VIRTUAL AIRSPACE MODELING AND SIMULATION PROJECT

A Highly Automated Integrated Operational Concept for the Future NAS

Harry N. Swenson, Robert K. Fong and Michael B. Downs
NASA Ames Research Center

NEXTOR NAS System Performance Workshop
March 17, 2006
• Project Goals and Objectives
• Technical Approach
• Operational Concepts (examples)
• Evaluation Framework
• Blended Operational Concepts
• Airspace Concept Evaluation System (ACES)
• Example Results from Concept Analysis using ACES
  – Individual Concept Based
  – Blended System-Wide Concept
• Summary
Goal and Objectives

The **Goal** of the VAMS Project is to identify and assess capabilities that lead to a significant increase in the capacity of the National Airspace System, while maintaining safety and affordability.

The VAMS **Objectives** and **Deliverables** are:

1. To define and evaluate operational concepts
2. To generate enabling technology roadmaps
3. To establish the capability to assess these concepts
Technical Approach

Set of Operational Concepts

Improved Models

Existing & New Models

Develop New Concepts

VAMS Framework (HLA RTI)

Assessment System

Run Time Data Collection

System

Other VAMS Sub-Framework Models

Other VAMS Sub-Framework Models

Other VAMS Sub-Framework Models

Other VAMS Sub-Framework Models

AER-based VAMS Sub-Framework

Aircraft VAMS Sub-Framework

Models

Models

Models

Models

FACET Benchmark

Baseline

Deliverable

Deliverable

Deliverable

Technology Roadmaps

Develop, Test & Verify Integrated System-Wide Simulation Capability

Validated Simulation System

Set of Operational Concepts

• Concept Assessment
• Scenario Requirements
• Evaluation Metrics

Scenarios & Metrics

Evaluated & Assessed Revolutionary Operational Concepts

Revolutionary Operational Concepts

Automated Airspace

UAV

RLV

Community Access

High-Flow Airports

Efficiency

Safety Environment

Compatibility

Security
Operational Concepts

Cruise
- Boeing - ATM Concept
- Metron - Weather
- Seagull - Massive PTP
- NASA ARCC - System-wide Optimization
- FAA/RTCA - Future ATM Concept
- University Planning Team

Transition
- NASA ARC - Advanced Airspace
- NASA LaRC - Wake Avoidance
- Raytheon - Terminal Area Concept

Surface
- Metron - Surface Traffic Automation
- Optimal Synthesis - Surface Operation Automation

Gate
- Taxi
- Takeoff
- Climb
- Descent
- Landing
- Taxi
Advanced Airspace Concept System Architecture

- Equipped
- Automated Trajectory Server; Conflict Resolution (>1 min. to separation violation)
- Assigned 4D Trajectories for all Aircraft in Sector
- Controller Interface
- Tactical Separation Assurance: TSAFE (<1 min. to separation violation)
- Unequipped
- Voice Link
Multiple Conflicts in High Density Airspace

- Must resolve “secondary” conflicts (two kinds)
  - Conflicts that occur shortly after the first (primary) conflict
  - New conflicts that arise in a candidate trial resolution
Concept PTP: Massive Point-to-Point and On-Demand Air Transportation - Sensis Technologies

En Route
Self-separating aircraft in high altitude airspace with 4D FMS-ATM trajectory negotiation in lower altitudes

Terminal
4D approach and departure trajectory contracts to/from dense hubs and local small airports

Surface
Non-towered airport ATM automation and precision landing guidance

Cross-cutting TFM
High-fidelity trajectory-based flight planning and replanning coordination between aircraft operator and ATSP from pre-flight to gate-in

Point-to-Point Concept Facilitates Efficient Use of:

- New Aircraft Types
- More Destinations

Result:
Potential Order of Magnitude Increase in NAS Capacity
Framework for Scenario & Metrics Development

Stakeholder Viewpoints (questions to be answered)

- operational scenarios

NAS Model

output metrics

evaluation metrics

• Number of traffic events (takeoffs, sector crossings, landings, etc.)
• Number of communication events (requests, clearances, directives, etc.)
• Throughput (traffic volume)
• Delay
• Safety incidents (proximity to minimum separation, incursions, encroachments, etc.)
• Elapsed flight times
• Fuel burn
• Capital investments
• Personnel workloads
• Etc.

