Key Technology Enablers for Improving UAS Safety in the NAS

Presented to:

Committee on Assessing the Risks of UAS Integration

Aeronautics and Space Engineering Board

National Academies

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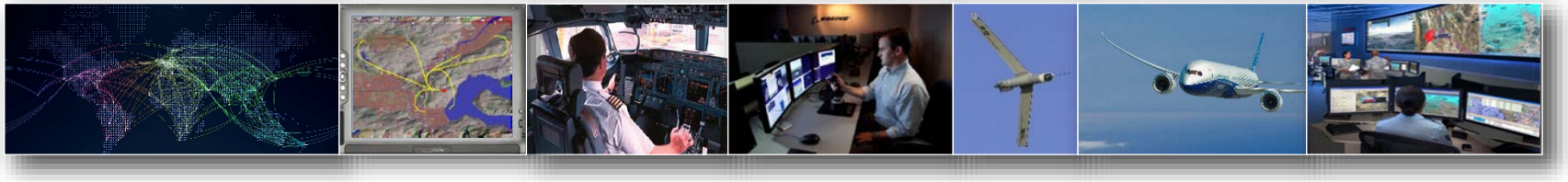
September 27, 2017



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Agenda

September 27, 2017

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- **Ecosystem**
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- **Key Technology Enablers**
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  - → Cyber Security
- **ecoDemonstrators**
- **Gaps**
- **Future Vision**
- **Call to Action**
- **Questions**

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Preface — Safety is Our Top Priority

- **Safety is the hallmark of the Boeing Company**
  - for our products (exemplary performance)
  - for our employees

- **Measured using three criteria:**
  - Perception of the flying public
  - Number of incidents
  - Expectation for improvement
- **Drives airplane / systems / system-of-systems design, CONOPS, technology insertion and training**
- ***MUST* be unchanged when UAS enter the NAS**

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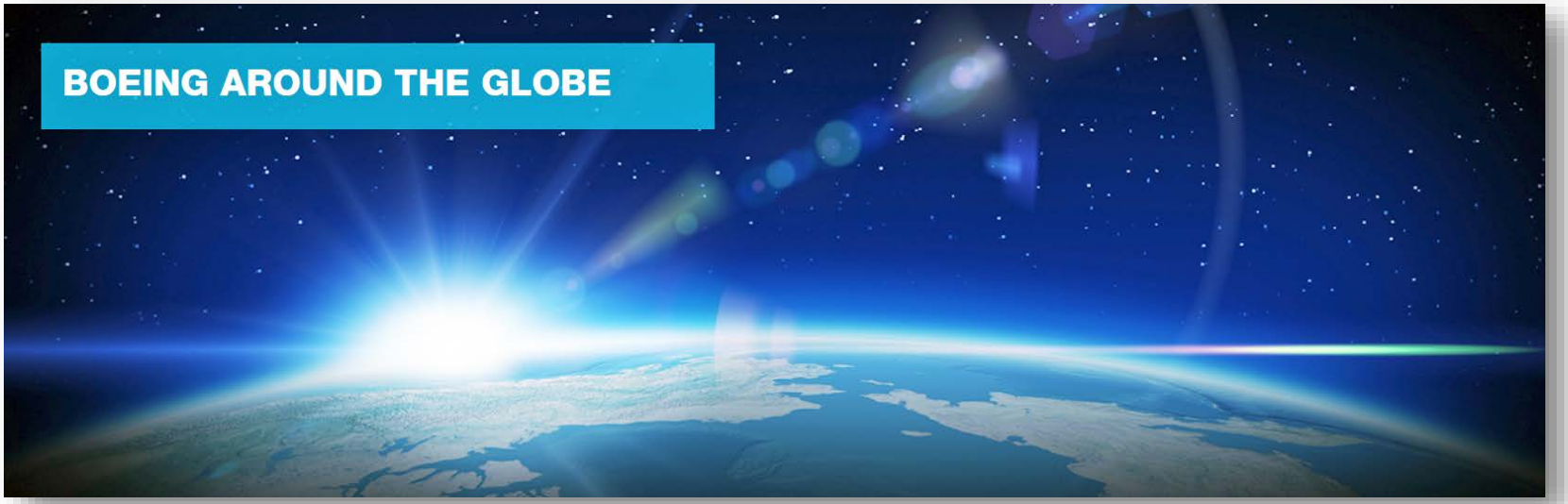
Global Focus



Boeing holds
15.6K+
patents worldwide

11
Boeing has
11 research and development centers
around the world

6 consecutive years
Boeing has been named
a top global innovator
among aerospace and defense companies

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Motivation — A New Playing Field

- 617,000 pilots needed in the next 20 years
- Traffic to grow 4.8 percent per year

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How autonomous are airplanes of today?

