Boeing Air Traffic Service (ATS) Data Link Perspectives and Capabilities

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    - Boeing participation

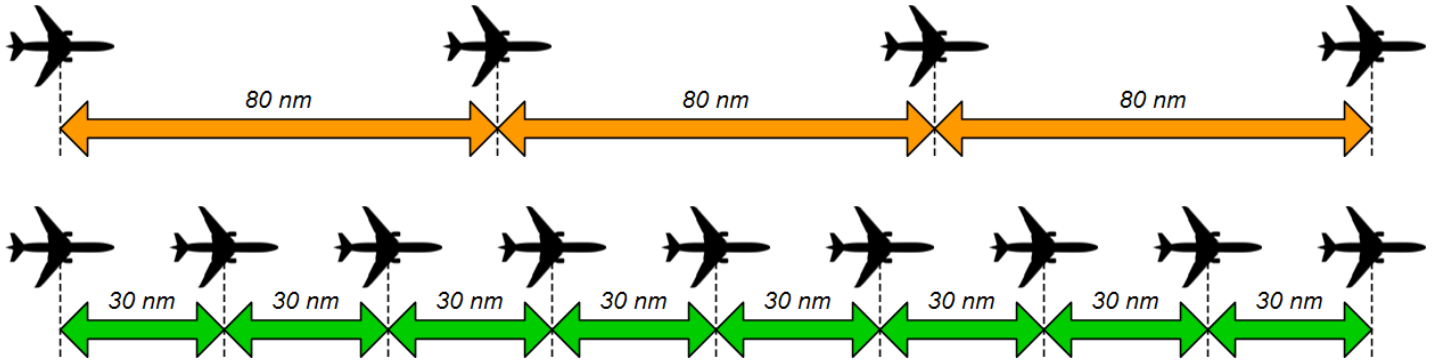
Key points are highlighted

Purposes

- ATS data link purposes
  - At least from Boeing's perspective…
  - Primary: 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: 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

Benefits

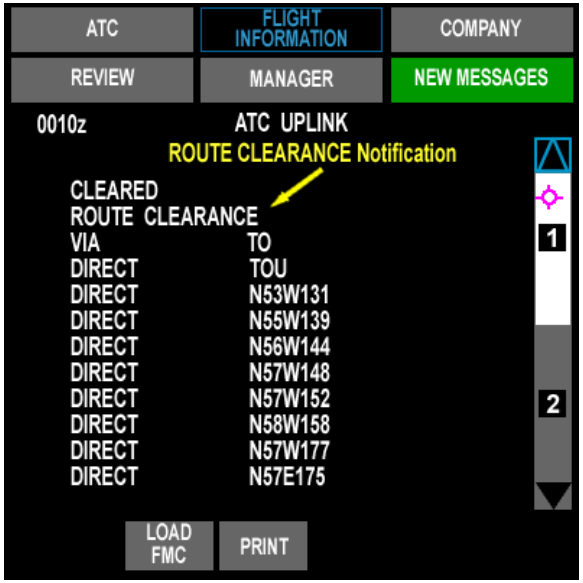
- Increased capacity
  - Reduced controller workload in continental airspace
  - Reduced separation in oceanic, polar, and remote airspace
    - For example, “30/30” separation in Pacific, RLatSM in North Atlantic

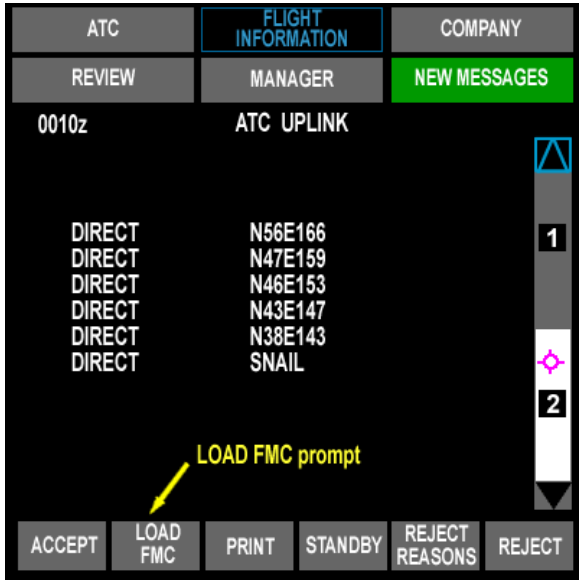


- Improved efficiency
  - Decreased fuel consumption and/or time enroute
    - For example, increased availability of optimum altitudes, Dynamic Airborne Reroute Procedure (DARP) reroutes that take advantage of new winds and temperatures aloft forecasts

Benefits

- Enhanced safety
  - 787 operator in *Aviation Week*: “integration of [CPDLC] with the autoflight system… enhances safety”
  - Navigation database validation avoids waypoint ambiguity
  - Avionics route clearance loading prevents navigation errors caused by manual transcription





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
  - Voice-over-IP (VoIP)
  - E-mail-over-WiFi
  - Facebook-over-4G LTE
  - FANS-over-Inmarsat Classic Aero SATCOM

Applications

- Application types
  - ATS Facilities Notification (AFN) / Context Management (CM)
    - Provides initial manual “log on” capability to flight crew, supports automated transfers of communications between ATS facilities
  - Automatic Dependent Surveillance – Contract (ADS-C)
    - Allows ATS providers to establish “contracts” with avionics for delivery of single, periodic, and/or event-based reports
    - 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, including free-text messages
    - Most beneficial when integrated with Flight Management Computer (FMC) or equivalent navigation avionics to enable route clearance loading, navigation database validation, and similar capabilities

