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Virtual Airspace Modeling and Simulation (VAMS) Project Third Technical Interchange Meeting

Prepared by Computer Sciences Corporation
Recording Secretaries:
Larry Babb
Robert Beard
Paul Rigterink
Henry Sielski

Edited by: Melinda F. Gratteau, Raytheon ITSS

Proceedings of a technical interchange meeting
sponsored by the
National Aeronautics and Space Administration
and held at
NASA Ames Research Center
Moffett Field, California
January 14-16, 2003

September 2003

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Virtual Modeling and Simulation (VAMS) Project
Technical Interchange Meeting Number 3
Table of Contents

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Preface

A three-day NASA Virtual Airspace Modeling and Simulation (VAMS) Project Technical Interchange Meeting (TIM) was held at the NASA Ames Research Center in Mountain View, CA, on January 14 through January 16, 2003. The purpose of this meeting was to share information about concepts and plans for activities sponsored by the VAMS Project. The overall goal of the VAMS Project is to provide the foundations required to define and assess the next generation air transportation system. The VAMS Project will identify and assess the performance of new operational concepts that, when incorporated into a future Air Traffic Management system, will result in a revolutionary improvement in system capacity, at an affordable cost and with no reduction in safety. These efforts will support:

- Improvements in the service provided by the nation's air transportation system.
- Continued growth in the air transportation system.
- Growth in the national economy.

This document describes the TIM presentations, given during the first two days of the TIM, and presents their related questions and answers.

The objectives of TIM 3 were as follows:

- Continue information exchange.
- Describe System Evaluation Assessment (SEA) Milestone 5, scenario and metric requirements, delivered on December 31, 2002.
- Define and begin to address the next steps for Milestone 5.
- Update the System-Level Integrated Concepts (SLICs).

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TIM #3 Agenda as Presented

PST	14-Jan., 2003 Tuesday	15-Jan., 2003 Wednesday
7:30	Facility opens and meeting registration	Facility opens
7:45		
8:00		12. Day 2 Intro/Daily Agenda (R. Fong)
8:15	NASA Greeting (S. Lozito)	13. Massive PTP On-Demand Air Transportation Concept (J. Sorenson, Seagull)
8:30	1. Project Comments (H. Swenson)	
8:45	2. TIM #3 Overview (S. Lozito)	
9:00	3. Scenarios and Metrics (S. Lozito)	14. Capacity Increasing ATS (A. Sipe, Boeing ATM)
9:15		
9:30	Break	
9:45		15. All Weather Capacity Increasing Concept (J. Krozel, Metron)
10:00	4. ATS Traffic Demand Modeling (J. Cavolowsky, E. Wingrove and D. Ballard, NASA ARC and LMI)	
10:15		Break
10:30		
10:45	5. SEA Scenario Analysis (J. Perkins, Volpe)	16. Surface Operation Automation Research (V. Cheng, Optimal Synthesis)
11:00	6. SEA Metric Analysis (J. Poage, Volpe)	
11:15		
11:30	7. SEA Human Performance Analysis (K. Corker, SJSU)	17. Automated Surface Traffic Control (B. Capozzi, Metron)
11:45		
Noon	Catered Lunch in Patio Room	18. University Concepts (A. Zellweger, NASA HQ)
12:15		
12:30		Catered Lunch in Patio Room
12:45		
1:00		
1:15		
1:30		19. Centralized Terminal Operation Control (J. Fergus, Northrop Grumman)
1:45	8. Scenario Data Sources (B. Kiger, Seagull)	
2:00		
2:15	9. VAST Real-Time Capability 1 (S. Malsom, NASA ARC)	20. Terminal Area Capacity Enhancing Concept (K. Arkind, Raytheon)
2:30		
2:45	Break	21. Wake Vortex Avoidance Concept (D. Rutishauser, NASA LaRC)
3:00	10. VAST Non-Real-Time Modeling (L. Meyn, S. Grabbe, S. Engelland, and T. Melconian)	
3:15		Break
3:30		22. Advanced Airspace System Concept (H. Erzberger and R. Paielli, NASA ARC)
3:45		
4:00		
4:15	11. CNS Load Analysis Tool (S. Mainger, C. Wargo, NASA GRC)	23. System-Wide Optimization (M. Jardin and B. Sridhar, NASA ARC)
4:30		
4:45	Wrap-up	24. Next Step and Preview of TIM #4
5:00		

1/18/03-MG&VD

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1.
Project Comments

Mr. Harry Swenson
Project Manager, Virtual Airspace Modeling and Simulation (VAMS)
NASA Ames Research Center

A copy of Mr. Swenson's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Swenson

VAMS Goals and Objectives, Deliverables, and Approach (Slides 1 – 4)

This is the third in the series of Technical Interchange Meetings (TIMs): TIM 1 on initial concept definition and technology roadmaps, TIM 2 on the analytical modeling of the NAS and real-time (RT) modeling capabilities, and now TIM 3 on scenarios and metrics and the questions that are extracted from the systems and concepts to be evaluated.

The goal of VAMS is to define and analyze concepts that can significantly enhance the National Airspace System capacity while maintaining safety and affordability.

The VAMS objectives are as follows:

- To define the potential advanced Concepts of Operations.
- To generate the technology roadmaps for these concepts.
- To establish the capability to assess and evaluate those concepts.

The products the VAMS Project is producing are:

1. Evaluated advanced airspace system concepts: Concept developers are producing concepts, articulating and defining the first level of how these concepts will work, and have produced at the end of this the first year of activity, a complete definition of how these concepts work, at the domain (surface, terminal, or en route) level or the system level spanning these domains.
2. Technology roadmaps to implement the proposed concepts: This involves identifying the supporting technologies necessary for the concept, their gaps and anticipated transition from today until the future. This is a secondary delivery of our activity. We are now getting the first deliveries from the concept developers and researchers.
3. Validated modeling and simulation capability: We have begun receiving intermediate deliverables on this the third deliverable.
   a. Non-real-time (NRT) modeling: Annual builds of NRT modeling and simulation system to help evaluate the concepts and obtain performance in a multi-objective sense: capacity, safety and cost.
   b. Real-time (RT) modeling and simulation: Annual updates of the RT simulation capability, especially important for human performance issues, and where we must delve deeply into a concept to extract human performance issues.

In this first year, we defined a suite of concepts spanning the major dimensions of the Air Transportation System, extracting out the questions that we need to analyze. We've also pulled together a modeling toolset. The concepts we've defined will also drive future improvements to that modeling toolset.

Last TIM you heard the approach to validation activities: comparing the baseline Air Transportation System with data coming out of the modeling toolset. Now we need to answer questions on scenarios and metrics to fully realize the viewpoints from the stakeholders and to be able to test concepts against it. That's what this TIM is concentrating on.

We will pull all this together into deliverables to provide NASA with evaluated concepts and technical roadmaps to support them and the questions extracted and tested with our modeling tool set to provide a good set of answers in a multi-objective sense: capacity, safety and cost.

Summary of Operational Concepts (Slide 5)

The following summarizes the operational concepts being developed by domain:

- Surface – Metron and Optimal Synthesis.
- Takeoff and Landing/Terminal – NASA Langley Research Center (LaRC), Raytheon, Northrop Grumman.
- Climb, Cruise and Descent – NASA Ames Research Center (ARC).
- System Level – Boeing, Metron, Seagull, University, NASA ARC, FAA/Radio Technical Commission for Aeronautics (RTCA), NASA/LaRC.

These 11 concepts are being refined and evaluated as a part of the VAMS Project.

Modeling and Simulation (Slides 6 – 8)

For real-time simulation, a major challenge is integrating the real-time facility into the tool set. For non-real-time simulation, software integration is the challenge.

For non-real-time, the February 2003 delivery will prove the feasibility of the approach providing an architectural foundation, a basic modeling toolbox, and assessments. The modeling toolbox emulates the current National Airspace System (NAS), simulates NAS-wide gate-to-gate activity at low resolution, and models an entire day in the NAS. Assessments measure delay, fuel costs, controller workload (this may be one parameter of safety), and traffic flow management. Five of the eight software validation tests have been completed and we estimate that all eight will be complete by February.

For RT, interim Test #1 was very successful, providing the high-level architecture (HLA)-based infrastructure, multi-simulator capability, and an initial version of the data communication toolbox. Four test scenarios, each verifying a key toolbox feature have been completed.

Scenario and Metric Framework (Slide 9)

The reason for the TIM this week is to examine and define the scenarios, metrics, and questions that we need to answer with these concepts. We've first broken the concepts up into the various elements. Questions to be answered include: Where do these operational scenarios need to be enhanced? What kind of modeling capability is necessary to answer these questions, and what kind of parameters and outputs are going to be utilized?

Evaluation and Assessment Accomplishments (Slides 10 – 11)

We defined our first simulation experiment to bring together an advanced concept coupling these three major facilities [Crew Vehicle Systems Research Facility (CVSRF), Airspace Operations Lab (AOL), Future Flight Central (FFC)] to capture and define the facility requirements, the data collection requirements, and the software agent requirements to span these three facilities, and answer questions related to our surface, terminal, and en route interactions.

Five scenarios are being pursued from the set of 16 possible: environmental dimensions, Gross National Product (GDP) growth (high/low), airline yields (high/low), limits to aviation system growth (many/few), and substitutes to air travel (good/poor).

The NRT scenarios are based on the first deliverables.

VAMS Schedule and Project Milestones (Slides 12 – 13)

This is second year of the project. We've completed initial definitions of the concepts and produced the first scenario and metric set that will be used to evaluate the concepts but, due to software interpretation issues, we are delaying the first build of the low-fidelity non-real-time modeling toolset until March. We are completing the designs for integrating multiple air traffic control facilities and non-real-time agents.

We hope this third TIM will foster cross-talk on ideas from each of the elements of the project to help keep them focused. It will also help surface additional information of interest to the VAMS Project and NASA management.

Programmatically, at our last TIM we said we were preparing for NASA's Non-Advocate Review. This was scheduled, but then cancelled by NASA Headquarters shortly before the review. We expect to support this review at some point in the future, but we are not sure when.

Synopsis of Questions and Answers for Mr. Swenson:

There were no questions from the TIM participants.

2.
Technical Interchange Meeting #3 Overview

Ms. Sandra Lozito
System Evaluation and Assessment (SEA) Lead
NASA Ames Research Center

A copy of Ms. Lozito's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Ms. Lozito

Ms. Lozito introduced herself as the host of TIM 3, which will focus on measures and metrics.

TIM 3 Objectives (Slide 3)

- Continue information exchange.
- Describe the System Evaluation and Assessment (SEA) Milestone 5, scenario and metric requirements, delivered on December 31, 2002.
- Define and begin to address the next steps for Milestone 5.
- Update the System-level Integrated Concepts (SLICs).

Synopsis of Questions and Answers for Ms. Lozito

There were no questions for Ms. Lozito from the TIM participants.

3.
System Evaluation and Assessment Sub-Element—Common Scenarios and Metrics Requirements—Milestone 5 Deliverable

Ms. Sandra Lozito
System Evaluation and Assessment (SEA) Lead
NASA Ames Research Center

A copy of Ms. Lozito's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Ms. Lozito

Recap (Slides 1 – 3)

System Evaluation and Assessment (SEA) is one of three VAMS elements. Milestone 5, the second major deliverable, was delivered in December 2002. It is in first draft stage and it is expected that it will iterate several times. Concept developers are encouraged to provide feedback and suggestions.

The relationship between the VAMS sub-elements has not changed. Ms. Lozito reiterated that the SEA effort would draw heavily on the self-evaluations from the concept developers to build the scenario and metric requirements of SEA. The scenario requirements thus developed will be used to evaluate the concepts delivered through the system-level integrated concepts (SLICs) and to help affect the development strategies within the virtual airspace simulation technologies (VAST).

The tasks of SEA are:

- To develop scenario requirements and metrics for evaluating the SLIC concepts (which is the focus of Tuesday morning's presentation).
- To conduct initial assessment of VAST Real-time tools.
- To conduct initial assessment of selected concepts.
- To conduct initial assessment of integrated concepts.
- To conduct final evaluation of the integrated concepts using the VAST tools.

Scenarios and Metrics Requirements (Slides 4 – 5)

As general guidance, the goal is to have scenarios and metrics to help evaluate the concepts from SLIC. The initial phase of the evaluation, concept developer self-evaluation, is already underway and will be used to assist in SEA scenario/metric development.

Although, there can and should be many scenarios and metrics, they must be applicable for broad evaluations since they must be used for domain-specific and multiple-domain concepts such as gate-gate. These scenarios and metrics must address multiple parts of the triad: Airline Operations Center (AOC), Air Traffic Control (ATC), and Flight Deck (FD).

The main emphasis of real-time and non-real-time scenarios will help evaluate the concepts against the program goal, i.e., increasing the National Airspace System capacity. Scenarios must also meet many additional requirements including:

- Test the concept's ability to maintain or increase safety.
- Cover all domains.
- Consider normal and non-normal events.

- Test in non-real-time and real-time environments.
- Test all parts of the National Airspace System triad (Airline Operations Center, Air Traffic Control and Flight Deck).
- Test single-domain and multiple-domain concepts (gate-gate).

SEA is writing the requirements for scenarios and VAST is developing the scenarios.

Materials in Milestone 5 Deliverable (Slices 6 – 11)

The Scenario and Metric Requirements, Milestone 5, was delivered to the VAMS Project Office in December 2002. This deliverable addressed the various and differing needs of the VAMS Project Office and the concept developers over several iterations. This led to a lengthy and somewhat partitioned document.

The Milestone 5 deliverable consisted of the following:

1) Introduction (including how to use the document).
2) Forecast and Demand [primarily data from Logistics Management Institute (LMI) provided to the Project Office].
3) Common Scenario and Metric Set (including evaluation questions, scenario elements, metrics, and dependent variables, which are the data that must be collected from the tests).
4) Storyboards (descriptions of how to test the concept in a non-real-time or real-time environment) for two sample concepts, Data Sources, Dependent Variables Calculations (e.g., calculations for capacity, workload, or other parameters).
5) Scenario Elements Breakdown (which identifies what's needed as a common set across all scenarios).

Source materials for Milestone 5 included concept and scenario descriptions from the concept developers, interviews with concept developers in some cases, data from LMI, Federal Aviation Administration's Operational Evolution Plan (OEP) metrics, research papers related to the concepts, and the concept development matrix (which outlines the functions required for each concept).

The Scenario/Metric Parameters chart (Appendix C) developed in brainstorming sessions and refined at TIM 2, shows the guiding principals and provides the foundation that a concept developer is expected to need in order to develop a scenario.

The Milestone 5 documents are as follows:

- Scenario/metric framework is the body and real thrust of recent development. It contains a list of common questions/issues for evaluating concepts and a common set of metrics.
- Concept analyses assess the details related to the scenarios and metrics framework. Analysis results are provided for each of the 11 VAMS concepts. A varying level of detail in the different concepts drove us to interview the concept developers for clarification.
- Storyboard examples provide the details necessary to build an RT or FT simulation for evaluating a concept.
- Dependent variables define "what's to be measured."
- Dependent variable calculations are the calculations required for determining various metrics (e.g., capacity or workload), either a common method or a definition.
- Forecast/demand data are the forecast and demand data, supplied by the Logistics Management Institute to the VAMS Project Office.
- Data Sources provide the sources of reference data for scenario development and use.

- Scenario Element Breakdowns consist of information about detailed scenario elements necessary for concept assessment. This provides guidelines for development and prioritization of scenarios characteristics.

Next Steps (Slide 12)

Next steps include the following:

1) Obtaining feedback from these sources:
    a. Concept developers regarding the analysis of their concepts: the accuracy of the information on the concept, the level of detail, and the format's usefulness/practicality.
    b. Project Office (from Project Management and VAST Real-Time and VAST Non-Real-Time).
2) Prioritizing requirements based on feedback received. Since it is clear that all things in the requirement set cannot be implemented, it is important to pick the most important items.

All products are available from the Project Office except individual concept assessments, since these assessments need to be iterated with the individual concept developers first.

All these documents are in first draft form. These documents will be updated within the next year, and will be continue to be further refined as "living documents." The documents will not be frozen until the third or fourth year of the VAMS Project when the building of specific simulations is begun.

Synopsis of Questions and Answers for Ms. Lozito

- Will the evaluation scenario storyboards be made available?

  Yes. The Project Office staff will provide access to this.

4. Scenario-Based Traffic Demand Modeling

Mr. Earl Wingrove
Logistics Management Institute

Mr. David Ballard
GRA, Inc.

Dr. John Cavolowsky
NASA Ames Research Center

A copy of the presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Cavolowsky, Mr. Wingrove and Mr. Ballard

Introduction (Cavolowsky) (Slides 0 – 2)

It was noted that hundreds of pages of material and data are condensed into a few slides. Reference material can be provided on request.

Reiterating the objective as "a more complete understanding of the potential environments in which NASA research will operate," Dr. Cavolowsky emphasized how understanding the future world(s) is necessary to achieve the broadest possible application of VAMS.

The three activities to be discussed were introduced.

Research Activity 1 — Describe the Economic Impacts of Air Transportation (Wingrove) (Slides 3 – 8)

What is the value of aviation to the economy? There were three sub-tasks for the first research activity:

1) Articulate what air transportation means within the nation's economy and why its continued vitality should be a national priority;
2) Survey prior efforts to capture the incremental value of aviation in the economy; and
3) Develop performance measures for policy makers, consumers of aviation, and associated industries that track development of air transportation technologies.

The summary of five hypotheses shown in Slide 4 is the condensation of many charts and analyses and forms the framework for the analysis of the first research activity.

All conceptual links must prove or demonstrate NASA's value proposition, i.e., how does aviation justify itself to its users. It appears that technology can improve performance, more efficiently using resources throughout the economy. The value proposition inverse is "How is the value destroyed?" Delay cost in 2000 was estimated at $9.4 billion, a real cost of inefficient use.

Metrics are the essential key to assessing the value of NASA's tools and techniques. The details for the three broad areas of National Airspace System performance (supply/demand, operational, and fiscal) are contained in Slides 36, 37, and 38, respectively.

Research Activity 2 — Generate 2022 Operational Scenarios (Ballard) (Slides 9 – 21)

The development of operational scenarios against which future NASA technologies can be evaluated was discussed while emphasizing that the future is not a point estimate, but a range of possibilities, all of which must be taken into account. Benefits of scenario-based planning include contingency planning and handling and characterizing complexity that evolves over time.

The National Airspace System is not currently in a "normal world" and probably won't get back to that until 2004 or 2005.

The four scenario drivers are as follows:

1) Gross Domestic Product (GDP) growth—GDP is the most important since it drives air travel, not vice versa.
2) Airline yields are the interesting tradeoffs of the last decade. High yields attract investment. Low yields attract passengers. Subtle management of yield controls the health of the airline industry in order to attract investment and passengers.
3) Limits to growth include security, noise, emissions, other environmental concerns, and ATC and airport capacities.
4) Substitutes for air travel (using a very broad definition) can change demand; e.g., video conferencing might replace face time.

While there are sixteen possible scenarios, eight are not logically consistent. Of the eight plausible scenarios, the two chosen for briefing at this conference are 1.) "economic growth (airlines recover)" and 2.) "low-cost carriers dominate." These two situations have dichotomous driver sets (i.e., different values in all drivers) and relatively high probability.

The predictions are dependent on assumptions; e.g., recovery is reached in 2004 and short haul is affected more than long haul. The demand for air transportation is impacted positively by real GDP (income elasticity of 1.25) and negatively by fare yields (price elasticity of -0.75). Passenger growth rates were estimated for each scenario. Cargo and international demand tend to grow at a faster rate than domestic. General aviation (GA) has very small numbers, but they are very "nasty" and subject to extreme upset, e.g., the Eclipse jet.

The components of future commercial aviation industry structure fall along three axes:

1) Low/high total volume of air travel.
2) Hub and spoke/point to point.
3) Scheduled/on-demand.

The first scenario — economic growth/airlines recover:

- Limits to aviation and/or poor substitutes for air travel mean that big airlines are "sitting pretty" and have pricing power in a high-growth economic environment.
- Further growth in hub and spoke system, with some growth in service to low-yield sectors and/or secondary airports.
- This is a high activity (but not highest) scenario. The highest activity scenario is "consumer rules," with high economic growth and low yields.

The second scenario—low-cost carriers dominate (or only low-cost carriers are left standing):

- A weak economy leads to sluggish demand. Low demand, few limits, and good substitutes mean fares are low and demand is price-sensitive. The shift to low-cost carriers accelerates.
- Low-cost carriers through a point-to-point system primarily satisfy the demand.

The predicted outputs include commercial passenger demand, cargo demand, and general aviation passenger demand in 2022.

Research Activity 3 — Translate 2022 Scenarios Into Airport-Level Demands (Slides 22 – 33)

The high-level operational predictions from activity two are narrowed down to the airport level.

Passenger flights into 102 airports (see Slides 42 and 43 for the list) are the focus of this presentation. Cargo flights into those 102 airports and GA flights into 2,865 airports were also examined.

The assumptions for all scenarios:

- Domestic growth is one value for all scenarios. International travel has a different growth applied to all scenarios, but only to “gateway” airports.
- Within each scenario, all domestic airports have the same passenger demand growth rate from 1997 to 2022. Similarly, within each scenario, international travel demands at the 102 airports have the same growth rate from 1997 to 2022.

The methodology was to create three baseline matrices for the 102 airports — 100 percent hub and spoke, 100 percent point to point, and a hybrid. The hypothetical point-to-point system was constructed using 1997 Origin and Destination. A 102 by 1 vector for international flights was created. The five scenarios were applied to the appropriate baseline matrices and vectors. Depending on the baseline matrix used, the numbers of flights and their distributions among the 102 airports change.

A passenger flight growth multiplier is calculated separately for domestic and international marker segments.

Applying growth multipliers to domestic and international flights leads to significant differences from the 1997 baseline.

Looking at San Francisco International Airport (SFO), the number of future daily domestic departures ranges from 619 to 1,047 depending on the scenario used. The lowest number of projected passenger flights at SFO is for the “low-cost carriers dominate” scenario.

Outputs include the operational demand for each airport for the following:

- Commercial passenger flights at 102 airports
- Cargo flights at 102 airports
- General aviation flights at 2,865 airports
- Flight schedules at each airport for each of four weight classes for the “airlines recover” scenario

Backup Slides (Slides 35 – 44)

These slides are provided as backup and were not discussed.

Synopsis of Questions and Answers for Mr. Wingrove and Mr. Ballard

- What are some examples of limits to growth?

  Security adds time and hassle. Airport expansion often causes disputes (e.g., SFO, Miramar). Environmental concerns limit the number of flights or limit expansion.

- 2022 is a boundary condition. What about interim points in time, e.g., 2012?

  The earlier periods are more restrictive. 2022 (20 years out) has more relevancy because the work changes independently of political considerations. For interim time points, interpolate, but Bayesian prediction is necessary on the interpolation.

- What roles do DoD flights and UAVs play in the predictions?

  None. They are out of scope. While Eclipse is getting a lot of attention, it’s either a substitute or an enhancement and is not estimated to have a big impact either way.

- Data on Slides 30 and 31 vary greatly. What plans are there to re-examine the data in five years?

  There are no plans to re-examine the data, but it certainly is an interesting thing to do and would help clarify which path (scenario) the airline industry is following.

- Comment: The average general aviation aircraft size is small and that implies many more flights for the same number of passengers.

A rapid increase in general aviation traffic could lead to en route congestion. However, general aviation flights are generally at different airports than are commercial flights and, thus, have little affect on the 102 large airports.

- Were different-sized general aviation aircraft taken into account?

  An average size was chosen for each of three categories of general aviation aircraft: single-engine, multi-engine, and jet-engine. An additional difficulty is that there is no way to isolate SATS demand from GA demand.

- Comment: Eclipse is planned as a six-passenger, 0.8-mach jet with a 41,000-foot ceiling to sell for less than $1 million.

- Comment: On a hub and spoke system, two legs mean two flights.

  If local commercial carriers dominate, then point-to-point is the primary mode of operation.

- Comment: Contrast hub and spoke to point-to-point.

  Hub and spoke provides more frequent flights, but some passengers have multiple legs.

  Point-to-point offers direct service from the traveler’s origin to destination, but generally offers fewer daily flights from which to choose.

  Southwest offers planning tools to create routings involving multiple legs.

5.
The Development of Operational Scenarios for VAMS/SEA Concept Evaluations

Mr. Jack Perkins
Volpe National Transportation Systems Center

A copy of Mr. Perkins's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Perkins

Starting Point (Slide 1)

We want to be able to develop scenarios that will allow us to evaluate the concepts by "holding them up to the light."

Framework for Operational Scenario Requirements Definition (Slides 3 – 11)

A "Socratic" approach was used to develop the requirements. Twenty team members divided up the concepts from the proposals and the early deliverables of the concept developers. This put the team in the role of the stakeholders, who then developed a series of questions to better define the concepts. The questions will be put in the form of a questionnaire to each of the 11 concept developers. The number of questions on the concept questionnaires varied. The final outcome is a clear and concise definition of each concept and what it purports to do. This will allow the development of a set of operational scenario requirements.

Synopsis of Questions and Answers for Mr. Perkins

There were no questions for Mr. Perkins from the TIM participants.

6.
Metrics for VAMS

Mr. James L. Poage
Volpe National Transportation Systems Center

A copy of Mr. Poage's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Poage

Why Metrics for VAMS (Slide 2)

Our team used the "Socratic" approach as well. It is useful to examine "why" to understand how the metrics will be used.

Approach to Design Actionable Measures and Requirements for Measures (Slides 3 – 6)

Requirements for measures help define their audience and how they will be used.

The use of a "narrative" to convey knowledge of the concept, along with qualitative measures, avoids the appearance that we are "dancing around the issues" with numbers.

Narrative Framework to Present Measures (Slides 7 – 8)

A hierarchical framework shows the relationship and contribution on a project-by-project basis. The framework also shows gaps and overlaps. This was done on the Advanced Air Transportation Technologies (AATT) project.

A flow framework was used for Safeflight 21 to tell the "benefit story." This approach allows the relationship of qualitative-to-quantitative measures.

Common Set of Measures (Slides 9 – 11)

Measures fall into three categories 1.) capacity, 2.) safety, and 3.) robustness. Details of the metrics will be reproduced on a compact disc of Milestone 5 deliverables. Some assumptions have been made, such as in the capacity area, e.g., folks won't want to fly at midnight.

Next Steps (Slides 12 – 13)

For the metrics framework, iterations between "top-down" and "bottom-up" approaches will be made. "Top-down" gives the view that decision makers want, while "bottom-up" is the view preferred by analysts.

A "manual" preliminary evaluation will ensure the evaluation process is workable.

Synopsis of Questions and Answers for Mr. Poage

- Comment: It's not clear how you will avoid "double counting" benefits.

  We need to do a sensitivity analysis, but flow frameworks will help with this, too.

- Is work going to be done to show the relationships between quantitative or qualitative metrics as described in columns 3 and 5 of your flow frameworks example?

  Yes, we'll have to explain the relationships of the metrics in a notional sense. Sometimes we're able to take the qualitative metrics directly out of the simulations and "sum them up" for the quantitative metrics in order to show the likelihood of achieving the end benefit. In other cases, we at least have to explain how the metrics are “indicators” of the likelihood of achieving the end benefits.

- What kind of insight will you get from a manual simulation of the evaluation?

  There will be some insight into the viability of the concept, as well as the evaluation.

7.
Human Performance Factors in OPCON Evaluation and Assessment

Dr. Kevin Corker
San Jose State University

A copy of Dr. Corker's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Corker

Introduction (Slides 1 – 3)

In the overall framework of metrics, human factors is integrated into many areas. Therefore, Dr. Corker elected to put in the "system category." An understanding the human factors aspects of highly automated airspace is necessary in selecting which concepts to pursue.

Human Performance matters of consequence are identified as the following:

- Impact on multiple operational entities.
- Noticeable changes in schedule, staffing, roles, and responsibilities.
- Change of range and span of decision making.
- Change in information characteristics of the system.
- Change in or new certification standards.
- Fundamental changes in airspace structure or use.

Operational Concepts (Slides 4 – 5)

A "small and quick list" of past operational concepts and data were used to provide insight into the current evaluation of air traffic management (ATM) systems.

The dimensions of this operational concepts study include: 1.) How well reliability, consistency, and predictability play-out in human performance terms; and 2.) How to represent variability at the national, corporate, and individual practice levels.

Dependent Variables (Slides 6 – 7)

The dependent variables are used to measure the areas of concern and include airport/airspace/aircraft variables, system level variability, and the "usual suspects" of human variables. System variability is driven by the diversity of concepts and by how far the concept differs from current process and practice.

Scenario Development (Slides 8 – 18)

Principal issues may not be met. "Normal operations" occur at a stable routine level that is not achievable in the simulation realm. Instead, we need to measure susceptibility to disruption. The measurable values may not be available or may not be the most relevant. Scalability is a significant issue because the methods used to compute scaling are not validated.

Possible solutions to meet these challenges exist. Characteristic response approaches use prior experience, often involved with "control by exception" decision support tools (DSTs). Difficulties to this method include: 1.) The control may be at, or beyond, human capacity; 2.) false alarms significantly lower workload capacity, and 3.) the rules are often subject to be gamed.

A second solution is to perform an information topology analysis to show the flow and where bottlenecks form and under what conditions.

Of the five metric classes—forecast, demand, system, environment, scope—the demand and system classes are most concept dependent.

One evaluation technique is to create a response matrix with characteristics as columns and problem areas as rows. Doing this leads to maps identifying study foci (Slides 12 – 14). Issues still exist. We're not sure how to cleave processes into systems for analysis. Further, there are areas of degraded operation, and we tend to only look at the "not noted/not corrected" situation. Different concepts define the operator actors in a variety of ways, making the analysis non-uniform. However, issues of dynamic criteria, ambiguity, response variability, bias, and adaptation should be tested in all concepts. This is the taxonomic way to get to the scenarios.

Another evaluation technique is information topology analysis (Slides 15 – 17) that shows all the key players and communications.

The last technique is a computational model of the process (Slide 18), with a special focus on the portions that involve human operators.

Choosing Approaches (Slides 19 – 20)

The challenge is to choose the proper method to do the analysis. If multiple axes of interest exist, then the value of scenarios can be plotted across multiple axes. For this kind of analysis, a balanced evaluation analysis (e.g., a regular polygon) is better than a "lumpy" shape.

The Data Operating Curve (DOC) approach is a way to ensure that a measured behavior actually yields value in evaluating concepts. This sets the lower limit on the simulation's ability to discriminate significant behavior.

Summary (Slide 21)

An assertion being made is that human factors limit, in some way, the characteristics of airspace operations. Technical systems can augment human performance provided we a.) can understand the human performances involved, and b.) can provide improvements that meet four criteria in human performance subtexts. The two most often violated are that the limitation is altered without altering the underlying operation, and the enhancement is exploited to set a new level of expected performance.

Synopsis of Questions and Answers for Dr. Corker

- Where are cognitive requirements captured?

  They are subsumed under the single term "procedural sequences." We will need a more explicit list.

- How are different types of people taken into account?

  People fill assigned roles. An assigned role has an expected level of expertise and a standard deviation about that expectation. There is an organizational impact when that expected level of expertise experiences large changes.

- Did you look at how human factors considerations might have influenced air traffic control at the "dawn of air travel"?

  No, but there are notable exceptions where human performance considerations would have led to a different process. For example, studying the two approaches at the Los Angeles Air Route Traffic Control Center (ZLA) during rushes. From a human-factors perspective, it shouldn't operate that way during rushes, but it does operate safely.

- The interaction charts provided are very detailed. Do you expect a chart for every concept for every situation?

No, all the techniques are applied simultaneously as a filter to identify places where there might be problems. Also, the characteristics of the problem can be used to drive the choice of simulation.

- In the “tube concept,” what is the problem?

  It’s not choosing a tube; it’s making the transition from manual to automatic control on entering the tube and the reverse transition when exiting the tube.

- What is going to happen to problems and benefits that you identify?

  Problems and benefits will be fed back to the concept developer(s).

- Comment: Sandra Lozito added that the concept developers have identified human-factors issues (or potential issues). In order to reflect human factors issues in the common criteria, the SEA team is doing a separate human-factors evaluation as part of the assessment activity.

8.
Scenario Data Sources

Mr. Brian Kiger
Seagull Technology

A copy of Mr. Kiger's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Kiger

Introduction (Slides 1 – 3)

Most participants at this conference will need scenario data. It will be used as an underlying foundation for scenario work, to ensure realism, validate concepts, help provide a basis for standardization and blending of concepts, and provide confidence in the results.

Context (Slides 4 – 7)

A list of available data sources is available in the reference shown on Slide 4. Common scenarios will be use as a basis for standardization while evaluation scenarios will be used to evaluate a specific VAMS concept.

Motivation (Slides 8 – 9)

VAMS concept developers will use the scenario data along with the simulation and configuration development tools to test the VAMS concepts. A key question will be how quickly can the data be manipulated to form new tests when conducting regression testing of a concept fix.

Data Discussions (Slides 10 – 17)

A key decision is what data are needed to determine high-value parameters. For instance, do winds aloft and lightning constitute a high-priority environmental (weather) data? Seagull is collecting data from primary and secondary data sources. Seagull is also modifying data from existing sources, as well as generating data from scratch, to meet the project's needs. Mr. Kiger noted that the data sources shown on the slides are not a comprehensive list. The methods used to determine the significance of the data are shown on Slide 17.

Suggested Actions (Slides 18)

A suggested data-capturing action plan is shown on Slide 18.

Synopsis of Questions and Answers for Mr. Kiger

- Comment: A participant cautioned that the data are not always "clean."

  I agree, the data must be reviewed and have the proper integrity.

- Are you validating deterministic or stochastic models?

  We don't distinguish. There will be scenario data for both.

- How will participants distinguish original data from data that have been modified?

  It may be necessary to put a descriptor in the data repository to distinguish between original and modified data.

- Are they collecting human performance data?

  Not yet.

9.
Virtual Airspace Simulation Technology, Real-Time Simulation Sub-Element (VAST-RT)

Mr. Scott Malsom
NASA Ames Research Center

A copy of Mr. Malsom's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Malsom

Relationship of VAST-RT to VAMS and Airspace Concept Evaluation System (ACES) (Slides 2 – 3)

The Virtual Airspace Simulation Technology, Real-Time (VAST-RT) is a set of human-in-the-loop (HITL) toolboxes that is being developed in a complementary fashion to the non-real-time or Airspace Concept Evaluation System (ACES) simulation. The non-real-time ACES and real-time tools will be used in cyclic fashion to evaluate the VAMS Operational Concepts. Many of the actual models will be developed for ACES and will be used there first to work out concepts. The models will then be used in the real-time simulator in a more detailed fashion. These results will then lead to refined models and concepts. ACES will use them again before further real-time simulations.

VAST-RT Concept (Slides 4 – 5)

A special collaborative development environment (CDE) function will be developed as an interface to the experimenters. Versions with a limited set of the functions that emulate the National Airspace System (i.e., models) have been developed as high-level architecture federates. Versions of the bridging functions that allow them to communicate with one another are now being completed. Some of these functions are software agents, while others will be full human-in-the-loop facilities, like Future Flight Central (FFC).

Legacy Configurations Evolve to VAST-RT Configurations (Slides 6 – 7)

In NASA Ames' Crew Vehicle Simulation Facility (CVSF), there exists a legacy monolithic set of software to manage, control, and interface various real-time human-in-the-loop hardware platforms, such as our Boeing 747 and Advanced Technology Simulators. The software components have been broken into smaller pieces and wrapped in code to communicate using high-level architecture. This allows the distribution of these pieces to different platforms, and different building locations. The complex simulation manager in the legacy has been replaced with a relatively smaller and simpler set of code known as the run-time interface (RTI) that will manage the distributed simulation.

Current and Proposed Target Generator (Slides 8 – 9)

Pseudo aircraft simulation (PAS) is the basis for the current target generator and is one of the most important components of the VAST-RT simulator. Eventually, a ground capability will be added to PAS, which will probably include a version of the Center-TRACOM Automatic System (CTAS) and the use of the Future Flight Central. The implementation of user-requested tools is also planned.

Summary (Slide 10)

To summarize, the VAST-RT team has developed the initial architecture and instituted an object-oriented management style to create truly functional code, versus prototype code, in an incremental fashion. The bridge code to interface the Future Flight Central will begin testing next week. The development of the target generator is on schedule, as is the critical design review which TIM participants are invited to attend.

Synopsis of Questions and Answers for Mr. Malsom

- How will agents be delivered for things like an airline operations center (AOC)?

  The agents will be delivered in two ways. First, stubs will be generated to test the interfaces and general functionalities of entities like AOCs. However, these are unlikely to work exactly like researchers want. So, in addition, functional and interface specifications will be delivered, which researchers can use to either define their own agents or to tell us how to build them. Then we'll try to implement them.

- How will you get human resources for simulations (like controllers) when they are needed?

  We've been doing this kind of thing for a long time, and we feel we can continue to reach back into our own pool of resources for most things. If "special" requests are made for people with unusual skills, we'll have to negotiate that with the researchers.

- What kind of changes did you have to make to the legacy code to make it work with high-level architecture?

  Usually, it was converting data structure-type interfaces to use network communication-type interfaces. This is an over-simplification, but generally accurate.

- Is your high-level architecture simulation distributed across several platforms now, and did you have to use different versions of the run-time interface (RTI) to accomplish this?

  Yes, it's distributed across several platforms, but no, we didn't have to use different versions of the RTI. However, it is possible that other facilities will use different RTIs. The bridge technology we're implementing will allow these distributed agents built around different versions of the RTI to work together.

- How much of NAS can the VAST-RT simulate?

  Right now, it can simulate one instance of each kind of model (a/c, airport, etc.). Eventually, we'll at least be able to manage one "city pair's worth" of facilities, and perhaps as many as a dozen of each model. However, the likely figure is four of each. The limitation is both one of data throughput and a fiscal limitation as to how many human beings you can involve in a single simulation.

- Have you developed interface standards for agents as yet? Are you moving in this direction?

  We're moving in this direction. We've promised the project office to have something in place by the critical design review. It will be similar to what ACES is doing.

- What do concept developers need to keep in mind about VAST-RT?

  Generally speaking, things like fleet mix, equipage, airspace dynamics, etc. I'll take an action item to provide a list to the concept developers.

Comment from Harry Swenson: We will need to carefully specify interfaces to bridge between real-time and non-real-time simulators (i.e., models).

10.
VAST Non-Real-Time Modeling

Mr. Larry Meyn
NASA Ames Research Center

A copy of Mr. Meyn's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Meyn

Introduction (Slides 1 – 2)

At TIM 2, there was a focus on ACES. This set of four presentations takes a step back. The VAST Non-Real-Time modeling presentations in Sections 10.1 through 10.3 describe recent developments in the Future ATM Concepts Evaluation Tool (FACET), the North Texas Research Station, and the Massachusetts Institute of Technology's Extensible Air Network Simulation (MEANS).

NRT Modeling (Slides 3 – 8)

Non-real-time modeling requirements (covered in earlier presentations) included evaluation criteria, fidelity, and coverage. Coverage requirements include how much does the model span and how many different scenarios can be run against it. Data requirements (see Brian Kiger's talk) include the input to the model and the data used to validate the model's outputs.

A plot representing a modeling spectrum plot of coverage versus fidelity is shown. Often, the hardest choice is where on the "curve" is the optimum place to do the evaluation in question. The choice is based on the concept development stage and the type of evaluation. Previously, there was a large hole in the center of the range of fidelity — that hole is being filled by ACES. Evaluating any concept will require the use of several models — ACES and other modeling tools will be required. Current ACES research focuses on the use of ACES to model a large, complex NAS system with strong agent interaction. There is an additional effort with other models, including FACET and MEANS, to provide a spectrum of models and allow ACES to leverage, or ultimately include, the results of those modeling efforts.

ACES provides a combination of modular design and high-level architecture that allows tailoring and inclusion of newer and legacy models to provide a set of flexible, scalable, standards-based modeling tools for evaluating ATM concepts.

There are other NRT modeling efforts for cognitive human performance, stochastic simulation, and environment as well as efforts to validate new and existing models through dataset selection and identification of critical parameters for validation.

Synopsis of Questions and Answers for Mr. Meyn

There were no questions for Mr. Meyn from the TIM participants.

10.1 Recent Developments in the Future ATM Concepts Evaluation Tool (FACET

Dr. Shon Grabbe
NASA Ames Research Center

A copy of Dr. Grabbe's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Grabbe

Introduction (Slides 1 – 3)

The Future ATM Concepts Evaluation Tool (FACET) is used to explore advanced ATM concepts and can be used to assess the integration of tools and concepts. It models airspace operations at the national level. The software is modular, is written in "C" and Java, and runs on desktop machines. Recent additions to FACET include integrated assessment of traffic flow management, distributed air-ground separation methods, probabilistic sector demand forecasting, and wind optimal rerouting.

Traffic Flow Management (Slides 4 – 7)

A recent study used FACET, to study a busy airspace region that was often affected by weather to look at alternate traffic flow during severe weather. The baseline sector counts were established and then weather reroute was performed. Sector overloading requiring additional traffic flow management (TFM) initiatives was shown. The additional initiatives studied were rerouting with nominal departure rates and rerouting with optimal departure rates. Using algorithms as the basis for constraints, FACET showed that total system demand is met with minimum delay. However, further algorithm work is necessary to uncover equity issues to ensure that rerouting and delays do not affect one airline disproportionately.

Conflict Detection and Resolution (CD&R) (Slides 8 – 9)

FACET includes two different conflict detection and resolution (CD&R) schemes. A FACET-based study was used to investigate distributed air ground – traffic management (DAG-TM) self-separation. FACET was used for initial feasibility assessment for airborne self-separation and then for more detailed studies. The results support the feasibility of airborne self-separation.

Probabilistic Demand Forecasting (Slides 10 – 11)

Departure time prediction accuracy is a key factor in trajectory prediction because approximately 90 percent of the aircraft are on the ground when the prediction is made.

Departure time uncertainty has been modeled as Gaussian distribution with mean and standard deviation derived from historical data. The distribution is used to forecast future probabilities of exceeding the number of aircraft in a sector. Probabilistic forecasting and deterministic forecasting are being compared to understand their respective benefits in the decision process.

Wind Optimal Rerouting (Slide 12)

A wind optimal route is generally better than the ideal "great circle" route. A complete presentation is contained in the presentation by Dr. Matt Jardin.

Synopsis of Questions and Answers for Dr. Grabbe

- Can FACET model airport departure rates?

FACET is data driven. Airport departure rates come from an enhanced traffic management system (ETMS) file.

- Can FACET model a ground delay program (GDP) due to severe weather?

  FACET has limited ability to model a GDP. However, it can model the GDP's impact and its effect on the National Airspace System.

10.2 MIT Extensible Air Network Simulation (MEANS)

Dr. Terran Melconian
Department of Aeronautics and Astronautics
Massachusetts Institute of Technology

A copy of Dr. Melconian's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Melconian

Note that Dr. Melconian did not address all slides included in the presentation.

Introduction and Background (Slides 1 – 7)

The MIT Extensible Air Network Simulation (MEANS) development started in 2001 as a Ph.D. thesis to evaluate the effect of congestion at hub airports on airline operations. It was expanded and improved to include new features to better model weather, ground delay programs, airline operations centers, disruptions, human interfaces, and uncertainties.

MEANS characteristics:

- Is event-based and non-real-time.
- Tracks aircraft through several flight states emphasizing ground-based effects (predominately turnaround and number of delayed passengers and missed flights).
- Includes arrival and departure rates at airports and how they propagate through the system.
- Is able to do one-day simulations on a desktop in a few minutes allowing extension to longer runs or multiple runs from the same starting point with stochastic data.

MEANS uses a basic progression of flight states in its simulation of each aircraft status.

MEANS uses data from a broad set of existing sources, each of which has imperfections. Airline service quality performance (ASQP) schedule data is useful because of tail numbers, but isn't complete. Enhanced traffic management system (ETMS) data is complete, but only has aggregates. ASQP data were padded with made-up flights to match the ETMS totals for MEANS use.

MEANS Modules (Slides 8 – 12)

The MEANS airline operations and weather module set the framework within which the other modules work.

The aircraft turn-around module is based on type of aircraft and airport.

Taxi-out and taxi-in are stochastic queues based on airline service quality performance (ASQP) data that include passing aircraft and airport configuration-specific distributions.

The airborne module determines the flight time between airports with stochastic distributions for each airport pair derived from historical data.

The tower and terminal radar approach control (TRACON) module sets the capacity of each airport.

Airport Capacity (Slides 13 – 17)

Airport capacity is the number of arrivals and departures than can be accommodated in a given time period. Capacity is affected by weather, runway configuration, fleet mix, individual controllers, and maximum allowable arrival hold time.

- Weather determines spacing conditions and runway configuration. If all runways are not equivalently equipped, then weather can significantly constrain numbers of operations.
- Runway configuration determines the interactions between events.
- Fleet mix determines spacing rules; e.g., many heavies means larger separation and lower event rates.
- Individual controllers vary in their ability (and willingness) to squeeze planes into the queues.
- Maximum allowable arrival hold time is the maximum time a controller can have a plane circle the airport. The shorter the maximum hold time, the less flexibility the controller has. This is a significant driver of capacity.

Pareto frontiers model the tradeoff between arrival and departure routes.

Methodology (Slides 18 – 19)

Flight generation uses a random selection of aircraft from the fleet mix to generate arrivals and departures in four weight classes. This model uses a Poisson distribution for arrivals into the TRACON, assumes that departure queues are always filled, and that the spacing is according to the Federal Aviation Administration documents.

Ground Delay Module (Slide 24)

Several methods have been identified for using the ground delay module:

- Initiated automatically when predicted capacity falls short by specified amount.
- Implemented with simplified Ration-by-Schedule algorithm with compression.
- Module sends airline "agents" assigned slots.
- Module re-assigns slots based on airline cancellations and rescheduling.

Airline Operations Module (Slide 25)

The Airline Operations Module will have three capabilities—simple airline agent, smart airline agent, or students as human-in-the-loop test subjects making, canceling, and rescheduling decisions.

Weather Module (Slide 31)

The Weather Module determines the observed and predicted weather at each airport based on historical data. Markov and other probabilistic models are under development for use in simulating observed weather and creating the desired weather for the modeling effort.

Outputs and Results (Slides 32 – 37)

Outputs include the details of every flight (e.g., changes, when they occur, time in the queue) as well as statistics.

The results for snow at Boston and for a good weather day at Phoenix are close to actual airline service quality performance (ASQP) data.

With a 20 percent cancellation, the total delay by airline and airport often drops by more than 20 percent. Large drops indicate airports that regularly operate close to capacity.

The visualization example (Slide 36) shows red arrows as delayed flights.

Other Features of Means (Slide 38)

The remote module allows MEANS to use a module without knowing its source code (a key to supporting collaborative development) or allows a module to be replaced by a human operator.

MEANS can be run repeatedly (each run is about two minutes) to support a Monte Carlo simulation and determine probability distributions of data.

Synopsis of Questions and Answers for Dr. Melconian

- What is the status of licensing the MEANS software?

  Negotiations are in progress and will be complete in less than six months.

10.3 NASA/FAA North Texas Research Station

Mr. Shawn Engelland
NASA Ames Research Center

A copy of Mr. Engelland's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Engelland

Introduction and Capabilities (Slides 1 – 6)

The NASA/FAA North Texas Research Station (NTX) is a unique NASA Ames facility with laboratory spaces, highly configurable computer networks, and office space located on the premises of the Fort Worth Air Route Traffic Control Center (ARTCC). NTX has research infrastructure installed at Fort Worth ARTCC, Dallas/Fort Worth (DFW) TRACON and towers, the American Airlines Operations Center, and the Delta Air Lines Dallas-Fort Worth (DFW) ramp tower.

The research station supports major field evaluations on tools such as the Passive Final Approach Spacing Tool (pFAST), Traffic Management Advisor (TMA), Collaborative Arrival Planning (CAP), Conflict Prediction and Trial Planning (CPTP), and Direct-to-Controller tool (D2). NTX provides field evaluation support — by serving as interface between Ames researchers and local operational facilities; studying facility operations identifying unique constraints, sensitive issues, and unforeseen opportunities; providing field test research infrastructure; and assisting with experiment setup, execution, and data collection (Center/TRACON Automation System (CTAS) recordings, observations, human factors surveys, voice recordings, etc.).

Currently, NTX is supporting several different CTAS prototype systems in operational daily use.

VAMS-Related Capabilities (Slides 7 – 11)

The NTX team consists of NASA and FAA personnel who maintain ongoing relationships with airports, airlines, and FAA centers. NTX has an extensive data archive and has supplied data for NASA and FAA studies. Of particular interest are airspace use and air traffic control operations studies where NTX has analyzed data from its NTX archives and made the results available to Ames researchers and FAA partners.

Examples of the types of data from Dallas-Fort Worth available to VAMS modeling efforts are shown in Slides 9-11.

Synopsis of Questions and Answers for Mr. Engelland

- Is NTX archived data available to non-Government personnel?

  Yes, to NASA contractors for use on NASA research projects.

- Comment from participant: NTX would be a strong source of data for simulations because of its proximity to DFW and the American and Southwest Airline Operations Centers (AOCs).

- Comment from participant: There is significant difficulty extrapolating Dallas-Fort Worth data, which is out in the middle of a big flat area, to other airports like San Francisco, San Jose or Oakland.

11.
VAST Communications, Navigation, and Surveillance Modeling

Mr. Steve Mainger
NASA Glenn Research Center

Mr. Chris Wargo
Computer Networks and Software, Inc.

A copy of Mr. Mainger and Mr. Wargo's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Mainger and Mr. Wargo

Objectives and Overall Status (Mr. Mainger, Slides 1 – 4)

The objectives for this effort are to develop requirements and technologies for communications, navigation, and surveillance (CNS) modeling that supports the evaluation of advanced airspace concepts and to develop models and tools.

A draft report has been written to identify and categorize existing CNS modeling and capabilities. He has leveraging the work already done on the Advanced Air Transportation Technologies (AATT) and on the Distributed Air Ground-Traffic Management (DAG-TM) Projects. In the next draft, simulation and development of modeling needs and a CNS modeling approach will be identified. This later work has been hampered by our difficulties in getting a company on contract to do this work. Also, a communications traffic-modeling tool, Future Aeronautical Subnet Traffic Emulator for Communications, Navigation, and Surveillance (FASTE-CNS), has been developed and is in test.

Future Aeronautical Subnet Traffic Emulator for Communications, Navigation and Surveillance (FASTE-CNS) Project (Mr. Wargo) (Slides 5 – 22)

The Future Aeronautical Subnet Traffic Emulator for Communications, Navigation and Surveillance Project (FASTE-CNS) development grew out of a need to perform communications load analysis studies on a continual basis to support operational concept evaluation and related CNS architecture definitions. It supports a "what if" systems analysis and the NASA VAMS Program by decomposing the communications traffic loads into their shared media components (i.e., the N and the S of CNS).

FASTE-CNS supports internet-based collaborative analyses from geographically dispersed NASA, FAA, university, and contract researchers.

FASTE-CNS displays communications loading for a typical flight profile or for a number of aircraft in a given airspace. High-level performance models are available for each current communication sub-network, or are user definable for future systems. Users can have private libraries of templates, use shared "public" libraries, or "approved" NASA ones.

Users can define application message sets from standard libraries or define their own application (and associated messages). The user then defines a traffic profile comprised of a series of applications and their associated media. A communications forecast data model is developed by combining a selected group of traffic profiles with an aircraft density profile to describe the total communications traffic of interest in a geographical region. Separate communication traffic profiles can be combined to create subsets of the total number of aircraft within a sub-region. Then FASTE-CNS can provide the researchers with a list of data link communications requirements within the region as a whole or by sub-region. If desired, a region can encompass the entire continental United States. FASTE-CNS can also support performance analysis by looking at system loading and frequency requirements on a sub-region by sub-region basis.

Currently, FASTE-CNS has been through integration and system test, and is preparing for a beta test program. Enhancements to the functionality and fidelity of the FASTE-CNS media performance models are planned. Also, a way to export FASTE-CNS configuration data using high-level architecture/run-time interface (HLA/RTI) to the rest of the VAMS system will be developed. A Web access mechanism will also be developed to VAST. In addition, a way to apply communications traffic to route models will be developed.

Synopsis of Questions and Answers for Mr. Wargo

- How could this tool be used to model the current NEXTCOM transition?

  This could be used for NEXTCOM-03 in a wider Controller-Pilot Data Link Communications (CPDLC)-1A mode by constructing appropriate profiles and modeling the current analog voice as digital.

- What library routines are currently available? For example, could I do a study to compare UAT4 to VHF Data Link (VDL) Mode 4 for automatic dependent surveillance-broadcast (ADS-B) applications to look at load and spectral analysis?

  Going into beta test, we know that we need good templates, but they aren't there yet. We have some from our Small Aircraft Transportation System (SATS) studies that are mostly airport focused. We also have some from a gap analysis that we did several years ago, including some ADS-B, but they're not complete. Basically, at this point it is necessary to go in and use the tool and set up these templates.

12.
Day 2 Introductions/Agenda

Mr. Sandra Lozito
Mr. Robert Fong
NASA Ames Research Center

In response to a written question, Sandy Lozito noted that products for Milestone 5 will, with the exception of the individual concept analyses, be put on a CDROM that will be delivered to VAMS TIM 3 participants approximately two weeks after the meeting. In addition, NASA will supply contact information for all VAMS TIM 3 participants. Other written questions will be answered as the meeting progresses. She also noted that Day 2 of the VAMS TIM 3 meeting would be devoted to the concept developers.

Rob Fong added that Day 2 of the VAMS TIM 3 meeting would provide the status of the development of each concept. He noted that Phase 1 of the VAMS Project essentially closed out today with its final deliverable – the final concept descriptions and scenarios for each concept. Phase 2 started February 15. In Phase 2, the concept developers will provide a self-assessment of their concept. In particular, their goals will be to substantiate and provide the benefits of their concept.

Rob Fong also noted that in the Day 2 the concept developers would present their final concept and their self-assessment plans in the following common format:

- Concept core idea.
- An objective statement of how the concept will achieve the postulated benefits.
- Concept self-assessment plans.

Each concept developer was asked to provide time to answer questions.

13.
Massive Point-to-Point and On-Demand Air Transportation System InvestigationD

Dr. John Sorenson
Seagull Technology, Inc.

A copy of Dr. Sorenson's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Sorenson

Concept Point-to-Point Team (Slide 2)

Dr. Sorenson acknowledged the contributions from the large team assembled to develop this concept.

How Concept Point-to-Point Will Work (Slides 4 –5)

Two mechanisms in the Point-to-Point (PTP) design increase capacity: 1.) Increased direct routing, and 2.) the unloading of impacted hubs.

Concept Point-to-Point Premise and Benefits (Slides 6 – 7)

All National Airspace System components will have to be augmented to implement this concept, not the least of which is the business practices of the major carriers. Issues of fractional ownership for regional jets may need to be addressed for them to break free of the hub and spoke model and improve the overall efficiency of the system.

Core Idea 1 – Provide Non-Towered Airports with Air Traffic Management Automation (Slides 9 – 11)

A key ancillary benefit to providing non-towered airports with air traffic management (ATM) automation is improved safety, as well as capacity. Under a Small Business Innovative Research (SBIR) grant, Seagull installed a voice-synthesis system at Moffett Field last year to test a portion of this concept. With a modified version of the traffic management advisor (TMA) or the Final Approach Spacing Tool (FAST) as the key ground software component, a system similar to this could provide sequencing and 4D conflict-free traffic advisories, as well as autonomous airfield information.

Core Idea 2 – Terminal Area Time-Based Air Traffic Management (Slides 12 – 13)

Conflict-free 4-D trajectories in the terminal area will be used to set non-conflicting required time of arrival (RTA) at anchor points and intermediate way-points for transitioning aircraft from en route to the terminal airspace. This concept will favor equipped aircraft over non-equipped ones, since 4D flight management systems (FMS) and cockpit display of traffic (CDTI) will be required to follow their assigned transitions within cells along precise paths. In the Point-to-Point concept, controllers will still be required to manage transitions between different airspace levels and types.

Core Idea 3 – Mechanize Strategic En Route ATM (Slides 14 – 16)

The key thought is the use of three altitude bands to stratify en route airspace based on equipage levels:

1) Z35 for Class C, or well-equipped aircraft (sectorless, self-separation).

2) FL270-345 air-ground trajectory negotiation (a la DAG-TM CE 6) with dynamic sectors for Class B (moderately equipped) and Class C aircraft.
3) Sectored bands below FL270 for Class A and climb/transition for Classes B and C.

Core Idea 4 – Expand Traffic Flow Management Processes and Extend Point-to-Point Fleet Operations (Slides 17–20)

The PTP concept propose the expansion of traffic flow management (TFM) processes into the airline operations center/fleet operator, assuming that the aircraft surveillance and weather data are available everywhere in a timely fashion. The fleet operator/dispatcher optimizes the individual aircraft/crew schedules to meet demand and business needs. Added to this the idea of Randy Kelly's Precision Control Tool that the Operator can use to advance or retard the aircraft to meet the required time of arrival in accordance with business needs.