- Current Capabilities:
  - Auto flight
  - Auto land
  - Thrust management
  - Navigation
  - Systems management
  - Airplane health monitoring and reporting

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UAS Business Ecosystem

Influencers

Federal Aviation Administration

U.S. Congress

International Civil Aviation Organization

European Aviation Safety Agency

National Aeronautics and Space Administration

Defense Advanced Research Projects Agency

Office of Management and Budget

National Academies of Science, Engineering and Medicine

Eno Center for Transportation (Policy)

Customers

Defense

DoD UAS Missions

OSD UAS

Services

BOEING System Safety

Platforms

Commercial

Fed/State/Local/Civil Gov't

Airlines

Academia & Industry

Massachusetts Institute of Technology

Near Earth Autonomy

Carnegie Mellon University

Stanford University

Microsoft

Southwest

American Airlines

Emirates

FedEx

Delta

United

General Atomics

Lockheed Martin

Insitu

Uber Elevate

Alphabet

Amazon

General Electric

Northrop Grumman

Airbus

NASA Jet Propulsion Laboratory

Sandia National Laboratories

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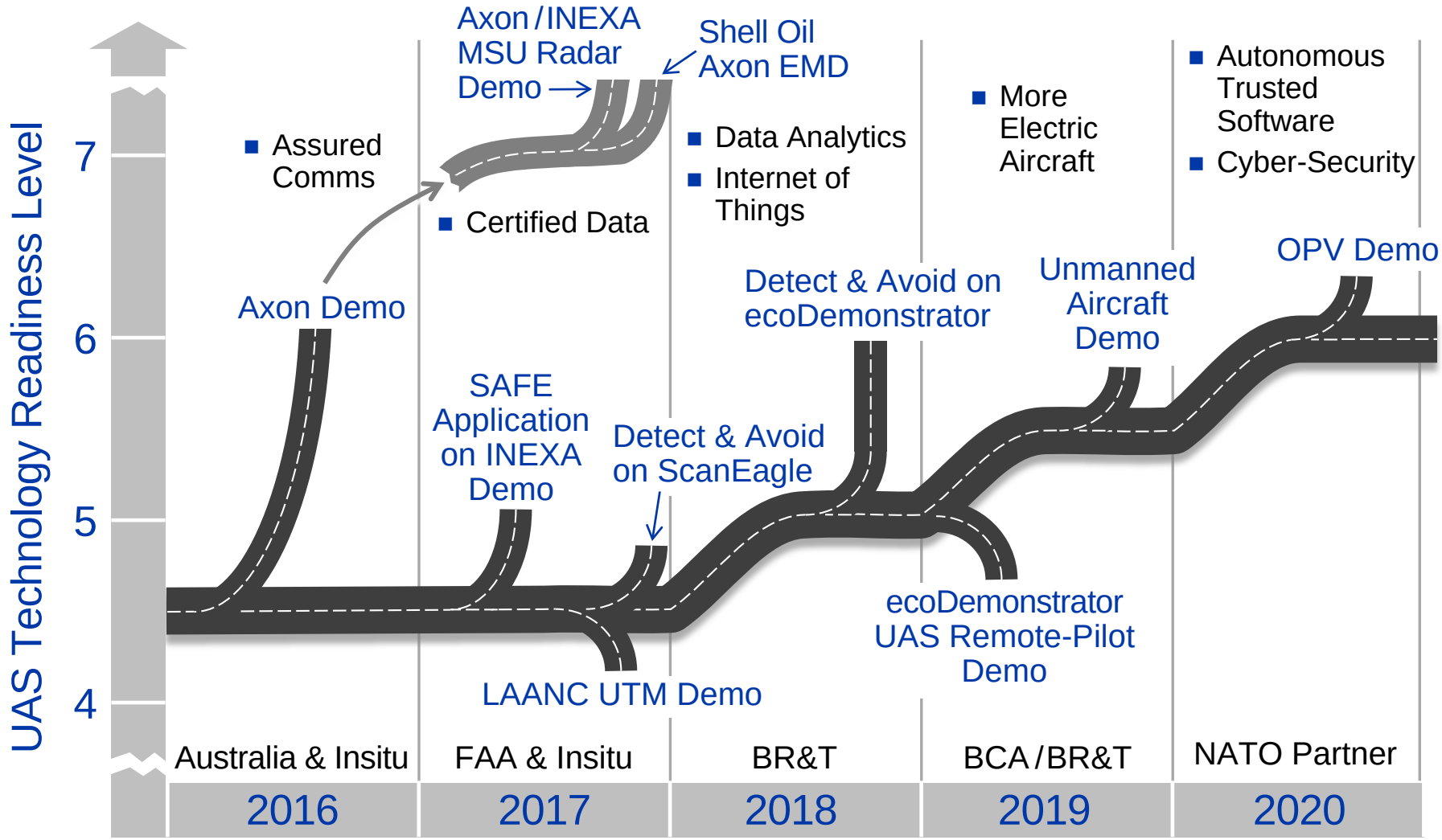
UAS Technology Demonstrations



