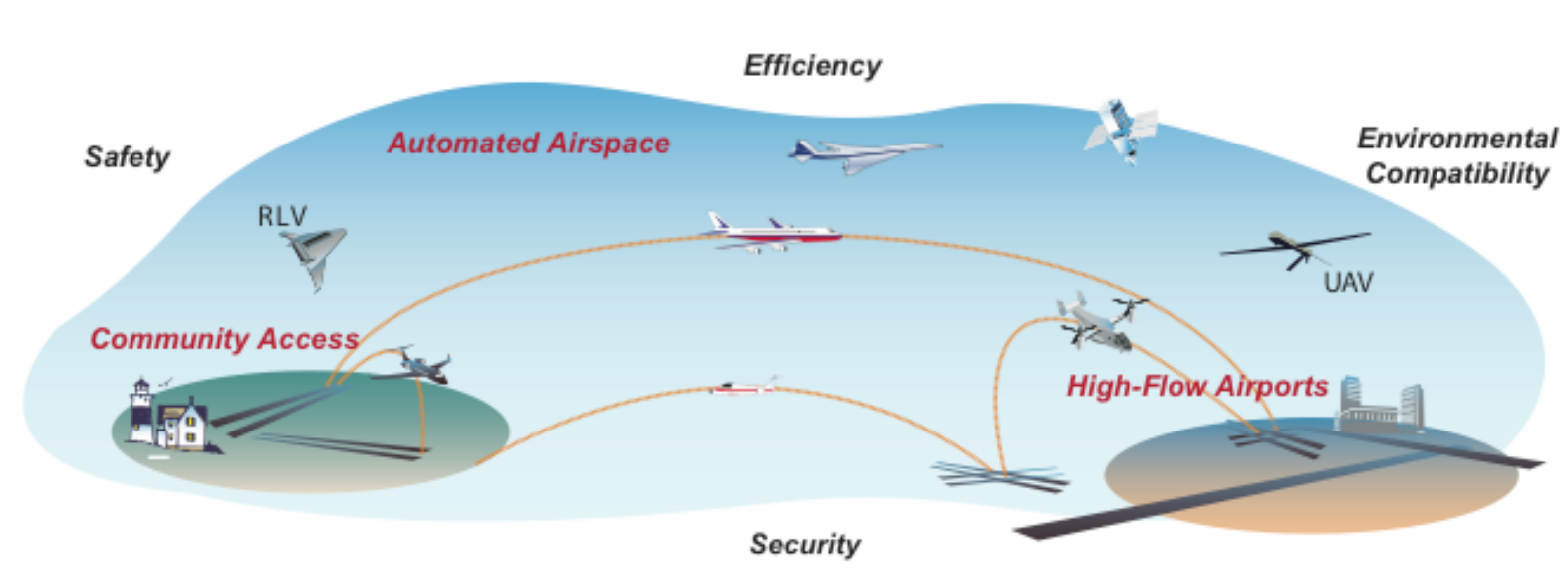
VIRTUAL AIRSPACE MODELING AND SIMULATION PROJECT

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

Outline

- **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

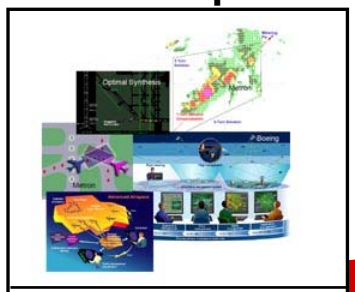
The Goal of the VAMS Project is to identify and assess capabilities that lead to a significant increase in the capacity of the National Airspace System, while maintaining safety and affordability.

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**

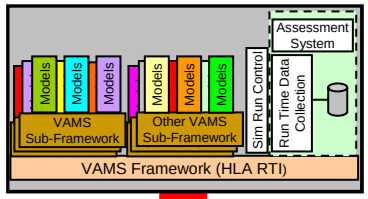
Technical Approach

Set of Operational Concepts

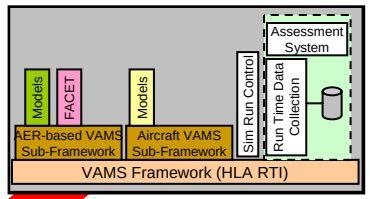


Develop New Concepts

Improved Models



Existing & New Models



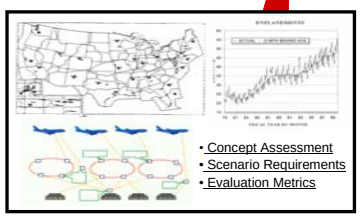
Develop, Test & Verify Integrated System-Wide Simulation Capability

Validated Simulation System

Benchmark

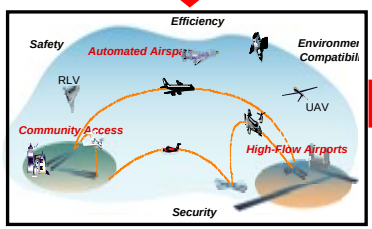
Baseline

Deliverable



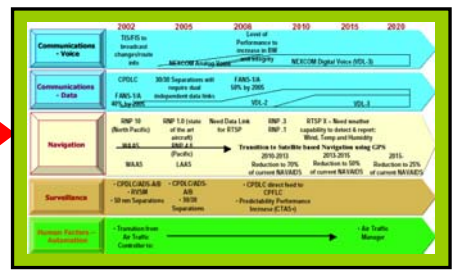
Scenarios & Metrics

Deliverable



Evaluated & Assessed Revolutionary Operational Concepts

Deliverable



Technology Roadmaps

Operational Concepts

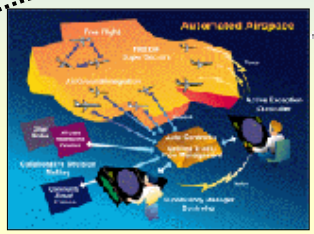
System-level

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

Cruise

climb

descent

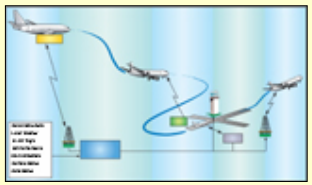


NASA ARC - Advanced Airspace

Transition

takeoff

landing

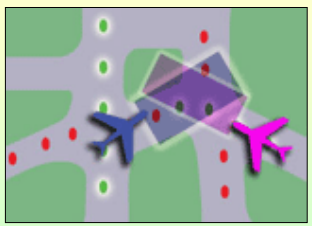


NASA LaRC - Wake Avoidance
Raytheon - Terminal Area Concept

Surface

taxi

taxi

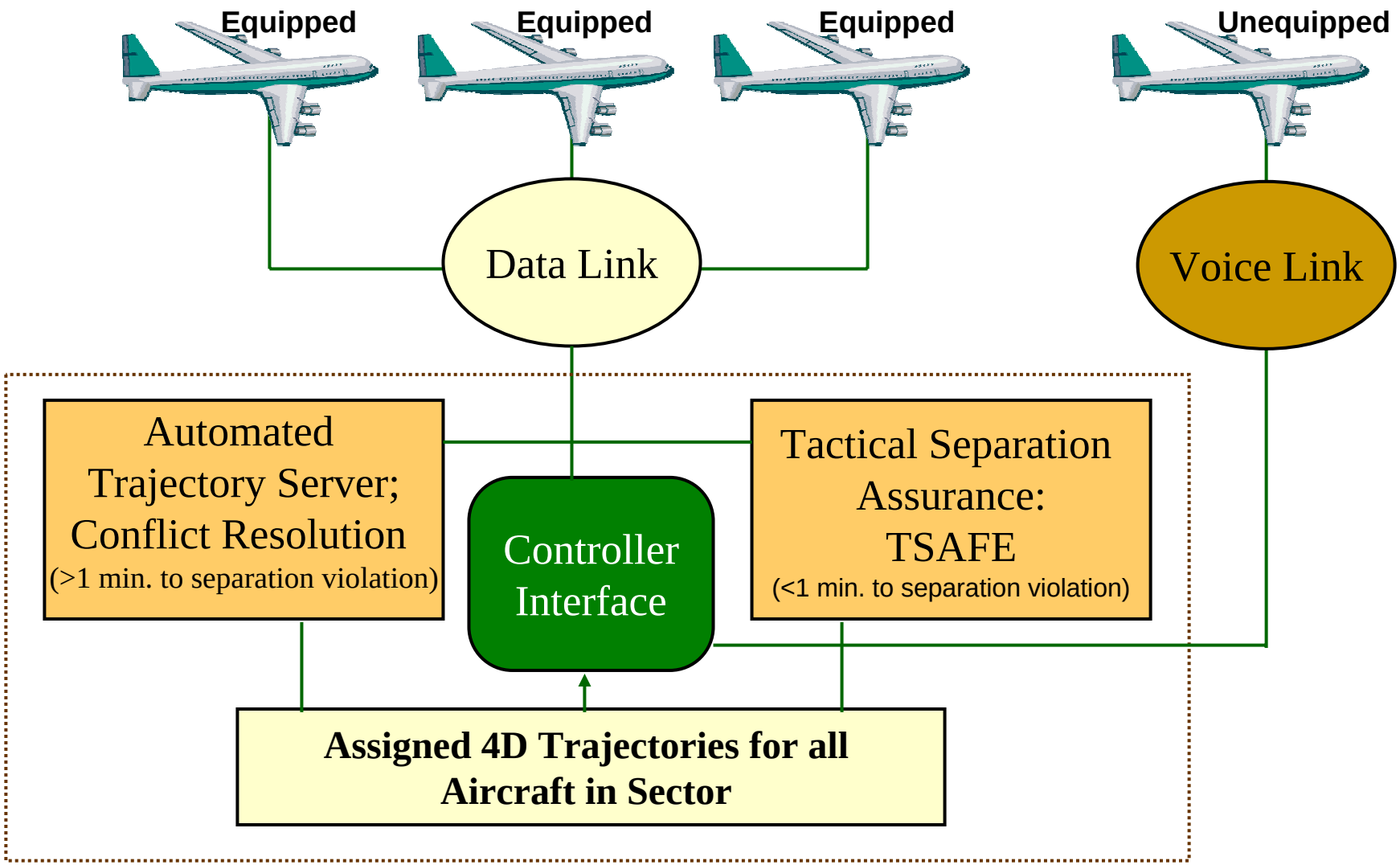


Metron - Surface Traffic Automation
Optimal Synthesis - Surface Operation Automation

