Preparing for Transition – Accommodation of Mixed Data Communication Equipage for a Harmonized Future

Gregory Saccone – Boeing Research & Technology
Ryan Hale – Boeing Research & Technology
Michael Matyas – Boeing Commercial Airplanes
Michael Olive – Honeywell

ICNS 2018
10 - 12 April 2018
As Communication, Navigation and Surveillance (CNS) technologies advance to achieve greater efficiency, airspace user requirements become more complex:

- Transition from traditional voice/nav aid/radar to include data link/performance-based navigation/automatic dependent surveillance
- These equate to more advanced aircraft equipage
- There is also more integration between the aircraft avionics and the ground system flight data processing systems, resulting in more exacting requirements:
  - Data formats and displays
  - Flight plan and uplink message creation and loading
  - Downlink information capability

Different airspaces also employ different technology and procedures.

Different airframes and avionics vendors have variations due to age of aircraft, cockpit design philosophies, aircraft capabilities, etc.

Managing this transition is a challenge.
There are three principal elements of aeronautical data communications systems:

<table>
<thead>
<tr>
<th>Applications</th>
<th>Integrated ATC services between an ANSP and airspace user (flight crew or avionics)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• E.g., CPDLC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Networks</th>
<th>Transport data between end users, including intermediate routing of messages as necessary to reach their intended destinations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• E.g., ACARS, ATN/OSI, TCP/IP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical Links</th>
<th>Connect specific systems directly with each other, using either wired or wireless communications.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• E.g., VDL Mode 2, Ethernet, and AeroMACS.</td>
</tr>
</tbody>
</table>

For global ATS data communications, there are essentially two application sets and two network standards at present:

- Applications: FANS-1/A and LINK2000+
- Networks: ACARS and ATN/OSI
Current Environment – Applications

- **Future Air Navigation System (FANS)**
  - FANS AFN, CPDLC, and ADS-C applications
  - Normally FMC-integrated – supports TBO and similar capabilities not possible with voice communications
  - Initially operational in South Pacific in 1995, now operational or planned in many areas worldwide

- **LINK 2000+**
  - Consists of LINK 2000+ CM and CPDLC applications
    - Subset of EUROCAE ED-110B Aeronautical Telecommunication Network (ATN) Baseline 1 (B1), which in turn is a subset of ICAO Doc 9705 ATN
  - Normally not FMC-integrated – does not support TBO
    - Limited message set intended to replicate 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
    - Original 2013/2015 mandate delayed five years to 2018/2020
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

Aeronautical Telecommunication Network Open Systems Interconnection (ATN/OSI)

- Based on OSI reference model and OSI standards
- 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/OSI protocols create a very large amount of overhead message traffic that is difficult for VDL Mode 2 to handle
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.
Baseline 2 (B2)

- Recently defined by RTCA SC-214 and EUROCAE WG-78
  - “Initial” standards were published in April 2014, Rev A standards were published in March 2016
  - Future revisions to be determined depending on ground deployment plans and specific services selected
- 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
- Rev A standard includes Advanced Interval Management (A-IM) and Dynamic Required Navigation Performance (D-RNP) service additions
Internet Protocol Suite (IPS)

- In development in ICAO (Doc 9896) and AEEC (ARINC 658, 858) and RTCA
- 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 application level backward compatibility by carrying AOC, AAC, and FANS ATS application messages that ACARS has traditionally carried, as well as carrying future B2 ATS application messages
- Boeing and others are working to accelerate IPS development
- Boeing, Honeywell, Inmarsat and SITA have successfully performed over-the-air tests of CPDLC-over-IPS-over-VDL Mode 2 and Swiftbroadband in both laboratory and flight test environments
The Coordination Committee (CCOM) consisting of FAA, SJU and EUROCONTROL members had identified an action to develop an air-ground data communications strategy and roadmap between the US and EU.

This was done by teams led by the FAA and SJU, and included industry participants from both US and Europe.