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Demonstration Case Study: Australia

- 7+ years of broad area BVLOS commercial UAS activities in Australia's National Airspace
- Daily BVLOS data collection operations for Australian resource companies since 2015 (presently 50km range @ >3000ft through close working relationship with CASA)
- 7+ years research and development and safety case development to enable safe expansion of Insitu's BVLOS area
- Real time airspace situational awareness, airband communications extensions and detect & avoid (ground and air) capabilities
- Incremental Boeing UTM technology integration into current operations

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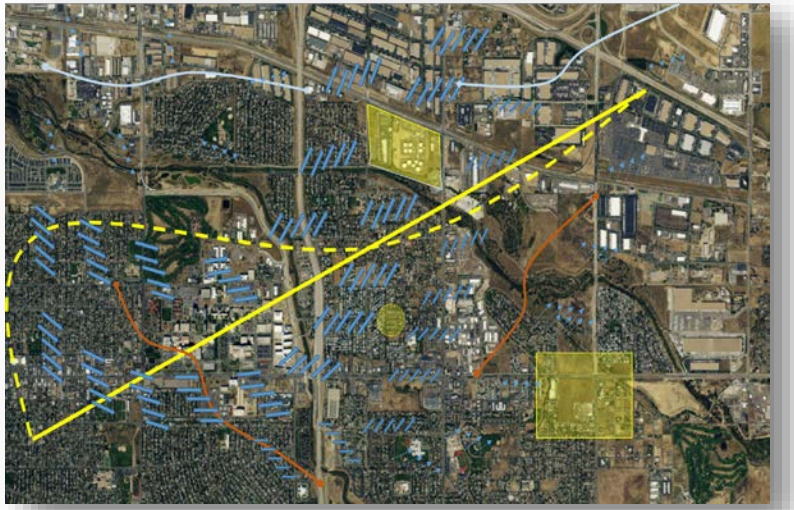
UTM Demonstration Case Study – U.S.

Low Altitude Authorization & Notification Capability (LAANC) Program w/ FAA



First Step to Implement a Digital and Scalable National UTM System

Progress-to-Date

- **Collaboration with FAA to apply private sector innovation to UTM concepts**
- **Automates manually intensive and costly authorization and notification requirements process**
- **Ensures time-critical information (e.g. news, emergency response)**
- **Integrates with Air Traffic Operations**
- **Provides secure, safe, and orderly exchange of small UAS-related information**
- **Demonstration in October**

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Applied Analytics Related to UAS Safety

- **When we utilize data analytics for UAS Safety we are also addressing UAS Security**
- **Focus is on Safety as integrated risk management**
- **Why invest in analytics?**
  - Economic impact
  - Continued Safety of the NAS
  - National Security