Core Idea 5 – Exploit Advanced Avionics (Slides 21 – 22)

Advanced Avionics, especially automatic dependent surveillance broadcast (ADS-B) and advanced flight management system (FMS), are critical to the PTP concept. Multiple required time of arricals (RTAs) will have to be met using precise 4D trajectories, and required total system performance parameters will be used for precise path control and optimal spacing assurance. The work by Titan at Langley Research Center on the Advanced Operations Planner (AOP) needs to be leveraged.

Core Idea 6 – Concept Evaluation Ideas (Slides 23 – 27)

Precise winds and weather, navigation, and surveillance (CNS) data need to be distributed everywhere on a continuous basis, especially to the flight deck, for the PTP concept to achieve its benefits. Chicago, Dallas-Fort Worth, and the West Coast corridor (Los Angeles to San Francisco) are what the PTP concept is currently looking at for its initial evaluation. Atlanta Hartsfield International Airport (ATL) may be added later. If time permits, a high- or medium-fidelity model of expanded terminal area is proposed to look at a second (i.e., PTP2) concept. This model should be compatible with ACES and use the Chicago O'Hare International Airport and the Chicago Air Route Traffic Control Center (ARTCC ORD/ZAU) corridor as the starting scenario. Safety issues and human performance analysis will also be taken into consideration.

Synopsis of Questions and Answers for Dr. Sorenson

- How realistic is the business case for this concept?

  The facilities (like Moffett and South County in this area) are there. Business travelers may be willing to pay more.

- Using a non-hub airport like Los Angeles International Airport (LAX) for your evaluation may not show full benefit. Also, the Los Angeles area already has lots of busy regional airports, like Burbank and Orange County. How will this affect your evaluation?

  The Los Angeles area is expected to be an area of significant growth. While it may not show all the benefits of Point-to-Point, it will certainly help.

- Have you done a failure modes analysis for this concept?

  Honeywell has started.

- Comment from Vern Rossow on elliptical airport design: Greg Condon proposed a circular design some time ago but the flaw in this design is the need for a wave-off or roll-out area right over the terminal building. Have you given consideration to the terminal design? Some designs require tremendously long concourses.

  No, not yet, but we should discuss this off-line.

- Follow-up on business cases discussion. JP Morgan-Chase have recently done a study to show hub airlines [e.g., United Airlines (UA), AMR Corporation] have the highest costs, while Southwest Airlines (SWA) (primarily PTP) has much lower costs. Do you see yourselves as being responsible for coming up with these kinds of statistics to validate your study, or do you see the SEA element as doing this?

  We'd prefer the SEA element do this. We'd prefer to focus on the technological feasibility and let the SEA element answer the economic ones. We're going to use the data that others provide.

- One key driver on requirements is load split between PTP and the traditional hub and spoke concepts (i.e., how much will switch from the latter to the former). Are you going to make this a study variable?

  Yes, we're going to max out the hub airport by adding up to 50 percent more traffic to them. Then the only thing you can do is to pour more concrete or move to the PTP airports.

- Do you envision use of conflict-free 4D trajectories in en route space or only in terminal airspace (i.e., use of trajectory "negotiation")?

  We envision self-separation being used in en route airspace (i.e., without an air/ground negotiation component). However, prior to the flight, we see traffic flow management, the airline operations center, and others sharing detailed flight plan data on particular flights to see statistically how likely they are to be conflict-free in en route space. If the flight is statistically too likely to have conflicts, then the plan will be collaboratively adjusted.

- Your concept assumes segregated bands of airspace by altitude, with transitions by equipped aircraft between them. You assume that this is efficient. Have you considered other ways to look at airspace?

  A lot more thinking outside the box (and simulations) needs to be done. (Recommendation by the questioner is that AATT-funded studies by the National Aerospace Laboratory of the Netherlands on self-separation be looked at in order to help with what are good versus not so good schemes).

- Have you had discussions on differences in separation standards between ground-based and self-separation and for self-separation? For self- separation, have you looked at the difference between the pilot separating the aircraft and the flight management system doing it?

  No, but they do need to be considered. They probably would be different.

14.
Boeing Air Traffic Management

Mr. Alvin Sipe
Lead Engineer, Boeing Air Traffic Manaagement

A copy of Mr. Sipe's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Sipe

Introduction (Slides 1 – 2)

Boeing is preparing a system-wide, capacity-increasing, air traffic management concept. Metron is helping with the surface portion of the concept. Mr. Sipe suggested that participants carefully look over the slides since he could not provide the same level of detail in his talk. He provided a chart of summary capacity factors (Slide 2) that describes airfield and airspace behavior with respect to capacity based on a recent NASA-sponsored study of the Chicago airspace. Mr. Sipe noted that capacity constraints are complex and dynamic and often are related to remote weather or other occurrences.

Context (Slides 3 – 6)

The top-level systems engineering development process used by Boeing is shown in Slide 3. The process is very iterative and driven by "measures of mission" and "measures of effectiveness." "Measures of performance" are allocated to system agents and resources that support system operation. Expected methods for integrating core and ancillary air traffic services in 2020 are shown in Slides 4 and 5. ATM providers define the timeframe in which they work as shown in Slides 5 and 6.

Air Traffic Management as an Integrated Set of Core Services (Slides 7 – 12)

A system functional flow diagram that depicts air traffic management as an integrated set of provider and user services is shown in Slide 7. The diagram shows shared service objectives and provides a performance measurement perspective. Further details of the airspace management, flow management, traffic management, and separation management services provided are shown on Slides 8-11. The method for allocating human roles and responsibilities requirements given the automation available is shown in Slide 12.

Capacity Benefits (Slide 13)

A preliminary subjective assessment of the capacity benefit of the Boeing concept under visual meteorological conditions, marginal visual meteorological conditions, and instrument meteorological conditions given current delay sources is given in Slide 13. Note the large impact on "other" delays, which represents a huge percentage of the current problem.

Operational Scenarios and Concept Summary (Slides 14 – 15)

Samples of demand scenarios and operation scenarios that will be needed to test the unique feature of the Boeing concept were briefly discussed.

Synopsis of Questions and Answers for Mr. Sipe

- Will Boeing use required total system performance (RTSP) for access/denial to the airspace?

  RTSP will be used for access control to airspace.

- How does their concept of operations deal with exceeding wake vortex standards or runway occupancy standards at an airport?

  The scheduler will know when the airport is operating behind capacity.

- What is the essence of the Boeing concept for providing capacity benefits?

  The core idea is better integration of provider and user services in order to get provider and user objectives in line. They will use a more information-rich flight plan than is available today. The benefit will be better use of resources.

- How do various functions interact? How is the locus of control determined? What is the stability of the relationship between the service providers?

  The time horizon breakdown will prevent problems between the agents. Each agent has certain objectives. Precision synchronization, feedback, and control will be required.

- How many people will be required?

  Flow management will be accomplished at a national level. Traffic management will be accomplished at a regional level. Separation management will be accomplished at a sector level. Sectors will be larger than the sectors used today.

- Comment from a participant: The goal will be for the users to get what they want, when they want it, and to be able to change their mind.

15.
Technologies Enabling All-Weather Maximum Capacity by 2020

Dr. Jimmie Krozel
Metron Aviation

A copy of Dr. Krozel's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Krozel

Introduction and Problem Statement (Slides 1 – 7)

Weather is probably the "weakest link" in all the concepts being developed so it is likely that ideas Metron is developing can be used by others. Currently, the National Airspace System is not robust to weather disturbances. Further, while the effect of the weather maximizes during the convective weather season, it is important to remember that every day is different and that weather-induced delays are significantly higher than non-weather related delays. The weather has effects that reduce capacity in all areas of the NAS: surface, terminal, and en route.

Approach to Problem Solution (Slides 8 – 10)

A trio of triads present themselves. A philosophical triad (human-centered design, interdisciplinary design, and multi-domain) is the first. The second is the user triad of key constituents: the flight deck, the airline operations center, and the air traffic service providers. Finally, a triad of core ideas to be explored is presented:

1) Flexible Traffic Management Considering Weather Constraints.
2) Coupled Weather and Traffic Predictions.
3) Situational Awareness, Coordination, and Information Transfer. It should be noted that the achievement of Metron's concept goals is tied to the assumption that the prediction of the weather, and its effects or constraints on traffic, will improve in the future. This prediction improvement is a key driving force behind the success in a great many other things in aviation. Weather prediction especially defines the distinction between tactical and strategic control domains.

Core Idea 1: Flexible Traffic Management Considering Weather Constraints (Slides 11 – 20)

Ideas in this area present themselves in all National Airspace System domains: surface, terminal, and en route, as well as the preflight area. In the surface arena, the Severe Weather Avoidance Program can be used to help with precise control of take-off times with ground stop and ground delay programs. Coordination of de-icing and runway snow removal can be done using surface management system (SMS)-like programs, such as those being looked at by Metron and Optimal Synthesis. Use of improved displays (heads-up, augmented reality, etc.) is envisioned for low-and zero-visibility ground conditions. To accomplish the goal and minimize controller workloads, new algorithms have been developed for generating one to four turns to avoid severe weather in the TRACON airspace. In transitional airspace, a new idea is to use the Integrated Terminal Weather System (ITWS) to help relocate aircraft flows, instead of individual aircraft. Another idea in transition airspace is to evolve from current coded departure routes (CDRs), that go from departure to arrival airports to something called range-based CDRs. Range-based CDRs extend out to a fixed-range from departure airports and merge with free-flight airspace, standard jet routes, or playbook routes. In en route airspace, high-capacity parallel wind-optimal routes can be dynamically defined to avoid weather constraints. This follows Matt Jardin's work on wind-optimal routing (see Jardin's presentation). Metron is also looking at ways to dynamically "tweak" playbook plays to develop parallel routes for coordination of large-scale TFM plans.

Core Idea 2: Prediction (Coupled Weather and Traffic Prediction) (Slides 21 – 23)

Weather prediction improvements can be incorporated into estimated time of arrival (ETA), sector demand and load capacities, and actual flow rate (arrival and departure) computations. Equations have been developed to look at meter crossing points and then predict runway arrivals on a statistical basis of what traffic might do in the presence of large weather disturbances. This can be done in the terminal area and in en route airspace. Techniques are also being developed to dynamically adjust the sector capacity based on weather disturbances.

Core Idea 3: Situation Awareness, Coordination, and Information Transfer (Slides 24 – 27)

This idea comprises coordination of weather data, shared situational awareness, and coordination of user goals and constraints. Weather data and its effects need to be collected from a variety of sources [ARINC's Meteorological Data Collection and Reporting System (MDCRS), pilot-reported weather data (PIREP), radar, satellite, surface] and compared, integrated, fused, coordinated, and distributed. Improved weather prediction is a hard problem, especially beyond one hour out. This isn't the focus of Metron's project, but it is essential for the project to proceed. This leads to improved situational awareness of weather data, i.e., making sure the controller, the flight deck, and the airline operations center are on the "same page" vis a vis weather information (forward, behind, strategic, and tactical). This will require a secure National Airspace System state/weather information distribution network and a new unique user interface concept to be developed. Finally, re-routes and deviations because of weather have to be developed to accommodate user goals and constraints, such that the capacities of the aircraft involved are taken into consideration. This will require better sharing and coordination of data between the airline operations center and the air traffic service provider (ATSP).

Benefit Mechanisms, Self-Assessment, and Conclusion (Slides 28 – 32)

Increased accuracy safety, responsiveness to user preferences, delay savings, equity (between airlines), improved human factors, and reduced environmental emissions are among the key benefits from improved weather robustness. The self-assessment of this concept relies on a scientific cluster-analysis classification of "weather days" done on another task. These weather classifications are 1.) no weather effect, 2.) typical weather, 3.) severe weather, and 4.) rare weather. Metrics for human-in-the-loop and non-real-time simulations are being selected and will be applied in each domain of interest. Scenarios from today's National Airspace System (2002) with, and without, concept core ideas are extrapolated to future National Airspace System (2020) for different weather days.

Synopsis of Questions and Answers for Dr. Krozel

- Did you consider today's numbers on airport capacity/throughput, or did you consider more aggressive ones based on new technology?

  For today's data, Metron uses today's number. For the future, we set up a "rough" future demand model. We are hopeful that we can rely on the data of others for this (i.e., Cavolowsky data) to give us a better demand estimate for the future at some point.

- Does your concept consider dynamic resectoring?

  Dynamic re-sectoring may be necessary, but we're not considering it at this time.

- Do you consider going "above" the weather, as well as around?

  Yes, we're looking at this in a true 4D solution sense, even though the diagrams in our presentation look 2D.

- Are you planning to perform a Monte Carlo analysis in terms of all the possible trajectories for determining the arrival times?

  Yes, for crossing the metering fixes to compute the arrival times at the arrival times we are treating all the possible trajectories in a statistical fashion.

- With regard to the uncertainty of the weather predictions used for your weather avoidance route computations, did you explicitly consider contingency planning? And if so, how was this communicated to the airline operations centers?

  Yes, while this wasn't something brought out during the presentation, there are two elements to this. First, we're not looking at strategic constraints as "hard" constraints, because they're hard to predict. We're looking at percentages of aircraft that could pass through the airspace with contingency plans, which they may have to use. When this turns into a tactical situation and the weather is known (i.e., within one hour), the contingency plans are left in place, but the probability that they'll be used is reduced. The problem today in a strategic sense is that users are treating things like the Collaborative Convective Forecast Product (CCFP) (i.e., two- to six-hour predictions) as a well-defined constraint or "truth," when in fact they're mostly wrong in some sense (location, size, etc.). Too many users are treating these things as the actual weather, and creating plans accordingly. Metron is looking at ways to change its interpretation or representation to make users think of these strategic weather forecast constraints as probabilistic, and then plan the flow through it as a statistical probability of "getting flights through," rather than as hard constraints. Users should become concerned about how to adjust once in the tactical domain, either by getting more planes through because the weather went in a "good" direction, or by using the contingencies.

16.
Surface Operation Automation Research (SOAR)

Dr. Victor H. L. Cheng
Optimal Synthesis

A copy of Dr. Cheng's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Cheng

Introduction (Slides 1 – 2)

The developers of the Surface Operation Automation Research (SOAR) concept have been focusing on capacity metrics, core concepts, integration of the ground-operation situation awareness and flow efficiency (GO-SAFE) and flight deck automation reliable ground operation (FARGO) systems, system performance, and providing a technology roadmap.

Airport Capacity Enhancement Issues and Goals (Slides 3 – 5)

Enhancement of airport capacity can increase ATC capacity and penalize efficiency. There is a tradeoff between increasing the effectiveness of the system and introducing other costs. Dr. Cheng noted that airport surface traffic density is inversely proportional to airline separation. The SOAR concept seeks a tradeoff between achievable traffic rate and an increase in traffic delay. The goal is to achieve 90 percent of ideal airport capacity while maintaining cumulative delay to within 10 percent of the cumulative ideal taxi time. The operating capacity will always be less than the theoretical capacity.

SOAR Concept and Functions (Slides 6 – 19)

The SOAR concept integrates the operation of the GO-SAFE tool, the FARGO tool, and the rest of the proposed Virtual Airspace Simulation Technologies (VAST) system. The goal is to make the system easier to configure and to improve the techniques for airport surface management. The system must provide taxi-route generation and editing as well as conflict detection and resolution capabilities. The components of the decision support system include a surface resource scheduler, a clearance manager, and a conformance monitor. Flight deck automation functions include an auto-taxi function and a pilot interface to allow the pilots to perform precision taxi maneuvers. A new type of pilot display (T-NASA display) is being considered.

The effect of SOAR Concept on Operations, System Performance, and Human Performance (Slides 19 – 23)

The method for integrating GO-SAFE and FARGO functions with the air traffic surface provider, flight crew, and aircraft functions along with the actions that must be performed is shown in Slide 19. The issues/changes that must be made to implement the SOAR concept are shown in Slide 20. The two main metrics for evaluating SOAR include achievable landing and departure rates and surface traffic efficiency relative to traffic delays. Other overall issues are operator workload and safety. Optimal Synthesis will use field tests, high-fidelity simulations, mid-fidelity simulations, low-fidelity simulations, human-factors analysis, HITL simulations, and computer simulations to evaluate SOAR.

Concept Development and Technology Roadmap (Slide 24)

A concept development and technology roadmap has been prepared that includes the communication, navigation, and surveillance needs in order to support the operational testing of SOAR.

Synopsis of Questions and Answers for Dr. Cheng

- Comment from a participant: Recent literature contains additional design considerations.
- Will airport capacity decrease/increase based on weather and will airport operations be able to set the rate of take-offs and landings?

  These variable rate functions are already included in SOAR.
- Can FARGO and GO-SAFE provide benefits separately?

  Yes, but major benefits are achieved through integration of the tools.

17.
Capacity Improvements Through Automated Surface Traffic Control

Dr. Brian Capozzi
Metron Aviation

A copy of Dr. Capozzi's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Capozzi

Introduction (Slides 1 – 5)

Dr. Capozzi introduced the need for a more efficient and adaptive airport surface by pointing out that in today's operation there is very little opportunity for planning beyond the end of the current queue. There is almost no way for controllers today to develop the synchronized flows that integrate and coordinate movement on the surface, including runways.

The solution is to automate in such a way that a plan can be developed for movement from the terminal airspace to the runway, on the surface, to the gates, and back again. This plan consists of time-based clearances and allows for dynamic adaptation of the plan. It takes into full account the pilot's ability to follow these clearances as well as situational awareness limitations. Such a plan eliminates myopic control of the airport, reduces communications problems and execution lags, and supports dynamic interaction with terminal, en route, and airport users.

The overall concept was summarized on a single figure (Slide 4), which partitioned activities into two main focus areas: 1.) capacity and implementation, and 2.) safety. The interfaces between the surface and the rest of the National Airspace System (NAS) include expected arrival times and trajectories, departure constraints and user preferences being received from the NAS, and airport status and constraints being sent from the surface back to the NAS.

Core Ideas and Benefits (Slides 6 – 9)

Core Idea 1: Collaborative runway management, which includes configuration planning (which runways are in use), runway assignment and sequencing (which runway assigned to which aircraft), and in what order), and runway slot scheduling (which aircraft in which slot).

Core Idea 2: Surface-wide planning, including coordinated, time-based surface trajectories for all aircraft, clearances delivered automatically to the flight deck, and parallel conformance monitoring for safety.

Core Idea 3: Interaction with NAS traffic flow management, which includes planned surface capability assessment and maintaining records of actually achieved surface performance.

Benefits from the concept include enabling the use of "lost" slots, supporting increased capacity in other domains, and providing greater flexibility to incorporate and satisfy user preferences.

Self-Evaluation, Simulations, and Summary (Slides 10 – 12)

The self-evaluation partitions into two approaches: 1.) analytical approaches for achieving "ideal" runway sequences, and 2.) simulation studies for modeling surface movement of aircraft and terminal-area aircraft activity. Leveraging of existing surface management system algorithms and results is planned.

Self-evaluation simulations use existing baseline models to help develop initial high-level results that are then "tweaked" based on the concept models. Comparison of the results from these two simulations then provides an assessment of the benefits of the concept.

In summary, the core ideas of this concept have been chosen to address key limitations of today's NAS:

- Cognitive processing.
- Information availability.
- Communication and execution lags.

Synopsis of Questions and Answers for Dr. Capozzi

- Have you considered using existing simulation models?

  Yes, models such as MIT's MEANS and other models, such as those at George Mason University, will be used to help establish the validity of models developed under this task.

- When evaluating, will you have a fairly complete planner?

  Yes, we plan to model the surface planner at a fairly high, abstract level, without having to go to the detailed level if possible. We will leverage the results from SMS.

- What is the difference between Core Idea 1 and SMS as currently planned?

  SMS helps the controllers do the job of runway management. It shows a picture of where the delays might be, but it has almost no decision-making authority. This concept replaces the whole path of planning with automation, along with a higher level of human interaction to use the automation.

- Are there any plans to use this tool to optimize airport design?

  That is an interesting idea. We haven't planned this, but it is an interesting extension of the concept.

- There appears to be a feedback loop missing in the overall diagram shown in Slide 4. Additionally, it is not a trivial matter to keep the system updated so that the planning function is working with updated data.

  I agree, there should be feedback from execution monitoring to surface traffic control. Surface traffic control then provides feedback into surface traffic planning via previously described information flows.

18.
University Concept Final Report

Dr. Andres Zellweger
NASA Ames Research Center

A copy of Dr. Zellweger's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Zellweger

Introduction (Slides 1 – 4)

This presentation is a slight update to that given at the first VAMS TIM last May (only one additional meeting was held last June). It also represents a draft of the final report (which was due in December). The primary difference from the presentation made at the first VAMS TIM is that there is more focus on framework, transition, and what could be accomplished.

Approach: Drivers, Inhibitors, and Transition Issues (Slides 5 – 11)

The approach of the University Concept Team was to identify drivers, inhibitors, and transition issues, and then brainstorm concepts that accommodate them. Then, research questions, possible transition approaches, and crosscutting research questions were investigated. A set of research questions that need to be explored to further the state of the art, independent of what concept is already be studied, were identified. There are two very different demand trends that act as key drivers: 1.) a demand for a high-end network, and 2.) a for a low-end network.

The high-end network will be very structured and used in highly urbanized areas where demand will continue to exceed capacity. Fractional ownerships, regional jets, air taxis, cargo carriers (with smaller aircraft), and general aviation at small (and mostly non-towered) airports near major urban areas partitions would utilize the low-end network. The team focused on the 2025 timeframe.

Safety and security are other key drivers. While the University Concept Team did not address safety, per se, safety research was discussed. Right now, there is no any inherent security built into our communications, navigation and surveillance (CNS) systems and this must be a requirement for the future. Also, with the advent of Homeland Security, there are some operational needs that will have to be met. The aspects of globalization vs. "what is best for the United States" must be considered, but most importantly, the future must be driven by policy for public benefit. This should be contrasted with the Radio Technical Commission for Aeronautics (RTCA) concept put out in December, which appears to favor special interests. The key inhibitors to change are affordability, CNS technology, and environment, as well as transition. Benefits-driven transition is not likely to work. For example, despite the availability of aircraft Data Link for over 25 years, controlled-pilot data link communications (CPDLC) has still not been deployed. The government may have to mandate equipage. At least we shouldn't let special interests require a payback at each step. The current culture of the NAS is extremely stable which is a transition inhibitor. As a result, the University Concept Team believes that cultural change should be a key topic of our future studies.

Study Overview: Concepts and Research Questions (Slides 12 – 34)

High-end concepts to optimize the use of airspace around our busiest airports have been developed. Other concepts that were studied looked at enabling instrument meteorological conditions (IMC) operations and transition to and from lower-density airports. Also identified were some high payoff research areas in case we are unable to move to these new concepts and are forced to stay with current air traffic management paradigm. It should be noted that these new concepts are not comprehensive and not mutually exclusive.

The tube concept is a high-density network concept and abstraction (like a flow) in which controllers can move high volumes of traffic between airports in a highly structured way. Tubes maximize the use of key resources (airspace and airports) in a way similar to TRACON flows, but are extended throughout the network. The tube concept uses many artifacts of the “highway” metaphor, including on-off ramps, breakdown lanes, detours, etc. It will require a redesign of the airspace and procedures to keep other aircraft out of the tubes. In a study at George Mason University, George Donahue’s students called these tubes “ribbons,” which may be more descriptive. It offers the best chance for early capacity improvements. To gain the greatest benefit during transition, the tube concept should be demonstrated in high-value target markets (e.g., Chicago O’Hare/New York City, Los Angeles/San Francisco, Washington-/NewYork/Boston, Los Angeles/Las Vegas). Limited corridors and simple ramps and other highway “artifacts” should be employed to keep technology and procedures simple. Preferences should be given to demonstration participants. Research areas include human roles, decision support tools, tube control methodology, separation assurance, dynamics in response to major perturbations like weather, planning and scheduling, transition (entry, exit, etc.), tube limitations and failures, and how to deal with aircraft outside the tubes.

The highly interactive dynamic planner concept will increase capacity at high-density airports and in high-density airspace while accommodating user schedule and efficiency needs. The core ideas are dynamic air-ground negotiation of trajectories such as distributed air ground traffic management (DAG-TM CE-6); gate-to-gate scheduling based on collaborative ground-based generation of a mix of required time of arrivals (RTAs) and optimal 4D conflict-free trajectories for all instrument flight rules (IFR) aircraft throughout an entire day; cooperative sharing of responsibility for executing, revising, and rescheduling the trajectory (this is difficult); and, most importantly, the delegation of separation assurance to the flight deck. This concept could evolve from the tube concept at high-altitude densities and gradually move to lower altitudes. The nature of the planning and negotiation process and achieving stability in the face of anomalies (like weather) are major (and difficult) research issues. Questions such as “How brittle is the concept to anomalies and failures?” have to be answered.

Low-end network concepts include those for autonomous instrument meteorological conditions (IMC) en route/terminal operations and airport operations. The latter is very similar to Seagull’s massive Point-to-Point Concept.

In the en route/terminal area it is predicted that by 2025 there will no longer be any “low-density” air space, as we know it today. Separation responsibility will go to aircraft and traffic management will be limited to density control. Sequencing and interaction will be done by procedure and “rules of the road.” This concept requires an increase in safety over today’s general aviation’s visual flight rules (VFR) and all planes will need to be equipped with advanced avionics that prevent flight into restricted zones. The latter has been demonstrated at NASA Langley Research Center, but there is an issue about whether it could be implemented at a reasonable cost. Finally, all the planes must be capable of dealing with weather problems. Many of today’s general aviation aircraft can’t fly over the weather, so this is also an issue. Some type of security monitoring will also be needed. The transition/demonstrations should be done in parallel to those for the high-density network concept in low-density regions (e.g., oceanic, Alaska, high altitude, one low-density low-altitude typical “trial” region), and then expanded to larger regions and altitudes lower than 170. Mandating equipment will accelerate transition. Research issues will have to address procedures and technologies, dynamic density limits for safety and communications, minimum equipage, failure and degraded modes, the exact nature of air traffic management function needed, and the role of humans.

The other low-end network concept (autonomous instrument meteorological conditions (IMC) airport operations) is designed to increase the capacity at non-towered airports without the need for additional air traffic control personnel. Again, this is similar to Seagull’s massive Point-to-Point concept. This concept shifts the responsibility for separation, taxi, takeoff, and landing to the aircraft. As in the en route/terminal autonomous IMC concept, air traffic management is responsible for density control. The Small Aircraft Transportation System (SATS) Program in Florida is a good example of a start at a transition for this concept. Research topics include: Hourly rate; sequencing and spacing control; density control;

separation criteria; communication, navigation and surveillance (CNS) and avionics requirements; ground-based infrastructure (e.g., lighting); how to handle unequipped aircraft; interface to air traffic management system (transition to/from en route/terminal system); and pilot qualifications and training.

Other concepts that need to be investigated include those for capacity-constrained airports. George Mason University has done some research into demand management. Regional airport systems and other topics will also demand research and development.

Crosscutting Research and Closing Thoughts (Slides 35 – 43)

Elements of a successful transition, air traffic management behavior/dynamics (current and future), and human factors are elements suggested for crosscutting research. Also, separation standards really need to be re-examined, with new paradigms for accomplishment (e.g., ground based vs. trajectory negotiation versus self-separation). Capacity variability, required time of arrival (RTA) approaches, airspace design, weather, and especially safety are also research areas.

Since the rest of the airspace can be operated as it is today, one benefit to these approaches is that the transition due to the introduction of these high- and low-end systems is eased. Gradually, both systems will expand and the current system will shrink and go away.

Synopsis of Questions and Answers for Dr. Zellweger

There were no questions for Dr. Zellweger from the TIM participants, however, there were some comments.

- The current ways of framing benefit costs are not flexible enough for these types of new systems. In addition, a problem with mandating equipment as a transition strategy came up in NEXCOM (RTCA's Next Generation Air-Ground Communication, Principles of Operations RDL Mode 3, DO-279), which is the rulemaking process.
- The University of California Berkeley's Partners for Advanced Transit and Highways (PATH) System works on an automated highway system and may be applicable.
- Dr. Zellweger also commented that while the University Team's work is "done," he is hopeful that he can find people to start doing the research necessary to carry these concepts to fruition.

19.
Centralized Terminal Operation Control (CTOC) Concept

Mr. John Fergus
Northrop Grumman

Mr. Dave Felio
Geneva Aerospace

A copy of Mr. Fergus' and Mr. Felio's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Fergus and Mr. Felio

CTOC Concept and Core Ideas (Slides 1 – 5)

The Centralized Terminal Operation Control (CTOC) Concept blends the roles of the terminal controller and the flight crew to provide remote control of aircraft in the terminal domain. Its implementation depends on the data link and flight management systems aircraft technologies. The concept depends on the four primary core ideas shown in Slide 5 with the two secondary core ideas shown at the bottom of Slide 5. In order to determine the benefits of the CTOC concept developers are analyzing the terminal domain for five airport: St. Louis International Airport, Lambert Field (STL); Dallas-Fort Worth (DFW); Atlanta (ATL); Los Angeles (LAX); and Minneapolis-St. Paul International Airport (MSP). In particular, knowledge about the effect of departure traffic and the effect of segregated arrival/departure operations is needed.

CTOC Objective (Slides 6 – 7)

A key component of their objectives are that CTOC operate in all weather conditions. The benefits, implementation mechanisms, and candidate metrics used for evaluation of the concept are shown in Slide 7.

CTOC Self-Evaluation Plans (Slides 8 – 11)

The CTOC developers are aggressively pursuing their own tools to be used for a self-assessment. In addition, they are setting the prototype test environment in the Dallas-Fort Worth areas as shown in Slides 9-11. Pieces of the prototype test environment will be replaced with VAST technology when it becomes available. The initial work has been completed and simulation tools are being developed early in order to mature their concept. Test tool functions that VAST will provide (such as weather effects) are not being pursued.

Synopsis of Questions and Answers for Mr. Fergus and Mr. Felio

- Please clarify the role of the terminal specialist?

  The role of the terminal specialist will depend on aircraft equipage.

  - Full CTOC—Terminal specialist provides separation monitoring of aircraft and CTOC provides trajectory commands.
  - CTOC-Assisted Mode (some CTOC functions available, i.e., data link)—Some support but HITL; CTOC provides clearances and advisories.
  - No CTOC—Manual control with enhancements provided to the terminal specialist such as trajectory conformance monitoring.

- What is the effect of interaction between arrival and departure flows?

  This is being studied using St. Louis and Minneapolis data.

- How do you gain capacity using this tool?

  Terminal and surface bottlenecks can be relieved.

- What are the boundaries between surface, terminal, and en route?

  The boundary between terminal and en route is the hand-off point.

20.
Terminal Area Capacity Enhancing Concept (TACEC)

Mr. Kenneth Arkind
Raytheon

A copy of Mr. Arkind's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Arkind

Introduction and Overview (Slides 1 – 5)

The Terminal Area Capacity Enhancing Concept (TACEC) has been revised and the slides reflect the change in concept focus. TACEC's domain is the terminal area, i.e., the airport surface and the surrounding airspace. Capacity is measured when the wheels are on the ground and passengers in the terminal. The TACEC concept proposes to double capacity by synchronizing at the terminal through what are today a series of asynchronous actions, via operational algorithms, avionics, and "autoland."

The core ideas are as follows:

- Calculation and execution of 4D trajectories.
- Reliable, secure data link.
- Reduced separation standards.
- Improved surveillance through the Wide Area Augmentation System (WAAS), multi-sensor fusion, Mode S mono-pulse secondary surveillance radar (MSSR).
- Airborne self-separation.
- Complex final approaches.
- Optimized surface movement.
- Integrated communication network in the terminal available to all stakeholders.
- Human centric system design.

Results of Investigations (Slides 6 – 8)

The TACEC concept developers reviewed elements of their concept and found that multi-aircraft formation landing and optimized surface movement provided the most capacity benefit. The terminal area does not provide sufficient airspace to significantly increase the National Airspace System capacity. Additional airports and runways are needed and wake vortex avoidance using flight corridors will also enhance capacity.

Impact of Investigations on Core Ideas (Slides 9 – 11)

The TACEC concept developers restated their core ideas (see Slide 9) based on their investigations. Further investigating the consequences of multiple flight corridor operations is ongoing. TACEC noted that this idea might generate increased environmental problems for today's airports.

Impact of Investigations on TACEC Objectives (Slides 12 – 13)

The TACEC concept developers revised their objective statement to use the following operational approaches:

- Multiple aircraft landings and departures in dynamic flight corridors
- Up-linked 4D trajectory flight paths
- Optimized surface movement (may need to redesign runways)
- Human-centered automation.

This approach is primarily dependent on efficient wake vortex avoidance.

Synopsis of Questions and Answers for Mr. Arkind

- Will there be changes in roles?

  Roles will be similar to what we have now for zero visibility landings.
- What about increased ground congestion?

  This will be an issue.
- Comment from participant: Current gate structure and gate procedures are inefficient. They occupy too much pavement.
- Comment from participant: Bottlenecks can't be pushed from one location (surface) to the next (terminal).
- Why wouldn't reduced surface separation standards help?

  Reduced separation in the terminal area is part of the TACEC concept to provide 4D trajectories that will be executed by the aircraft. The main problem is runway occupancy time.
- Are the benefits of TACEC the same as those of Wake Vortex Avoidance System (Wake VAS)?
- The TACEC concept avoids wake vortex. David Rutishauser (WakeVAS) provides a better characterization of wave vortex in order to lessen the wait time for wake vortex to dissipate.

21.
Wake Vortex Avoidance System (WakeVAS) Concept of Operations

Mr. David Rutishauser
NASA Langley Research Center

A copy of Mr. Rutishauser's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Mr. Rutishauser

Separation Rules (Slides 1 – 3)

The current arrival and departure system is governed by separation rules from the FAA's controller's handbook that are summarized in Slide 2. These rules are static and based on empirical measurements and field tests. It is hoped that information collected over the last 30 years on wake behavior will allow for increases in capacity by increasing arrival and departure rates.

Aircraft Vortex Spacing System (AVOSS) (Slides 4 – 5)

The NASA Aircraft Vortex Spacing System (AVOSS) has demonstrated the current state of the art in providing weather-dependent, dynamic aircraft spacing for wake avoidance at Dallas-Fort Worth. Products of the AVOSS program include data, a platform for development, and demonstration of a concept for system integration.

Concept of Operations (CONOPS) (Slides 6 – 11)

The process being used for Wake Vortex Avoidance System (Wake VAS) is to down-select from various options. It is expected that a hybrid of ground-based (wake sensors) and airborne systems (weather information) will be developed to provide accurate wake hazard durations and enhance situational awareness. The roles and responsibilities for users of the hybrid system are described in Slide 9. The system must augment airport weather systems with new wake and weather sensor data as well as prediction algorithms. The developers need to define the region of protected airspace as well as the requirements for the sensors.

Research Questions, Policy Changes, and Infrastructure Requirements (Slides 12 – 13)

Research questions that need to be answered include the need for better equipment, more weather and wake vortex information, a new probabilistic wake predictor, resolution of political issues, human factor design, and how to obtain high-resolution weather data. The AVOSS sensors are considered research quality, not operations quality. In particular, there is no consensus on a wake hazard definition.

Self-Evaluation Approach and Process (Slides 14– 17)

The NASA Langley Research Center personnel in charge of self-evaluation of the concept prepared the self-evaluation approach and process shown in Slide 14. Details of the expected solution space are shown in Slide 15. The candidate list of airports that will be used to test the concepts is shown in Slide 16. References to past work are shown in Slide 17.

Synopsis of Questions and Answers for Mr. Rutishauser

- Do you have a ballpark figure on how conservative the present separation rules are?

  Based on the Dallas-Fort Worth data, the primary issue is the two-thirds of the time runway occupancy time, not wake vortex.

- What will controller do if your concept is in place?

  The controller provides wake-safe spacings when necessary. Research is being conducted on when the controller needs wake vortex information.

- What high-resolution data are required?

  3D wind measurements at a frequency of 10 Hertz over the region of interest are needed.

- What useful information do Local Area Augmentation System (LAAS) and Wide Area Augmentation System (WAAS) collect?

  Wind measurements may be useful. The WAAS and LAAS data do not go high enough above the surface.

22.
Advanced Airspace Concept

Dr. Heinz Erzberger, Mr. Russell Paielli
NASA Ames Research Center

A copy of Dr. Erzberger's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Erzberger and Mr. Paielli

Introduction, Goals, and Overview (Erzberger) (Slides 1 – 8)

The Advanced Airspace Concept (AAC) is applicable in all domains however, most work has been done so far in en route space. Goals are to double en route and non-final approach (TRACON) terminal airspace, over current separation standards, and increase landing rate by 20 percent, even without the wake vortex prediction improvements. Reduction of operational controller errors by 50 percent and a workload reduction can also be realized.

The Advanced Airspace Concept consists of a ground-based component, the Advanced Airspace Computer System (AACS). The AACS is essentially a fully developed center/TRACON automation system (CTAS) which generates conflict-free 4D trajectories and sends them to equipped aircraft via a data link. Pilots then use their flight management systems (FMS) to execute these trajectories. An independent ground-based system (tactical separation-assisted flight environment or TSAFE) checks for near-term conflicts and issues advisories (messages via data link) to maintain separation. TSAFE protects against primary ground system and FMS failures. The goal is for TSAFE to be relatively simple in algorithms and implementation, so as to facilitate certification of its safety and effectiveness. It will also monitor conformance of equipped aircraft to negotiated trajectories. Operationally, the AAC combines several conventional sectors into super sectors, in which controllers handle strategic tasks and unequipped aircraft, but are not responsible for separation assurance of equipped ones.

The 4D trajectory generator is a key component of the AACS. The AACS functions for en route airspace include issuing conflict resolution maneuver advisories that are specified as 4D trajectories, such as vertical plane maneuvers. The AACS will also issue trajectories and advisories for arrival metering, including path stretch maneuvers for time control through its Communication Manager component. In the terminal area, the AACS will issue messages for final approach spacing, similar to the final approach spacing tool (FAST), that include turn-to-base spacing control maneuvers and arrival/departure versus over-flight conflict resolution.

Key Ideas, Trajectory Specification, and TSAFE (Mr. Paielli) (Slides 9 – 11)

Aircraft will request a trajectory from the ground or submit a trajectory to the ground for approval. The ground will then check the submitted trajectory for conflicts within the next 30 minutes (parameter to be determined). If the submitted trajectory is free of conflicts for that period, the ground will approve the trajectory, otherwise the ground will modify the trajectory to remove the conflicts, then uplink it as the assigned trajectory. The aircraft will be able to submit a new trajectory for approval at any time, and the approval process will then be repeated. Automated ground-based conflict detection will issue amended trajectories to resolve conflicts, and that automated resolution will increase sector capacity and reduce operational errors. When necessary, the automated detection of trajectory non-conformance will hand the situation off to controllers.

4D trajectories with flight technical error tolerances will be assigned to aircraft. Parametric models need to be defined for all segment types: cruise, climb, descent, turn, etc. Along-track, cross-track, and vertical error tolerances need to be defined for each segment. Generally, these error tolerances will be specified based on required navigation performance (RNP) specifications; however, these could be relaxed in sparse traffic. Along-track error tolerances will be set to reduce the need for throttle control, and along-track assigned position will be updated periodically for the same reason. The idea is that throttle control should rarely be used en route except when a conflict is created by the actual current speed of the aircraft. National and international standards will be needed for trajectory specifications to promote flight management system (FMS) compatibility with ground systems. Development of these standards will not be easy, but is probably necessary.

For conforming equipped aircraft, the tactical separation-assisted flight environment (TSAFE) confirms that the trajectory assignments from AACS are conflict-free for the next 4 minutes (parameter to be determined) and monitors that each equipped aircraft is in conformance with its assigned trajectory. TSAFE detects and alerts aircraft for critical maneuvers and no-transgression zones. For non-conforming or unequipped aircraft, TSAFE detects imminent potential conflicts and generates resolution maneuvers/advisories and will also perform a hand-off to controllers, if necessary. This can be applied to today's system.

Evaluation Strategy and Conclusion (Slides 12 – 17)

The initial focus of airspace capacity evaluations is on en route transition airspace and the performance of conflict resolution algorithms. For this capacity evaluation, the AAC concept developers are assuming that controllers can be taken from their current role of separation assurance, and this responsibility can be automated. Non-real-time simulations will use ACES. Recorded live traffic from several high-density sectors in Cleveland (ZOB) airspace will be used. 4D trajectories and conflict lists will be generated as aircraft enter and depart airspace. A procedure-based algorithm will be used to generate conflict resolutions. Traffic densities will by gradually increased using the "cloning" method, until resolution rate exceeds a limit value.

Evaluations of TSAFE will include its effectiveness in detecting conflicts to prevent operational errors. For this, live traffic will be used with TSAFE running in shadow mode to predict loss of separation incidents. The short range (three-minute dead reckoning) conflict detection algorithms have been inserted into CTAS and recorded data from known incidents of operational error will be played back. Also, John Andrews at MIT Lincoln Labs will conduct an analysis of TSAFE's failure modes Finally, estimates of controller workload will be made. Kevin Corker, of San Jose State University, will be using the Air Man Machine Integration Design and Analysis System (Air-MIDAS) to do this work.

The AAC has the potential to increase capacity and reduce operational workload. The elements of the concept have been defined. TSAFE has the potential to reduce operational errors significantly and could be implemented as part of the Direct to Controller Tool (D2) Conflict Probe. The evaluation of this concept will be focused on determining capacity of en route transition airspace using non-real-time simulation.

Synopsis of Questions and Answers for Dr. Erzberger and Mr. Paielli

- Controllers don't like being put in the middle of a conflict "mess" (i.e., the TSAFE handoff situation). How will you make this acceptable to controllers?

  They'll get at least two minutes to address the situation before loss of separation occurs.

- A figure of four minutes was used to address the timeframe for TSAFE action. Is this four minutes to collision or loss of separation?

  Loss of separation.

- Have you changed your en route conflict resolution approach from algorithmic to heuristic?

  We think that a heuristic approach, that is, trying to mimic what a controller would do, gives us the best chance of being understood by the controller, without any complicated underlying algorithms. It still uses the underlying 4D trajectories to improve efficiencies, but how we select them mimics what we think a controller would do. This is much like what we've done for altitude in D2 today. The conflict detection algorithm is still algorithmic based.

- You mentioned changing the role of controllers to be more strategic in nature. How will the controllers react to put constraints on the 4D trajectory in the presence of weather?

  Either the AAC could develop 4D trajectories around a weather system automatically i.e., by the addition of a constraint, or it could be "guided" manually with the 4D generator doing the "dirty work." Regardless, each trajectory is generated and checked for conflicts.

- It seems like this concept could work in a jet-route structure or an free-flight environment. I can see how an overtake situation would work in free-flight. However, how would an overtake situation work in a jet-route situation?

  We're just concentrating on the main safety aspects to begin with, but we could add an "overtake" function later. This could involve use of change in altitude.

- Could you discuss your decision to "assign" trajectories to these equipped aircraft in light of the fact that they all have advanced flight management systems and they know more about the aircraft's flight parameters than the ground does.

  That is a good question. The aircraft could request its own fully specified trajectory, which would be down-linked, and if it were conflict-free for 20 minutes, it would be "assigned." The ground would also use vertical tracking and error parameters that will end up being tighter than those specified procedurally by controllers now, making the trajectory much more efficient. This requires establishing standards (national and international) for these trajectories, which will be a big deal. This is part of the "baggage" associated when all these other concepts say they need to have 4D trajectories. It was tried before, and died, but now maybe the time is right. Things are in place to make this more feasible now. We know about the undesirable effect of throttle control and to not specify the along-track error too precisely. We just track the time error and only do throttle control when we detect an otherwise unavoidable conflict.

23.
System-Wide Optimization of the NAS

Dr. Matt Jardin
NASA Ames Research Center

A copy of Mr. Jardin's presentation is attached as part of the appendix and is available on the Web at http://www.asc.nasa.gov/vams/.

Key Comments by Dr. Jardin

Problem Scope and Objectives (Slides 1 – 5)

The System-Wide Optimization (SWO) concept developers are focusing on developing key algorithms necessary for the system-wide optimization of the National Airspace System. Their objective is to develop a real-time method to optimize and de-conflict the trajectories of all aircraft in en route airspace. The quantitative goals of the SWO concept are:

- Reduce direct operating costs by 4.5%
- Save over 500 hours of flight time each day.
- Achieve potential savings of nearly $1 million per day ($360 million per year).
- Increase capacity while maintaining safety.

Core Ideas and High-Level System Concept (Slides 6 – 8)

The key algorithms necessary for system-wide optimization of the National Airspace System that the SWO team is developing include:

- Sequential trajectory optimization and conflict resolution.
- Neighboring optimal wind routing (NOWR).
- A conflict grid for conflict detection.

Another algorithm they are developing that was not described at this meeting is enhanced 4D flight plans. Real-time re-optimization is required for large disturbance mitigation.

Core Idea Descriptions (Slides 9 – 11)

The concept developers noted that sequential optimization is possible because the airspace is sparsely occupied. Wind optimal routes were shown to be significantly different from great circle routes. The details for the NOWR algorithm can be found in the reference shown in Slide 11.

Analysis and Simulation Results (Slides 12 – 26)

The Future ATM Concepts Evaluation Tool (FACET) was used to calculate wind optimal routes. In one example (New York to San Francisco), the NOWR algorithm saved 20 minutes and in another example (Miami to Seattle) the NOWR algorithm saved 7.2 minutes. Dynamic programming was used to evaluate the performance of the NOWR algorithm. NOWR solutions were achieved in 40 milliseconds, and were within 0.25 percent of the true optimum solutions. The NOWR performance results are shown in Slide 15.

A conflict grid and a conflict resolution algorithm are used to identify and resolve conflicts for sequential optimization of trajectories. The concept developer's results can be demonstrated using system simulation. In addition, Slide 26 shows a calculation of how much airspace capacity can be increased by decreasing aircraft separation limits.

Scenario Development (Slides 27 – 28)

Real air traffic data were used to generate realistic simulated air traffic data. The procedure is presented in Slides 27 and 28.

Roadmap and Conclusion (Slide 29 – 30)

The roadmap the concept developers will use to go from a 2D simulation to a 3D simulation and increase the fidelity of the simulations is shown on Slide 29. They have developed and demonstrated the basic 2D algorithms to date.

Synopsis of Questions and Answers for Dr. Jardin

- What about mismatches in schedule due to a strong jet stream?

  An ideal system would re-optimize the routes based on new wind information. They need to look at scheduling.

- What is the difference between your optimized routes and those calculated by the airlines?

  Airlines do not consider all routes because of constraints in the present system. In a free-flight environment, too much time would be required for the airlines to compute optimal routes using their current methods.

- Is the time difference you showed in your slides due to a difference in the airline following a jet route rather than using free-flight?

  This is a fair statement. However, wind optimal routes can change dramatically over six hours and this would affect results. In the example shown, the filed flight plan was nearly wind optimal, but because of the significant time variation in optimal routes, filed flight plans might end up being significantly sub-optimal. Regular updates in the flight plans are required to take advantage of updated wind information.

24.
Next Steps and Preview of TIM #4

Mr. Harry Swenson
NASA Ames Research Center

There was no presentation material for Mr. Swenson's closing remarks.

Key Comments by Mr. Swenson

- The future demand report will be distributed, sometime after the end of January.
- Team meetings will continue on Thursday, January 16, to address issues.
- TIM 4 will be August 19–21, 2003. There were timing issues that drove the date.
- The focus of TIM 4 will be the following issues:
  - Concept self-assessments.
  - ACES Build 1, its initial use, and lessons learned.
  - ACES Build 2 status.
  - System Evaluation and Assessment (SEA) evaluation prioritization—which concepts will be evaluated first and how will they be evaluated.

Synopsis of Questions and Answers for Mr. Swenson

There were no questions for Mr. Swenson from the TIM participants.

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Appendix A
VAMS Project Acronyms

Acronym	Definition
AAC	Advanced Airspace Concept
AACS	Automated Airspace Computer System
AATT	Advanced Air Transportation Technologies
ACES	Airspace Concept Evaluation System
ADS-B	Automatic Dependent Surveillance-Broadcast
AOC	Airline Operations Center
AOL	Airspace Operations Lab
AOP	Advanced Operations Planner
AQSP	Airline Service Quality Performance (ASQP) data contains reported delays by segment of flight.
ARC	Ames Research Center
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATL	Atlanta Hartsfield International Airport
ATM	Air Traffic Management
ATSP	Air Traffic Service Provider
AVOSS	Aircraft Vortex Spacing System
CAP	Collaborative Arrival Planning
CD&R	Conflict Detection and Resolution
CDE	Collaborative Development Environment
CDR	Critical Design Review or Coded Departure Route
CDTI	Cockpit Display of Traffic
CNS	Communications, Navigation, and Surveillance
CONOPS	Concept of Operations
CPDLC	Controller-Pilot Data Link Communications
CPTP	Conflict Prediction and Trial Planning
CTAS	Center/TRACON Automation System
CTOC	Centralized Terminal Operation Control
CVSRF	Crew Vehicle Systems Research Facility
D2	Direct-to-Controller Tool
DAG-TM	Distributed Air Ground—Traffic Management described on http://human-factors.arc.nasa.gov/ihh/DAG_WEB/intro.html
DFW	Dallas/Fort Worth Airport
DoD	Department of Defense
DST	Decision Support Tool
ETA	Estimated Time of Arrival

Acronym	Definition
ETMS	Enhanced Traffic Management System
FACET	Future ATM Concepts Evaluation Tool
FARGO	Flightcheck Automation Reliable Ground Operation
FAST	Final Approach Spacing Tool, a modified version of TMA
FASTE-CNS	Future Aeronautical Subnet Traffic Emulator for Communications, Navigation, and Surveillance
FD	Flight Deck
FF	Free Flight
FFC	Future Flight Central
FMS	Flight Management System
FT	Fast Time
GA	General Aviation
GDP	Ground Delay Program
GO-SAFE	Ground-Operation Situation Awareness and Flow Efficiency
HITL	Human in the Loop
HLA	High-Level Architecture
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
ITWS	Integrated Terminal Weather System provides accurate, easy-to-use storm and wind forecasts that allow aircraft controllers to make better decisions.
LAAS	Local Area Augmentation System
LaRC	Langley Research Center
LAX	Las Angles International Airport
LMI	Logistics Management Institute
MDCRS	ARINC's Meteorological Data Collection and Reporting System (MDCRS) is designed to support improved weather forecasting, particularly for upper-air wind and severe weather.
MEANS	MIT Extensible Air Network Simulation
MIDAS	Man Machine Integration Design and Analysis System
MSP	Minneapolis-St. Paul International Airport
MSSR	Mono-pulse Secondary Surveillance Radar
NAS	National Airspace System
NOWR	Neighboring Optimal Wind Rating
NRT	Non-Real Time
NTX	North Texas Research Station
OAK	Oakland International Airport
ORD/ZAU	Chicago O'Hare International Airport and the Chicago ARTCC
PAS	Pseudo Aircraft Simulator
pFAST	Passive Final Approach Spacing Tool
PIREP	Pilot-REPorted Weather Data

Acronym	Definition
PTP	Point To Point
R&D	Research and Development
RNP	Regional Navigation Performance
RT	Real Time
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
RTI	Run-Time Interface
RTSP	Required Total System Performance
SATS	Small Aircraft Transportation System
SBIR	Small Business Innovative Research—a grant from the federal government to a small business
SEA	Systems Evaluation and Assessment
SFO	San Francisco International Airport
SJC	San Jose (California) International Airport
SLIC	System-Level Integrated Concepts
SMS	Surface Management System
SOAR	Surface Operation Automation Research
STL	St. Louis International Airport, Lambert Field
SWA	Southwest Airlines
TACEC	Terminal Area Capacity Enhancement Concept
TFM	Traffic Flow Management
TIM	Technical Interchange Meeting
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control
TSAFE	Tactical Separation-Assisted Flight Environment
UA	United Airlines
VAMS	Virtual Airspace Modeling and Simulation
VAST	Virtual Airspace Simulation Technologies
VDL	VHF Data Link
VFR	Visual Flight Rules
WAAS	Wide Area Augmentation System
WAKE VAS	Wake Vortex Avoidance System
ZLA	Los Angeles ARTCC
ZOB	Cleveland ARTCC

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Appendix B
List of Attendees

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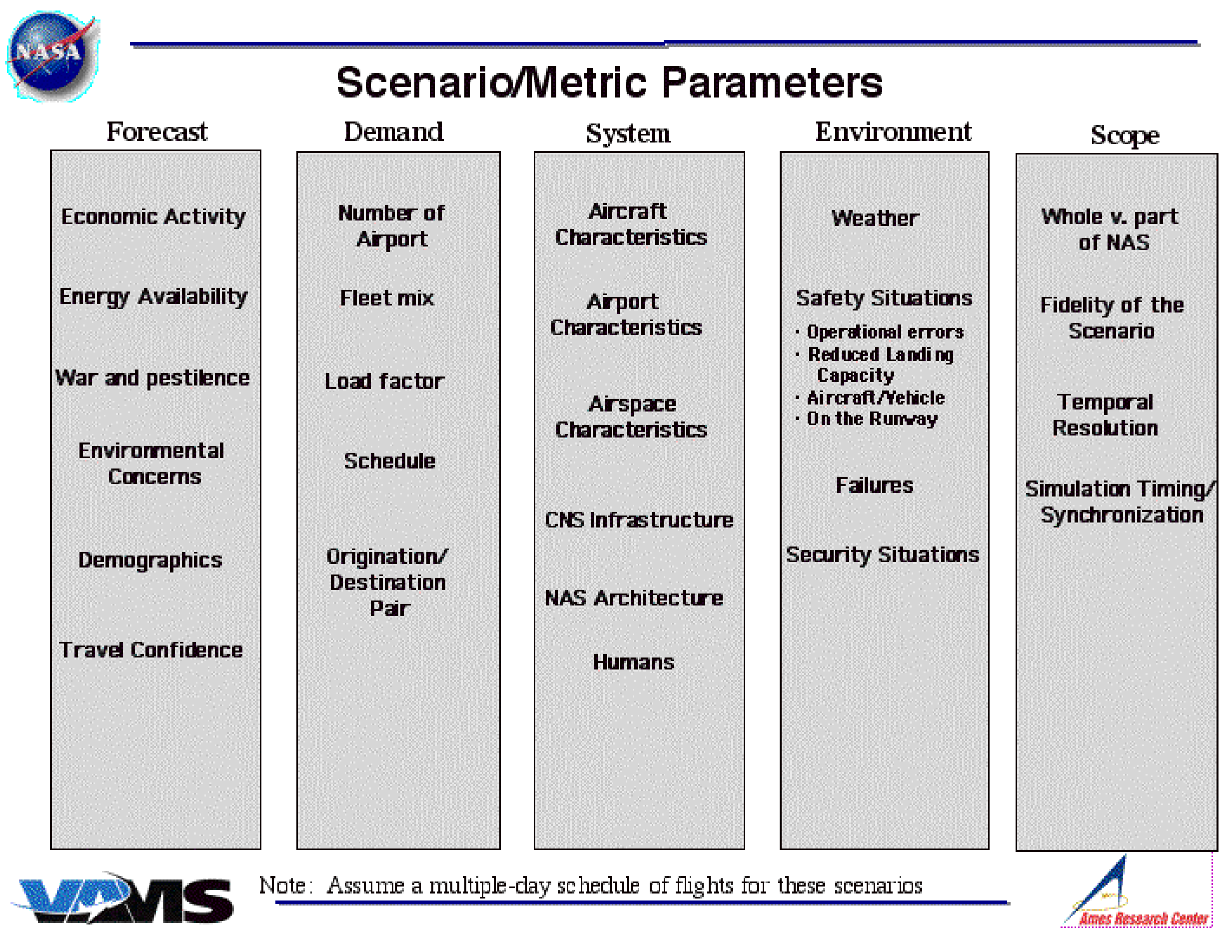
John	Cavolowsky	NASA Ames Research Center	(650) 604-4434
Chun-Hung	Chen	George Mason University	(215) 898-3967
Victor	Cheng	Optimal Synthesis	(650) 210-8282
Jesse	Clayton	Metron Aviation, Inc.	(703) 234-0753
Thomas	Cochrane	Raytheon ITSS	(650) 604-1376
Kevin	Corker	San Jose State University	(408) 275-8231
George	Couluris	Seagull Technology, Inc.	(408) 364-8200
Russ	Cusimano	ePM LLC	(916) 635-9572
Rod	David	NASA Ames Research Center	(650) 604-5040
Carl	Dean	Boeing ATM	(703) 714-1143
Victoriana	Delossantos	Raytheon ITSS	(650) 604-2857
Dallas	Denery	NASA Ames Research Center	(650) 604-5427
George	Donohue	George Mason University	(703) 993-3359
Michael	Downs	Raytheon ITSS	(650) 604-3801
Shawn	Engelland	NASA Ames Research Center	(817) 858-7634
Heinz	Erzberger	NASA Ames Research Center	(650) 604-5425
David	Felio	Geneva Aerospace	(972) 317-3122
John	Fergus	Northrop Grumman IT	(817) 354-4335
Robert	Fong	NASA Ames Research Center	(650) 604-3779
John	Foster	Northrop Grumman IT	
David	Foyle	NASA Ames Research Center	(650) 604-3053
Nazaret	Galeon	Dichroma, Inc.	(650) 604-2014

