# Boeing Air Traffic Service (ATS) Data Link Experience and Capabilities

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  - Additional information (as needed)

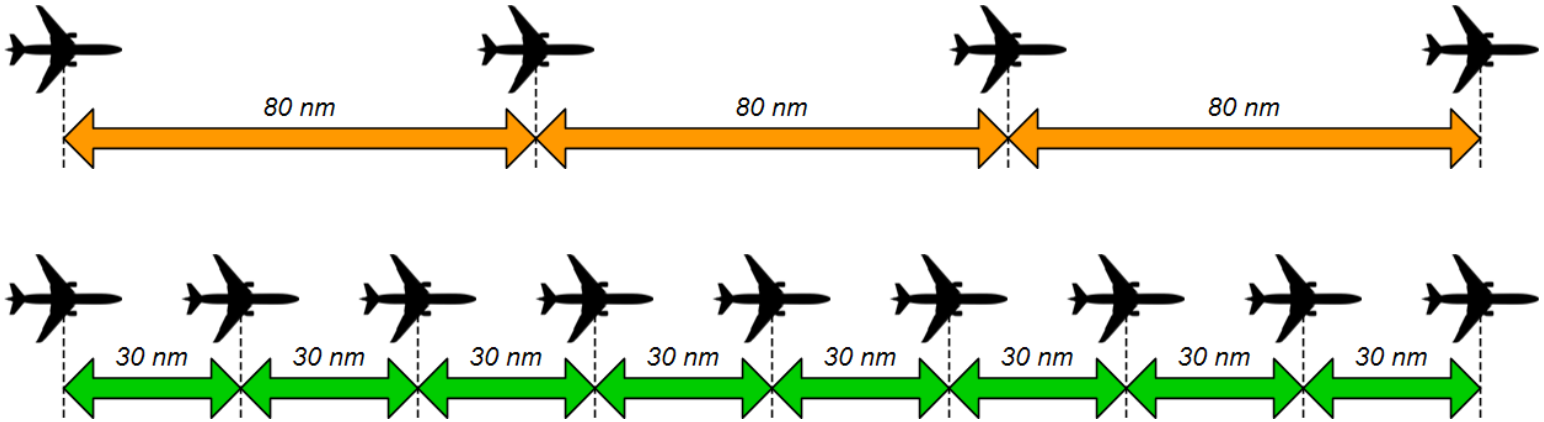
Key points are highlighted

# ATS Data Link Purposes

- Primary purpose: Integrate avionics and ground automation to enable beneficial capabilities not possible with voice communications
  - For example, enable trajectory-based operations (TBO)
    - Departure Clearance (DCL) service now being deployed in domestic United States is an early form of TBO
- Secondary purpose: Supersede voice communications when and where appropriate
  - Enable communications via data link
    - For example, a climb clearance request and response
  - Enable surveillance via data link
    - For example, automated position reports

# ATS Data Link Benefits (1/2)

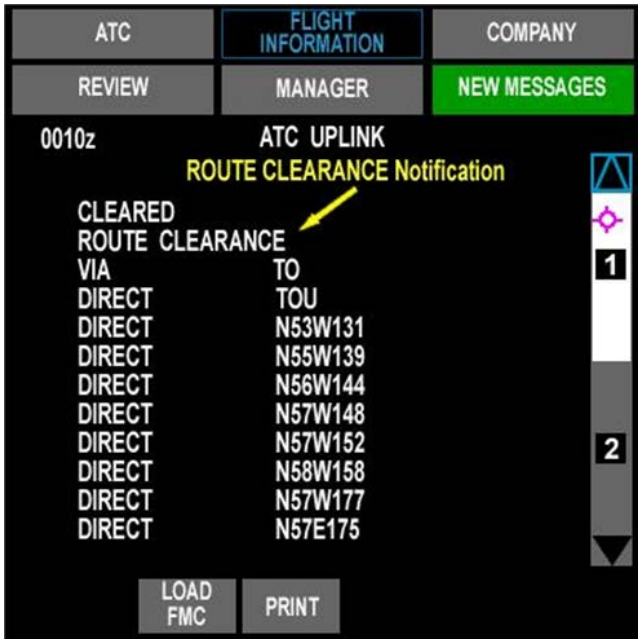
- Increased capacity
  - Reduced controller workload in continental airspace
  - Reduced separation in oceanic, polar, and remote airspace
    - For example, “30/30” separation in Pacific, RLatSM in North Atlantic




- Improved efficiency
  - Decreased fuel consumption and/or time enroute
    - For example, Dynamic Airborne Reroute Procedure (DARP) reroutes

# ATS Data Link Benefits (2/2)

- Enhanced safety
  - 787 operator in *Aviation Week*: “integration of [CPDLC] with the autoflight system… enhances safety”
  - Avionics route clearance ‘autoloading’ prevents navigation errors caused by manual transcription


# ATS Data Link Architecture

- Data link may be divided into two parts:
  - Applications: Functions which provide services to users
  - Infrastructure: Networks and subnetworks (links or media) which connect applications
- In other words, applications-over-infrastructure, like:
  - Voice-over-IP (VoIP)
  - E-mail-over-WiFi
  - Facebook-over-4G LTE
  - FANS-over-VDL Mode 2

# Application Types (1/2)

1. ATS Facilities Notification (AFN)
   - Or equivalent, namely Context Management (CM)
   - Provides initial manual "log on" capability to flight crew
   - Supports subsequent automated transfers of communications from one ATS facility to another
2. 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

# Application Types (2/2)

## 3. 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
    - For example, dM9 REQUEST CLIMB TO [altitude] and uM20 CLIMB TO AND MAINTAIN [altitude]
- 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
  - Route clearance loading is faster (benefiting efficiency) and more accurate (benefiting safety) than voice communications with manual transcription and manual entry

# Application Sets: FANS

1. Future Air Navigation System (FANS)
   - Consists of FANS AFN, CPDLC, and ADS-C applications
   - Normally FMC-integrated – supports TBO and similar capabilities not possible with voice communications
   - Generic avionics implementation is called “FANS-1/A”
     - “FANS-1” is Boeing’s implementation, “FANS-A” is Airbus’s
   - Initially operational in South Pacific in 1995, now operational or planned in many areas worldwide
     - Phased mandate in progress for FANS in North Atlantic
     - FANS required to use L888, Y1, Y2, Y3 routes in western China
     - Domestic US: FANS use for operational DCL service began in August 2015, FANS use in enroute airspace is planned for 2019

