Overview of NASA’s Next Generation Air Transportation System (NextGen) Research

Harry N. Swenson
Research Scientist
http://www.aeronautics.nasa.gov/asp/airspace
Contents

• NASA’s Aeronautics Research Portfolio
• Fundamentals of the Current Air Transportation System
• Air Transportation Research Challenges
• Current Research Highlights and Significant Accomplishments
• Concluding Thoughts
NASA Aeronautics Programs

**Fundamental Aeronautics Program**
Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

**Aviation Safety Program**
Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.

**Airspace Systems Program**
Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.
Contents

• NASA’s Aeronautics Research Portfolio

• Fundamentals of the Current Air Transportation System

• Air Transportation Research Challenges

• Current Research Highlights and Significant Accomplishments

• Concluding Thoughts
Today Basic Air Transportation Operation

- Taxi
- Gate
- Controller
- Dispatch
- Takeoff
- Climb
- En route
- Terminal
- Landing
- Descent
- Surface

Voice communication between Controller and Contractor.
Flight Across the United States Airspace from San Francisco (SFO) to Washington DC (IAD)
One Day of En-route Operations in the United States (starting at 7 pm Eastern)
One Day of World Wide Air Transportation Operations
Weather Impacts for Air Transportation Traveling to the New York Area (starting around 7 am local time)
Weather Impacts for Air Transportation Traveling to the Dallas Texas Area (starting around 3 am local time)
Extremely Off-Nominal Conditions
(Look for it around 13:30 UTC 10:30 am local EDT)
National Airspace System
Aggregate Statistics Per Flight

<table>
<thead>
<tr>
<th></th>
<th>Time (minutes)</th>
<th>Distance (Nautical-miles)</th>
<th>Fuel Burnt (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>19</td>
<td>5</td>
<td>474</td>
</tr>
<tr>
<td>Climb</td>
<td>16</td>
<td>76</td>
<td>1,911</td>
</tr>
<tr>
<td>Cruise</td>
<td>70</td>
<td>465</td>
<td>6,787</td>
</tr>
<tr>
<td>Descent</td>
<td>14</td>
<td>68</td>
<td>349</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Min. Time (minutes)</th>
<th>Max. Time (minutes)</th>
<th>Min. Fuel Burnt (lbs)</th>
<th>Max. Fuel Burnt (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>11</td>
<td>43</td>
<td>274</td>
<td>1,073</td>
</tr>
<tr>
<td>Climb</td>
<td>5</td>
<td>56</td>
<td>520</td>
<td>18,704</td>
</tr>
<tr>
<td>Cruise</td>
<td>0</td>
<td>1,039</td>
<td>0</td>
<td>375,350</td>
</tr>
<tr>
<td>Descent</td>
<td>4</td>
<td>40</td>
<td>175</td>
<td>1,942</td>
</tr>
</tbody>
</table>

- 24-hours from 8:00 UTC May 3 to 8:00 UTC May 4, 2007.
- High-volume, low-delay day, 56,267 flights (71% jets, 17% turboprops, 12% piston).

Complex operations – Multiple facilities, aircraft, people, and equipment
Any improvements need to consider many angles – makes vital R&D
National Airspace System Delays

Period: September’08 – August’09 (Source FAA), Roughly 25% aircraft get delayed

Transportation Systems Analysis Model (TSAM) Predictions

<table>
<thead>
<tr>
<th></th>
<th>Daily Flights</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
<td>2025</td>
</tr>
<tr>
<td>Commercial</td>
<td>28,404</td>
<td>48,349</td>
</tr>
<tr>
<td>Domestic</td>
<td>25,211</td>
<td>41,498</td>
</tr>
<tr>
<td>International</td>
<td>3,193</td>
<td>6,851</td>
</tr>
<tr>
<td>General Aviation</td>
<td>18,052</td>
<td>23,329</td>
</tr>
<tr>
<td>Cargo/Freight</td>
<td>2,419</td>
<td>4,036</td>
</tr>
<tr>
<td>Total</td>
<td>48,875</td>
<td>75,714</td>
</tr>
</tbody>
</table>

Weather is a big delay contributor – Can’t change it but we can optimize around it
Today Basic Air Transportation Operation
Contents