Applications

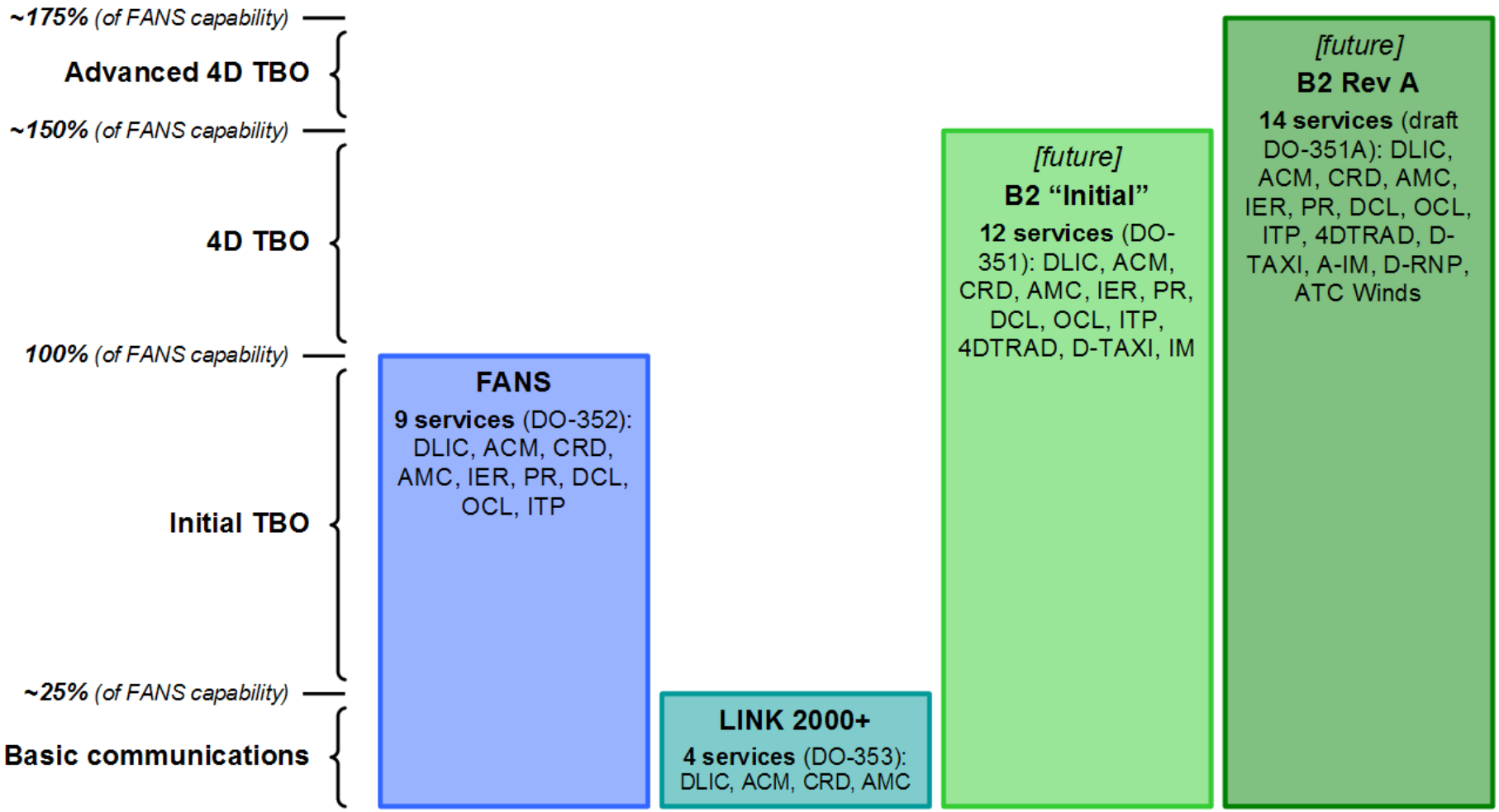
- Application sets
  - Future Air Navigation System (FANS)
    - Consists of FANS AFN, CPDLC, and ADS-C applications
    - Initially operational in South Pacific in 1995, now operational or planned in many areas worldwide
    - Normally FMC-integrated – supports TBO and similar capabilities not possible with voice communications
    - Generic avionics implementation is called FANS-1/A
      - FANS-1 is Boeing's implementation, FANS-A is Airbus's implementation
      - "FANS-1/A+" adds CPDLC uplink message latency detection
  - LINK 2000+
    - Consists of LINK 2000+ CM and CPDLC applications
    - Initially operational in Europe in 2009, but deployment is facing both operational and technical obstacles
      - Technical problems led multiple airlines to stop using LINK 2000+

Applications

- LINK 2000+ *(continued)*
  - Normally not FMC-integrated – does not support TBO
    - Subset of Baseline 1 (B1) capability intended to reduce frequency congestion and controller workload, so limited CPDLC message set only replicates common voice phraseology
    - Low benefits (limited message set, no TBO) but high costs (large and complex requirements set and code base)
- *[future]* Baseline 2 (B2)
  - Consists of B2 CM, CPDLC, and ADS-C applications
    - CPDLC adds speed schedule and one-second required time of arrival (RTA) precision, 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