Stakeholder Viewpoints (questions to be answered)

- concepts

- operational scenarios

NAS Model

output metrics

evaluation metrics

- Scenario Elements:
  - NAS Domain
  - NAS Perturbations (e.g. Wx, Security Incidents)
  - Origin/Destination Demand
  - Assumed Technologies
  - Human/Machine Performance
  - Defined ATM Procedures
  - Assumed Equipage
  - Fleet Mix
  - Etc.

Simulations

Empiric Analysis

1. Scope:
   - issues
   - NAS Domain
   - challenges
   - assumptions

2. Top Level Descriptions:
   - core ideas
   - functions

3. Detailed Descriptions:
   - performance
   - roles, responsibilities of humans & machine
   - human factors
   - user interfaces

4. NAS infrastructure & technology impacts:
   - transition planning
   - architecture
   - technology requirements

* a defined city pair air route
Performance Measures and Metrics

**Capacity**
- Total Flights Flown
- Total commercial flights per day
- Total passenger trips
- Total Passenger revenue miles for metro pairs
- Average airport arrival rates
- Average airport departure rates
- Average block time
- Passenger arrivals / departures per hour
- Distance per OD
- Comparison of average number of flights to average delay
- Total System Delays by category
- Available seat miles
- Time required for surface movement per flight
- Ratio of VMC to IMC capacity
- Comparison of AAR and ADR with peak throughput

**Efficiency**
- Total aircraft travel time for (constant demand)
- Total aircraft miles flown
- Average Flight time per origin/destination pair
- Fuel burn index
- Average of aircraft over an arrival fix per hour during peak periods
- Surface traffic efficiency
- Average number of gate arrival and departure times

**Throughput**
- Airport IMC and VMC throughput compared with Airport IMC and VMC throughput Index (AITI, AVTI)
- Peak airport Throughput
- Peak Sector or Center throughput
- Peak En route Throughput

**Predictability**
- Number of flights more than 15 minutes late
- Average and standard Deviation of the difference between actual and planned flight time
- Number of passengers more than 15 minutes late arriving
- Average departure delay
- Average number of minutes late per flight

**Human Factors**
- Average number of aircraft controlled per controller position
- Estimated workload of controllers

**Safety**
- Point of closest approach
### VAMS System-Wide Concept Blending

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Surface (ATCT)</th>
<th>Terminal (TRACON)</th>
<th>En Route (ARTCC)</th>
<th>National (ATCSSC/AOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 AAC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 SWO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 WVAS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 PTP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 All Weather</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 TACEC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 SOAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Universities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 OEP v5+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**System-Wide Concepts**

- Resolve Overlaps and Gaps Across Domains (e.g., Aircraft Systems)

**Synthesized System-Wide Operating Concept**
Improved Predictability through Intent-based Strategic Planning
Increased Airborne Throughput Utilizing Automated Separation Assurance
Increased Capacity through Dynamic Traffic Management Techniques

Flexible Traffic Management in All-Weather Conditions

Gate-to-Gate 4D Trajectories With Time-based Traffic Management

Adaptive Airspace Structures

Adaptive Airport Configurations

“Better-Equipped, Better-Served” Flight
Reduced Aircraft Separation in All-Weather Conditions thru Advanced Ground and Air Technologies
Allocation of Tasks between Human and Automation

Humans:
- Direction and Management of Automation
- Decision-making
- Handling of Unequipped Aircraft
- Strategic Direction of Response to Anomalous Conditions

Automation:
- Creation, validation, Clearance Delivery, and Conformance Monitoring of 4D Trajectories
- Tactical Handling of Anomalous Conditions
- Automated Failure Backup
The Airspace Concept Evaluation System (ACES) Modeling Toolbox

**National Traffic Management**
Fast-time, nationwide gate-to-gate simulation of ATM-FD-AOC operations
- Full flight schedule with flight plans, 4-D gridded winds, gate-to-gate operations

**Regional Traffic Management**
Thousands of participating agents:
- National 1
- Regional 20
- Local 100s
- Airports 100s
- Aircraft 10,000s
- Airlines 10s

**Local Approach and Departure Traffic Management**

**Airport and Surface Traffic Management**

**High Fidelity 4-DOF Trajectory Model**
- Based on laws of physics and aerodynamics
- Realistic pilot-based control laws
- Includes elliptic-Earth trajectory propagation
- Contains modeling for aircraft/pilot variability
Performance Comparison of Current System and AAC (Simulation of Cleveland Center Airspace)

Delays due to auto resolutions; TFM flow restrictions not required.

