Beyond NextGen: AutoMax Overview and Update

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NextGen Concepts and Technology Development Project
Outline

• Main Message

• National Airspace System State of the Art

• Need for Auto Characteristics for Airspace Operations System

• AutoMax
  – Goals, Scope, Motivation and Potential Benefits, Examples Directly Applicable to Airspace Operations

• Research: Questions, Design Approach, and Needed Capabilities

• Enabling Capability: SMART NAS

• Challenges

• Progress, Products and Metrics

• Summary

Research Planning is in Progress
Main message

• National and Global Needs
  – Develop scalable airspace operations management system to accommodate increased mobility needs, emerging airspace uses, mix, future demand
  – Be affordable and economically viable

• Sense of Urgency
  – Saturation (delays), emerging airspace uses, proactive development

• Autonomy is Needed for Airspace Operations to Meet Future Needs
  – Costs, time critical decisions, mobility, scalability, limits of cognitive workload

• AutoMax to Accommodate National and Global Needs
  – Auto: Automation, autonomy, autonomicity for airspace operations
  – Max: Maximizing performance of the National Airspace System

• Interesting Challenges and Path Forward
State of the Art
Gate-to-Gate Concepts and Technology

Flow and Airspace Planning

En Route with Weather Avoidance

Surface Operation

Surface Operation

Departure

Arrival

JOINT ECONOMIC COMMISSION (2007) FINDS DELAY BETWEEN 4.3 AND 5.3 MILLION HOURS
COST OF DELAY $41B
ADDITIONAL 740M GALLONS OF FUEL
State of the Art
Barriers To Meeting Air Transportation Needs

• Operational efficiency and airspace complexity (diversity, volume, capacity) are constrained by human workload limitations

• Limited automation and decision support tools lead to suboptimal decisions and inefficiencies
  – Surface, arrival, departure, and metroplex operations
  – Sector based rather than trajectory based
  – Uncertainties
  – Limited number of aircraft handled in a sector

• Limited ability to simultaneously provide safe (keeping aircraft separated), efficient (fuel and environment), and expeditious (fewer delays) flow
  – Particularly under high density conditions, where focus shifts to safety and expediency, while efficiency suffers

• Current system is not adequate to meet future needs
Need for Auto characteristics in Airspace Operations System – Safety, Efficiency/Scalability, & Mobility

- Human simply executes automation guidance where rapid decisions and execution is needed – Traffic Collision Avoidance System (TCAS)
- Rare normal events may lead to human skill degradation – Aircraft stall management
- High complexity leads to suboptimal human decision making – safe, expeditious, and efficient operations
  - Probabilistic weather, multiple constraints (*too much information for humans to make sound decisions*)
  - Arrival, departure, and surface operations optimization (*too much information and not enough time*)
  - Metroplex traffic management (*required precision and combinations are too high for human capability*)
- High workload limits capacity and throughput – Human workload limits number of aircraft
- Human-centric system costs limit mobility – Air taxi/On-demand aircraft with two pilots or personal air vehicles requiring piloting skills
- Labor cost differences impact competitiveness – Huge cost difference in global economy
- Enable new operations with high productivity – Low altitude UAS operations

Need for auto enablers due to complexity, diversity, demand, costs pressures, and newer needs
**AutoMax Goals**

- Increase **mobility** of passengers, goods, and services
- Allow **diverse** vehicle mix and airspace uses (e.g., air travel, wind turbines, commercial space launches)
- Enable **scalability** to accommodate future demand
- Accommodate a variety of **business models** (e.g., hub-and-spoke, point-to-point, air taxi, sharing, etc.)
- Maintain highly efficient, predictable, agile, scalable, and **affordable** airspace operations system
- Maintain global **competitiveness** and domestic viability by innovation in technology and business models to manage airspace operations

AutoMax is a research initiative aiming to achieve above goals using justifiable and optimal combination of "auto" characteristics for management of future airspace operations
Examples of Auto Properties for Airspace Operations

