National Aeronautics and Space Administration

Feasibility of a Networked Air Traffic Infrastructure Validation Environment for Advanced NextGen Concepts

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NextGEN

Contents

Introduction

- **National Airspace Modernization is Necessary**
  - Delays are costly
  - Congestion, Pollution, Safety
  - High user demand
- **ATM Concepts of Operation (ConOps) Have Been Developed**
  - Rely on Advanced Technologies like Automatic Dependent Surveillance-Broadcast (ADS-B) and Controller-Pilot Data Link Communications (CPDLC)
- **Current State of Research and Development**
  - Modeling
  - Analysis
  - Human-in-the-Loop simulations
- **The Next Step**
  - In-situ flight testing is required to demonstrate full capabilities of ConOps
  - Design requirements, technologies, performance and interoperability standards must be solidified

In Situ Validation Challenges

- **Cost**
  - Airline profit margins are thin
  - Government resources are scarce
  - ADS-B In is expensive ~$130k - $1.2M per aircraft
  - Full-scale flight trials are extremely expensive

- **Message Standards**
  - Commercial Off-the-Shelf systems must comply with existing standards
  - Many advanced concepts not yet supported
  - Additional message content may accelerate user returns on investment
  - Changes will require equipage replacement

Networked Air Traffic Infrastructure Validation Environment (NATIVE)

- **The Challenge**
  - Reduce the cost of validating concepts and message content standards
  - Encourage airlines to equip and participate as partners in flight tests
- **The NATIVE Approach**
  - Emulate advanced data links with existing real-time simulations
    - e.g., ADS-B, CPDLC, and other functions for air-to-air and air/ground data exchange
  - Use easily-installed test equipment and a simple ground-based computing system
    - e.g., In-flight Internet, Tablet PCs, Electronic Flight Bags, Cloud Computing, etc.
  - Transfer data using in-flight Internet as a two-way data link
    - Using retail-grade cellular or satellite connectivity