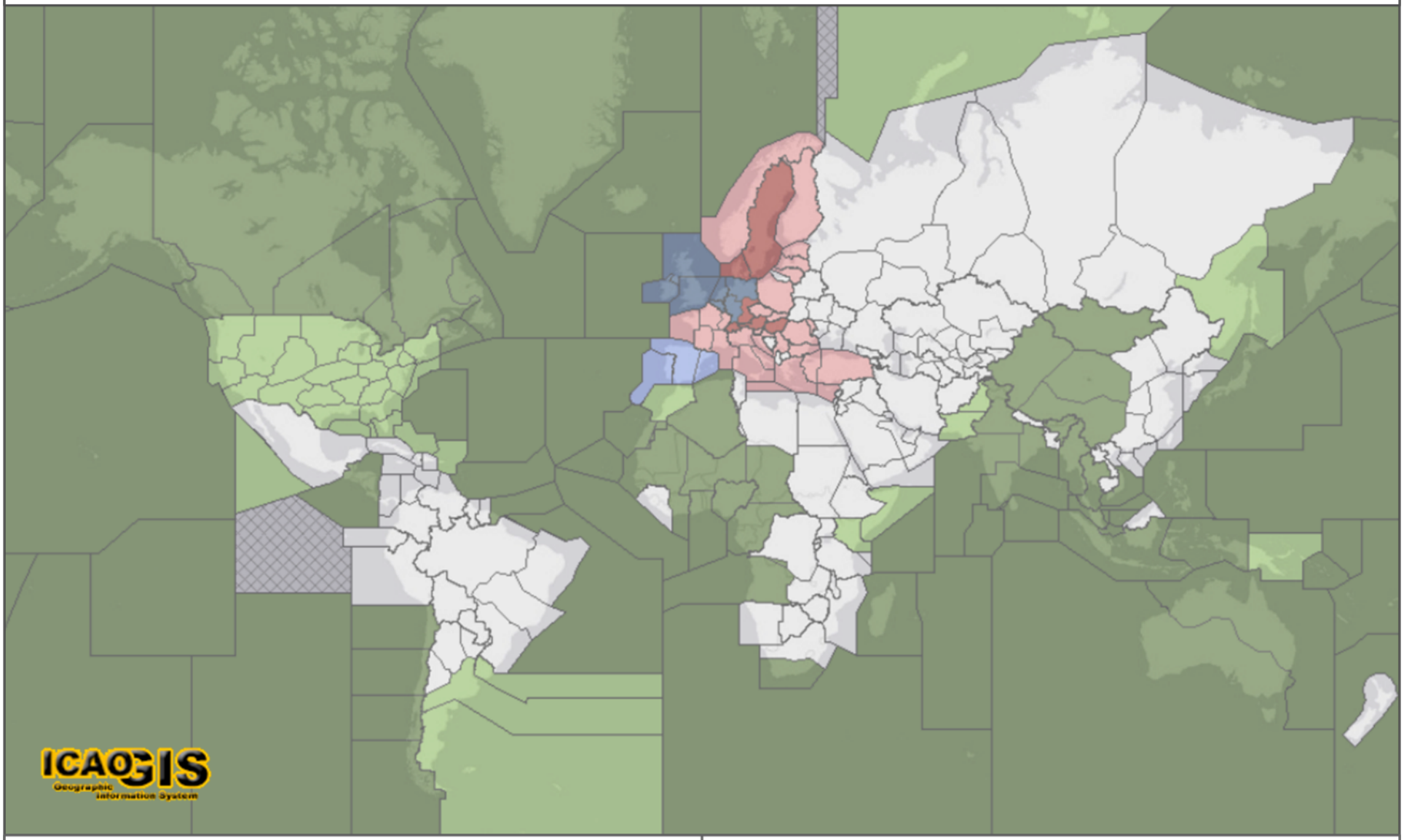
Applications

- Capability comparison of application sets:



Air Traffic Services (ATS) Data Link Map

April 2016



Flight Information Region (FIR) boundaries are provided by ICAO.
Service availability is depicted to the best of Boeing's knowledge.
Service is not necessarily available throughout an indicated FIR.

- FANS operational
- FANS planned
- FANS and LINK 2000+ operational
- FANS and LINK 2000+ planned
- LINK 2000+ operational
- LINK 2000+ planned
- No services operational or planned
- FIR not delegated by ICAO

Applications

- Boeing capabilities
  - FANS-1
    - Boeing has made “FANS-1/A+” CPDLC uplink message latency detection available on all its airplane models
  - LINK 2000+
    - LINK 2000+ implementation in Communications Management Unit (CMU) avionics is stand-alone solution
      - Not integrated with FMC or equivalent navigation avionics – no route clearance loading, navigation database validation, etc.
  - FANS-2
    - 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

Applications

- Boeing capabilities *(continued)*

	737NG/ 737MAX[1]	747-400[2]	747-8	757/767[1]	777[4]	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**[3]	**Yes** (FANS-2) *Standard*	**Yes** (CMU) *Optional*	**Yes** *Optional*	**Yes** (FANS-2) *Optional*	**No**[3]

[1] FMC-based FANS-1 and CMU-based LINK 2000+ capabilities on 737NG/737MAX 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 and CMU to gain "FANS-1/A+" and LINK 2000+ capabilities as part of FANS-2

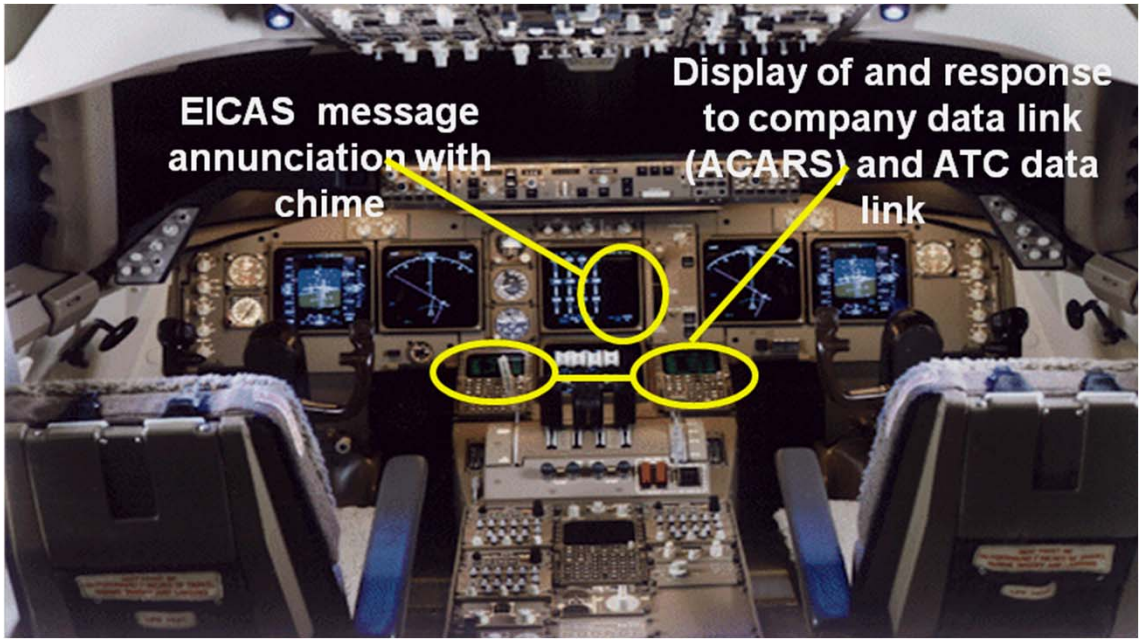
[3] Unless via third-party CMU Supplemental Type Certificate (STC)