gate

gate

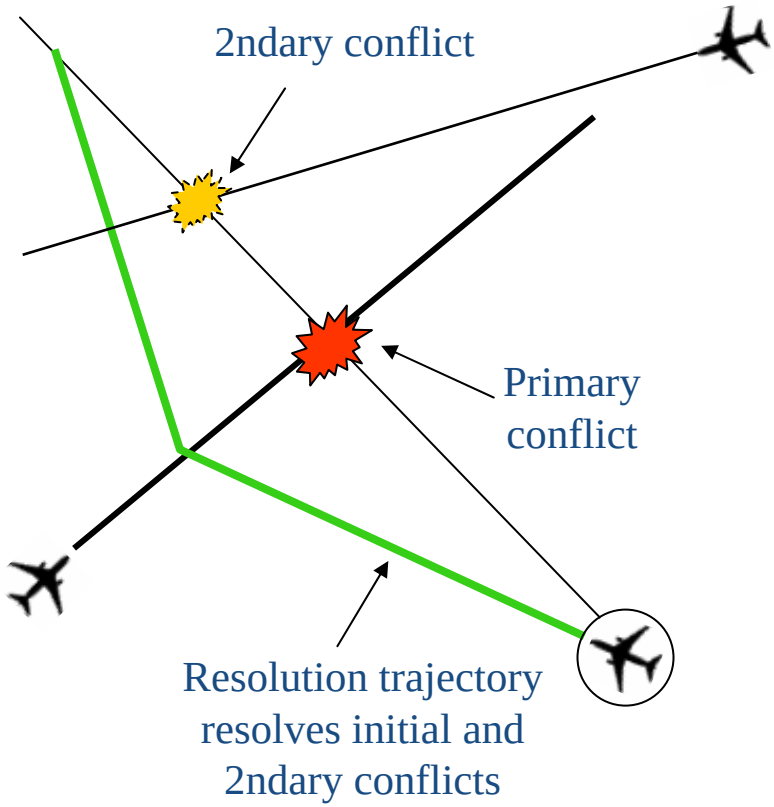
Advanced Airspace Concept System Architecture

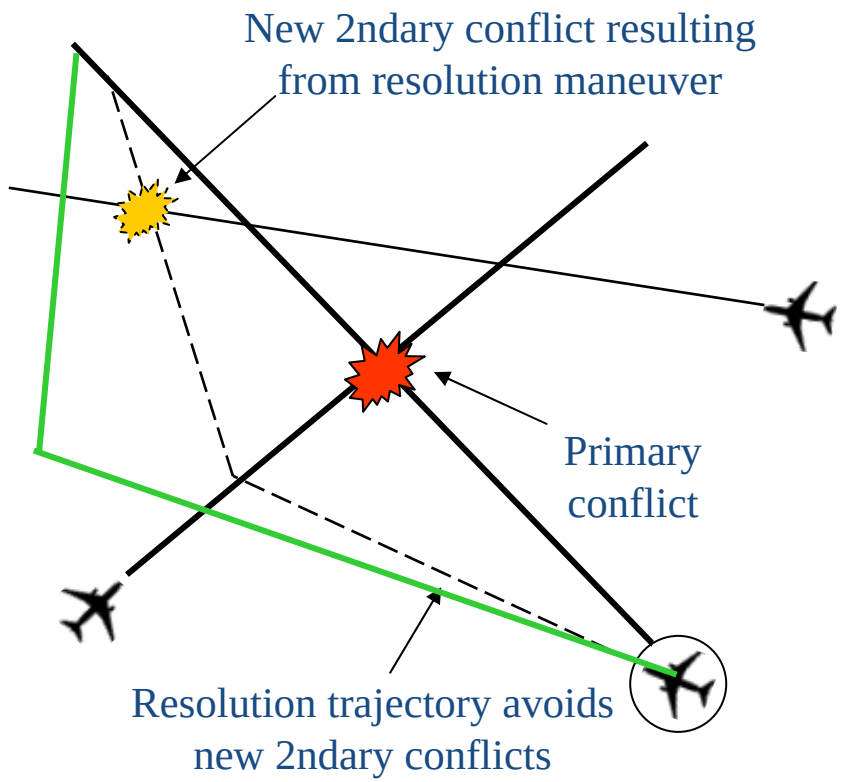


Heinz Erzberger, NASA ARC

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



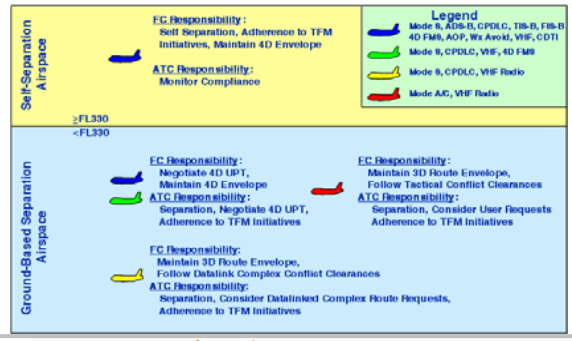


Heinz Erzberger, NASA ARC

Concept PTP: Massive Point-to-Point and On-Demand Air Transportation - Sensis Technologies

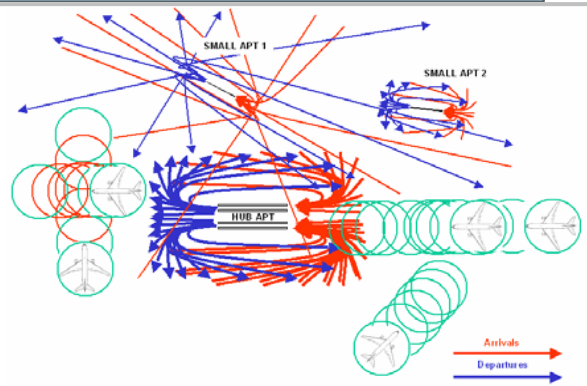
En Route

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



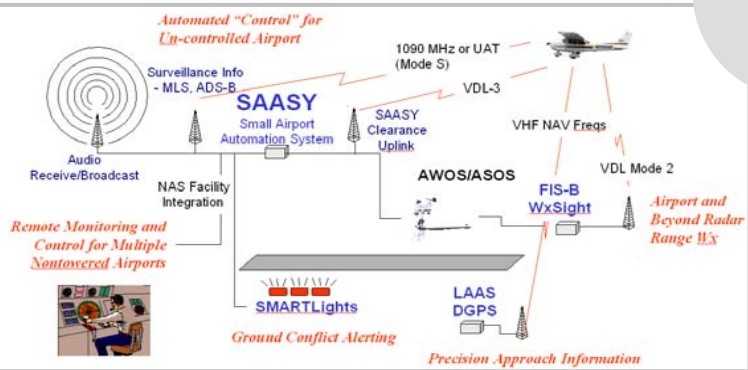
Terminal

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

Seagull Technology

TITAN

UNITED

Team PTP

Honeywell

ITT Industries

FedEx

Framework for Scenario & Metrics Development

Stakeholder Viewpoints (questions to be answered)

concepts → **operational scenarios** → **NAS Model** → **output metrics** → **evaluation metrics**

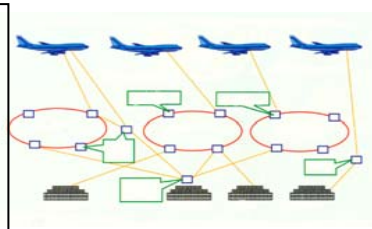
Stakeholder Viewpoints (questions to be answered)

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

2. Top Level Descriptions:
- core ideas
- functions

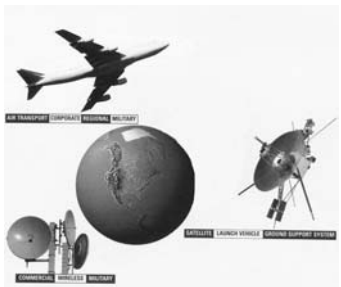
3. Detailed Descriptions:
- performance
- roles, responsibilities of humans & machine
- human factors
- user interfaces

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



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

- 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.

- Average aircraft flight time per air route
- Average aircraft payload per flight mile
- Operational cost per passenger mile
- Average taxi time from pushback to wheels up during peak traffic periods per specific airports or taxi paths within airports
- Average voice channel occupancy time per departure from pushback to take off
- Average Airport arrival rate during peak periods
- Rate of arrivals per controller hour per airport
- Aircraft (or engine, or other component) maintenance costs per flight mile
- Etc.

