Challenges for Achieving the Full Potential of PNT in Civil Aviation

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With the help of faculty and students from ICAT
Components of Air Transportation Infrastructure

- **Airports**
  - Runways
  - Terminals
  - Ground transport interface
  - Servicing
  - Maintenance
- **Air Traffic Management**
  - Communications
  - Navigation
  - Surveillance
  - Control
- **Weather**
  - Observation
  - Forecasting
  - Dissemination
- **Skilled personnel**
- **Cost recovery mechanism**
System Evolution Drivers

- Increasing Demand
- Safety
- Capacity & Access
- Efficiency & Environment
Model of Evolution of Air Transportation System

Drivers

System Capability

Implementation Process
Safety and Environmental Approval Processes

Solution Refinement Loop

Stakeholder Preferences

Change Process

Negotiation Loop

Collective Decision Making

Objective Formation

Awareness Building Process

Stakeholder Values, Context

Stakeholder Awareness

Public Awareness

Catalytic Event

System Behavior

NAS

Capability Opportunities
System Evolution Challenges

- Maintaining High Level of Safety
- Complexity
- Achieving Operational Benefits
  - Airborne Elements
  - Infrastructure Elements
  - Procedures
- Multi-Stakeholder Considerations
  - Mixed Equipage
- Environmental Considerations
  - Noise
  - Emissions
System Complexity
FAA “Simplified” NAS Architecture
Stakeholder Benefits Dependent Upon Approved Applications and Operational Capabilities

Capabilities
- Aircraft Operational Capability
- Operational Procedures
- ATC Operational Capability

Applications
- Application 1
- Application 2
- ....
- Application x

Stakeholder Benefits
- stk₁
- stk₂
- stk₃

Level of Benefit/Cost
- Significant
- Some/Indirect
- None/Insignificant

Disaggregate benefit/cost approach adapted from Marias and Weigel
Modernization Cannot Compromise Exceptionally High Level of Aviation Safety

Fatal Accidents | Worldwide Commercial Jet Fleet | 1959 through 2017

Source: 2017 Boeing Statistical Summary
SAFETY MANAGEMENT SYSTEMS

ICAO Annex 19

FAA Order 8000.369B

1. This order establishes the Safety Management System (SMS) policy for the Federal Aviation Administration (FAA) and requirements for FAA organizations incorporating SMS and/or International Civil Aviation Organization (ICAO) State Safety Program (SSP) frameworks to form the overall FAA SMS. Specifically, this order:

   a. Further safety management by evolving to a more process-oriented system safety approach with an emphasis on Safety Risk Management (SRM) and Safety Assurance.

   b. Sets forth basic management principles to guide the FAA in safety management and safety oversight activities.

   c. Requires adopting a common approach to implementing and maturing an integrated SMS, including fostering a positive safety culture and other attributes as applicable.

   d. Defines the roles and responsibilities of the FAA organizations, FAA SMS Executive Council, and FAA SMS Committee regarding safety management.

2. This order applies to the following Lines of Business (LOB) and Staff Offices: Air Traffic Organization (ATO), Aviation Safety Organization (AVS), Office of Airports (ARP), Office of Commercial Space Transportation (CST), the Office of the Next Generation Air Transportation System (NGATS), and the Hazardous Materials Safety Program in the Office of Security and Hazardous Materials Safety (SHMS). This order is written to allow for application to other FAA organizations as deemed appropriate by the Administrator.