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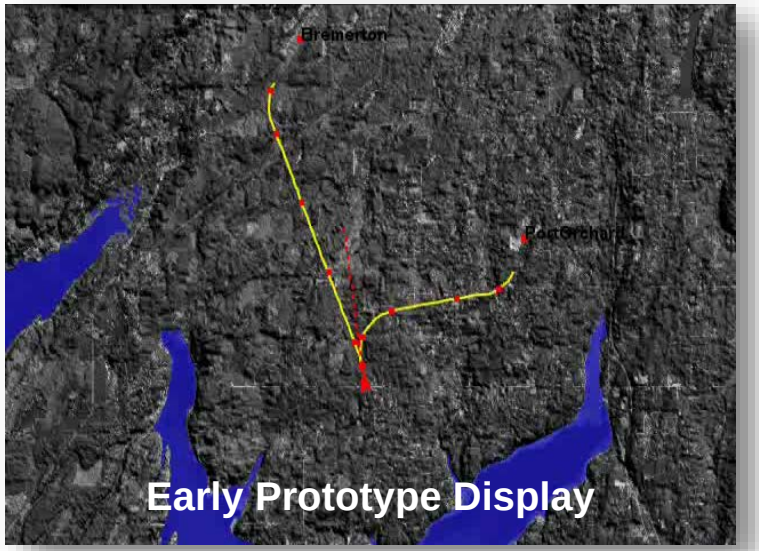
Key Technology Enablers

Safe Area Flight Emergency (SAFE)

(Software Application)



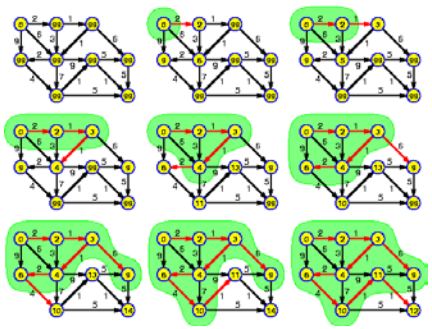
Early Prototype Display

Importance and Impact

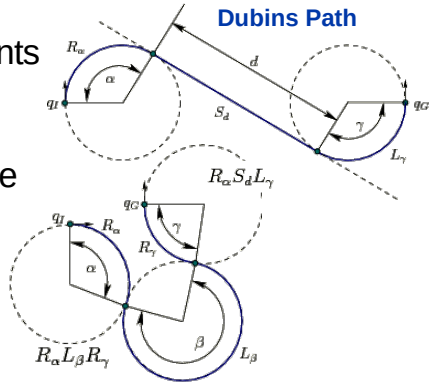
- **Unplanned UAS emergency landings can result in injury or loss of life and property**
- **Operators are limited to using training, line-of-sight vision, familiarity with area to select a safe landing area**
- **Problem is more difficult at low altitudes and over populated areas**

Progress-to-Date

- **Two algorithm approaches are utilized for trajectory determination**
- **Method #1 – Dijkstra's Algorithm**
  - Finds the shortest paths between nodes which may represent road networks
  - The algorithm can be used to find the shortest route (least cost) between one point and all other points



- **Method #2 – Dubins Algorithm**
  - Refers to the shortest curve between two points in the 2D Euclidean plane with constraints
  - Extended to 3D to solve where straight flight is no longer possible
  - Limits the area that can be preprocessed in real time