Shon	Grabbe	NASA Ames Research Center	(650) 604-1746
Melinda	Gratteau	Raytheon ITSS	(650) 604-2808
John	Griffin	NASA Ames Research Center	(650) 604-5447
Susan	Hinton	Raytheon ITSS	(650) 604-0167
Becky	Hooey	Monterey Technologies, Inc.	(650) 604-2399
Alex	Huang	Seagull Technology	(408) 364-8200
George	Hunter	Seagull Technology, Inc.	(530) 677-2046
Carla	Ingram	Northrop Grumman IT	(650) 604-3887
Earnest	Inn	Northrop Grumman/Logicon	(650) 604-3249
Douglas	Isaacson	NASA Ames Research Center	(650) 604-0874
Mike	Jackson	Honeywell	(612) 951-7748
Kevin	James	NASA Ames Research Center	(650) 604-0178
David	Jara	San Jose State University	(650) 604-6282
Matthew	Jardin	NASA Ames Research Center	(650) 604-0724
Richard	Jehlen	Federal Aviation Administration	(202) 493-4257
Yoon	Jung	NASA Ames Research Center	(650) 604-4796
Randall	Kelley	Seagull Technology	(303) 755-6136
Rod	Ketchum	FAA ACB-100	(650) 604-3072
Brian	Kiger	Seagull Technology, Inc.	(408) 364-8200
Edmund	Koenke	Genasys, Inc.	(609) 625-7266
Parimal	Kopardekar	Federal Aviation Administration	(650) 604-2782
Jimmy	Krozel	Metron Aviation, Inc.	(503) 274-8316
Andrew	Lacher	The MITRE Corporation	(703) 883-7812
Ronald	Lehmer	Northrop Grumman IT	(650) 604-4677
Diana	Liang	Federal Aviation Administration	(202) 385-7254
Sandra	Lozito	NASA Ames Research Center	(650) 604-0008
Steven	Mainger	NASA Glenn Research Center	(216) 433-3548
Scott	Malsom	NASA Ames Research Center	(650) 604-1164
David	Maroney	The MITRE Corporation	(703) 883-7917
Lynne	Martin	San Jose State University	(650) 604-0648
Terran	Melconian	Massachusetts Institute of Technology	(617) 253-0993
P.K.	Menon	Optimal Synthesis	(650) 210-8282
Fred	Messina	Raytheon Company	(508) 490-3661
Larry	Meyn	NASA Ames Research Center	(650) 604-0222
Mary	Miller	Raytheon C^3I Systems	(508) 490-3660
Raymond	Miraflor	NASA Ames Research Center	(650) 604-0604
Martin	Mooij	San Jose State University	
Jeff	Morang	San Jose State University	
Thomas	Mulkerin	Mulkerin Associates, Inc.	(703) 644-5660
Monicarol	Nickelson	NASA Ames Research Center	(650) 604-0422

Lee	Olson	Federal Aviation Administration	(202) 267-7358
Russell	Paielli	NASA Ames Research Center	(650) 604-5454
Kee	Palopo	Raytheon ITSS	(640) 604-1379
Steve	Penny	Metron Aviation	(703) 234-0754
Jack	Perkins	USDOT/Volpe National Trans. Center	(617) 494-3431
James	Poage	USDOT/Volpe National Trans. Center	(617) 494-2371
Robert	Powers	NASA Langley Research Center	(757) 864-6483
Leighton	Quon	Northrop Grumman/Logicon	(650) 604-3073
John	Rekstad	Federal Aviation Administration	(202) 267-3011
Roger	Remington	NASA Ames Research Center	(650) 604-6243
Fernando	Rico-Cusi	NASA Langley Research Center	(757) 864-5206
Paul	Riedl	ePM, LLC	(480) 657-8956
Paul	Rigterink	Computer Sciences Corporation	(301) 921-3049
Tom	Romer	NASA Ames Research Center	(650) 604-6463
David	Rosen	Orbital Sciences	(650) 604-6267
Vernon	Rossow	NASA Ames Research Center	(650) 604-4570
Karlin	Roth	NASA Ames Research Center	(650) 604-6678
David	Rutishauser	NASA Langley Research Center	(757) 864-8696
Nicole Sacco	Racine	Titan Corporation	(609) 625-5669
David	Schleicher	Seagull Technology	(408) 364-8200
Bob	Schwab	Boeing Air Traffic Management	(425) 373-2522
Al	Schwartz	Federal Aviation Administration	(609) 485-4226
Barry	Scott	Federal Aviation Administration	(650) 604-6379
Henry	Sielski	Computer Sciences Corporation	(408) 752-9952
David	Signor	Seagull Technology	(408) 364-8219
Alvin	Sipe	The Boeing Company	(425) 373-2517
George	Skaliotis	USDOT/Volpe Center	(617) 494-2665
Phil	Smith	Ohio State University	(614) 292-4120
George	Solomos	The MITRE Corporation	(703) 883-5554
John	Sorensen	Seagull Technology, Inc.	(408) 364-8200
Edward	Stevens	Raytheon C3 Systems	(508) 490-2686
Douglas	Sweet	Seagull Technology	(408) 364-8237
Harry	Swenson	NASA Ames Research Center	(650) 604-5469
Leonard	Tobias	NASA Ames Research Center	(650) 604-5430
Mark	Triesch	ePM, LLC	(512) 470-2107
Earl	Van Landingham	Orbital Sciences, Inc.	(703) 222-8206
Matt	Vance	The Boeing Company	(703) 584-2727
Savita	Verma	San Jose State University	(650) 604-5718
Chris	Wargo	Computer Networks & Software, Inc.	(443) 994-6137
Earl	Wingrove	Logisitics Management Institute	(703) 917-7387

John	Wise	Honeywell	(604) 436-5536
Andres	Zellweger	NASA Headquarters	(202) 358-0544
Robert	Zimmerman	Raytheon ITSS	(650) 604-3656

Appendix C
Scenario and Metric Parameters



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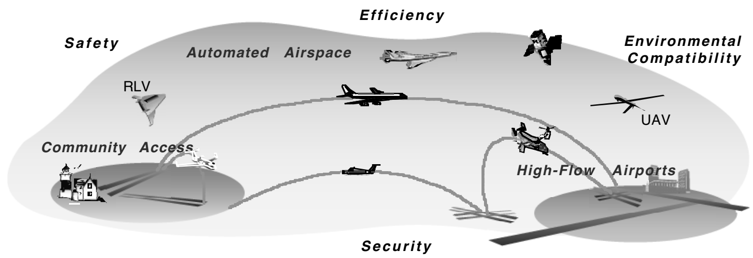
Appendix D
Presentations

VIRTUAL AIRSPACE MODELING AND SIMULATION PROJECT

Technical Interchange Meeting III



Harry N. Swenson
Project Manager
NASA Ames Research Center

January 14-15, 2003

Goal and Objectives

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

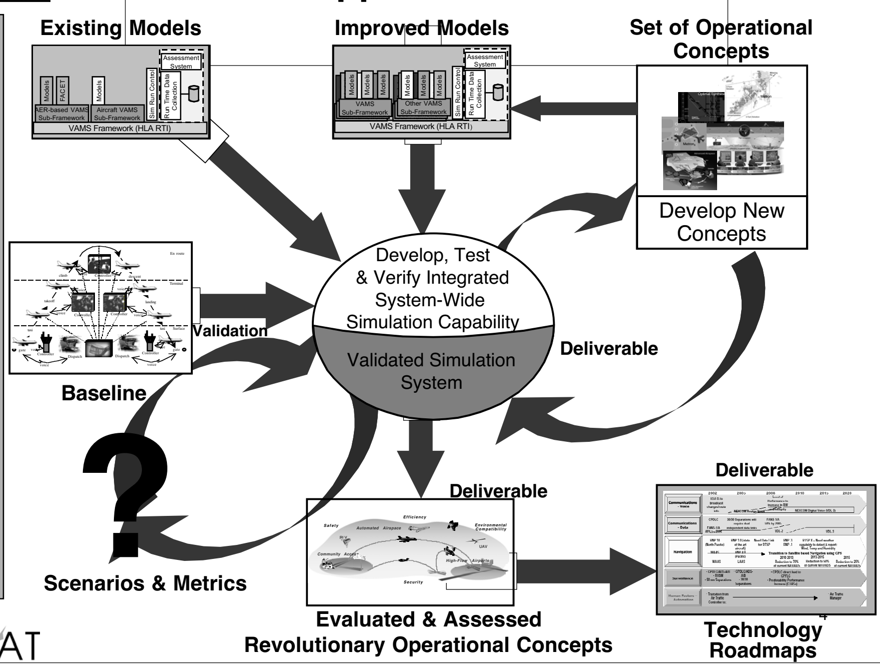
The VAMS Objectives are:

- **To define potential operational concepts.**
- **To generate supporting technology roadmaps.**
- **To establish the capability to assess these concepts.**

Deliverables / Products

- Evaluated advance airspace system concept(s).
  - Interim evaluations at domain and system level.
- Technology roadmap(s) to implement proposed concept(s).
  - Annual updates of roadmaps at domain or system level.
- Validated modeling and simulation capability to assess new operational concepts at the domain and system-wide level.
  - Annual builds of non-real-time modeling and simulation capability.
  - Annual updates of real-time simulation capability.

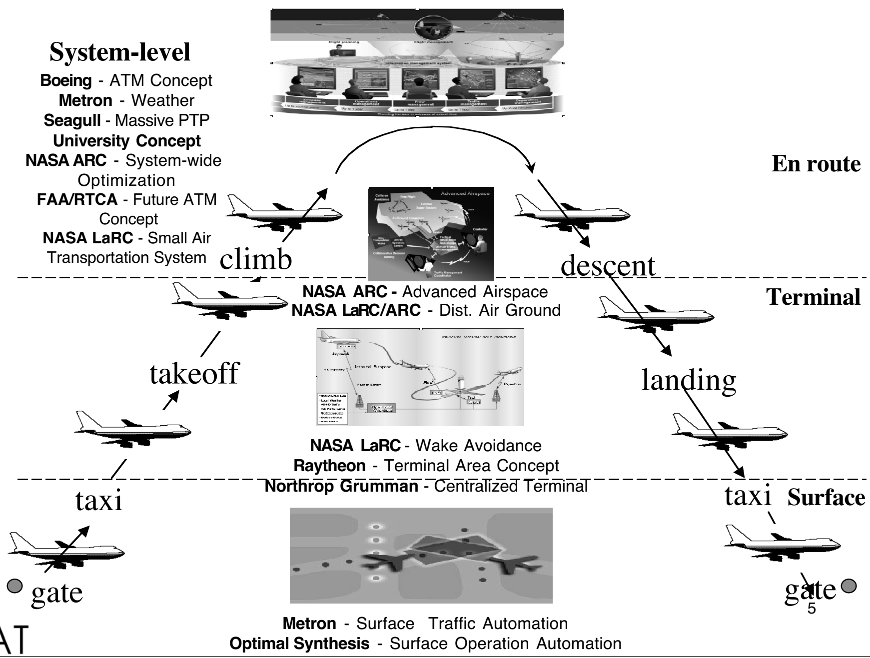
Approach



Operational Concepts Identified

VAMS

Virtual Airspace Modeling & Simulation - TIM III



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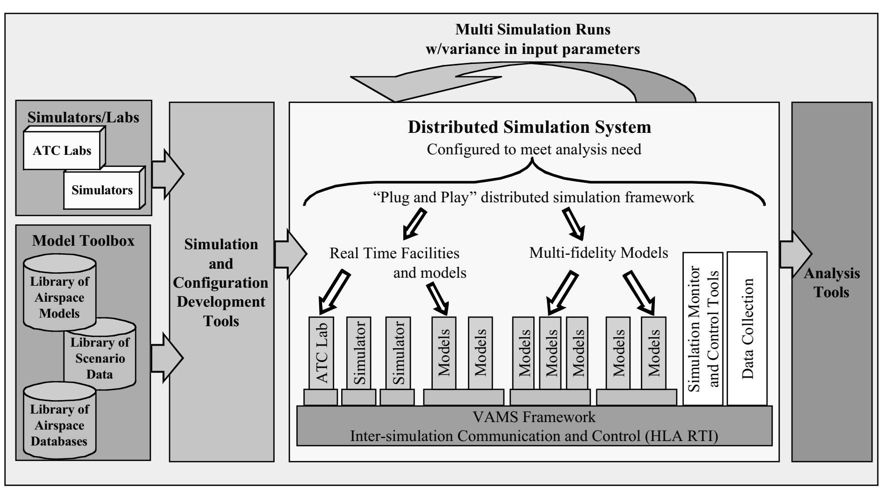
Modeling and Simulation Description

VAMS

Virtual Airspace Modeling & Simulation - TIM III



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Non-Real-Time System-Level Modeling and Simulation System Accomplishments

- *April 2002:* **Demonstrated a proof-of-concept prototype.**
  - –Selected the DoD's HLA-RTI infrastructure with agent-based software to enable fast-time NAS-wide simulation
  - –Established a modeling lab that leverages existing and emerging models and tools
- *February 2003:* **Proving the feasibility of the approach to capture the interactions between NAS entities.**
  - –The baseline system, Build-1 provides:
    - Architectural foundation
      - –Creates an agent infrastructure
      - –Develops a robust HLA framework
    - Basic modeling toolbox
      - –Emulates the current NAS
      - –Simulates NAS-wide, gate-to-gate at low-resolution
      - –Models entire day-in-the-NAS scenario
      - –Some emphasis on modeling TFM interactions
    - Assessments
      - –Measure delay (gate, taxi, airborne)
      - –Fuel costs
      - –Controller workload (# of vectors, speed changes, # TFM restrictions, CD&R activity)
      - –TFM activity
  - –Five software tests have been completed; each verifies a key feature of the simulation system.

Virtual Airspace Modeling & Simulation - TIM III

Real-Time Modeling and Simulation System Accomplishments

- *August 2002:* **Conducted Preliminary Design Review (PDR.)**
  - –Selected the DoD's HLA-RTI infrastructure with agent-based software
  - –Established a series of progressive Interim Tests to prove and deliver incremental operational simulation capabilities to the Project
- *November 2003:* **Interim Test #1provides the functionality approved in the PDR and establishes a firm baseline configuration for building the remainder of the VAST-RT simulation system,**
  - –The baseline system, Build-1 provides:
    - Architectural foundation
      - –HLA based infrastructure
      - –Robust multi-simulator capability
    - Version 1 of the data communication toolbox
      - –Emulates the current legacy systems
      - –Provides enhanced communications capabilities
  - –Four test scenarios have been completed; each verifying a key feature of the simulation system.

Scenario and Metric Framework

Stakeholder Viewpoints (questions to be answered) → operational scenarios

Stakeholder Viewpoints (questions to be answered) → evaluation metrics

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

1. Scope:
- •Issues
- •NAS Domain
- •Quantitative Goal

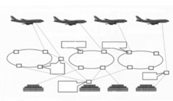
2. Top Level Descriptions:
- •Core ideas
- •Assumptions

3. Detailed Descriptions:
- •Performance
- •Functions
- •Human Performance

4. NAS infrastructure & Technology impacts:
- •Transition planning
- •Architecture
- •Technology requirements

5. NAS operational risks
- •Ensuring system integrity and redundancy
- •Security
- •Safety

6. Key Project Attributes
- •Benefits/metrics
- •Cost/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
- •Traveling public

Simulations

Empiric Analysis

Output 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
- •Noise
- •Environmental impact

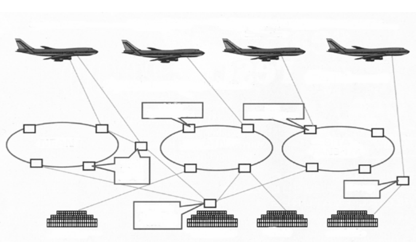
Evaluation metrics:
- •Average aircraft flight time per air route*
- •Average aircraft payload per flight mile
- •Operational cost per passenger mile
- •Average taxi time from pushback to wheels up during peak traffic periods per specific airports or taxi paths within airports
- •Average voice channel 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
- •Predictability

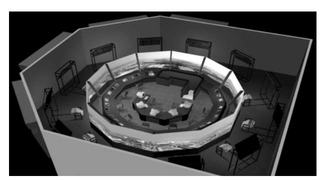
* a defined city pair air route

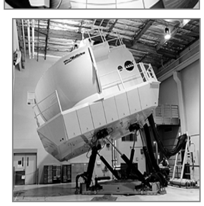
Evaluation and Assessment Accomplishments

Virtual Airspace Modeling & Simulation - TIM III

Develop Methods & Requirements







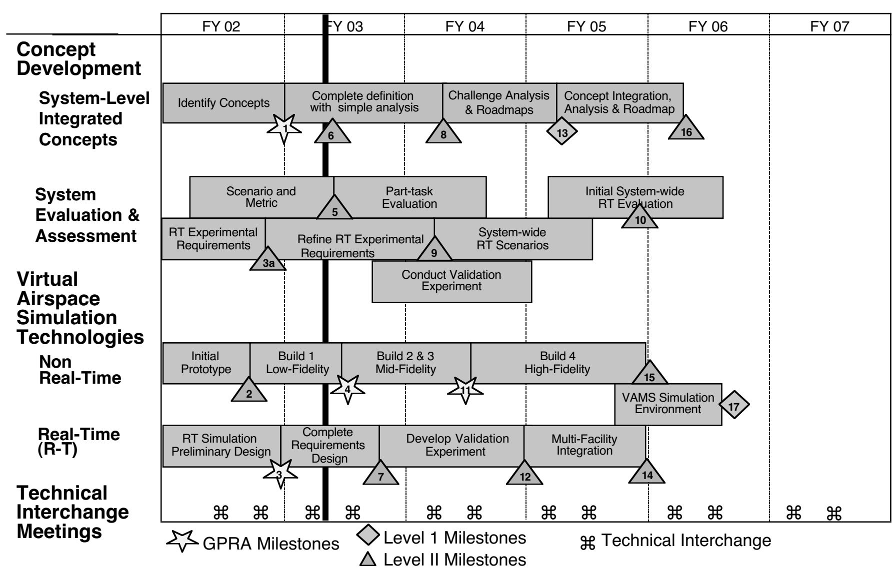
- **Requirements to support validation of the real-time capabilities**
  - **Facility requirements**
  - **Data collection requirements**
  - **Software agent requirements**
- **Delivered 6/28/02**

Evaluation and Assessment Accomplishments

- Economic Forecast and Demand (GRA,LMI)
  - Scenario Planning
    - GDP Growth (H/L), Airline Yields (H/L), Limits to Aviation System Growth (Many/Few), Substitutes to Commercial Air Travel (Good/Poor)
  - Five Scenarios pursued
- Non-Real Time Scenario and Metrics (VAMS Common Scenario Set)
  - Concept Analysis
  - Storyboards
  - Data Sources
  - Dependent Variables
  - Scenario Element Breakdown
  - Dependent Variable Calculations

AT

VAMS Schedule



AT

Project Milestones

1	"Identify candidate future ATS capacity-increasing operational concepts"	09/30/02
2	"Develop initial prototype VAST NRT airspace model toolbox w/system-level capabilities"	04/30/02
3A	"Complete definition of Initial Real-Time experimental requirements"	06/28/02
3	"Complete VAST RT environments definitions and preliminary design "	09/30/02
4	"Complete Build 1 VAST NRT state-of-the-art airspace models toolbox with the ability to assess economic impact of new technology and NAS operational performance and the ability to model the dynamic effects of interactive agents"	12/31/02
5	"Complete preliminary description of common scenario set & evaluation criteria for operational concept assessment"	01/01/03
6	"Complete operational concept and roadmaps for introducing Wake vortex avoidance into the Air Transportation System"	01/15/03
7	"Complete VAST Real-Time requirements and initial design"	06/30/03
8	"Complete self-evaluation of concepts and roadmaps"	02/13/04
9	"Complete definition of initial VAST Real-Time experiments"	04/30/04
10	"Complete preliminary evaluation of selected operational concepts (RT only)"	09/01/05
11	"Complete Build 3 VAST NRT toolbox with cognitive human performance attributes and CNS models"	08/30/04
12	"Complete verification of initial VAST RT capabilities against an AATT derived operational concept"	09/30/04
13	"Complete analysis and of capacity-increasing concepts and roadmaps w/VAST models, simulations & Common Scenario Set"	12/15/04
14	"Complete verification of VAST Real-Time Multi-Facility capabilities"	06/30/05
15	"Complete Build 4 VAST NRT toolbox for advanced operational concept analysis "	09/30/05
16	"Complete definition and analysis of single system-level operational concept and roadmap"	03/30/06
17	"Complete development of RT/NRT VAST simulation and modeling tools for Air Transportation System technology development"	06/30/06

Virtual Airspace Modeling and Simulation Project (VAMS)
Technical Interchange Meeting #3

Sandy Lozito
System Evaluation and Assessment (SEA) Lead
NASA Ames Research Center

VAMS TIM #3
Moffett Training and Conference Center
January 14 & 15, 2003

Outline

- TIM #3 Objectives
- Agenda
- Logistics

TIM Objectives

- Continue information exchange with VAMS participants
- Describe SEA Milestone 5 - Scenario and Metric Requirements
- Define and begin to address next steps for Milestone 5
- Updates on the SLIC concepts

TIM Agenda

PST	14-Jan Tuesday	15-Jan Wednesday
7:30	Facility opens	Facility opens
7:45	and	
8:00	Meeting Registration	Daily Agenda
8:15	NASA Greeting (Lozito)	Massive PTP On-Demand Air
8:30	Project Comments	Transportation Concept (Seagull)
8:45	(Swenson)	Capacity Increasing ATS Concept
9:00	TIM #3 Overview	(Boeing)
9:15	(Lozito)	All Weather Capacity Increasing
9:30	Scenarios and Metrics	Concept (Metron)
9:45	(Lozito)	Break
10:00	Break	
10:15		Surface Operation Automation
10:30	ATS Traffic Demand Modeling	Research (Optimal Synthesis)
10:45	(Cavolowsky, Wingrove	Automated Surface Traffic
11:00	and Ballard)	Control (Metron)
11:15		Centralized Terminal Operation
11:30	SEA Scenario Analysis	Control (Northrop Grumman)
11:45	(J. Perkins)	
Noon		Catered Lunch
12:15	Catered Lunch	in Patio Room
12:30	in Patio Room	
12:45		
1:00		University Concepts
1:15	SEA Metric Analysis	(A. Zellweger)
1:30	(J. Poage)	Terminal Area Capacity Enhancing
1:45	SEA Human Performance	Concept (Raytheon)
2:00	Analysis	Wake Vortex Avoidance Concept
2:15	(K. Corker)	(NASA Langley Res. Ctr.)
2:30	Scenario Data Sources	CNS Load Analysis Tool (Wargo)
2:45	(B. Kiger)	Break
3:00	Break	Advanced Airspace System
3:15	VAST Non-Real-Time Modeling	Concept (NASA Ames Res. Ctr.)
3:30	(L. Meyn, S. Grabbe,	System-Wide Optimization
3:45	S. Engelland, and T. Melconian)	(NASA Ames Res. Ctr.)
4:00		EXTRA
4:15	VAST Real-Time Capability 1	
4:30	(S. Malsom)	Next Step and
4:45	Wrap-up	Preview of TIM #4
5:00		

TIM Logistics

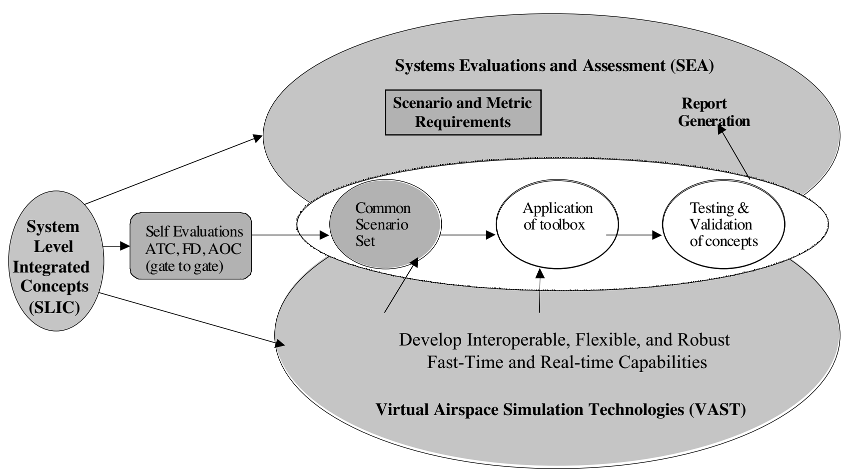
- Phone Calls
  Messages can be left at (650) 604-2926 or 604-2082
- Computing
  Macintosh computers and hookups for laptops are available for your use in the Fireside area.
- Refreshments & Registration
- Restrooms
  Located on the right side of the ballroom and on your left just as you pass the registration area.

Systems Evaluation and Assessment (SEA) Sub-Element

Common Scenarios and Metrics Requirements
Milestone 5 Deliverable

Sandy Lozito
Level 3 Manager
Systems Evaluation and Assessment Element

System Evaluation and Assessment Relationship between the Sub elements



System Evaluation and Assessment General Tasks

- Develop scenarios and metrics for evaluation of the SLIC concepts
- Conduct an initial validation assessment of the VAST real-time tools
- Conduct an initial assessment of the selected concepts
- Conduct an initial assessment of the integrated concepts
- Conduct the final evaluation of the integrated concept(s) using the VAST tools

Scenarios/Metrics

- Scenarios and Metrics will be used to help evaluate the concepts from VAMS/System-Level Integrated Concepts
  - Initial evaluation of concepts will be self-evaluation
  - The scenarios/metrics for self-evaluation will be used to assist the SEA scenario/metric development
- There can be many scenarios and metrics, but ultimately they must be applicable for broad evaluations
  - Scenarios addressing multiple airspace domain and concepts addressing more specific domains
  - Scenarios addressing multiple parts of the triad (AOC/ATC/FD)

Scenario Requirements

- Scenarios are necessary for the evaluation of the "capacity-increasing" concepts
- Scenarios must test the concepts' ability to increase capacity and maintain (or increase) safety
- Scenarios must cover all domains (e.g., surface, terminal, enroute)
- Scenarios must consider normal and non-normal events
- Scenarios must cover real-time and fast-time testing
- Scenarios must test all parts of the NAS triad: AOC, ATC, flight deck
- Scenarios must be able to test both single-domain concepts and more broad concepts
- SEA is writing the requirements for the scenarios

Documents in MS5
Scenario and Metric Requirements

- Introduction
- Forecast and Demand
- Common Scenario and Metric Set
  - Evaluation questions
  - Scenario Elements
  - Metrics
  - Dependent variables
- Concept Evaluations
- Storyboard (only two concepts)
  - Point-to-Point (Seagull)
  - Surface Operations Automation Research (Optimal Synthesis)
- Data Sources
- Dependent Variables Calculations
- Scenario Elements Breakdown

Source Materials for MS5

- Concept descriptions from concept developers
- Scenario descriptions from concept developers
- Interviews with many concept developers
- Logistics Management Institute
- FAA's Operational Evolution Plan Metrics
- Research papers relevant to concepts
- Concept development matrix

Scenario/Metric Parameters

Forecast	Demand	System	Environment	Scope
Economic Activity	Number of Airport	Aircraft Characteristics	Weather	Whole v. part of NAS
Energy Availability	Fleet mix	Airport Characteristics	Safety Situations • Operational errors • Reduced Landing Capacity • Aircraft/Vehicle On the Runway	Fidelity of the Scenario
War and pestilence	Load factor	Airspace Characteristics	Failures	Temporal Resolution
Environmental Concerns	Schedule	CNS Infrastructure	Security Situations	Simulation Timing/ Synchronization
Demographics	Origination/ Destination Pair	NAS Architecture		
Travel Confidence		Humans		

Note: Assume a multiple-day schedule of flights for these scenarios

Summary of the Milestone 5 Documents (1)

- Scenario/metric framework
  - Common questions/issues for the concepts
  - Common set of metrics
- Concept analyses
  - Details related to the scenario and metric framework
  - Separate analyses for each of the eleven VAMS concepts
- Storyboards (2 examples)
  - Development details necessary to create a simulation for concept investigation
  - One example appropriate for real-time simulation development (SOAR)
  - One example appropriate for fast-time simulation development (PTP)

Summary of the Milestone 5 Documents (continued)

- Dependent Variables
  - Specific metrics and measures for real/fast time simulation
  - Variables relevant to concept assessment
- Dependent Variable Calculations
  - Recommended calculations for determination of various metrics (e.g. capacity calculations, workload calculations)
  - Metric calculations from various sources, including OEP, SLIC element, etc.
- Forecast/Demand Data
  - Forecast and demand data used within the Program/Project
  - Assumptions about economy, aircraft type, etc.
  - Provided by LMI

Summary of the Milestone 5 Documents (continued)

- Data Sources
  - Sources of reference data for scenario development and use
  - Weather data, air traffic management data, etc.
- Scenario Element Breakdowns
  - Provide further information about detailed scenario elements necessary for concept assessment
  - Guidance for development and prioritization of scenario characteristics

Next Steps

- Feedback from concept developers regarding their concept analysis
  - Accuracy of information
  - Level of detail
  - Format preferences
- Feedback from VAMS 0ffice
  - Development capabilities
  - Level of detail
- Prioritization
  - Prioritize requirements based on concept developer's feedback and VAMS Project Office feedback

VAMS Ames Research Center

Scenario-Based Traffic Demand Modeling

Technical Interchange Meeting
January 14-15, 2003

Earl Wingrove
David Ballard

PROJECT BACKGROUND AND OBJECTIVE

Background

- The NASA Aeronautics research program has increased its emphasis on air traffic management (ATM) technologies in response to heightened national needs.
- NASA is considering programs to develop technologies for an advanced national airspace system (NAS).
- However, it is necessary to have a solid understanding of the broader economic environment in which those technologies will operate.

Objective

- A more complete understanding of the potential environments in which NASA research will operate enables solutions that are robust under a wide variety of conditions.

BRIEFING OUTLINE

- ✈Research Activity 1: Describe economic impacts of air transportation
- ✈Research Activity 2: Generate operational scenarios for the year 2022
- ✈Research Activity 3: Translate operational scenarios into airport-level demands

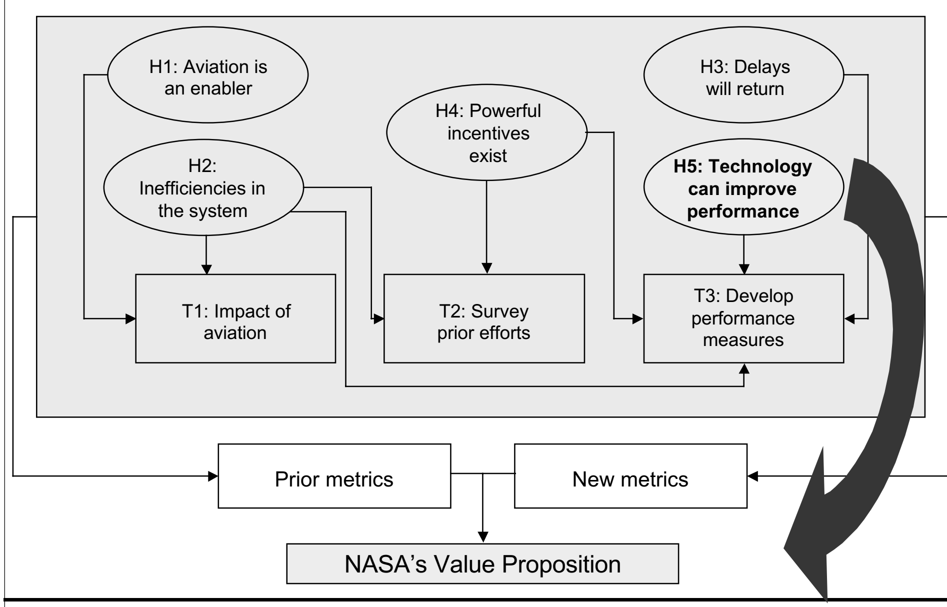
RESEARCH ACTIVITY ONE

- ✈ Describe the current state of knowledge on the relationship between transportation and the economy and how that affects the NASA air transportation research program:
  - ✈ T1: Articulate what air transportation means within the nation's economy and why its continued vitality should be a national priority
  - ✈ T2: Survey prior efforts to capture the incremental value of aviation in the economy
  - ✈ T3: Develop performance measures for policy makers, consumers of aviation, and associated industries (e.g., service providers) that track development of air transportation technologies

FRAMEWORK FOR ANALYSIS – PRINCIPAL HYPOTHESES

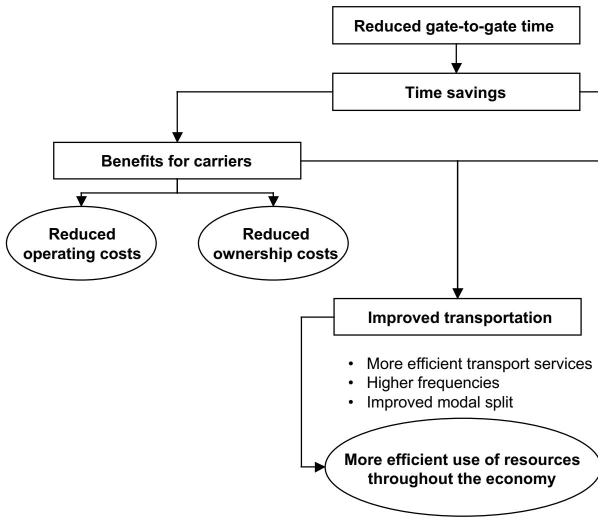
- **H1: Air transportation is an enabler of economic activity**
  - People and goods rely on aviation to realize economic benefits
  - Aerospace and associated industries generate significant economic output
- **H2: The aviation system is marked by implicit/explicit inefficiency**
  - ATC, security, other delays are costly
  - Hubs dominate as a proportion of overall enplanements
- **H3: In spite of current doldrums, delays will return**
  - Passenger and cargo growth will rebound
  - Existing technology will again be stretched
  - Competition, particularly from low-cost carriers, will intensify
  - Impact of new security measures on operations remains largely unknown
- **H4: New solutions must be consistent with incentives that govern**
  - Producers (controllers, pilots, airports, technology providers [NASA, Boeing, Lockheed, Raytheon, etc.])
  - Consumers (passengers, shippers, air carriers, policy makers)
  - "Perfect" solutions are not achievable – there are always trade-offs
- **H5: Technology can improve system performance**
  - NASA produces technology
  - To identify and measure improvement, there must be consensus on metrics

CONCEPTUAL LINKAGES IN RESEARCH ACTIVITY ONE



TECHNOLOGY CAN IMPROVE PERFORMANCE

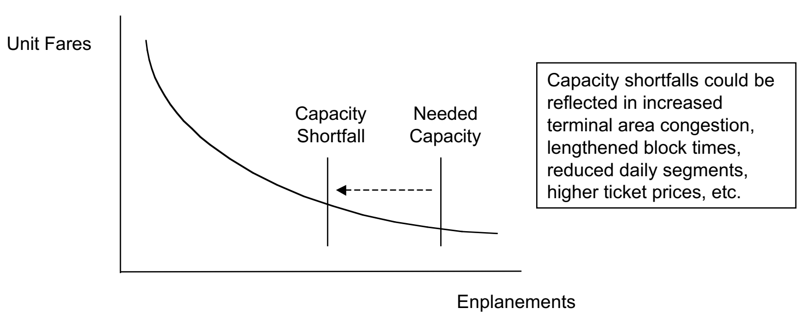
✈ Increased capacity in the NAS is a common aim of key system stakeholders that will benefit passengers and operators.



NASA'S VALUE PROPOSITION

✈ NASA will confirm its value proposition by demonstrating that its technologies add value for key industry stakeholders.

✈ For example, air carriers, airports, and passengers want to avoid the following scenario, which may be caused by a shortfall in NAS capacity.



✈ Inadequate capacity and rising fares would constrict demand, lowering enplanements and reducing gross revenues.

✈ A 2002 DRI-WEFA study of the economic impacts of US civil aviation estimates delay costs for year 2000 commercial passenger operations at $9.4 billion.

METRICS ARE KEY

- ✈ While NASA's products, once implemented, will affect numerous stakeholder groups, FAA is the principal customer.
- ✈ Therefore, the impacts of NASA products should be gauged by FAA's metrics for improved NAS performance.
- ✈ Three broad areas of NAS performance can be improved by NASA's tools and techniques:
  - ✈ Supply/Demand – availability/efficiency of airspace in terminal and en route areas
  - ✈ Operational – efficiency/optimization of airline and general aviation movements
  - ✈ Fiscal – asset utilization/cost performance for key NAS stakeholders

RESEARCH ACTIVITY TWO

- ✈ Review the previous scenarios developed for NASA by the National Research Council ("Scenario-Based Strategic Planning for NASA's Aeronautics Enterprise"), and revise, update, and expand them as required to reflect current and future conditions. In particular, emphasis will be placed on developing operational scenarios against which future NASA technologies can be evaluated.

WHY SCENARIO-BASED PLANNING?

- The future is not simply a point estimate for a small set of variables, especially for longer-term assessments
- Want plans and planning tools that are "robust" to plausible variability in operating environments
- Even firm micro linkages between drivers of future become weaker with longer forecast horizons
- For longer-term planning (forecast horizon is 2022)
- Contingency planning
- Handling and characterizing complexity

FUNDAMENTAL ELEMENTS

- Define scenario space
  - Select drivers/constraints
- Determine base or starting values (not necessarily drivers)
  - GDP and traffic response
  - Pricing and traffic response
  - Input prices
- Determine constraints on future opportunities
  - Infrastructure
  - Substitutes
- Combinations/Number of scenarios
  - Number of drivers/constraints (N)
  - Number of values for each (M)
  - Number of scenarios (M^N)
- Drivers of scenarios need not be parameters of greatest analytic interest

THE FOUR SCENARIO DRIVERS

Four parameters used to develop scenarios:

- ✈ **GDP Growth**—High or low: Recognizes that economic growth drives air travel; driven by population and productivity
- ✈ **Airline Yields**—High or low: Yields are fare per mile; high fares mean industry is profitable and can attract investment for modernization; low fares stimulate consumer demand, all other factors equal; driven by demand/capacity balance, industry structure and government regulation
- ✈ **Limits to Aviation System Growth**—Many or few: Barriers limit ability to expand at moderate costs; driven by noise and emissions rules, ATC and airport capacity, airport access, security requirements, etc.
- ✈ **Substitutes to Commercial Air Travel**—Good or poor: More attractive substitutes serve to discipline prices and reduce demand for commercial air travel, while poorer substitutes provide pricing power to carriers, other things equal; includes aviation and non-aviation substitutes

SCENARIO MATRIX

Scenario	GDP Growth	Airline Yields	Limits to Aviation System Growth	Substitutes to Commercial Air Travel	Probability
Economic growth/ Airlines recover	***high***	***high***	***many***	***poor***	***20%***
Economic growth/ Consumer rules	high	low	few	poor	10%
Substitutes take share	high	low	many	good	15%
Growth limits prevail	low	high	many	poor	15%
Low Cost Carriers dominate	***low***	***low***	***few***	***good***	***20%***
Three other plausible scenarios	N/A	N/A	N/A	N/A	20%

Note: Probabilities represent LMI/GRA consensus. While a total of 16 scenarios are possible, eight of them were regarded as implausible. Of the remainder, five scenarios were regarded as likely and were analyzed further.

FORECAST BASELINES

Recovery reaches year 2000 levels:
- ✈ Domestic passenger 2004
- ✈ International passenger 2003
- ✈ Domestic cargo 2004
- ✈ International cargo 2004
- ✈ GA passenger miles 2005

Short-haul impacted more:
- ✈ Longer average stage lengths
- ✈ More RPMs/Op (fewer SH operations)

Parameter	Base Value
Domestic passenger RPMs	513 B
Type of domestic network	Hub-Spoke
International passenger RPMs	181 B
Domestic cargo RTMs*	14.7 B
International cargo RTMs*	14.5 B
Belly vs. all cargo split	
Domestic cargo	30/70
International cargo	50/50
GA passenger miles** (@ 65% LF)	13.9 B
Single-engine	2.9 B
Multi-engine	4.4 B
Jet-engine	6.6 B

* Includes freight/express and mail
**Includes fractionals

ESTIMATING GROWTH IN AVIATION TRANSPORT SERVICES

Principal drivers of commercial aviation activity are:
- ✈ Real GDP annual growth (between 2.3% and 6.3% over 18-year periods)
- ✈ Fares/yields, which have been at historically low levels for a year

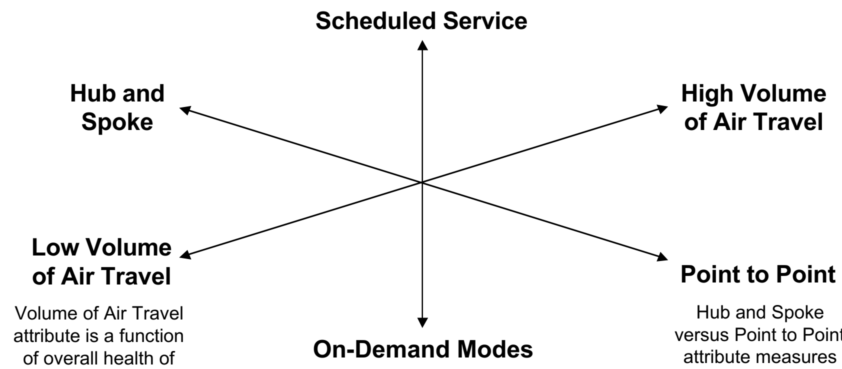
Aviation activity responds:
- ✈ Positively to increases in the GDP growth rate (income elasticity of 1.25)
- ✈ Negatively to increases in yields (price elasticity of –0.75)

Other factors – limits to system growth and quality of substitutes – may constrain growth

To estimate domestic passenger growth rates in each scenario:
- ✈ GDP growth set at “high” value of 4.0% or “low” value of 2.5%
- ✈ Yield changes set at “high” value of 0.5% annual growth or “low” value of –0.1%
- ✈ Include growth-retarding effects of system growth limits or effective substitutes if present in scenario (subtract 0.5% for each constraint)
- ✈ Other market sectors have grown more rapidly than domestic passenger sector

To estimate GA activity, extrapolate from past flight hour and load factor data, using trends in vehicle size and engine type, plus GA share of domestic passenger miles

COMPONENTS OF FUTURE COMMERCIAL AVIATION INDUSTRY STRUCTURE



Volume of Air Travel attribute is a function of overall health of economy, demographic trends, security issues, and relative attractiveness of competing surface modes

Scheduled versus On-Demand attribute measures the degree to which scheduled air carriers satisfy air travel demand relative to personal and corporate GA aircraft

Hub and Spoke versus Point to Point attribute measures the degree to which passengers travel directly from their true origin to their true destination

"ECONOMIC GROWTH/AIRLINES RECOVER"

Description

- ✈ High GDP growth, coupled with many limits to aviation system growth and poor substitutes for commercial services, implies that airlines will be able to raise fares (yields). This scenario, although not the one with the highest level of traffic growth, is perhaps the most favorable for the major network carriers.

Level of Growth in Traffic

- ✈ Tracks GDP growth closely

Locus of Growth:

- ✈ Further growth in hub and spoke system
- ✈ Growth by LCCs and others serving low yield sectors at secondary airports

New Systems:

- ✈ On-demand modes do not improve relative to scheduled service

SCENARIO GROWTH RATES FOR "ECONOMIC GROWTH/AIRLINES RECOVER"

Parameter	Average Annual Growth Rate	2022 Value
Domestic passenger RPMs	4.1%	1,056 B
Type of domestic network		Hub-Spoke continues
International passenger RPMs	5.5%	500 B
Domestic cargo RTMs	5.5%	38.5 B
International cargo RTMs	6.0%	41.4 B
Belly vs. all cargo split		
Domestic cargo		25/75
International cargo		50/50
Total GA passenger miles*	4.2%	28.2 B
Single-engine	2.6%	4.5 B
Multi-engine	2.6%	6.8 B
Jet-engine	5.7%	16.9 B

*Includes fractionals and SATS

"LOW COST CARRIERS DOMINATE"

Description

- ✈ A weak economy, coupled with few limits to growth and attractive substitutes, bodes poorly for the growth of traditional airlines. Fares are low and demand is price-sensitive; the shift of travel to LCCs continues.

Level of Growth in Traffic

- ✈ In the airline sector, LCCs grow relative to network carriers
- ✈ Network carriers stagnate and try to shift parts of their networks to RJs

Locus of Growth

- ✈ Secondary carrier airports

New Systems

- ✈ On-demand modes maintain share because there are few limits on aviation system growth

SCENARIO GROWTH RATES FOR "LOW COST CARRIERS DOMINATE"

Parameter	Average Annual Growth Rate	2022 Value
Domestic passenger RPMs	2.7%	828 B
Type of domestic network		Point-to-Point
International passenger RPMs	3.5%	348 B
Domestic cargo RTMs	3.5%	27.3 B
International cargo RTMs	4.0%	32.0 B
Belly vs. all cargo split		
Domestic cargo		27/73
International cargo		50/50
Total GA passenger miles*	2.8%	22.1 B
Single-engine	1.2%	3.5 B
Multi-engine	1.1%	5.3 B
Jet-engine	4.2%	13.3 B

*Includes fractionals and SATS

OUTPUTS FROM RESEARCH ACTIVITY 2

For each specified future aviation industry environment/scenario:

2022 U.S. commercial passenger demand:
- ✈ Domestic passenger demand in terms of RPMs
- ✈ Degree to which domestic scheduled passenger service is provided via hub-and-spoke vs. point-to-point network
- ✈ International passenger demand in terms of RPMs
- ✈ All assumptions used in commercial passenger demand forecasting

2022 U.S. air cargo demand:
- ✈ Domestic air cargo in terms of RTMs (U.S. internal RTMs only)
- ✈ International air cargo (between one of the U.S. airports and one of the foreign airports) in terms of RTMs
- ✈ Belly vs. all cargo split
- ✈ All assumptions used in air cargo demand forecasting

2022 U.S. GA passenger demand:
- ✈ Transported passenger miles (TPM) in GA aircraft
- ✈ Disaggregation by aircraft type
- ✈ All assumptions used in GA passenger demand forecasting

RESEARCH ACTIVITY THREE

- ✈ Develop a set of demand forecasts, incorporating both aggregate travel volumes and the distribution among airport-pairs and air vehicles, for each of the scenarios defined under research activity two:
  - ✈ Passenger flights
  - ✈ All cargo flights
  - ✈ GA itinerant flights

METHODOLOGY – PASSENGER FLIGHTS

- ✈ Assumptions Applied to All Scenarios:
- ✈ Two market segments have different growth rates:
  - ✈Domestic
  - ✈International
- ✈ Within each scenario, all domestic airports have the same passenger demand growth rate from 1997 to 2022
- ✈ Within each scenario, international travel demands at the 102 airports have the same growth rate from 1997 to 2022
- ✈ International passenger flights at the 102 airports include departures by both U.S. and foreign flag airliners

METHODOLOGY – PASSENGER (CONT.)

- ✈ Methodology for Developing 2022 Passenger Flight Demand:
  - ✈Created three baseline matrices for in-network domestic flights; out-of-network domestic flights represented by a 102-by-1 vector
  - ✈Created a 102-by-1 vector for international flights using the data from DOT's U.S. international air passenger and freight statistics
  - ✈Used operational parameters to link travel demand with flight demand
  - ✈Applied flight growth multipliers from the five scenarios to the appropriate baseline matrix and the domestic and international vectors

METHODOLOGY – PASSENGER (CONT.)

Three Baseline Matrices for Domestic Flights:

- ✈ Baseline One:
  - ✈Reflects current Hub-and-Spoke system
  - ✈Constructed a 102-by-102 airport-pair matrix using 1997 OAG data
- ✈ Baseline Two:
  - ✈Assumes a hypothetical Point-to-Point system
  - ✈Constructed a 102-by-102 airport-pair matrix using 1997 Origin and Destination (O&D) data
- ✈ Baseline Three:
  - ✈ Assumes a 50/50 split between current Hub-and-Spoke and pure Point-to-Point systems

A SAMPLE OF IN-NETWORK SCHEDULED PASSENGER FLIGHT DEPARTURES

Airport	Hub-and-spoke	Point-to-point	50/50 Split
ATL	672 (3.49%)	420 (3.04%)	546 (3.30%)
ORD	904 (4.70%)	499 (3.62%)	702 (4.25%)
SFO	443 (2.30%)	329 (2.38%)	386 (2.34%)
IND	164 (0.85%)	166 (1.20%)	165 (1.00%)
PVD	100 (0.52%)	94 (0.68%)	97 (0.59%)
SAT	113 (0.59%)	127 (0.92%)	120 (0.73%)
DAY	79 (0.41%)	60 (0.43%)	70 (0.42%)
LIT	63 (0.33%)	69 (0.50%)	66 (0.40%)
MSN	39 (0.20%)	37 (0.27%)	38 (0.23%)
…			
102 Airports Total	19,240 (100%)	13,801 (100%)	16,521 (100%)

METHODOLOGY – PASSENGER (CONT.)

Passenger Flight Growth Multiplier: G

$$G_i = \frac{2022 RPMs}{1997 RPMs} * \frac{1997 size}{2022 size} * \frac{1997 L.F.}{2022 L.F.} * \frac{1997 length}{2022 length}$$

Where:
G is a flight growth multiplier;
size is average aircraft size (number of seats);
L.F. is load factor; and
length is average stage length.

Since domestic and international market segments have their own operational parameters, the multipliers for the two market segments are calculated separately.

METHODOLOGY – PASSENGER (CONT.)

Convert Domestic RPM Growth Multipliers
to Flight Growth Multipliers

Scenario	Domestic Scheduled RPMs in 2022 (billion)	RPM Growth Multiplier 2022/1997	Convert to Flight Growth Multiplier 2022/1997	Domestic Load Factor	Domestic Average Aircraft Size	Domestic Average Stage Length
4. Airlines recover	1,056	2.35	1.97	0.72	150	880
6. Consumer rules	1,232	2.74	2.32	0.74	145	880
7. Substitutes take share	1,056	2.35	1.92	0.74	150	880
12. Growth limits prevail	772	1.72	1.40	0.74	150	880
13. LCCs dominate	828	1.84	1.57	0.76	140	880
1997 baseline	449			0.69	143	812

METHODOLOGY – PASSENGER (CONT.)

Convert International RPM Growth Multipliers
to Flight Growth Multipliers

Scenario	International Scheduled RPMs in 2022 (billion)	RPM Growth Multiplier 2022/1997	Convert to Flight Growth Multiplier 2022/1997	Int'l Load Factor	Int'l Average Aircraft Size	Int'l Average Stage Length
4. Airlines recover	500	3.15	2.97	0.76	230	3,350
6. Consumer rules	599	3.77	3.47	0.78	230	3,350
7. Substitutes take share	599	3.77	3.47	0.78	230	3,350
12. Growth limits prevail	348	2.19	2.07	0.76	230	3,350
13. LCCs dominate	348	2.19	2.07	0.76	230	3,350
1997 baseline	159			0.74	245	3,036

DAILY PASSENGER FLIGHT DEPARTURES AT SFO

Calculation 1: Domestic Scheduled Passenger Flights

Scenario	Operation System	**Baseline 1997**: Daily Domestic Departures	Flight Growth Multiplier	**2022 Daily Domestic Departures**
4. Airlines recover	H&S	508	1.97	1,001
6. Consumer rules	50/50 Split	451	2.32	1,047
7. Substitutes take share	50/50 Split	451	1.92	866
12. Growth limits prevail	50/50 Split	451	1.40	631
13. LCCs dominate	P2P	394	1.57	619

DAILY PASSENGER FLIGHT DEPARTURES AT SFO

Calculation 2: International Scheduled Passenger Flights

Scenario	Operation System	**Baseline 1997**: Daily International Departures	Flight Growth Multiplier	**2022 Daily International Departures**
4. Airlines recover	P2P	55	2.97	164
6. Consumer rules	P2P	55	3.47	192
7. Substitutes take share	P2P	55	3.47	192
12. Growth limits prevail	P2P	55	2.07	114
13. LCCs dominate	P2P	55	2.07	114

DAILY PASSENGER FLIGHT DEPARTURES AT SFO

Calculation 3: Total Scheduled Passenger Flights

Scenario	**Baseline 1997**: Total Daily Passenger Departures	**2022 Total Daily Passenger Departures**
4. Airlines recover	563	1,165
6. Consumer rules	506	1,238
7. Substitutes take share	506	1,058
12. Growth limits prevail	506	746
13. LCCs dominate	449	733

OUTPUTS FROM RESEARCH ACTIVITY 3

- ✈ Operational Demand at the Airport Level:
  - ✈2022 commercial passenger flights at 102 airports for each of the five scenarios
  - ✈2022 all-cargo flights at 102 airports for each of the five scenarios
  - ✈2022 itinerant flights by GA aircraft at 2,865 airports for each of the five scenarios

BACKUP CHARTS

WHAT IS A VALUE PROPOSITION?