A paper detailing the initial analyses as well as opportunities for further investigation was produced and presented to the CCOM.
The U.S. and the EU air/ground data communication roadmaps for ATM operations in their respective Continental and Oceanic airspaces point to a harmonized environment based on:

- Baseline 2 (B2) for the ATM operational service applications,
- ATN/IPS for the network, and
- A mix of current VDL Mode 2, new high bandwidth SATCOM and a new terrestrial physical data link and other means suitable for ATM operational services
Challenges of Network Transition

- The US and EU agree on a harmonized Data Link end state (B2 using ATN/IPS over various physical links)
  - The US does not plan to implement OSI-based protocols; Segment 2 is planning to use ATN/IPS
  - The EU has implemented ATN/OSI-based protocols, but is still dealing with performance issues (mandate delayed by 5 years, 2018 for ground, 2020 for aircraft)

- ATN/IPS was designed to support multiple applications types
  - Includes FANS-1/A, LINK2000+ and B2 as well as other ACARS-based applications

- But we still need to deal with the network transition challenge to get to the agreed on end-state:
  - US, and likely rest of the world: ACARS to ATN/IPS
  - Europe: ATN/OSI to ATN/IPS
Ground Gateways could help to handle the transition
- Ground accommodation of different network technologies; retains airline investment
- Flexibility in architecture and deployment
- Could provide addressing advantages (e.g. similar to CM server)
- Payloads remain in original format – no breaking of checksums at the application level
- Still areas to clarify, but viewed as viable to airframers, CSPs, avionics OEMs
Boeing and others started exploring aspects of the gateway based on Joint ATN/IPS Research project work done to date

- Started with ATN/OSI – ATN/IPS as per initial validation work
- In-line with joint partner plans, progressing to ACARS – ATN/IPS
- Eventual end state of triple-stack ground gateway (not triple stack in air!)

Gateway is used for testing purposes and requirements analysis and development

- Confirm proof of concept, feasibility
- Support CM, CPDLC transactions
- ATN/OSI – ATN/IPS, ATN/IPS – ATN/OSI traffic flow
- Initial performance analysis
- Outputs from gateway testing will be back into requirements development in relevant standards bodies
ATN/IPS – ATN/OSI Gateway Functional Diagram

End-End Correlation between Gateway and aircraft

Maintained correlation between aircraft connection and ground connection

End-End Correlation between Gateway and ATC

VDLM2 Ground Station

ATN/OSI Equipped Aircraft

ATN/IPS ATN/OSI Gateway

Protocol Conversion and flight correlation

OSI Router (Depending on architecture choices)

IP, UDP, TCP/UDP

IP Network

ATN/IPS ATC

IP
Gateway Software:
- Air-ground end system correlation
- State machines
- Messaging (OSI primitive – IPS primitive)
- Data (OSI PDU to IPS ATNPKT)
Example Message Flow

CM-Logon Request created and sent

Correlation performed between aircraft and ground system; ground system addresses determined, state machines created

CM-logon information packaged in ATNPKT

CMLlogonRequest APDU extracted, along with relevant dialog service parameters

CM-Logon Request received via IPS
### ATN/IPS Gateway Sample Screen Shot

**EIN1235**

24 Bit Address: 414637  
Dep: EIDW  
Dest: KSEA

**CM**  
47002781435056000000000001234567890101636D  
127.0.0.1:5910

**CPDLC**  
470027C183657500414637001000040141303101706D  
127.0.0.1:5911

#### ATN/OSI (Doc 9880)

<table>
<thead>
<tr>
<th>Application</th>
<th>Primitive</th>
<th>State</th>
<th>Primitive</th>
<th>Seq R</th>
<th>Seq S</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPDLC</td>
<td>PMCPDLC_MESSAGE_REQ</td>
<td>CPDLC-DIALOGUE</td>
<td>D_DATA</td>
<td>2</td>
<td>1</td>
<td>CPDLC D-TRANSFER</td>
</tr>
</tbody>
</table>