* 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

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

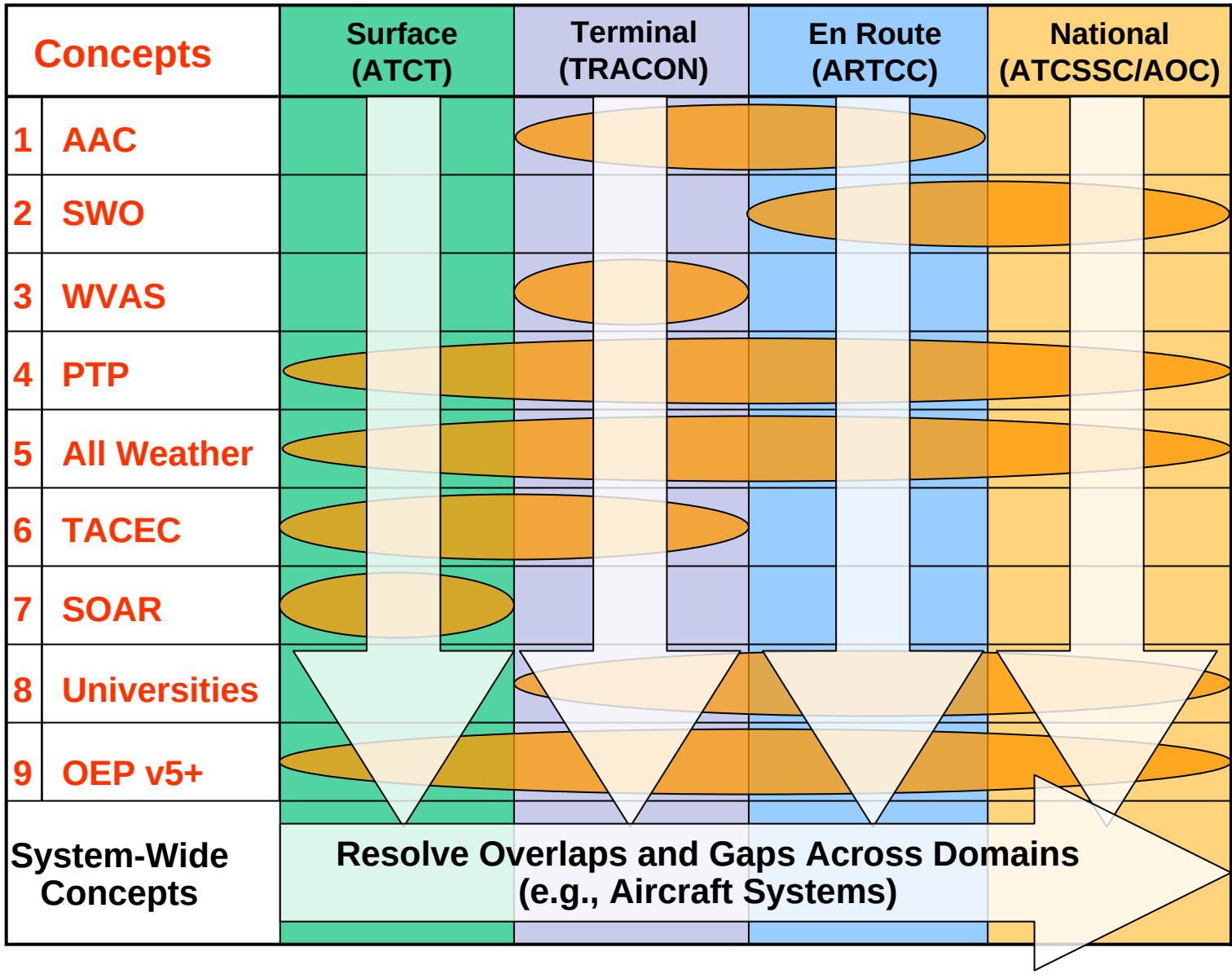
Efficiency
- Total aircraft travel time for (constant demand)
- *Total aircraft miles flown*
- Average Flight time per origin/destination pair
- *Fuel burn index*
- Average of aircraft over an arrival fix per hour during peak periods
- Surface traffic efficiency
- Average number of gate arrival and departure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

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

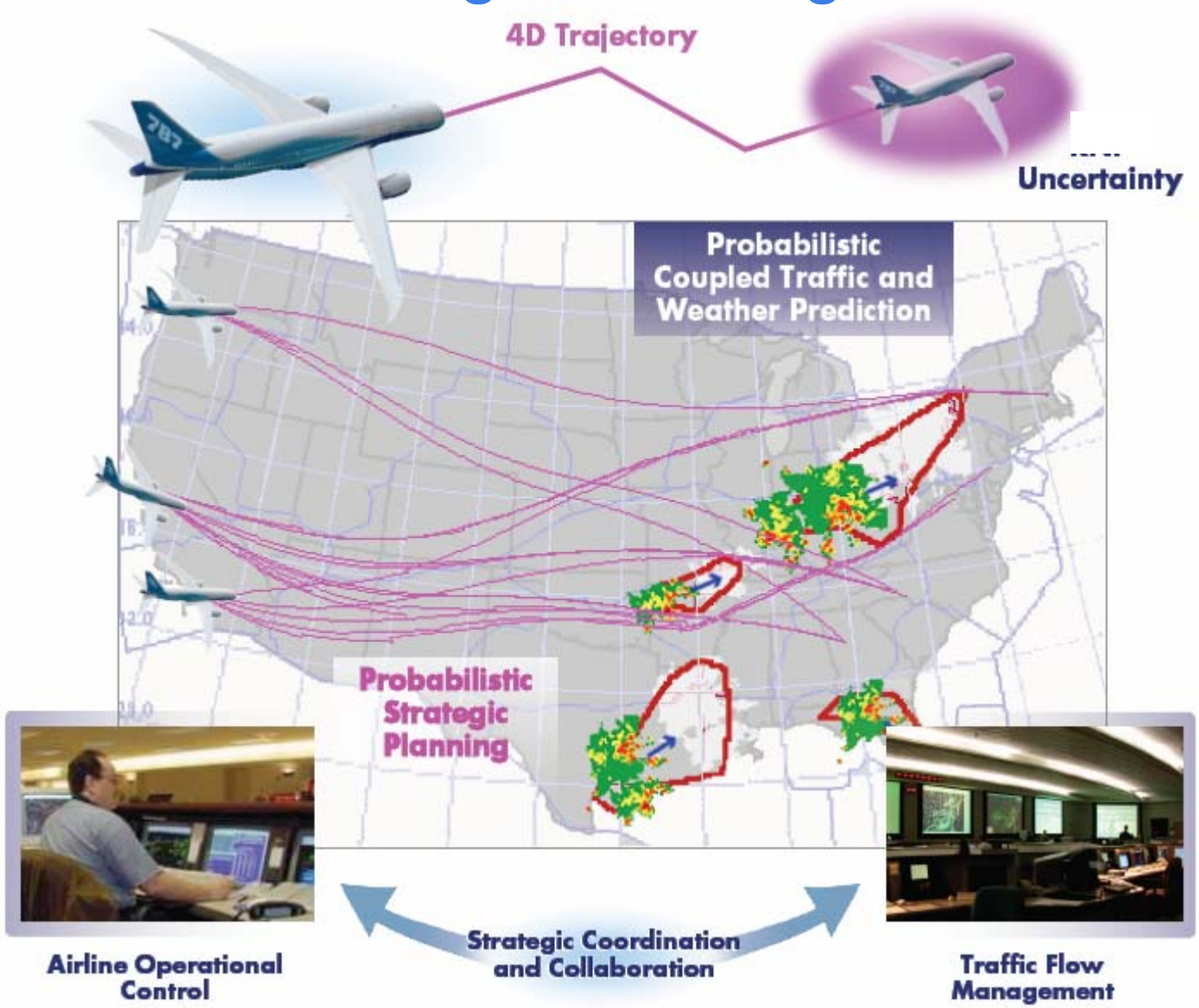
Human Factors
- Average number of aircraft controlled per controller position
- Estimated workload of controllers