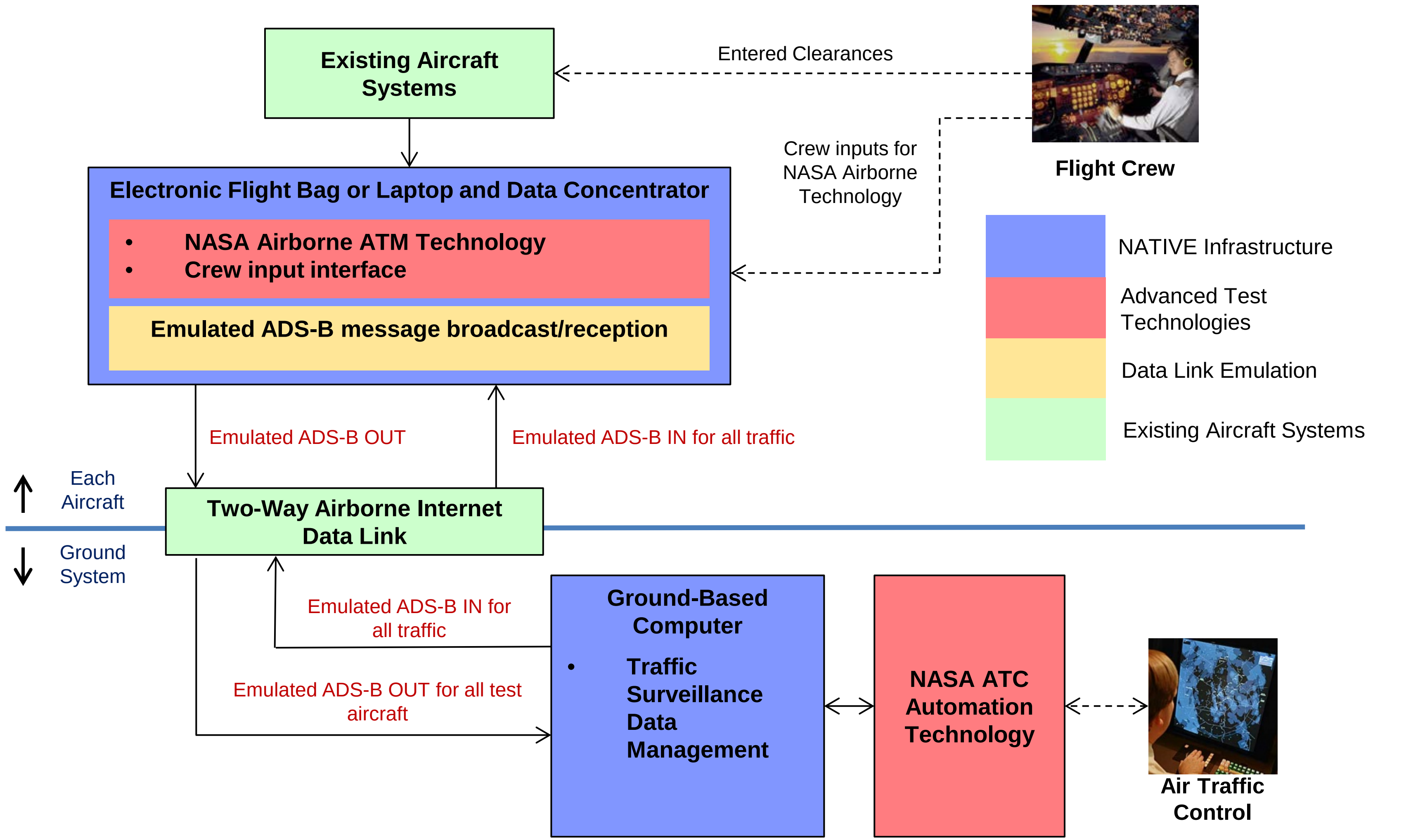
Anticipated NATIVE Benefits

- **Reduces *In Situ* Flight Test Costs**
  - Lower installation and certification costs
  - Flight trial preparation time is substantially reduced
  - Components can be reused several times at many sites
- **Provides a Virtual Validation Environment**
  - Enables rapid adaptation of the test system as standards evolve
  - Easily modifiable to explore and test potential new standards for message content and transfer rate
- **Adds Experimental Control**
  - Simulated aircraft may augment the actual aircraft during tests
- **Reduces Flight Trial Execution Risk**
  - Algorithms and software reside on the platforms on which they were developed
- **Supports Maturation of Concepts that May Benefit Users**
  - May address needs specified in the 2011 Aviation Rulemaking Committee on ADS-B In

NATIVE Flight Test Partnership

- **The Idea**
  - Airlines and other aircraft operators participate as partners in validation trials of proposed future ATM concepts and enabling technologies
- **Operators Provide**
  - Aircraft equipped with in-flight Internet
  - Flight crew
- **Research Organizations and Service Providers Provide**
  - Computing platforms
  - Flight deck automation and display technologies
  - Ground-based components

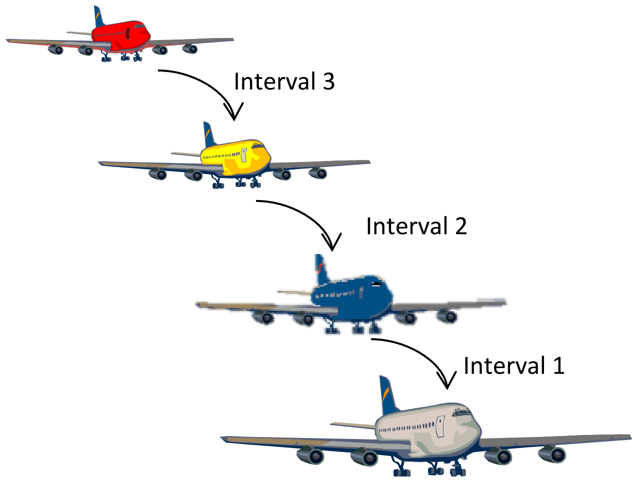
NATIVE ADS-B Emulation Overview



NATIVE Feasibility Study Overview

- **Aspects Examined**
  - Design Configurations for Two ADS-B ConOps
  - Data Transfer Loads and Computational Complexities
  - Performance Requirements of Two In-flight Internet Providers
  - Hardware and Software Requirements
  - Economic Factors and a Preliminary Cost-Benefit Analysis

Flight Deck Based Interval Management (FIM)