• NASA’s Aeronautics Research Portfolio
• Fundamentals of the Current Air Transportation System
• Air Transportation Research Challenges
• Current Research Highlights and Significant Accomplishments
• Concluding Thoughts
NextGen-Airspace Project: 
Air Transportation Needs to Research

Domain and operations are complex and require sustained R&D to address challenges. NASA has the skills and experience to change the Airspace System.
Contents

- NASA’s Aeronautics Research Portfolio
- Fundamentals of the Current Air Transportation System
- Air Transportation Research Challenges
- Current Research Highlights and Significant Accomplishments
- Concluding Thoughts
SA Elements of Automation for a Future Airspace System

Research Focus Area
Separation Assurance

Problem
• Human controller workload limits current airspace capacity
• Mixed equipage must be safely managed

Major Research Threads
• Conflict detection and resolution algorithm development and analysis (aircraft and ground-based)
• Functional allocation
• Safety assessment

Research Being Pursued
• Automation and operating concepts for separation, metering, and weather avoidance in en route and transition airspace
• Concepts and algorithms for higher levels of separation assurance automation
• Efficient (conflict-free) arrivals into capacity constrained airspace
• Airborne and ground-based separation assurance concepts and technologies
• Separation assurance and collision avoidance algorithm compatibility

Partners: Lockheed Martin, GE, NRAs (Purdue, Stanford, UC Santa Cruz, L3, LMI, CSU Long Beach, Raytheon, Sensis)

Increased productivity, safety, and scalability
Research Thread: Functional Allocation

**Problem/Need**
- Identify characteristics, strengths, and weaknesses of various SA concepts
  - Humans vs. automation and aircraft vs. ground-based

**Approach**
- A series of human-in-the-loop simulations that examine homogeneous, mixed, nominal and off-nominal conditions

**Progress**
- Functional allocation examination approach planned
- First study preparations underway

**Next Step**
- Produce comparable results from coordinated studies
- Develop mixed operational concepts
- HITL coordinated concept evaluations (e.g., homogeneous operations, mixed operations)
- Nominal and off-nominal operations

**Implications on costs, roles/responsibilities, and architecture**
In-trail Climb/Descent Procedures
(Development of ASAS applications in procedural airspace)

**Problem/Need**
- Development of airborne separation assistance applications
- Specifically focused on in-trail climb/descent procedures in oceanic airspace

**Approach**
- Developed ADS-B based in-trail climb/descent procedures

**Partners**: FAA, Quantas and Air Services Australia

**Results**
- ICAO approved the procedures
- Documentation is completed
- Technology transition

**Next Step**
- FAA and partner airlines to do a field test in FY11

Aircraft will be able to fly at efficient altitudes and won’t be stuck behind slow aircraft due to controller workload – increased productivity and efficiency
Problem/Need
• Functional allocation (air and ground)
• Ground-based and airborne concepts, algorithms, and analysis need to be comparable

Approach
• Develop experiment plans with common scenarios and metrics to enable comparisons

Progress
• Common definitions, scenarios, and metrics have been identified
• Technical plans are approved by project

Next Step
• Simulations in December 2009 and February 2010

Functional allocation research has implications on costs, roles/responsibilities, and architecture
Research Transition Team
En Route Descent Advisor (EDA)

Needs/Why Care?
Fuel efficient descents that meet efficient, time-based constraints set up for demand/capacity imbalance

Focus
Technology transfer of En Route Descent Advisor

Progress/Results
Field test at Denver Center for descent trajectory prediction accuracy (15 days, 360 flights)
Participants: United and Continental B757, B737, and A319/320, and FAATC’s Bombardier
Results: (median: Top of Descent accuracy = 5.5nm, meter fix accuracy = 12 sec) – As compared with current state-of-the-art = 1 min
Lesson Learned: Need better top of descent predictions, meter fix accuracy is good

Next Steps
Complete hardware integration testing and overall readiness for HITL
Continue scenario development and testing
Technology transition package

September 2009 Denver ARTCC Field Test - Preliminary Results
Top of Descent Error