Safety
- Point of closest approach

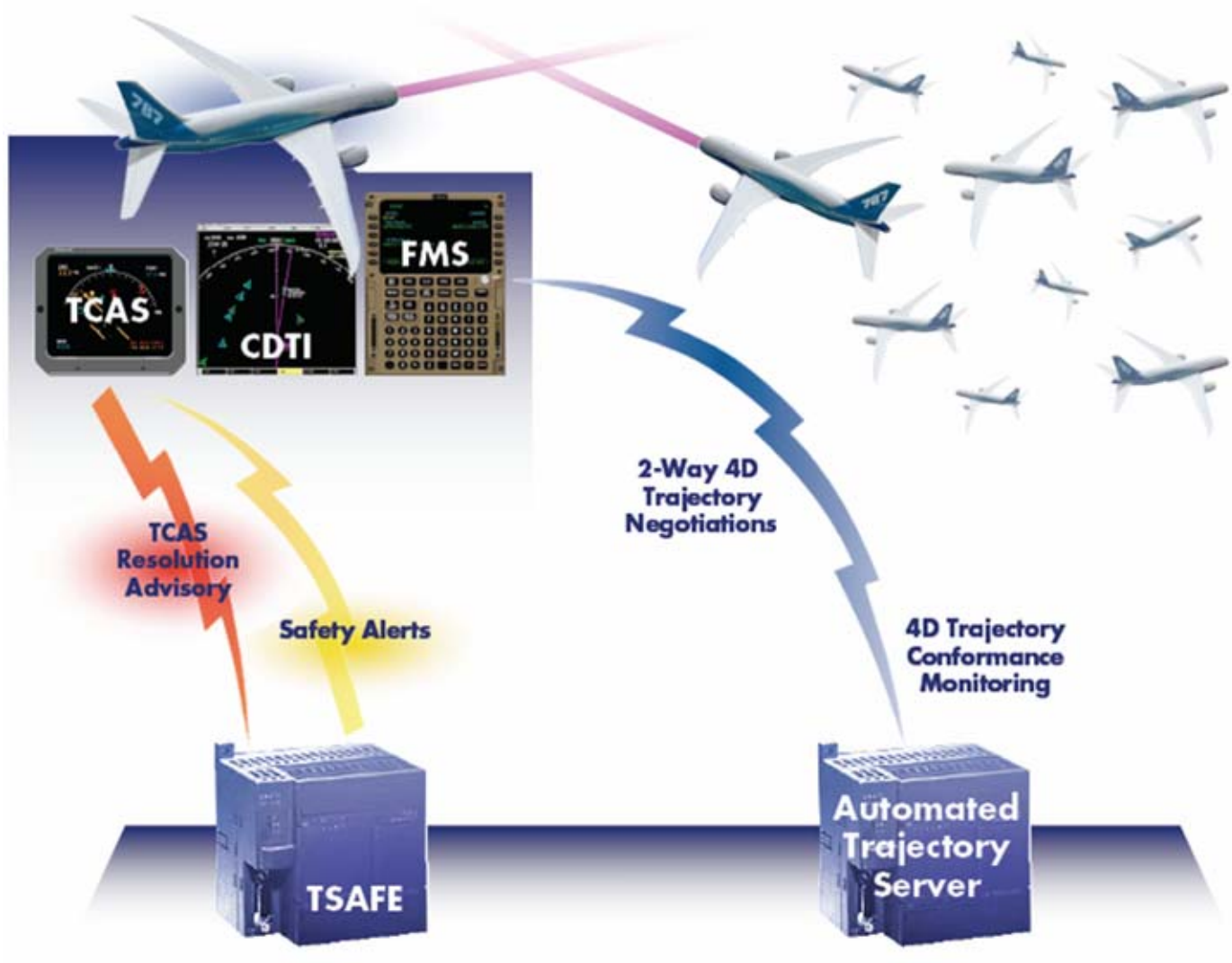
VAMS System-Wide Concept Blending



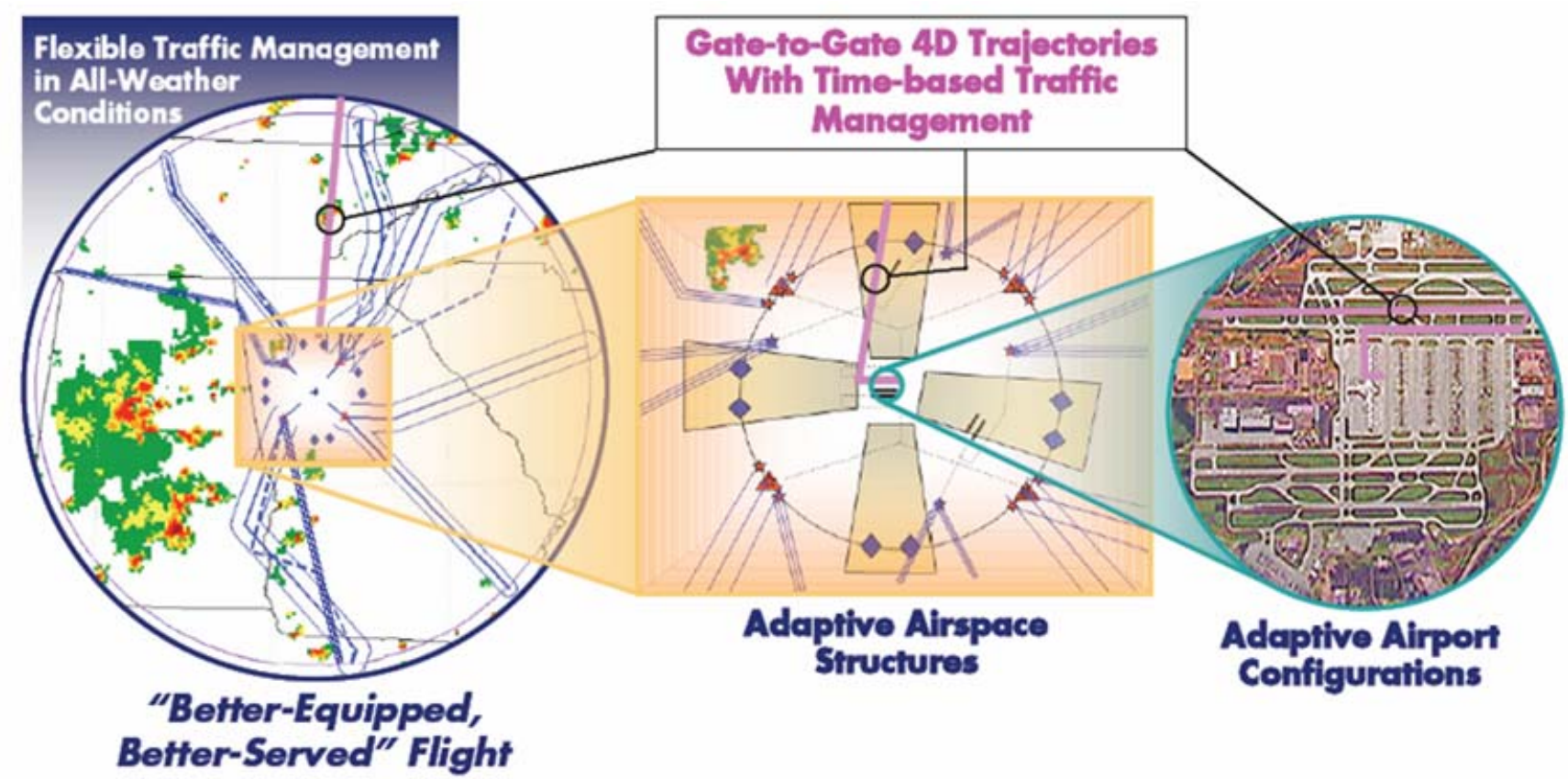
Improved Predictability through Intent-based Strategic Planning



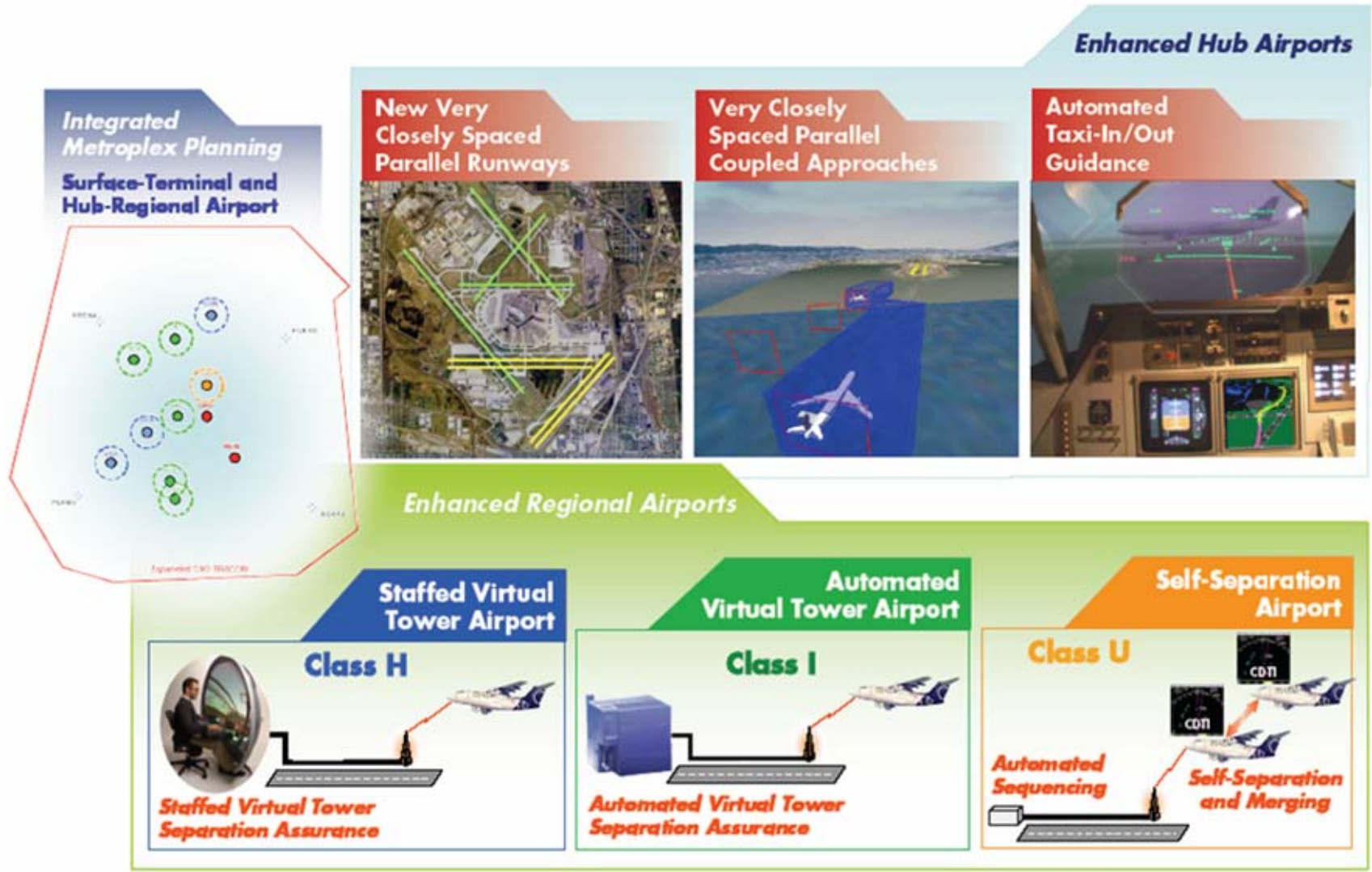
Increased Airborne Throughput Utilizing Automated Separation Assurance



Increased Capacity through Dynamic Traffic Management Techniques



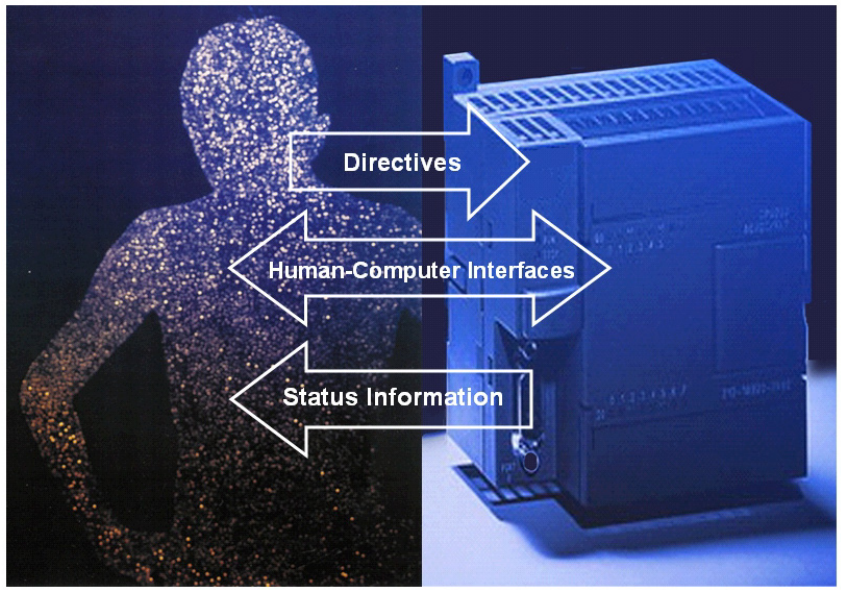
Reduced Aircraft Separation in All-Weather Conditions thru Advanced Ground and Air Technologies



