivalently, Context Management (**CM**)	- Provides initial manual "log on" capability to flight crew; - Supports subsequent automated transfers of communications from one ATS facility to another.
	Automatic Dependent Surveillance – Contract (**ADS-C**)	- Allows ATS providers to establish "contracts" with avionics for delivery of single, periodic, and/or event-based reports; - Events: waypoint change, altitude change, lateral deviation, etc; - Report data: latitude, longitude, altitude, time, predicted route, etc; - Provides position reporting, separation assurance, route conformance monitoring, and trajectory synchronization capabilities.
	Controller-Pilot Data Link Communications (**CPDLC**)	- Provides pre-defined message elements for request and delivery of clearances and reports (altitude, crossing constraint, lateral offset, route modification, speed change, free-text, and other categories); - Most beneficial when integrated with Flight Management Computer (FMC) or equivalent navigation avionics; - Enables route clearance loading, conditional clearance monitoring, and validation against navigation database.

The infrastructure for aeronautical communications has been provided by two main networking technologies: ACARS and ATN.

Aircraft Communications Addressing and Reporting System (ACARS) is a character oriented, teleprinter exchange (telex) based network. It was originally deployed in 1978 to reduce flight crew workload by automatically reporting phase of flight changes and more generally to transport messages no larger than approximately 3.5 kilobytes (kB). ACARS carries both ATS and AOC messages. Its usage and protocols are defined in various ARINC standards (ARINC 618-7, 2013, ARINC 620-8, 2014).

Aeronautical Telecommunications Network (ATN) is a bit oriented, Open System Interconnection (OSI) based network that supports air-ground and ground-ground applications. ATN was designed starting in the mid-1980s as an ICAO-compliant network for ATS applications (ICAO Doc 9705, 2002). Although intended to handle AOC applications, the associated business case never materialized. ATN is only deployed in Europe.

ACARS and ATN have several limitations (bandwidth, cost of infrastructure and operation) that challenge the implementation of next generation Air Traffic Management (ATM) concepts such

as advanced forms of Trajectory-Based Operations (TBO) since it requires high performance but low cost data exchanges between aircraft and ground systems. Envisioning the means to address these bandwidth limitations, the industry (Boeing, Honeywell, Inmarsat, SITA and others) are researching the potential use of a high performance Internet Protocol Suite (IPS) network in the eventual place of ACARS and ATN. More details regarding IPS will be provided in Section 3.

Infrastructure subnetworks comprise both line-of-sight (LOS) and beyond line-of-sight (BLOS) communication systems. Eight datalink subnetworks are operating or planned. Details of each subnetwork can be found on Table 3:

Table 3: LOS and BLOS subnetwork infrastructure

	Sub-network	Characteristics
Short-Range LOS	VHF Digital Link (VDL) Mode 0/A	- Uses original "Plain Old" ACARS (POA) protocol; - Provides link for aircraft over or near land.
	VDL Mode 2	- For ACARS, uses ACARS over Aviation VHF Link Control (AVLC) (AOA) protocol; - For ATN, uses ISO 8208 (ITU X.25) protocol; - Provides link for aircraft over or near land.
	AeroMACS (*future implementation*)	- Aeronautical Mobile Airport Surface Communications; - Will be based on IEEE 802.16 WiMAX; - Will provide high-speed IP-oriented link for aircraft on airport surface.
Long-range BLOS	HF Data Link (HFDL)	- Provides polar coverage; - Generally, a last-choice link due to performance challenges.
	Inmarsat Classic Aero SATCOM	- Does not provide polar coverage.
	Iridium SATCOM	- Provides polar coverage.
	Inmarsat SwiftBroadband	- High-speed, uses Internet Protocol (IP); - Does not provide polar coverage.
	Iridium Certus (*future implementation*)	- Will be high-speed, use IP; - Will provide polar coverage.

2.2. ATS application sets

ATS applications are implemented via two *application sets*: FANS-1/A and LINK 2000+.

FANS-1/A (where the "1" stands for the system implemented by Boeing, and "A" for Airbus´s) consists of AFN, CPDLC and ADS-C applications that use the ACARS network. FANS-1/A normally supports TBO and other capabilities not possible with voice communications. Initially operational in 1995 (in the South Pacific), FANS-1/A now is operational worldwide and planned in many areas, as can be observed in Figure 2.