- ✈ An organization's "Value Proposition" is the best articulation of why its product or service is compelling to customers.
- ✈ If customers understand the value proposition, they know why a given provider of products or services offers the best choice in a given market.
- ✈ It is useful for organizations focused on continuous improvement to develop and execute against a value proposition because such an exercise tends to sharpen focus and highlight strengths.
- ✈ Key steps in the construction of a value proposition include:
  - ✈ Careful definition of customer groups and key stakeholders
  - ✈ Thorough, although not necessarily complex, description of key product offerings
  - ✈ Clear illustration of the operational improvement offered to the customer
  - ✈ "ROI" analysis that demonstrates specific justification to the customer

SUPPLY/DEMAND METRICS

- Enroute capacity: Supply of airspace
- Terminal capacity: Supply of airspace
- Separation: Demand based on traffic
- Taxi times: Demand based on efficiency of operations
- Flight plan deviation: Demand on airspace
- Arrival and departure rates: Supply of airspace
- Length of visual approach: Supply of airspace
- Greater runway usage: Demand on fixed infrastructure

OPERATIONAL METRICS

- Reliability: Scheduled vs. actual
- On-time departures: Scheduled vs. actual
- Availability: Facility and service downtime
- Ground delays: Schedule adherence
- Ground stops: Schedule adherence
- Controller workload: FAA operations
- Passenger efficiency: Sunk labor costs
- Hub performance: Asset utilization

FISCAL METRICS

- Margin (RASM-CASM): Target vs. actual
- Fuel burn: Target vs. actual
- Labor efficiency: Target vs. actual
- Load factors: Service attractiveness
- Yield: Service attractiveness/reliability
- Turnaround time: Asset utilization
- Average daily block time/flight segments: Target vs. actual
- Infrastructure investment: Allocation of scarce resources
- Full price of travel: Value to customer

ENUMERATION OF SCENARIOS

Scenario Number	GDP Growth High/Low	Airline Yields High/Low	Limits to Av. System Growth Many/Few	Substitutes to Commercial Aviation Poor/Good
1	High	High	Few	Good
2*	**High**	**High**	**Few**	**Poor**
3	High	High	Many	Good
4*	**High**	**High**	**Many**	**Poor**
5	High	Low	Few	Good
6*	**High**	**Low**	**Few**	**Poor**
7*	**High**	**Low**	**Many**	**Good**
8	High	Low	Many	Poor
9	Low	High	Few	Good
10*	**Low**	**High**	**Few**	**Poor**
11	Low	High	Many	Good
12*	**Low**	**High**	**Many**	**Poor**
13*	**Low**	**Low**	**Few**	**Good**
14*	**Low**	**Low**	**Few**	**Poor**
15	Low	Low	Many	Good
16	Low	Low	Many	Poor

* = plausible scenarios

ESTIMATING GROWTH IN GA PASSENGER MILES

Estimating baseline (year 2000) GA transported passenger miles (TPMs):

- ✈ Use FAA GA Survey values for flight hours for corporate, business, personal and air taxi users, by aircraft type
- ✈ Estimate available GA passenger seat miles using averages for seats per aircraft type and aircraft speed
- ✈ Estimate GA TPMs using assumed 65% load factor

Estimating GA passenger activity for scenarios:

- ✈ Recognize differing growth rates for different aircraft types (single engine, multi-engine and jet engine), with jet engine GA transport experiencing most active growth
- ✈ Current GA share (2.6%) of total domestic passenger miles (domestic passenger RPMs plus GA TPMs) used as central tendency for future GA share
- ✈ Poor environment for GA (due to few limits to system growth and unattractive substitutes to scheduled service models) reduces future GA share; good environment increases GA share
- ✈ Current split of GA transported passenger miles among vehicle types used as expected split in least aggressive GA growth scenario (#6); faster GA growth more concentrated in jet engine aircraft
- ✈ GA transported passenger mile growth rates imputed from scenario GA future share and activity split among aircraft types

102 LMINET AIRPORTS

Airport	Hub Status	FAA Cargo Airport?	Airport	Hub Status	FAA Cargo Airport?
ABQ	M	yes	CRP	S	no
ALB	S	yes	CVG	L	yes
ANC	M	yes	DAB		no
ATL	L	yes	DAL	M	no
AUS	M	yes	DAY	S	yes
BDL	M	yes	DCA	L	no
BFL		no	DEN	L	yes
BHM	S	yes	DFW	L	yes
BNA	M	yes	DSM	S	yes
BOI	S	yes	DTW	L	yes
BOS	L	yes	ELP	M	yes
BTR	S	no	EUG		no
BUF	M	yes	EWR	L	yes
BUR	M	no	FAT		yes
BWI	L	yes	FLL	L	yes
CHS	S	no	FNT		yes
CLE	M	yes	GFK		no
CLT	L	yes	GRR	S	yes
CMH	M	no	GSO	S	yes
COS	S	yes	HNL	L	yes

102 LMINET AIRPORTS (CONT.)

Airport	Hub Status	FAA Cargo Airport?	Airport	Hub Status	FAA Cargo Airport?
HOU	L	no	MIA	L	yes
HPN	S	no	MKE	M	yes
IAD	L	yes	MLB		no
IAH	M	yes	MSN		no
ICT	S	yes	MSP	L	yes
IND	M	yes	MSY	M	yes
ISP	S	no	OAK	M	yes
JAX	M	yes	OKC	M	yes
JFK	L	yes	OMA	M	yes
JNU		no	ONT	M	yes
LAN		yes	ORD	L	yes
LAS	L	yes	ORF	S	yes
LAX	L	yes	PBI	M	no
LGA	L	no	PDX	L	yes
LGB		no	PHF		no
LIT	S	no	PHL	L	yes
MCI	M	yes	PHX	L	yes
MCO	L	yes	PIT	L	yes
MDW	L	no	PVD	M	yes
MEM	M	yes	RDU	M	yes

102 LMINET AIRPORTS (CONT.)

Airport	Hub Status	FAA Cargo Airport?	Airport	Hub Status	FAA Cargo Airport?
RIC	S	yes	TVC		no
RNO	M	yes	TYS	S	yes
ROC	S	yes			
RSW	M	yes			
SAN	L	yes			
SAT	M	yes			
SBA		no			
SDF	M	yes			
SEA	L	yes			
SFO	L	yes			
SJC	M	yes			
SLC	L	yes			
SMF	M	no			
SNA	M	no			
STL	L	yes			
SWF		yes			
SYR	S	yes			
TPA	L	yes			
TUL	M	yes			
TUS	M	yes			

Hypothetical Point-to-Point Matrix

Service Regression Results

Market	Distance	Seats	Statute Miles	Intercept	R-Squared	Load Factors
large	long	0.006006942	-0.001271873	2.2303	0.94	0.7
large	short	0.006624361	-0.012321804	6.8956	0.73	0.6
small	long	0.696095181	-0.001423347	0.6961	0.77	0.6
small	short	0.037807886	-0.002793974	0.7272	0.53	0.5

Daily Service = seats * x + statute miles * y + intercept

Rounded up to whole flight

No service where Daily service <= .499999

Data source is OAG

Long versus short split at 500 miles

Large versus small split at 100 daily passengers

The Development of Operational Scenarios for VAMS/SEA Concept Evaluations

Starting Point:

Principal Assumption: To be successful, the evaluation of VAMS Concepts is an intellectual problem for which the solution must be based in reality, not theory.
Therefore:

1. **Identify National Air Space (NAS) stakeholders and their VAMS programmatic concerns.**

2. **Understand market-oriented alternatives to meeting stakeholder concerns.**

3. **Analyze the interaction between the application of a concept's core ideas, new technologies, costs, schedule, and VAMS program goals.**

4. **Develop Concept Evaluation scenarios that can determine if the implementation of a VAMS Operational Concept is likely to produce measurable benefits for the various stakeholders. Evaluation methods will utilize fast time modeling, real-time simulations, and analytic studies.**

Scenario Requirements – The Stakeholders Who Will Use the Concept Evaluation Results and for What?

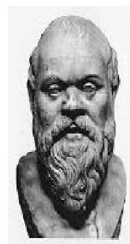
- **NASA: Promising concepts to pursue**
- **FAA: Promising concepts to support**
- **Air carriers: Impacts of potential concepts on their operations, revenues, and costs**
- **Manufacturers: Impacts of potential concepts on their products, revenues, and costs**
- **Pilots: Impacts of potential concepts on their tasks**
- **Air traffic controllers: Impacts of potential concepts on their tasks**
- **General aviation: Impacts of potential concepts on their operations, access to services, and costs**
- **Cargo carriers: Impacts of potential concepts on their operations, revenues, and costs**
- **Airport operators: Impacts of potential concepts on their operations, revenues, and costs**
- **Flying public: Impacts on air travel service, safety, security, and travel costs**
- **General public: Impacts on noise and air pollution, safety and security**
- **U.S. Government**
  - **Executive Branch – Office of Management and Budget: Benefits and costs; feasibility and directions of concepts; relation to related NASA programs**
  - **Congress: Benefits and costs to stakeholders; feasibility and directions of concepts**

Framework for VAMS/SEA Operational Scenario Requirements Definition

Operational Concept Description → **Concept Analysis** → **Development of Stakeholder Viewpoints (questions to be answered)*** → **Operational Scenario Requirements Definition**

1. **Scope:** issues, NAS Domain, challenges, assumptions
2. **Top Level Descriptions:** core ideas & functions
3. **Detailed Descriptions:** performance, roles, responsibilities @ humans & machine, human factors, user interfaces
4. **NAS Infrastructure & Technology Impacts:** transition planning, architecture, technology requirements
5. **NAS Operational Risks:** ensuring system integrity and redundancy, security, safety
6. **Key Project Attributes:** benefits/metrics, cost/metrics

SEA Team
Sandy Lozito
et al.



***Essentially a Socratic Method of Investigation:**

Socrates assumed that truth is embodied in correct definition. Precise definition of terms is held to be the first step in the problem solving process.

"One cannot know a thing until it is thoroughly defined."

Questions serve as a logical, step-wise guide for analyzing a VAMS Concept from stakeholder viewpoints. Operational scenarios are key elements in the definition of how a concept will work. In terms of evaluation, the scenarios will provide a means for reality testing a concept.

VAMS/SEA is using a reiterative structured analysis to define Operational Scenarios for each of the VAMS concepts. This analysis is founded in dialogue of which the TIMS are an integral part.

This is similar to Socrates' use of the dialectic.

Socrates believed that through the process of structured dialogue (dialectic), where all parties (stakeholders) to the conversation were asked to clarify their ideas, the final outcome of the conversation will be a clear statement of what a concept means.

The scenario requirements analysis is evolutionary: with each concept deliverable and at ensuing TIMS, the SEA team will reassess the evolving operational concepts with a common structured analysis. It will refine scenario elements, evaluation metrics, and the methods that will be used to evaluate each concept through ongoing conversation with the concept developers and stakeholders.

VAMS/SEA Concept Analysis Structure

1. Identify the stated objectives of the VAMS concept.

2. Define the NAS operational constraint or constraints being targeted by the concept (i.e. airline scheduling, airport design, weather, etc.)

3. Specify the core ideas supporting the concept mindful that the functions of these ideas must logically address means of reducing the specific NAS capacity constraints identified in step 2.

4. Identify critical areas of concept implementation risk. Risk factors include technology, safety, security, cost, and environment.

5. Develop likely stakeholder questions to be answered through concept evaluations.

6. Define critical operational scenario elements required to evaluate a concept.

VAMS Concepts included in scenario requirements analysis:

1. Advanced Airspace System – NASA Ames
2. Massive Point-to-Point On-Demand – Seagull
3. Capacity Increasing ATS – Boeing
4. Automated Surface Traffic Control – Metron
5. All Weather - Metron
6. Centralized Terminal Operation Control – Northrop Grumman
7. Surface Operation Automation Research – Optimal Synthesis
8. Terminal Area Capacity Enhancing Concept – Raytheon
9. University Concepts – A. Zellweger, et al.
10. Wake Vortex Avoidance – NASA Langley
11. FACET – NASA Ames

Stakeholder Questions & Scenario Elements

Examples from analysis of Seagull MPTP Concept

1. What kind of commercial passenger air carrier operations will be needed to support massive point to point air travel? What will the airline fleets look like? What will the airport operations look like?	▪Development of a probable range of passenger demand assumptions driving MPTP city-pair air carrier operations ▪Fleet mix vis. airport operational scales (the kinds of aircraft serving various kinds of airports) ▪Aircraft operational costs (by aircraft type and by carrier type) ▪Flight deck & AOC technology requirements and equipage rates and costs ▪ATM infrastructure and operations requirements and costs
2. How much will massive point to point air travel cost the public?	▪Market share by carrier type vis. passenger arrival/departure distribution ▪Airport access infrastructure requirements & costs ▪Environmental factors ▪Flight deck & AOC technology requirements and equipage rates and costs ▪ATM infrastructure and operations requirements and costs

Result 1: Definition of a Common set of evaluation questions.

These will be the conversational starting point for reiterative concept analyses.

1. **How much increase in NAS capacity will be gained from the concept?**
2. **What are the safety impacts?**
3. **What are the security impacts?**
4. **How does the concept impact human factor issues for AT controllers, pilots, airline operations centers, and other relevant participants?**
5. **What is the magnitude of other benefits provided by the concept? E.g.: Efficiency (total and for individual stakeholders); Predictability; Access and Mobility?**
6. **What will be the benefits to various stakeholder groups?**
7. **What are the environmental impacts? E.g.: Noise, Emissions, Energy use, Quality-of-life**
8. **How robust is the concept regarding conditions under which it will operate?**
9. **How does the concept affect the operations and planning of the major participants in the NAS?**
10. **What will be the total cost and costs to various stakeholder groups?**
11. **What is the likely level of support by various stakeholders in factors critical to concept implementation? E.g.: Equipage required by aircraft operators; Work process change; NAS infrastructure investments**

Result 2: Definition of a Comprehensive set of operational scenario requirements resulting from analyses of eleven VAMS initial concept deliverables. Sandy Lozito is the manager and guardian of these definitions.

Metrics for VAMS

January 14-15, 2003

Presented to:

Technical Interchange Meeting 3, VAMS

Presented by:

James L. Poage

Volpe National Transportation Systems Center

Why Metrics for VAMS?

- Uses of metrics
  - » Make and justify decisions of whether concept is promising and will be pursued in research
  - » Show impact of VAMS project
- What are criteria for deciding whether concept is promising to pursue?
  - » Does the concept provide a meaningful benefit?
  - » Are the costs to implement and operate acceptable?
  - » Does the concept not degrade safety or the environment?
  - » Is the concept likely to be implemented?
  - » Is the concept of interest to stakeholders?

Approach to Design Actionable Measures

1. **Requirements** for measures
   » Who will use the measures?
   » What decisions will each audience make with the measures?
2. **Narrative Framework** to present measures
   » What message will be told to each audience?
   » How do we present the desired messages?
3. **Quantitative and Qualitative** Measures
   » What quantitative and qualitative measures will we use?

1. Requirements for Measures

Who will use the measures?

- Developers
  - » Program managers
  - » NASA management
  - » Concept developers contractors
- Service providers
  - » FAA
  - » Airports
- Industry
  - » Aircraft operators
  - » Airframe and avionics manufactures
- Funders
  - » OMB
  - » Congress

1. Requirements for Measures (cont'd)

Common Set of Evaluation Questions

- How much capacity will be gained from the concept?
- What is the magnitude of other benefits provided by the concept?
- What will be the benefits to various stakeholder groups?
- What are the safety impacts?
- What are security impacts?
- What are the environmental impacts?

(cont'd . . .)

James Poage - Volpe Center

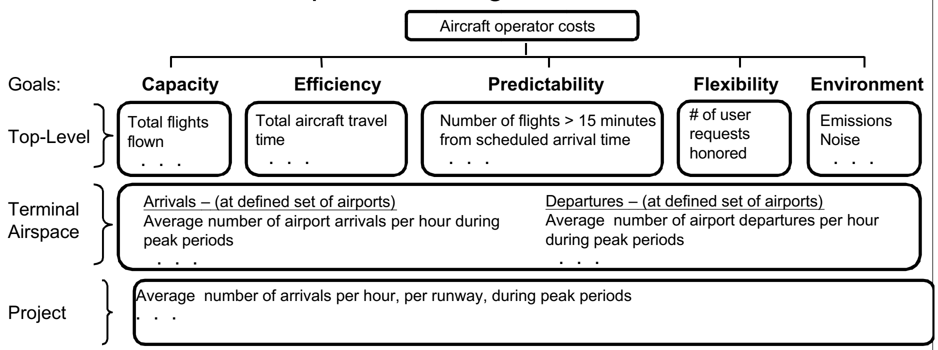
1. Requirements for Measures (cont'd)

Common Set of Evaluation Questions (cont'd)

- How does the concept impact human factor issues for AT controllers, pilots, airline operations centers, etc.?
- How robust is the concept regarding conditions under which it will operate?
- How does the concept affect the operations and planning of the major participants in the NAS?
- What is the total cost and costs to various stakeholders?
- What is the likely level of support by various stakeholders?

2. Narrative Framework to Present Measures

- Example: Hierarchical framework – shows how individual concepts relate to goals



James Poage - Volpe Center

2. Narrative Framework to Present Measures (cont'd)

- Example: Flow framework – shows how activities produce benefits

Capabil-ities	Direct Impacts	Direct Impact Metrics	Benefit Impacts	Benefit Impact Metrics
• Display in cockpit of surrounding traffic/equipment ⋮	• Pilot able to better identify aircraft to follow • Pilot awareness of all proximate traffic positions ⋮	• Pilot response time for ATC traffic call-out • Flight time from final approach fix to touchdown ⋮	• Reduced arrival delays • Increased predictability of arrival times ⋮	SAFETY • Accident rate during final approach maneuvers • USER ENHANCEMENT • Arrival rate • FAA COST SAVINGS • Voice channel occupancy time •

Capabilities → Direct Impacts → Direct Impacts measures → End-Benefits → End-Benefit Measures

3. Measures: Common Set - Capacity

1. How much capacity will be gained from concept?

- Total flights flown (in a year)
- Total passenger trips (in a year)
- Total passenger revenue miles for selected metro-pairs (in a year)
- Total cargo moved (in a year)
- Average airport arrival rates during peak periods (total over year NAS-wide and annual average for selected airports)

•
•
•

James Poage - Volpe Center

3. Measures: Common Set - Safety

2. What are the safety impacts?

- Number of accidents and accident rate (in a year)
- Number of fatalities and fatality rate (in a year)
- Number of incidents and incident rate (of particular type, e.g., runway incursions, loss of separation, operational errors, pilot deviations, etc.) (in a year)
- Precursor incident and procedural non-compliance by human operators in the system (scenario specific and real-time based measure)

•
•
•

3. Measures: Common Set - Robustness

8. How robust is the concept regarding conditions under which it will operate?

- Average aircraft arrivals and departure during VFR versus during IFR weather
- Average and standard deviation of flight speed from gate departure to gate arrival (NAS-wide in a year and for representative sample of origin-destination pairs)
- Average recovery time from changing conditions, failures, or other negative events (from model/simulation results where possible)

•
•
•

Next Steps

- Refine and focus metrics based on evolving detailed information on
  - » Concepts
    - – What functions and impacts will the concepts provide?
    - – How will they provide these functions and impacts?
  - » Evaluation models/simulation capabilities
    - – What impacts can be evaluation with the models/simulation capabilities?

(cont'd . . .)

Next Steps (cont'd)

Example: Refined questions for Massive Point-to-Point and On-Demand Air Transportation System

- How much of an increase to NAS capacity is the concept likely to achieve if implemented? How many airports are candidates?
- Can the massive point-to-point concept enable the same capacity during IFR conditions as in VFR conditions?
- Can the massive point-to-point concept reduce total travel time per passenger?
- What kind of airlines operations will be needed to support massive point-to-point air travel? What will be the costs of the required new technologies? What will the airline fleets look like?
- How much will massive point-to-point air travel cost airlines & public?
- How safe will massive point-to-point air travel be?
- How accessible will massive point-to-point air travel be to travelers?
- How much public resistance will there be to airport expansions? What kind of airport operations and how much of an environmental impact can communities tolerate in their neighborhoods?

Next Steps (cont'd)

- Examine how metric values be can calculated
  - » Fast time models
  - » Real-time simulation
  - » Analysis
- Develop evaluation frameworks for each concept
- Conduct manual simulation of evaluation process for select concept(s)

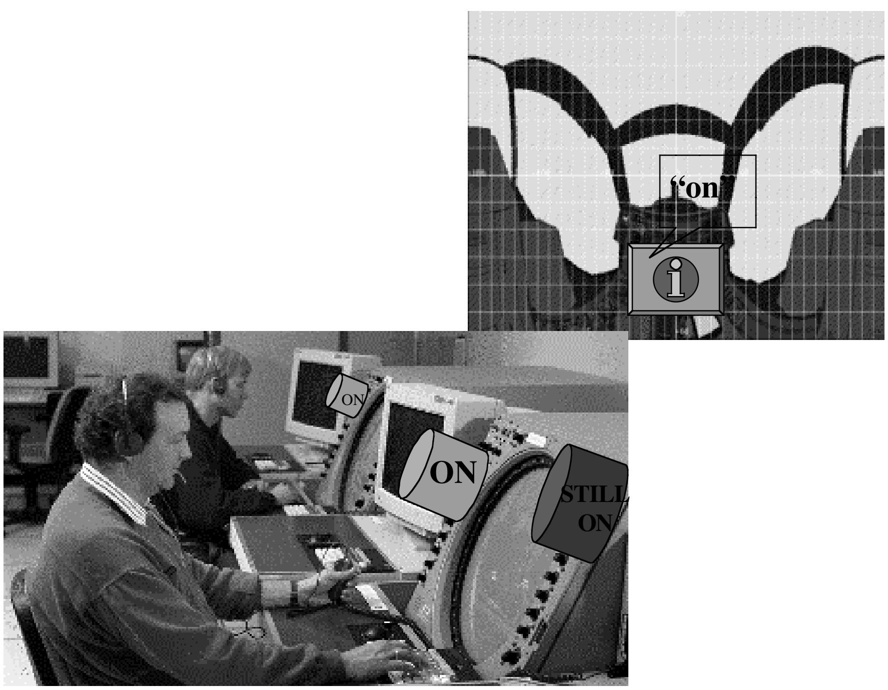
Human Performance Factors in OPCON Evaluation & Assessment

Kevin Corker

Martijn Mooij

Liza Tam

San Jose State University



Matters of Consequence in Human Performance in Operations

- Impact multiple operational entities in the airport/airspace
- Noticeable change in schedule, staffing, roles and responsibilities
- Change in scope of the range & span of decision making
- Change in fundamental informational characteristics of the system (displays, alerts, controls, communications, etc.)
- Changes in, or development of, new certification standards, MELs, etc
- Fundamental changes in airspace structure or use (segregated airspaces etc.)

Operational Concepts Community Evaluated

- **AAC (1993)**
- **Data Link Communications CPDLC Oceanic Trails (1979, 1994)**
- **Terminal Productivity Concepts (PRM & TAP AILS) (1991, 1993)**
- **Reduced Vertical Separation Minima (1994)**
- **National Route Program (FAA 1994)**
- **Programe for Harmonized Air Transport Research in Europe (PHARE Demonstrations 1,2,3) (1995-2000)**
- **Free Flight RTCA (1995), FAA Response Action Plan (1996)**
- **Collaborative Decision Making (FAA, ATA, NASA, 1998)**
- **AATT Operational Concept Development (Boeing, Honeywell, Lockheed Martin, NASA LaRC, DAG) (1994-present)**
- **Surface Movement Advisor System (1997-8)**
- **ADS-B/CDTI Ohio Valley trials >> Safe Flight 21 (2000-2001)**
- **CAPSTONE (2001- present)**
- **CTAS TMA- Time-based Metering, PFAST (1995-present)**
- **URET (1995 – present)**
- **Free Flight Phase 1 (ancillary technologies)**
- **OEP (2001- present)**

Dimensions of study for OPCONS

- **Reliability/Consistency/Predictability**
- **Coverage (range of operations, airspaces, operational characteristics—efficiency, safety, observability, predictability)**
- **Technical Complexity (what sensors, boxes, software, CNS requirements)**
- **Procedural Complexity (what selection, training, dynamic, memorial, documentation footprint)**
- **Cultural (national, corporate, practice) variability**
- **Information Flow**
  - **Timeliness, density, relevance, degree of interpretation, transformation, and integration**
- **Recoverability**
  - **Levels of safety**

Dependent Variables

- Airport/Airspace/Aircraft Variables
  - # of A/c per unit volume/unit time
  - Fuel use, aircraft life-cycle costs
  - Conflicts & configurations
  - Schedule deviations/million operations…
  - Number Operations
- System Level Variability
  - Stability
  - Predictability
  - Robustness
  - Environmental (noise, air, etc)
  - Distance of the proposed concept from the current …

Dependent Variables

- Human Variables
  - Reaction Time
  - Performance Time
  - Performance Sequences
  - Training Footprint
  - Errors & performance profiles
  - Communication (frequency, duration, content analysis)
  - Eye Movement
  - Physiological Correlates o Behavior (EEG, Cardiac Arrhythmia, Pupillary Diameter, GSR, Blink Rate…
  - Subjective workload, Situation awareness
  - Cooper-Harper Ratings (handling qualities of the opcon)
  - Usability assessments
  - (t)required/(t)available

Scenario Development & Metrics Issues: Human Performance Perspective

- **Normal Operations occur at stable routinized level**
  - ***OPCON's susceptibility to disruption needs to be measured at that operating point, and at transition to non-routine***
- **Level Of Specificity & Definition**
  - ***All components, or many critical elements of an Operational Concept may be at a level of specificity wherein the measurable variables are not available***
- **Dependent and Response Variables**
  - ***Those that are measurable are not the relevant diagnostic of system performance***
- **Scalability**
  - ***Predictive performance scaling in fast time & real time simulations is unvalidated***

Possible Solution Paths

- Characteristic Response Method
  - Translate prior experience in joint human-artifact complex dynamic systems to current OPCON
    - Control by exception design for DST
    - Reversion for failure modes assuming a supervisory control paradigm
    - Gaming in operating modes governed by a minimax rule
- Define units of the OPCON
  - Analysis following the fault lines of human-system performance
- Cognitive Process and Information topology analysis
  - Bottlenecks and optimization opportunities based on state of system, control opportunity and distributed knowledge
  - Minimum information requirements and control requirements: Requisite Variety
- Models at varied and matched levels of aggregation

Scenario/Metric Parameters

Forecast	Demand	System	Environment	Scope
Economic Activity	Number of Airport	Aircraft Characteristics	Weather	Whole v. part of NAS
Energy Availability	Fleet mix	Airport Characteristics	Safety Situations • Operational errors • Reduced Landing Capacity • Aircraft/Vehicle On the Runway	Fidelity of the Scenario
War and pestilence	Load factor	Airspace Characteristics	Failures	Temporal Resolution
Environmental Concerns	Schedule	CNS Infrastructure	Security Situations	Simulation Timing/ Synchronization
Demographics	Origination/ Destination Pair	NAS Architecture		
Travel Confidence		Humans		

Concept Independent (stipulated by the SEA/VAMS)

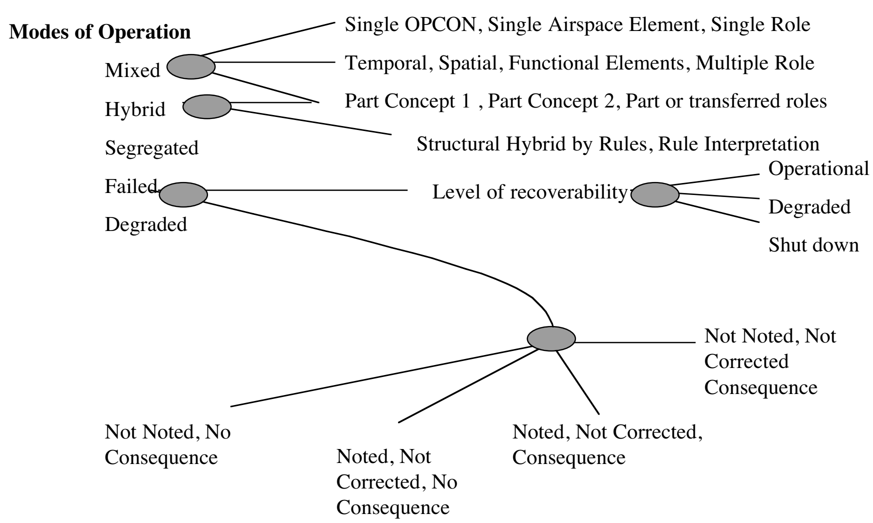
Concept Dependent

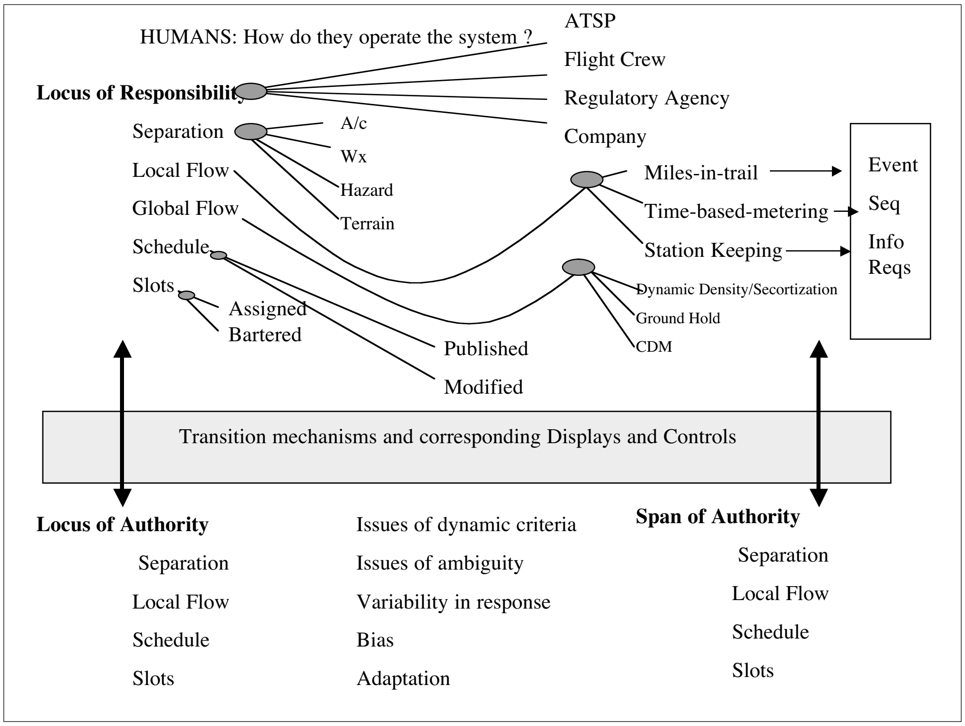
Note: Assume a multiple-day schedule of flights for these scenarios

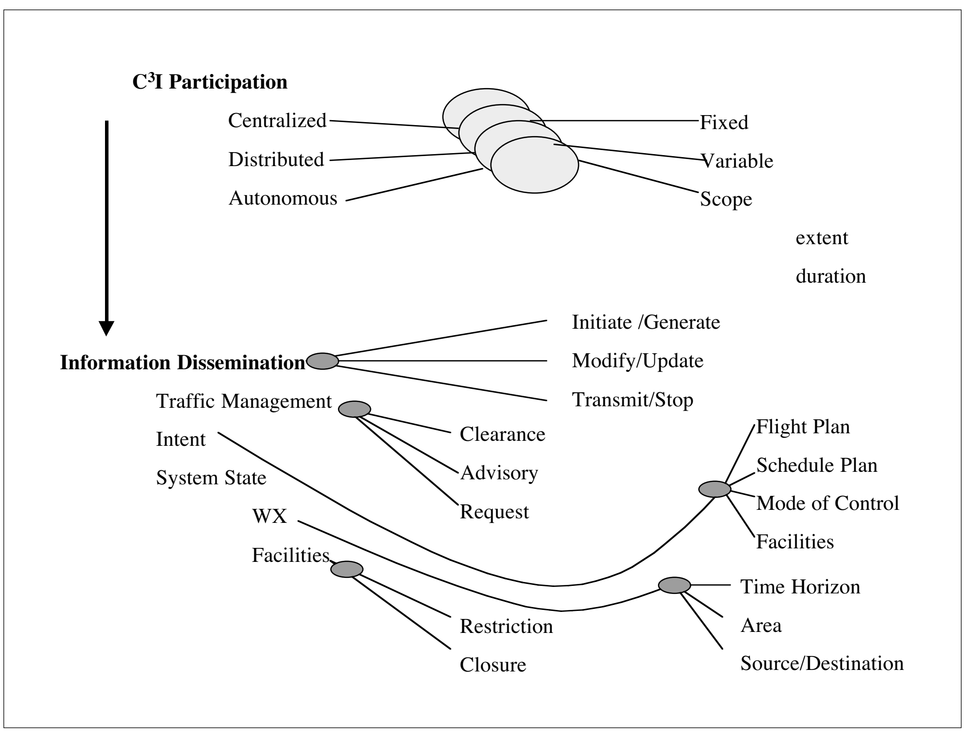
Chsaractersitic Response Matrix of Measures and Perturbations

OPCON	Roles, Responsibilities & Information	Problem Solving Strategy Processes	System Constraints
Ambiguity			
Dynamically Changing Risk			
Organizational & Social Pressures			

Defining Units of the OPCON and Derivative Study Foci



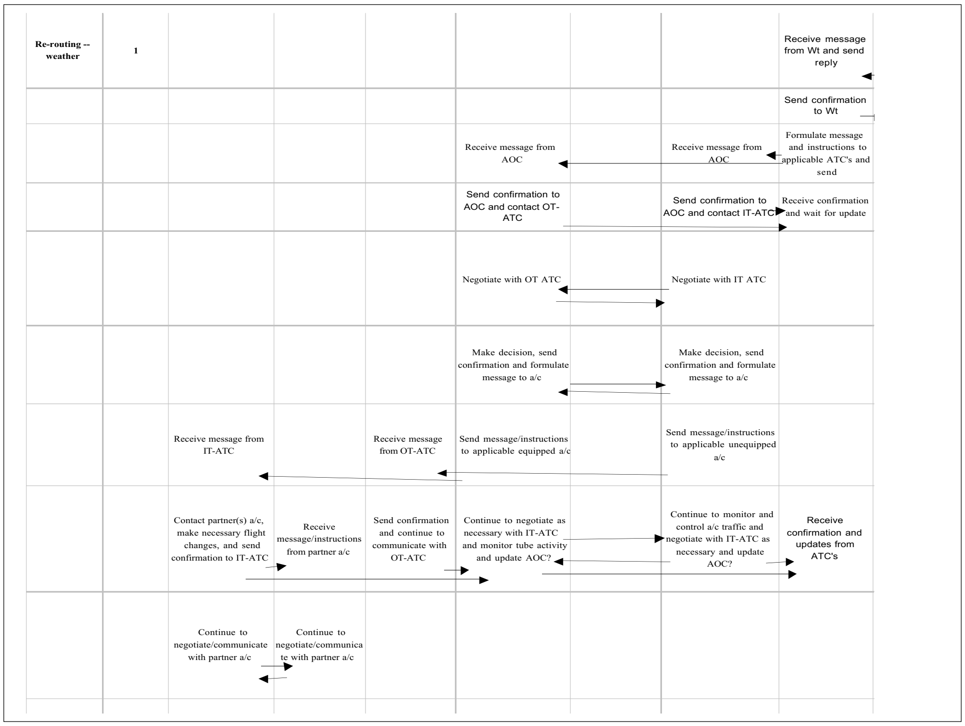

HUMANS: How do they operate the system ?
ATSP
Flight Crew
Regulatory Agency
Company
Locus of Responsibility
Separation
A/c
Wx
Hazard
Terrain
Local Flow
Global Flow
Schedule
Slots
Assigned
Bartered
Published
Modified
Miles-in-trail
Time-based-metering
Station Keeping
Dynamic Density/Secortization
Ground Hold
CDM
Event
Seq
Info
Reqs
Transition mechanisms and corresponding Displays and Controls
Locus of Authority
Separation
Local Flow
Schedule
Slots
Issues of dynamic criteria
Issues of ambiguity
Variability in response
Bias
Adaptation
Span of Authority
Separation
Local Flow
Schedule
Slots

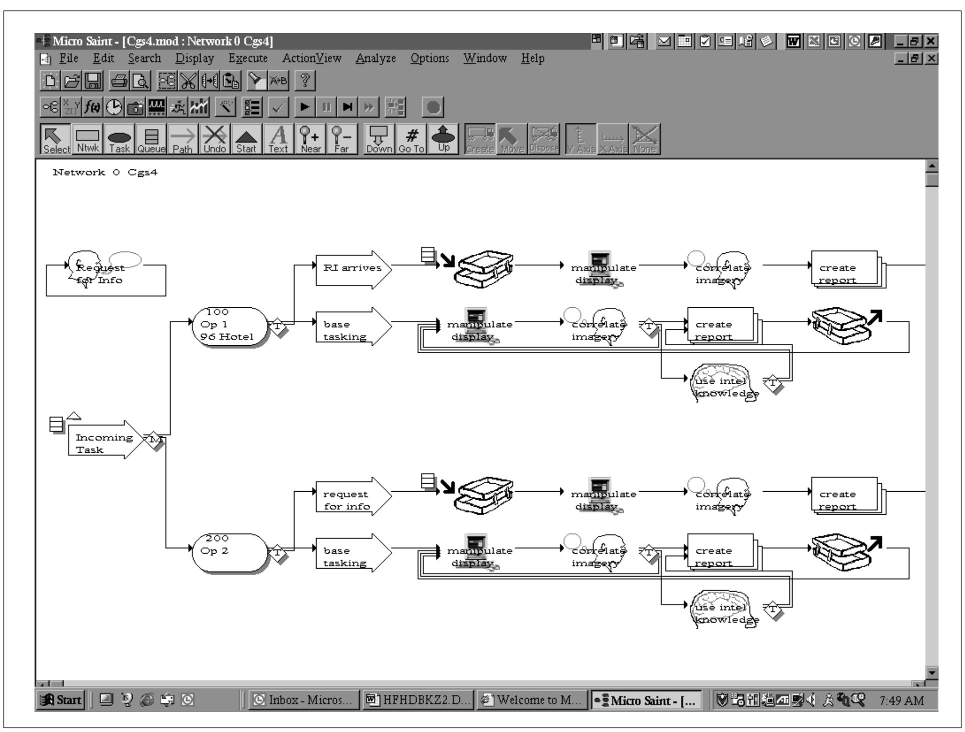

C3I Participation
Centralized
Distributed
Autonomous
Fixed
Variable
Scope
extent
duration
Information Dissemination
Initiate /Generate
Modify/Update
Transmit/Stop
Traffic Management
Intent
System State
WX
Facilities
Clearance
Advisory
Request
Flight Plan
Schedule Plan
Mode of Control
Facilities
Time Horizon
Area
Source/Destination
Restriction
Closure

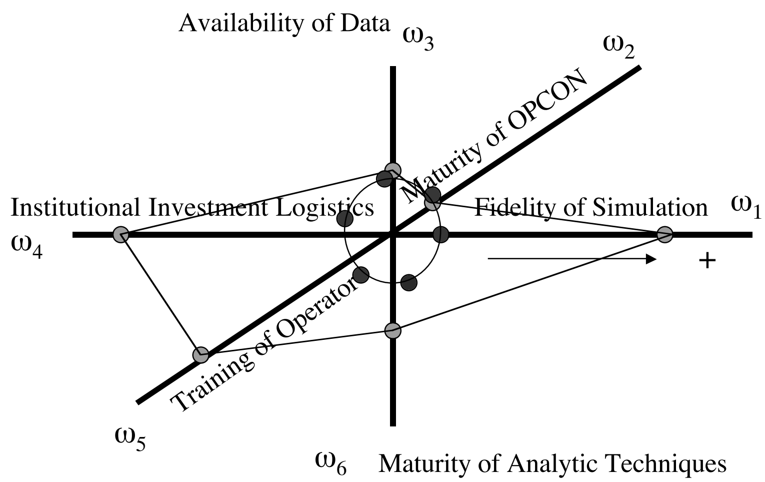
Cognitive Process and Information Topology Analysis

University Tube Operations					Key Players			
		AIRCRAFT EQUIPPED	**PARTNER A/C (do we need this too?)**	**AIRCRAFT UNEQUIPPED**	**ATC INNER TUBE MANAGER**	**ATC *partner* TUBE MANAGER (do we need this too?)**	**ATC OUTER TUBE MANAGER**	**AOC**
Conflicts								
	Modeling Priority							
Merge into tube	**1**						Receive flight schedule and sequence information	Set flight schedule and sequence and send to OT-ATC
		Receive flight information					Formulate message to a/c and send	
		Confirm flight plan to ATC and record information					Receive confirmation from a/c and give confirmation/update to AOC	Receive confirmation from OT-ATC
		Formulate message to IT-ATC and send flight information			Receive flight information/status from a/c entering tube			
		Receive confirmation/insturctions and partner a/c frequency from inner tube ATC			Formulate message to a/c and send confirmation and any applicable instructions/flight plans and partner a/c flight information (radio frequency)			
		Formulate message to partner a/c and inner tube ATC and send flight information	Receive message from partner a/c and send confirmation					
		Send confirmation to			Receive confirmation from a/c and wait for next a/c			

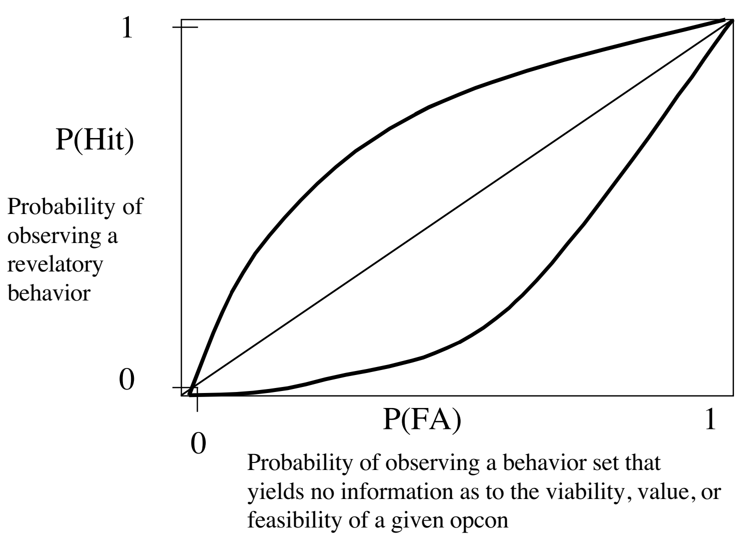
Intersection	**1**	Detect upcoming intersection and contact tube manger ATC			Receive message from a/c and review situation			
		Receive message from tube manager ATC and send back confirmation			Formulate flight plan changes (if any) and contact apllicable a/c			
		Make necessary changes to flight path and continue to communicate with partner a/c	Communicate with partner a/c		Receive message form a/c and review situation			
					Contact outer tube ATC to check for conflicts/status and wait for reply Contact intersecting tube's manager ATC??	Should this 'partner' (if any) tube manager ATC be included here in the communications and negotiations?	Receive message from inner tube ATC, examine situation, send confirmation back to inner tube ATC	
					Receive confirmation and wait for instructions			
		Receive message from ATC if more changes			Receive message/information from outer tube ATC, review situation and send anothr		Send message back to inner tube ATC with any flight plan change requests	


Re-routing -- weather
1
Receive message from Wt and send reply
Send confirmation to Wt
Receive message from AOC
Receive message from AOC
Formulate message and instructions to applicable ATC's and send
Send confirmation to AOC and contact OT-ATC
Send confirmation to AOC and contact IT-ATC
Receive confirmation and wait for update
Negotiate with OT ATC
Negotiate with IT ATC
Make decision, send confirmation and formulate message to a/c
Make decision, send confirmation and formulate message to a/c
Receive message from IT-ATC
Receive message from OT-ATC
Send message/instructions to applicable equipped a/c
Send message/instructions to applicable unequipped a/c
Contact partner(s) a/c, make necessary flight changes, and send confirmation to IT-ATC
Receive message/instructions from partner a/c
Send confirmation and continue to communicate with OT-ATC
Continue to negotiate as necessary with IT-ATC and monitor tube activity and update AOC?
Continue to monitor and control a/c traffic and negotiate with IT-ATC as necessary and update AOC?
Receive confirmation and updates from ATC's
Continue to negotiate/communicate with partner a/c
Continue to negotiate/communicate with partner a/c


Micro Saint - [Cgs4.mod : Network 0 Cgs4]
File Edit Search Display Execute ActionView Analyze Options Window Help
Select Ntwk Task Queue Path Undo Start Text Near Far Down Go To Up Create Move Dispose Y Axis X Axis None
Network 0 Cgs4
Request for Info
RI arrives
manipulate display
correlate imagery
create report
100 Op 1 96 Hotel
base tasking
manipulate display
correlate imagery
create report
use intel knowledge
Incoming Task
request for info
manipulate display
correlate imagery
create report
200 Op 2
base tasking
manipulate display
correlate imagery
create report
use intel knowledge
Start
Inbox - Micros...
HFHDBKZ2.D...
Welcome to M...
Micro Saint - [...
7:49 AM



Data Operating Curve (DOC)



Fidelity of the analysis/simulation sets the lower limit of discriminability of significant behavior

Summary Perspective on OPCOn Evaluation and Assessment

- **Assertion:**
  - Safety and Capacity of airspace operations is limited by the cognitive, perceptual, or attentive characteristics of the managers, controllers, operators in that airspace.
  - Technical aiding systems (&/or procedures) can be designed to assist the human operators and offset the limitation(s)
    - Identified what and how the limit is manifest
    - Develop technologies that work to remove that limitation(s)

      And don't impose others,

      Only alter the limitation & otherwise don't change the airspace operation,

      Enhancement will not be exploited to reach a new level of human constraint ,

      Can revert to safe operations in case of all foreseeable failure modes

Scenario Data Sources

Brian Kiger
Seagull Technology
14-Jan-2003

Overview

- Data Significance Prelude
- Context
- Motivation
- Data Discussions
  - Key Scenario Example
  - Key Scenario Parameters
  - Data Mining
  - Data Significance
- Suggested Actions

Data Significance Prelude

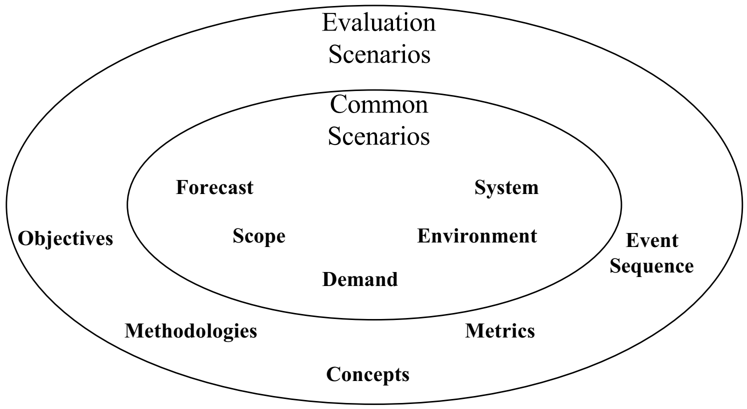
- Ensure realism with high fidelity data
- Test validity of concept
- Creates a basis for standardization
- Repository of data affords the developer more attention on the concept
- Ability to quickly modify data creates more thorough analysis

Context

- An important concern for usability of identified potential scenario parameters was the availability of existing data sources. The Seagull SEA Team searched for information about available data sources for all important scenario parameters
- A key data source index was generated to locate data sources

D. Schleicher, A. Huang, G. Couluris, S. Lockwood, B. Kiger, D. Signor, R. Kelley, "Proposed SEA Scenario Requirements", Seagull Technology, Nov. 2002.

Context: Scenario Building Blocks



Common Scenarios:

Concept-independent data to support all desired VAMS concept evaluations

Evaluation Scenarios:

All data needed to support a specific VAMS concept evaluation

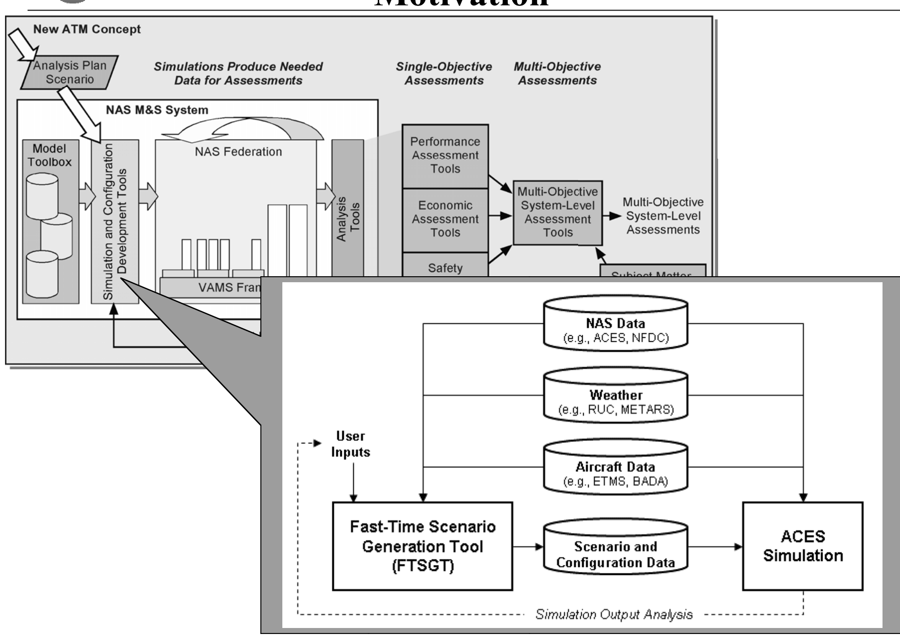
Context: Common Scenarios

- **Forecast**
  Delineates the state of the NAS in which the SLIC concept will be tested, including “NAS today” and projections of a future NAS.
- **Demand**
  Provides a definition of the passenger and cargo transportation demand and the aircraft and flight characteristics desired by the airspace users satisfying the transportation demand.
- **Scope**
  Provides a definition of the range of the physical, temporal, and operational dimensions of the Common Scenario.
- **System**
  Provides a definition of the characteristics of the National Airspace System into which one would insert aspects of a new air traffic management operational concept. Detailed information from the System category can be used as the basis from which to measure the benefits of any given operational concept and can provide a common baseline to be used for generating apples-to-apples benefits comparisons.
- **Environment**
  Provides a definition of the weather, safety, and security aspects to a Common Scenario that would cause significant disturbances to the nominal air traffic flow.

Context: Evaluation Scenario

• OBJECTIVES	• CONCEPTS	• METHODOLOGIES	• EVENT SEQUENCE	• METRICS
• questions	• flight management	• analysis	• pilot actions	• capacity/ throughput
• assumptions	• air traffic management	• fast-time simulation	• ATC actions	• efficiency
	• fleet management	• real-time simulation	• TFM actions	• taskload
	• communicati on		• AOC actions	• safety
	• navigation		• disturbances	• environment
	• Traffic surveillance		• demand/ capacity imbalances	• acceptability
	• weather surveillance			• cost

Motivation

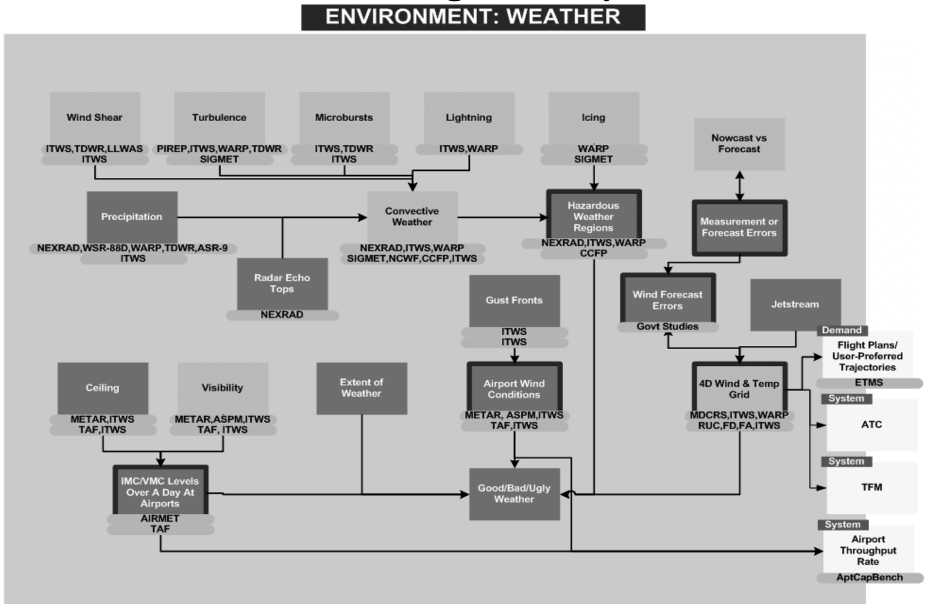


Motivation: Testers of the Concepts

- Under what conditions does the concept fail?
  - Do we have the right data to excite all modes of our concept?
- Where does the concept excel in benefits?
  - What data sets are required to demonstrate concept benefits?
- What are the boundaries of the concept?
  - What data is required to determine costs, physical & operational?
- What modifications to the concept are needed to fix a “bug”?
  - What data is needed to create the problem? Is the data at the same fidelity as the concept?
- How do we know that one concept is scrutinized equally to another concept?
  - Is the data standardized across the concepts?
- How quickly can we iterate?
  - Can the data be quickly manipulated to form new tests?

Determination of High Priority Parameters

ENVIRONMENT: WEATHER



High-Priority Scenario Parameter List

- **Forecast:**
  - Time Period, Direct Operating Costs, Airline Yields, GDP Growth, Substitutes to Commercial Air Travel, Limits to Aviation System Growth
- **Demand:**
  - Flight Plans, User Preferred Trajectories, Flight Schedules, RPM, Load Factor, Passenger/Cargo Forecast for each OD pair, Fleet Mix, Airline Network Configuration
- **System:**
  - **Aircraft:** Aircraft Model/Type, Aircraft Performance, Fuel Burn, Emissions, Noise Profile, Equipage Rates, Number of Available Seats, Weight, Wake Turbulence Category, SRS Category
  - **Airport:** Noise Abatement Procedures, Gates, Cat I/II/III Instrument Approaches, Runway Characteristics, Runway Configuration, Taxiways, Ramps, Airport Location, Airport ID
  - **Airspace:** Airspace Boundaries, Fixes, Airways/Routes, Sector Capacity
  - **Flight Management:** Fix Crossing Performance, Runway Occupancy Time Performance, Weather Avoidance Strategy, Inter-Aircraft Separation Performance
  - **ATM: Air Traffic Control:** Airspace and Staff Management, ATC Procedures (w/ separation standards), ATC Separation Buffer Size, Operating Procedures Retention and Application, Airspace Routing and Traffic Structuring, Airspace CD&R Application, Runway Traffic Management, Ground Traffic Management, Route Clearance Issue
  - **ATM: Traffic Flow Management:** TFM Procedures with Separation Standards, NAS wide Airport Planning (GDP/GSP), NAS-wide Reroute Planning, Flight Plan Approval, Regional Flow Planning (MIT, TBM, Reroutes), Terminal Area Flow Planning (MIT, TBM), Airport Operating Planning (AAR)
  - **Communication:** Message Transmission Frequency of Occurrence, Ground Equipage – Communication, Actual Communication Performance, Required Communication Performance, Fleet Equipage – Communication
  - **Navigation**: Fleet Equipage Rate – Navigation, RNP, Required Vertical Navigation Performance
  - **Surveillance**: Required Surveillance Performance, Trajectory Intent Errors, Ground Equipage – Surveillance, Actual Surveillance Performance, Fleet Equipage – Airborne Surveillance
  - **Fleet Management**: Flight Delay Policy, Flight Cancellation Policy
- **Environment:**
  - **Weather:** Hazardous Weather Regions, Measurement or Forecast Errors, Wind Forecast Errors, Apt Wind Conditions, 4D Wind and Temp Grid, IMC/VMC Levels
  - **Safety and Security:** Security Situations, Safety Situations, Failures
- **Scope:**
  - Physical Scope, Temporal Scope, Operational Scope, Model Fidelity

Data Mining

- Primary Sources
  - Critical Recordings: SAR, CDR
  - Airspace design: NFDC
  - Weather: RUC, WARP, ITWS
- Secondary Sources
  - TMA
- Modify data from existing sources
  - Flight Plan modification
  - Airport Loading or AOC schedules
  - Modify accuracy of surveillance or navigation
- Generate data from scratch
  - Model communications via data link instead of voice
  - Model new airports or configurations
  - Model new aircraft performance characteristics

Primary Data Sources

- **Forecast:**
  - APO Economics, Form 41, DOC Bureau of Economic Analysis
- **Demand:**
  - ETMS, T-100, APO Forecasts, Passenger O&D Survey, OAG
- **System:**
  - **Aircraft**: 7110.65, Manufacturer Data, BADA, Performance Manuals, Boeing/ICAO Indices, INM, T-100, Airline Ops
  - **Airport:** Airport Facility Directory, NFDC, Airport Plan, EPS, NOAA Charts, TAF, ACES, ACB01, AC 150/5060-5
  - **Airspace**: NFDC, ACES, NOS, ETMS, NOTAM-D
  - **Flight Management**: SAR, CDR, ASDE, Government Studies, Airline Operations manuals, ETMS
  - **ATM: Air Traffic Control**: 7110.65, SAR, CDR, Studies
  - **ATM: Traffic Flow Management**: TFM Logs, ATCSCC Logs, 7110.65
  - **Communication**: Government Studies, Industry Studies, NAS Architecture
  - **Navigation**: Industry Studies, Avionics Specs, FAA AC
  - **Surveillance**: EDX Data, Government and Industry Studies
  - **Fleet Management**: none
- **Environment: Weather:**
  - NEXRAD, ITWS, WARP, CCFP, Government Studies, METAR, ASPM, ITWS, TAF, MDCRS, RUC, FD, FA, AIRMET
- **Environment:**
  Safety and Security:
  - none
- **Scope:**
  ETMS, ACES, NOS, NFDC

Secondary Data Sources

CM_SIM File

ADD_FLIGHT_PLAN 231 N737DX/PHX.0918 ZFW N737DX 0918 -NS- 2656 T/B734/F PHX./.DR..BKW.JASEN2.IAD/1515 HOB288032 1148 330 430 ESTIMATED_FP

#Newly received flight plan info

#ADD_FLIGHT_PLAN elapsed_time enhanced_ACID data_source_config_id callsign cid(center id) tid(tracon id) beacon code ac_type route coordination_fix faa_coord_time assigned_altitude file_speed flight_plan_status

#where flight_plan_status: PROPOSED_FP(still on the ground), ESTIMATED_FP(in air out of Center airspace), DEPARTED_FP(taken off)

TMC_INPUT 55935 PROC_TGUI 23 BROADCAST_ALL

```
#TMC input messages to the cm_sim file
#TMC_INPUT elapsed_time    input_source (PROC_TGUI, PROC_CM, etc.)   23    message
#where    message:
#
#              AIRCRAFT_FIND_SLOT    ACID
#              AIRPORT_FLOW_CHANGE    airport_name    acceptance_rate    start_time
#             DELETE_AIRPORT_FLOW     airport_name    time
#             FREEZE_HORIZON_SETTINGS    fhs_string
#             TWO_WAY_METERING    flag(1:ON    0:OFF)
#             PRIORITY_AIRCRAFT    ACID    user_constraint_modes    PRIORITY_MODE(1:ON   0:OFF)
```

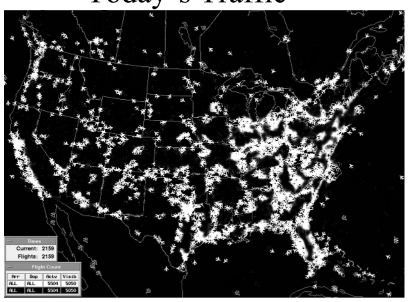
AC_DATA 56 CAA844/ILE.0318 427.12259 138.05383 313537N 0975427W 14100 236 29.07816 0 54.24 62 F N N ZFW

#tracked data for an aircraft
#AC_DATA elapsed_time enhanced_ACID x y latitude longitude altitude ground_speed heading vertical_speed time sector_id coast(T/F) turn_status altitude_status data_source_config_id

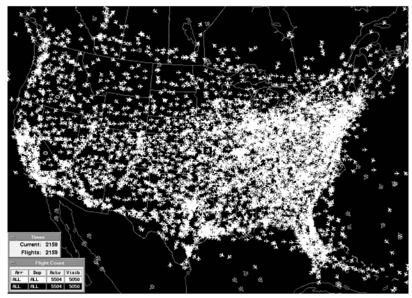
Modification of Data

- Flight Plans
- Track Information
- Communications
- Navigation Capabilities
- Airport Loading
- Aircraft Characteristics
- ATC Tools
- Wx Conditions
- Safety Procedures
- Passenger Demand
- Economics
- Recovery Time

Today's Traffic

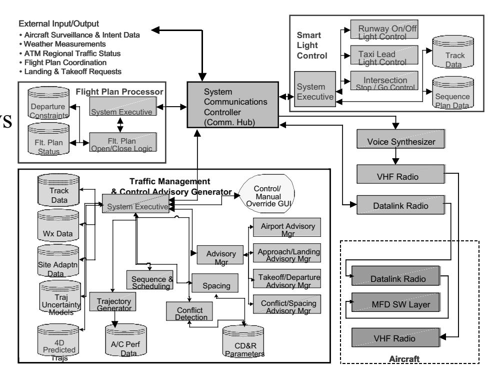


2020 Traffic



Generate Data from Scratch

- Communication Latency
- Self Separation
- Airspace Changes
- Procedural Changes
- New Aircraft Types
- Modified Equipment Capabilities
- New Airports or Runways



Data Significance

- Ensure realism with high fidelity data
  - Routes, Airspace Boundaries, Tracks, Wx
- Test validity of concept
  - The concept is measured against realistic, high integrity data
- Creates a basis for standardization
  - Utilization of the same data for common scenarios
- Repository of data affords the developer more attention on the concept
  - With a defined process, each developer will not have to search for the data
- Ability to quickly modify data creates more thorough analysis
  - Need the tools to move the data to 2020 timeframe

Suggested Data Capturing Actions

- Determine what data is required for the common and evaluation scenarios
- Determine the level of fidelity required
- Determine which data source provides required information
- Create a process for capturing data sources
- Ensure that common data sources are accessible to all SLIC developers
- Determine how data will be manipulated to generate the appropriate tools
- Determine which data will be generated from scratch

VAST Non-Real-Time Modeling

Larry Meyn

Shon Grabbe

Shawn Engelland

Terran Melconian

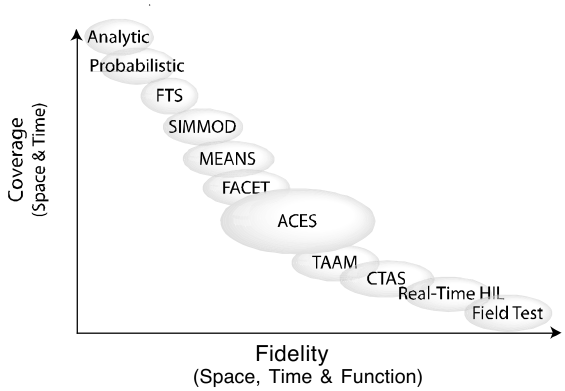
Outline of Presentation

- **Non-Real-Time Modeling Needs**
- **Current Research**
  - **ACES**
  - **Other Non-Real-Time Modeling Research**
- **Highlight Presentations**
  - **Recent Developments in FACET**
    Shon Grabbe
  - **North Texas (NTX) Research Station Capabilities**
    Shawn Engelland
  - **MIT Extensible Air Network Simulation (MEANS)**
    Terran Melconian

Non-Real-Time Modeling Needs

- **Modeling Requirements**
  - **Evaluation Criteria**
    Capacity, delay, safety, economics, environment, etc.
  - **Fidelity Requirements**
    Spatial, temporal, functional, discrete vs. continuous, etc.
  - **Coverage Requirements**
    Regional vs. national, stochastic & scenario variations, etc.
- **Data Requirements**
  - **Model Data**
    Sector geometry, aircraft performance, schedules, etc.
  - **Validation Data**
    Flight plans, weather, track data, TFM actions, etc.