Allocation of Tasks between Human and Automation

Humans:

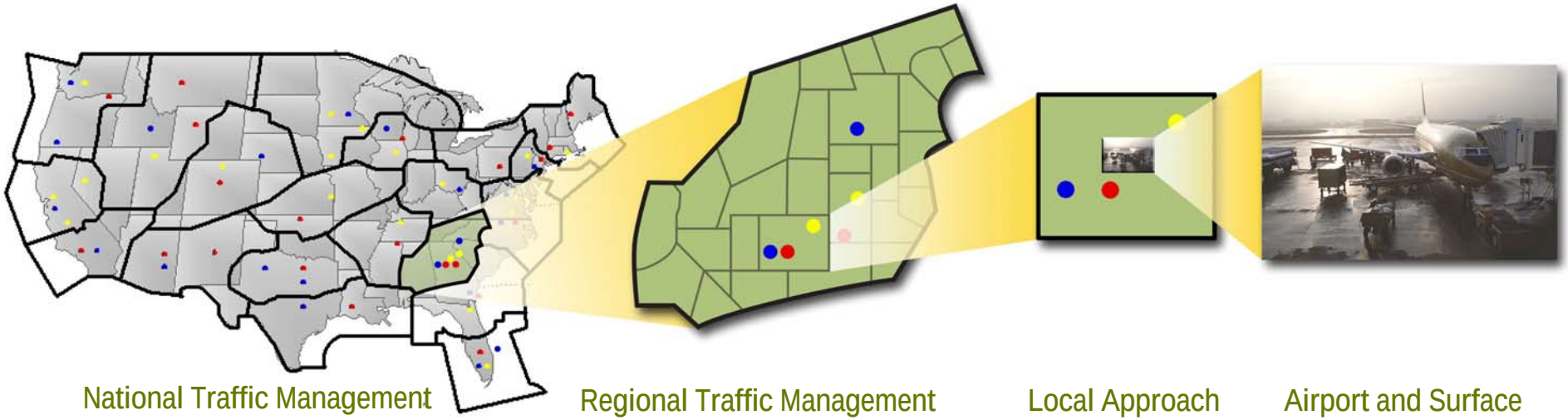
- Direction and Management of Automation
- Decision-making Handling of Unequipped Aircraft
- Strategic Direction of Response to Anomalous Conditions



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

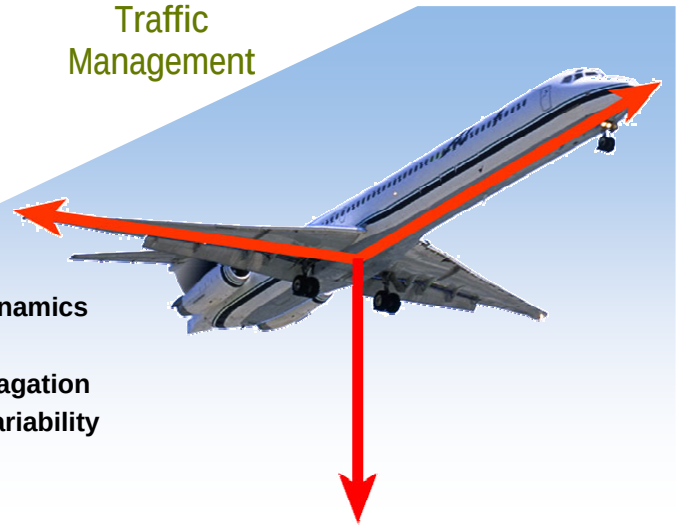
Regional Traffic Management

Thousands of participating agents:

• National	1
• Regional	20
• Local	100s
• Airports	100s
• Aircraft	10,000s
• Airlines	10s