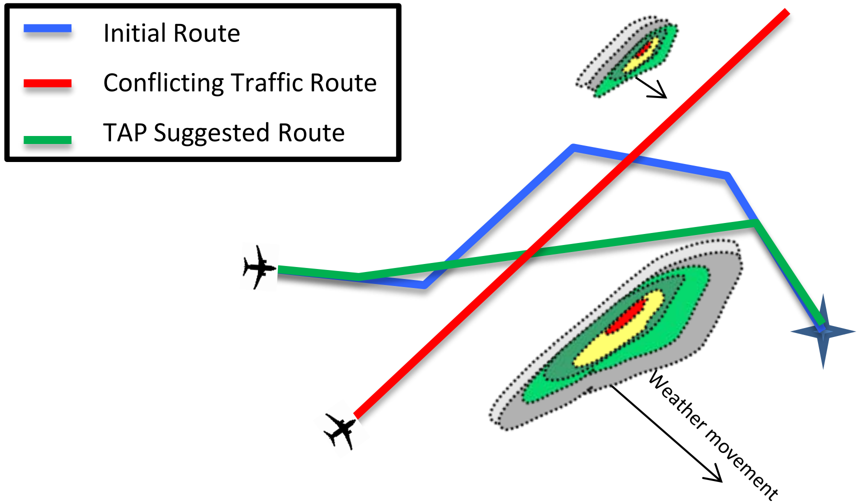
Purpose

Efficiently space aircraft arrival streams

Summary of FIM Configurations

	Traffic Sent to Aircraft	Algorithm Location	ADS-B In Model Location	Air-to-Ground Data	Ground-to-Air Data
Configuration 1	All	Air	Air	Emulated ADS-B	Emulated ADS-B or CPDLC
Configuration 2	Partial	Air	Ground	Emulated ADS-B	Emulated ADS-B
Configuration 3	None	Ground	Air	Emulated ADS-B	Emulated CPDLC

Traffic Aware Strategic Aircrew Requests (TASAR)



Purpose

Allow flight crew to perform flight path optimizations

Summary of TASAR Configurations						
	Traffic Sent to Aircraft	Algorithm Location	ADS-B IN Model Location	ADS-B System	**Air-to-Ground Data**	**Ground-to-Air Data**
Configuration 1	All	Air	Air	Optional	N/A	Emulated ADS-B + Weather
Configuration 2	Partial	Air	Air	No	Emulated ADS-B	Emulated ADS-B + Weather
Configuration 3	None	Ground	None	No	Emulated ADS-B	Emulated CPDLC + Weather

Technical Feasibility: Bandwidth Requirements Per Aircraft

Bandwidth Requirement Breakdown

Data	Bandwidth (kbps)
Ownship ADS-B	0.68
All US NAS ADS-B	7300
ADS-B within 90nmi range	720
Speed guidance	0.13
National NEXRAD Weather Mosaic	190
Ownship TASAR-required	5.2
Intent (100 waypoints)	3.9
All US NAS Aircraft Situation Display to Industry track	52

Bandwidth requirements for FIM and TASAR configurations

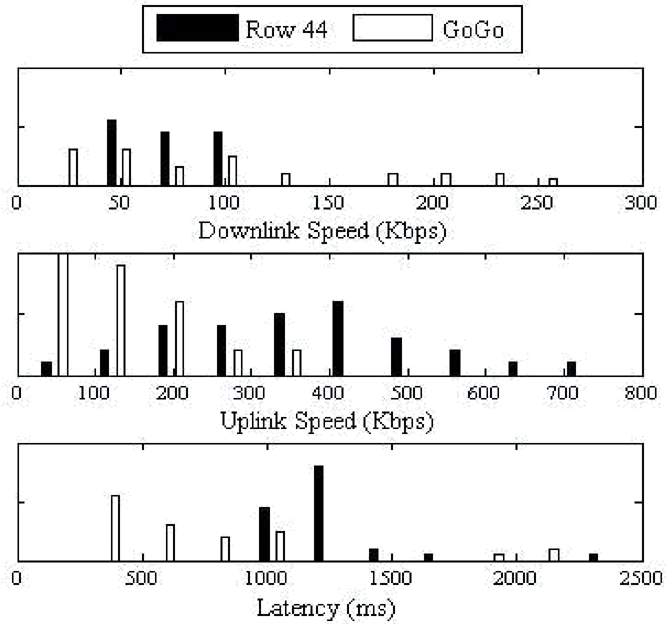
	Downlink (kbps) Upper Limit	Uplink (kbps) Upper Limit
FIM 1	1.7	7300
FIM 2	1.7	720
FIM 3	1.7	0.61
TASAR 1	0	460
TASAR 2	1.7	1000
TASAR 3	10	7.8