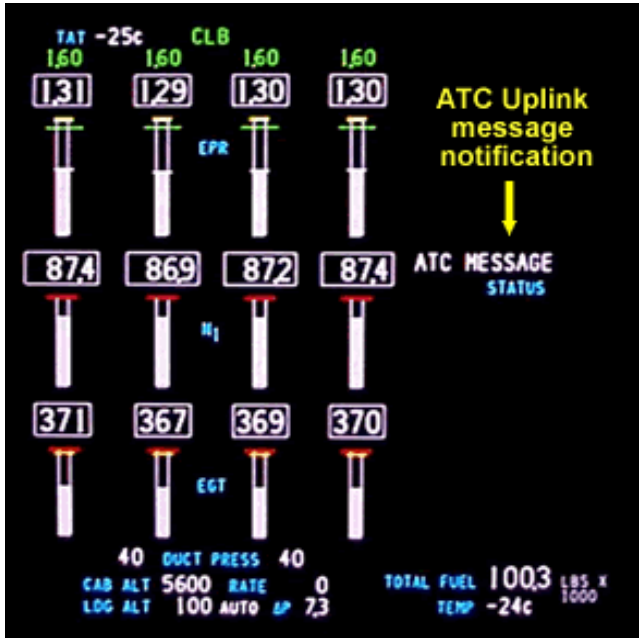
[4] 777 offers concurrent FANS-1 and LINK 2000+ capabilities, but they are not sufficiently integrated to be called FANS-2

- Contact Boeing to discuss possible FANS interoperability testing opportunities with its avionics labs

747 Operation

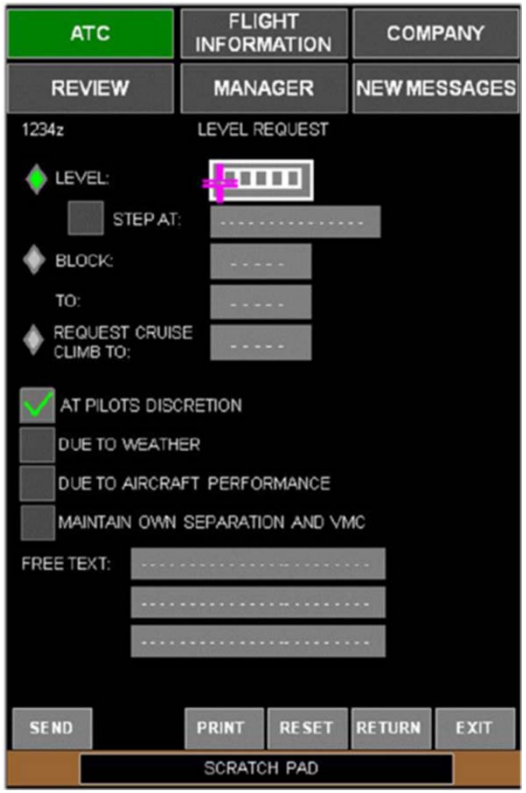
- MCDU provides primary interface
  - **ATC** key provides access to ATS datalink functions
- EICAS provides **ATC MESSAGE** visual alerts
- MAWEA provides high-low chime aural alerts
- Older-design airplanes (737, 757, 767, and MD-11) are similar