Local Approach and Departure Traffic Management

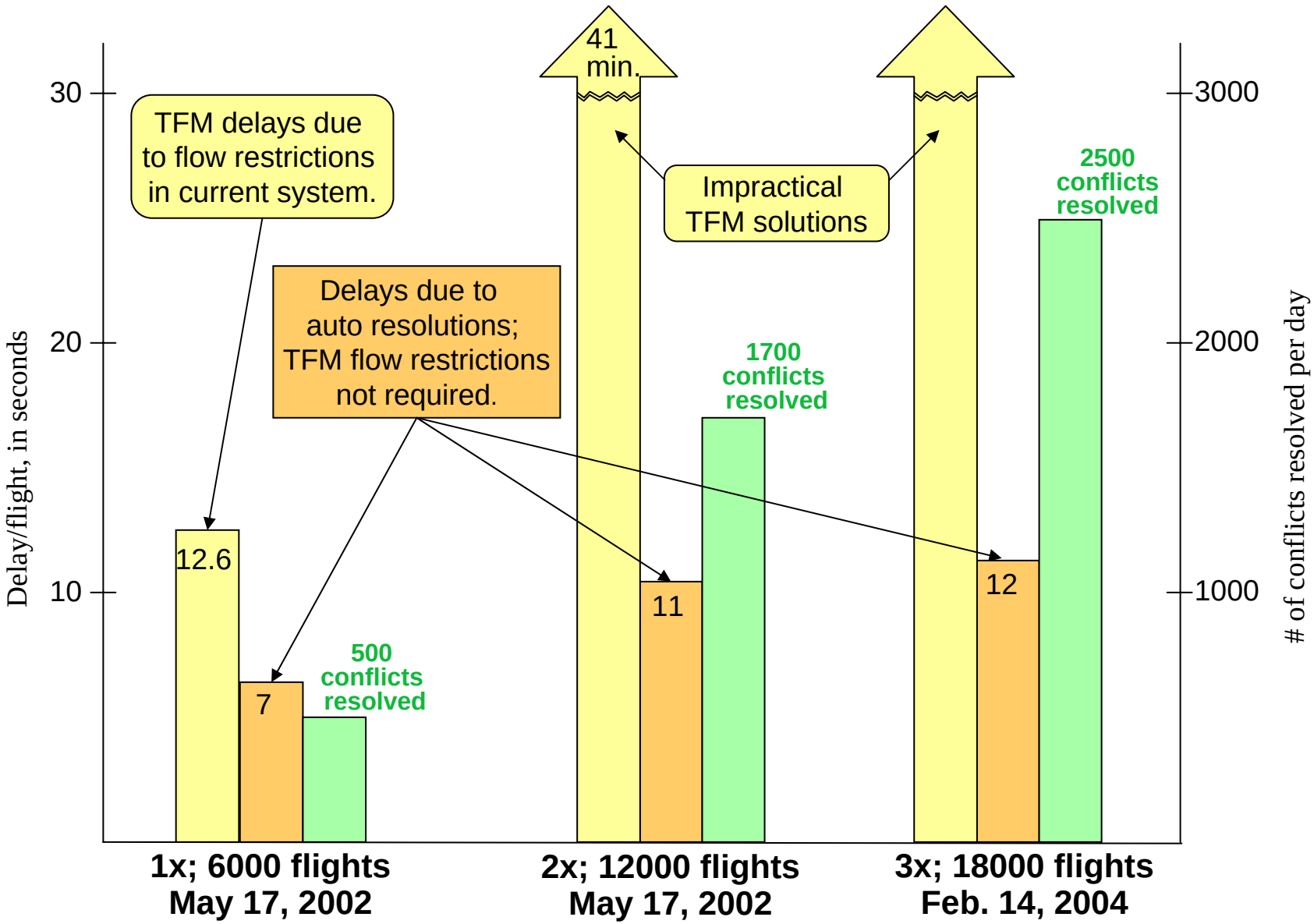
Airport and Surface Traffic Management



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**

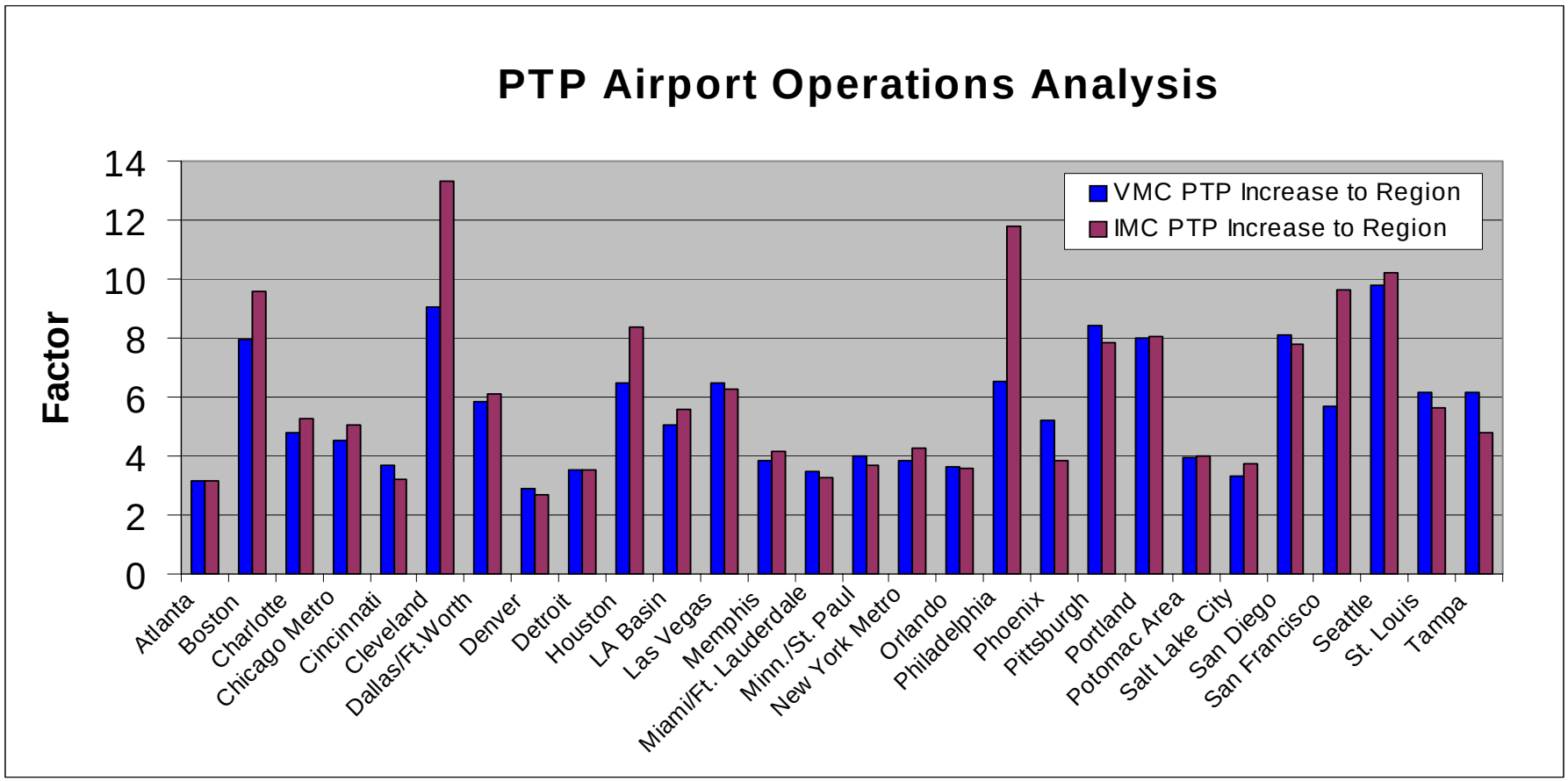
Performance Comparison of Current System and AAC (Simulation of Cleveland Center Airspace)



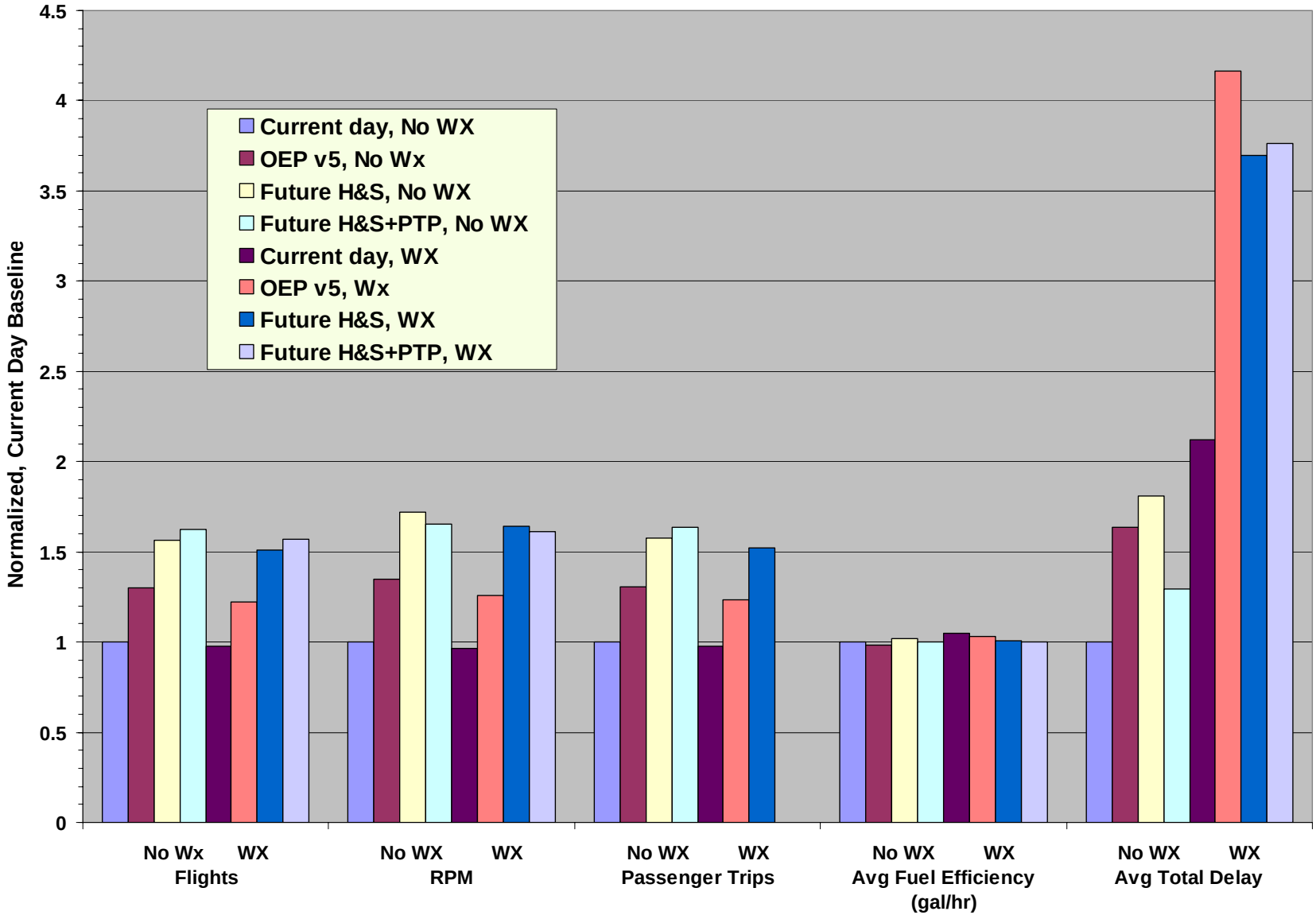
NAS-wide Benefit Results

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

$$PTP\ Increase_{Region} = \frac{\sum All\ Airport\ Capacity_{Region}}{\sum OEP\ Airport\ Capacity_{Region}}$$



Example Results – Flights, RPM, and Trips

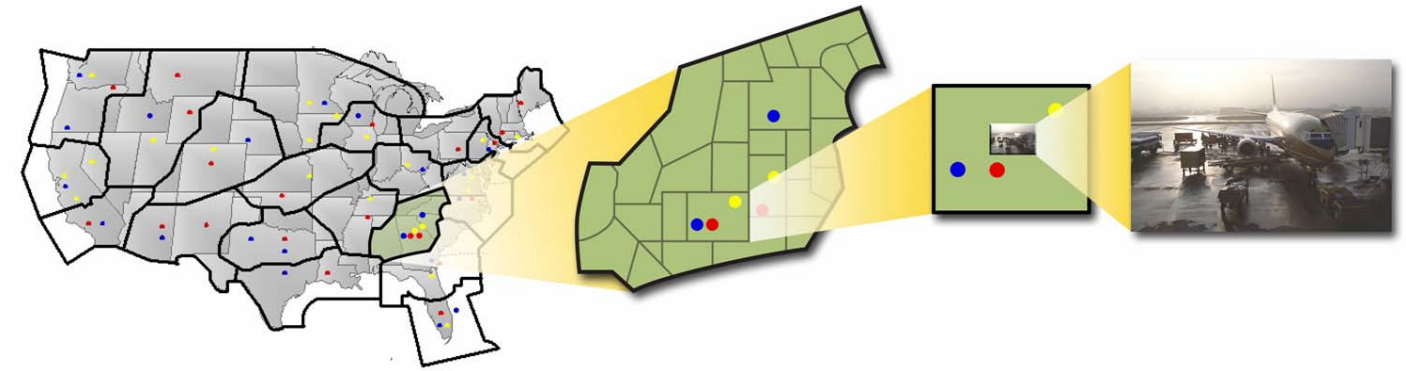


Summary

- 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

System	Demand					
	Current Day	OEP 2015	Future H/S (+50%)	Future H/S +PTP (+50%)	Future H/S (+100%)	Future H/S + PTP (+100%)
Current Day	**X**					
OEP 2015		**X**	**#**	**#**	**#**	**#**
VAMS SWC		**#**	**X**	**X**	**X**	**X**