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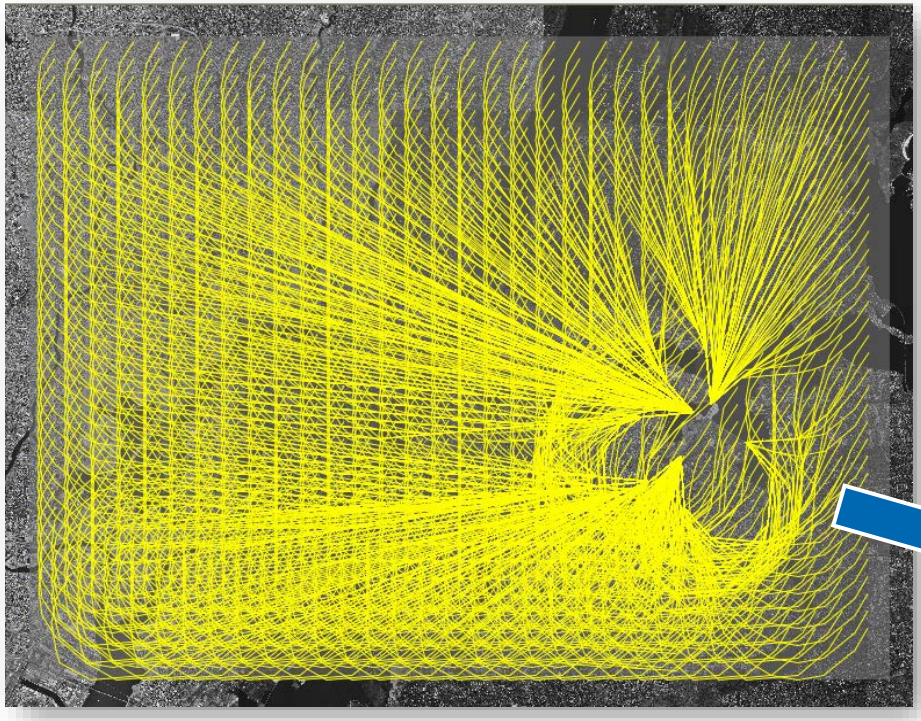
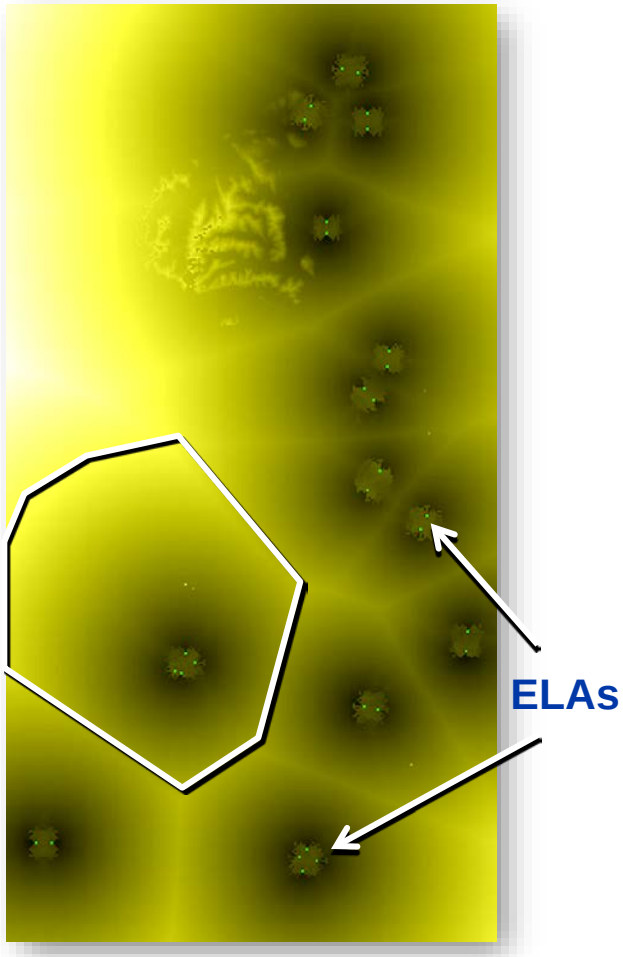
Spanning Tree Group [SAFE continued]



This example illustrates the spanning trees generated for La Guardia Airport for a heading of 210º and down-sampled by a factor of 30



Spanning Tree Group

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Key Technology Enablers

Reliable and Secure CNS and Networks

NASA SASO-CNS RSCAN Project

Importance and Impact

- **Remotely-piloted UAS operations**
- **Increasingly-autonomous operations**
- **Eventual fully-autonomous operations**

Progress-to-Date

- **Requirements and architectures for UAS CNS in controlled airspace**
  - ATN/IPS consistent with ICAO ATM vision
  - Cooperation with manned aviation
  - Assume remote pilots, stationary or mobile
  - Build security into the architecture
- **Trusted next generation ATM data links**
  - Spectrum Fileted OFDM (f-OFDM)
  - Fileted Bank Multicarrier (FBMC)
  - Non-Orthogonal Multiple Access (NOMA)
  - Pattern Division Multiple Access (PDMA)
- **A resilient navigation system**
  - Global Navigation Satellite Systems
  - IMU & on-board clock
  - Reliable hardware and software architecture
  - Image based navigation
  - Multilateration RF based signals