# Application Sets: LINK 2000+

## 2. LINK 2000+

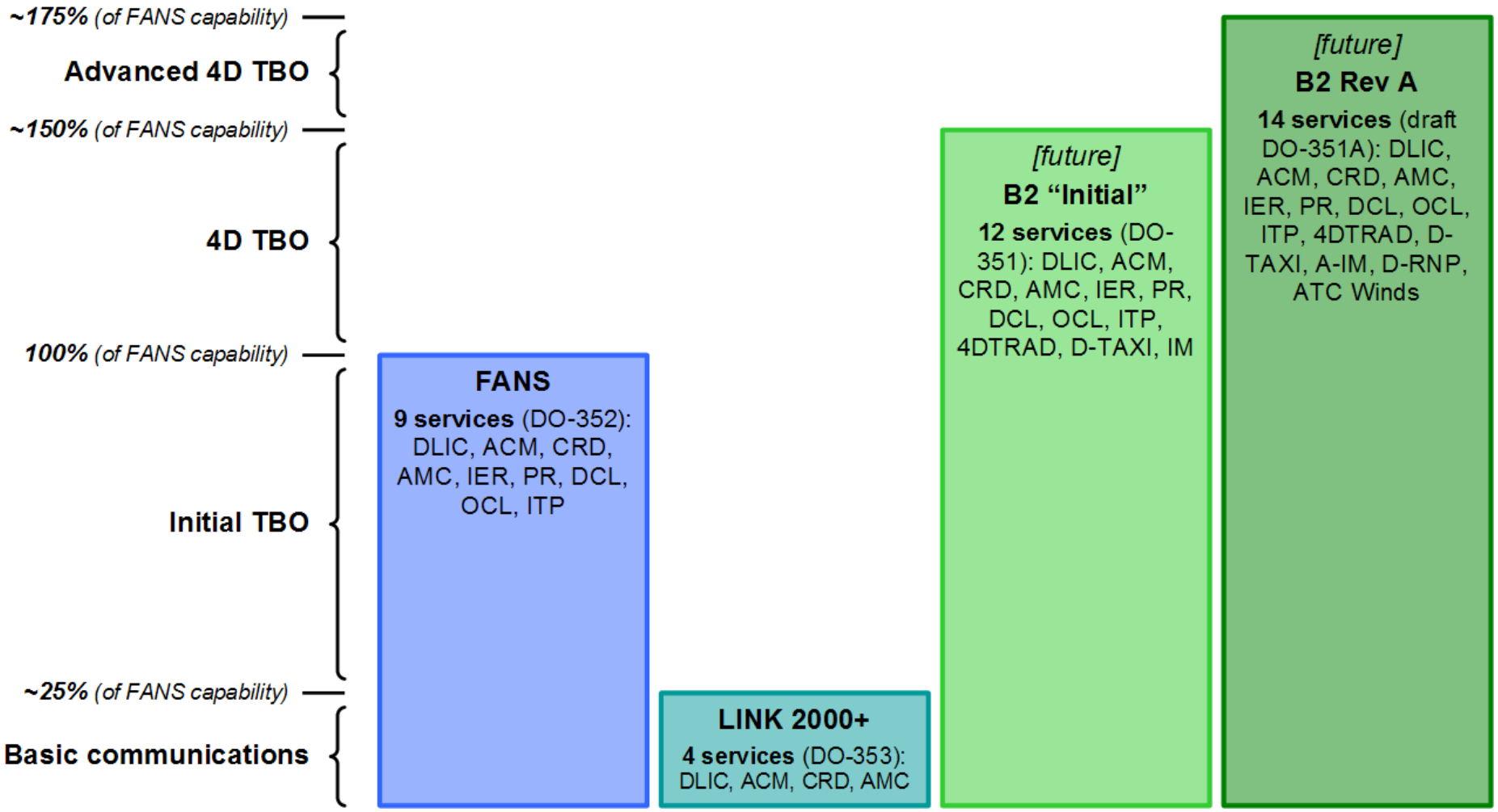
- Consists of LINK 2000+ CM and CPDLC applications
  - Subset of EUROCAE ED-110B Aeronautical Telecommunication Network (ATN) Baseline 1 (B1) capability, which in turn is a subset of ICAO Doc 9705 ATN capability
- Normally not FMC-integrated – does not support TBO
  - Intended to reduce frequency congestion and controller workload, so limited message set only replicates common voice phraseology
  - Low benefits (small message set, no TBO) but high costs (very large and complex requirements set and code base)
- Initially operational in Europe in 2009
  - Deployment is facing both operational and technical obstacles
    - Technical problems led multiple airlines to stop using LINK 2000+
  - Original 2013/2015 mandate now delayed five years to 2018/2020

# Application Sets: Baseline 2

## 3. *[future]* Baseline 2 (B2)

- Consists of B2 CM, CPDLC, and ADS-C applications
  - CPDLC adds speed schedule, one-second time precision, etc.
  - ADS-C adds Extended Projected Profile (EPP) for trajectory synchronization
- New services include 4-Dimensional Trajectory Data Link (4DTRAD) and Data Link Taxi (D-TAXI)
- FMC-integrated – supports TBO and similar capabilities not possible with voice communications
- Recently defined by RTCA SC-214 and EUROCAE WG-78
  - "Initial" standards were published in April 2014, Rev A standards are in publication process now