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

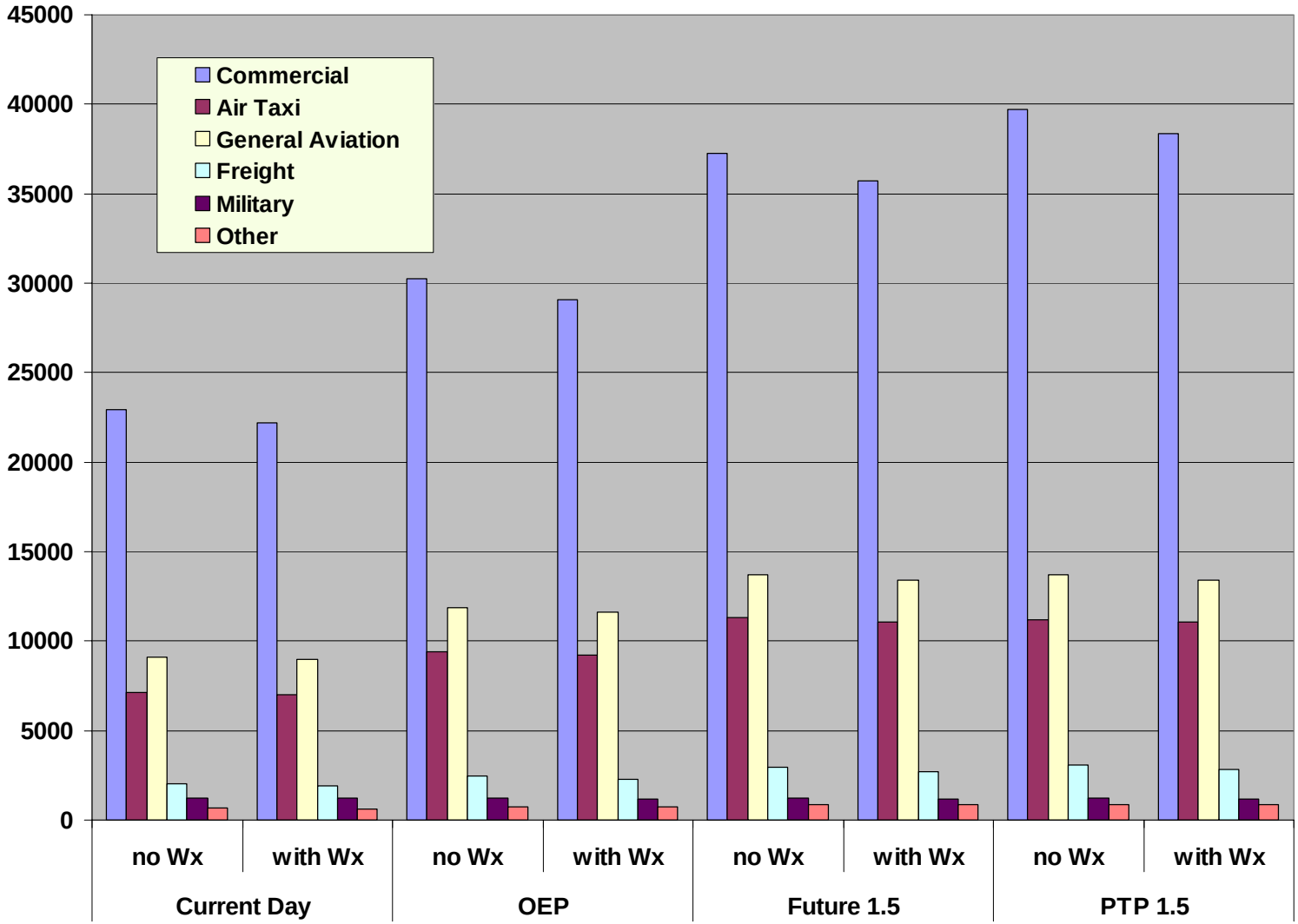
A. Benchmark 2004 Report: Current Day Airport Operating Capacities
B. FAA Advisory Circular 150/5060-5 Airport Capacity and Delay
C. ASPM Airport Operating Capacities
D. Adaptation Controlled Environment System (ACES)
E. Koenke and Abramson White Paper (Aug 2005)
F. VAMS Blended Concept Descriptions

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

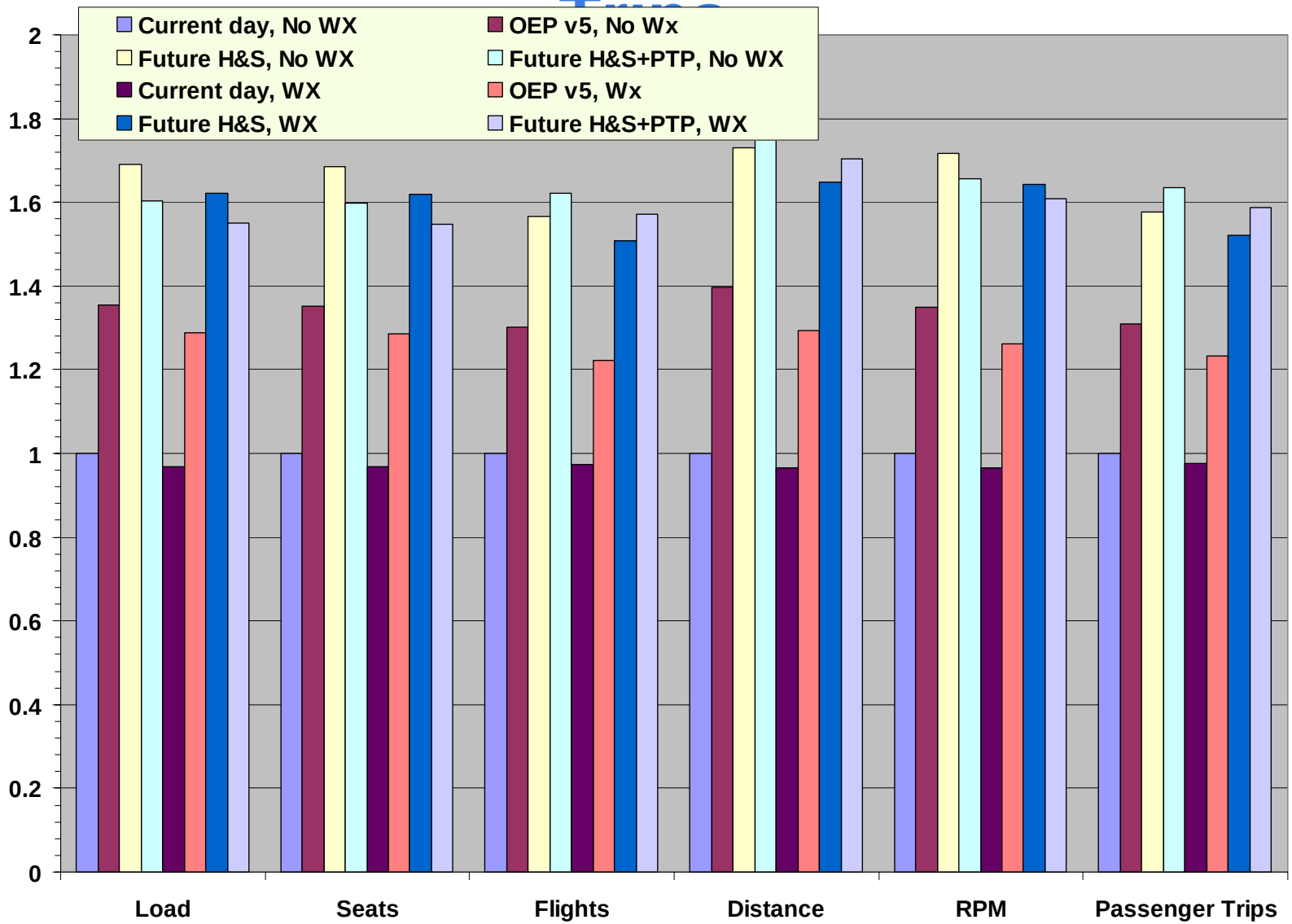
PSCA Results, Flights and BMK Ops

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

PSCA – Traffic Mix

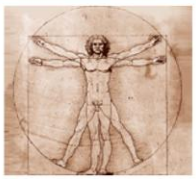


Example Results – Flights, RPM, and Trips



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

HLA Comm Toolbox

HLA Comm Toolbox

CVSRF ATC Lab

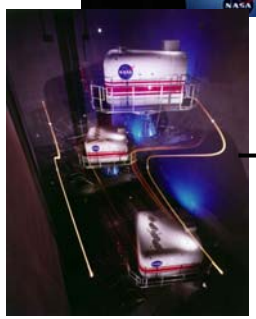
Advanced Concepts Flight Simulator

HLA Comm Toolbox

HLA Bridge

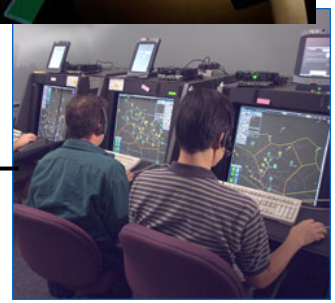
FutureFlight Central

Vertical Motion Simulator



HLA Comm Toolbox

ADRS Portal



Airspace Operations Laboratory

Surface Management System (SMS)