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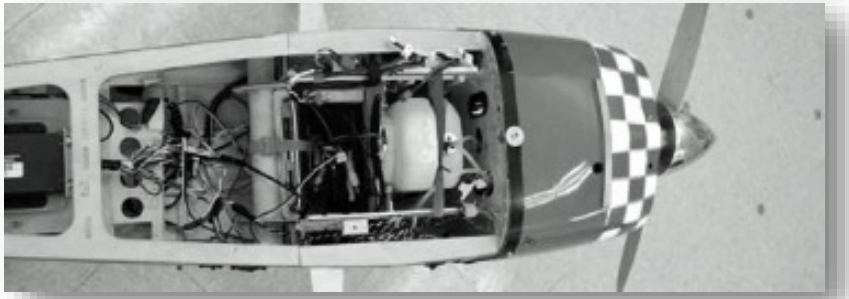
Key Technology Enablers
Trusted Software



Trusted Software Center
University of Illinois Urbana / Champaign

Importance and Impact

- **Replaces pilot intelligence**
- **Normally operates in real-time**
- **Potential vulnerability**
- **Standards are undefined**

Progress-to-Date

- **Navigation algorithms are mature and fielded today**
- **Extensive testing has occurred**
- **Autonomy for operations is next**
- **Image identification is the key**
- **Autoland / takeoff is middle-level TRL**
- **Focused technology areas are:**
  - Highly scaleable trustworthy networks for complex sensors and and device systems
  - Network security and protocols
  - Scaleable traffic and system trust engineering methods
  - Trusted wireless networking
- **Trusted software for NextGen ATM systems**

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Key Technology Enablers
Electric Power

Boeing Blended Wing Body Concepts

Importance and Impact

- Creates lower environmental impact
- Leverages trend to replace fossil fuels in transportation
- Today, it is not weight neutral with JP-8 but there is large technology headroom
- In many ways electrics are beating technology roadmap timelines

Progress-to-Date

- Aviation trend is toward more electric
  - 1 MW on 787
  - 3 MW on 777X
  - ? MW on UA-X
- Experience has been positive (low weight) and negative (quality) at the same time
- Improvements are available from materials (SiC → GaN → Graphene) but cost is a concern
- Goal is to match long-haul turbine engine reliability / safety
- Aviation and automotive are synch-ronized in pursuit of electric power
- Investments are ongoing – China / US / Europe

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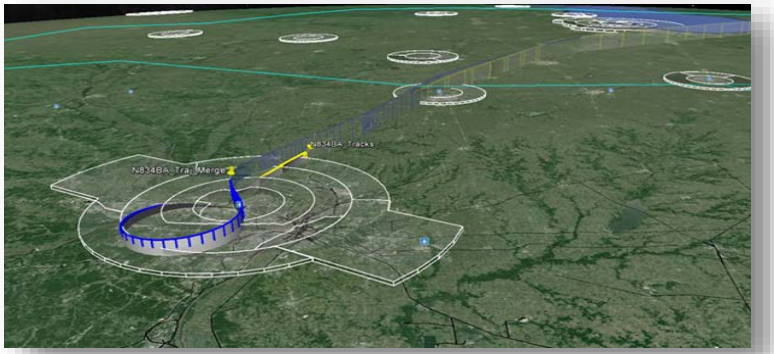
Key Technology Enablers

Live-Virtual-Constructive Platform



Live 737 Flight as 'Large UAS' Embedded in Air Traffic Simulation

Importance and Impact

- **Live flight for realism**
- **Virtual for HITL simulation**
- **Constructive for traffic**
- **Geo and time aggregated for "What-if" Study**

Progress-to-Date

- **Live flight test of aircraft trajectory downlink**
- **Real 737 avionics test of air-ground trajectory synchronization negotiation**
- **Background traffic simulated for existing and future architectures**
- **Communication protocols and options simulated**
- **Disparate simulators plus live aircraft one coherent simulation**
- **Preparation for:**
  - Detect and Avoid certification testing
  - Capabilities of Full data link flight, reduced crew operations, and air-ground trajectory synchronization and negotiation on ecoDemonstrator 2019