# Application Sets: Capability Comparison



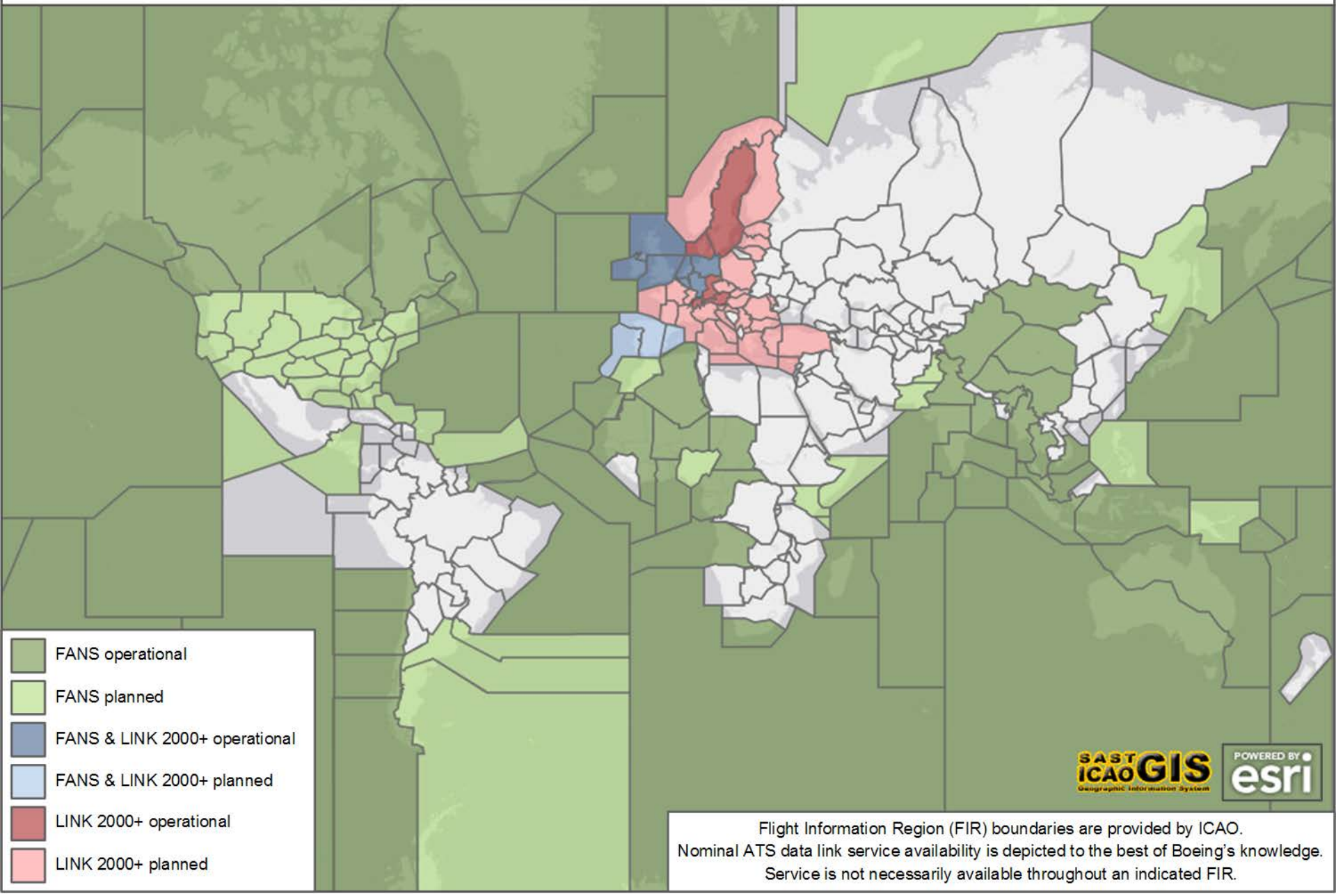
# Application Sets: ICAO ASBU Support

| ASBU Module and Title | | FANS | LINK 2000+ | *[future]* B2 |
|---|---|---|---|---|
| Block 0 | B0-05, Improved Flexibility and Efficiency in Descent Profiles | Yes | No | Yes |
| | B0-10, Improved Operations through Enhanced En-Route Trajectories | Yes | No | Yes |
| | B0-40, Improved Safety and Efficiency through the Initial Application of Data Link En-Route | Yes | Partial | Yes |
| Block 1 | B1-10, Improved Operations through Optimized ATS Routing | Partial | No | Yes |
| | B1-40, Improved Traffic Synchronization and Initial Trajectory-Based Operation | Partial | No | Yes |
| Block 2 | B2-05, Improved Flexibility and Efficiency in Descent Profiles Using VNAV, Required Speed, and Time at Arrival | Partial | No | Yes |

# Air Traffic Services (ATS) Data Link Map

July 2015





# Application Sets: Boeing Capabilities (1/2)

- FANS
  - FANS-1 “+” adds RTCA DO-258A CPDLC uplink message latency detection to original RTCA DO-219 FANS-1 CPDLC
    - No ATS providers use the latency detection function, however
- LINK 2000+
  - LINK 2000+ implementation in Communications Management Unit (CMU) avionics is “stand-alone”
    - Not integrated with FMC or equivalent navigation avionics – no route clearance loading, navigation database validation, etc.
  - FANS-2 application ‘superset’ is integrated combination of FANS-1 “+” and LINK 2000+ application sets
    - Enables seamless transfers between FANS and LINK 2000+ centers
    - Provides common flight crew interface
    - Integrated with FMC or equivalent navigation avionics

# Application Sets: Boeing Capabilities (2/2)

| | 737NG[1] | 747-400[2] | 747-8 | 757/767[1] | 777[4] | 787 | MD-11 |
|---|---|---|---|---|---|---|---|
| **FANS-1** | **Yes** ("+") *Optional* | **Yes** *Optional* | **Yes** ("+") *Standard* | **Yes** ("+") *Optional* | **Yes** ("+") *Standard* | **Yes** ("+") *Standard* | **Yes** ("+") *Optional* |
| **LINK 2000+** | **Yes** (CMU) *Optional* | **No[3]** | **Yes** (FANS-2) *Standard* | **Yes** (CMU) *Optional* | **Yes** *Optional* | **Yes** (FANS-2) *Optional* | **No[3]** |

[1] FANS-1 "+" and CMU-based LINK 2000+ capabilities on 737NG and 757/767 are mutually exclusive due to host system and flight crew interface differences

[2] 747-400 may be upgraded with 747-8 FMC to gain FANS-1 "+" and LINK 2000+ (as part of FANS-2) capabilities

[3] Unless via third-party CMU Supplemental Type Certificate (STC)

[4] 777 offers concurrent FANS-1 "+" and LINK 2000+ capabilities, but they are not sufficiently integrated to be called FANS-2

# Application Sets: Considerations

- Interoperability: FANS, LINK 2000+, and B2 applications are not directly interoperable
  - On avionics side, Boeing's "dual-stack" FANS-2 solution integrates FANS and LINK 2000+ capabilities
  - On ground system side, ATS providers may implement interoperability standards
    - For example, RTCA DO-305A for FANS-ATN B1 interoperability
- Operational standard: ICAO *Global Operational Data Link Document (GOLD)*, 2nd Ed.
  - In-work (late 2016?) revision will be titled ICAO Doc 10037, *Global Operational Data Link (GOLD) Manual*, 1st Ed.

# Infrastructure: Networks (1/2)

1. Aircraft Communications Addressing and Reporting System (ACARS)
   - In use since late 1970s, now main network worldwide
   - Used by FANS ATS applications
     - Also used by Aeronautical Operational Communications (AOC) and Aeronautical Administrative Communications (AAC) applications
2. Aeronautical Telecommunication Network (ATN)
   - Based on Open Systems Interconnection (OSI) reference model
   - In use since early 2000s, but used only in Europe
   - Used only by LINK 2000+ ATS applications
     - Technical problems apparent in design and implementation of multiple layers of protocol stack
       - For example, by design the ATN protocols create a very large amount of overhead message traffic that is difficult for VDL Mode 2 to handle

# Infrastructure: Networks (2/2)

## 3. *[future]* Internet Protocol Suite (IPS)

- In development in ICAO (Doc 9896) and AEEC (ARINC 658)
- IPS use is acknowledged as a strategic goal
  - Will move towards a simplified and cost-effective architecture
  - Will allow maximum flexibility and compatibility
  - Will provide backward compatibility with existing AOC, AAC, and FANS ATS applications that have traditionally used ACARS, as well as compatibility with future B2 ATS applications
- Boeing is working to accelerate IPS development
  - Boeing, Honeywell, and SITA have successfully performed over-the-air tests of CPDLC-over-IPS-over-VDL Mode 2
  - Follow-on flight tests are planned for mid-2016