Meter Fix Crossing Time Error

En Route Descent Advisor will increase fuel efficiency and meet-time accuracy

Partners
FAA, Sensis, Boeing, United, Continental Airlines, MITRE
Significant Accomplishments

- Field test to support En Route Descent Advisor
  - Better understanding of trajectory uncertainties (median: meter fix 12 sec, Top of Descent 5.5 nm)
  - May require air/ground coordination for TOD
- Separation assurance technologies are maturing (ground based and aircraft based)
  - Traffic, time, and weather constraints

Products beginning to show impact and promise
ASDO Elements of Automation for a Future Airspace System

Research Focus Area
Airspace Super Density Operations

Problem
• Human control of spacing, merging, and separation assurance limits the capacity of the terminal airspace
• Mixed equipage must be safely managed
• Interactions between arrivals and departures

Major Research Threads
• Arrival Operations (integrated scheduling, sequencing, and merging and spacing)
• Integrated arrival and departure operations
• Metroplex operations optimization

Research Being Pursued
• Algorithms that simultaneously solve/optimize the sequencing, merging, de-confliction and spacing
• Regional resource utilization or metroplex operations
• Closely spaced parallel runways

Partners: FAA, UPS, MITRE, ACSS, NRAs (MIT, Purdue, Metron, SJSU, Mosaic ATM)

On-time arrival/departure, reduce costs, impact on environment, safety and scalability
Super-Density Operations Vision

- Continuous Descent Arrivals (CDAs) for individual aircraft
  - Efficient arrivals from top of descent to meter fix or runway threshold with other (interfering) traffic

- CDAs with merging multiple aircraft flows to one airport
  - Using ANSP 4D trajectory management to schedule complex, conflict-free flows to the runway
  - Using Flight Deck merging and spacing capability to enable efficient multiple CDAs/TAs to runway threshold
  - Closely spaced parallel approaches where possible

- Integrated arrival, departure, and surface operations that maximize efficiency and throughput

 Increased automation needed to cover multiple airport and interactions
Research Thread: Arrival Operations

**Problem/Need**
- Develop new concepts, procedures and algorithms to maximize arrival rates to a single airport, as well as reduce fuel burn, emissions, and noise

**Approach**
- Develop concepts, algorithms, and examine feasibility and benefits for variety of capabilities

**Progress**
- Developed multiple concepts across the entire ASDO domain
- Evaluated several concepts independently
  - Scheduler development
  - Flight Deck Merging and Spacing
  - Controller Managed Spacing Scenarios
  - Very Closely Spaced Parallel Runways Operations
  - Tactical Conflict Prediction and Resolution Algorithms

**Next Steps**
- Scheduling tool must consider integrated perspective

**Partners:** FAA, UPS, MITRE, and NRAs (MIT, Metron, Purdue, SJSU, Mosaic ATM)

**On-time arrival, reduce fuel burn, and increase productivity**
Algorithms and Procedures for Merging and Spacing Operations to Single Runway

Problem/Need
- Increase throughput and execute efficient profile
- Develop and verify acceptance of procedure
- Examine performance

Approach
- Conduct human-in-the-loop simulation to determine performance and acceptability
- Off-nominal (vectors, speed, spacing)

Results
- Precise spacing (±5 sec)
- Acceptable and stable

Partners:
FAA, UPS, ACSS

Increase throughput and execute as efficient profiles as possible
TRACON Operational Error Analysis

**Problem/Need**
- Increase safety in TRACON airspace
- Human workload limits

**Summary of Operational Error Taxonomy**
- 59 involved arriving aircraft
- 44 involved aircraft on final approach (compression)
- 15 involved metroplex traffic
- 4 involved arrival/departure interaction at same airport
- 3 were procedural in nature

**Approach**
- 73 DFW TRACON operational errors investigated to understand the specific nature of each incident, and categorized to develop a taxonomy of situations, causes and resolutions

**Progress/Results**
- TRACON Operational error data analysis – detected all conflicts
- Median lead time = 38 sec.

**Next Step**
- Wider data set, intent information, sensitivity, false alert and stochastic

**Partner:** FAA

---

*Increase productivity and safety in TRACON airspace*
Research Transition Team
Efficient Flow into Congested Airspace
Overview

Needs/Why Care?
- Fuel efficient descents that meet efficient, time-based demand/capacity balance

Focus
- Demand/capacity imbalances analysis based on historical data
- Advanced scheduling
- Implementation of EDA concept for fuel efficient descents in medium/heavy traffic
- Interval Management

Progress
- RTT was reformulated to broaden the scope
- RTT plan to cover these four elements
- En Route Descent Advisor field test

Next Steps
- Work with the FAA for TFM, Flight Deck Merging and Spacing/Interval Management, and Advanced Scheduling for specific products.