Technical Feasibility: Two Major U.S. Domestic In-Flight ISPs

- **Gogo**
  - AirTran, American, Delta, Frontier, United, Virgin America
  - Network Technology: ground-based cellular
  - Air-to-Ground (ATG) 3 System (operational)
    - Theoretical peak throughput = 3.1Mbps
  - ATG-4 System (currently rolling out)
    - Theoretical peak throughput = 9.8Mbps
- **Row 44**
  - Allegiant, Southwest
  - Network Technology: space-based Ku-band satellite
    - Theoretical peak throughput = 11Mbps

Technical Feasibility: In-Flight Internet Test

- **Measured Performance Characteristics of Gogo and Row 44**
  - Tested during the cruise phase of a routine five-hour commercial cross country U.S. flight
  - Data recorded at 5-minute intervals to obtain averages based on location and spikes in shared bandwidth usage
- **Limited Sample**
  - Connectivity shared among passengers throughout the trip
  - May not indicate expected performance capabilities
- **Median Results**
  - Gogo
    - Uplink: 100kbps
    - Downlink: 82kbps
    - Latency: 560ms
  - Row 44
    - Uplink: 340kbps
    - Downlink: 72kbps
    - Latency: 1200ms



Technical Feasibility: Internet Latency Impact Assessment

- **Performed at Langley Research Center**
  - High-Fidelity Simulation
- **Simulated FIM with NATIVE and ADS-B**
  - Lead: Boeing 757
  - First-in-Trail: Boeing 777
    - Internet data link emulation
  - Second-in-Trail: Boeing 737
    - ADS-B data link emulation
- **Results for NATIVE-borne Guidance Algorithm**
  - withstood 25s±50% mean latency
  - unaffected by up to 2% dropped packets

Presented in Detail In:

J. Grisham, N. Larson, J. Nelson, J. Reed, M. Suggs, M. Underwood, Y. Papelis and M. Ballin, "Proof-of-Concept of a Networked Validation Environment for Distributed Air/Ground NextGen Concepts," to be presented at *AIAA Aviation Technology, Integration, and Operations*, Los Angeles, 2013.

Technical Feasibility: Other Concerns

- **Security**
  - No flight-critical data transferred during flight tests
  - ADS-B is an unsecured data link
  - Internet transmissions can be encrypted
- **Reliability**
  - Cellular coverage gaps in mountains and below 10,000ft
    - Additional towers can be assembled near test facilities
    - Software updates are required for on-board Internet
  - Ku-band Satellite Rain Fade
    - At ~1”/hr., transmission is attenuated ~5dB
- **Integrity**
  - TCP/IP assumed: ensures packet integrity
    - User Datagram Protocol does not guarantee integrity

Preliminary Cost-Benefit Analysis

- **Compared Costs of Two Configurations for Concept Validation**
  - FIM-1 test scenario with 15 aircraft used for the analysis
  - **NATIVE Configuration**
    - ADS-B emulated with on-board simulations and in-flight Internet
    - Guidance algorithms and ADS-B simulator reside on Class II Electronic Flight Bag (EFB)
    - Traffic limited to 128 targets for direct comparison with ADS-B
  - **ADS-B Configuration**
    - Utilizes actual ADS-B In/Out avionics
    - Requires traffic computer
    - Traffic information limited to display traffic information file
    - Guidance algorithms reside on Class II EFB

Preliminary Cost-Benefit Analysis Results

- Possible **~$3.3M** savings using NATIVE for the example scenario
- Further savings may be obtained from repeated use
- Possible savings by validating technologies on test platforms
- Possible benefit through validating candidate message standards
- Can transcend proposed future data link capabilities
- May enable and incentivize timely adoption of ADS-B In

Conclusion and Parting Thoughts

- **NATIVE Enables Reduced-cost and Flexible *In Situ* Validation**
  - NATIVE can emulate proposed future data links for *in situ* flight tests
  - In-flight ISPs can provide suitable data link emulation
  - A positive investment case for NATIVE exists
  - NATIVE gains value with increasing numbers of flight tests performed
  - NATIVE may accelerate the adoption of ADS-B In
- **Exciting Growth Potential**
  - **ATM Cloud Computing Concepts**
    - Some services available in the near-term if not safety-critical
    - Entrepreneurial visions may utilize the NATIVE approach to provide services
  - **Internet Streaming Flight Management System and Aircraft Systems Data**
    - May enable concepts not currently envisioned
    - 4GB over a six-hour flight = 9Mbps throughput requirement