# Infrastructure: Subnetworks – Short-Range

- Short-range, line-of-sight
  - VHF Digital Link (VDL) Mode 0/A
    - Uses original “Plain Old” ACARS (POA) protocol
  - VDL Mode 2
    - For carrying ACARS messages, uses ACARS over Aviation VHF Link Control (AVLC) (AOA) protocol
    - For carrying ATN messages, uses ISO 8208 (ITU X.25) protocol
    - Boeing, Honeywell, SITA are developing a more robust and efficient backward-compatible VDL Mode 2 variant for ACARS and IPS
  - *[future]* AeroMACS
    - Based on IEEE 802.16 WiMAX
    - Will provide a high-speed, Internet Protocol (IP) oriented link for aircraft on airport surface

# Infrastructure: Subnetworks – Long-Range

- Long-range, beyond line-of-sight
  - Inmarsat Classic Aero SATCOM
  - Iridium SATCOM
    - Provides polar coverage
  - HF Data Link (HFDL)
    - Provides polar coverage
  - Inmarsat SwiftBroadband SATCOM
    - High-speed, IP-oriented
    - FAA Performance-based operations Aviation Rulemaking Committee (PARC) Communications Working Group (CWG) is currently conducting an operational evaluation of FANS-over-SwiftBroadband performance with promising results so far
  - *[future]* Iridium Certus (using Iridium NEXT constellation)
    - Will be high-speed, IP oriented

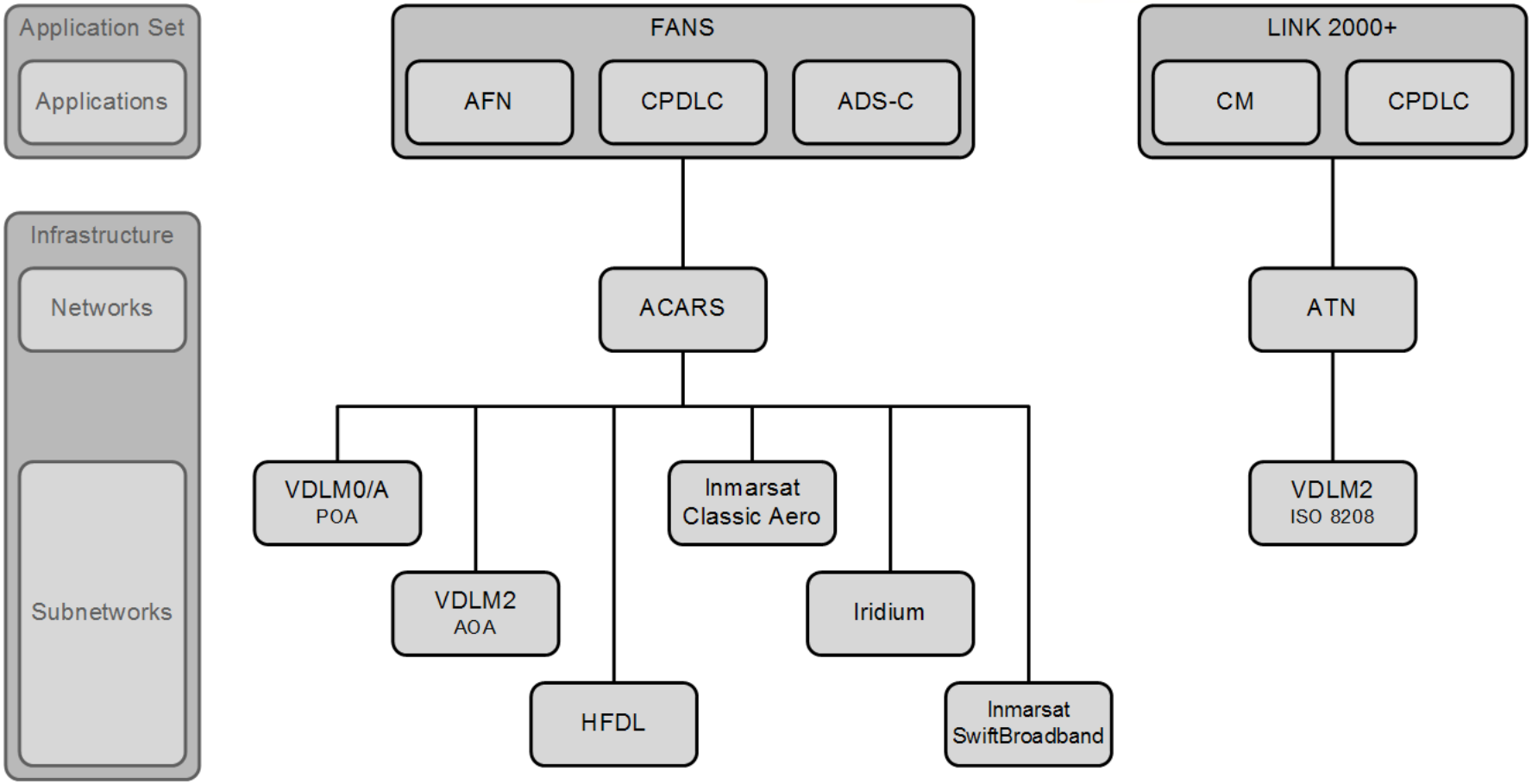
# Infrastructure: Boeing Capabilities

- Networks
  - All Boeing airplanes are capable of using ACARS
  - Boeing airplanes that have LINK 2000+ capability are also capable of using ATN
- Subnetworks
  - All Boeing airplanes are capable of using VHF, SATCOM, and HF subnetworks
    - Typical subnetwork preference order: VHF (VDL Mode 2 then VDL Mode 0/A), then SATCOM (Inmarsat or Iridium), then HF
    - Newer avionics offer customization of subnetwork preferences, geographic regions, POA frequencies, AOA service providers, etc.
- Depending on the aircraft type, some infrastructure capabilities are standard and some are optional

# Infrastructure: Considerations

- Operational standard: ICAO Doc 9869, *Manual on Required Communications Performance (RCP)*, 1st Ed.
  - In-work (late 2016?) 2nd Ed. will be re-titled *Performance-Based Communication and Surveillance (PBCS) Manual*
  - Modern performance-based approach is superior to earlier technology-specific approaches
- Latency (continuity) performance is primarily determined by subnetwork, not by network or application
  - For example, FANS-over-VDL Mode 0/A and FANS-over-VDL Mode 2 generally perform well, although FANS-over-HFDL generally does not perform well

# Architecture Diagrams




- FANS applications are independent from ACARS router, which switches between subnetworks to maximize communications availability according to operator preferences