LINK 2000+ consists of CM and CPDLC applications that use the ATN network. Intended to reduce frequency congestion and controller workload, the limited LINK 2000+ CPDLC message set only replicates common voice phraseology. LINK 2000+ has low benefits since it does not allow TBO operations (not FMC-integrated) against high implementation costs, and its deployment is facing both operational and technical obstacles. LINK 2000+ has not expanded outside of Europe.

Figure 1 depicts the conceptual architecture for both application sets. ACARS has evolved to use multiple sub-networks, including VDL Mode 0/A, using the "Plain Old" ACARS (POA) protocol, VDL Mode 2, using the ACARS over Aviation VHF Link Control (AVLC) or AOA protocol, high frequency data link (HFDL), Inmarsat Classic Aero SATCOM, Iridium Short Burst Data (SBD) SATCOM, and imminently Inmarsat SwiftBroadband SATCOM. ATN is currently limited to one subnetwork, terrestrial VDL Mode 2. Other subnetworks can technically be supported by ATN, but it is very costly to specify and develop, and again the business case is limited.

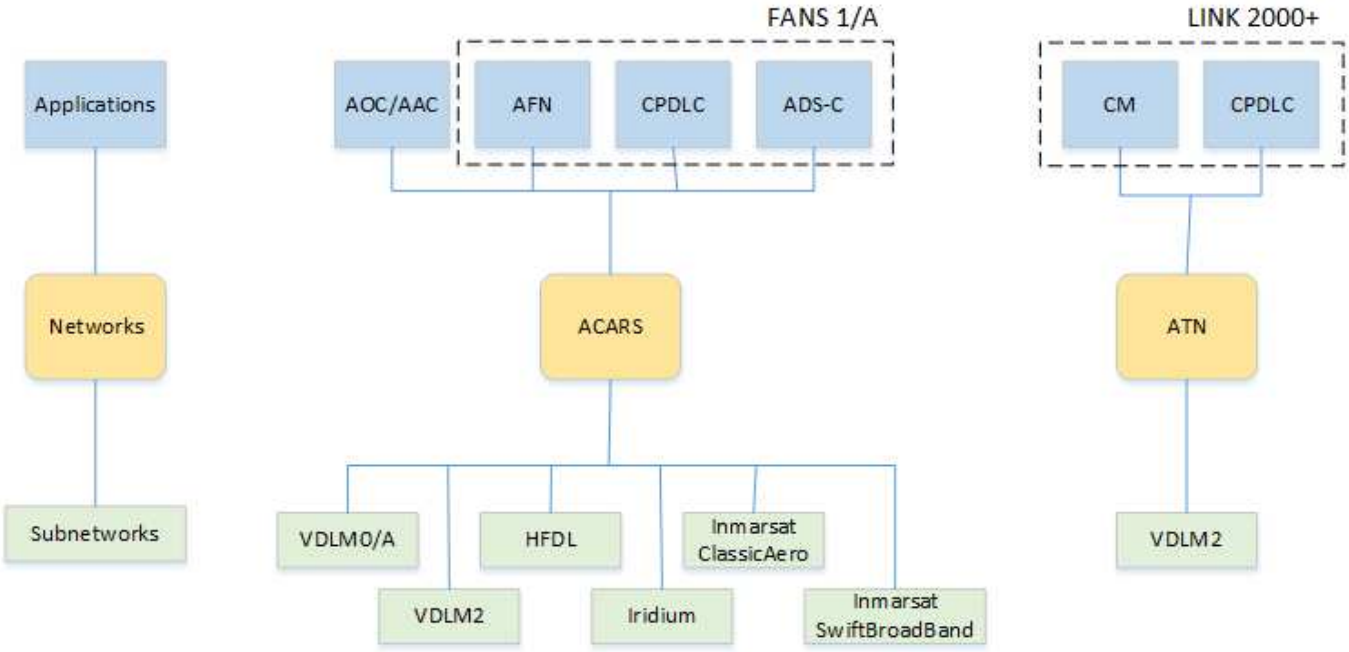


Figure 1: Conceptual architecture for FANS-1/A and LINK 2000+.