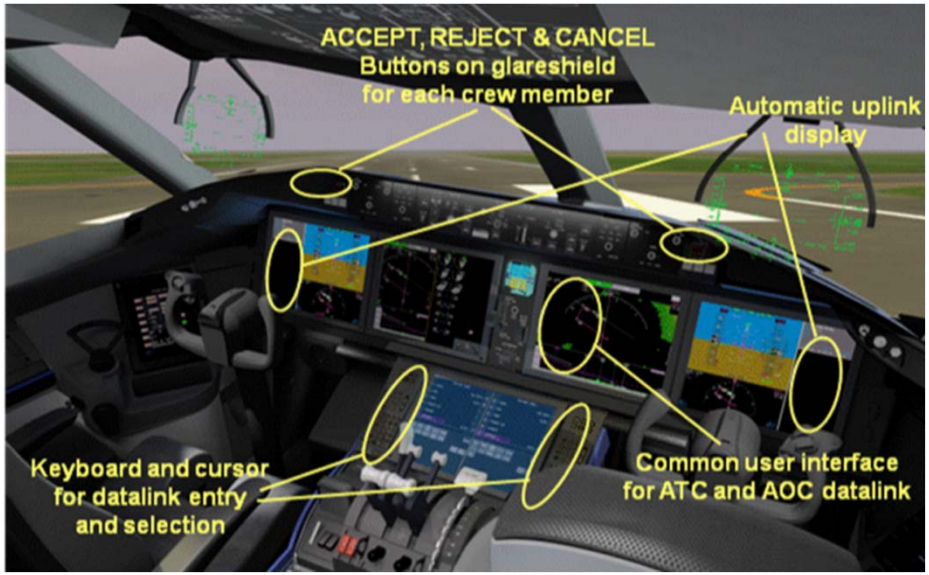


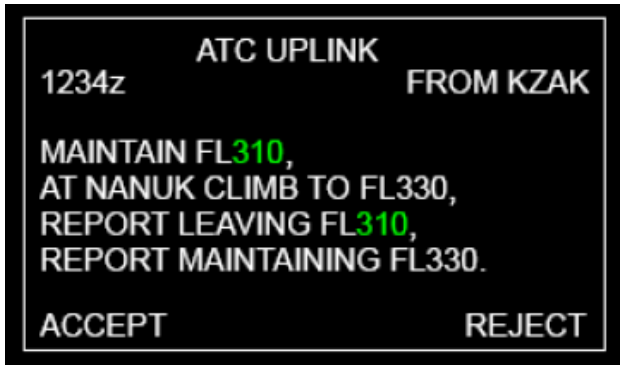


787 Operation

- 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

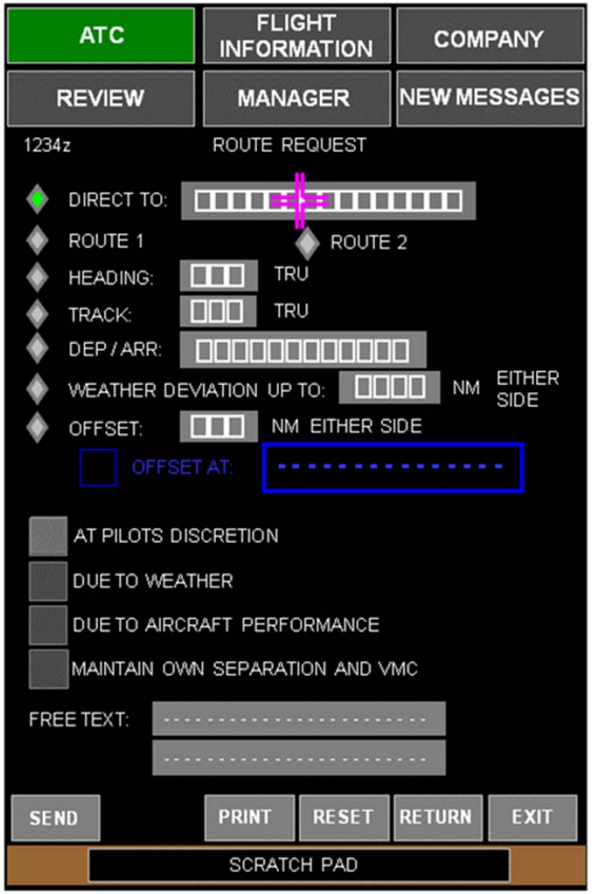


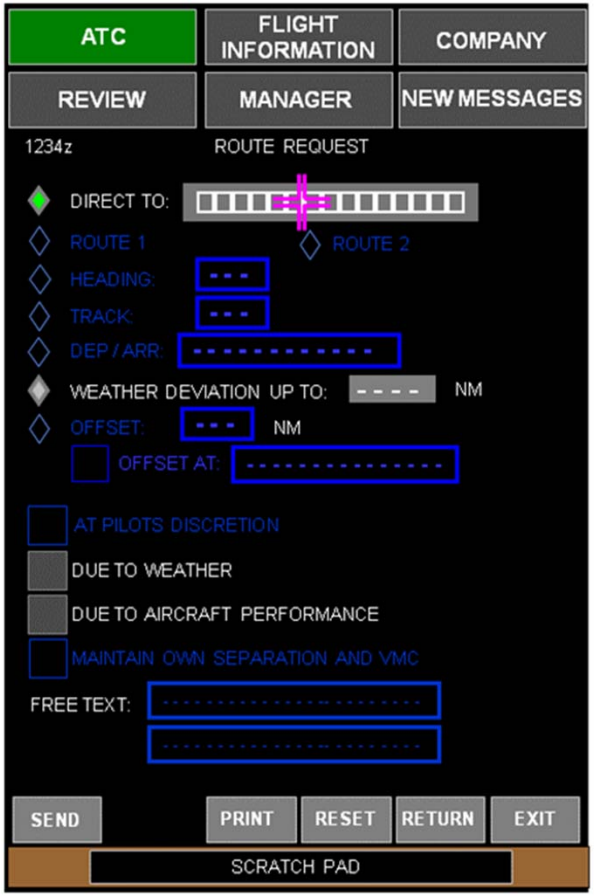




FANS-2 Displays

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





Infrastructure

- Networks
  - 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) applications
  - Aeronautical Telecommunication Network (ATN)
    - Based on Open Systems Interconnection (OSI) reference model
    - In use since early 2000s, but only in Europe and only by LINK 2000+
      - Technical problems are apparent in design and implementation of multiple layers of protocol stack
  - *[future]* Internet Protocol Suite (IPS)
    - IPS use is acknowledged as a strategic goal
      - Will move toward a simplified and cost-effective architecture
      - Will allow maximum flexibility and compatibility

Infrastructure

- Subnetworks
  - Short-range, line-of-sight subnetworks
    - VHF Digital Link (VDL) Mode 0/A
      - Uses original “Plain Old” ACARS (POA) protocol
    - VDL Mode 2
      - For ACARS messages, uses ACARS over Aviation VHF Link Control (AVLC) (AOA) protocol
      - For ATN messages, uses ISO 8208 (ITU X.25) protocol
    - *[future]* AeroMACS
      - Based on IEEE 802.16 WiMAX
      - Will provide high-speed IP-oriented link for aircraft on airport surface