TFM delays due to flow restrictions in current system.

Impractical TFM solutions

- 1x; 6000 flights May 17, 2002: 7 conflicts resolved
- 2x; 12000 flights May 17, 2002: 11 conflicts resolved
- 3x; 18000 flights Feb. 14, 2004: 12 conflicts resolved

Delay/flight, in seconds

# of conflicts resolved per day

- 12.6 delays per flight
- 41 min delay
- 500 conflicts resolved
- 1700 conflicts resolved
- 2500 conflicts resolved
NAS-wide Benefit Results

- Using Diversion of 34 CONUS OEP Apt Demand to PTP Auxiliary Apts

\[
PTP\text{ Increase}_{\text{Region}} = \frac{\sum \text{All Airport Capacity}_{\text{Region}}}{\sum \text{OEP Airport Capacity}_{\text{Region}}}
\]

PTP Airport Operations Analysis

- VMC PTP Increase to Region
- IMC PTP Increase to Region
Example Results – Flights, RPM, and Trips

- Flights
- RPM
- Passenger Trips
- Avg Fuel Efficiency (gal/hr)
- Avg Total Delay

Legend:
- Current day, No WX
- OEP v5, No Wx
- Future H&S, No WX
- Future H&S+PTP, No WX
- Current day, WX
- OEP v5, Wx
- Future H&S, WX
- Future H&S+PTP, WX
Summary

• VAMS has developed and analyzed a wide range of innovative operational concepts that provide significant increases in capacity for the National Airspace System (NAS).

• VAMS has created a non-real time, system-wide analytical simulation and modeling tool set that has explored domain specific and systemic performance characteristics of the VAMS innovative concepts.

• VAMS has developed and applied an blending and synthesis process for the integration of Operational Concept Elements into a capacity increasing System-Wide Operational Concept.

• VAMS is currently documenting the System-Wide Operational concept along with the synthesis and analysis process including research issues encountered. (Just entered peer review.)
Backup Slides
PSCA - ACES Experimental Conditions

- ACES Build 4.0.2_NASA
- Weather days
  - Perfect – all facilities in VFR
  - Nominal – actual 5/17/02 weather
- Sector capacities – See Below
- Airport capacities – See Below
- CD&R – Off
- Delay Maneuvers – Off
- Arrival Fix Spacing – Off
- Arrival Fix TRACON Delay – Off
- Departure Fix TRACON Delay – Off
- AOC Operation – Off
- Tail Tracking – Off
- Airport mode – Nodal
- En-route weather modeling
## PSCA - Trial Matrix

<table>
<thead>
<tr>
<th>System</th>
<th>Demand</th>
<th>Current Day</th>
<th>OEP 2015</th>
<th>Future H/S (+50%)</th>
<th>Future H/S +PTP (+50%)</th>
<th>Future H/S (+100%)</th>
<th>Future H/S +PTP (+100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Day</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEP 2015</td>
<td>X</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>VAMS SWC</td>
<td>#</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Legend:**
- Black - Need to run
- Red - Run if 50% is good
- # - they are needed for a direct comparison, considered optional for now

**Other Notes:**
- Current x Current run could be used to characterize/establish acceptable delay
- OEP2015 x OEP2015 could also be used to characterize/establish acceptable delay
- Need to run matrix for all Wx days chosen (perfect and nominal)
- Is OEP 2015 is approximately 1.5X?
- First runs performed would be 1) future H/S+PTP (50%) X VAMS System-wide Concept, perfect weather
## PSCA - Operating Conditions