Future developments of applications set are referred by *Baseline 2* (B2). Initial standards were published in April 2014, and Rev A standards were published in March 2016. B2 consists of CM, CPDLC and ADS-C applications. It is FMC-integrated and capable of supporting TBO, 4-Dimensional Trajectory Data Link (4DTRAD) and Data Link Taxi (D-TAXI). Boeing may implement the B2 applications as FANS-3 in the mid-early 2020s.

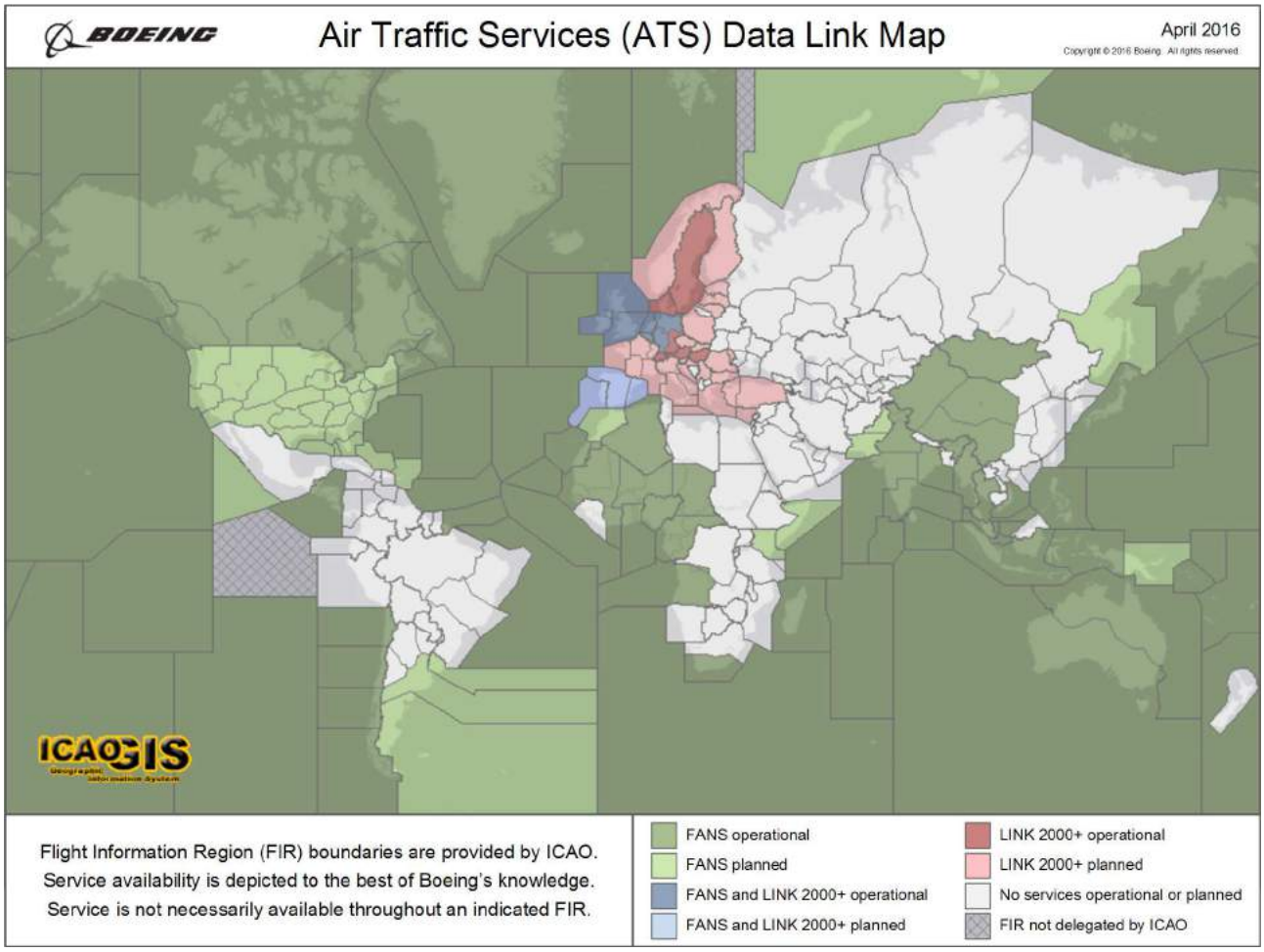


Figure 2: Datalink implementation map.