# Recommendations

- Deploy FANS service in Brazilian domestic airspace
  - Harmonizes with current FANS service in Atlântico FIR
  - FANS supports TBO and similar capabilities not possible with voice communications
  - FANS avionics are readily available
    - For example, 737NG FMC has built-in FANS-1 capability
  - FANS offers a positive business case
    - DECEA would likely gain benefits similar to those that the FAA is gaining with FANS deployment in US domestic airspace
    - Particularly compared to LINK 2000+, which has high costs but low benefits and also serious unresolved technical problems
- Apply a performance-based approach to subnetwork use
  - For example, consider applying an RCP specification instead of requiring specific technology such as VDL Mode 2

# *Additional Information (as needed)*

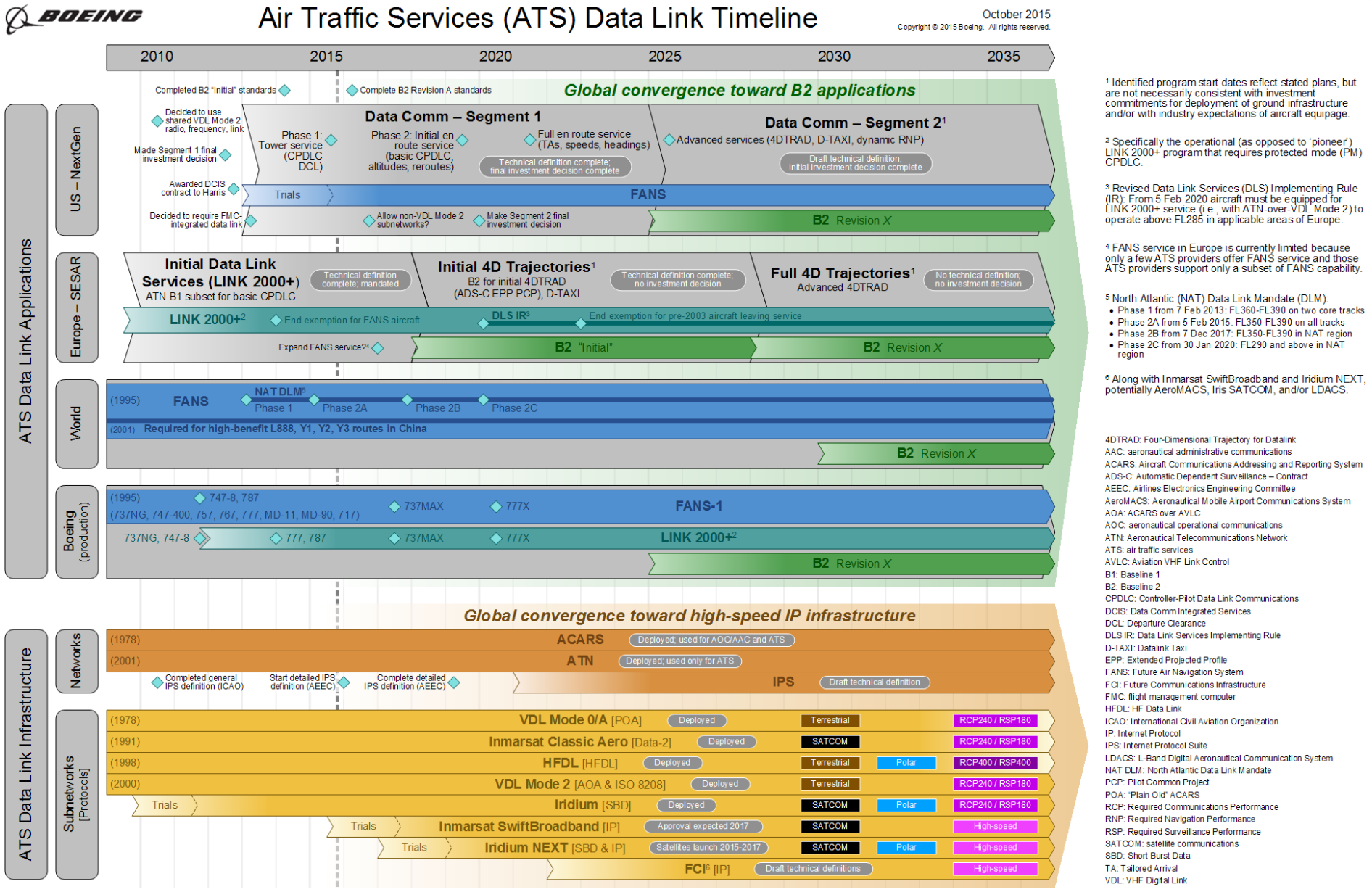
# ATS Data Link Definition

- ICAO Doc 4444, *Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM)*:

  ***Air traffic service (ATS).*** A generic term meaning variously, flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service).

- Accordingly, ATS data link is provision of air traffic control, flight information, and similar services via data communications

# ATS Data Link Timeline




[1] Identified program start dates reflect stated plans, but are not necessarily consistent with investment commitments for deployment of ground infrastructure and/or with industry expectations of aircraft equipage.

[2] Specifically the operational (as opposed to 'pioneer') LINK 2000+ program that requires protected mode (PM) CPDLC.

[3] Revised Data Link Services (DLS) Implementing Rule (IR): From 5 Feb 2020 aircraft must be equipped for LINK 2000+ service (i.e., with ATN-over-VDL Mode 2) to operate above FL285 in applicable areas of Europe.

[4] FANS service in Europe is currently limited because only a few ATS providers offer FANS service and those ATS providers support only a subset of FANS capability.

[5] North Atlantic (NAT) Data Link Mandate (DLM):
- Phase 1 from 7 Feb 2013: FL360-FL390 on two core tracks
- Phase 2A from 5 Feb 2015: FL350-FL390 on all tracks
- Phase 2B from 7 Dec 2017: FL350-FL390 in NAT region
- Phase 2C from 30 Jan 2020: FL290 and above in NAT region

[6] Along with Inmarsat SwiftBroadband and Iridium NEXT, potentially AeroMACS, Iris SATCOM, and/or LDACS.