The Modeling Spectrum



- **Modeling is a trade-off between coverage & fidelity**
- **Model choice is based on:**
  - **Concept development stage**
  - **Type of evaluation, i.e. capacity, safety, cost, interactions, etc.**
- **Comprehensive concept development and evaluation will require the use of several different models**
- **ACES is intended to fill a critical modeling role**
- **One modeling tool cannot be used for all evaluations**

Current Research

- Airspace Concepts Evaluation System (ACES) Development
  - Our principal focus
  - Targeted toward modeling a large, complex NAS system with strong interaction between agents
- Other Non-Real-Time Modeling Efforts
  - Addressing the need for a spectrum of models
  - Leveraging other model development efforts
  - Identifying and developing models for inclusion in ACES
  - Addressing the need for model validation

Airspace Concepts Evaluation System

- Modular design will allow simulations to be tailored to meet specific research needs for scope and fidelity.
- HLA architecture will allow incorporation of legacy models, facilitate the reuse of models in other systems and allow for future integration with other HLA systems.
- Designed to model the interactions of NAS agents that can lead to non-linear system behavior.
- Forsakes the short-term benefits of augmenting legacy simulations in order to develop a modeling tool capable of evaluating a wide range of future ATM concepts.

A long-term commitment to provide a flexible, scalable, standards-based modeling tool for evaluating ATM concepts.

Reference: Sweet, D. N., Manikonda, V., Aronson, J., Roth, K. and Blake, M., "Fast-Time Simulation System for Analysis of Advanced Air Transportation Concepts," AIAA 2002-4593, Aug. 2002.

Other Non-Real-Time Modeling Efforts

- Cognitive Human Performance Modeling
  - Human/team performance model enhancements in APEX
  - Modeling of the Advanced Airspace Concept (NARI & SJSU)
- Stochastic Simulation
  - Terminal, weather and TFM enhancements in MEANS (MIT)
  - Development of probabilistic and stochastic models (ARC)
- Environmental Models
  - Noise, emissions & wake vortex (ARC)
- Validation of new and existing airspace models
  - Selection of datasets for a typical day (Metron Inc.)
  - Identification of critical parameters for model validation (GMU)

References:

Meyn, L., "Probabilistic Methods for Air Traffic Demand Forecasting," AIAA 2002-4766, Aug. 2002.

Mueller, E. R. and Chatterji, G. B., "Analysis of Aircraft Arrival and Departure Delay Characteristics," AIAA 2002-5866, Oct. 2002.

Roy, S., Sridar, B. and Verghese, G. C., "An Aggregate Dynamic Stochastic Model for an Air Traffic System," To be published.

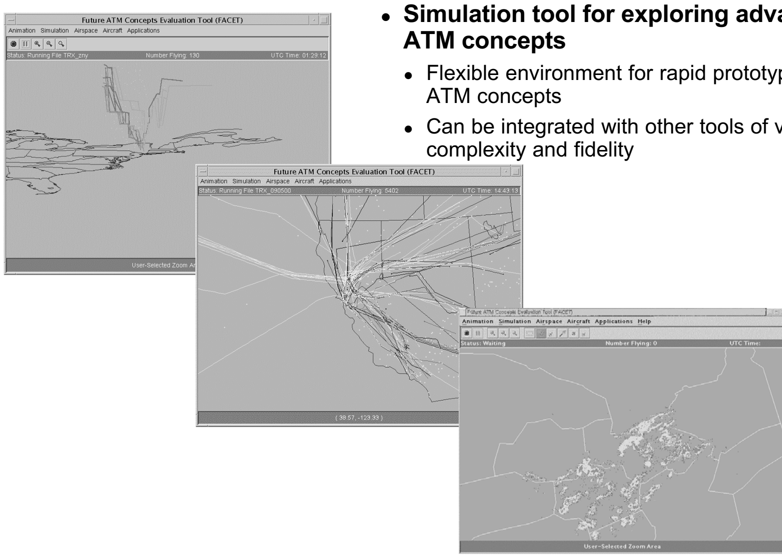
Highlight Presentations

- **Recent Developments in FACET**
  Shon Grabbe
- **North Texas (NTX) Research Station Capabilities**
  Shawn Engelland
- **MIT Extensible Air Network Simulation (MEANS)**
  Terran Melconian

Recent Developments in the Future ATM Concepts Evaluation Tool (FACET)

Shon Grabbe
NASA Ames Research Center
Moffett Field, CA 94035
January 14, 2003

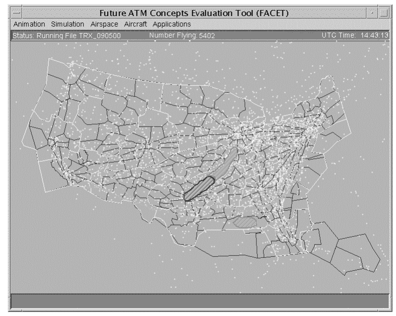
"Future ATM Concepts Evaluation Tool (FACET)



- **Simulation tool for exploring advanced ATM concepts**
  - Flexible environment for rapid prototyping of new ATM concepts
  - Can be integrated with other tools of varying complexity and fidelity

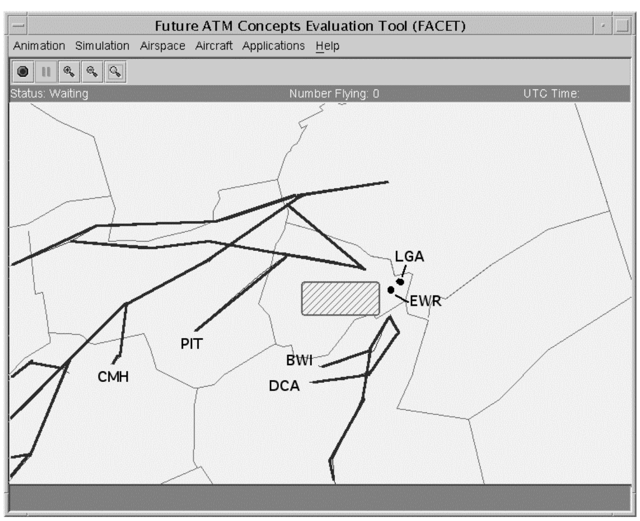
Introduction to FACET

- **Balance between fidelity and flexibility**
  - Model airspace operations at U.S. national level (over 5,000 aircraft)
  - Modular architecture for flexibility
  - Software written in "C" and "Java" programming languages
  - Can be used for both off-line analysis and real-time applications



- **Recent Additions to FACET**
  - Integrated Assessment of Traffic Flow Management Initiatives
  - Distributed Air-Ground Separation Methods
  - Probablistic Sector Demand Forecasting
  - Wind Optimal Rerouting

Integrated Assessment of Traffic Flow Management Initiatives



(NO WESTGATES/RBV Playbook Plan)

Alternative TFM Initiatives During Severe Weather

Sector (File / Edit / Table)

Time	ZNY34	ZNY10
Cap	17	17
13:06	13	14
13:21	11	18
13:36	10	18
13:51	13	14
14:06	10	14
14:21	8	9
14:36	9	14
14:51	7	18

Nominal Sector Counts

Sector (File / Edit / Table)

Time	ZNY34	ZNY10
Cap	17	17
13:06	20	9
13:21	20	12
13:36	13	15
13:51	15	10
14:06	14	10
14:21	10	8
14:36	13	11
14:51	10	16

Weather Reroute
(NO_WESTGATES)

[A] Rerouting + Nominal Departure Rates

Time	ZNY34	ZNY10
Cap	17	17
13:06	15	9
13:21	14	12
13:36	13	14
13:51	12	10
14:06	11	11
14:21	9	8
14:36	12	11
14:51	11	16

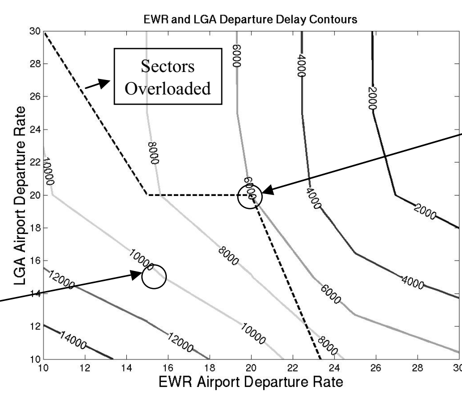
[B] Rerouting + Optimal Departure Rates

Time	ZNY34	ZNY10
Cap	17	17
13:06	16	9
13:21	15	12
13:36	13	14
13:51	13	11
14:06	13	10
14:21	13	8
14:36	15	11
14:51	8	16

Rerouting results in Sector overloading and requires additional TFM initiatives.

Delays Associated with TFM Initiatives

Time	ZNY34	ZNY10
Cap	17	17
13:06	15	9
13:21	14	12
13:36	13	14
13:51	12	10
14:06	11	11
14:21	9	8
14:36	12	11
14:51	11	16



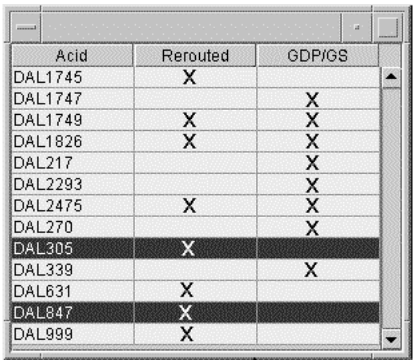
[A] Rerouting + Nominal Departure Rates Total Delay = 10361 sec.

[B] Rerouting + Optimal Departure Rates Total Delay = 5986 sec.

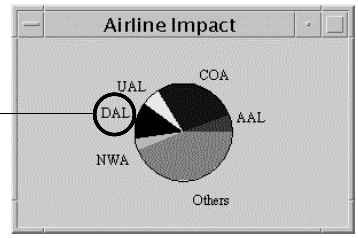
Time	ZNY34	ZNY10
Cap	17	17
13:06	16	9
13:21	15	12
13:36	13	14
13:51	13	11
14:06	13	10
14:21	13	8
14:36	15	11
14:51	8	16

Using FACET, total system demand is met (increase in capacity) with minimum delay

Airline Impact of Rerouting and Departure Delays



Acid	Rerouted	GDP/GS
DAL1745	X	
DAL1747		X
DAL1749	X	X
DAL1826	X	X
DAL217		X
DAL2293		X
DAL2475	X	X
DAL270		X
DAL305	X	
DAL339		X
DAL631	X	
DAL847	X	
DAL999	X	

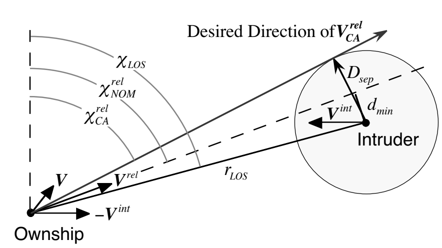


Red: Active Flights

Yellow: Proposed Flights

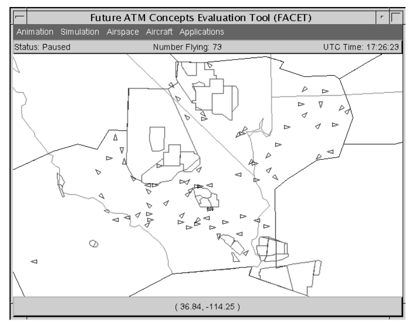
Conflict Detection and Resolution

- **Two qualitatively different Conflict Detection and Resolution (CD&R) schemes are currently available in FACET**
  - Geometric Optimization approach (developed at NASA Ames)
  - Modified Potential Field approach (developed at MIT Lincoln Lab)
  - CD&R capabilities utilized for DAG-TM studies on airborne self-separation
- **Geometric Optimization approach**
  - Seeks to minimize deviations from nominal trajectory
  - Geometric characteristics of aircraft trajectories are utilized to derive closed-form analytical expressions for efficient conflict avoidance
    - » Best heading-speed combination
    - » Heading only
    - » Speed only
    - » Altitude-rate only



Studies on Self-Separation for DAG-TM

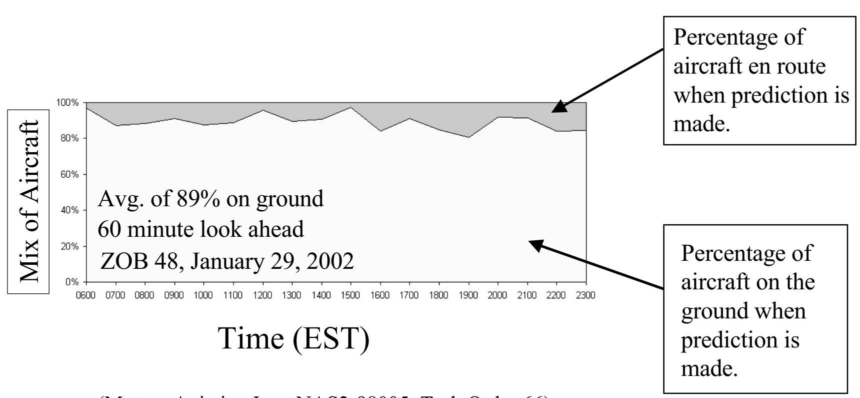
- **Free Maneuvering is a key element of DAG-TM**
  - Airborne self-separation is necessary to enable Free Maneuvering
- **Initial feasibility evaluation of airborne self-separation**
  - Focus on system-level performance characteristics and issues
  - Conducted simulation studies in FACET
- **FACET-based studies**
  - Performance evaluation of airborne separation assurance for free flight
  - Agent-based approach to conflict resolution with spatial constraints
  - Properties of air traffic conflicts for free and structured routing



- **Results support feasibility of airborne self-separation**

Probabilistic Sector Demand Forecasting

- Departure time prediction accuracy is a key factor in terms of long term trajectory prediction accuracy.



(Metron Aviation Inc., NAS2-98005, Task Order 66)

Probabilistic Sector Demand Forecasting

- Departure time uncertainty has been modeled as Gaussian distributions for major airports with means and standard deviations derived from historical delay data.
- Departure delay distributions are used with the trajectory prediction process to forecast the probability of exceeding the monitor alert levels by specified number of aircraft.
- Probabilistic demand forecasting is being compared with deterministic demand forecasting to assess the benefit for decision making.

Sector Counts (Inst. Max) as of 1

File Edit Table

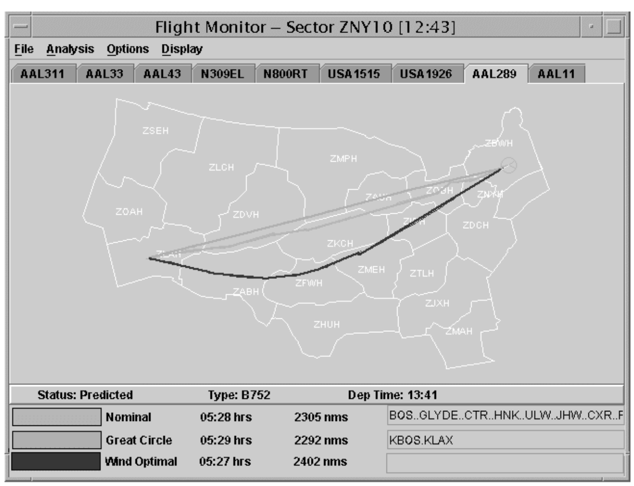
Time	ZOB29	ZKC84	ZLA30	ZNY42	ZDC12
Cap	18	15	13	15	16
19:00	19	9	14	16	12
19:15	21	21	13	17	18
19:30	17	20	14	20	14
19:45	22	10	11	18	18
20:00	22	10	9	22	23
20:15	12	13	15	16	19
20:30	10	13	11	18	12
20:45	14	9	8	9	11

Stochastic Sector Counts (Inst. M

File Edit Table

Time	ZOB29	ZKC84	ZLA30	ZNY42	ZDC12
Cap	18	15	13	15	16
19:00	100	0	100	100	0
19:15	100	100	22	92	100
19:30	28	100	51	100	19
19:45	53	1	0	65	89
20:00	36	1	0	100	100
20:15	0	1	41	84	69
20:30	0	3	3	6	15
20:45	0	0	0	0	0

Wind Optimal Rerouting



More details will be provided tomorrow by Matt Jardin.

NASA/FAA North Texas Research Station

Shawn A. Engelland
Aviation Operation Systems Development Branch
NASA Ames Research Center

Outline

- **Introduction to NTX**
  - **Facilities**
  - **Field Evaluations**
  - **Prototype Daily Use**
- **VAMS-Related Capabilities**

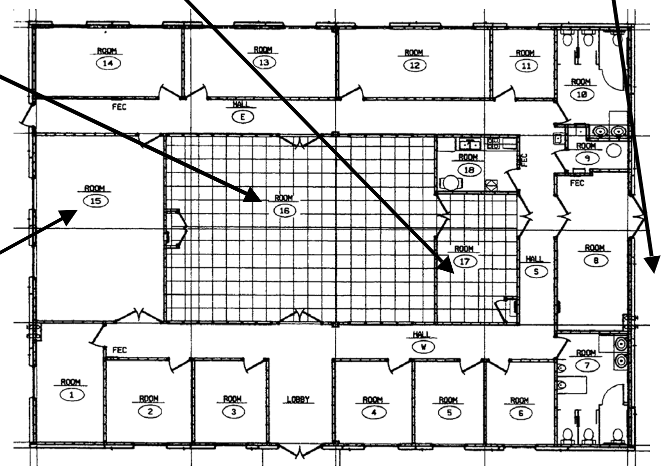
NTX Facilities - Laboratory

Auxiliary Lab
Dim: 11’ x 18’
Features: same as primary lab
Uses: isolated research work area

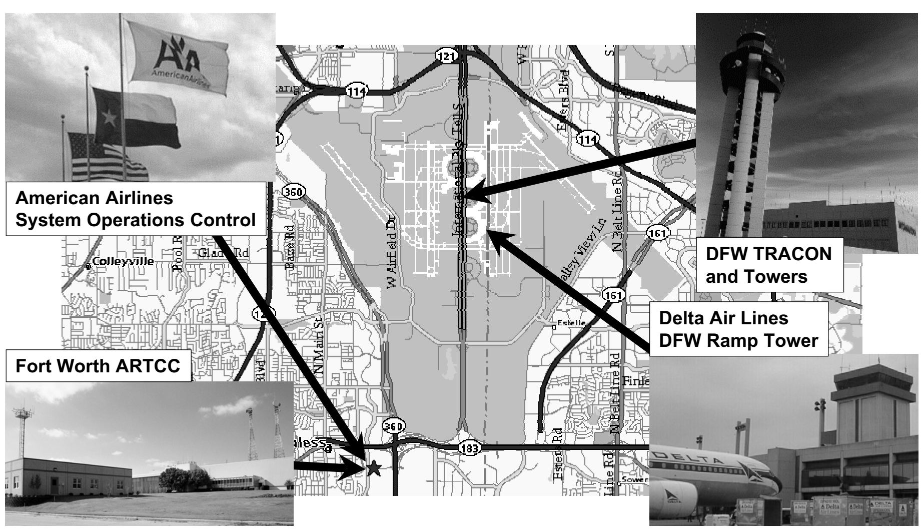
Primary Lab
Dim: 27’ x 38’
Features: raised floor, ample power and network capacity, highly reconfigurable
Uses: general purpose research work area

Conference Room
dim: 17’ x 27’
uses: visitors, briefings, training, etc.

Radio Communications Tower
Dim: 60’
Features: platform with 6 antenna mounts
Uses: TARTS, wireless LAN, etc.



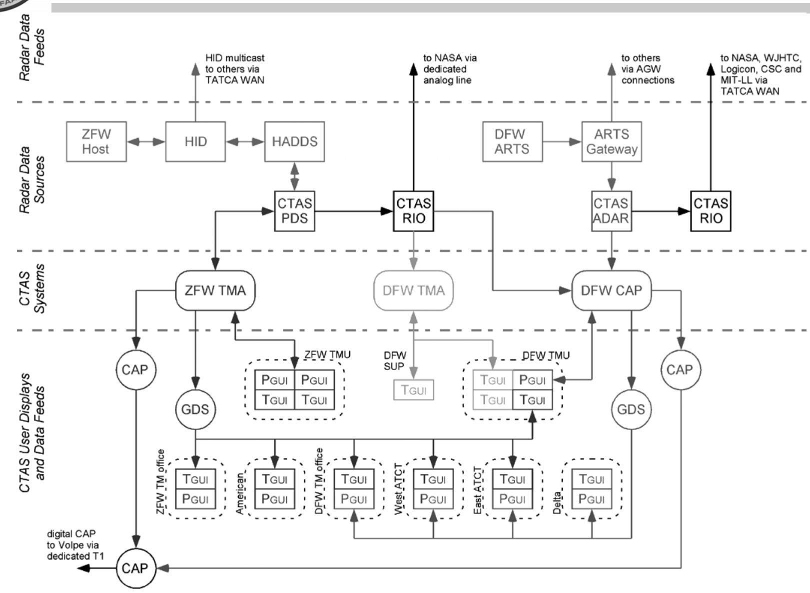
NTX Facilities – CTAS Installations



Decision Support Tool Field Evaluations

- **Major Field Evaluations**
  - **Passive Final Approach Spacing Tool (pFAST)**
  - **Traffic Management Advisor (TMA)**
  - **Collaborative Arrival Planning (CAP)**
    - » **Display System**
    - » **Digital Data Feed**
  - **Conflict Prediction and Trial Planning (CPTP)**
  - **Direct-To Controller Tool (D2)**
- **Field Evaluation Support Provided By NTX**
  - **Serve as interface between Ames researchers and local operational facilities (FAA, airlines, airports etc.) – identify key players, develop relationships and build trust**
  - **Study facility operations identifying unique constraints, sensitive issues and unforeseen opportunities**
  - **Design, procure, deploy, maintain and document field test research infrastructure**
    - » **Requires significant coordination with operational facilities**
    - » **Work with researchers to identify requirements and make necessary adjustments to accommodate operational environment**
  - **Assist with experiment setup, execution and data collection (CTAS recordings, observations, human factors surveys, voice recordings, etc.)**
  - **Archive data and assist with analysis**

CTAS Prototype Daily Use



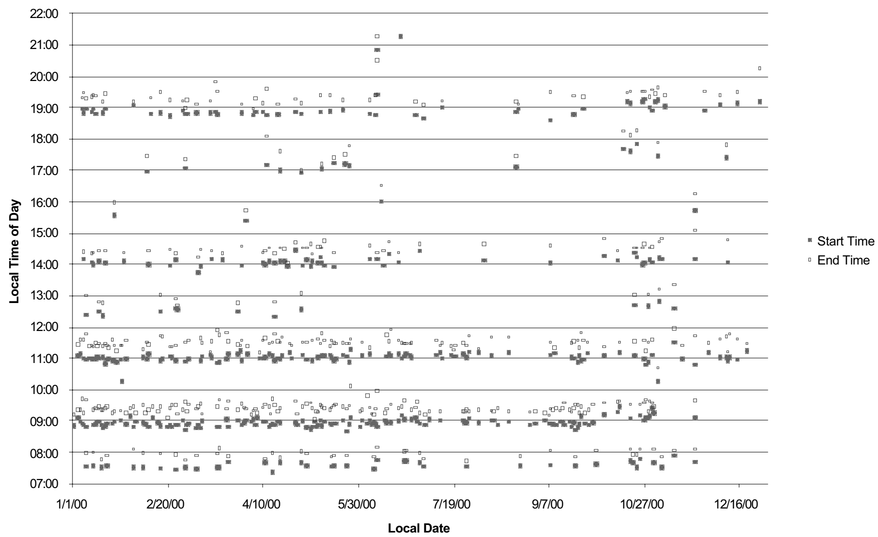
VAMS-Related Capabilities

- **Personnel**
  - NASA Team: An experienced and motivated resident team of six engineers and computer specialists each with many years of ATC field site experience
    - Several engineers with strong backgrounds in simulation modeling
    - Experience preparing and utilizing Host simulation scenarios
    - Expertise in processing and analyzing ATC data
  - FAA Team: Air Traffic personnel assigned to NTX provide invaluable ATC expertise and insight
- **Relationships**
  - FAA ZFW ARTCC: Facility Management, Traffic Management, NATCA, Automation, Airways Facilities, Quality Assurance, System Requirements, Airspace and Procedures
  - FAA D10 TRACON/DFW Towers: Facility Management, Traffic Management, Automation, Airways Facilities, Programs and Procedures, NATCA
  - FAA Southwest Region: Air Traffic Division staff and NAS Implementation (i.e. facilities engineering)
  - DFW Airport: Capacity Design Team, Operations, Planning
  - Other: American Airlines, Delta Air Lines, Southwest Airlines, FAA WJHTC, MIT-LL at DFW, DOT Volpe Laboratory

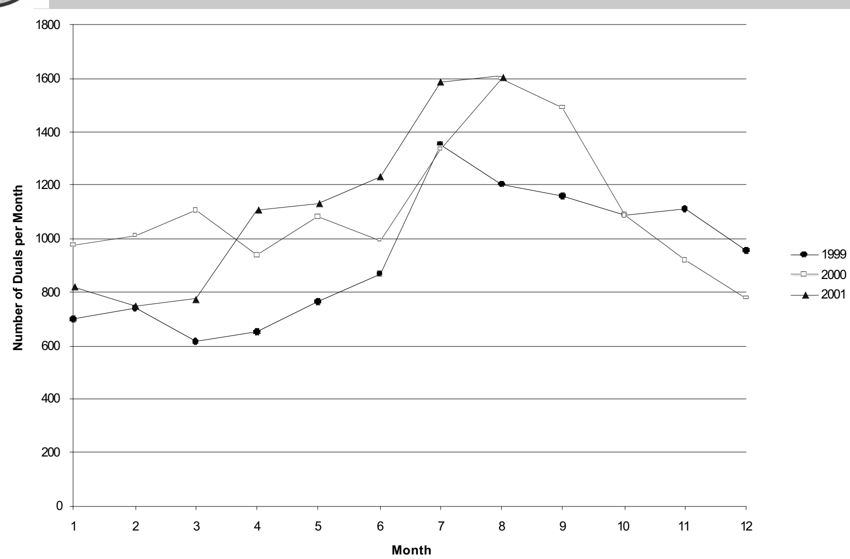
VAMS-Related Capabilities - Continued

- **NTX CTAS Data Archive**
  - More than 5 years of daily-use CTAS data from ZFW and DFW
  - Main archive includes real-time CTAS recordings plus post-processed summary and statistical data
  - Separate relational database stores archive summary information and environmental data to provide context
- **Data Sets and Analytical Results Delivered**
  - Data supplied to AATT and Free Flight to support CTAS benefits analysis
  - Data supplied to D/FW Airport consultants for SIMMOD model development
  - Data requests from Ames researchers often require quick-turn modifications to NTX post-processing utilities
  - Deliveries include unique data sets (e.g. CAD files and tower photos for FFC sim, TMU logs, ARTS traffic count statistics, op error data, etc) obtained via aforementioned relationships
- **Airspace Utilization and ATC Operations Studies**
  - In-house analysis of data in NTX archives
  - Results made available to Ames researchers and local FAA partners
  - Similar analyses performed for other ATC domains

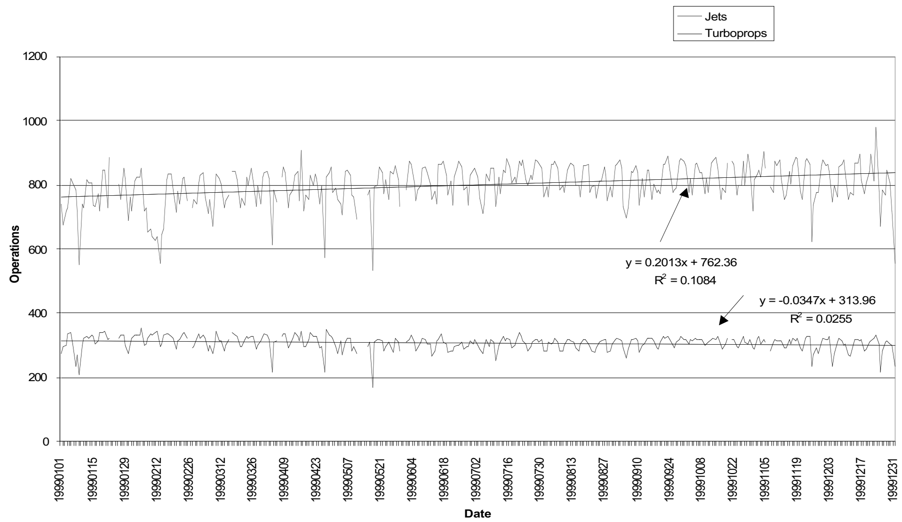
ZFW Metering for 2000



Variation in DFW Dual Arrivals



1999 DFW Arrival Tally



MIT International Center for Air Transportation

MIT Extensible Air Network Simulation (MEANS)

Professor John-Paul Clarke
Department of Aeronautics & Astronautics
Massachusetts Institute of Technology
Cambridge, MA

Motivation

- **Tool to model local and network effects:**
  - Air traffic control & flow management technology and strategies
  - Airline scheduling & recovery algorithms and strategies
- **Modeling framework to capture:**
  - Interactions between air traffic control and airline operations
  - Effects of uncertainty on system performance

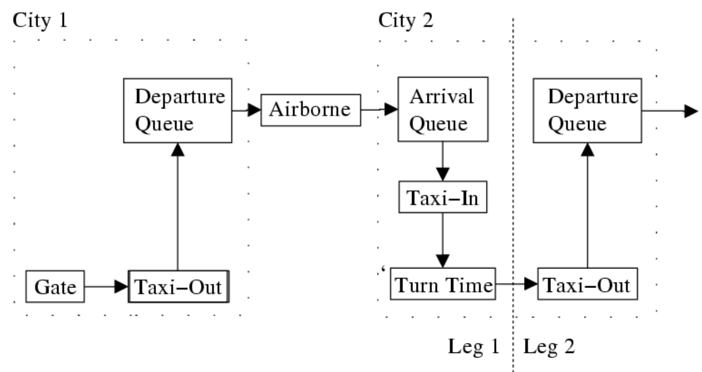
Background

- **Development started at the beginning of 2001**
  - Developed initially as a tool to evaluate the effect of congestion at a hub airport on the network of an airline
  - Expanded soon thereafter to evaluate ideas related to CDM and airline scheduling
- **Continuous improvements**
  - GDP model
  - Pareto Frontier generation
  - Weather
  - Airline disruption recovery
  - Human-in-the-loop airline operations interface

Overview

- **MEANS is an event-based simulation**
- **Tracks aircraft through several states**
  - Emphasis on ground-based effects
  - Tracks passengers if desired
- **Arrival and departure rates at airports are constrained**
  - This produces delays which propagate throughout the system
- **Used in past 1-day simulations; can be extended to work with longer runs**

Flight States



Data Sources

- **Schedule**
  - ASQP database
  - CODAS ETMS database
- **Airport Capacities**
  - FAA Benchmark Report
  - Theoretical Generation
- **Airborne, Taxi, Ground Times**
  - Historical Data (ASQP)
- **Weather**
  - CODAS Weather database

Schedule

- **ASQP data**
  - Useful because it has tail numbers
  - Not complete
- **ETMS data**
  - Complete, but aggregate only
- **ASQP data is used as a base, and "padded" with made-up flights to match the totals in the ETMS data**

Modules

- **Aircraft Turn-Around**
- **Taxi-Out & Taxi-In**
- **Airborne**
- **Tower & TRACON**
- **Ground Delay**
- **Airline Operations**
- **Weather**

Aircraft Turn-Around Module

- **Determines the amount of time aircraft needs to get ready for departure**
- **Options**
  - Input-output model for turn-around time as a function of arrival delay for each airline and aircraft type (at each airport if desired)
    - Based on MIT M.Eng. Thesis by William Vanderson (supervised by Bill Hall and J.-P. Clarke)

Taxi-Out & Taxi-In Module

- **Determines the time aircraft needs to reach departure queue (taxi-out) and gate (taxi-in)**
- **Options**
  - Stochastic distributions for each airport developed from ASQP data
    - Passing behaviour of aircraft included
    - Distributions can be developed for a specific configuration and traffic volume
    - Calculated using algorithm developed by Francis Carr based on technique developed by Idris, Clarke, Bhuva and Kang

Airborne Module

- Determines the flight time between airports i.e. takeoff at origin to arrival queue at destination
- Options
  - Stochastic distributions for each airport pair developed from ASQP and ETMS data
    - Modelled as normal distribution

Tower & TRACON Module

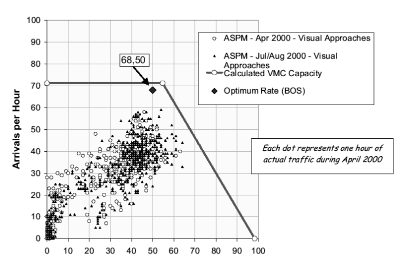
- Sets the capacity of each airport and serves arrival and departure demand (i.e. aircraft in queues)
- Options
  - Arrival and departure rate from historical data
  - Pareto frontier based on historical data
  - Pareto frontier based on simulation
  - Air traffic control agent

Airport Capacity

- Number of operations (arrivals and departures) that can be performed in a specified time period
- What affects airport capacity?
  - Weather Conditions
  - Runway Configuration
  - Fleet Mix
  - Maximum Allowable Arrival Hold Time
  - Individual Controllers

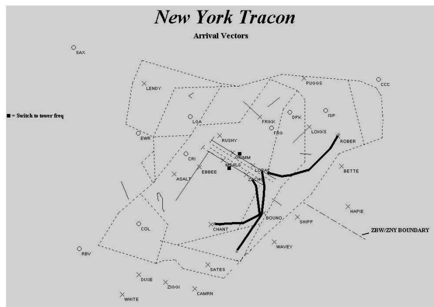
Pareto Frontiers

- Curve representing the trade off between two variables (arrival and departure rates)
- Specific Pareto frontier selected based on weather and wind direction
- Operating point based on arrival and departure demand



Arrivals

- Planes becomes tower and TRACON responsibility once they cross into the TRACON

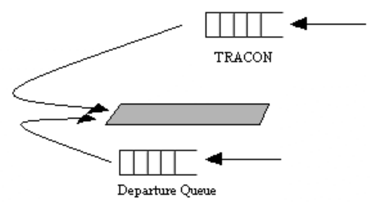


Departures

- Departures becomes tower responsibility once they push back from the gate or leave the ramp area
- Departures queue up on taxiways waiting for clearance from the tower

Runway(s)

- Runway is a shared resource that must be used by both the arrivals and departures
- Interaction between arrivals and departures limited by airport capacity



Methodology

- **Flight Generation**
  - Fleet mix used to randomly generate arrival and departure schedule with aircraft of four weight classes (Heavy, 757, Large, Small)
- **Flight Scheduling**
  - Possion arrival into TRACON

$$f(x) = \frac{\lambda^x \cdot e^{-\lambda t}}{x!}$$

  - Departure queue always filled
- **Flight Spacing**
  - Based on minimum spacing requirements in FAA 7110.65

Methodology (2)

- Optimal sequence – alternating departures with arrivals – selected provided maximum arrival hold time limit will not violated
  - AAAADDDD - 630.6s
  - AADDAADD - 555.8s
  - ADADADAD - 406.2s

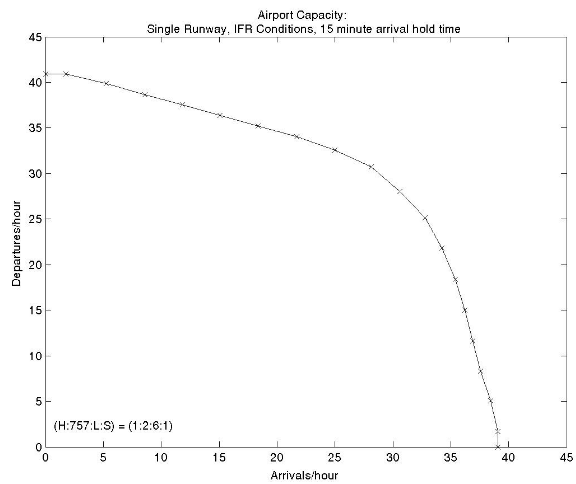
Second Event \ First Event	A	D
A	111s	55.4s
D	60.0s	79.2s

- Arrivals are processed before departures if arrival hold time limit will be violated

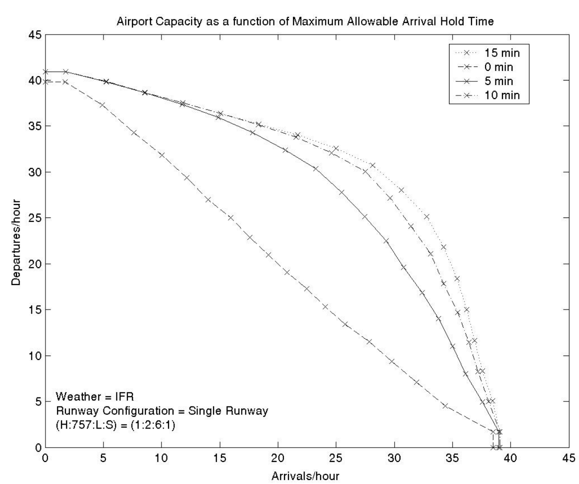
Methodology (3)

- Flights are processed through the queues for 10 hrs at a time
  - Approximates peak hrs of operation
  - Arrival hold time effect
- Arrival rate varied from 0 to 60 arrivals/hour
- Output arrival/departure rates are radially averaged

Simulated Pareto Frontier



Effect of Arrival Hold Time



Status of Tower & TRACON Module

- **Several IFR configurations completed:**
  - Single runway
  - Two independent parallel runways
  - Two close parallel runways
  - Two very close parallel
- **Other configurations in development**
  - Crossing runway under IFR
  - Corresponding VFR configurations

Ground Delay Module

- **Manages arrival slots at airports with reduced capacity**
- **Ground Delay Program (GDP)**
  - GDP initiated automatically when predicted capacity falls short by specified amount
  - GDP implemented with simplified Ration-by-Schedule algorithm with compression
  - Module sends airline "agents" assigned slots
  - Module re-assigns slots based on airline cancellations and rescheduling

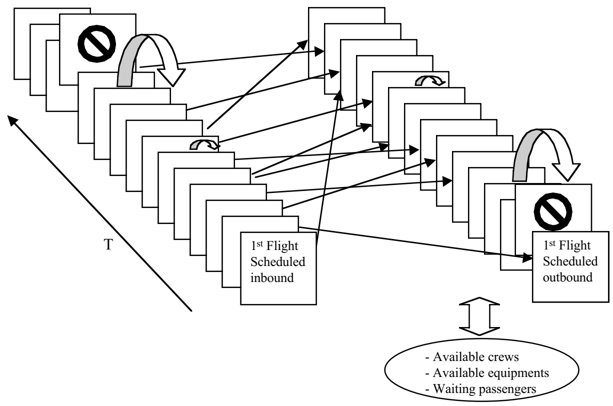
Airline Operations Module

- **Determines flights that should be cancelled and/or rescheduled in response to delays or mechanical failures**
- **Options**
  - Simple airline “agent” cancels all flights delayed over a specified time and push back all departures
  - Human-in-the-loop test subjects make decisions about cancellation and rescheduling of flights
  - “Smart” airline agent determines optimum cancellation and rescheduling strategy based on current situation

“Smart” Airline Agent

- **Model incorporates:**
  - Information latency
  - Decision making process
- **Timing (completed)**
  - Stochastic time lags
- **Decision Making (under development)**
  - Optimum cancellation and rescheduling strategy based on current situation (information available at given time) and impact of decision on airline cost
  - Based on MIT Sc.D. Thesis by Michael Clarke

Airline Response to Reduced Capacity

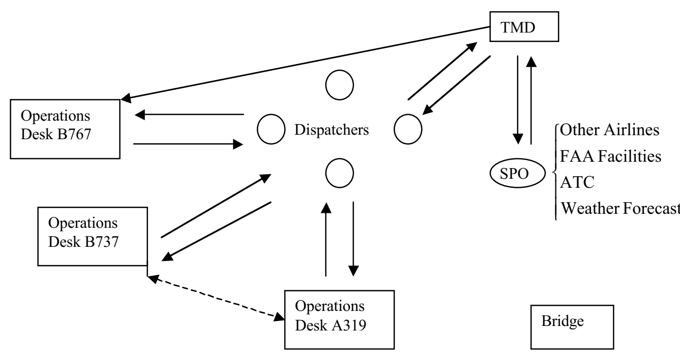


Processes

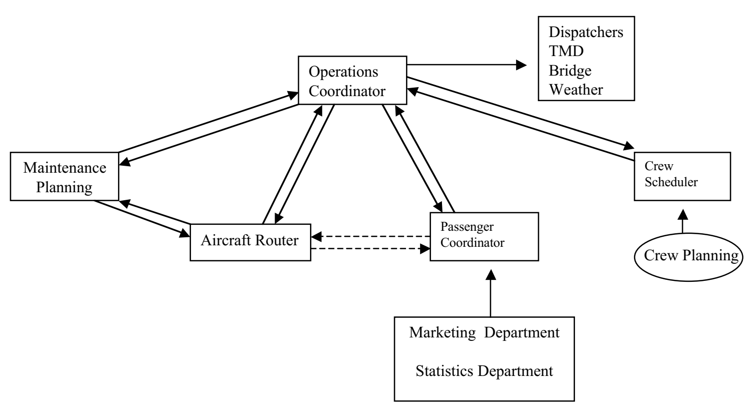
Process	Launched by	Operators
Ground delay program	Message from ATC	SOCs Aircraft Routers Crew schedulers Dispatchers ATC coordinators
Cancellation Plan	Severe weather forecast	SOCs Aircraft routers Crew schedulers
Recovery from long delay	Expected delay >30min	SOCs Aircraft routers Crew schedulers

Source: Pujet & Feron (Partial)

Typical Information Flow



Operations Desk



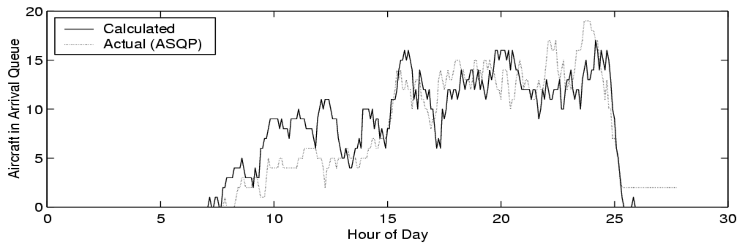
Weather Module

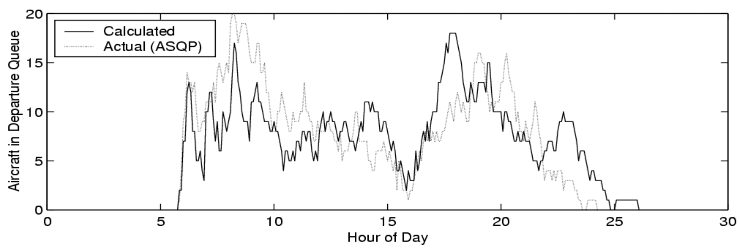
- Determines "observed" and "predicted" weather at each airport
- Options
  - Actual and predicted weather from historical data
  - Markov model of observed weather (under development) and probability distributions for mapping observed weather to predicted weather (development just commencing with help from Lincoln Labs)

Output

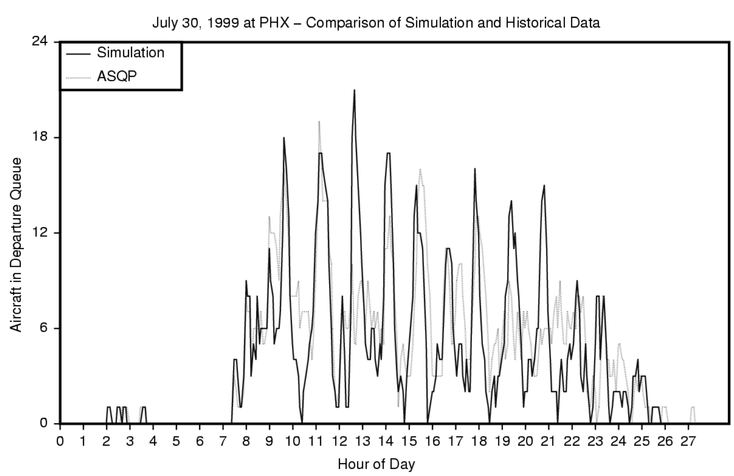
- Detailed results for every flight
- Distilled statistics
  - Delay percentages/averages
  - Cancellations, expected missed connections
  - Direct delay cost to airlines in dollars
- Visualization tools allow examination of bank structure and tracking of delayed flights

Results - GDP at Boston





Results - Peak Day at Phoenix



Results - 20% Cancellation

September 17, 1999

Total Systemwide Delay: 412223
Total Cancelled Flights: 0

carrier	**delay(min)**
AA	29485
UA	28215
DL	25251
NW	21957
...	

city	**delay(min)**
LAX	54944
DFW	45049
MIA	32586
MSP	26974
DTW	21407
CVG	19833
ORD	18700
SEA	17125
STL	16851
LGA	15799

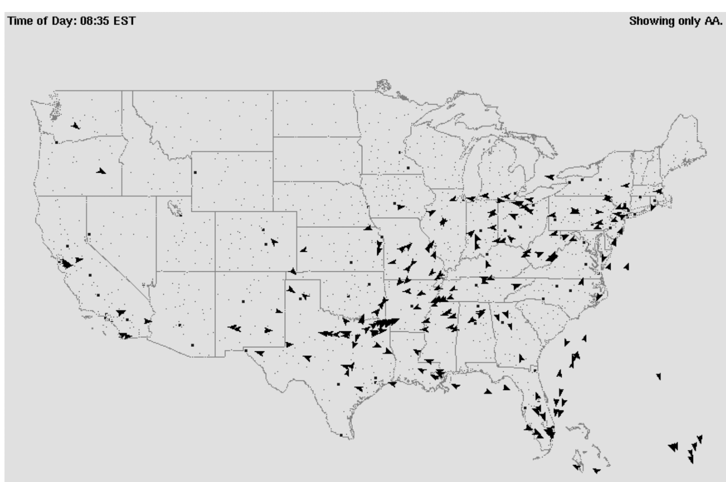
September 17, 1999 minus 20%

Total Systemwide Delay: 181008
Total Cancelled Flights: 0

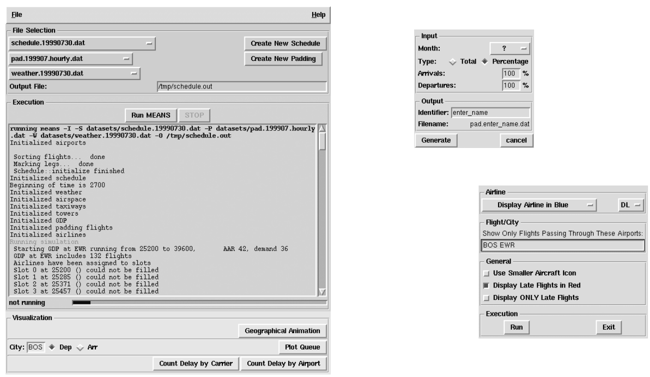
carrier	**delay(min)**
DL	14528
NW	13889
UA	12190
AA	11121
...	

city	**delay(min)**
MIA	15803
MSP	14323
DFW	12617
DTW	10762
CVG	10414
SEA	9157
STL	7757
ORD	7274
SFO	7184
PIT	6557

Visualization Example



Graphical Interface



- Previous command-line interface still available when desired

Other Features

- **Remote-Module Interface**
  - Allows other sites to provide a module for MEANS without needing to release source code
  - Can also be used to let a human operate certain components as the simulation runs
- **Stochastic Modelling Framework**
  - Framework to run MEANS repeatedly as a Monte Carlo simulation and collect results from each run
  - Tools to extract probability distributions of interesting parameters from these data

MEANS Team

- Prof. John-Paul Clarke
- Terran Melconian (Chief Engineer)
- Elizabeth Bly '03 (Airport & TRACON)
- David Smith '03 (Weather)
- Fabio Rabbani, S.M. '04 (Airline Operations)
- Georg Theis, M.S.T. '04 (Ground Delay)

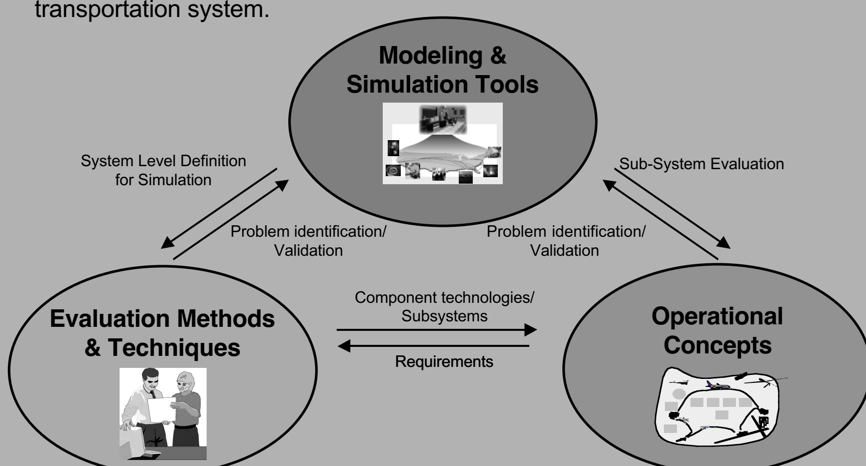
VAST-RT

Virtual Airspace Simulation Technology Real Time Simulation Sub-Element (VAST-RT) TIM #3

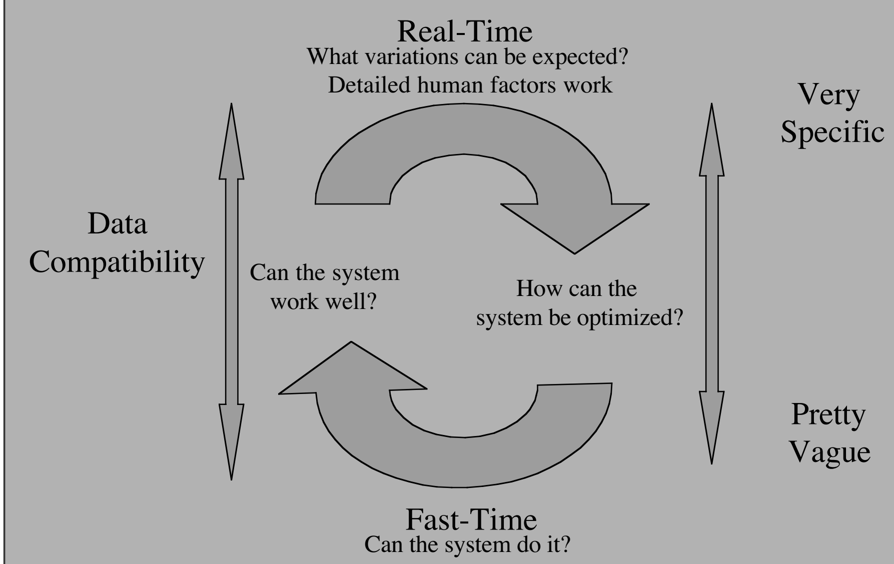
VAST-RT

VAST WITHIN VAMS

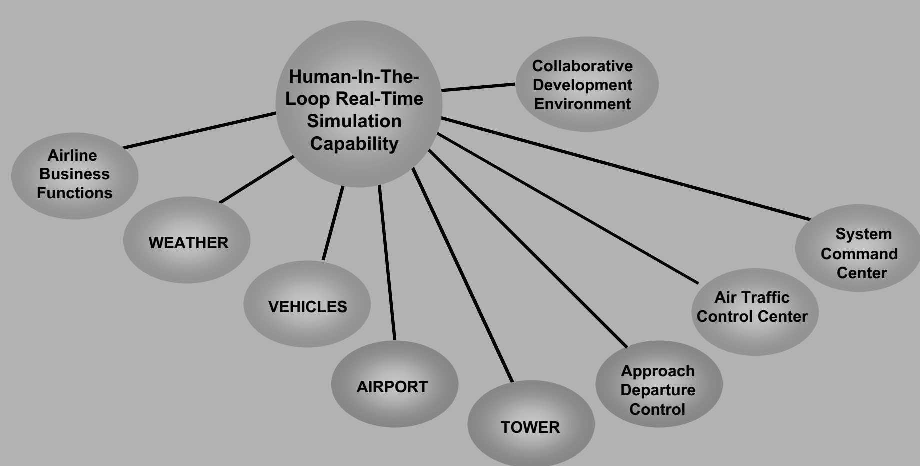
Develop the capability to simulate operations within the National Airspace System (NAS) to levels of fidelity sufficient for the research being performed. This capability will provide a safe, cost-effective, common, flexible, and accessible platform for evaluating ATM concepts for the future air transportation system.