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Key Technology Enablers

Internet of Things and Data Analytics

Data Science Lab

Importance and Impact

- **Information from transient data**
- **Analytics for decision support**
- **Entity Analytics identify patterns**
- **Patterns allow pre-emption**

Progress-to-Date

- **Data Lake from all sources**
- **Simple analytics and statistics**
- **Entity analytics identifying hidden patterns and behaviors**
- **Deep sense learning**
- **Alerts services**
- **Cross reference and re-analyze**
  - Runway acceptance rates every 15 min
  - Weather conditions
  - Aircraft types
  - Aircraft equipage
  - Runway aids and service levels
  - Warnings of acceptance rate changes to airline dispatchers and airports hours ahead of impact, identifying aircraft that will be delayed

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Key Technology Enablers
Cyber Security

Cyber Security

Importance and Impact

- **End-to-end cyber security is essential for UAS mission success**
- **Our tools are used to protect:**
  - Networks and data management
  - Imagery, video, maps, terrain exploitation and dissemination
  - Information sharing with large data volumes

Progress-to-Date

- ***Twisted*** **application allows massive amounts of data to be ingested, normalized, extracted or federated**
- ***Hardwall*** **enables rapid bi-directional cross-domain transfer to accelerate info-sharing, at Protection Levels 3, 4 and 5**
- ***Data Master*** **provides end-to-end geo-spatial data management from multiple client connections**
- **Passive network monitoring quickly identifies network threats without disruption to performance**

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ecoDemonstrator Flying the Future Now

- Accelerate technology
  - Learn by doing
  - Speed implementation
  - 18 to 24 month rhythm
- Collaborate with government, suppliers and industry
- Inspire action and innovation

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ecoDemonstrators 2018 - 2019

ecoDemonstrator **2018**

- Propulsion advancements
- Advanced materials
- Efficient flight operations

ecoDemonstrator **2019**

- Smart cabin
- Autonomy

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Freighter of the Future

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Gaps

- **Scaleability (can begin to be addressed using Modeling & Simulation / FAA capabilities)**
- **All-weather operations (need accurate and predictable, micro-weather and turbulence)**
- **Reliability of UAS platforms (mostly uncertain to date)**
- **Encourage UAS equipped with sensors (primarily for data analytics and UTM tracking)**
- **No regulatory framework exists**

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Future Vision

- **Be globally aware but start with a U.S.-centric plan**
- **FAA's core mission is undergoing a 10X to 100X increase in traffic as UAS are integrated in the NAS**
  - Traffic scale-up must be accomplished safely
  - Confidence of the flying public must be preserved
- **Keeping the NAS Safe is essential for:**
  - UAS global competitiveness
  - Economics (reduced crews)
  - UAS threat mitigation

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Future Vision [continued]

- **Scaleability of the NAS is an essential feature**
  - Test and build confidence in scale-up
  - Examine impacts of weather, hacking
  - Must remove the brittle elements of ATM
  - Explore susceptibility of systems to rogue actors

VISION — Continued Safe Operations of All Aircraft in the NAS

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Call to Action

- **The next steps in UAS safety development**
  - *Conduct an integrated research program on safety*
    - Lever best practices, tools, and knowledge from commercial airplanes experience
    - Lever invariants to predict UAS safety
    - Lever research results to inform certification
  - *Develop a fully integrated UAS CONOPS for the NAS*
    - Scaleable to system level
    - Validated by modeling and simulation
  - *Explore a benefits-driven understanding of UAS economics*
- **Policy and technology must be synchronous in deployment**
  - Impact on American competitiveness
  - Impact on policy adjustments

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Call to Action [continued]

- **Recommend formation of UAS policy-related laboratory**
  - Speeds policy creation
  - Ensures UAS global market competitiveness
  - Informs system-of-systems validation and verification related to UAS
- **Follows the conceptual model for driverless autos**
  - First topics to examine:
    - UAS as threats (Homeland Security)
    - UAS as opportunities (business enablers)
  - Workshops are recommended process
- **Possible laboratory sites – Eno Center for Transportation or the National Academies**

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3,000,000 parts. One mission.

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Questions?

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Connect / Protect / Explore / Inspire

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