#### ATN/IPS (Doc 9896)

<table>
<thead>
<tr>
<th>CPDLC</th>
<th>PMCPDLC_MESSAGE_REQ</th>
<th>CPDLC-DIALOGUE</th>
<th>D_DATA</th>
<th>2</th>
<th>1</th>
<th>CPDLC D-TRANSFER</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPDLC</td>
<td>PMCPDLCMESSAGE_IND</td>
<td>DPDL DIALOGUE</td>
<td>D_DATA</td>
<td>1</td>
<td>1</td>
<td>CPDLC D-TRANSFER</td>
</tr>
<tr>
<td>CPDLC</td>
<td>PMCPDLC_START_CNF</td>
<td>DPDL DIALOGUE</td>
<td>D_STARCNF</td>
<td>1</td>
<td>0</td>
<td>CPDLC D-START-RC</td>
</tr>
<tr>
<td>CPDLC</td>
<td>PMCPDLC_START_REQ</td>
<td>CPDLC-START-REQ</td>
<td>D_START</td>
<td>0</td>
<td>0</td>
<td>CPDLC START-SENT</td>
</tr>
<tr>
<td>CM</td>
<td>CM_LOGON_RSP</td>
<td>CM-IDLE</td>
<td>D_STARCNF</td>
<td>1</td>
<td>0</td>
<td>CM D-START-RC</td>
</tr>
<tr>
<td>CM</td>
<td>CM_LOGON_IND</td>
<td>CM-LOGON</td>
<td>D_START</td>
<td>0</td>
<td>0</td>
<td>CM D-START-SENT</td>
</tr>
</tbody>
</table>

**Message History**

- **CPDLC**  
  14:51:34  
  PMCPDLC_MESSAGE_REQ  
  CPDLC-DIALOGUE  
  D_DATA  
  2  
  1  
  CPDLC D-TRANSFER

- **CPDLC**  
  14:51:33  
  PMCPDLCMESSAGE_IND  
  CPDLC-DIALOGUE  
  D_DATA  
  1  
  1  
  CPDLC D-TRANSFER

- **CPDLC**  
  14:51:32  
  PMCPDLC_MESSAGE_IND  
  CPDLC-DIALOGUE  
  D_DATA  
  1  
  1  
  CPDLC D-TRANSFER

- **CPDLC**  
  14:50:17  
  PMCPDLC_START_CNF  
  CPDLC-DIALOGUE  
  D_STARCNF  
  1  
  0  
  CPDLC D-START-RC

- **CPDLC**  
  14:50:10  
  PMCPDLC_START_REQ  
  CPDLC-START-REQ  
  D_START  
  0  
  0  
  CPDLC START-SENT

- **CM**  
  14:49:54  
  CM_LOGON_RSP  
  CM-IDLE  
  D_STARCNF  
  1  
  0  
  CM D-START-RC

- **CM**  
  14:49:51  
  CM_LOGON_IND  
  CM-LOGON  
  D_START  
  0  
  0  
  CM D-START-SENT
ATN/IPS Gateway Benefits

- Preservation of airline and ANSP investments in end system implementations
  - No changes to flight deck and flight data processing applications

- Flexibility in architecture and deployment
  - The ATN/IPS Gateway can be hosted at ANSPs, CSPs, or a combination

- Data payloads remain in original encoded format and are untouched
  - Application data and integrity checks are intact and preserved from an end-end perspective

- Potential for application addressing advantages
  - If implemented similar to a CM-server concept, would require fewer addresses

- Enhanced security context
  - Addition of a potential gateway security endpoint to provide a form of link-layer security

- Transition assistance with aircraft
  - Regardless of equipage, would allow continued benefits while building towards end state goals
ATN/IPS Gateway Areas for Further Clarification

Topology Options

- Keep in mind most aviation networks do not fully support native protocols (e.g. OSI, ACARS) once the data has reached the ground
- Lots of options for architecture, but need to take current topologies into account
  - Service provider-defined from air-ground access points
  - Co-located with existing boundary routers (e.g. with existing OSI routers)
  - ANSP co-located at end system locations
  - Centralized location, tunneled network access
- Details of intermediate protocols...extend network, transport end-points
- How to handle access from multiple air-ground stations to a single gateway
  - E.g. if a single gateway is in the US, how is traffic routed from different VHF Ground Stations to that single gateway?
- How many gateways would be necessary?
Areas for Further Clarification, cont’d (1)

- Performance characteristics and validation
  - Ensure that actual communications and surveillance performance (ACP and ASP) are not adversely affected
  - Mapping of states between protocols, consistent behavior

- Addressing requirements and mapping
  - Single gateway addresses per region/ANSP would simplify on-board NSAP data bases
  - Would need some mapping between Facility Designation and IP addresses/NSAP addresses
  - Would end system addresses be transitioned to become Gateway addresses?
    - Minimize changes to on-board NSAP data bases
Areas for Further Clarification, cont’d (2)

- Correlation Requirements need to be confirmed
  - Different than flight data processing system flight plan correlation
  - Is enough information available at connection time to know which ground system has the connection to which aircraft?