Michael P. Huerta
Administrator

Distribution: Electronic

Initiated By: AVS-1
Two Approaches to Safety Analysis

• Equivalent Level of Safety
  – If technical performance can be shown to be equivalent or superior to existing system then system is assumed to maintain or improve safety
  – Useful for Technology Substitution
  – Tends to replicate existing system
  – Performance gains are often marginal

• Target Level of Safety
  – Proposed system or procedure must meet target safety levels defined by risk analysis
  – Requires assumptions and modeling which must be accepted by regulators
  – Limited number of successful examples
    • UAS Part 107, RVSM North Atlantic
ATM Modernization Efforts

- Hypothesis: High safety performance of current system (with SMS) makes it difficult to implement real operational improvements.
  - Technical Transition Easier than Operational Procedure Transition
NextGen-SESAR-ICAO
Common Technical Elements

**Navigation**
- PBN
- RNAV/RNP

**Surveillance**
- ADS-B

**Communications**
- CPDLC
- VDL Mode 2
NextGen-SESAR-ICAO
Common Technical Elements

Navigation
- PBN
- RNAV/RNP

Surveillance
- ADS-B

Communications
- CPDLC
- VDL Mode 2
Performance Based Navigation
RNAV and RNP

NEXT GEN Components: RNAV/RNP
Moving to Performance-Based Navigation

Conventional Routes
Today’s airways connect ground-based navigation aids

RNAV
Area Navigation (RNAV) routes follow defined “waypoints”

RNP
Required Navigation Performance (RNP) routes within specified “containment area”

>95% air carrier fleet
>30% air carrier fleet

Limited Design Flexibility
Increased Airspace Efficiency
Optimize Use of Airspace

Source: Federal Aviation Administration
Source: Bruce Declene FAA
Benefit - RNAV Enabled Direct Routing

China

US

Not Quite - Free Flight
Benefit - RNP Based Improved Access

- Pioneered by Alaska Airlines

Source: Brian Kelly, Boeing
Challenge - Existing Infrastructure and Limited Benefit Limit GBAS Procedures GLS (GPS/GNSS)

- Highest Benefits for New Procedures in Locations Without Existing ILS
- Difficult to supersede existing ILS
  - ILS Air and Ground infrastructure widespread
- Operator Benefits Limited
Safety Benefit – Improved Situation Awareness
Honeywell EGPWS (TAWS)
Prototype MIT Terrain Alerting Displays

Collaboration with Don Bateman Honeywell

Jim Kuchar Thesis 1995
Catalytic Event Implementation Example

Drivers

System Capability

Implementation Process

Safety and Environmental Approval Processes

Solution Refinement Loop

Selected Actions

Change Process

Negotiation Loop

Stakeholder Preferences

Collective Decision Making

Objective Formation

Stakeholder Values, Context

Awareness Building Process

System Behavior

Catalytic Event

Capability Opportunities

Public Awareness

Stakeholder Awareness
Catalytic Event – American Airlines Flight 965

- Cali, Colombia December 20, 1995
- US Mandate Proposal April 1998
- Implemented March 2000
Fatalities by Accident Category

Total Fatalities = 6,795 (6,484 onboard)
- 2003 fatalities = 484 (483 onboard)

Number of fatal accidents 105 total
- Loss of control in flight: 32
- CFIT\*: 24
- Mid-air collision: 2
- In-flight fire: 2
- Fuel tank explosion: 2
- Structure: 1
- Takeoff configuration: 1
- Landing: 16
- Runway incursion: 3
- Wind shear: 8
- Misc. fatality: 3
- Fuel exhaustion: 12
- RTO\*: 1
- Turbulence: 2
- Unknown: 258

Note: Accidents involving multiple, non-onboard fatalities are included. Accidents involving single, non-onboard fatalities are excluded. Fatalities/accidents are placed in one category only.

* CFIT = Controlled Flight Into Terrain
** RTO = Refused Takeoff
Fatalities by CICTT Aviation Occurrence Categories
Fatal Accidents | Worldwide Commercial Jet Fleet | 2008 through 2017

- External fatalities (Total 125)
- Onboard fatalities (Total 2261)

Number of fatal accidents (55 total)

Note: Principal categories as assigned by CAST.
For a complete description of CAST/ICAO Common Taxonomy Team (CICTT) Aviation Occurrence Categories, go to www.intlaviationstandards.org.
THE CFIT FATAL AND NON FATAL ACCIDENT RATES HAVE BEEN DECLINING