- **Autonomicity**: system focused self-management, technologies for
  - *Self-configuration*: Capacity-to-safety transition in operations (two extremes, such as Microsoft Windows normal mode vs. safe mode)
  - *Self-optimization*: Optimization based on changing conditions in traffic, weather, and disruptions
  - *Self-protection*: Anomaly detection (e.g., GPS degradation) and reaction; e.g., lower position accuracy leads to increased buffers and reduced capacity
  - *Self-healing*: Recovery from degradation

- **Autonomous operations and autonomy technologies for**
  - Non-towered airports, flow management, unmanned vehicles, personal and passenger air vehicles

- **Automation Technologies**
  - Conflict detection and resolution, route planning, severe weather avoidance, reduced crew operations, remotely operated vehicles

*Increased “auto” automation, autonomy, and autonomicity are needed to meet future needs*
Important Research Questions

• What is the overall design that enables safe, scalable, sustainable, affordable mobility options for future?

• How should control be distributed between human and auto (e.g., dynamic and adaptive locus of control)? What are the ideal human roles?
  – Relying on human limits scalability vs. unexpected management of operations

• What are the functional and networking architecture design options that are scalable, modular, extensible to meet future capability needs?

• What are the performance improvements, cost, and benefits that justify AutoMax need?

• What are the nominal and off-nominal, degraded conditions under which AutoMax must function?

• What verification, validation, and certification methods enable auto properties based operational system?

• What is the transition path of the system from current operations to future?

• What is the most effective approach to change management and acceptance of a system that is based on auto properties?

Adaptive levels, design, performance, cost/benefits, V&V, and change management are areas of research
Two-Pronged Approach

- Overall design – *ab initio* or clean sheet

- Develop specific targeted capabilities to address needs
Approach 1: *Ab Initio* or Clean Sheet Design

- Need research rather than a priori decision on human/machine role which may lead to premature point design
- Develop rigorous system design approach for optimal design to address performance
- Functions, allocations, sensors, data analytics, redundancies, CNS, vehicle/system interaction, software, human interfaces, etc.
  - Be forward and backward compatible to the extent possible
  - Offer adaptive autonomy and locus of control for human-machine interaction
  - Offer plug-and-play so that future trends can be accommodated by additional technology evolutions
  - Possess sufficient intelligence to ensure appropriate response to unanticipated events under uncertainty
    - State of the art in machine intelligence may not be adequate
Challenges

• Technology development for larger-scale air traffic management – lessons learned from prior efforts (e.g., AAS, AERA)

• Verification and validation of systems and technology providing autonomicity

• Assured safety of autonomous operations

• Certification of auto enabled systems

• Role of humans (adaptive automation, how much) – Cognitive echelons

• Harmonized transition from current NAS to AutoMax future

• Cyber physical security

• Social acceptance of auto-based systems and operations

• Legal considerations about responsibility of undesirable event
Examining AutoMax Concepts, Algorithms, and Technologies: SMART NAS

- New simulation capability called Shadow Mode Assessment using Realistic Technologies for the National Airspace System (SMART NAS) is being developed

- Motivation
  - General agreement that National Airspace System (NAS) needs to transform, and the pace of transformation is rather slow
  - NAS is a complex system with high safety requirements
    - Results in incremental and evolutionary changes that are validated
  - Such incremental upgrade approach is rather slow and does not consider integrated operations efficiently – could take many decades to get to “true” next generation and beyond

- Focused on longer-term concepts exploration and their interactions
  - Functional requirements, information flows, automation/human and air/ground allocations

SMART NAS needed to research and define AutoMax specifics
SMART NAS (continued)

- Objectives
  - Develop approach to faster validation of concepts, technologies and their integration, and future autonomy architectures
  - Reduce the time to validate concepts, technologies and their interactions
  - Provide plug-and-play capability that is modular and based on open architecture principles to compare alternative approaches
  - Provide real-time assessment of technologies as compared with current operations
  - Provide live, virtual, and constructive distributed environment

- SMART NAS capability is a community resource to reach transformed future

- SMART NAS will allow examination of design alternatives, “auto” architectures, variety of roles of human-machine interface

- Open architecture based capability - Opportunity to redesign the airspace operations system using SMART NAS

- Allows examinations of overall design options as well as targeted capabilities
Progress