VAST-RT & ACES

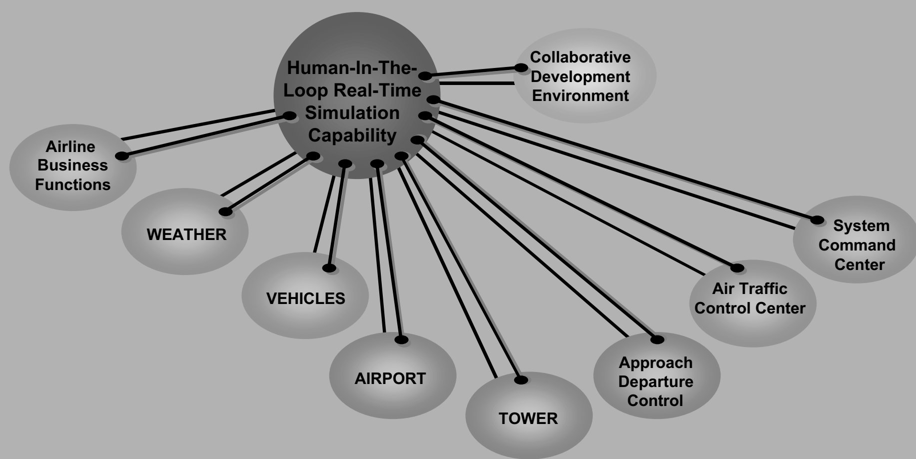


VAST-RT CONCEPT



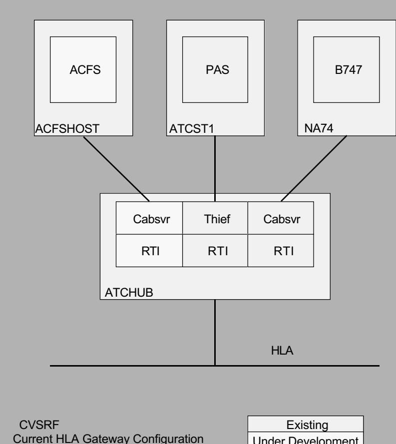
VAST-RT

VAST-RT CONCEPT

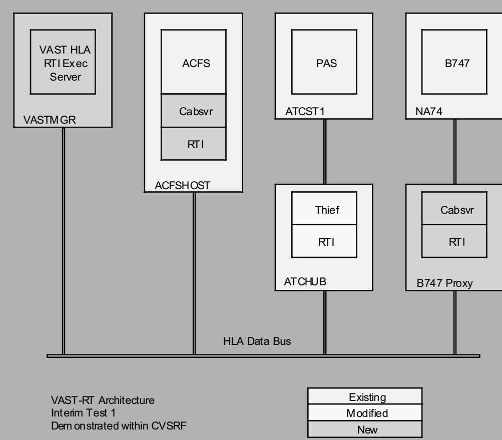


VAST-RT

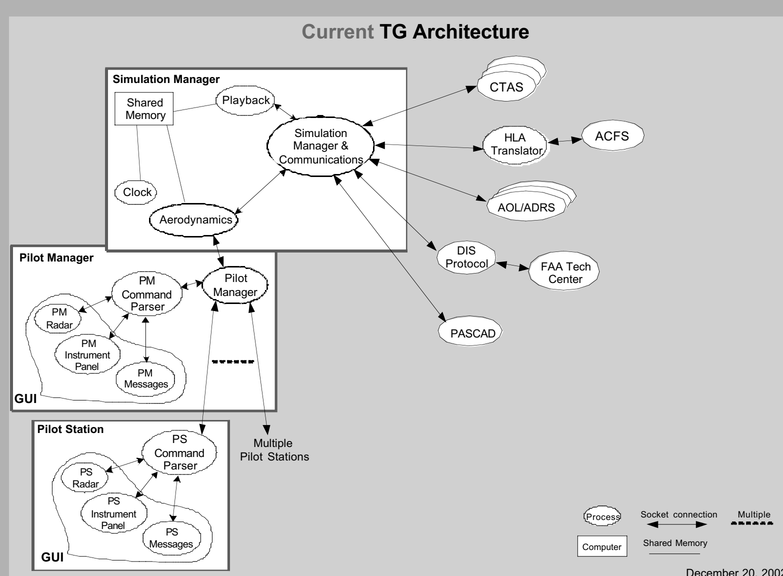
Legacy Configuration



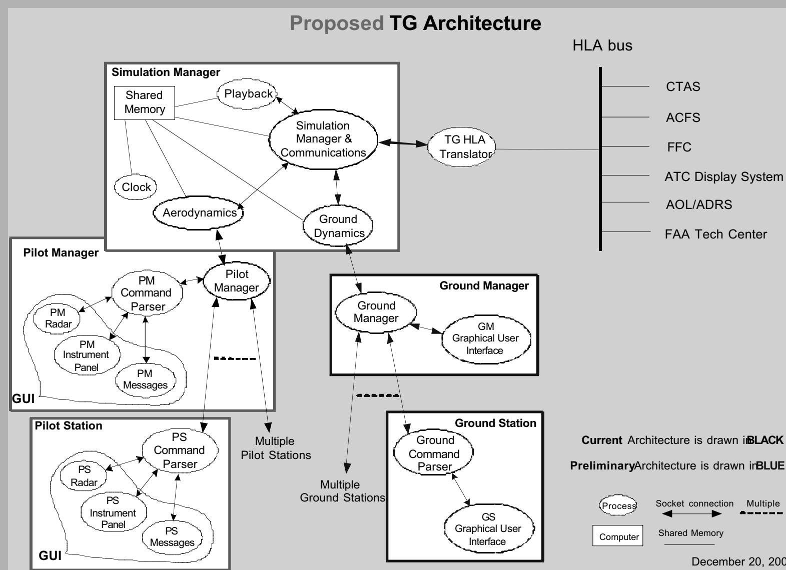
VAST-RT Configuration



Current Target Generator



VAST-RT Proposed Target Generator



VAST-RT Summary

- Interim Build Process working well
- Baseline architecture delivered
- Target generator design on schedule
- Critical Design Review on schedule

Massive Point-to-Point and On-Demand Air Transportation System Investigation

Concept PTP Overview

Virtual Airspace Modeling and Simulation (VAMS) Project
Technical Interchange Meeting 3
15 January 2003

John Sorensen
Seagull Technology, Inc.
Tel: (408) 364-8200, jsorensen@seagull.com

Concept PTP Team

Seagull Technology

- Overall program management
- Integration of Concept PTP sub-concepts
- ATM automation sub-concepts development
- Flight ops sub-concept development
- Scenario development and evaluation planning
- Cost/benefit analysis
- Coordination with VAST toolbox development
- Documentation and reporting

UNITED

- Demand demographics
- AOC sub-concepts development
- Fractional jet operations
- Project review

FedEx Federal Express

- Demand demographics
- Airport automation requirements
- Project review

Honeywell

- Flight deck avionics sub-concepts
- Flight crew human factors analysis
- System security sub-concepts

System Resources Corp. A Titan Company / **TITAN**

- NAS transition planning
- NAS architecture
- Concept evaluation planning
- Traffic controller/manager human factors
- System safety

ITT Industries

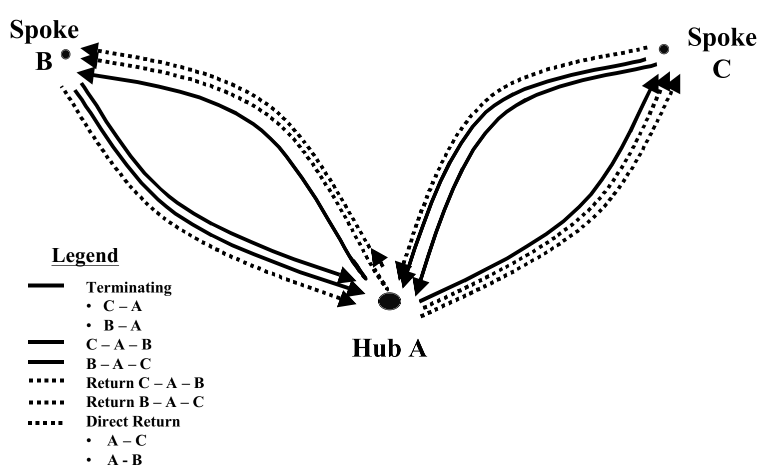
- CNS infrastructure
- Weather information infrastructure
- NWIS infrastructure

Outline

- Expected Concept PTP Potential Benefits
- Core Ideas
- Self Assessment Plans

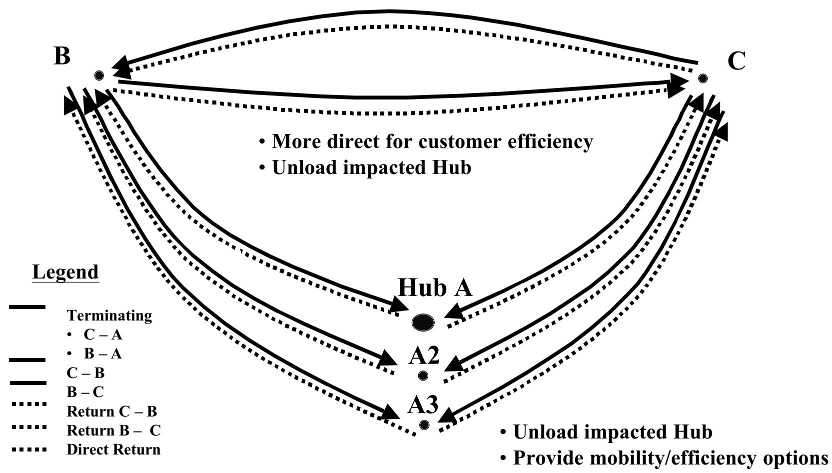
How Concept PTP Will Work

Current Hub-Spoke Design:



How Concept PTP Will Work

Point-to-Point Design Has Two Mechanisms to Increase NAS Capacity:



Concept PTP Premise

- **Increase National Airspace System (NAS) Capacity by:**
  - **Facilitating and Incorporating Massive Use of Point-to-Point (PTP) and On-Demand Air Transportation between Non-Hub Airports –**
    - **i.e., Broaden the number of nodes and connectors within the grid**
- **Requires Augmenting NAS Components to Implement the Concept**
  - **Air Traffic Management Systems**
  - **Fleet Operations, CNS, and Weather Information Infrastructure Aircraft Equipage, Fleet Mix and Number**
  - **Commercial Aircraft Operations Management Processes**
    - **Large scheduled air carriers (travel and shipping)**
    - **Regional carriers, charter carriers, and air taxi operators**
    - **Business and fractional jet ownership organizations**
    - **Other aircraft operators (e.g., UAV, rotorcraft)**

Key Concept Benefits

- **Harness underutilized public (and private) airports plus the potential of ATM and AOC automation, advanced avionics, and CNS technologies potential to increase overall NAS CAPACITY**
  - **Benefits analysis will estimate potential overall capacity gain**
  - **Greater number of airports in use can also relieve capacity-limited hub-spoke airports**
- **By-product of concept is an increase in overall transportation system EFFICIENCY**
  - **Benefits analysis will measure a reduction in total travel time**
  - **Facilitates more direct and timely door-to-door service (mobility)**

Enabling Concept PTP Core Ideas

To Mechanize Concept PTP Requires Development of Six Core Ideas:

ATM Automation
- **1. Provide Non-Towered Airports with ATM Automation**
- **2. Utilize Expanded Terminal Area Time-Based ATM**
- **3. Mechanize Strategic En Route ATM in New Airspace Structure**
- **4. Expand Traffic Flow Management Capability**

Airline Operations Automation
- **5. Expand Fleet Operations (Dispatch) for Collaboration and Flight Timing Control**

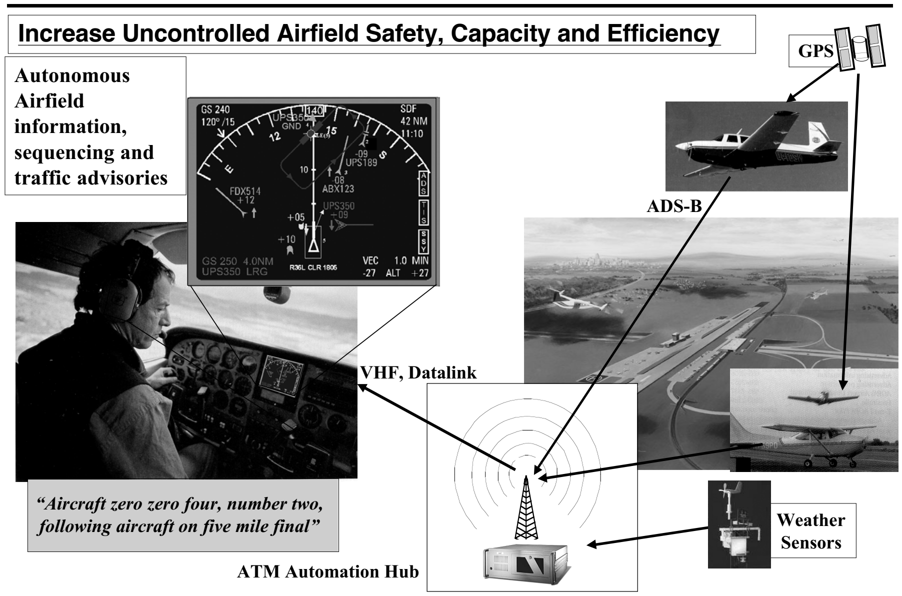
Advanced Avionics
- **6. Accommodate Broader Aircraft Spectrum and Exploit Advanced Avionics Equipage**

Incorporate CNS, NWIS, and Weather Information Infrastructure and Technology Advancements to Enable Core Ideas

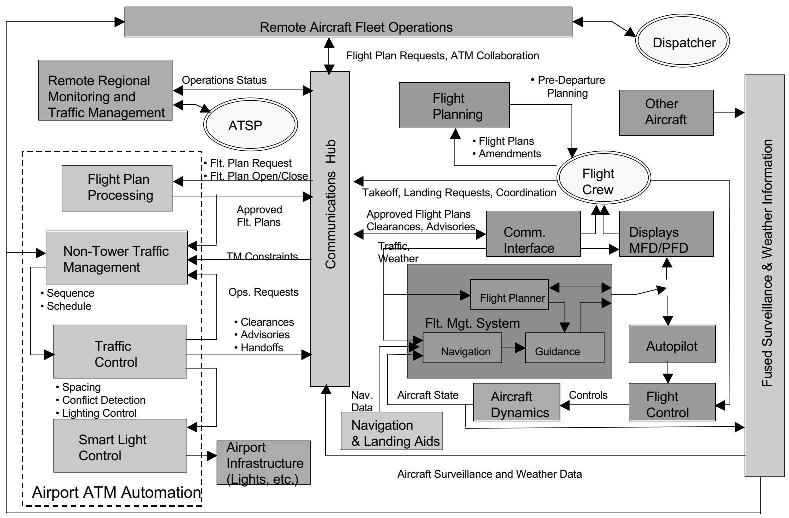
Core Idea 1 - Provide Non-Towered Airports with ATM Automation

- **Provide same traffic advisory, sequencing, weather and airport information as towered airport**
- **Provide LAAS and smart airport lighting for precision approach/departure**
- **Enable same capacity during IFR as in VFR**
- **Provide mechanism for the Greater NAS to monitor and incorporate small airport operations into emerging ATM decision support tools and automation**
  - **Monitoring small airport operations – additional benefit to provide system security**
- **Increase small airport safety and perceived safety as well as capacity and travel efficiency**

Core Idea 1 - Non-Towered Airport ATM Automation



Core Idea 1 - Non-Towered Airport ATM Automation

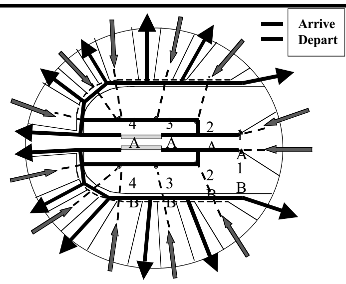


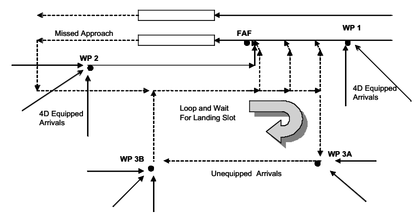
Integrated Airport ATM Automation – Flight Deck Functional Architecture

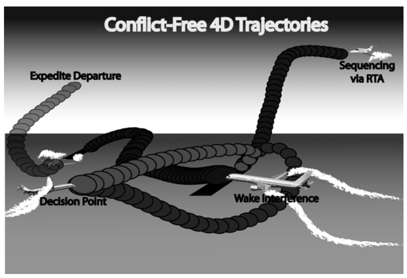
Core Idea 2 - Utilize Expanded Terminal Area With Time-Based ATM

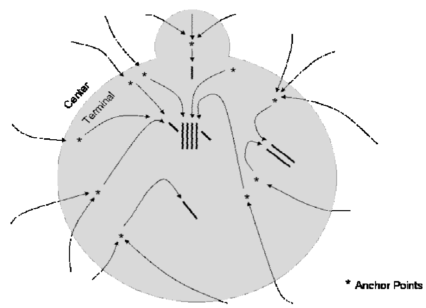
- **Broaden terminal (TRACON) region to encompass smaller surrounding airports**
- **Redesign terminal airspace and corner-post feeder fixes**
  - **Flexible runway anchor (way) points**
  - **Flexible climb and descent corridors**
  - **Direct paths for 4D equipped aircraft**
- **Expand Traffic Management Advisor (a la Multi-Center TMA) concept to set non-conflicting required time-of-arrival (RTA) at anchor points and intermediate waypoints for transitioning aircraft**
- **Use aircraft 4D FMS and CDTI to follow assigned transition to/from en route, approach/departure paths and RTAs (non-conflicting cells move along precise paths)**
- **Work with Regional TFM to respond quickly to changing runway and airspace conditions**

Core Idea 2 - Terminal Area Time-Based ATM





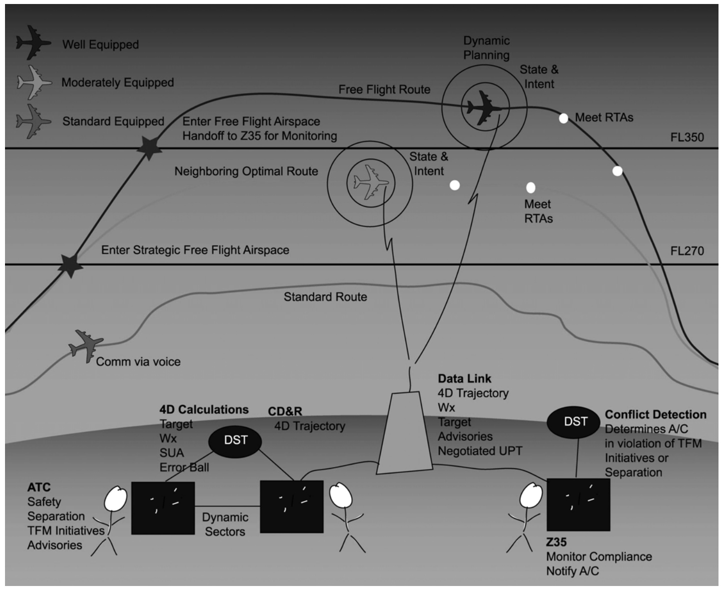




Core Idea 3 - Mechanize Strategic En Route ATM

- **Use 4D guidance (either FMS or Operator PCT provided) to meet flight plan destination RTAs**
- **Airspace segregated into three altitude bands to exploit three aircraft equipage levels for separation assurance and increased en route capacity**
  - **Sectorless airspace for FL350 and above – equipped for self separation ("Well equipped," or Class C aircraft); "Z35"**
  - **Dynamic sectors for FL270 to FL345 – air-ground trajectory negotiation ("Moderately equipped," or Class B aircraft) and self separation (Class C); sector sizing adjusted to traffic densities and complexities**
  - **Sectored altitude bands below FL270 used by non-equipped managed aircraft ("Standard equipped," or Class A aircraft) plus climb/descent transition for Classes B and C**
- **Harness aircraft self separation (*a la* DAG TM CE-5 and CE-6) with ADS-B and 4D trajectory intent/guidance – for Class C and Class B aircraft**
- **ATM continues to provide tactical separation assurance backup, for self-separating aircraft**

Core Idea 3 - Mechanize Strategic En Route ATM



Core Idea 3 - Mechanize Strategic En Route ATM

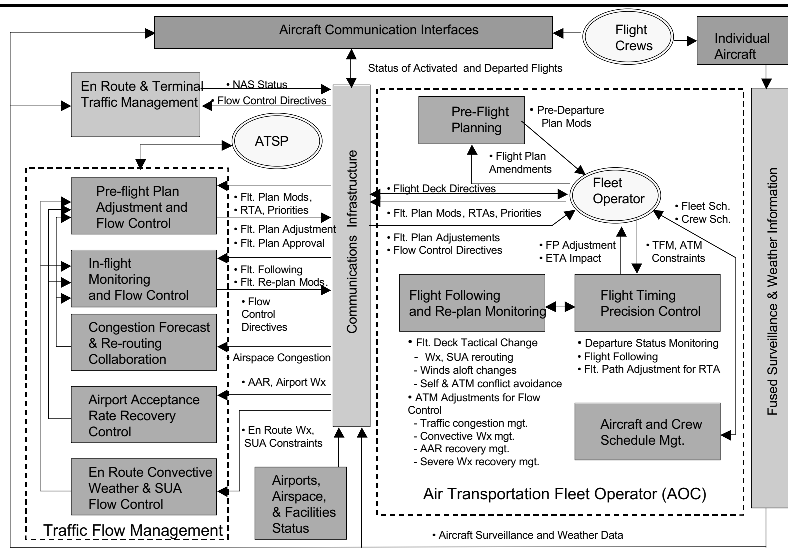
Legend:
- ADS-B, TIS-B, FIS-B, ADL, AOP, 4D FMS, RTSP
- ADS-B, ADL, 4D FMS, RTSP
- No Additional Requirements

Airspace	Altitude	Responsibilities	Responsibilities
Free Flight Airspace	≥FL350	FC Responsibility: Separation, Adherence to TFM Initiatives, Maintain 4D-UPT Z35 ATC Responsibility: Monitoring Compliance	
Free Flight Airspace	<FL350, ≥FL270	FC Responsibility: Separation, Adherence to TFM Initiatives, Maintain 4D-UPT ATC Responsibility: Monitoring Compliance	FC Responsibility: UPT, Maintain 4D-UT Envelop ATC Responsibility: Separation, Neighboring 4D-UT, Adherence to TFM Initiatives
Transitional Airspace	<FL270, ≥FL180	FC Responsibility: UPT, Maintain 4D-UT Envelop ATC Responsibility: Separation, Neighboring 4D-UT, Adherence to TFM Initiatives	FC Responsibility: Route, Maintain 3D-Route Envelop ATC Responsibility: Separation, 4D-Route, Adherence to TFM Initiatives, Advisory Info
Transitional Airspace	<FL180	FC Responsibility: UPT, Maintain 4D-UT Envelop ATC Responsibility: Separation, Neighboring 4D-UT, Adherence to TFM Initiatives	FC Responsibility: Route, Maintain 3D-Route Envelop ATC Responsibility: Separation, 4D-Route, Adherence to TFM Initiatives, Advisory Info

Core Idea 4 - Expand TFM Processes

- **National (N-TFM) and Regional Traffic Flow Management (R-TFM) review submitted pre-flight plans and compute suggested path and timing adjustments to lower statistical potential of conflict and to even spatial density**
  - **_ Fleet Operators submit optimal flight plans with desired time of arrival**
  - **_ TFM collaborate on plan adjustments with Operators**
  - **_ Adjustments include flow control measures**
  - **_ N-TFM focus on international and transcontinental flights**
  - **_ R-TFM focus on high density shorter flights**
- **During flight:**
  - **_ Provide flow control input to account for shifting weather, SUA status, traffic congestion and destination runway conditions**
  - **_ Provide timely assistance to recover flight plans due to AAR and airspace recovery, in accordance with Operator business priorities**

Core Idea 4 - Expand TFM Processes



Integrated TFM-Fleet Operator Process Functional Architecture

Core Idea 5 - Expand PTP Fleet Operations (Dispatch)

- Fleet Operator/dispatcher optimizes individual aircraft/crew schedules to meet transportation demand and business priorities
- Aircraft flight plans optimized but with timing and path constraints or adjustments (from both N-TFM and R-TFM)
- Operator uses Precision Control Tool to regulate estimated time of arrival in accordance with submitted flight plan and business priorities
- Operator works closely with TFM, en route ATM, and flight crews to keep information on flights current and flight priorities managed
- Coordinated flights include both scheduled and on-demand (taxi) cases

Core Idea 5 - Expand PTP Fleet Operations (Dispatch)

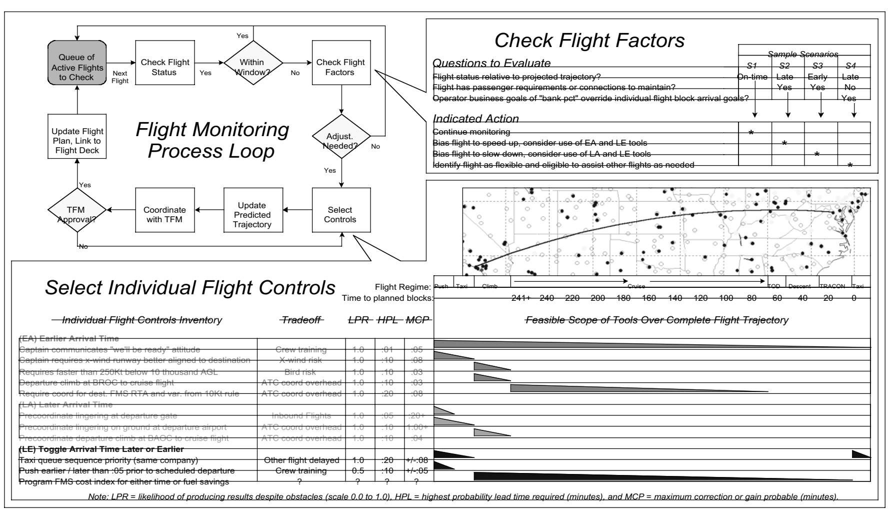
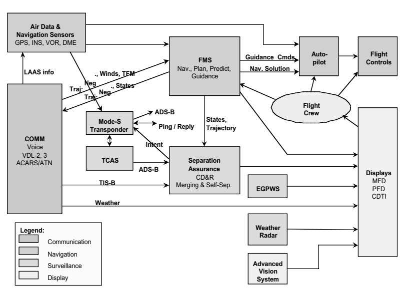


Figure 2-21. Content of the Precision Control Tool (PCT)

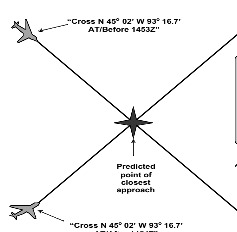
Core Idea 6 - Exploit Advanced Avionics

- **Economic benefits promote use of highly equipped aircraft**
  - **Precise 4D (multi-RTA) guidance to follow timed flight plans**
  - **Required total system performance (RTSP) for precise path control and optimal (reduced) spacing for separation assurance**
  - **Strategic conflict detection and collaborative resolution (CD&R)**
    - **Leverage NASA's Autonomous Operations Planner (AOP)**
  - **Flight re-planning ability to adapt to changing winds/weather, traffic, SUA status, and arrival/departure RTAs**
  - **ADS-B for total airspace surveillance, CD&R, and flight plan monitoring**
  - **Full data link capability**
    - **ATM/Operator information exchange with aircraft FMS**
    - **Collaborative flight/traffic management automation**
  - **Wake vortex sensing/mapping/display for separation safety**
- **Fleet size and types optimally fill the O-D demand**

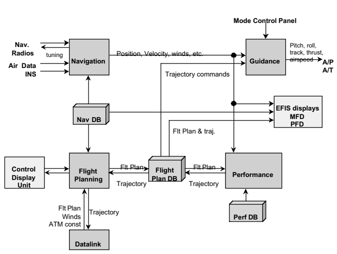
Core Idea 6 - Exploit and Promote Advanced Avionics Equipage



Avionics Tightly Integrated With ATM Automation via ADL



4D RTA Used For Separation Assurance



Advanced FMS Capability Used for Precision Trajectory Control

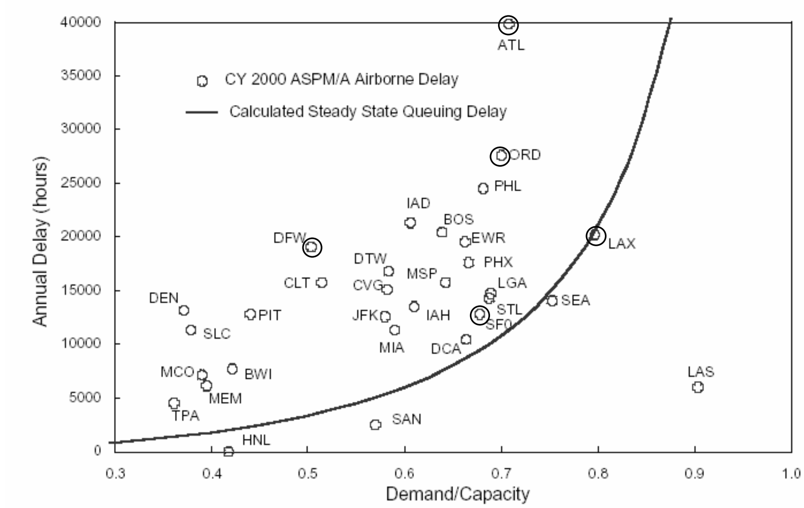
Enable Concept PTP via Integrated CNS and Weather Information Infrastructure

- **Communications - Data links, wireless, and land lines tie all nodes of system together at all times**
  - NAS-Wide Information System (NWIS) realized
  - All aircraft have continuous communications coverage
- **Navigation - GNSS enhanced with redundant ground system**
  - All aircraft guided and monitored to be within flight plan envelopes for increased airspace capacity (plus security benefit)
- **Surveillance - All aircraft under continuous surveillance**
  - Either ADS-B or radar transponder equipped
  - Linked ground stations provide seamless aircraft state and intent data
- **Winds/weather/atmosphere - Integrated meteorological sensor system provides common weather data to all nodes**
  - Collaborative flight planning, re-planning, trajectory timing, weather avoidance based upon common data set

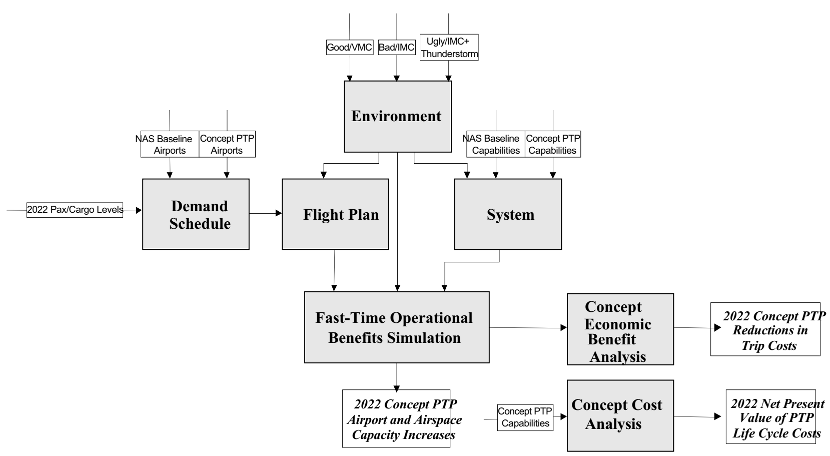
Concept PTP Evaluation Plans

- **Determine increase in capacity possible from Concept PTP**
  - Define capacity as number of passengers and tons of freight hauled
  - Examine urban regions that are capacity constrained
    - ORD and ZAU
    - West Coast Corridor (Bay Area and LA Basin)
  - Select an array of suitable auxiliary airports to complement Hubs
  - Use two mechanisms to provided increased capacity while capping traffic in/out of impacted Hubs
    - Direct PTP flights between Spokes and smaller airports (bypass Hub)
    - Direct flights into auxiliary airports in same urban area as Hub
  - Develop city-pair flight plans to and from region
  - Estimate types and numbers of aircraft involved
  - Compute parametric measure of concept's ability to provide capacity increase
    - Treat percentage of on-demand flights as system parameter

Concept PTP Evaluation Plans



Concept PTP Evaluation Plans



General Self-Evaluation Methodology

Concept PTP Evaluation Plans

- **Design high fidelity model of expanded terminal area**
  - **Set up to examine technical feasibility of PTP 2**
    - **Use of 4D FMS and ATM automation to interweave complex trajectories**
    - **Examine effect of parametric separation requirements on capacity**
    - **Examine effect of good, bad, and ugly weather days**
  - **Collaborate with other terminal area concept developers**
  - **Make compatible with ACES design**
  - **Use ORD/ZAU for starting scenario**

- **Attack highest priority safety issues**
  - **For example, reduced separation with ADS-B and measures of Required Total System Performance (RTSP)**

- **Take next step in human performance analysis**

Presentation to:

NASA VAMS TIM #3

System Wide Capacity Increasing Concept

Boeing
Air Traffic Management
Metron Aviation

Alvin Sipe

Lead Engineer

15 January 2003

Export Compliance Notice
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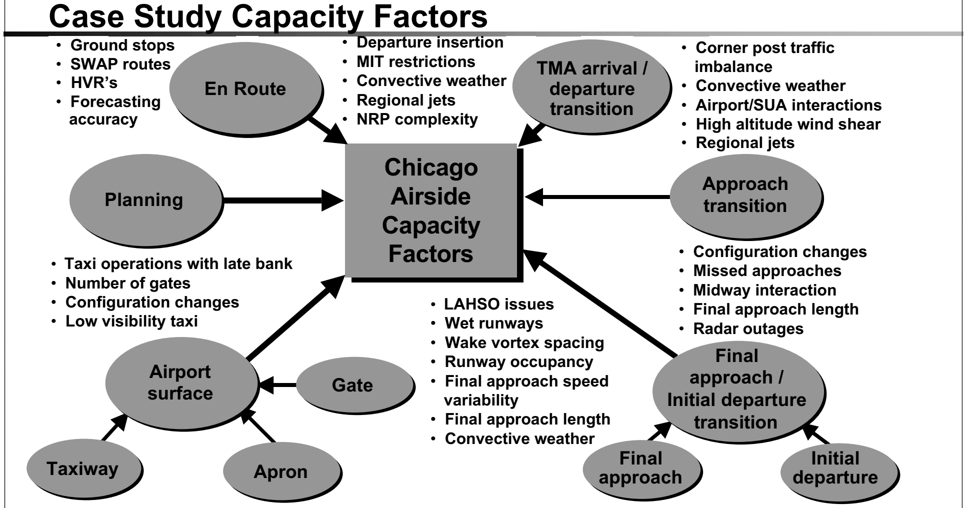
Additional questions should be addressed to your designated Boeing Export Compliance Administrator.
Contact Jodie Carvo 425.373.2783

Operational Issues

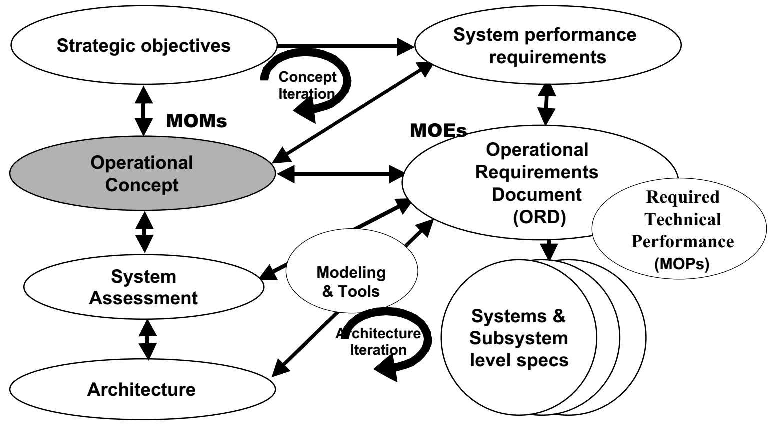
Case Study Capacity Factors



- **Complex, inter-acting constraints dynamically change airport and airspace capacities**

Source: *NASA Sponsored Airspace Preliminary Design Case Study*

System Engineering Context for Operational Concept



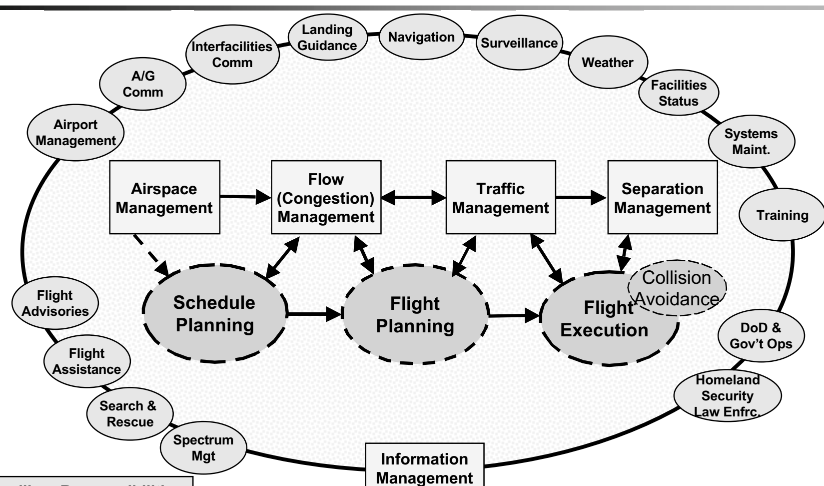
MOM – Measures of Mission

MOE – Measures of Effectiveness

MOP – Measures of Performance

ATM_0119

System Wide Capacity Increasing Concept Context



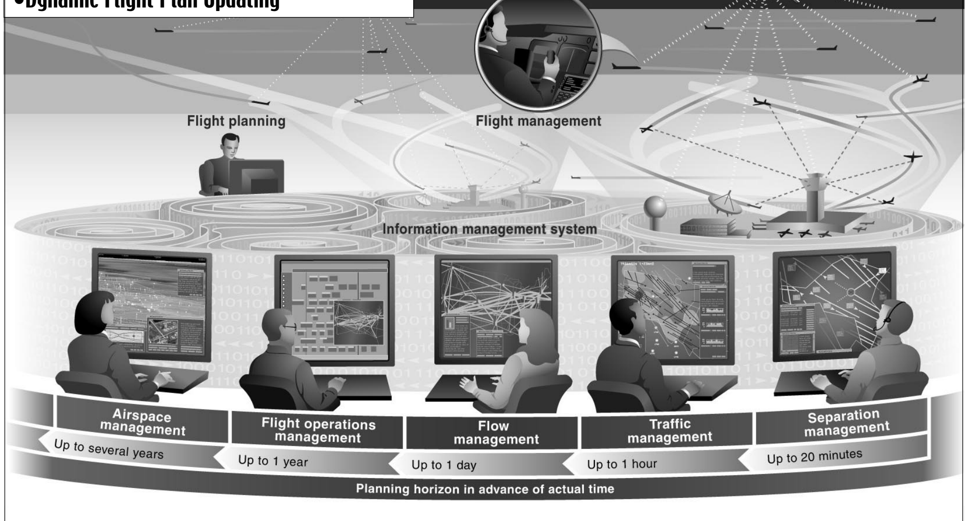
ATM Ancillary Responsibilities

Air Traffic Domain Core Responsibilities

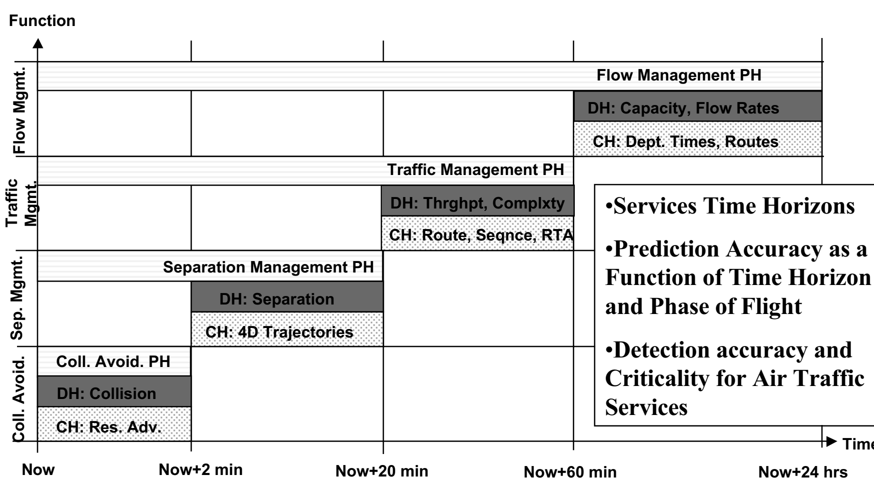
Typical Airspace Operator Responsibilities

Management = Monitor, Assess, Plan, and Execute

- Integrated Services with Time Partitioning
- Enriched Trajectory Based Flight Plans
- Required Total System Performance (RTSP) Based Flight Planning
- Dynamic Flight Plan Updating



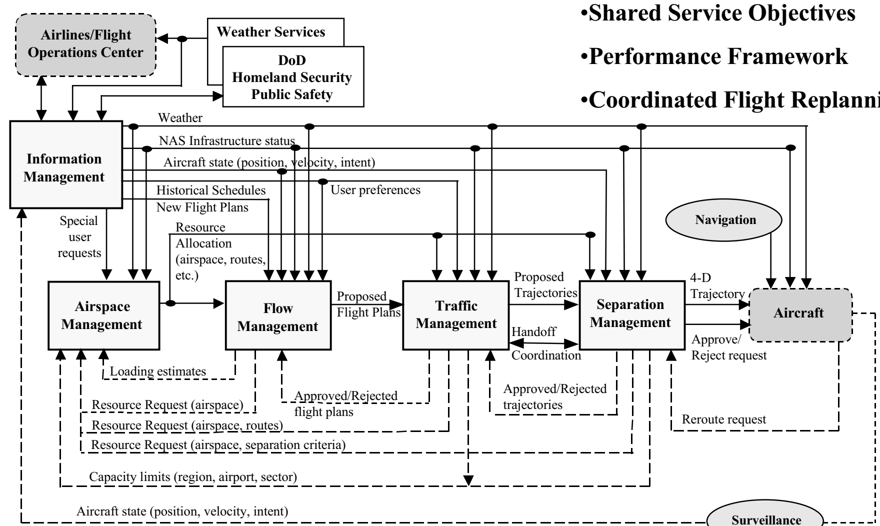
Time Partitioning of ATM Services



- Services Time Horizons
- Prediction Accuracy as a Function of Time Horizon and Phase of Flight
- Detection accuracy and Criticality for Air Traffic Services

PH: Prediction Time Horizon DH: DetectionTime Horizon CH: Control Time Horizon

Air Traffic Management as an Integrated Set of Core Services



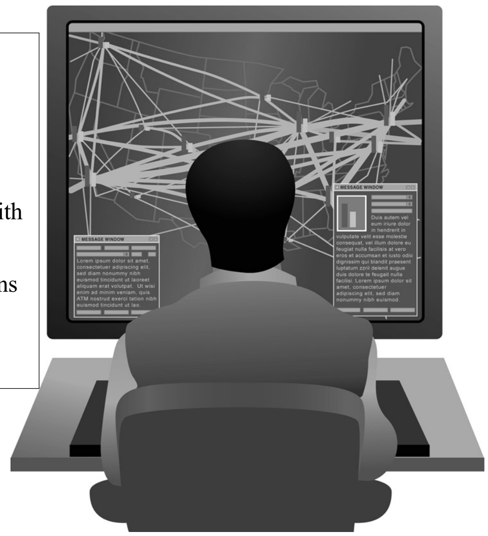
- •Shared Service Objectives
- •Performance Framework
- •Coordinated Flight Replanning

Airspace Management

- •Dynamic Infrastructure Health Monitoring
- •Estimation of Actual Total System Performance
- •Determination of Required Total System Performance
- •Time Horizon Determination and Allocation to ATM Services
- •Dynamic Airspace Configuration
- •Long Term Monitoring and Feedback of System Performance

Flow Management

- •Enhanced Flow Prediction with Uncertainty Estimation
- •Enriched Constrained Resource Set
- •Equity Based Allocation of Delay
- •Uncertainty Based Flow Planning with Discounting
- •Schedule Connectivity Considerations
- •Flight Plan Controls
- •Back Up Flow Planning



Traffic Management

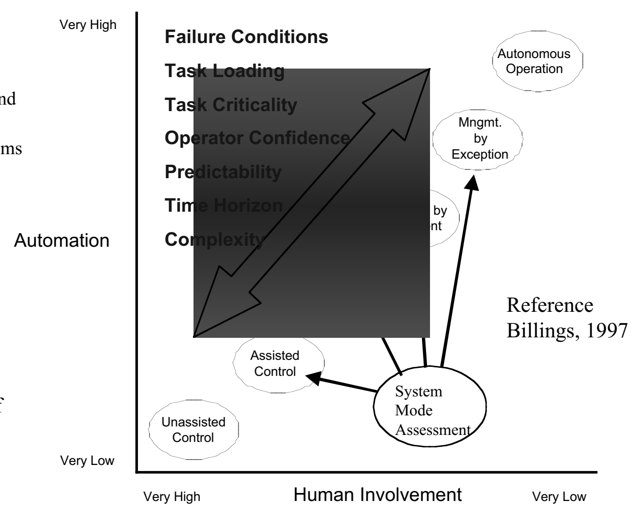
- •Multi-sector Traffic Planning
- •Surface, Terminal and En Route Planning Integration
- •Complexity and Spacing Management
- •Traffic Management Coordination
- •Flight Plan Controls
- •Back Up Traffic Management

Separation Management

- •Sector Based Separation Management
- •Precision Procedural Control
    - •Procedural Lateral and Vertical Separation
    - •Enhanced ETA and RTA Longitudinal Control
- •High Performance Trajectory Datalink Communication
- •Enlarged Sector Span of Control
- •Separation Management Monitoring and Back Up Modes
- •Coordination with Aircraft Collision Avoidance

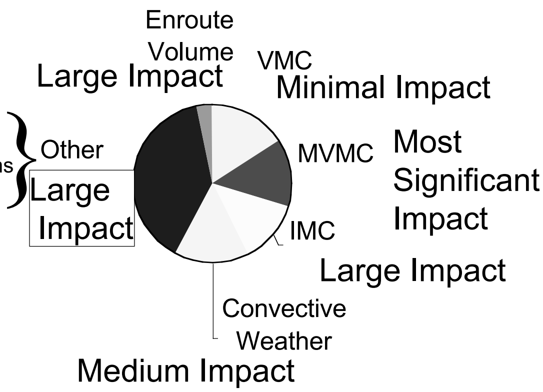
Human Roles and Responsibilities

- Human as System Manager
    - – Human involved, informed and in command
    - – Humans and automated systems able to monitor each other
    - – Automated systems are predictable
    - – Automation is supportive of human
    - – Automation guards against human limitations
- Multiple, Selectable Levels of Automation
- Dynamic optimal allocation of functions between human and machine



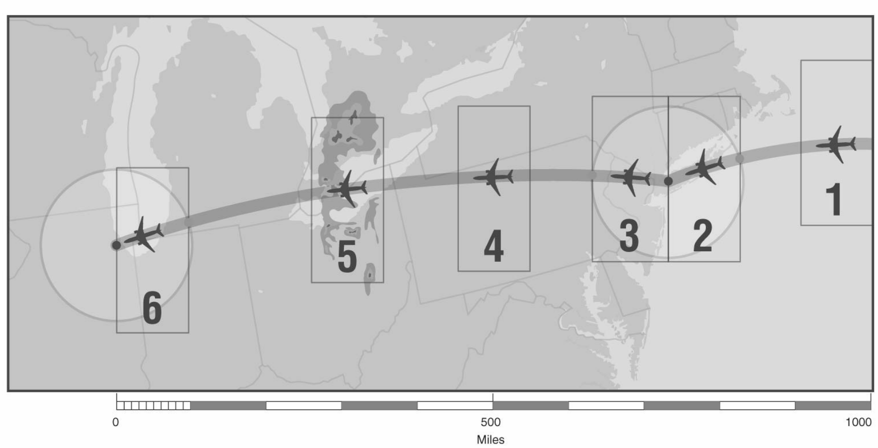
Preliminary Assessment of Capacity Benefits

-Weather effects not already captured
  (e.g. snow removal after storms)
-Air Traffic Control equipment problems
-Airline operation problems
-Propagation effects of weather delay



VMC – Visual Meteorological Conditions
MVMC – Marginal Visual Meteorological Conditions
IMC – Instrument Meteorological Conditions

Operational Scenarios



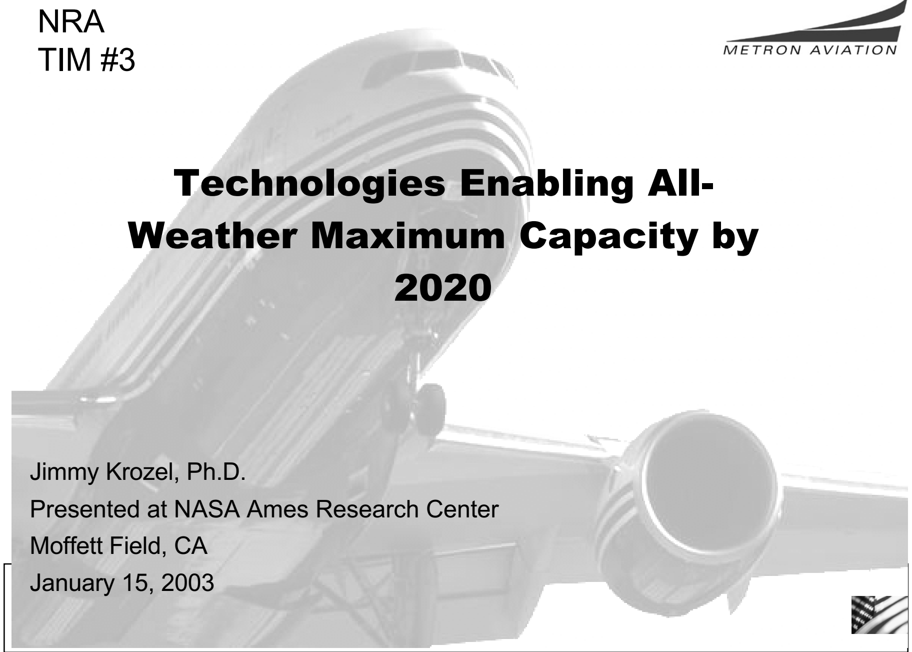
Summary

- Enriched Trajectory Based Flight Plans
- Required Total System Performance (RTSP) Based Flight Planning
- Dynamic Flight Plan Updating
- Integrated Services with Time Partitioning
- Services Time Horizons
- Prediction Accuracy as a Function of Time Horizon and Phase of Flight
- Detection Accuracy and Criticality for Air Traffic Services
- Shared Service Objectives
- Performance Framework
- Coordinated Flight Replanning

NRA
TIM #3

METRON AVIATION

Technologies Enabling All-Weather Maximum Capacity by 2020

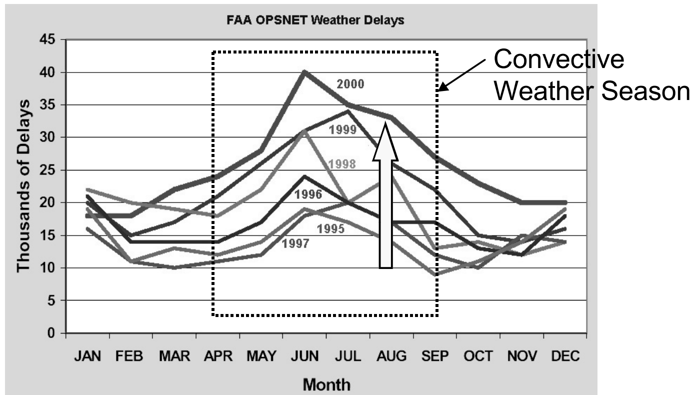


Jimmy Krozel, Ph.D.
Presented at NASA Ames Research Center
Moffett Field, CA
January 15, 2003

Agenda:

- **Need for All-Weather Capabilities**
- **Core Ideas for the All-Weather Capacity-Increasing Concept**
- **Benefit Mechanisms from the Core Ideas**
- **Self Assessment Plans for the Next Phase of Project**
- **Conclusions**

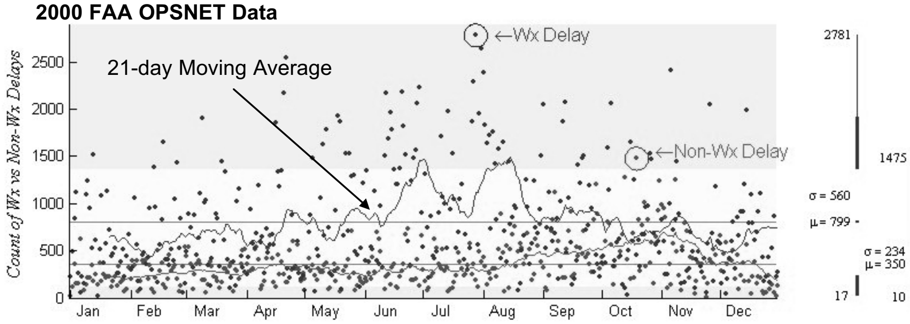
General: The NAS is not Robust to Weather Disturbances



Weather related delays are currently increasing, especially during summer "Convective Weather Season"

Specific: The NAS is not Robust to Weather Disturbances

2000 FAA OPSNET Data



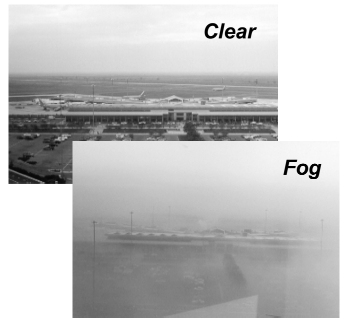
While the effect generally maximizes during the Convective Weather Season, everyday is different!