FIGURE 4: DISTRIBUTION OF CFIT ACCIDENT RATES (FATAL VS NON-FATAL) PER YEAR

Source: IATA GADM DB 2008-2017
ATC Benefit – RNAV Procedures

ATL Departure Procedures Before RNAV

- Departures are vectored
  - Headings, altitudes and speeds issued by controllers
  - Large number of voice transmissions required
- Significant dispersion
  - Tracks are inconsistent and inefficient
- Limited exit points

Source: Bruce DeCleene, FAA
ATC Benefit – RNAV Procedures

ATL Departure Procedures After RNAV

- Departures fly RNAV tracks (not vectored)
  - Headings, altitudes and speeds are automated (via avionics)
  - Voice transmissions reduced (30-50%)
- Dispersion Reduced
  - Tracks more consistent and efficient
- Additional exit points available

Source: Bruce DeCleene, FAA
Challenge – RNAV Track/Noise Concentration

BOS Runway 33L Departures: 2010-2015

2010

2015
Challenge – RNAV Track/Noise Concentration

BOS Noise Complaint Locations

2010

2017

6.1 nmi
6.1 nmi
NextGen-SESAR-ICAO
Common Technical Elements

Navigation
- PBN
- RNAV/RNP

Surveillance
- ADS-B

Communications
- CPDLC
- VDL Mode 2
Current Radar Surveillance Limitations

- Update Rate
  - Terminal – 4.2 sec
  - Enroute – 12 sec

UA 123
350C
B757 310
Separation Assurance Considerations

- Personal Safety Buffer
- Minimum Separation Standard
- Procedural Safety Buffer
- Surveillance Uncertainty
- Hazard Zone
Improved Surveillance has not led to Reduced Separation Standards

WHEN STANDARDS WERE DEVELOPED (e.g. 1950s for en route radar)

IMPROVED SURVEILLANCE ENVIRONMENT (e.g. today for en route radar)

- Surveillance has improved, but separation minima have not changed: procedural safety buffer has implicitly increased
**ADS-B (1 sec update)**

**Air Traffic Control (ATC)-Based Applications**
- Surveillance
- Separation procedures
- Trajectory-based operations

**Cockpit-Based Applications**
- Self-separation
- Equivalent VFR operations
- Traffic & runway awareness
- Airspace, weather, terrain awareness
- Precision Navigation

**Ground Component**
- ADS-B In: Information transmitted from ground to the aircraft

**Air Vehicle Component**
- ADS-B Out: Position & intent broadcast from aircraft to ground or other aircraft
- Avionics Integration

**Air to Air**
- Aircraft Cockpit
  - Cockpit-Based Applications
    - Self-separation
    - Equivalent VFR operations
    - Traffic & runway awareness
    - Airspace, weather, terrain awareness
    - Precision Navigation

**Air to Ground**
- Operating Procedures
  - ATC-Based Applications
    - Surveillance
    - Separation procedures
    - Trajectory-based operations

**Global Navigation Satellite System**
- Radar Tracks
- Other Aircraft

**Coverage Volume**
- Air to Air: Information transmitted from one aircraft to another
- Air to Ground: Information transmitted from ground to the aircraft

**Avionics Integration**
- ATC Integration

**Aircraft Cockpit**
- Cockpit-based applications
  - Self-separation
  - Equivalent VFR operations
  - Traffic & runway awareness
  - Airspace, weather, terrain awareness
  - Precision Navigation

**Air Traffic Control (ATC)**
- Radar Tracks
- Other Aircraft

**Global Navigation Satellite System**
- Radar Tracks
- Other Aircraft
Benefit - Cockpit Display of Traffic Information
ANSP Benefit – Surveillance of Remote Regions

Australia Example

ADS-B Track

Radar Track

Source: Greg Dunstone
ADS-B Program Manager
Worldwide ADS-B Coverage

One Week of ADS-B Tracks

Source: FlightAware
Extensive US Radar Coverage Limits Benefits
Stakeholder Benefits Dependent Upon Approved Applications and Operational Capabilities