Flow management, scheduling, and merging and spacing needed to increase arrival efficiency in congested airspace
Research Focus Area
Traffic Flow Management

Problem
• Planning involves multiple time scales (local, regional, and national)
• Multiple decision with different goals (pilots, dispatchers, ATSP flow managers)
• Decision making under uncertainty (e.g., weather)

Research Threads
• Modeling, simulation and optimization techniques to minimize total system delay (deterministic and stochastic)
• Decision-making under uncertainty (weather integration)
• Collaborative traffic flow management

Research Being Pursued
• Optimization methods for advanced flow management
• Probabilistic and stochastic methods to address system uncertainties
• Weather Translation
• Collaborative Traffic Flow Management


Demand/capacity imbalance needs to be addressed with demand management options as efficiently as possible
**TFM Research Threads Progress: Decision Making Under Uncertainty**

<table>
<thead>
<tr>
<th>Ceiling and Visibility</th>
<th>In Flight Icing</th>
<th>Turbulence</th>
<th>CWAM (0-2hrs)</th>
<th>CoSPA (0-6 hrs)</th>
<th>LAMP-CCFP (0-24 hrs)</th>
<th>Ensemble Forecasts (0-48hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Translation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deterministic Routing</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stochastic Routing</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stochastic Ground Holding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated Decision Making</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Partners:** MIT-LL, NOAA, NRA (Mosaic ATM, Metron)

- Reliable weather forecasts products under development for the 2+ hr time horizon
- Significant computational challenges remain for solving NAS-wide TFM problems with a 6+ hr planning horizon under uncertainty

**Abbreviations:**
- CWAM - Convective Weather Avoidance Model
- CoSPA - Consolidated Storm Prediction for Aviation
- LAMP – Localized Aviation MOS (Model Output Statistics) Program
- CCFP – Collaborative Convective Forecast Product
Early Integrated TFM Concept Definition and Development

Problem/Need

• Understand integrated impact of current TFM operations controls (e.g., ground holding, airborne holding, rerouting)
• Develop and test an integrated TFM architecture

Approach

• Completed several experiments testing different strategies and applying specific TFM controls

Results

• Scheduling algorithms effective at alleviating sector congestion
• Tactical rerouting dominant for avoiding en route weather

Next Step

• Compare with actual operations

Partners: MIT-LL, NOAA, NRA (Mosaic ATM, Metron, UC Berkeley, University of Michigan)

Need to develop flow management strategies to reduce delays
Research Transition Team
Flow-Based Trajectory Management (FBTM)
[Multi Sector Planner]

Needs/Why Care?
Who manages trajectory?
Between traffic flow and tactical controller

Focus
Investigate roles, procedures, functions, operations, and tools
Flow based Trajectory Management

Progress/Results
Initial concept of operations
Human-in-the-loop simulations
Subjective data indicates acceptability
Objective data is being analyzed
Lessons Learned
Mixed equipage environment
Determine benefits
Investigating collaboration between MSP and an “airspace manager”

Next Steps
Determine feasibility and benefits of one or more candidate MSP updates
Complete analysis and report
Plan and conduct appropriate follow-on simulations to study mixed equipage and benefits

Capabilities, roles, and responsibilities for trajectory management need to be addressed
Significant Accomplishments

- FAA is investigating the use of San Francisco Stratus algorithms (NRA research)
  - Potential savings: $2.9M/year

- Multi-sector planner investigations are helping FAA
  - Roles and responsibilities
  - Functions

Products beginning to show impact and promise
DAC Elements of Automation for a Future Airspace System