2.3. Boeing ´s airplanes capabilities

All Boeing airplanes are capable of using ACARS over VHF, SATCOM, and HF subnetworks depicted in Table 3. Boeing airplanes that have LINK 2000+ capability are also capable of using ATN subnetworks. FANS-1 "+" adds uplink message latency detection per RTCA DO-258A CPDLC to the original RTCA DO-219 FANS-1 CPDLC; however, no ATS providers use the latency detection function yet. Boeing also implemented the FANS-2 application 'superset' as an integrated combination of FANS‑1 "+" and LINK 2000+ application sets. FANS-2 enables seamless transfers between FANS and LINK 2000+ centers, providing common flight crew interface and integration with FMC or equivalent navigation avionics.

The capabilities of each Boeing commercial airplane model are depicted in Table 4:

Table 4: Boeing commercial airplane model capabilities

	Aircraft						
	737NG/MAX	**747-400**	**747-8**	**757/767**	**777**	**787/777X**	**MD-11**
FANS-1	**Yes** (“+”) **Optional**	**Yes Optional**	**Yes** (“+”) **Standard**	**Yes** (“+”) **Optional**	**Yes** (“+”) **Standard**	**Yes** (“+”) **Standard**	**Yes** (“+”) **Optional**
	or		***and***	***or***	***and***	***and***	
LINK 2000+	**Yes** (CMU) **Optional**	**No**	**Yes** (FANS-2) **Standard**	**Yes** (CMU) **Optional**	**Yes Optional**	**Yes** (FANS-2) **Optional**	**No**

3. INTERNET PROTOCOL SUITE – IPS

Future ATM concepts, such as four-dimensional aircraft trajectory and real time flight plan information, require increased data exchanges between aircraft and ground systems that are not fully supported by the current ACARS and ATN networks. A new, broadband network infrastructure must be implemented in order to promote advances in traffic management. Boeing, Honeywell, Inmarsat and SITA are researching the potential use of a high performance Internet Protocol Suite (IPS) network in the eventual place of ACARS and ATN, recognizing that the transition to an updated infrastructure must have no impact on the existing flight deck and applications (Saccone, Olive, Matyas, & Smith, 2015).

IPS can provide a more efficient and robust network infrastructure. Its use will move toward a simplified and cost-effective architecture and allow maximum flexibility and compatibility. The preliminary IPS specification (ICAO Doc 9896, 2011) is based on standard commercial Internet Protocol (IP) network technology designed (or profiled) to support the performance required for aeronautical safety services. It will also support legacy ACARS applications (AOC, FANS-1/A messaging) by carrying ACARS messages and/or data.

IPS will use LOS and BLOS subnetworks, including satellite communications (Inmarsat SwiftBroadband, Iridium Certus), AeroMACS, and VHF Digital Link (VDL) Mode 2. Future communication networks such as the L-band Digital Aeronautical Communication System (LDACS) will also be supported as they are introduced.

There are many benefits of transitioning to the IPS: commonality with mainstream communication protocols is one major advantage, permitting greater availability of commercial off-the-shelf (COTS) solutions and technical expertise, and migration toward IPS-based solutions for ground-ground messaging.

From the application level, the introduction of IPS will not change existing ATS and AOC applications, including FANS-1/A as well as AOC/AAC applications. An IPS-based solution should also serve as a basis for compatibility with advanced ATS applications, such as the B2 applications (Saccone, Olive, Matyas, & Smith, 2015).

Figure 3 presents the transition to IPS protocol. The protocol stack for air-ground communications would also be simplified with IPS: many of the aviation-unique legacy protocols are replaced by a unified IPS-based architecture, which allows multiple applications to take advantage of the capabilities of the different communication media without the need for new or additional protocol stacks.