4DTRAD: Four-Dimensional Trajectory for Datalink
AAC: aeronautical administrative communications
ACARS: Aircraft Communications Addressing and Reporting System
ADS-C: Automatic Dependent Surveillance – Contract
AEEC: Airlines Electronics Engineering Committee
AeroMACS: Aeronautical Mobile Airport Communications System
AOA: ACARS over AVLC
AOC: aeronautical operational communications
ATN: Aeronautical Telecommunications Network
ATS: air traffic services
AVLC: Aviation VHF Link Control
B1: Baseline 1
B2: Baseline 2
CPDLC: Controller-Pilot Data Link Communications
DCIS: Data Comm Integrated Services
DCL: Departure Clearance
DLS IR: Data Link Services Implementing Rule
D-TAXI: Datalink Taxi
EPP: Extended Projected Profile
FANS: Future Air Navigation System
FCI: Future Communications Infrastructure
FMC: flight management computer
HFDL: HF Data Link
ICAO: International Civil Aviation Organization
IP: Internet Protocol
IPS: Internet Protocol Suite
LDACS: L-Band Digital Aeronautical Communication System
NAT DLM: North Atlantic Data Link Mandate
PCP: Pilot Common Project
POA: "Plain Old" ACARS
RCP: Required Communications Performance
RNP: Required Navigation Performance
RSP: Required Surveillance Performance
SATCOM: satellite communications
SBD: Short Burst Data
TA: Tailored Arrival
VDL: VHF Digital Link

# Other Considerations (1/2)

- ATS data link is a system-of-systems
  - After the initial FANS deployment in the Pacific in the mid-1990s, many stakeholders regarded FANS as “done”
  - Operational and technical problems showed that in reality ATS data link is a complex system-of-systems that requires consistent involvement
  - As a result, Boeing and other stakeholders formed regional groups to monitor performance and resolve problems
    - For example, the Informal South Pacific ATS Coordinating Group (ISPACG) FANS Interoperability Team (FIT)
  - For FANS use in US domestic airspace, the FAA proactively formed the Data Comm Implementation Team (DCIT)

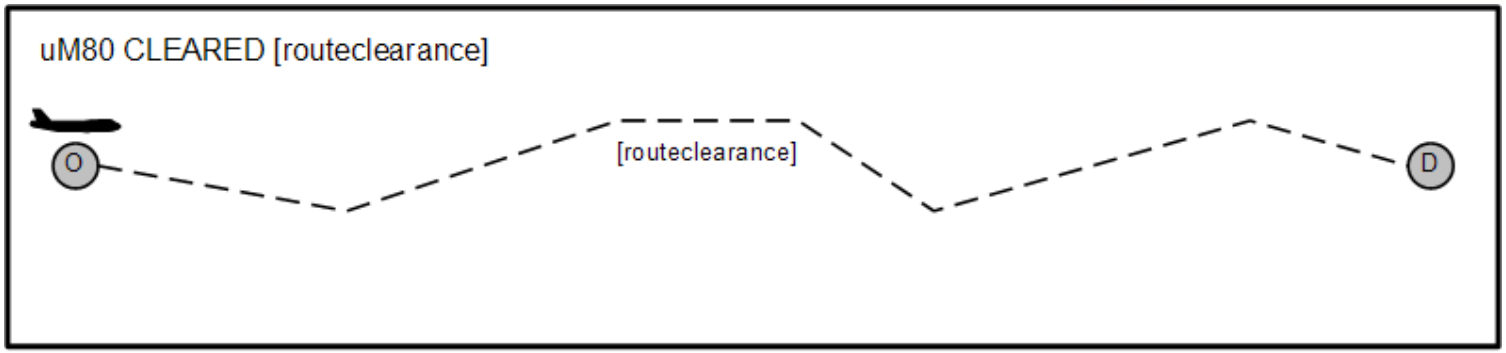
# Other Considerations (2/2)

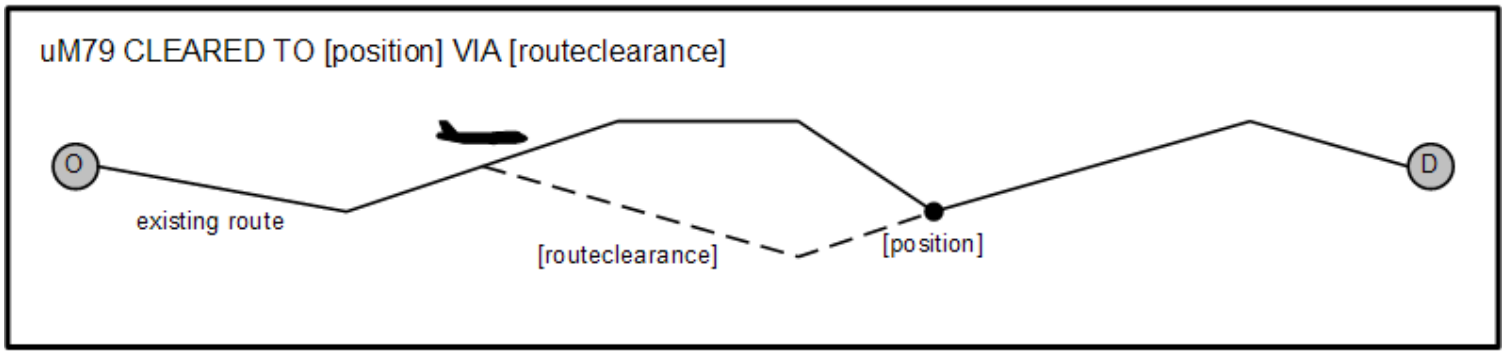
- Boeing can support Brazil's ATS data link deployment
  - Boeing has supported ATS data link deployments in many areas of the world
    - Pacific, North Atlantic, Asia, Europe, Canada
    - Also the FAA's Data Comm program for FANS use in US domestic airspace
  - Boeing can offer technical advice as needed
    - Not only regarding its avionics, but also regarding the larger ATS data link system-of-systems
  - Boeing can offer opportunities to perform interoperability testing with its avionics

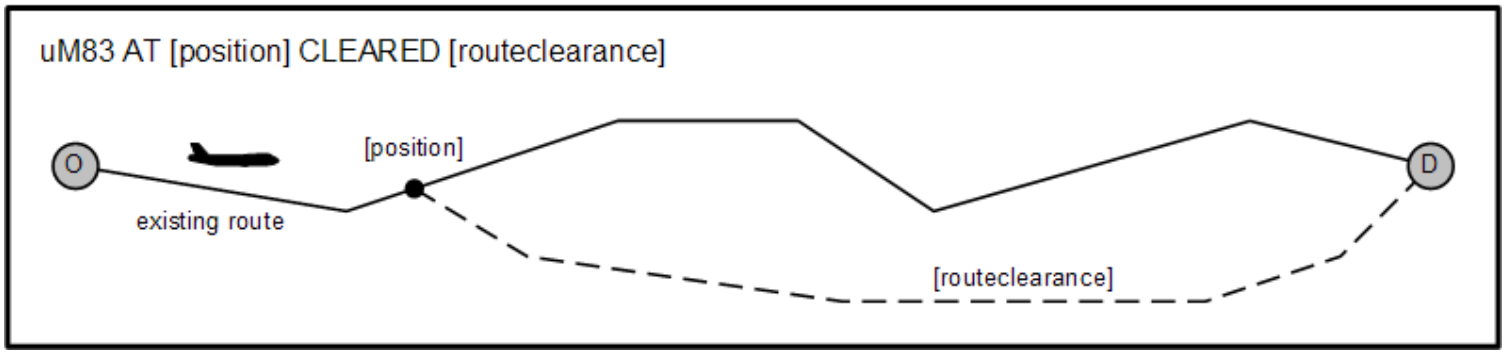
# Route Clearance Delivery

- Voice: Manual, takes several minutes
  1. Controller advises pilot of route clearance
  2. Pilot indicates ready for route clearance
  3. Controller reads route clearance
  4. Pilot writes down route clearance
  5. Pilot reads back route clearance
  6. Pilot enters route clearance into FMC
- CPDLC: Automated, takes a few tens of seconds
  1. Controller sends route clearance
  2. Pilot commands FMC to load route clearance
  3. Pilot reviews route clearance
  4. Pilot sends WILCO response