- Conducted literature review

- **Workshop 1**: Included air traffic management research subject matter experts
  - Goal: Discuss AutoMax needs and identify initial opportunities and approaches

- **Workshop 2**: Included NASA space and exploration system autonomy experts from ARC, DRFC, JPL, JSC, KSC, LaRC, and MFSC
  - Goal: Discuss lessons learned from space and exploration community on the needs of autonomy/autonomous operations
  - Interesting findings: key lessons have similar characteristics
  - Pressures on costs (e.g., multiple successive launches)
  - Communication lags (e.g., 7 minutes of terror for Curiosity landing)
  - Tactical decision making with time criticality (e.g., launch abort)

- **Inter-center research planning team** has been formed; conducted first meeting to identify initial areas; work will continue through December 2013 to develop an initial research plan

Identified opportunities and studied lessons learned
Products

- Concepts/visions that enable divergent views about future
- Design alternatives: trades, analysis, methods, and functional architectures
  - Overall design – *ab initio* or clean sheet
  - Requirements related to architecture, sensors/data/fusion, CNS, reliability, bandwidth, security, safety, human-machine adaptive levels, redundancies, interfaces, etc.
- Safety, costs, benefits, assured autonomy, and certification – justification and methods
- Technology suites and their specifications to show impact with targeted opportunities
- End-to-end AutoMax Live, Virtual, and Constructive Distributive Environment demonstration – validate requirements
- Change management – acceptance and path to deployment
- Overall requirements, roadmap to address future needs and opportunities to improve operations

Identified opportunities and studied lessons learned
Metrics for AutoMax

- Mobility metrics (newer in terms of affordability, commute time, etc.)
- Economic value of airspace use (newer metric)
- Total airspace operations/cost to operate
- Airspace user mobility and access for different types of aircraft/vehicles
- System scalability, capacity, throughput, predictability, resiliency, adaptability
- Cost per passenger mile
- Number of tons of cargo and number of passengers
- On-time arrivals and departures
- Delays, Fuel/energy efficiency, Extra miles flown from optimal path
- Emissions
- Network efficiency
- Accommodation of different types of vehicles operating in the NAS and associated NAS-wide system performance
- Accommodation of different types of business models
Summary

- *NextGen* portfolio focuses largely on efficiency
- *AutoMax* research addresses the future mobility needs, airspace operations needs, and pressures in efficiency and productivity
- *AutoMax* will produce justifiable and optimal *Auto* technologies with opportunities to make impact along the way
- *AutoMax* products will impact in stages and also lead to overall redesigned system
- *SMART NAS* will assist in examination of functional architecture alternatives
- Proceedings of two *AutoMax* pre-planning workshops and a large literature survey relevant to automation and autonomy is now in editing for publication as a NASA Technical Report; available in Oct-Nov 2013
- *AutoMax* research plan is expected by CY13 – Be back to report
Innovate Relentlessly
Terminology

- **Automation/automated process**: Replace manual process with software/hardware that follow a programmed sequence

- **Autonomy**: Allows participants to operate on their own, based on internal goals, with little or no external direction. Participants can be human or machines. Autonomy implies self-governance and self-direction. Autonomy is a delegation of responsibility to the system to meet goals

- **Autonomicity**: Builds on autonomy technology to impart self-awareness to system/mission, which includes configuration, optimization, healing, protection. These are enabled by self-awareness, self-situation, self-monitoring, and self-adjustment

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**Auto in AutoMax refers to combination of all “Auto” properties**
Auto Motivation and Benefits

- Ensure global competitiveness for carriers
  - Competition in international market – cost structures are different
- Affordable travel and economic viability for domestic operators
  - Costs: 25% labor and 25% fuel
- Accrue greater economic value from airspace (e.g., UAS goods and service delivery, wind turbines)
  - Lower altitude airspace is underutilized
- Accommodate much larger operations with increased service provider productivity
  - Limits of current system, service provider costs, cognitive workload, lack of automation, and delays
- Enable mobility for anywhere, anytime, anybody with choices
  - New airspace uses and mobility options are emerging rapidly

Increased competition and future needs offer opportunity for better “Auto” based system