The Weather related Delays are significantly higher than the Non-Weather Related Delays

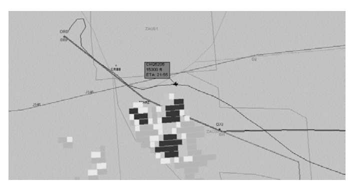
Problem Situations: Weather Reduces Capacity

Surface

1. **Snow, Ice, Slush, or Water on Runway**
2. **Low Visibility Produced by Fog, Rain, Snow, or other Conditions**
3. **Aircraft Requiring De-icing**
4. **Shifting Wind Direction Changes the Runway Configuration**
5. **Large Scale Weather System Causes Weather-Related GDP/MIT Constraints at Multiple Airports Simultaneously**



Problem Situations: Weather Reduces Capacity

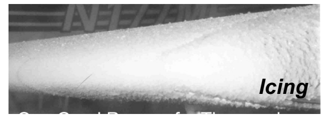


Terminal/Transition

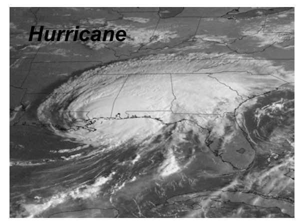
1. **Isolated Weather Cell Affecting an Arrival or Departure Stream**
2. **Weather Constraints Affecting Coupled Arrival/Departure Streams**
3. **Weather Constraints Initiating Arrival/Departure Strategic Trade-offs (30-60 Min. Lead Time for Planning)**
4. **Weather Constraints Impacting Arrival Airspace Capacity (2-4 Hr. Planning Horizon)**

Problem Situations: Weather Reduces Capacity

En Route



1. **Unanticipated Clear Air Turbulence**
2. **Icing Forces Aircraft Deviations**
3. **Convective Weather with High Tops and Convection**
4. **Multiple Clusters of Weather Cells within the Same Center**
5. **Impassable Line of Weather from Canada to South**
6. **Convective Storm over Midwest where high Density Flows must go around weather**
7. **Convective Storm covering Northeast**
8. **Extremely Strong Jet Stream**
9. **Hurricane in the Southeast**
10. **Volcanic Ash in Atmosphere**

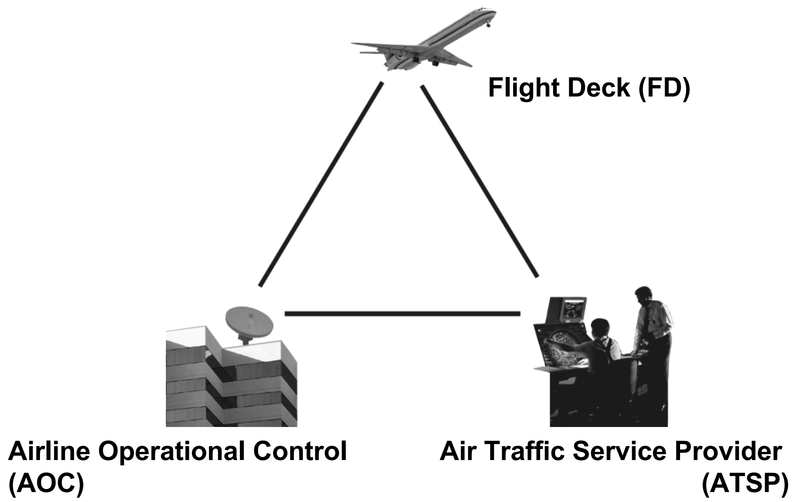


Triad of Philosophies:

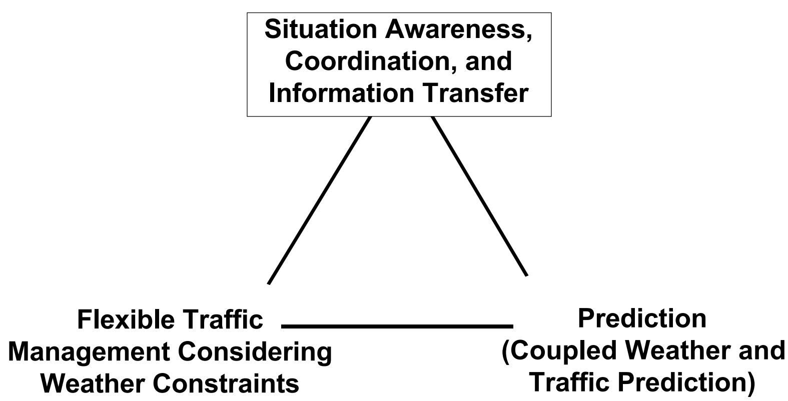
Human-Centered Design Philosophy

Inter-Disciplinary Design Philosophy — **Multi-Domain Philosophy**

User Triad:



Core Idea Triad:



Core Idea 1:

Situation Awareness, Coordination, and Information Transfer

Flexible Traffic Management Considering Weather Constraints

- Preflight
- Surface
- Terminal
- En Route

Prediction (Coupled Weather and Traffic Prediction)

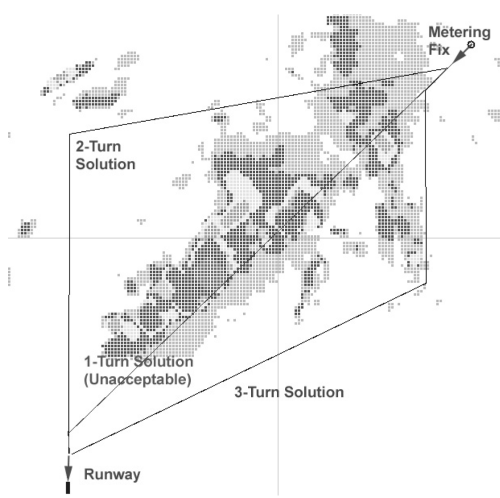
Core Idea 1.1: Pre-Flight Planning to Manage Airport Flow Rates

- **Long-Term Probabilistic Weather Forecasts**
- **GDPs**
- **Fix-Based GDPs**
- **Distance-Based 1st Tier, 2nd Tier GDPs**
- **Cancellations**
- **User Priorities and Constraints**

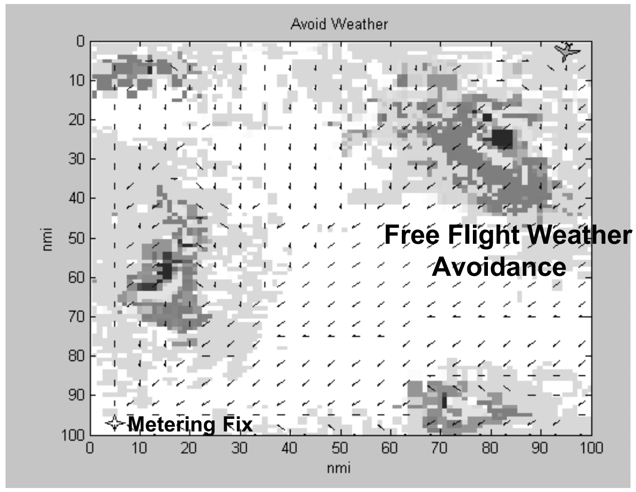
Core Idea 1.2: Precise Control of Take Off Time to Address Weather Constraints

- Passback of Terminal/Transition airspace weather constraints for departure flights
- Ground Stop and GDP EDCTs in support of SWAP
- APREQs for timing of departure releases for capping / LAADR maneuvers into overhead streams
- EDCT Compliance through SMS, including coordination of de-icing and snow removal vehicles on runways
- Augmented Reality, HUD, and EMM Displays for low and zero visibility conditions

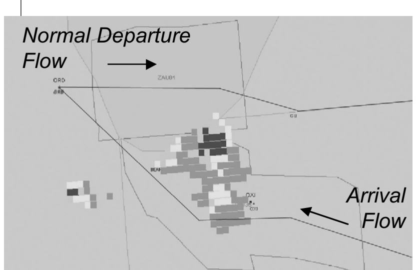
Core Idea 1.3: Weather Avoidance in the TRACON

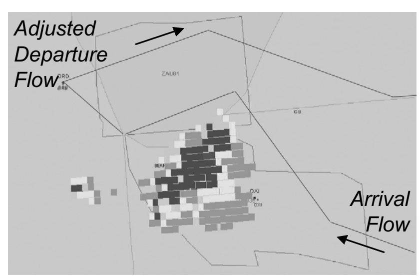


Core Idea 1.4: Weather Avoidance Algorithms for the Transition Airspace



Core Idea 1.4: Weather Avoidance Algorithms for the Transition Airspace

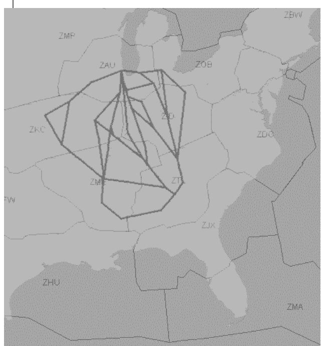


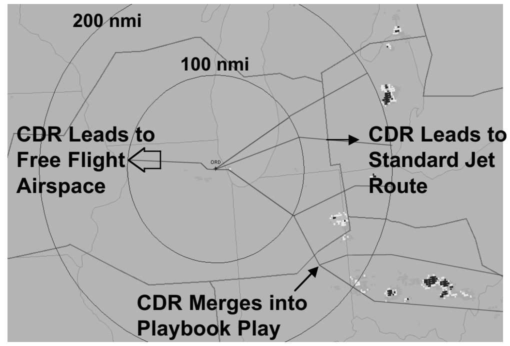


Departure Flow Unaffected by Arrival Flow Weather Avoidance Route

Departure Flow Re-Designed with Arrival Flow Weather Avoidance Route

Core Idea 1.4: Weather Avoidance Algorithms for the Transition Airspace

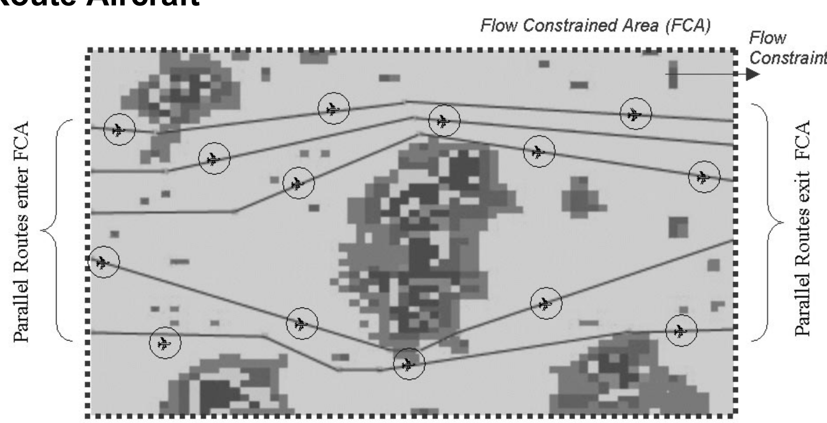




Current CDRs Extend from Departure Airport to Arrival Airport

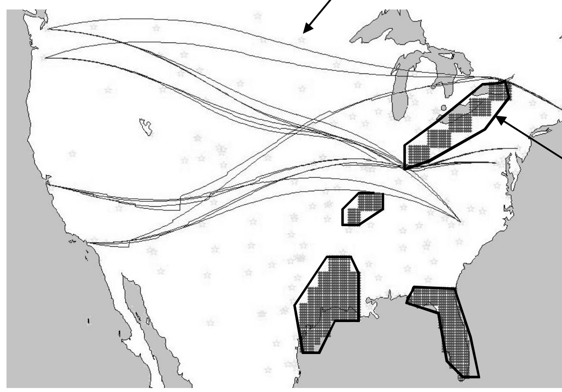
Range-Based CDRs Extend out a Fixed Range and Merge with Free Flight Airspace, Standard Jet Routes, or Playbook Plays

Core Idea 1.5: Weather Avoidance Algorithms for En Route Aircraft



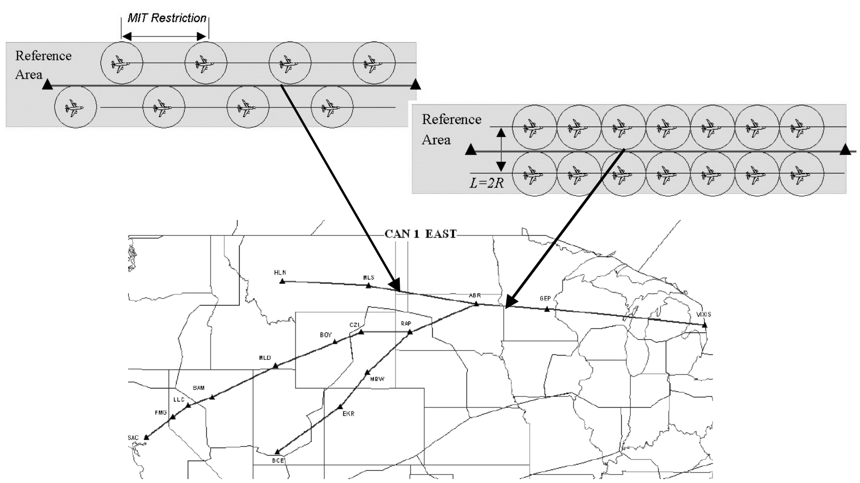
Parallel Routes Dynamically Defined Around Weather Constraints

Core Idea 1.5: Wind-Optimal Free Flight Routes



Method of Jardin (NASA) modified to avoid large Weather Constraints

Core Idea 1.6: Coordination of Large Scale TFM Plans



Parallel Routes Applied to Playbook Plays

Core Idea 2:

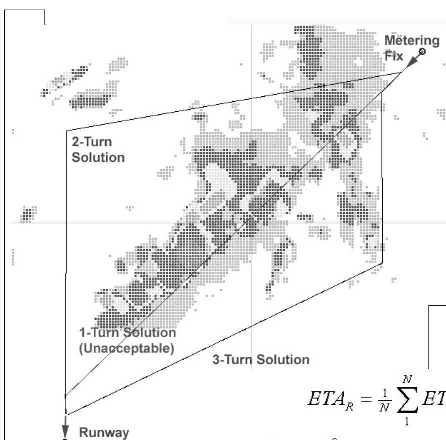
Situation Awareness, Coordination, and Information Transfer

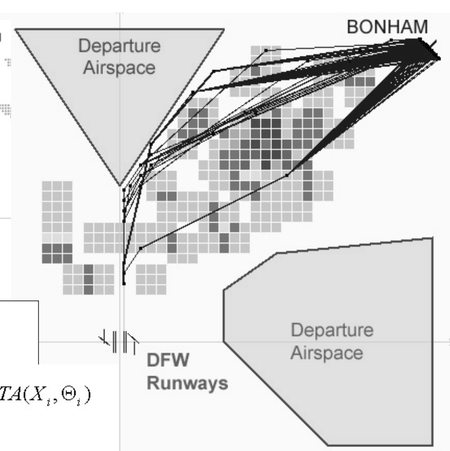
Flexible Traffic Management Considering Weather Constraints

Prediction (Coupled Weather and Traffic Prediction)

- Estimated Times of Arrival
- Sector Counts
- Flow Rates: AARs and ADRs

Core Idea 2.1: Incorporate Weather Predictions into ETAs





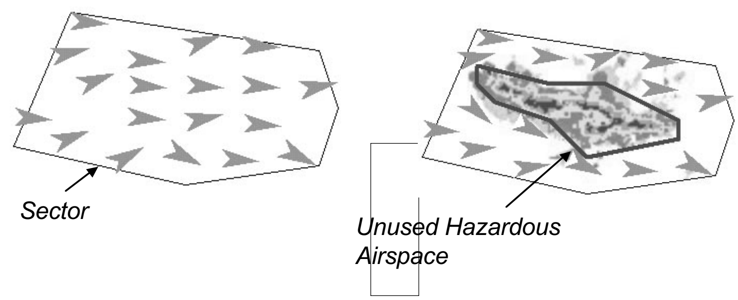
$$ETA_R = \frac{1}{N}\sum_{1}^{N} ETA(X_i, \Theta_i)$$

variance σ^2

$$\sigma^2 = \frac{1}{N}[\sum_{1}^{N} ETA(X_i, \Theta_i)^2] - ETA_R^2$$

Core Idea 2.2: Sector Demand Predictions and Weather

- **Estimate Sector Loads based on Trajectory Predictions that include Weather Constraints**
- **Dynamically adjust the Sector Load Capacity to account for the amount of Unused Hazardous Airspace Present in the Sector**



Core Idea 3:

Situation Awareness, Coordination, and Information Transfer

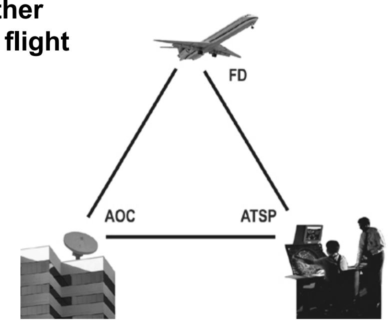
- Coordination of Weather Information
- Shared Situation Awareness
- Coordination of User Goals and Constraints

Flexible Traffic Management Considering Weather Constraints

Prediction (Coupled Weather and Traffic Prediction)

Core Idea 3.1: Coordination of Weather Information

- **Weather information (actual weather and its effects) from a variety of sources needs to be collected, compared, integrated, fused, coordinated, and distributed.**
- **Information on the surface needs to be combined with information in the air to provide NAS-wide mosaic of weather conditions affecting all phases of flight**
- **Sources include:**
  - MDCRS data
  - PIREPs
  - Radar Data
  - Satellite Data
  - Surface Conditions



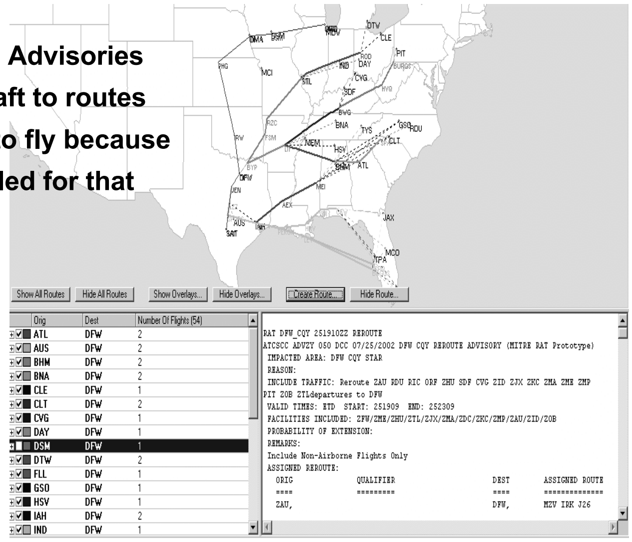
Core Idea 3.2: Shared Situation Awareness

- The User Triad needs to share the same perspective, or awareness, of weather-related information, so that the best strategy for mitigating weather effects can be communicated and coordinated
- Shared awareness can be accomplished through both a common view and a remote perspective view
- Users must have quick and easy access to this shared mode
- A secure NAS state/weather information distribution network and a unique user interface concept are required

Core Idea 3.3: Accommodate NAS User Goals/Constraints

- **Weather Reroute Advisories that assign aircraft to routes they are unable to fly because they can't be fueled for that long a route**

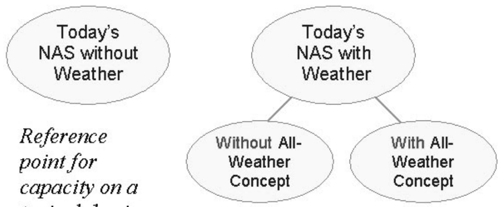
- **E.g., An F100 cannot fly a major reroute DFW to ORD (pink route on the left on map)**



Benefit Mechanisms:

- More **accurate** take off time prediction and EDCT compliance
- Increased **safety** due to better predictions of aircraft trajectories clear of hazardous weather
- Increased airport and en route **throughput** through weather avoidance algorithms that dynamically adjust flows
- **User preferences** included in solutions
- Weather avoidance algorithms lead to **delay savings** that directly benefit the airlines schedule integrity
- **Equity** enforced through user preferences and DST solutions
- **Human factors** benefits from a common situation awareness and better human-computer interfaces
- Reduced **environmental emissions**

Approach to Self Assessment:



Reference point for capacity on a typical day in today's NAS

Benefit of the All-Weather Capacity-Increasing Concept if implemented in today's NAS

Benefit of the All-Weather Capacity-Increasing Concept if implemented in the future NAS

- **No Weather**
- **Typical Weather**
- **Severe Weather**
- **Rare Weather**

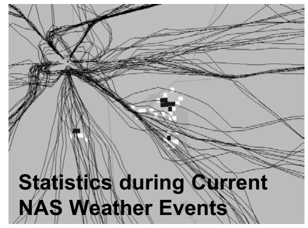
Metrics:

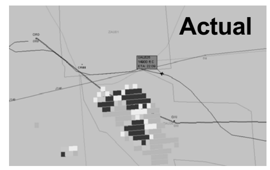
- **Define Metrics**
- **Select the Metrics that apply to the domain or type of experiment**
  - **- Human-In-The-Loop (HITL)**
  - **- Fast-Time**

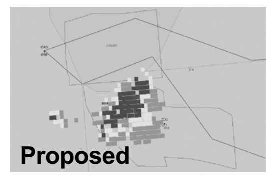
Metric	Category
Capacity	Airport Capacity
	En Route Sector Capacity
	NAS Capacity
	Throughput
Flexibility	User Preference
	Equity
Efficiency	Government, Airline, & Passenger Costs
	Airspace Utilization
Predictability	Time Variability
	EDCT Compliance
	Sector Demand
Safety	Weather Exposure
	Conflict Alerts
	Workload
Environment	Noise
	Pollution
Delay	Average Delay
	Average Block Time
Human	Human Performance
Factors	Human Behavior
	Preference Metrics

Self Assessment Comparisons:

- **Select Domain of Interest (e.g, Transition to Metering Fix)**
- **Select Metrics**
- **Compare scenarios from today's NAS (2002) with/without concept Core Ideas and future NAS (2020)**
- **Investigate benefits for different types of days in the NAS (no weather to extreme weather) for tradeoffs**







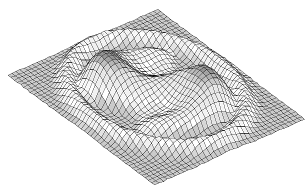
Conclusions

- **Weather poses Complex Constraints that affect each domain of the NAS differently, varying day by day**
- **The Core Ideas Required to address weather constraints:**
  - **Flexible Traffic Management Considering Weather Constraints**
  - **Prediction (Coupled Weather and Traffic Prediction)**
  - **Coordination and Information Transfer supporting a Shared Situation Awareness**
- **Self Assessment will proceed to demonstrate Core Ideas on different types of weather (typical, severe, rare) and for 2002 vs. 2020 over all domains of interest**

Surface Operation Automation Research — SOAR —

Dr. Victor H. L. Cheng
Optimal Synthesis Inc.
Los Altos, California

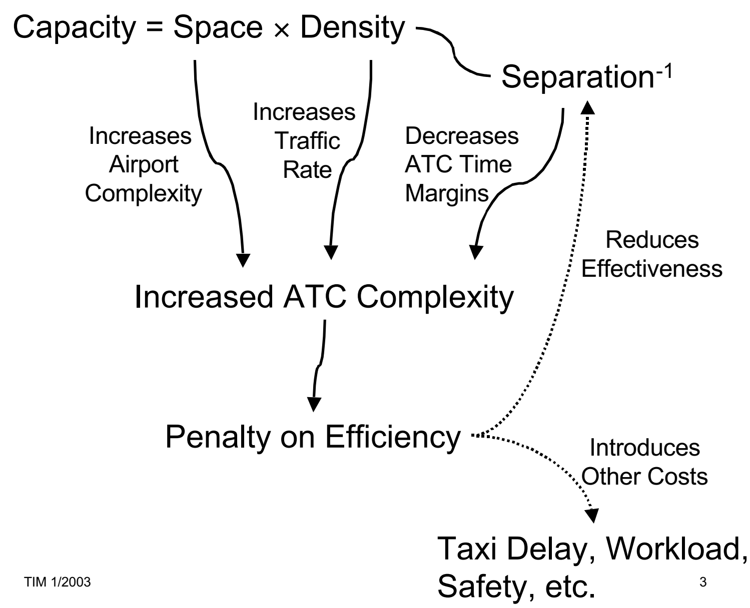
Virtual Airspace Modeling and Simulation (VAMS)
Air Transportation System Capacity-Increasing Research
Technical Interchange Meeting
January 14–15, 2003



Outline

- **Airport Capacity Enhancement Issues**
- **SOAR Concept**
- **ATM Automation Functions**
- **Flight-Deck Automation Functions**
- **Integrated Operation of SOAR Systems**
- **System Performance**
- **Human Performance**
- **Concept Development and Technology Roadmap**

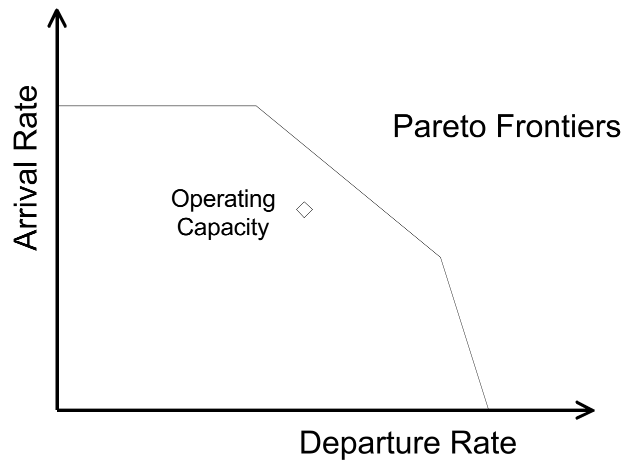
Airport Capacity Enhancement Issues



Quantitative Goals

- **Bi-objective airport capacity problem: Pareto frontiers describe balance between departure and arrival traffics.**
- **Achievable airport capacity can be maximized by lowering priorities of other surface traffic: undesirable taxi delays.**
- **SOAR concept seeks enhancement with tradeoff between two efficiency factors:**
  - **Reduction in achievable traffic rate, a penalty on arrival/departure efficiency**
  - **Increase in taxi delay, a penalty on surface traffic efficiency**
- **Quantitative goals: enhance and strike balance between these efficiency factors, e.g. simultaneously**
  - **achieve 90% of the ideal airport capacity**
  - **maintain cumulative delay to within 10% of the cumulative ideal taxi time**

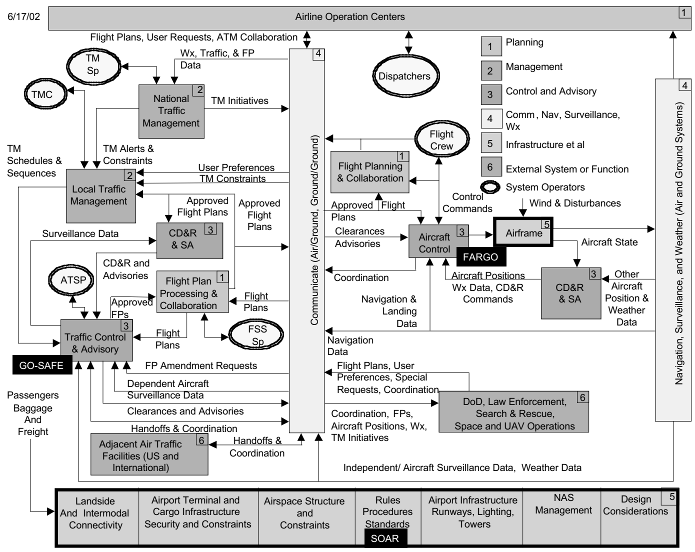
Bi-objective Capacity Optimization



SOAR Concept

- Advanced automation in Centralized Decision-making, Distributed Control (CDDC) paradigm
- Centralized Decision-Making: Ground-Operation Situation Awareness and Flow Efficiency (GO-SAFE) for Surface Traffic Management (STM) Automation
  – Basic functions studied under previous SBIR Phase II effort
- Distributed Control: Flight-deck Automation for Reliable Ground Operation (FARGO) for Flight Deck Automation
  – Feasibility of high-precision taxi control demonstrated in previous SBIR Phase I study
- Integrated operation of both systems
  – GO-SAFE to help issue efficient time-based taxi clearances
  – FARGO to help execute taxi clearances

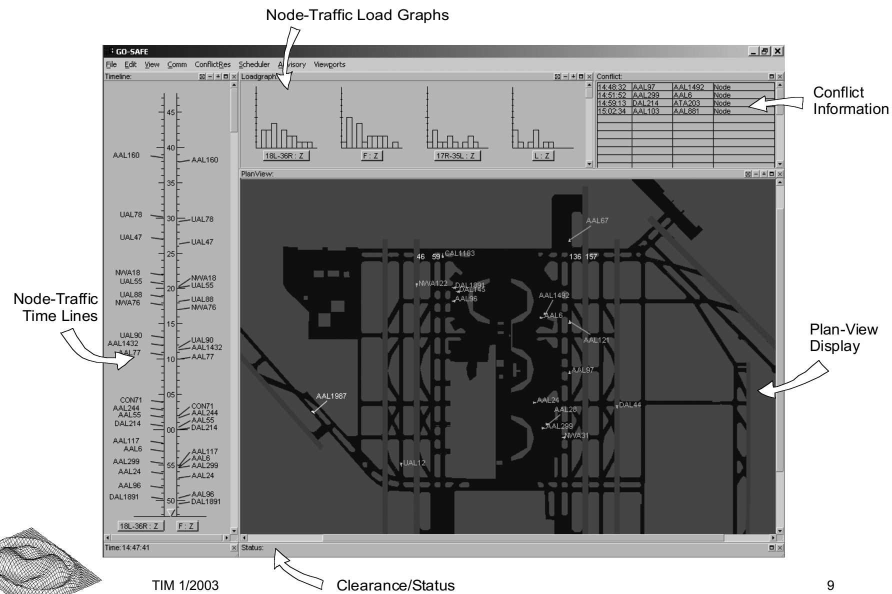
GFI Model with SOAR Technology Components



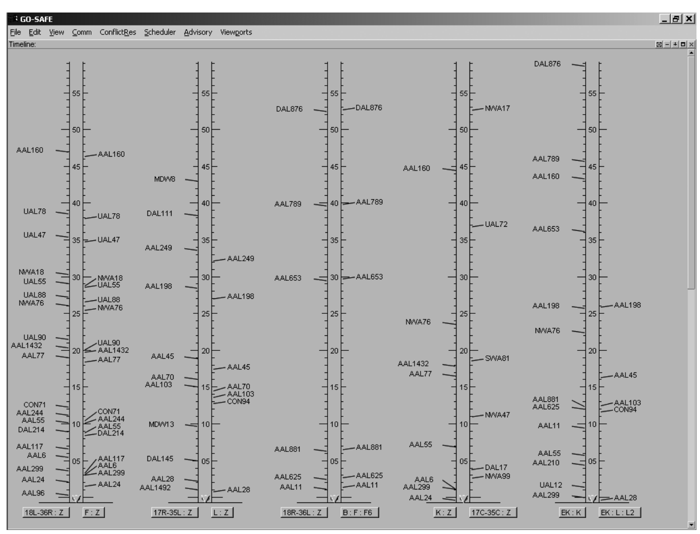
STM Automation Functions

- User interface, including situational display for monitoring surface traffic, and alerting of impending problems
  - Updated to allow easy reconfiguration to support Phase II evaluations
- Taxi-route generation and editing
  - Previous taxi-route generation based on dynamic programming for route optimization
  - GO-SAFE software architecture allows inclusion of multiple route-generation techniques
  - Route editing functions enabled by GUI: end-point change, route change, timing change
- Conflict detection and resolution
- Decision support tool for efficient and safe operation

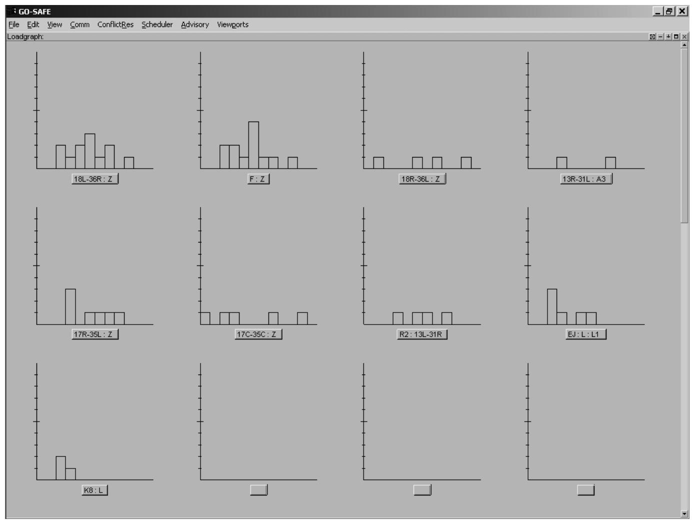
Overview of GO-SAFE GUI



Sample Full-Screen Time-Line Display



Sample Full-Screen Load-Graph Display



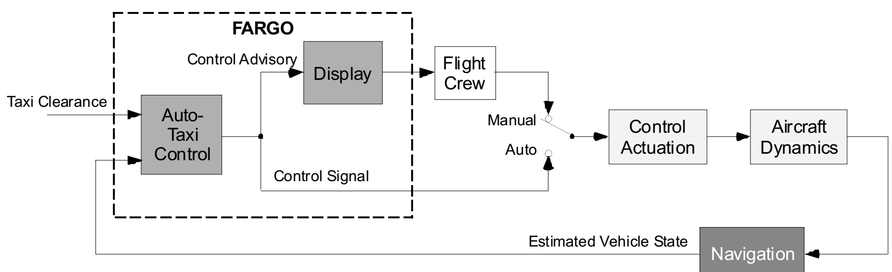
Conflict Detection and Resolution

- **Requirements for conflicts on airport surface not as serious as for IFR flights: in current operations, cockpit crew is responsible for separation while taxiing.**
- **Conflicts of taxi routes in internal representations of GO-SAFE can be resolved**
  – **Manually by controller through route editing**
  – **Automatically by GO-SAFE with timing changes**
- **All time-based taxi routes must be conflict-free.**
- **Clearances composed of conflict-free routes will facilitate detection of real-world conflicts**
  – **Any conflicts caused by flights with cleared routes must mean the flights have deviated from the routes.**

Decision Support System

- Surface Resource Scheduler
  - Runway usage for landing, takeoff and crossing traffic
  - Other surface resources: special facilities (e.g. de-icing), identified choke points
- Clearance Manager
  - Manages and issues advisories/clearances
  - Encodes clearances according to route definition, including crossing time restrictions
  - Monitors clearances and flight clearance status
  - Assists with route changes: “what-if” capability to predict impact of modified routes
- Conformance Monitor
  - Monitors aircraft compliance with clearances
  - Detect incursions and conflicts with other flights or ground vehicles

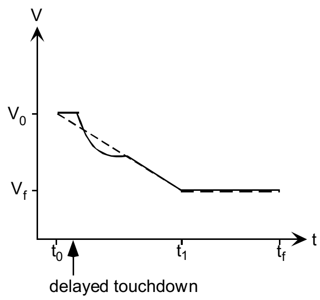
Flight-Deck Automation Functions



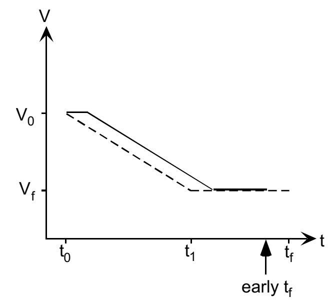
- Auto-taxi function
  - Precise control of aircraft taxi to execute clearance
  - Potential use of time-based taxi routes, decoded from clearance
  - Guidance signal for driving pilot interface
- Pilot interface to allow the pilots to perform precision-taxi
  - Far-term: fully automatic taxi
  - Near-term: control signals generated by the auto-taxi function to direct manual control

Auto-Taxi Control

- **Nominal guidance assures passenger comfort and safety.**
- **Must be robust in off-nominal situations: e.g. prolonged flare during landing.**



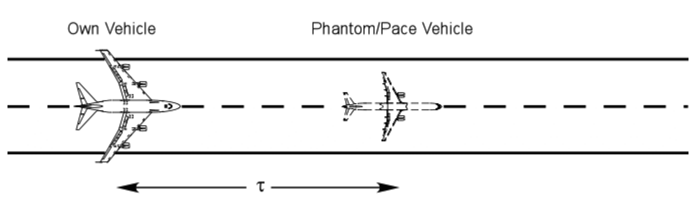
- Excessive deceleration



- Speed too high at turnoff
- Arrival too early at scheduled intersection

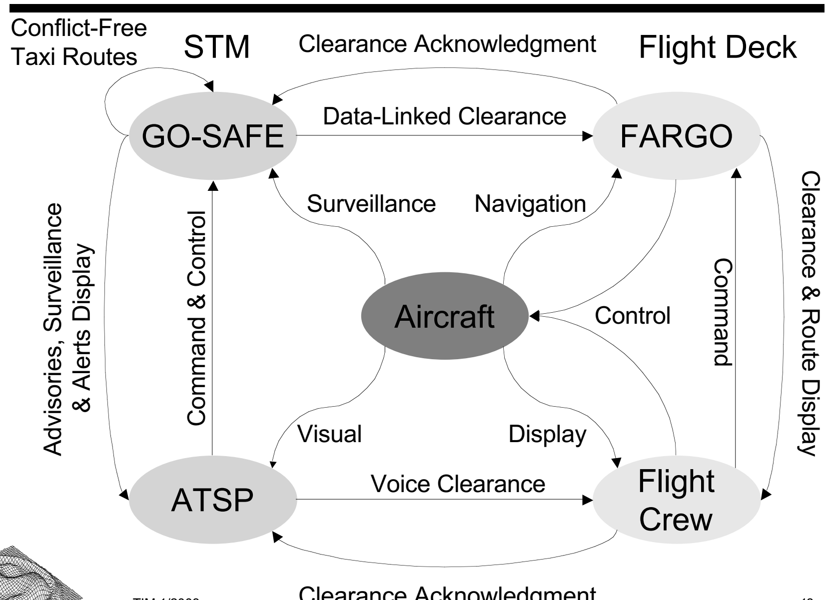
Pilot Interface Considerations

- **Traditional flight director with speed bug is unsuitable.**
- **Pace-vehicle concept allows separation to increase with speed.**
- **Special consideration needs to be given to**
  - **Acceleration/deceleration**
  - **Stop/go events**
- **Suitable for HUD implementation: integration with T-NASA**



T-NASA Displays

Integrated Operation of SOAR Systems



Operational Implications of SOAR Concept

- **Complex taxi routes with time constraints ⇒ data-link clearances preferred over voice communcation**
- **Tower controller**
  - **Cannot expect immediate acknowledgment**
  - **Will likely use pre-clearances**
- **Flight crew**
  - **Cockpit crew may be distracted from flight control**
    - **Reading out clearances for agreement between crew members**
    - **Understanding details of time-based routes**
    - **Responding via console input**
  - **Route information can be more easily entered into FMS.**
- **Use of data-link clearances with encoded taxi routes may change hand-off procedure between local controller and ground controller.**

System Performance

- **Common Performance Factors**
  - **Achievable landing and departure rates**
  - **Surface traffic efficiency in terms of taxi delays**
  - **Workload**
  - **Safety**
- **GO-SAFE**
  - **Scheduler effectiveness**
  - **Taxi routes: efficient and conflict free**
  - **Conformance monitor: warning signs of separation violations**
  - **Controller-interface effectiveness**
- **FARGO**
  - **Taxi-control effectiveness**
  - **Pilot-interface effectiveness**
  - **Conflict detection using ADS-B and TIS-B**

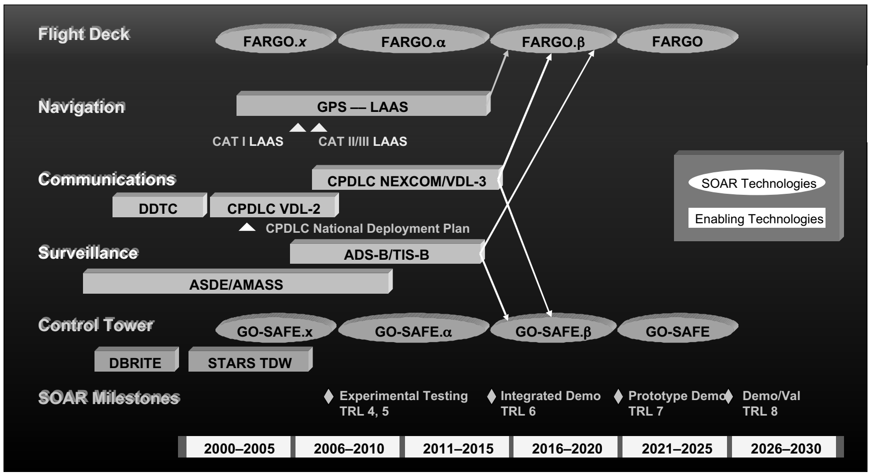
Performance Evaluation

- Field Tests: Ultimate operational evaluations
- High-Fidelity Simulations
  - GO-SAFE, PAS or GO-Sim, Aircraft Simulation + FARGO
  - Potentially human in the loop
  - Suitable for evaluation of system and human performance
- Mid-Fidelity Simulations
  - GO-SAFE to schedule and sequence flights, with taxi-route generation to predict timing
  - Operator latency and accuracy can be included in computation
  - Suitable for studying impact of surface traffic on arrival/departure traffics, interface with TRACON traffic
- Low-Fidelity Simulations
  - Empirical formulation of runway capacity for arrival and departure traffics
  - Suitable for assessing impact on system-wide concepts

Human Performance

- Human-Factors Analyses
  - Human-factors experts critiquing individual design features and operational procedures
- Human-in-the-Loop Simulations
  - Controllers evaluating GO-SAFE and pilots evaluating FARGO
  - Pseudo-pilots operating PAS or GO-Sim to increase traffic realism
- Computer Simulations
  - Human behaviors too complex to be adequately modeled in computer simulations
  - Possible to identify required human operator actions in accordance with operational procedures
  - Actions modeled in simulation and data collected
  - Post-simulation analyses to include time and effort considerations in performing required actions, to assess human performance in executing procedures

Concept Development and Technology Roadmap



Centralized Terminal Operation Control (CTOC) Concept

Capacity Increasing Concept TIM #3
NASA Ames Research Center
January 14-15, 2003

NORTHROP GRUMMAN Information Technology

Geneva Aerospace integrated systems technology

Overview

- CTOC Concept
- CTOC Core Ideas
- CTOC Objective
- CTOC Self-Assessment Plans

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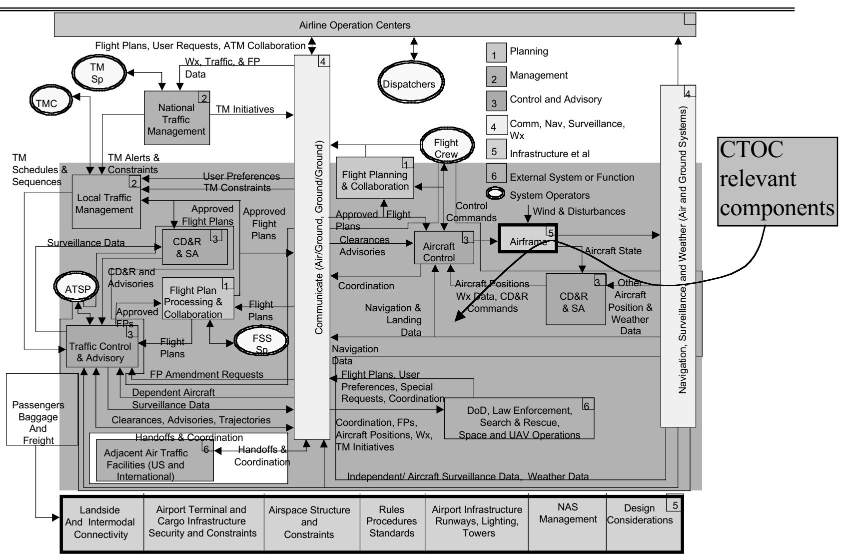
CTOC Concept

- The Centralized Terminal Operation Control (CTOC) provides remote control of aircraft in the Terminal domain
- CTOC merges the role of the controller and flight crews
- CTOC will interface to DSTs and/or enhanced ATM systems in the En Route, Terminal, and Surface environments to ensure predictable, consistent, conflict-free trajectories
- CTOC depends on aircraft technologies (i.e. data link and FMS) for response to Clearances/Advisories and Trajectory Commands from the Central Remote Controller

CTOC Concept



Modified VAMS Model of ATM Functions

CTOC Core Ideas

- Remote control of one or multiple aircraft from a single terminal specialist supported by a ground-based computer system
- Remote control will extend existing automation in the terminal domain and reduce variability in separation
- Trajectory commands based on deconflicted trajectories will be sent from CTOC to the aircraft FMS
- Remote control of terminal aircraft may be adjusted based on Air Traffic Management flow constraints
- Terminal specialists will have the capability to take control of aircraft to prevent unauthorized use
- Pilots will have the ability to override CTOC commands for safety reasons only

CTOC Objective

- Overall CTOC objectives are to demonstrate key ground-based and airborne technologies for the remote control of terminal area aircraft in all weather conditions to maximize terminal airspace capacity. The objectives are achieved through requirements definition and the development, integration and demonstration of enabling technologies, along with simulation-based demonstration and design verification. In demonstrating these objectives, the concept will show:
  - Greater terminal area throughput in all weather conditions
  - Reduced variability of separation for terminal area aircraft due to controller/pilot response
  - Increased terminal area safety due to control to predictable and consistent trajectories in the terminal area

VAMS CTOC Benefits/Metrics

Benefit	Mechanism	Candidate Metric(s)
Increased Capacity	Control to predictable and consistent trajectories in Terminal area	Throughput, Flow Rates, Arrival Delay, Departure Delay, Overall Delay, Time/Distance Flown
	Arrivals and departures make better use of Terminal airspace	Throughput, Flow Rates, Arrival Delay, Departure Delay, Overall Delay, Time/Distance Flown, Tracks
	Reduce variability in separation for aircraft-to-aircraft, aircraft-to-obstruction, and aircraft-to-airspace	Separation Distances, Conflicts
	Eliminate missed approaches due to verbal communication errors	Missed Approach Count
Increased Efficiency	Control to predictable and consistent trajectories in Terminal area	Tracks, Workload
	Improve situational awareness between Terminal ATC and airline users	Workload
	Eliminate missed approaches due to verbal communication errors	Missed Approach Count
	Collaborative arrival/departure management with airlines	Workload
	Reduce workload for Terminal area ATC and flight crews	Workload
	Provide communication between CTOC and FMS through data link	Comm Load, Workload
Increased Safety	Control to predictable and consistent trajectories in Terminal area	Separation Distances, Safety Incident Count, Conflicts, Workload
	Improve situational awareness between Terminal ATC and airline users	Safety Incident Count
	Provide communication between CTOC and FMS through data link	Comm Load
	Provide trajectory conformance monitoring	Separation Distances, Conflicts, Workload
	Provide flight deck override to CTOC	Safety Incident Count
	Provide ATC override for case of unauthorized use of Terminal airspace	Unauthorized Use of Airspace Count
Reduced Costs	Terminal area operating costs	Operating Costs, Staffing Levels

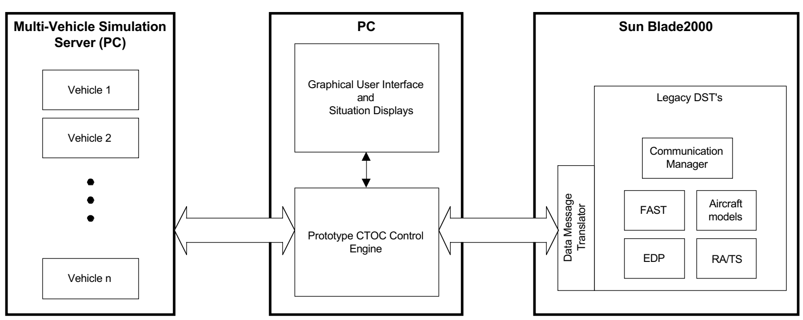
VAMS CTOC Self-Assessment

- Continue Terminal operations analysis started in Phase One
- Prototype Simulation Environment currently being integrated
- Will leverage CTAS toolset to establish de-conflicted trajectory data
- Preliminary active CTOC control laws synthesized
- Initial trials conducted on time delay separations
  - Demonstrates basic functionality
  - Provides domain for initial communication requirements studies
  - Currently simulating a generic GA airport to minimize complexity
- Next Steps
  - Integrate relevant airport
  - Validate extended CTAS functionality
  - Build multiple aircraft models
  - Ensure weather capabilities are addressed
  - Build multiple terminal area models

CTOC Prototype Simulation Test Environment

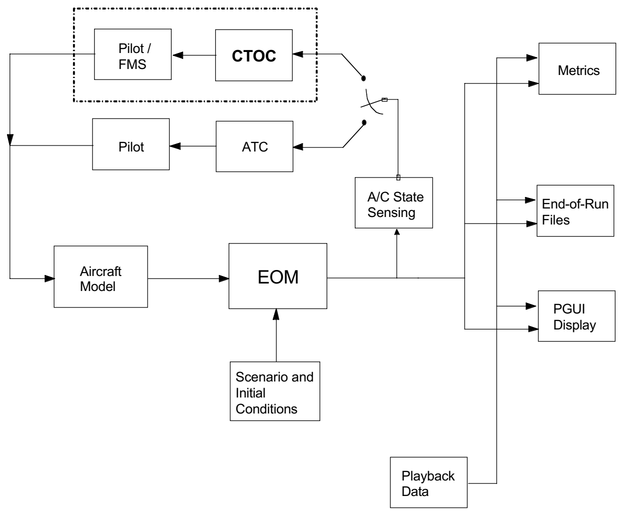
- Early-on progress will be established with a temporary simulation capability
  - Important for initial CTOC concept exploration and requirements definition
  - Will help to fine-tune CTOC-driven VAST requirements
  - Will provide valuable insight into merging and integration issues with other concepts
- Decision Support Tools will be an integral part of the CTOC success
- Closely-related NASA efforts have produced a toolset which provides an excellent starting point
  - FAST, EDP
  - CTAS-developed evaluation tools
- Geneva Aerospace's multiple vehicle dynamic simulation provides the real-time propagation of aircraft states

CTOC Prototype Simulation Test Environment



- Translator/extractor software being developed to interface existing situation display to FAST software
- Legacy DST's are hosted in existing environment to minimize development
- CTOC control engine will synthesize advisory commands by using CTAS-based DST's
- Will provide early-on insight into integration and merging issues, as well as providing an environment for initial CTOC requirements development

CTOC Prototype Simulation Functional Architecture



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Summary

- Initial Phase of Concept Development Work Completed
- Top-level requirements have been identified, and flow-down structure has been established (TBD's/TBR's in place)
- Self-evaluation sim tool has been designed and integration is underway
- Will soon be prepared to enter the next phase of CTOC concept development
  - Requirements analysis and allocation
  - Detailed design and modeling of CTOC-specific elements
  - Detailed concept studies
  - VAST requirements definition

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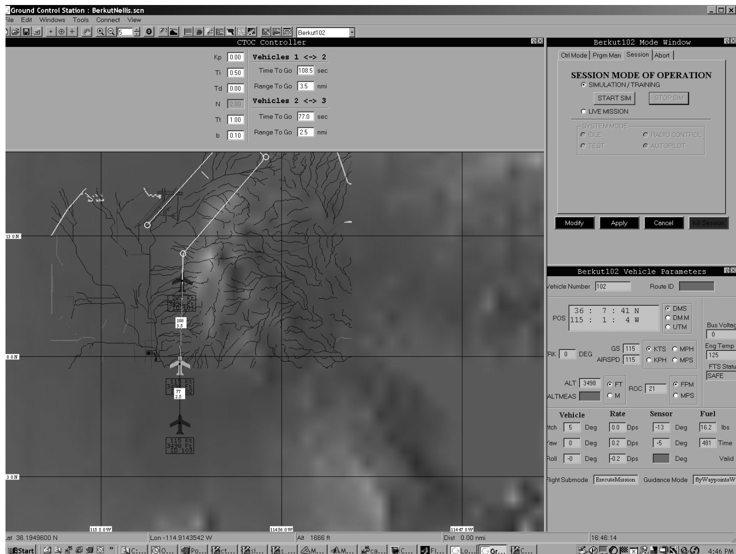
VAMS

GUI for Prototyped Sim



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University Concept Team
Final Report

Andres Zellweger
15 January, 2003

The Team

Paul Abramson	Dennis Koehler
Kevin Corker	Ed Koenke
George Donohue	Jim Poage
John Hansman	Bill Wood
John Kern	Dres Zellweger

Tap academic creativity, balance
with ATM and flight ops expertise

The Charge

-Develop Future Concepts

-Identify Transition Paths

- **Identify Research Agenda**

Conduct 5 2-day meetings (Jan – June, 2002)
Deliver Final Report (late 2002)

Our Approach

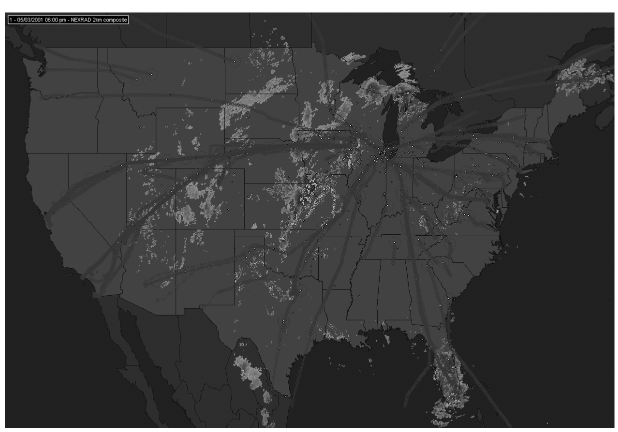
- Identify *drivers*, *inhibitors*, and *transition issues*
- Brainstorm *concepts* to accommodate these
- Identify *research questions* related to concepts
- Develop high level cut at possible *transitions*
- Identify *cross-cutting research questions*

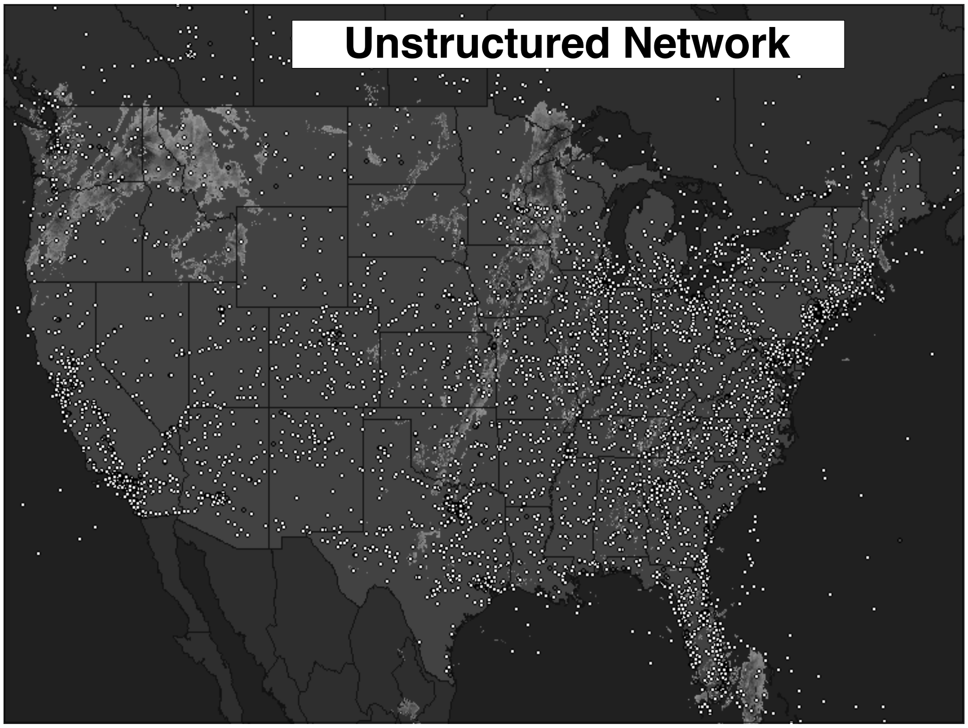
Drivers

Two Very Different Demand Trends

- High-end:
  - Demand at highly utilized urban airports will continue to exceed capacity
- Low-end:
  - Fractionals; air taxi; RJs
  - Low-cost carriers using smaller airports near major urban areas
  - Cargo carriers using smaller aircraft
  - New GA aircraft

Structured Network Example





Other Drivers

Safety - a first principle

Security - inherent system requirements and operational needs

International Competition – Tension: globalization vs. "what's best for U.S."

Future must be driven by policy for public benefit, not vested interests of special interest groups

Change Inhibitors

- **Affordability**
- **CNS Technology**
- **Environment**

Transition

Transition problems have been an inhibitor

- Our team thinks it's important to learn from the past and understand what is required for successful transition to a new concept
- Benefits driven transition not likely to work! Government may have to mandate equipage
- Need to address economics, implementation and operational policy, and stakeholder positions

Culture extremely stable – a transition inhibitor

Study Overview

- To deal with drivers, this study developed concepts and R&D for a range of airspace:
  - Concepts for "High density airport system" – making the best use of our national resource
  - Concepts to enable IMC operation to and from lower density airports
- Major airports will be a primary sources of bottlenecks in foreseeable future. We identified some approaches for attacking this problem.
- We identified high payoff research in case we are not successful in moving to new concepts and are forced to stay with current ATM paradigm.

- Note: Concepts are not comprehensive, not mutually exclusive

Concepts for High-End Network

- Tube Concept
- Highly Interactive Dynamic Planner

High Density Network: The Tube Concept

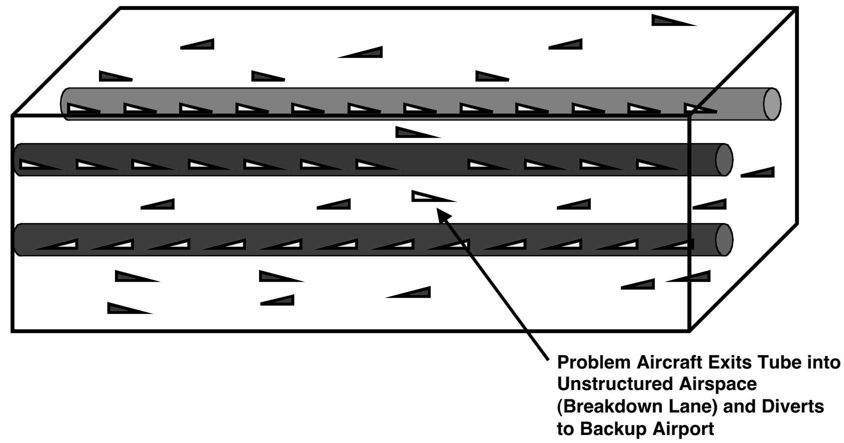
- Between High Volume Airports
- Highly Structured Routing for Efficiency
- Potentially limited operator flexibility, similar to TRACON flows but extend throughout network
- Maximum utilization of key resources (airports and airspace)
- Inner Loop Control goes to aircraft (RTA, In-Trail Separation, Pair-wise Maneuvering) to increase predictability and capacity
- Outer Loop control may go to the controller who can modify tube flows, control sequence, scheduling etc.