A. Benchmark 2004 Report: Current Day Airport Operating Capacities  
B. FAA Advisory Circular 150/5060-5 Airport Capacity and Delay  
C. ASPM Airport Operating Capacities  
D. Adaptation Controlled Environment System (ACES)  
F. VAMS Blended Concept Descriptions

<table>
<thead>
<tr>
<th>Run</th>
<th>Demand</th>
<th>Capacity Definition (see legend above)</th>
<th>Condition</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Day No Weather</td>
<td>Current Day</td>
<td>A,B,C,D</td>
<td>VFR</td>
<td>VFR at all airports</td>
</tr>
<tr>
<td>Current Day Moderate Weather</td>
<td>Current Day</td>
<td>A,B,C,D</td>
<td>VFR/IFR</td>
<td>Airport State Files Sector MAP Scenario File</td>
</tr>
<tr>
<td>OEP No Weather</td>
<td>OEP 2015</td>
<td>A,B,C,D,E</td>
<td>VFR</td>
<td>VFR at all airports</td>
</tr>
<tr>
<td>OEP Moderate Weather</td>
<td>OEP 2015</td>
<td>A,B,C,D,E</td>
<td>VFR/IFR</td>
<td>Airport State Files Sector MAP Scenario</td>
</tr>
<tr>
<td>Future 1.5x No Weather</td>
<td>Future 2020</td>
<td>A,B,C,D,E</td>
<td>VFR</td>
<td>VFR at all airports</td>
</tr>
<tr>
<td>Future 1.5x Moderate Weather</td>
<td>Future 2020</td>
<td>A,B,C,D,E,F</td>
<td>VFR/IFR</td>
<td>Airport State Files Sector MAP Scenario</td>
</tr>
<tr>
<td>Future PTP 1.5x No Weather</td>
<td>Future 2020</td>
<td>A,B,C,D,E,F</td>
<td>VFR</td>
<td>VFR at all airports</td>
</tr>
<tr>
<td>Future PTP 1.5x Moderate Weather</td>
<td>Future 2020</td>
<td>A,B,C,D,E,F</td>
<td>VFR/IFR</td>
<td>Airport State Files Sector MAP Scenario</td>
</tr>
</tbody>
</table>
### Scenario Description

<table>
<thead>
<tr>
<th>Metric</th>
<th>Current Day</th>
<th>OEP</th>
<th>Future 1.5</th>
<th>PTP 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Wx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flights in NAS</td>
<td>43016</td>
<td>56004</td>
<td>67341</td>
<td>69744</td>
</tr>
<tr>
<td></td>
<td>41927</td>
<td>54102</td>
<td>64903</td>
<td>67651</td>
</tr>
<tr>
<td>Domestic flights</td>
<td>40394</td>
<td>52543</td>
<td>63047</td>
<td>65441</td>
</tr>
<tr>
<td></td>
<td>39319</td>
<td>50679</td>
<td>60656</td>
<td>63359</td>
</tr>
<tr>
<td>International flights</td>
<td>2622</td>
<td>3461</td>
<td>4294</td>
<td>4303</td>
</tr>
<tr>
<td></td>
<td>2608</td>
<td>3423</td>
<td>4247</td>
<td>4292</td>
</tr>
<tr>
<td>Operations at Benchmark airport</td>
<td>28919</td>
<td>38758</td>
<td>47728</td>
<td>47174</td>
</tr>
<tr>
<td></td>
<td>28044</td>
<td>37233</td>
<td>45780</td>
<td>45602</td>
</tr>
<tr>
<td>% operations at benchmark</td>
<td>67.2%</td>
<td>69.2%</td>
<td>70.8%</td>
<td>67.6%</td>
</tr>
<tr>
<td></td>
<td>66.8%</td>
<td>68.8%</td>
<td>70.5%</td>
<td>67.4%</td>
</tr>
</tbody>
</table>
PSCA – Traffic Mix