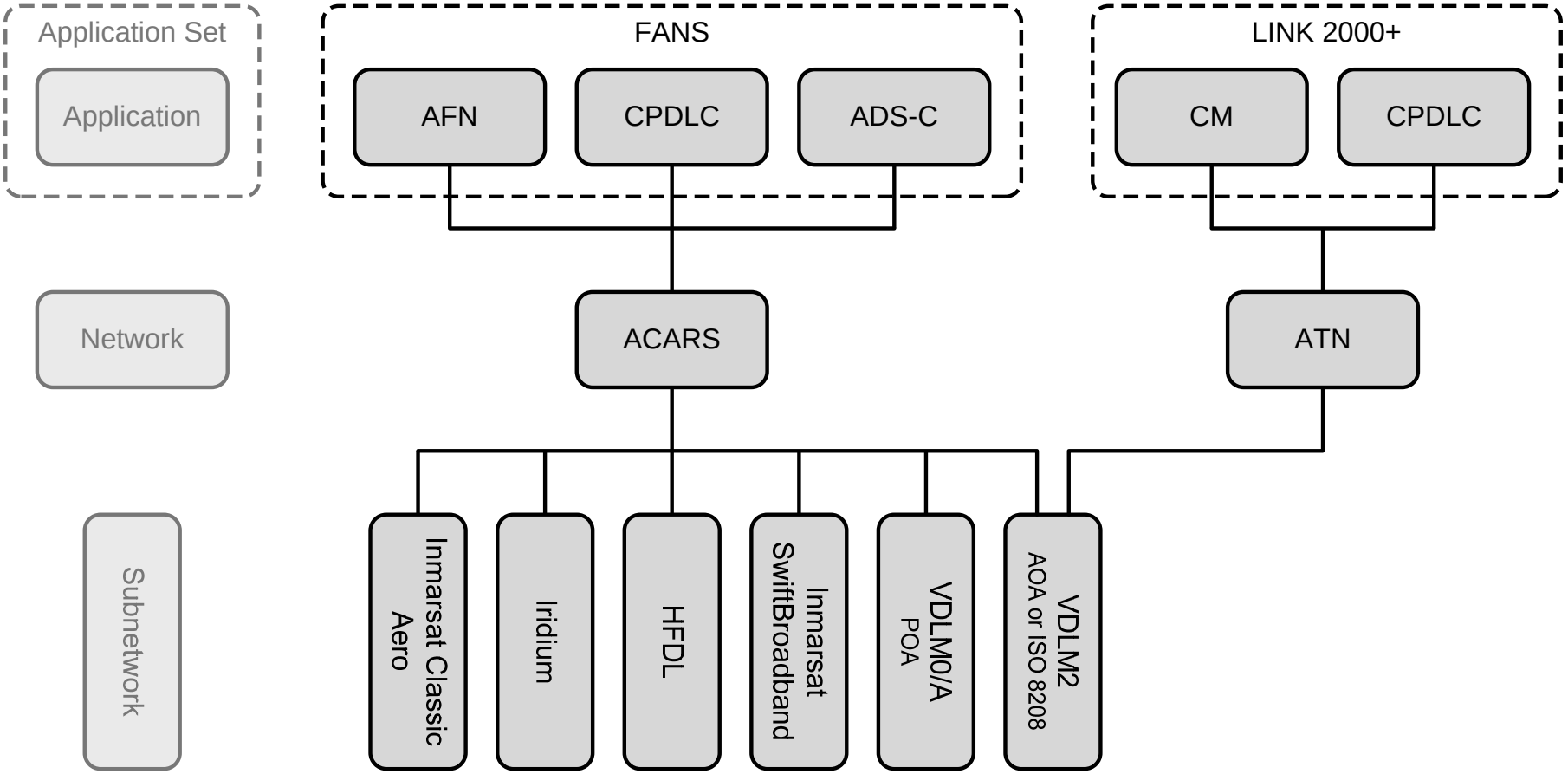
Infrastructure

- Subnetworks *(continued)*
  - Long-range, beyond line-of-sight subnetworks
    - Inmarsat Classic Aero SATCOM
    - Iridium SATCOM
      - Provides polar coverage
    - HF Data Link (HFDL)
      - Provides polar coverage
      - Generally a last-choice subnetwork due to performance challenges
    - Inmarsat SwiftBroadband SATCOM
      - High-speed, IP-oriented
      - FAA Performance-based operations Aviation Rulemaking Committee (PARC) Communications Working Group (CWG) is currently evaluating the viability of FANS-over-SwiftBroadband, with promising results so far
    - *[future]* Iridium Certus (using Iridium NEXT constellation)
      - Will provide high-speed, IP-oriented link and polar coverage