DST

Toolbox

Toolbox

UAV Simulator

GoSAFE Surface Automation Tool

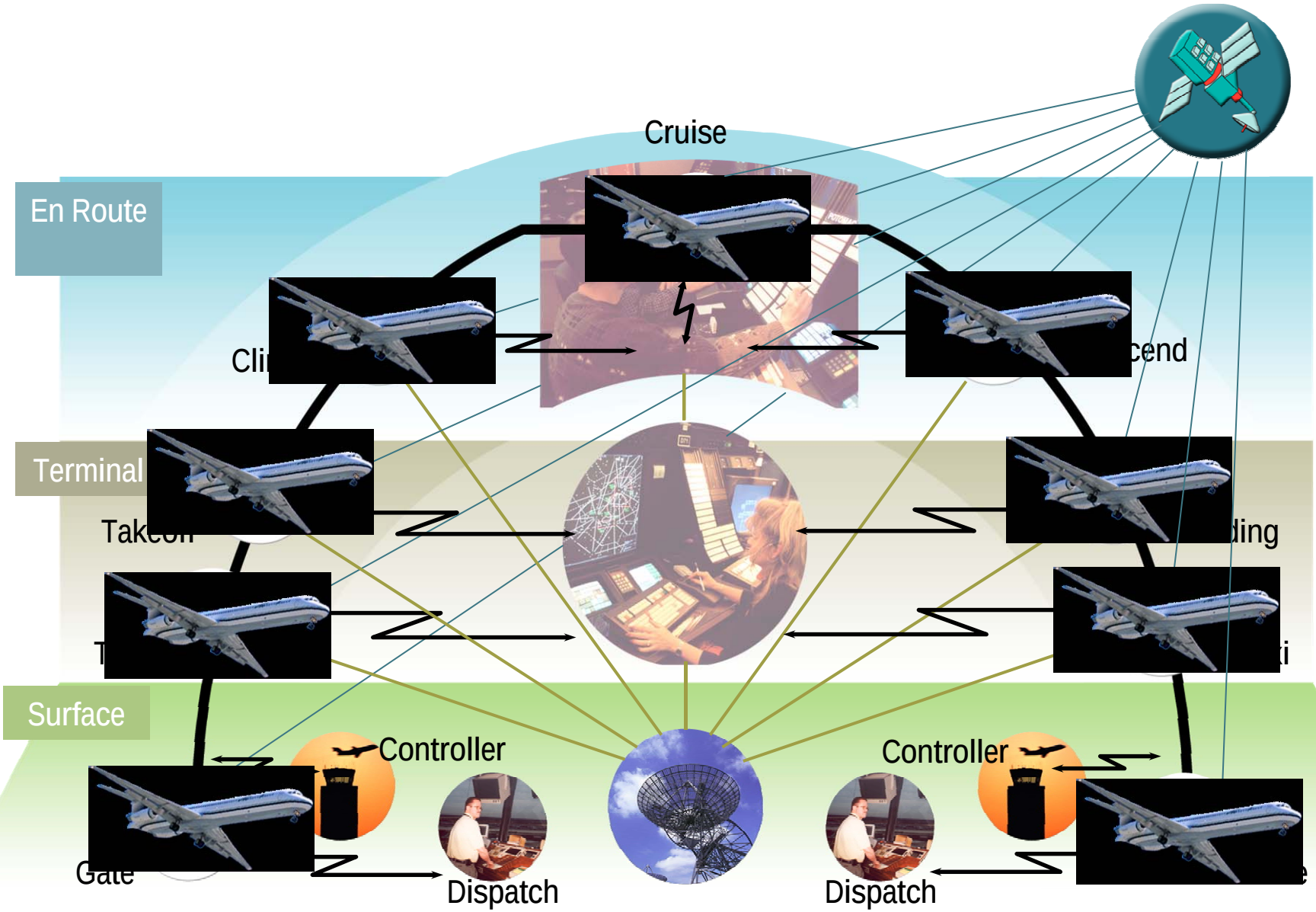
DST

Toolbox

HLA Comm Toolbox

Airspace Traffic Generator

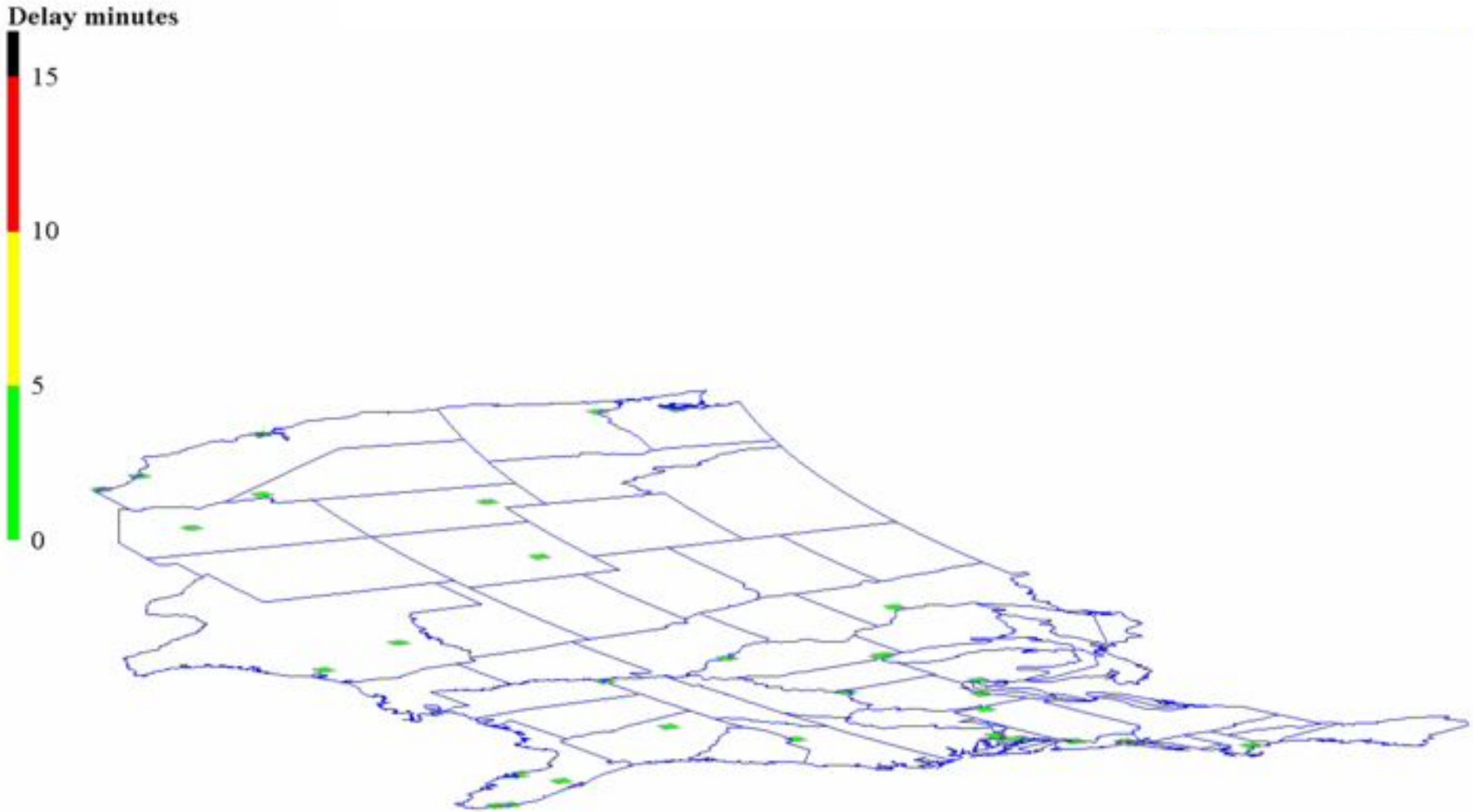
Model Interactions within ACES



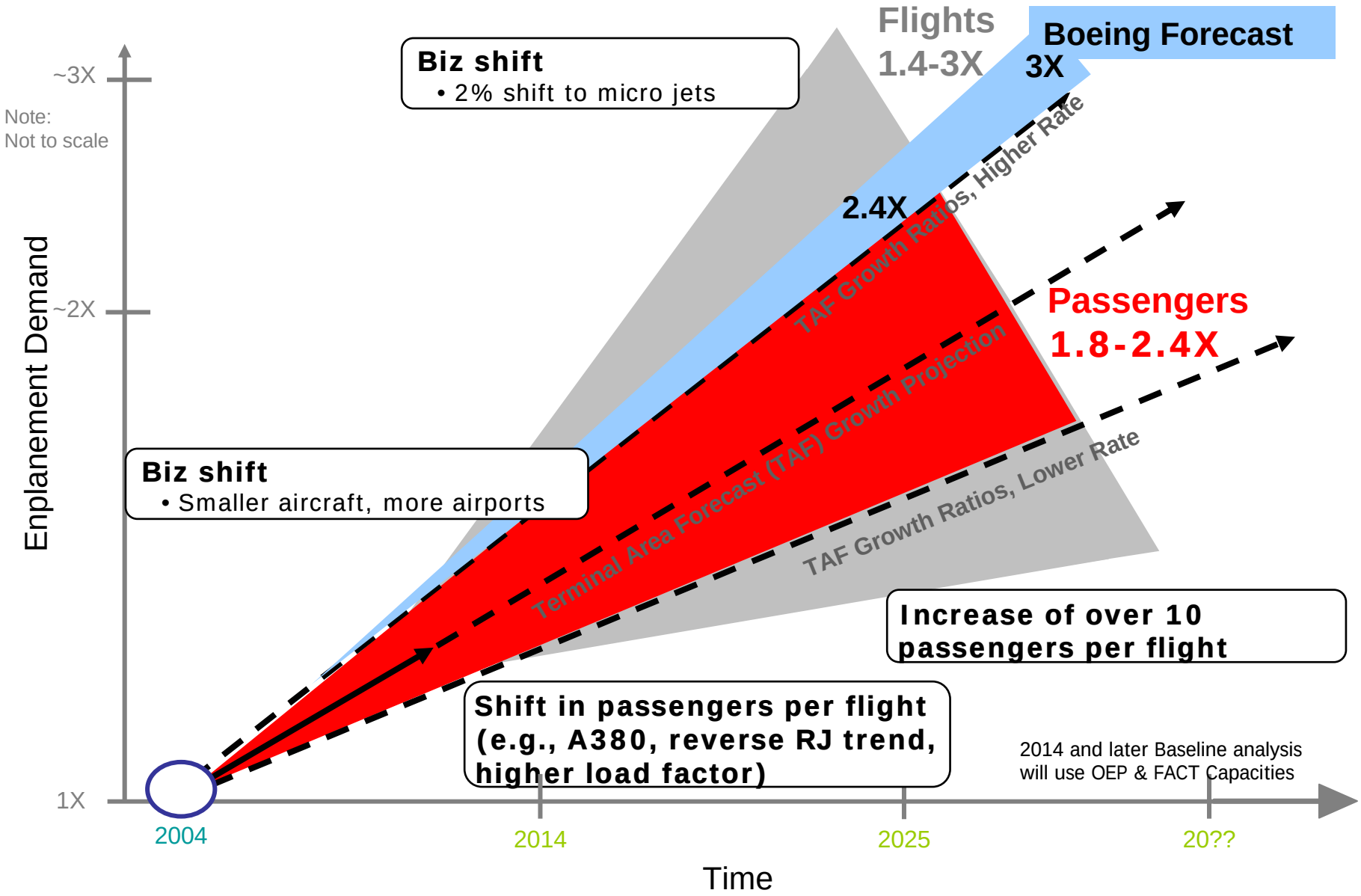
ACES Simulation of AAC Automated Resolution

- **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

ACES Atlanta Security Event Analysis



JPDO* Future Demand Projections



* JPDO Evaluation and Analysis Division