Research Focus Area
Dynamic Airspace Configuration

Problem
• Limited degrees of freedom for airspace changes (e.g., combine two adjoining sectors) and controller interchangeability
• Substantial time to modify airspace (years) and train controllers (months)

Research Thread
• Capacity management

Research Being Pursued
• Structure of the airspace (e.g., corridors-in-the-sky)
• Algorithms for airspace configurations - benefits and feasibility considerations
• Generic airspace

Partners: FAA, MITRE, NRAs (Metron, Mosaic ATM, and CSSI)

Demand/capacity imbalance needs to be addressed by resource management (airspace capacity and controller resources)
Research Thread: Airspace Capacity Management

Problem/Need
- Determine airspace structures, their feasibility and benefits
- Develop algorithms for airspace changes and examine feasibility and benefits
- Define generic airspace concepts and assess their feasibility and benefits

Approach
- Concepts, algorithms, analysis, and simulations

Progress
- Develop concepts and algorithms for corridors-in-sky
- Develop algorithms for airspace boundary adjustments
- Early human-in-the-loop simulations to study boundary adjustments
- Generic airspace concepts

Next Step
- Feasibility and benefits of corridor
- Detailed feasibility and benefits of adaptable airspace
- Feasibility, benefits, and applicability of generic airspace

Manage Demand/Capacity imbalance by capacity adjustments rather than demand management
Airspace Redesign Benefits Analysis

**Problem/Need**
- Benefits of airspace redesigns are less understood
- Airspace allocations and TFM interactions need to be studied

**Approach**
- Number of airspace partitioning approached were combined using common scenarios
- Use simplified complexity metrics
- Examine airspace changes and flow restrictions

**Results**
- Airspace redesigns reduce delay
- Opens up airspace
- Iterations not converging

**Next Steps**
- Detailed benefits analysis
- Frequency of changes and limit number of sectors
- DAC-TFM interactions

Airspace and flow management need to be coordinated

<table>
<thead>
<tr>
<th></th>
<th>Recovered Throughput</th>
<th>Reduced Delay</th>
<th>Complexity Balancing</th>
<th>Demand/Capacity Balancing</th>
<th>Number of Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>470</td>
</tr>
<tr>
<td>Flight Clustering</td>
<td>55%</td>
<td>59%</td>
<td>13.4</td>
<td>0.16</td>
<td>1031</td>
</tr>
<tr>
<td>Voronoi Genetic</td>
<td>50%</td>
<td>63%</td>
<td>14.0</td>
<td>0.17</td>
<td>565</td>
</tr>
<tr>
<td>Mixed Integer Programming</td>
<td>31%</td>
<td>33%</td>
<td>12.5</td>
<td>0.18</td>
<td>593</td>
</tr>
</tbody>
</table>
Research Transition Team
Dynamic Airspace Configuration (DAC)
Flow Corridors

Needs/Why Care?
- Demand-capacity imbalance
- Mixed equipage

Focus
- What are the needed airspace structures?

Progress
- Developed algorithms and strategies
- Determined the best criteria for a network
- Developed methods for dynamically assessing a flow corridor

Next Steps
- Analyze flow corridor utilization (mixed equipage)
- Examine feasibility of using flow corridors for mixed equipage
- Two years to complete

Inherent problem with corridor networks designed to increase user pool:
- Short-hop flights not amenable to utilize any corridor network
- 40% of domestic aircraft fly less than 250 nmi

Corridors may be useful for dedicated and segregated operations to increase efficiency – Still don’t know if they are beneficial and necessary?
TPSU Elements of Automation for a Future Airspace System

Trajectory Prediction, Synthesis and Uncertainty

Research Focus Area: Trajectory Prediction, Synthesis and Uncertainty

Problem
• Lack of understanding of trajectory uncertainty characteristics
• Lack of functional specific requirement and standards
• Lack of interoperability of trajectory prediction techniques

Research Threads
• Trajectory requirements
• Trajectory uncertainty prediction
• Trajectory interoperability
• Trajectory validation

Research Being Pursued
• Trajectory predictions accuracy as a function of time, model parameters, meteorological effects and aircraft intent modeling
• Trajectory modeling requirement, analysis, and validation

Partners: Lockheed Martin and NRAs (L3, U of Minnesota)