Disaggregate benefit/cost approach adapted from Marias and Weigel
System Processes Required to Achieve Operational Capability

System Description & Specification Development
- **System Description**: (desired capabilities to artifacts)
- **Specification Development**: (artifacts to detailed specifications)

Safety-Derived Requirements
- **Incorporation of Safety-Derived Requirements**: (detailed specifications to safety requirements)

Operational Approval
- **Safety Approval**: (safety-derived requirements to operational capabilities)

Airborne Components
- **Pilot Certification & Training**
- **Aircraft Certification**
- **Operator Certification**
- **Avionics Specifications**
- **Link Specifications**

Procedural Components
- **ATC Op Policies**
- **Rulemaking**
- **Airspace**
- **Datacom Standards**
- **Acquisition Policies**

Infrastructure Components
- **ATC Automation**
- **Flight Crew Roles**
- **Avionics**
- **Application Specifications**
- **Controller Roles**

Legend
- **System Element Property/State**
- **Element Assessment or Implementation Processes**
- **Required Predecessor**

Roland Weibel (PhD Thesis)
### Proposed ADS-B Procedures

**FAA Application Integrated Work Plan v2.0 2010**

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Limited Operator Benefits and Mixed Equipage
Required ADS-B Out Mandate

DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
14 CFR Part 91
RIN 2120–AI92

Automatic Dependent Surveillance—
Broadcast (ADS–B) Out Performance
Requirements To Support Air Traffic
Control (ATC) Service

AGENCY: Federal Aviation
Administration (FAA), DOT.
ACTION: Notice of proposed rulemaking
(NPRM).

SUMMARY: This notice proposes
performance requirements for certain
avionics equipment on aircraft operating

• ADS-B “Out” mandate by 2020
• Impacts
  – Class A, B, C
  – Mode C veil (30 nm radius)
  – Class E above 10,000
• Requires DO-260A Change 2
• Nav Source Requirements
  – NAC of 9 ~30 meters
  – NIC of 7 (0.3 nm)
• Final commitment date of 2013 for
all ground infrastructure
Satellite Based ADS-B

Aireon ADS-B via Low Earth Orbiting (LEO) Satellites

Source: NavCanada
Satellite Based ADS-B Enables Surveillance in Remote and Oceanic Regions

One Week of ADS-B Tracks

Source: FlightAware
Challenge - Operator Benefits Require Changes to Oceanic ATC Procedures and Systems

North Atlantic Oceanic Tracks

Reduced Lateral Separation – ADS-B or ADS-C
Reduced Track Separation – RNP
User Preferred Routing – Potential ADS-B but requires major ATM procedure changes
Future Challenge – Integration of UAM and UAV will Require Changing Separation Standards

Over 100 companies (of varying credibility) have announced UAM vehicles

### Flying Full-Scale Prototypes
- **Airbus A³ Vahana**
- **Opener Blackfly**
- **eHang 216**
- **Volocopter 2x**
- **Kitty Hawk Flyer**
- **Joby Aviation S4**
- **Workhorse Surefly**
- **Kitty Hawk Cora**
- **Lilium Lilium Jet**
- **Moller Skycar**

### Other Well Funded Developers
- **Boeing – Aurora Flight Sciences**
- **Rolls-Royce**
- **Embraer**
- **Terrafugia**
- **Airbus**
- **Pipistrel**
- **Karem**
- **Bell**

### Many Additional Vehicle Concepts

MIT estimates over $2 Billion invested in UAM vehicles, infrastructure, and technology
SFO Southeast Flow Example
Grey Area not Accessible for Independent Ops

99.5\textsuperscript{th} percentile containment boundaries for conventional SFO operations in western flow

99.5\textsuperscript{th} percentile containment boundaries for conventional SFO operations in southeast flow
Questions?
Satellite Based ADS-B
Iridium Orbital Constellation

Source: NavCanada