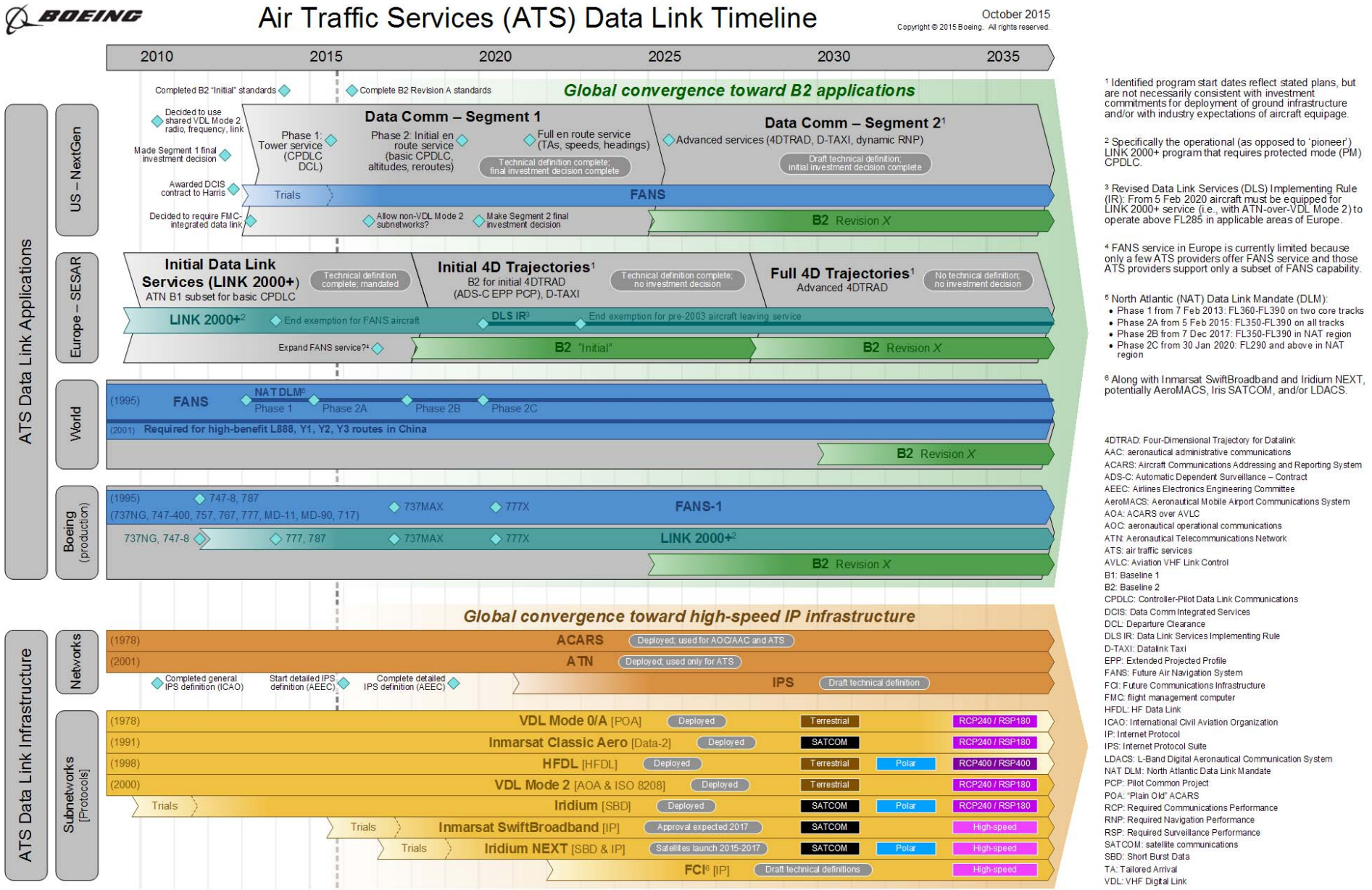
Infrastructure

- Boeing capabilities
  - Networks
    - All Boeing airplane models are capable of using the ACARS network
    - Most Boeing airplane models are capable of using the ATN network
  - Subnetworks
    - All Boeing airplane models 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 HFDL
      - Newer avionics offer customization of subnetwork preferences, geographic regions, POA frequencies, AOA service providers, etc.
  - Depending on the airplane model, some network and subnetwork capabilities are standard and some are optional

Architecture Diagram



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

PBCS

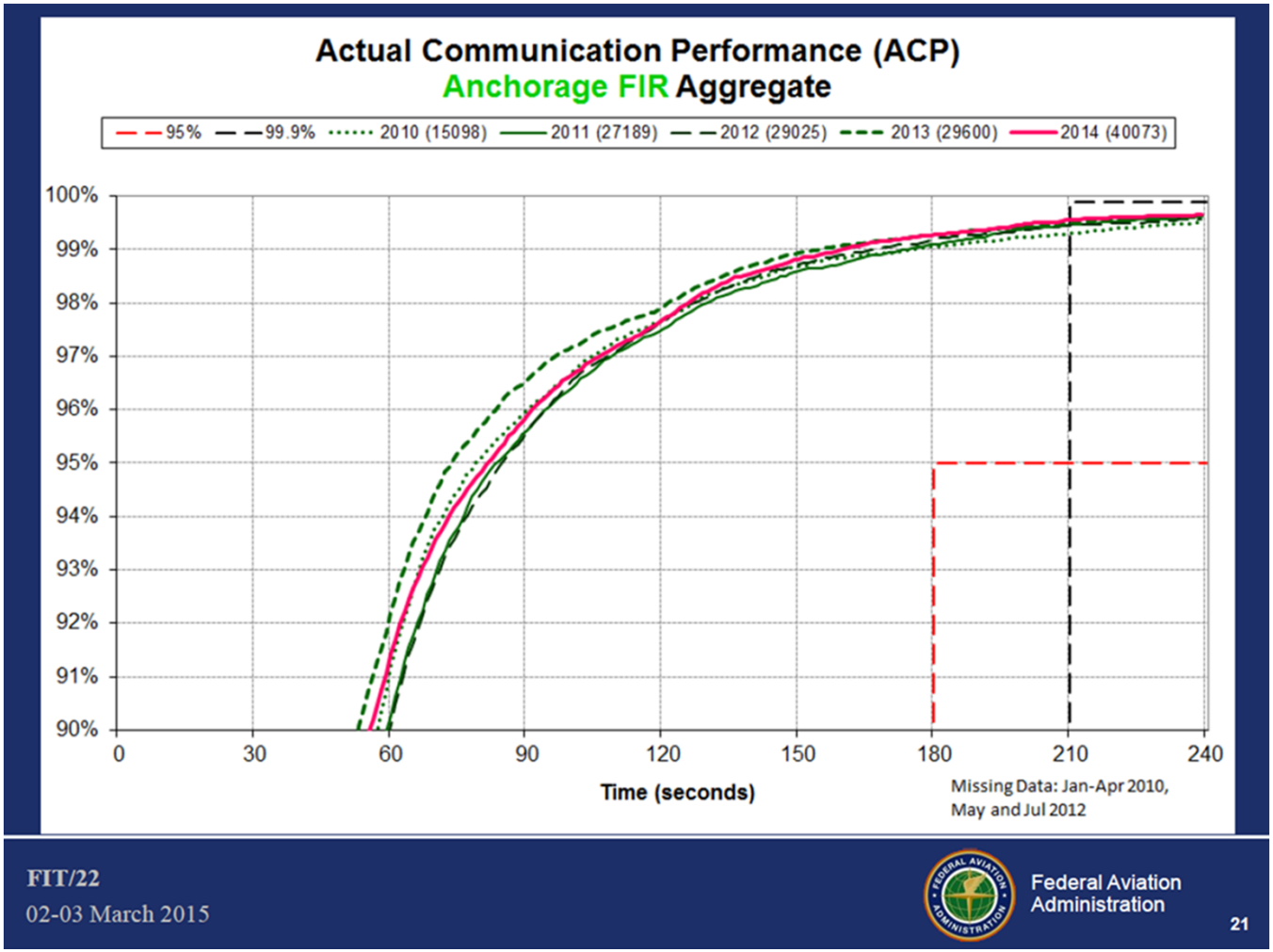
- Performance-Based Communication and Surveillance (PBCS)
  - PBCS is a concept for prescribing and complying with objective operational criteria for communication and surveillance performance
    - This modern performance-based approach is more effective than earlier technology-specific approaches
  - PBCS includes Required Communication Performance (RCP) and Required Surveillance Performance (RSP) specifications
    - RCP and RSP specifications include availability, integrity, and continuity requirements
    - Continuity “overdue time” requirement provides name; for example, RSP180 requires that 99.9% of ADS-C reports be delivered to ATS provider within 180 seconds