Users need accurate predictions and safety critical automation needs interoperable trajectories
Research Thread: Interoperability

**Problem/Need**
- Lack of interoperability of trajectory prediction techniques
  - Trajectory based operations
  - Precise trajectories for reducing uncertainty (e.g., Separation assurance vs. TFM)

**Approach**
- Improve trajectory prediction of disparate system through the exchange of trajectory information
- Examine real-time data exchange needs for different applications

**Progress (10%)**
- Identified candidate trajectory predictors for data exchange
  - 4D-FMS and CTAS
- Standalone trajectory generators developed

**Next Steps**
- Identify critical information for exchange
- Implement common data exchange language and real-time exchange
- Involve industry (e.g., FMS)

**Partners:** NRA (L3)

Trajectories need to be interoperable to ensure maximum precision and compatibility
## Complex Combination of Constraints

### Problem/Need
- Develop capability to handle multiple constraints in altitude, speed and time (needed for better predictability)

### Approach
- Ground-based Center-TRACON Automation System
- Aircraft based Flight Management System

### Results
- Initial capabilities for 4DFMS and CTAS are developed

### Next Step
- Conduct research to determine needs and implications on interoperability
- Validation is necessary

### Partners: GE

---

**Ability to meet complex combination of constraints to support 4D trajectory-based operations**
Trajectory Uncertainty Modeling for EDA

**Problem/Need**
- Examine trajectory uncertainty with look-ahead time

**Approach**
- Develop model of the trajectory prediction error due to weight, wind and performance as a function of look-ahead time

**Progress/Results**
- Developed initial method to model uncertainty
- Developed application for En Route Descent Advisor

**Next Steps**
- General model for trajectory uncertainty prediction
- Validation

**Partners:** NRA (L3) and Lockheed Martin

Need to clearly understand trajectory uncertainties and technology requirements
SLDAST Elements of Automation for a Future Airspace System

System-Level Design, Analysis and Simulation Tools

Research Focus Area System-Level Design, Analysis and Simulation Tools

**Problem**
- Complex and interacting concepts and technologies
- Collective impact of concepts and technologies is not easily understood

**Expected Impact or End Result**
- System level impact assessment
- Interactions between key research focus areas

**Research Being Pursued**
- Metrics, scenarios, assumptions, and models
- Interaction studies
- System-level performance assessment

**Partners:** Volpe, NRAs (SJSU, GMU, U. of Virginia, OSI, and Sensis)

Collective impact of concepts and technologies need to be clear
Human Factors Assessment I

Problem/Need
• Identify (initial) human-performance-related considerations

Approach
• Detailed cognitive walkthrough
• Expert opinions through NRA

Supported by NRA team (SJSU)

Progress (Examples)
• Trust and reliance when automation is safety-critical
• Non-overlapping task distributions (mixed equipage)
• Degraded conditions

Next Steps
• Use the lessons learned during further maturity process

Partners: NRA (SJSU), and Volpe

Ultimately, humans will be part of the system. What is their role?
# Concluding Thoughts

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Description</th>
</tr>
</thead>
</table>
| Objectives/Needs          | • On-time performance  
• Reduce operator costs (fuel)  
• Increase system productivity  
• Minimize impact on environment  
• Design for scalability, safety, predictability |
| Current state of the art  | • Capacity and throughput is limited due to human centric nature (not scalable)  
• Weather causes large delays  
• Uncertainty  
• Interactions limit capacity |
| Approach                  | Advance concepts, procedures, and technologies for both ground and aircraft                                                              |
| Lessons learned           | • Uncertainty (weather, wind, traffic, etc.)  
• Solutions will involve roles/responsibilities, automation, procedures, and air/ground integration  
• Off-nominal situations and mixed equipage need to be carefully examined  
• Interactions among traffic  
• RTTs need to stay focused |
| Impact                    | • FAA: Increase productivity  
• Users: Reduce costs and increase on-time performance  
• Manufacturers: Sell more aircraft and accessories  
• Public: Fly as needed and minimum delays |
| NASA's role               | Complex domain, unique and relevant skills, experience (ground-based and aircraft), JPDO identified NASA as lead on many research items |