- Commercial
- Air Taxi
- General Aviation
- Freight
- Military
- Other

Current Day
OEP
Future 1.5
PTP 1.5
Example Results – Flights, RPM, and Trips

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current day, No WX</th>
<th>OEP v5, No Wx</th>
<th>Future H&amp;S, No WX</th>
<th>Future H&amp;S+PTP, No WX</th>
<th>Current day, WX</th>
<th>OEP v5, Wx</th>
<th>Future H&amp;S, WX</th>
<th>Future H&amp;S+PTP, WX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seats</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flights</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Trips</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Major Air Transportation System Performance Dimensions

A. Pax/Cargo Demand
- Current
- Terminal Area Forecast (TAF) 2014 and 2025
- 2X TAF based constrained growth
- 3X TAF

B. Fleet Mix/Aircraft Types
- Current Scaled
- Regional Jets
- New Vehicles
  - Micro Jets
  - TiltRotors
- UAV
- SST
- E-STOL

C. Business Model/Schedule
- Current (mostly Hub&Spoke)
- More Point To Point + regional airports
- Massive smaller airport utilization

D. NAS Capability
- Current
- 2010 OEP
- Increased Capacity of:
  - Surface
  - Runways
  - Terminal
  - En route
- Systemic
  - CNS
  - SWIM
  - Weather Prediction
  - Other

E. Disruptions/Weather
- Good Weather (Wx)
- Bad Wx
  - Airport IFR
  - En route
  - 7 Wx days
- Disruption
  - Sudden shutdown of an airport or region
Human Performance Evaluation Capability

• Provide for high-fidelity evaluation of human performance and/or roles and responsibilities issues of new operational concepts
• Integrate models, simulation labs and facilities into a distributed network
• Leverage existing facilities and models
• Reconfigurable to meet different concept requirements
Facility Integration Innovations

- **Facility Integration Tools**
  - Bridges - connect components with different implementations of an HLA communications protocol to VAST-RT
  - Portals - connect components with non-HLA communications protocols to VAST-RT
  - Ownership Handoff Manager - allows control of an aircraft to pass to different facilities as the aircraft moves through space

- **Distributed Simulation Tools**
  - Data collection
  - Centralized simulation clock
  - A generic component to supply data unavailable from some facilities, but needed by other components or facilities

- **Other Research Tools**
  - Displays and Decision Support Tools to support AOC participation
  - Interfaces to non-ATM research tools
  - Displays for simulation monitoring and observer participation
Human Performance Evaluation Capability
September 2005

B747 Level D Simulator
Advanced Concepts Flight Simulator
Vertical Motion Simulator
Surface Management System (SMS)
GoSAFE Surface Automation Tool

HLA Comm Toolbox
HLA Comm Toolbox
HLA Comm Toolbox
HLA Comm Toolbox
HLA Comm Toolbox
HLA Bridge
ADRS Portal
UAV Simulator

CVSRF ATC Lab
FutureFlight Central
Airspace Operations Laboratory
Airspace Traffic Generator
Model Interactions within ACES
ACES Simulation of AAC Automated Resolution

• Includes realistic models of aircraft performance, guidance functions and 4D trajectories

• Monte Carlo like simulation environment
  - Each 24 hour long ACES run includes thousands of conflict encounters
  - Provides unbiased and statistically significant results

• Results for Cleveland Center Traffic
  - Investigated range of traffic densities and res. parameters
    - 1X, 2X, 3X traffic density
    - Time to first loss range for generating resolutions: 1-8 minutes
    - Conflict free range for resolutions: 12 minutes
    - All types of conflicts, including arrival vs. arrival
    - Airspace and traffic above 10,000 ft
  - Dominant conflicts
    - 60 % non cruise or mixed cruise non- cruise
  - Resolution strategy
    - Comparison of performance for vertical and horizontal resolution priority
JPDO* Future Demand Projections

**Passengers**

- 2004: ~1X
- 2025: 1.8-2.4X

**Shift in passengers per flight**
- (e.g., A380, reverse RJ trend, higher load factor)

**Biz shift**
- 2% shift to micro jets
- Smaller aircraft, more airports

**Flights**
- 1.4-3X
- 3X

**Terminal Area Forecast (TAF) Growth Projection**
- 2014 and later Baseline analysis will use OEP & FACT Capacities

**Enplanement Demand**

- ~3X
- ~2X

* JPDO Evaluation and Analysis Division