PBCS

- PBCS *(continued)*
  - PBCS also includes post-implementation monitoring to assess performance and investigate problem reports
    - Regional groups perform this function, including:
      - South Atlantic (SAT) FANS Interoperability Team (FIT)
      - North Atlantic (NAT) Technology and Interoperability Group (TIG)
        - Formerly the Communications, Navigation, and Surveillance Group (CNSG)
      - European Data Link Services (DLS) Central Reporting Office (CRO)
      - Informal Pacific ATC Coordinating Group (IPACG) FIT
      - Informal South Pacific ATS Coordinating Group (ISPACG) FIT
      - FIT Asia

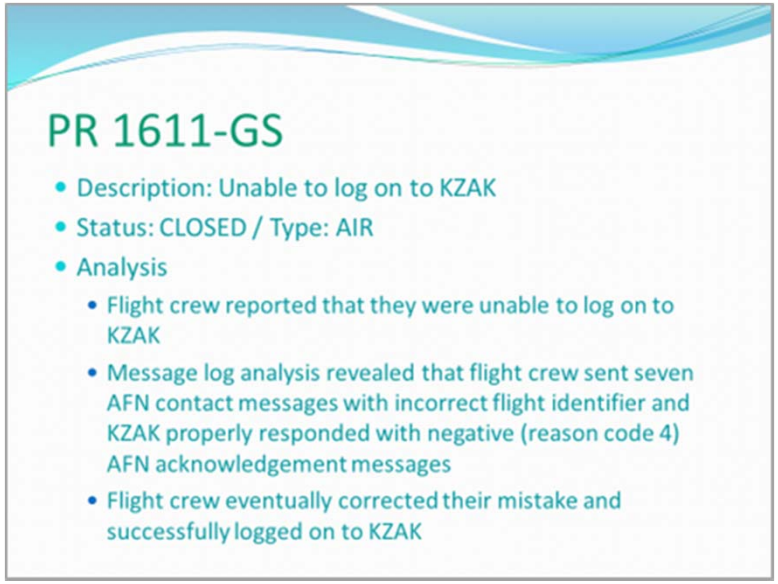
PBCS

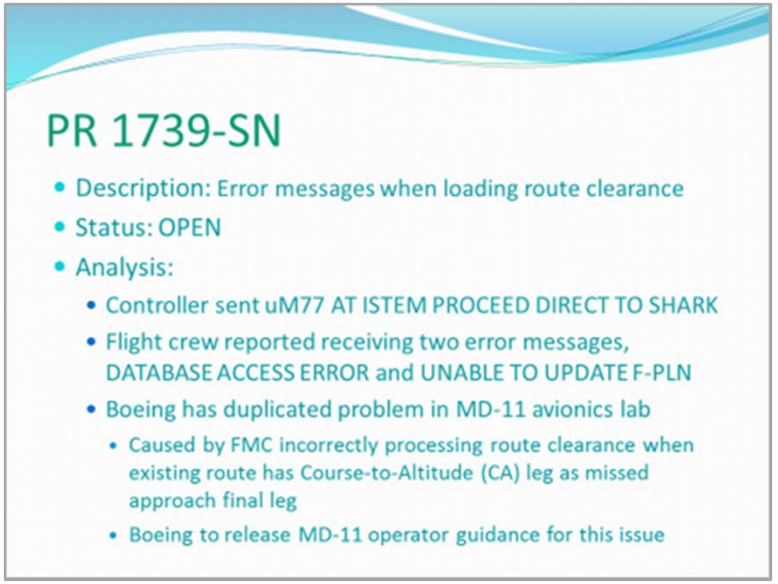
- PBCS post-implementation monitoring *(continued)*
  - ATS providers assess performance in their control areas



PBCS

- PBCS post-implementation monitoring *(continued)*
  - Regional sub-groups investigate problem reports, including:
    - SAT Central FANS Reporting Agency (CFRA)
    - NAT Data Link Monitoring Agency (DLMA)
    - IPACG Central Reporting Agency (CRA)
    - ISPACG CRA
    - FIT Asia CRA
  - These sub-groups provide briefings at regional group meetings





PBCS

- PBCS post-implementation monitoring *(continued)*
  - Boeing provides NAT DLMA, IPACG CRA (for US airspace), ISPACG CRA, and FIT Asia CRA problem report investigation services
  - In that role, Boeing would welcome coordination with the SAT CFRA
    - Especially for avionics and network problems that occur across regions
  - As Boeing itself, Boeing offers to support SAT CFRA problem report investigations that involve Boeing airplanes
    - Partial list of closed problem reports against Boeing airplane models:

PR	System	Description	Status	Notes
1358-MM	777	777 "ack-n-toss" issue (ACARS avionics acknowledge receipt of FANS uplinks but do not deliver them to the FANS avionics)	CLOSED	CLOSED with availability of 777 AIMS-2 BPV17.1 software
1405-GS	787	787 loses SATCOM link after losing VHF Cat B link	CLOSED	CLOSED with availability of 787 CMF BP2.5 software
1480-SN	MD-11	MD-11 sends unexpected ADS-C lateral deviation report	CLOSED	CLOSED with availability of MD-11 FMC -922 software
1534-GS	787	787 does not respond to AFN uplink messages	CLOSED	CLOSED with availability of 787 CMF BP2.5 software
1585-GS	787	787 does not respond to ADS-C uplink messages	CLOSED	CLOSED with availability of 787 CMF BP2.5 software
1726-RP	747-8	747-8 Inmarsat Classic Aero SATCOM avionics issues	CLOSED	CLOSED with availability of Rockwell Collins SDU-2200 part number 822-2556-103
1760-GS	787	787 SATCOM avionics issues	CLOSED	CLOSED with availability of 787 CMF BP3 software
1798-GS	787	787 fails to send armed MAINTAINING [altitude] reports	CLOSED	CLOSED with availability of 787 CMF BP3 software
1943-RP	747-8	747-8 (or 747-400 with 747-8 FMC) AFN protocol errors	CLOSED	CLOSED with availability of 747-8 FMC BP3.1 software

Conclusion

- Boeing is a strong supporter of ATS data link and the benefits it provides
- Boeing is working to improve existing ATS data link technologies and procedures and to develop new ones
- Both as the CRA/DLMA for other regions and as Boeing itself, Boeing offers its assistance to the SAT FIT and SAT CFRA

Thank you

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