- Ground-ground ATN/IPS architectures and consideration
  - How this would fit with existing ATN/OSI ground architectures

- Protocol discrepancies
  - Ensure that certain corner cases where there may be slight technical differences (e.g. ATN/OSI Provider Abort instances) do not have an operational impact
ATN/IPS Gateway Future Work

- Testing with prototype ATN/IPS avionics (Boeing, Honeywell, other research partners)
- Further testing with Boeing test bench aircraft, live aircraft
- Plans for ground-ground ATN/IPS, including architecture and integration with existing ATN/OSI as appropriate
- Integration of ACARS component (coordinating with research partners)
- Further requirements refinement based on testing
- Inclusion of requirements into AEEC, ICAO and RTCA standards as appropriate
The ATN/IPS Gateway concept appears to be a promising way to achieve US – EU harmonization goals:

- Supports both the current US and EU near-term data communications plans
- Maximizes stakeholder investment in current equipage, on both the air and ground, while providing a transition path to the future
- Provides flexibility in deployment options and potential advantages in areas like security and addressing
- Supports applications other than ATS-only, enhancing the business case for operators

There are still challenges to be addressed and further definition required

- These areas are being addressed by Boeing, Honeywell and other joint research partners as well as other organizations in research and development
- ICAO, AEEC and RTCA standards committees are also working on this
Thank you!
Boeing, Honeywell, and many others have recognized limitations of existing ACARS and ATN/OSI

- Aviation-unique protocols, which drive-up life cycle costs
- Technical issues with current ATN/OSI deployment in Europe
- ATN/OSI and ACARS are not designed to support IP-based applications that take advantage of broadband IP communication links
- Security provisions for ACARS and ATN/OSI are not deployed

ICAO Doc. 9896 defines Internet Protocol Suite (IPS) for Safety Services

- Specifies an adaptation layer that allows existing (B1) and future (B2) services to interface with standard transport protocols (e.g., TCP, UDP) and operate over IP-based links
- Ground rule is to have no changes to existing applications when migrating from OSI to IPS network protocols
- Update in process to define encapsulation for existing ACARS applications, including FANS and AOC messages
- Boeing and Honeywell contributed to the initial IPS standards

Industry Standards in AEEC and RTCA are currently underway
IPS Protocol Transition
Boeing Research & Technology and Honeywell Aerospace Advanced Technology are conducting joint research to pursue common interests in IPS technology.

Efforts include laboratory and field demonstrations of IPS technology using:
- Representative avionics hardware running prototype IPS software
- Simulated IPS ground end systems
- Live (operational) air-ground communication links

Key Objectives
- Validate existing IPS technical provisions in ICAO Doc. 9896
- Identify implementation constraints
- Analyze the impact on avionics and avionics architectures
- Identify opportunities for further IPS investigation, definition, and standardization
Service Applications

Diagram from “European Union and United States Air/Ground Data Communications Strategy”, 7 November 2017
### Consolidated Air/Ground Data Comm Services and Technology Roadmap

#### CY 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

**USA/Europe Oceanic**  
- **Application**  
  - FANS 1/A  
  - ACARS  
  - VDL2 (ACARS) & VDL20 (ACARS)  
  - SATCOM Classic – Class C (ACARS)

**USA/ Europe Network**  
- **Physical Link (Subnetwork)**  
  - Initial Enroute  
  - B2 revA  
  - Advanced Services  
  - B2 revB and beyond (B3)

**Europe Continental**  
- **Application**  
  - EUR ATN B1  
  - OSI  
  - VDL2 (OSI)

**USA Continental**  
- **Application**  
  - FANS 1/A  
  - DCL  
  - Initial Enroute  
  - Full Enroute  
  - B2B  
  - Advanced Services

**KEY**  
- Supports ACARS  
- Supports IPS  
- Supports OSI  
- Under Consideration  
- Expected Sunset Timeframe

#### Expected Sunset Timeframe
- EUR Only  
- EUR & US  
- SATCOM Class B  
- Future Potential Class A (IPS)  
- Future Terrestrial Datalink  
- AeromACs – Airport Surface Only

Diagram from “European Union and United States Air/Ground Data Communications Strategy”, 7 November 2017