# FANS CPDLC Route Clearances



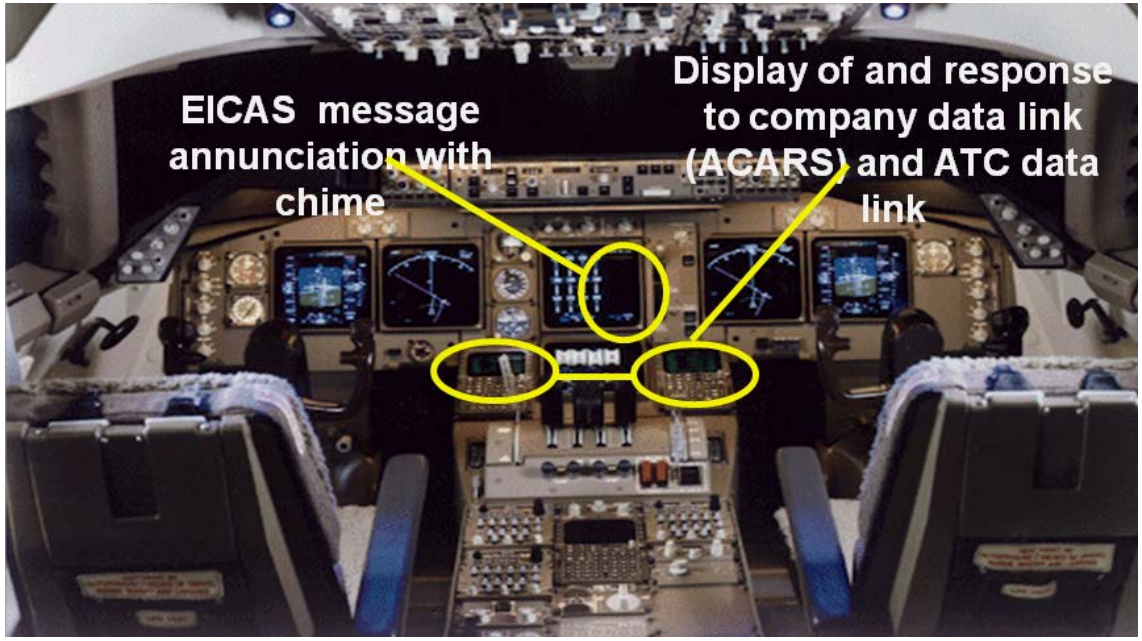



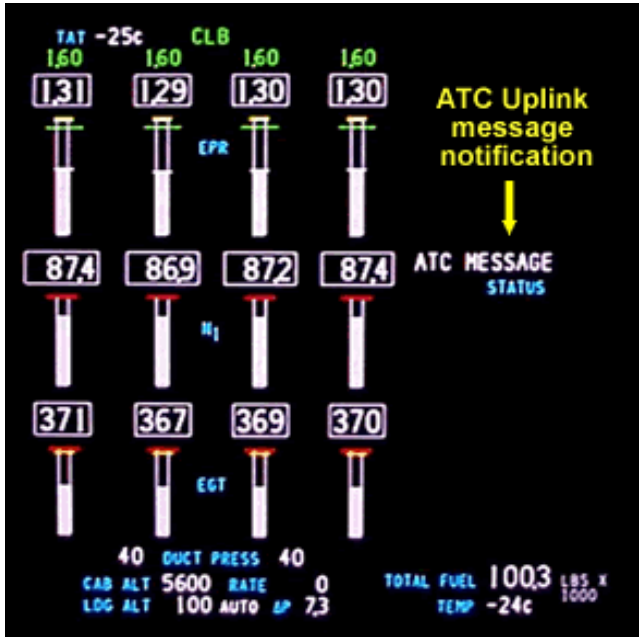
# Technical Standards

- Applications
  - FANS: RTCA DO-258A, ARINC 622-4
  - LINK 2000+: ICAO Doc 9705 2nd Ed., EUROCAE ED-110B, Eurocontrol Specification 0116
  - *[future]* B2: RTCA DO-350A, RTCA DO-351A
- Networks
  - ACARS: ARINC 620-8
    - Defines ATS provider interface to CSPs like SITA
  - ATN: ICAO Doc 9705 2nd Ed., EUROCAE ED-110B, Eurocontrol Specification 0116
  - *[future]* IPS: ICAO Doc 9896, ARINC 658, probably others
- Subnetworks
  - CSPs provide subnetwork access to ATS providers

# 747-400 Operation

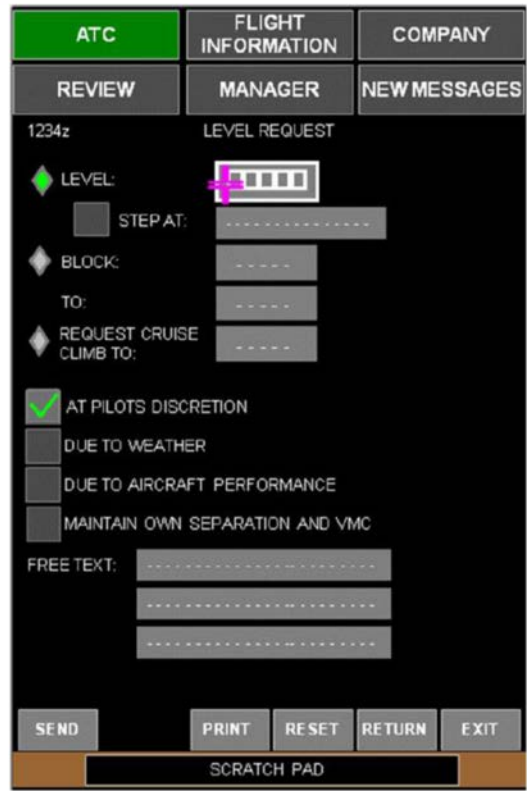
- MCDU provides primary interface
  - **ATC** key offers quick access to FANS functions
- EICAS provides **ATC MESSAGE** visual alerts
- MAWEA provides high-low chime aural alerts
- Older-design airplanes (737, 757/767, and MD-11) are similar