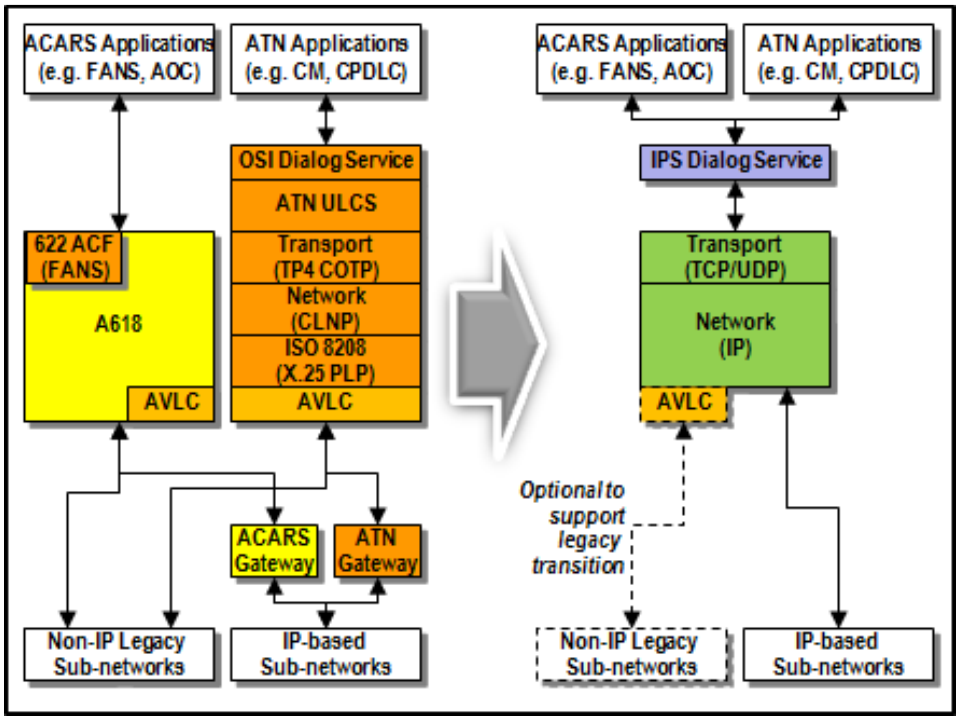


Figure 3: IPS protocol transition.

By August 2016, Boeing, Honeywell, Inmarsat and SITA, through their Joint Research Program, had conducted successful laboratory and in-flight demonstrations of LINK 2000+ CM and CPDLC message exchange using IPS over SwiftBroadband and over VDL Mode 2. The demonstrations that utilized VDL Mode 2 also successfully proved the concept of the connectionless VDL Mode 2 variant, which is expected to be more robust than the connection-oriented variant that has experienced problems in Europe. Future work to be developed includes: prototype CMU updates, performance characterization for IPS over VDL Mode 2, more in-depth SATCOM testing, ground gateway requirements and plans to update relevant industry standards (Saccone & Matyas, 2016).

4. CONCLUSIONS AND RECOMMENDATIONS FOR IMPLEMENTATION IN BRAZIL

In this paper, a brief introduction to safety services, as well as the current set of ATS applications (FANS-1/A, LINK 2000+) and aeronautical communication infrastructures (ACARS,

ATN) was provided, followed by an explanation of the future IPS network infrastructure, the implementation of which is expected to provide the technical and cost performance necessary for future ATM modernization.

Boeing is in favor of the deployment of FANS-1/A service in Brazilian domestic airspace, since it harmonizes with current FANS-1/A service in Atlantico FIR. In addition to providing a positive business case, FANS-1/A supports future ATM advancements, such as TBO, that are not possible with LINK 2000+. FANS-1/A avionics are also readily available, given that all modern Boeing commercial airplane models have FANS-1 capability, as depicted in Table 4. DECEA would likely gain benefits similar to those that the FAA is gaining with FANS-1/A deployment in United States domestic airspace.

Boeing can also support Brazil´s ATS datalink deployment providing opportunities to perform interoperability testing with its avionics as well as any technical advice as needed. Boeing has supported ATS datalink deployments in many areas of the world (Pacific, North Atlantic, Asia, Europe, and Canada) as well as the FAA's Data Comm program for FANS-1/A use in United States continental airspace.

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