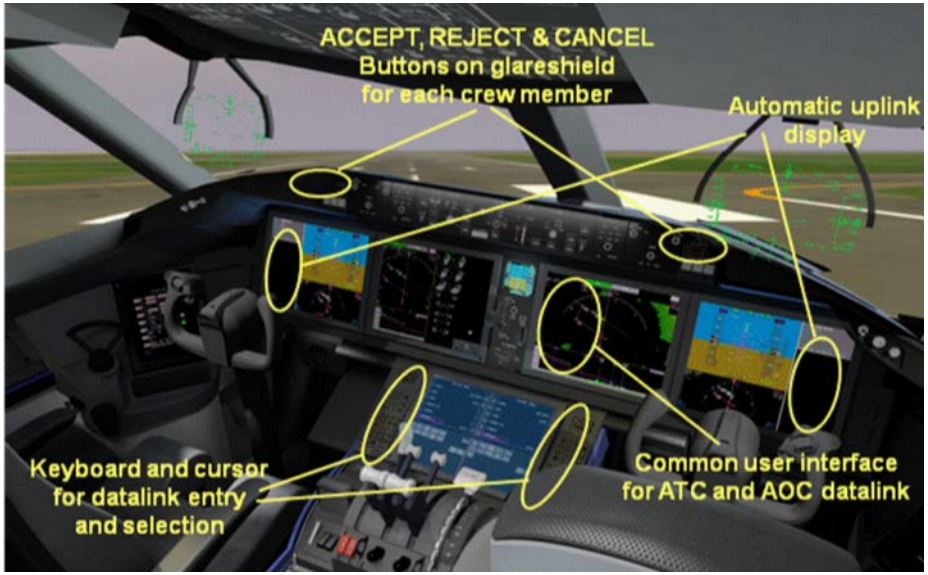



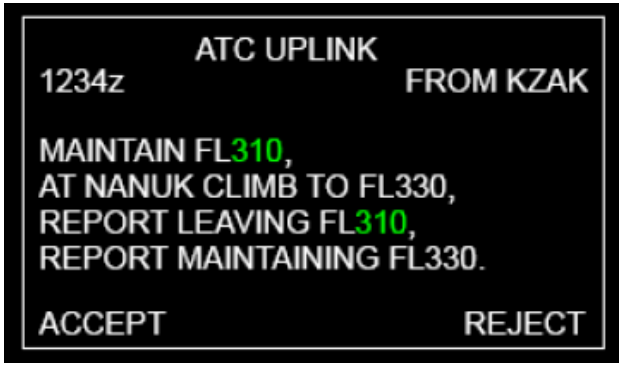



# 787 Operation

- MFD, keypad, and cursor provide primary interface
- EICAS provides •**ATC** visual alerts and high-low chime aural alerts
- Large-format displays automatically show CPDLC uplink messages in primary field of view
- ACCEPT, CANCEL, and REJECT glareshield buttons permit rapid responses to CPDLC uplink messages
- Newer-design airplanes (777) are similar

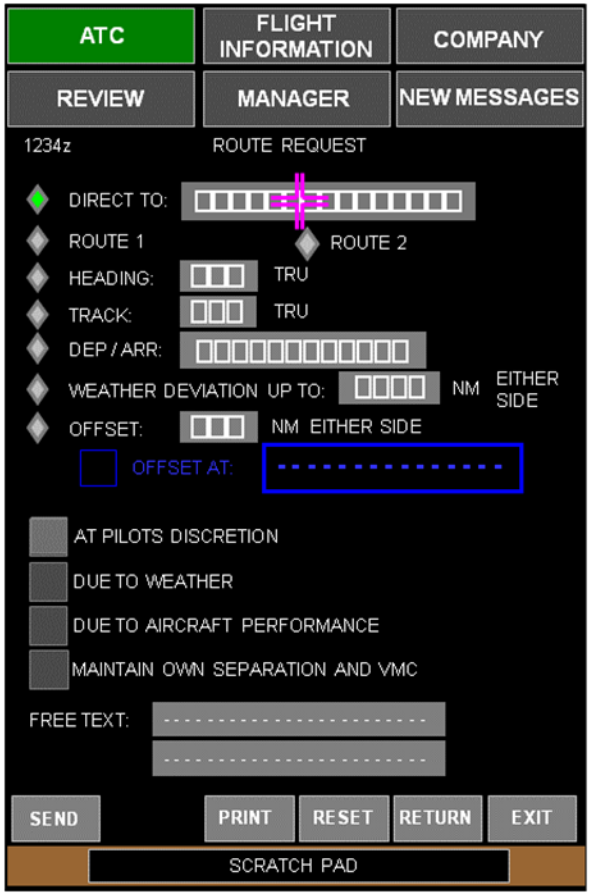


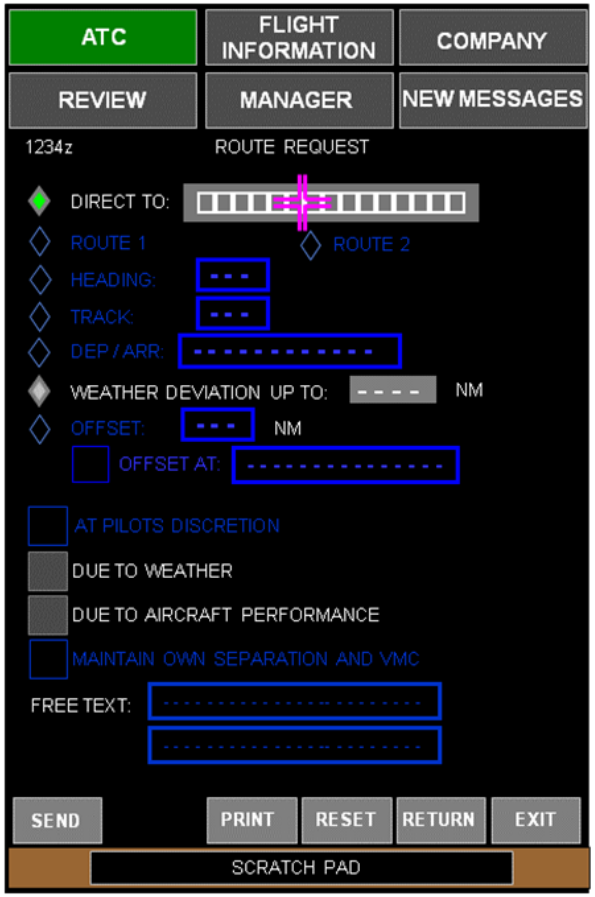



# FANS-2 Displays

- Common displays for FANS and LINK 2000+
  - Options unavailable with the smaller LINK 2000+ CPDLC message set are disabled



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