Power of tube is to create an abstraction that allows the controller to deal with many aircraft

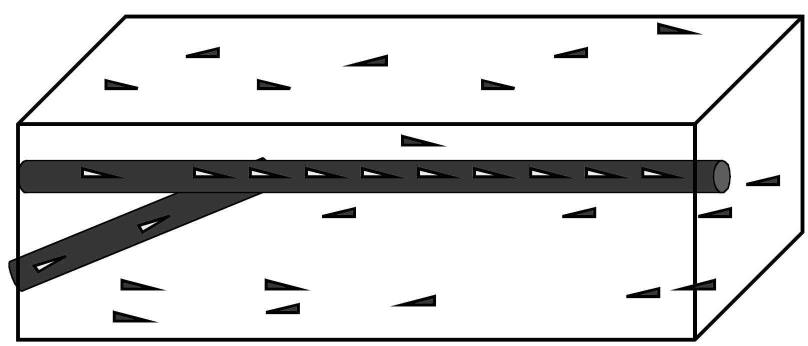
The Tube Concept (cont'd)

- Highway metaphor (std routes, on-off ramps, breakdown lane, standard detours around obstructions such as weather)

Tube Concept
Interleaved Structured and Unstructured Airspace



Tube Concept
On-Ramp



The Tube Concept (cont'd)

- Ability to use scarce resource (high volume airport) justifies stringent equipment and operating constraints
- Requires a redesign of airspace and procedures
- Best chance for early capacity and predictability increase

Tube Concept - *Transition*

- Demonstrate in Experimental Corridors in High Value Target Markets (get participation of one or more operators)
  - ORD-NYC
  - LA-SFO
  - Washington-New York-Boston
  - LA - Las Vegas
- Limited corridors, simple on/off ramps, break-down lanes
- Pair wise self separation (station keeping) for closer spacing
- Keep technology and procedures simple
- Give preference to demo participants
- # of corridors grows as we get experience
- Control paradigm for tubes will change as sophistication of a dynamic tube system grows

Tube Concept - *Research*

- Role of Human in the system (Pilot, Controller, Dispatcher)
- Decision Support Tools (Flight Deck, Ground Based)
- Tube Control Methodology (Station keeping, RTA, 4D path?)
- Separation Assurance within tubes
- Tube Dynamics – Changes to tubes in response to weather, wind, turbulence or other perturbations
- How is planning and scheduling done?
- How do aircraft enter and exit tubes?

Tube Concept – *Research (cont'd)*

- Tube merges/splits/etc
- What are limits of tubes (i.e. does it get too complex? Can we deal with uncertainties? etc)?
- How do you deal with different capabilities of aircraft (esp. speed)?
- How do you handle failures?
- What are appropriate access, priority, and equipage policies to achieve desired impacts?
- How do you deal with aircraft flying outside the tubes?

High Density Network:
Highly Interactive Dynamic Planner

- Goal - Concept will achieve the maximum capacity of high density airport/airspace system while satisfying user schedule and efficiency needs.

- Core Ideas
  - Dynamic air-ground negotiation of trajectories
  - Gate-to-gate scheduling based upon collaborative ground-based generation of a mix of RTAs and optimal 4 D conflict-free trajectories for all IFR aircraft throughout an entire day;
  - Cooperative sharing (between air and ground) of the responsibility for executing, revising, and rescheduling (as needed) the 4 D trajectory; and
  - Delegation of separation assurance to the flight deck

Highly Interactive Dynamic Planner
Transition

- Could evolve from tube concept
- Start in high altitude, high density en route airspace
- Gradually include more altitudes, lower density routes

Highly Interactive Dynamic Planner - *Research*

- Roles of Pilots, Controllers, Dispatchers in planning, execution, and replanning processes
- Nature of planning and negotiation process – how do you set up a national plan, how do you replan, how do airlines negotiate
- Dealing with major anomalies and achieving stability of the planning/replanning processes
- How to avoid over constraining the problems
- How brittle is concept to anomalies and failures?
- How tightly do you control? (buffers, spare space)
- What are potential failures? How do you deal with them?
- Can you isolate problems to keep anomalies from spreading?

Concepts for Low-End Network

- Autonomous IMC en route/terminal operations
- Autonomous IMC airport operations

Autonomous IMC En Route/Terminal Operations

By 2025, no longer "low density" – we predict too many planes for ATC as we know it today

- Separation responsibility goes to aircraft
- Traffic management limited to density control
- Sequencing and interaction done by procedure and rules of road
- Requires an increase in safety over today's VFR system (GA VFR safety is an order of magnitude lower than commercial)
- All planes must be equipped
- Restricted zones that aircraft can't fly into (avionics protection)
- Capable of dealing with weather problems – many of the aircraft can't fly over weather!

Autonomous IMC En Route/Terminal Operations - *Transition*

- Demo in Parallel to High Density Network
- Initial Demos in Low Density Regions
  - Oceanic
  - Alaska
  - High altitude
  - Low density, low altitude typical "trial" regions
- Expand to larger regions at lower altitudes (below 17,000ft?)
- Mandating equipment will accelerate transition

Autonomous IMC En Route/Terminal Operations - *Research*

- What are procedures and technologies necessary for Autonomous Operations?
- What are airspace "dynamic density" limits in airspace with less structure?
  - for safety?
  - for communications?
- What is minimum equipage necessary for different user categories?
- What are failure and degraded modes and how do you handle them? (avionics, ground monitor, ground equip, etc.)
- What kind of ground "ATM" function is needed?
  - density control
  - security monitoring
  - infrastructure monitoring
  - search and rescue
- How do you deal with adverse weather?
- What are human roles, including interaction with ATM?

Autonomous IMC Airport Operations

- **Goal**: increase the IMC capacity at non-towered airports without the need for adding traditional air traffic control
- Aircraft are responsible for self-separation and self-sequencing
  - Fully distributed? Automated ground support?
- Aircraft responsible for landing, taxiing, and takeoff
- (Automated?) Air Traffic Management is responsible for density control

Autonomous IMC Airport Operations
Transition

- Introduce:
  - At typical airports with relatively low activity, on a regional basis
  - In communities that believe that airport growth will bring economic benefits

- (SATS demo program in Florida is a good example)

Autonomous IMC Airport Operations
Research

- Feasibility?
- Hourly rate (10-15)?
- Distributed, airborne sequencing and spacing only?
- Density control?
- Separation criteria?
- CNS and avionics requirement?
- Ground based infrastructure?
- Unequipped aircraft?
- Interface to ATM system (does ATM deliver aircraft to a "metering fix"?
- Pilot qualifications and training?

-

Capacity Constrained Airports

- Demand Management
- Regional Airport System
- R&D for added capacity

Crosscutting Research

- **What are elements of a successful transition?**
  - Look at historical lessons learned
  - Understand major transition factors – incentive strategies; individual vs global benefits; culture; labor; role of policy in transition; equipage strategies
  - Major change will be accomplished incrementally
  - Impact of policy on concepts

- **- Understanding current and future ATM system behavior/dynamics**
  - Non-linearities – models
  - Use of performance and observational data
  - Disturbed behavior; brittleness; stability
  - Demand and its evolution
  - Failure modes; complexity; limiting factors for specific concepts
  - Handling anomalies – e.g.,when many flight paths are to be changed? What are conditions required to keep system stable?

- **Human factors**
  - Multi-state system operation – transition, awareness of state
    - Coordination
  - Information requirement
  - Failure modes and effects – role of human
  - Quantification for parameterization of system loads
  - Workforce skill mix of the future - selection and training
  - Automation and human roles
  - Span of control – time phased hierarchy

- **Separation standards –some examples:**
  - Dynamic wake vortex separation standards
  - Time based separation
  - Relation to CNS; impact of intent
  - Standards for different concepts/airspace
  - Criteria for separation standards

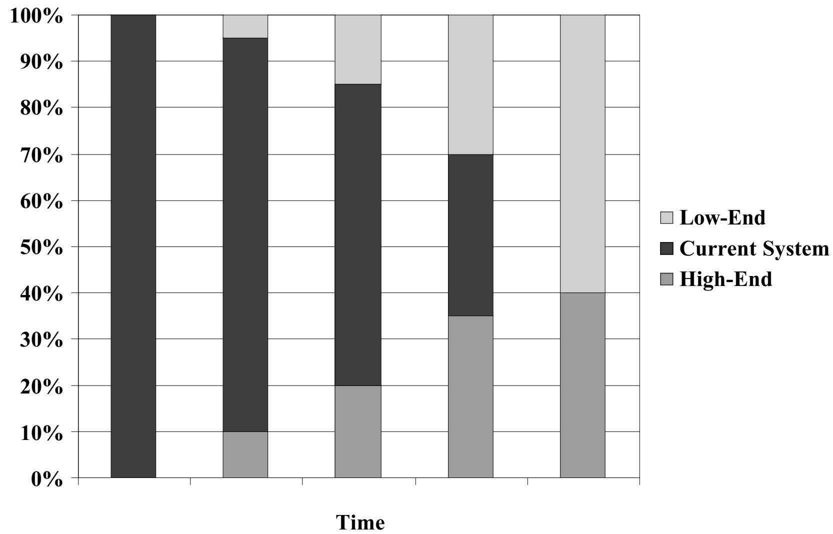
- **Ways to reduce capacity variability**
  - What causes it
  - How do you control/manage it
  - What is the capacity variability that the system must be designed around – buffers etc (e.g., – security, wake vortex, weather , airport arrival rate)
- **4D Planners vs. Self-Separation**
  - Trades (advantages/disadvantages) between 4D conflict free trajectory planners and air-to-air self separation
- **RTA approaches**
  - What are the limits on achievable performance in real world conditions
  - Trade off predictability and tight to plan
  - RTA accuracy impact on performance of the system
  - Control architecture

- **Airspace Design**
  - What are criteria to segment airspace that provide meaningful capacity gains? How much segmentation is feasible? What are airspace density limits for safety, communications, etc.?
  - How do we make Oceanic Airspace more like Domestic En Route Airspace? (special issues associated with international considerations, ICAO, FIRs, and mixed equipage)
- **Weather**
  - Predictability
  - Option based weather analysis
- **Safety**
  - Need a safety methodology for new concepts
  - What are the alternative target levels of safety
  - What should safety metrics target numbers be
  - How do you infer safety metrics for very rare events
- **Benefit/Cost Analysis**
  - Need new methods to include societal benefits
  - Methods to consider differential cost sharing

Closing Thoughts

Ease of transition makes this set of concepts particularly appealing

- While High- and Low-End systems are introduced, rest of airspace will operate as it does today
- Eventually, we envision:
  - High end network expands
  - Low end network expands
  - Current system shrinks and may go away


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Low-End
Current System
High-End
Time

Thank You!

Continue Current ATM Paradigm

- If the paradigm shift that we endorse does not take place:
  - Economy will adapt!
  - But won't get economic benefits of aviation (lobster will be hard to get in Kansas City)
  - Non-part 121 will slowly be driven out of transportation business.
- We will have a system that can't get close to meeting demand
- More ATM by dispatchers is likely
- Demand management will become a necessity

- We identified high payoff research for existing paradigm

TACEC

Terminal Area Capacity Enhancement Concept

Advanced ATM Concept for 2020

prepared for
VAMS Technical Interchange Meeting #3
NASA Ames Research Center
14-15 January 2003

Agenda

– **TACEC Overview**

– **Results of investigations**

– **Revised Concept focus**

– **Impact of revision on TACEC Core Ideas**

– **Objective Statement**

– **Summary**

Terminal Area
Operating Domain

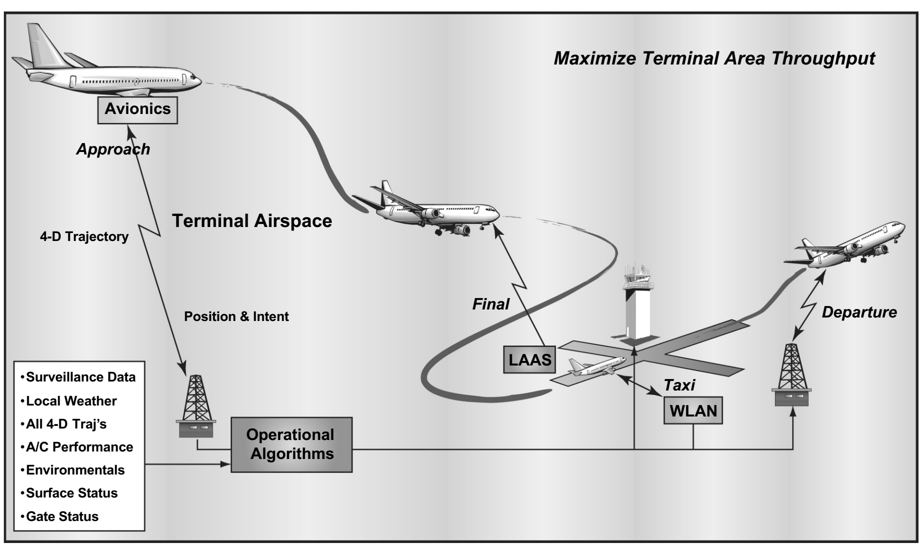
Raytheon
Network Centric Systems

- The Terminal Area is defined as airspace surrounding an airport or airport group (similar to today's TRACON) as well as the airport surface (runway, taxiway and ramp). In addition the Terminal Area includes gate and street side operations.
- For comparison purposes the Terminal Area is similar to the operations environment addressed in the FAA's Operational Evolution Plan for Arrival and Departure Rate

Capacity can only be claimed if you can put the wheels on the ground and the passengers in the terminal……………...

TACEC Overview

Raytheon
Network Centric Systems



Terminal Area Capacity Enhancement Concept

Raytheon
Network Centric Systems

Increasing capacity in the Terminal Area relies on following Core Ideas:

- **Accurate 4D Trajectory Calculation and aircraft execution of required trajectories**
- **Highly reliable and secure data link**
- **Reduced separation standards**
- **Improved surveillance**
  - **WAAS enhanced GPS**
  - **Multi-sensor surveillance fusion**
  - **Mode S MSSR**
- **Airborne self separation**
- **Complex finals - curvilinear, multi-aircraft formations landings using LAAS**
- **Optimized surface movement**
- **Integrated Terminal Area information network (all stakeholders)**
- **Human Centered System**

Concept Review Results

Raytheon
Network Centric Systems

Element	Projected Capacity Benefit	Comments
4D Trajectories/ Aircraft execution of required trajectories	10%	Optimized for current arrival/departure operations (Similar to FAST)
Reduced separation standards	No direct benefit	Necessary to support optimized 4D trajectories
Airborne self separation	No direct benefit	Element of redundancy in fully automated 4D trajectories
Complex finals - curvilinear	Minimal benefit	Primary benefit is noise reduction
Multi-aircraft formation landing	Linear increase	Fundamental change in terminal operations
Optimized surface movement	Linear increase	Must accommodate multi-aircraft landings

ATMS AIR TRAFFIC MANAGEMENT SYSTEMS

Interim Conclusion

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- Terminal area does not provide sufficient airspace to significantly increase the NAS capacity.
  - Capacity gains for optimizing sequencing, approach/departure maneuvers, and airspace usage cannot provide the needed growth.
  - In a gate to gate evaluation, the gains achieved in the enroute domain can not be translated into increased passenger movements.
- Building more runways can provide the needed capacity, but not all airports can accommodate the requirements.
  - New airport facilities require 20+ years to construct
  - Current parallel runway spacing needs significant real estate
  - Political/Social issues remain
- Closely spaced parallel landings can provide needed capacity for all airports
  - revolutionary approach in wake vortex avoidance using “flight corridors” drastically reduces needed real estate.

ATMS AIR TRAFFIC MANAGEMENT SYSTEMS

Wake Vortex Avoidance using Flight Corridors[1]

Raytheon
Network Centric Systems

- Revolutionary NASA concept based on minimizing aircraft separation to avoid wake vortex avoidance.
- Instead of waiting (time=distance) until the vortices disperse, the flight corridor concept establishes “tunnels” in space which represent each aircraft’s wake vortex generation over time.
- These tunnels become the “non-transgression” zones similar to today’s parallel runway operational concept.
- Multi-aircraft landings and departures can be configured by dynamically establishing the tunnels as flight corridors, monitoring weather and actual aircraft position.

1. Rossow, Vernon R. “Use of Individual Flight Corridors to Avoid Vortex Wakes”, AIAA Atmospheric Flight Mechanics Conference, 5-8 August 2002, Monterey, CA

Re-Stated Core Ideas

Raytheon
Network Centric Systems

- Accurate 4D Trajectory Calculation and aircraft execution of required trajectories
  - Focus on the "entry/exit" of dynamic flight corridors. Accurate sequencing, position and timing of all aircraft entering or leaving the terminal area to match corridor needs.
- Improved surveillance
  - Accuracy, reliability, and availability to support 4D trajectory requirements.
- Airborne self separation
  - What role in flight corridor operation?
- Complex finals - curvilinear, multi-aircraft formations landings using LAAS
  - Focus on LAAS capability to achieve needed accuracy to control flight paths.
- Optimized surface movement
  - Accommodate multi-aircraft landings/departures
- Integrated Terminal Area information network (all stakeholders)
  - Fully integrated weather monitoring (both ground and airborne sources) to predict impacts on wake vortex movement.

Human Centered Systems and Flight Corridors

Raytheon
Network Centric Systems

- Multiple Flight Corridors are a paradigm shift from today's parallel runway standards.
  - Entirely new concept in final approach monitoring is required
  - Roles of human and automation must be re-evaluated
- Key goal of automation/display solution is the maintenance of appropriate situational awareness for human (ground and flight crew) operators.
  - Need to deal with exception cases
  - Dynamic recovery performance
- New visualization approaches will be developed and evaluated.

Key Issues Beyond Technology

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Network Centric Systems

- **Environmental**
  - Significantly increasing the number of operations at today's airports will generate pollution/noise output beyond allowable levels.
  - Vehicle technology development over the next 20 years is not adequate to offset 100% increase in airport operations.
  - Flight paths can be used to minimize noise, but constraints remain on approach/departure routing.

- **"Enterprise" solution which trades benefits gained by capacity increases with standards of living by those affected is needed.**

Revised Objective Statement

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Network Centric Systems

TACEC will provide significant capacity increase in the Terminal Area domain by utilizing the following operational approaches;

1. Multiple aircraft landing and departures using dynamic flight corridors to insure wake vortex free operations.
2. Up-linked 4D trajectory flight paths optimized for staging the aircraft's entry/exit into/from the flight corridors.
3. Optimized surface movements (taxi routing, gate assignment, etc) to allow multi-aircraft operations.
4. Human centered automation approach which maintains required situational awareness in flight corridor operations.

Summary

Raytheon
Network Centric Systems

- Terminal Area Capacity Enhancement is primarily dependent on efficient wake vortex avoidance.
- A novel approach to avoiding wake vortices has been proposed by NASA using the idea of a “flight corridor” as a non transgression zone.
- Implementation requires both accurate, reliable, and available wake vortex location and aircraft position knowledge.
- Raytheon in partnership with NASA will investigate the feasibility of such a solution based on;
  - LAAS, WAAS performance and interaction with aircraft (both current and future)
  - Integrated weather solutions (ground and aircraft based sensors)
  - Human Centered automation solution
  - Surface movement operations for multi-aircraft arrival/departures

Wake Vortex Avoidance System (WakeVAS) Concept of Operations

VAMS Technical Interchange Meeting
15 January 2003

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Separation Rules [1]

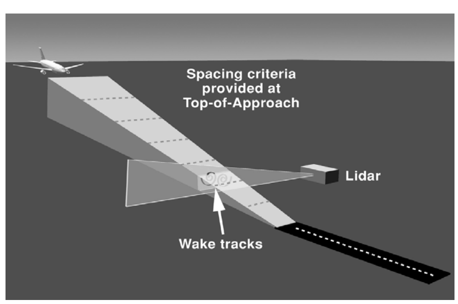
Terminal Configuration >	Single Runway; Parallel Runways < 2500' separation	Intersecting Runways
Departures	Behind B757 or Heavy – 2 min hold; 3 min if intersection or opposite direction same runway, OR Radar separation minima 1. Heavy behind heavy- 4mi 2. Large/Heavy behind B757 –4mi 3. Small behind B757 – 5mi 4. Large behind heavy – 5mi 5. Small behind heavy – 5mi For pairs not listed the separation is 3 miles	2min behind B757 or heavy departure or landing if projected flight paths will cross; includes parallel runways more than 2500' in separation if will fly through the airborne path of other aircraft
Arrivals	Radar separation minima (at threshold): 1. Heavy behind heavy- 4mi 2. Large/Heavy behind B757 –4mi 3. Small behind B757 – 5mi 4. Large behind heavy – 5mi 5. Small behind large – 4mi 6. Small behind heavy – 6mi For pairs not listed the separation is 3 miles, except 2.5 miles in cases when 50 second runway occupancy time is documented Non-Radar Minima: 2 min behind Heavy/B757 except for small follower, 3 min	2 min for aircraft arriving after a departing or arriving Heavy/B757 if arrival will fly through airborne path of other aircraft

Current Separation Rules

- Wake separation rules are static, based on empirical measurements, and represent a response to worst-case persistence of wake hazard
- Over 30 years of wake research and the technologies demonstrated in AVOSS have produced the potential for a dramatic increase in knowledge about the persistence of wake hazard
- Introduction of systems and procedures that utilize this improved knowledge of wake hazard durations will allow for increases in capacity

Background: NASA Aircraft VOrtex Spacing System (AVOSS)

- Goal:
  - Demonstrate an integration of technologies to provide weather-dependent, dynamic aircraft spacing for wake avoidance
  - Operate real-time in a relevant environment
- System demonstrated at Dallas Fort-Worth Airport in July 2000; Represented the culmination of six years of field testing, data collection, and technology development



Products of the AVOSS Program

- AVOSS effort represented the most comprehensive wake and weather data collection effort to date
  - Over 10,000 wakes measured with relevant ambient weather parameters captured
  - Measurements collected at three locations over the course of six years
- AVOSS provided platform for subsystem development & integration
  - Major progress made in wake modeling and sensing
  - Weather subsystems were integrated in new ways and data fusing algorithms were developed
- Demonstration of concept for system integration
  - Example guides future operational concept development

CONOPS Development

Real-Time Wake Hazard Knowledge

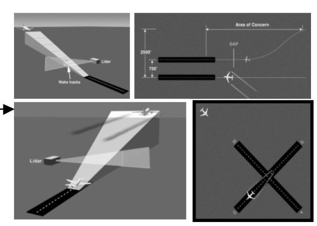
- **Weather sensing and prediction**
- **Wake hazard predictions**
- **Wake sensing**

→

Procedures/Rules

Interfaces

→



- **Controller Tool**
  - **Passive**
  - **Active**
- **Flight Deck**
  - **Intuitive Displays**
  - **NAV/Guidance Integration**

- **Ground System**
- **Airborne System**
- **Hybrid System**

CONOPS Core Ideas

- Utilize hybrid of ground-based and airborne systems to gain dynamic knowledge of wake hazards
- System required to provide accurate wake hazard durations, controllers use hazard information to modulate spacing
- Information also provided to pilots of appropriately equipped aircraft to enhance situational awareness

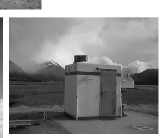
WakeVAS CONOPS

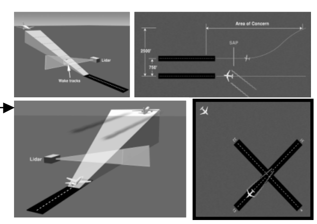
Real-Time Wake Hazard Knowledge

• Airport weather system augmentations; ground sensors and link to aircraft; wake prediction algorithm

Procedures/Rules

Interfaces





• Controller Tool (responsible for spacing)

- **• coarse**
- **• fine**

• Flight Deck (increase SA)

- **• Intuitive Displays**
- **• NAV/Guidance Integration**

• Hybrid System

CONOPS Cont.

- Roles/responsibilities
  - System provides wake-safe spacing recommendations
    - Coarse: Determination of wakes factor/no-factor and duration
    - Fine: wake spacing transparently integrated into approach spacing tool
  - Controllers responsible for implementing system spacing/separation
  - Pilots of adequately equipped aircraft have wake hazard regions defined and displayed for SA
    - Requires two-way aircraft-ground data link
    - Wake locations not shown, just wake-safe, wake-unsafe regions
    - Will aid in visual approach operations
    - Approach spacing tools will reduce variance and maximize benefit

CONOPS Architecture

- Airport weather system augmented with wake and weather sensors and prediction algorithms
  - Wake algorithm provides probabilistic wake behavior output
  - Terminal Area Planetary Boundary Layer Prediction System (TAPPS) - like microscale weather prediction for wake hazard durations [2]
  - Fusing algorithm combines sensor data and closes a feedback loop between wake and weather predictions and measurements

CONOPS Cont.

- Appropriately defined region of protected airspace for runway configuration and operation targeted (single runway or multi-runway complex; approaches and departures)
- Closed-Loop prediction system senses current conditions diverging from predictions and adjusts to more conservative spacing and changes prediction of duration appropriately

Research Questions

- Accuracy/performance of all subsystems (wake/weather sensors)
- Development of probabilistic wake predictor
- Temporal and Spatial variation of relevant weather parameters (weather sensor placement and coverage)
- Safety analysis; rare event quantification
- Definition of wake hazard strength
- Quantification of weather prediction duration
- Quantification of dynamic spacing impacts on NAS
- Pilot/Controller workloads/display designs
- Data link requirements
- High resolution weather data

Changes/Requirements

- Policy changes
  - Amend current wake separation rules to incorporate dynamic, technology-dependent spacing
  - Consensus on wake hazard definition
- Infrastructure Requirements
  - Standards for aircraft weather data
  - Airport weather suite upgrade
  - Communication link message/bandwidth requirements

WakeVAS Concept
Self-evaluation Approach and Process [3]

- Define solution space
  - Initial airport set
  - Inherent operational attributes
- Define analyses and scenarios
  - Correlate specific airports with their indigenous operational attributes
  - Capture maximum solution space coverage and aircraft operations
- Analysis and Results
  - Capacity and air traffic flow impacts and sensitivities at local, regional, and national system-level
    - RAMS Simulation Tool -- local and regional
    - AwSIM/Draper Simulation Tool -- enroute and national
- Refine and extend solution space and analyses
  - Add airports to simulation based on the characteristics of the reference set of initial airports
  - Extrapolate capacity and air traffic flow results to analyze
  - economic impacts

WakeVAS Concept Solution Space

Airport Parameter	Environment	Aircraft	NAS-level	Subsystem-level
Single runway	Frequency of Instrument/ visual operations	Approach/ Departure speeds	Traffic mix/schedule	Subsystem performance and requirements
Multi-runway	Prediction input parameters	Climb gradients	Dynamic spacing impacts	Wx prediction horizon
Noise Impacts	Seasonal/ diurnal variations of wx	Operational weights	Efficiency gains	Human performance
Traffic mix/ schedule	Geographic climatology	Equipage rates	Contingency operations	Interfaces
Equipment mix	Discrete events (fronts, convective)	FAA Weight Category		
Local procedures, constraints				
Capacity limits/ source				

Partial WakeVAS Evaluation Matrix [4].

Airport	ATL	BOS	DFW	EWR	LAX	LGA	ORD	SFO	JFK	MIA	MEM	CLT
Configuration	2 pair Closely Spaced Parallel Runways (CSPRs)	CSPR & Int.	2 pair CSPRs	CSPR & Int.	2 pair CSPRs	Int.	Int.	2 pair CSPRs	2 pair indep	1 pair indep	1 pair CSPRs & Int.	1 pair indep & int.
Operation to Test	Single-rwy Arr. & Dep.	CSPR & Int. Arr. & Dep.	Single-rwy Arr. & Dep.	CSPR & Int. Arr. & Dep.	CSPR Arr. & Dep.	Int. Arr. & Dep.	Single-rwy & Int. Arr. & Dep.	CSPR Arr. & Dep.	Single-rwy Arr. & Dep.	Single-rwy Arr. & Dep.	CSPR & Int. Arr. & Dep.	Single-rwy & Int. Arr. & Dep.
% B757 & Heavy	22	13	11	12	21	9	10	25	31	12		
% hours below VMC for CY2000	35	34	31	22	55	25	39	49	28			

References

1. *Air Traffic Controller's Handbook,* FAA Order# 7110.65N.
2. Kaplan, Michael L.; Lin, Yuh-Lang; Charney, Joseph J.; Pfeiffer, Karl D.; Ensley, Darrell B.; DeCroix, David S.; and Weglarz, Ronald P.: *A Terminal Area PBL Prediction System at Dallas-Fort Worth and its Application in Simulating Diurnal PBL Jets*, Bulletin of the American Meteorological Society, Vol. 81, No. 9, September 2000.
3. R. Yackovetsky, Airspace Systems, Concepts and Analysis Competency, NASA LaRC.
4. Cooper, W., Levy, B., Lunsford, C., Mundra, A., Smith, A.; *An Evaluation of Selected Wake Turbulence ATC Procedures to Increased System Capacity,* MITRE CAASD report delivered to the FAA, Enclosure to F064-L-015, 28 June 2002.

VAST
Communications, Navigation, and Surveillance Modeling

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January 15, 2003

OBJECTIVES

- **Develop requirements for CNS modeling that supports evaluation of advanced airspace concepts**
  - Identify and categorize CNS modeling and simulation capabilities and needs
  - Identify CNS modeling approach
- **Develop communication, navigation and surveillance models for today's system, technologies currently being considered within the FAA's OEP, and technologies being considered for the future**
  - Develop and demonstrate standard communications traffic model for assessing CNS model elements and architectures
  - Integrate CNS modeling activities into Airspace Modeling Toolbox

CNS Modeling

STATUS

Identification and categorize of existing CNS capabilities for modeling and simulation

- Exploration for sources of model or simulation needed - Draft study in submitted and an update being prepared

Identify CNS modeling and simulation needs

- Existing AATT and DAG-TM CNS requirements from the basis of this activity

CNS modeling approach

- Definition being worked.

CNS Modeling

STATUS

- **Develop and demonstrate standard communications traffic model for assessing CNS model elements and architectures**
  - FASTE-CNS development to provide communications, navigation or surveillance traffic profiles
    - Acceptance Test Conducted 12/20/02
    - Beta Testing Start 03/03
- **Integrate CNS modeling activities into Airspace Modeling Toolbox**
  - Awaiting Contractor Start

FASTE-CNS Project Summary

- Title: Future Aeronautical Subnetwork Traffic Emulator for Communications, Navigation & Surveillance (FASTE - CNS)
- Project: Develop a dynamic communications estimating tool that is accessible via the Internet. FASTE-CNS supports collaborative research by providing a means to define and assess the communications traffic loading associated with aeronautical related applications.
- Plan/Deliverables:
  - Phase I. System Design/Software Development (Complete)
    - System Specification & System Design Drawings & Reviews
    - Software Requirements & Detailed Design Document & Review
    - Software Development, Integration & Test
  - Phase II. Hosting & Evaluation (Planned for 2nd Qtr FY03)
- Today's Status: Preparing SOW for Phase II: Beta Test Phase

Background

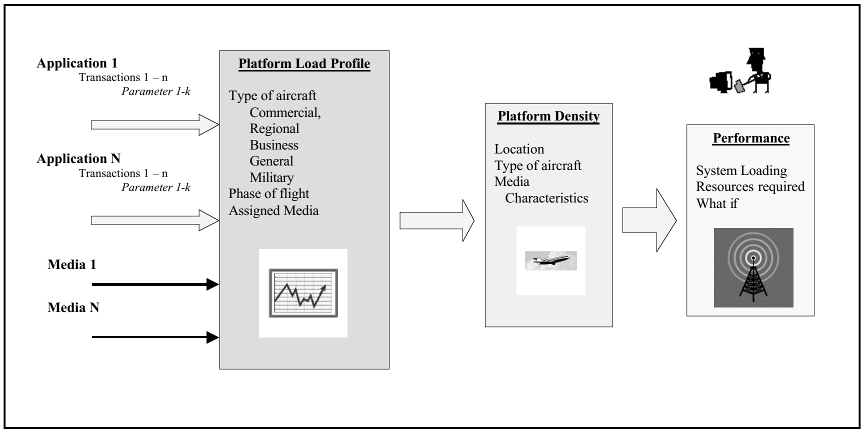
- Studies of future operational concepts and related CNS architecture definitions.
- A common, recurring study task is the communications loading analysis.
- Each study has this similar and costly activity.
- Desire granularity in loading projections but often settle for macro assessments due to cost or lack of information.
- Need to develop an industry consensus on future applications, transaction dimensions, and future aircraft population.
- Support the “what if” systems analysis and the NASA VAMS Program.

VAMS-CNS

CNS Modeling

Glenn Research Center

Generic Loading Analysis



All Driven by Operational Concepts

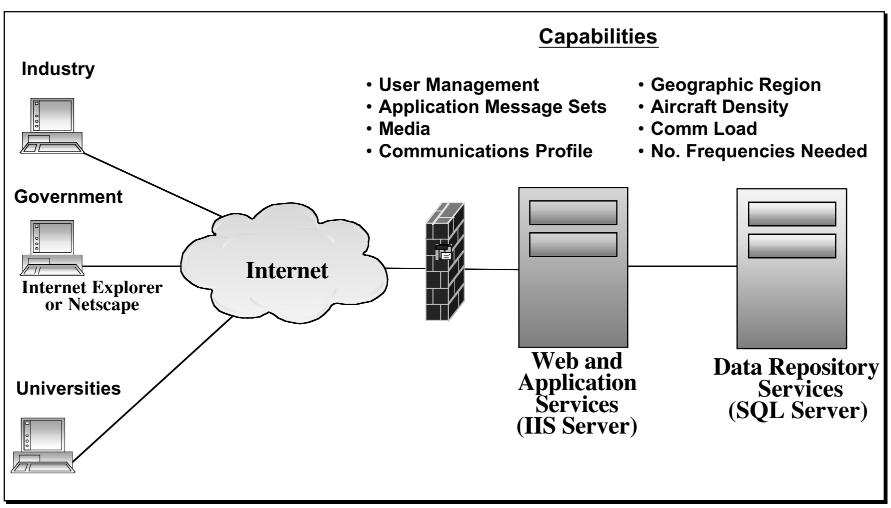
01/15/2003 SWM

VAMS-CNS

CNS Modeling

Glenn Research Center

FASTE-CNS System Architecture



01/15/2003 SWM

CNS Modeling

Features

- Each application profile may be allocated to different communication subnets.
- Each researcher may keep a number of application profiles on file for later use as well as have access to sets of typical applications profiles.
- Loading displayed for a typical flight profile.
- Airspace model depicts number of aircraft within selected airspace.
- Aggregate assessment of throughput requirements calculated to allow assessment of resources for various subnetworks.
- High-level performance models for the communications subnetworks available.
- Means to collaborate between researches provided.

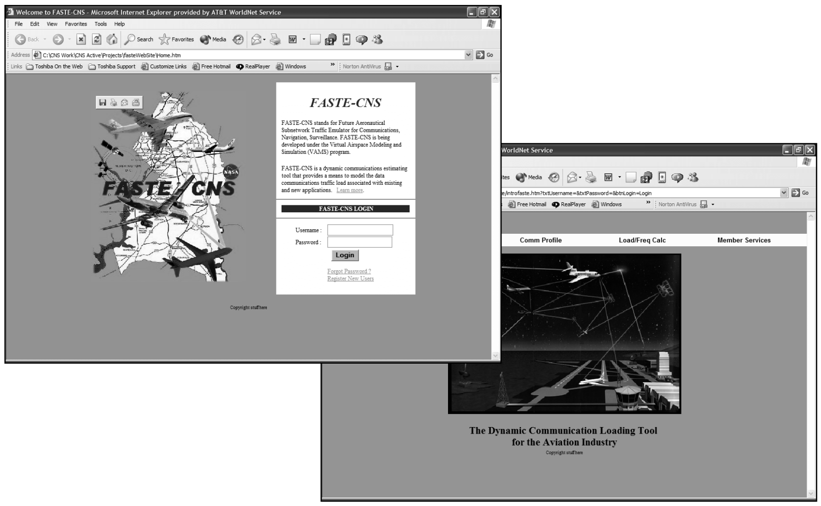
CNS Modeling

Internet-Based

FASTE-CNS is an Internet-based aeronautical communications calculation capability that will support geographically dispersed NASA, FAA, university, and contractor communications evaluations for the future aeronautical environment of the 48 contiguous states in the Continental United States (CONUS).

- Authorized users access the system using common web browsers such as Internet Explorer and Netscape.
- User Accounts
  - FASTE-CNS provides a mechanism to establish user accounts.
  - Account holders can establish their own user identification (ID) and password.

Home Page



User Inputs are Flexible

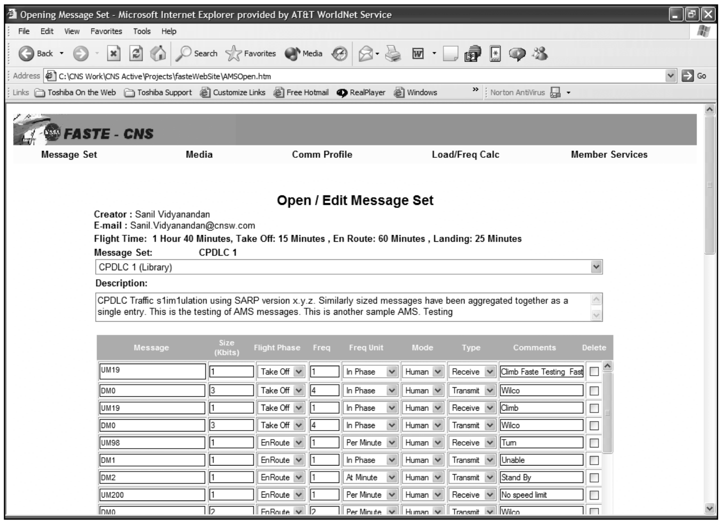
- Application Message Sets
  - A user can define the communicated messages associated with an application.
  - Select and use an application from a library of public applications, or save it as a private application for his/her use.
  - Print desired application message sets.
- Communications Traffic Profiles
  - A user can define a communications traffic profile, which is a series of applications and their associated media.
  - Select and use a profile from a library of public profiles, or can save it as a private profile for his/her use.
  - Print desired profiles.

VAMS-CNS

CNS Modeling

Glenn Research Center

Message Set Definition



VAMS-CNS

CNS Modeling

Glenn Research Center

Communications Forecast Data Model

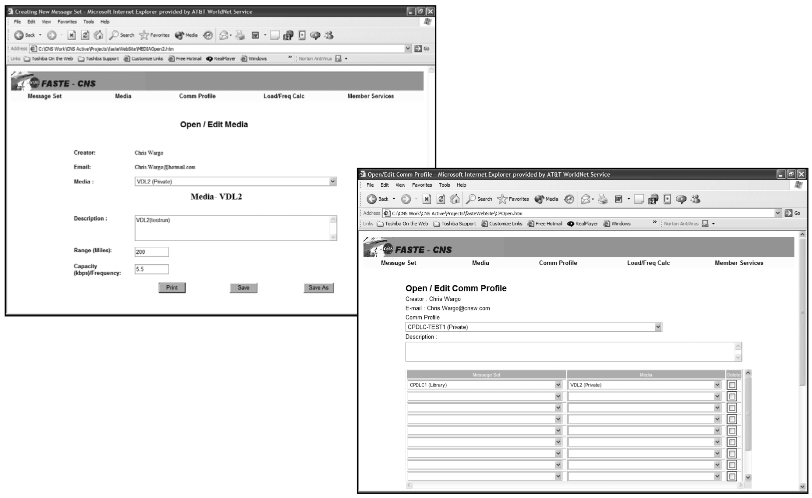
- A communications forecast data model combines a user-selected group of communications traffic profiles and an aircraft density profile to describe the total communications traffic of interest in a geographical region.
- A user can assign separate communications traffic profiles to subsets of the total number of aircraft within a sub-region.
- The communications traffic loads for each type of media within a region (and its sub-regions) can be printed to provide researchers with an understanding of the data link communications requirements within the region.

VAMS-CNS

CNS Modeling

Glenn Research Center

Creating a Comm Profile



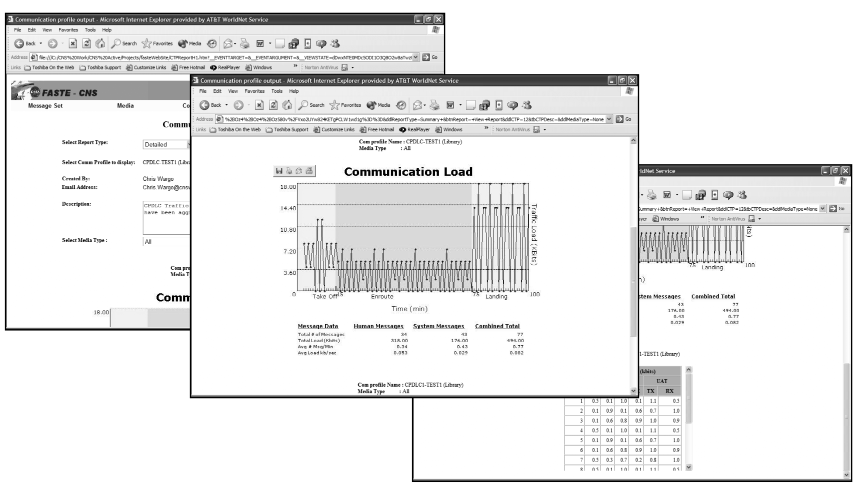
01/15/2003 SWM

VAMS-CNS

CNS Modeling

Glenn Research Center

Communications Load Display



01/15/2003 SWM

CNS Modeling

Researchers Can Collaborate

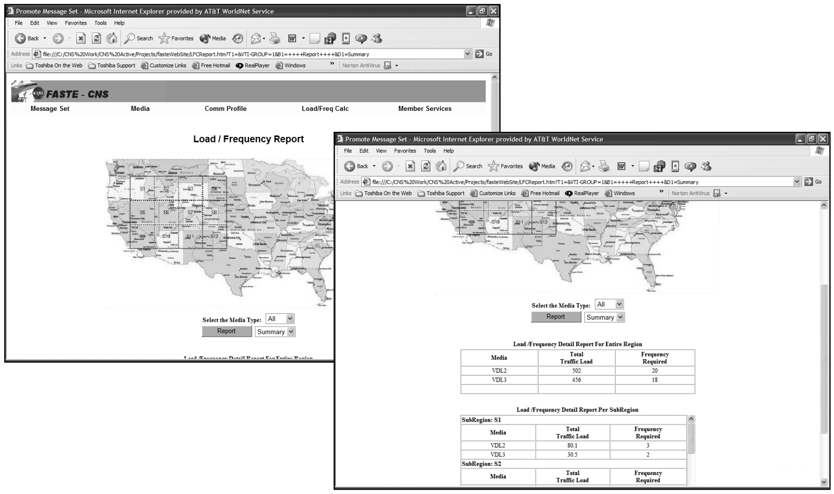
- Aircraft Density Profiles (Fleet Placement)
  - A user can define a geographic region composed of contiguous sub-regions and assign a number of aircraft to each sub-region to define an aircraft density profile. The largest profile supported covers the entire CONUS.
- Load & Frequency Calculation Model
  - A user can associate a comm profile with each group of aircraft to define a load & frequency calculation model.
  - Select and use a model from a library of public models, or save a new model as a private model for his/her use.
  - Print desired models.

CNS Modeling

Performance Modeling

- System Loading and Frequency Requirements
- FASTE-CNS calculates the loading requirements needed to support the geographical region defined in the density profile.
- FASTE-CNS calculates the frequency requirements needed to support the geographical region defined in the density profile.
- Results can be displayed in textual format.

Load/Frequency Report



VAMS-CNS

CNS Modeling

Glenn Research Center

Phase II Potential Functions

- Enhance Media Performance Models
- Use as a configuration tool to set-up and define the tests that other CNS models would perform
- Export configuration data using HLA/RTI to the Virtual Airspace Modeling and Simulation (VAMS) System
- Import route models and apply communications traffic loading results from the route concept models
- Develop as web access mechanism to the NASA Virtual Airspace Modeling and Simulation Toolkit.

CNS Modeling

Next Project Steps

- Seek participants for BETA test
- Increase functionally and fidelity of subnetwork models

VAMS-CNS

CNS Modeling

Glenn Research Center

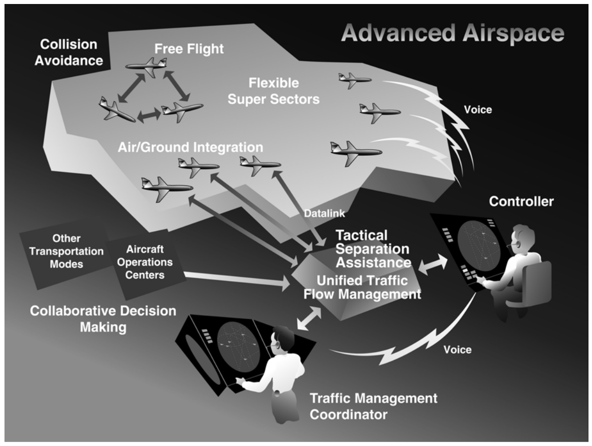
Demonstration

- Contact:

  - Chris Wargo
    Computer Networks & Software, Inc.
    chris.wargo@cnsw.com
    443-994-6137

01/15/2003 SWM

Advanced Airspace Concept



VAMS TIM #3; January 14-16, 2003
Presenters: Heinz Erzberger and Russ Paielli
NASA Ames Research Center
Moffett Field, CA

Performance Goals

(Current separation standards)

- Application to selected airspace from takeoff to touchdown
- Double capacity of en route airspace
- Double capacity of terminal area airspace
- Increase landing rate of runways by 20%
- Reduce operational errors by 50%
- Significant reduction in controller workload

Overview of Advanced Airspace Concept

Ground-based system generates conflict-free 4D trajectories and sends them to equipped aircraft via data link

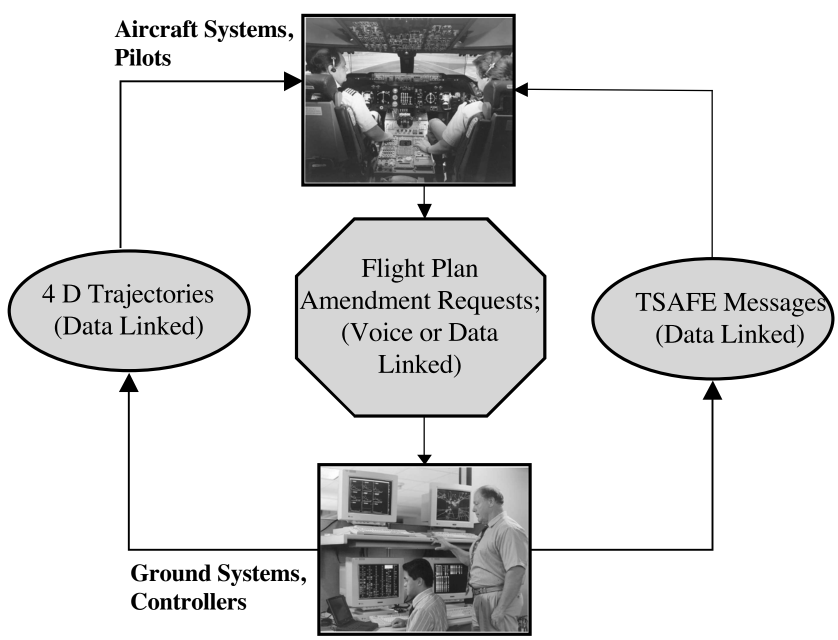
Pilots use Flight Management Systems to execute trajectories

Independent ground-based system checks for near term conflicts and issues advisories to maintains safe separation

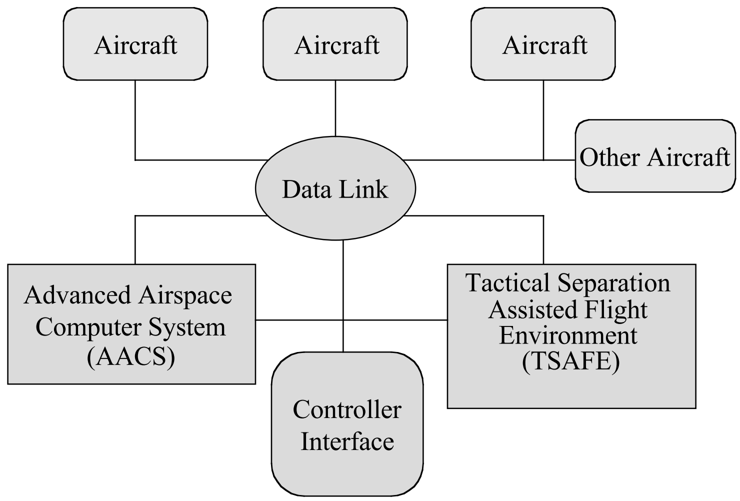
Advanced Airspace sectors consist of several conventional sectors combined into super-sectors

Controllers handle strategic tasks and unequipped aircraft but are not responsible for separation assurance of equipped aircraft in Advanced Airspace sectors

Ground-Air Interactions in Advanced Airspace

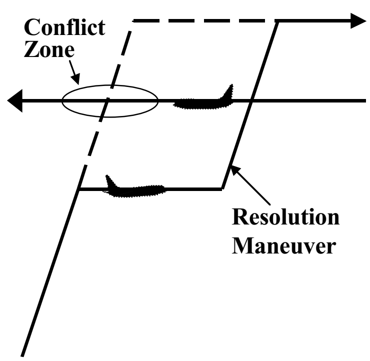


Advanced Airspace Architecture

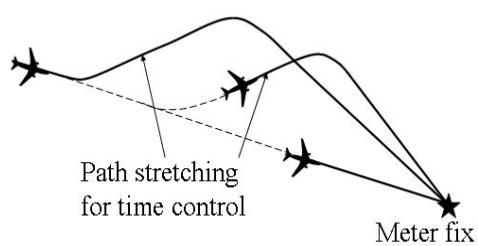


AACS Functions: En Route

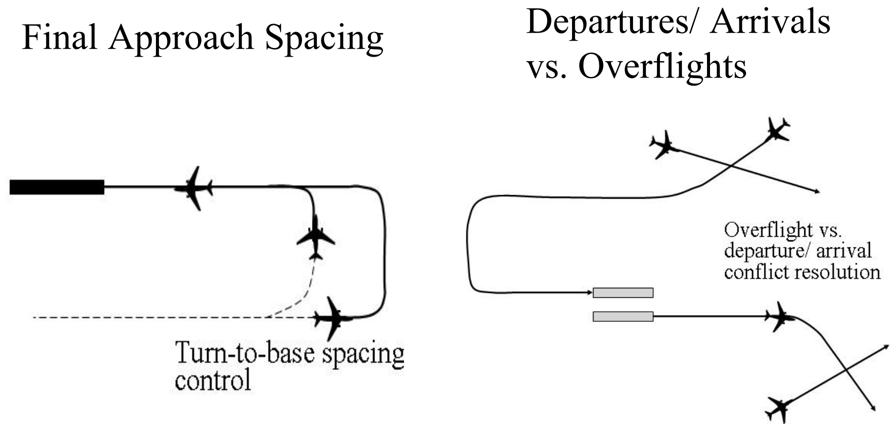
Conflict Resolution,
Vertical Plane Maneuver



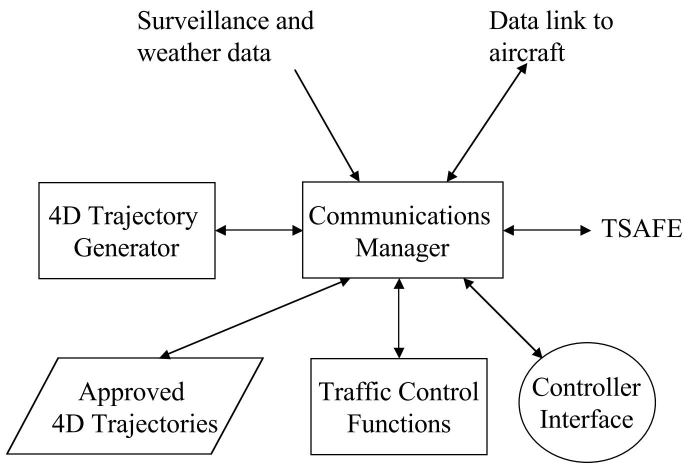
Arrival Metering



AACS Functions: Terminal Area



AACS Architecture



KEY IDEAS OF AUTOMATED AIRSPACE

- 4D trajectory assignment for equipped aircraft
  - Replaces (CTAS) trajectory prediction based on 2D flightplan, tracking data, winds
  - Aircraft requests trajectory, ground assigns trajectory
  - Specified tolerances on flight technical error
- Automated conflict detection and resolution on ground, amended trajectories uplinked to resolve conflicts
  - Increases sector capacity
  - Reduces operational errors
- Automatic detection of trajectory non-conformance and handoff to human controller when necessary

TRAJECTORY SPECIFICATION

- Equipped aircraft will be assigned 4D trajectories with flight technical error tolerances
  - Parametric models needed for all trajectory segment types: cruise, climb, descent, turn, etc.
  - Error tolerances specified for along-track, cross-track, and vertical axes
  - Error tolerances based on RNP, but could be relaxed in sparse traffic
  - Along-track assigned position updated periodically to reduce need for throttle control
- National/International standard needed for FMS compatibility with ground systems

TSAFE FUNCTIONS

- Conforming equipped aircraft:
  - Confirm that trajectory assignments from AACS are conflict free for next ~4 minutes
  - Monitor aircraft conformance to assigned trajectories
  - Detect and alert aircraft for critical maneuvers and no-transgression zones
- Non-conforming and unequipped aircraft:
  - Detect imminent potential conflicts
  - Generate resolution maneuvers when necessary
  - Handoff to human controller if necessary

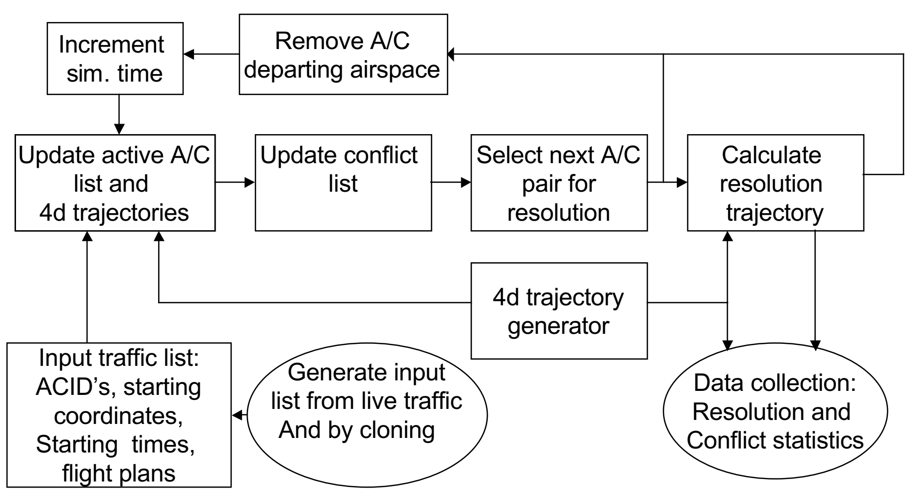
Evaluation Strategy

- Airspace Capacity
  - Initial focus on en route transition airspace
  - Performance of resolution algorithms
  - Use fast time simulation based on ACES/FACET
- Safety
  - Effectiveness of TSAFE to detect near term conflicts and to prevent operational errors
  - Use of live traffic in shadow mode to evaluate accuracy in predicting loss of separation incidents
  - Analysis of failure modes
- Controller workload
  - Estimate workload using human performance models in fast time simulation environment

Procedure for using Fast Time Simulation to Evaluate Capacity

- Record live traffic entering selected airspace
  - Record entry point coordinates, entry times, and associated flight plans for each aircraft
  - Subset of Cleveland Center airspace
- Generated 4D trajectories for each aircraft starting at entry points and times
- Generate and update conflict list as aircraft enter and depart airspace
- Determine trajectories that resolve conflicts using procedure-based algorithm
- Increase traffic density in steps by cloning live traffic until capacity limit is reached
  - Capacity limit is reached when resolution rate exceeds a limit value

Fast Time Simulation of AAC



Safety: Evaluation of TSAFE

•Short range conflict detection algorithms inserted into CTAS

•Evaluation of detection efficiency using live data and archived records of operational errors in progress

•Operational error cases under evaluation:

- Erroneous climb or descent clearance: 9 cases
- Misunderstood altitude at meter fix: 2 cases
- Level off at wrong altitude: 1 case
- Overtake during arrival merge: 1 case
- Erroneous direct clearance: 1 case
- Attempt to resolve non-existent conflict: 1 case

Controller Workload and Performance Analysis

- Purpose
  - Model & Analyze the AAC Concept of Operations using Human-system Performance Model (Air MIDAS)
  - Estimate workload as function of traffic density and controller tasks
- Status
  - Airspace Design completed (Cleveland combined sectors 47& 49)
  - Procedures for AAC, TSAFE & Baseline operations defined and encoded
  - Baseline Operations Simulation Run

Concluding Remarks

- Advanced Airspace Concept has potential to increase capacity substantially by reducing controller workload associated with tactical separation monitoring and control
  - Application to en route, terminal airspace and final approach control
- Elements of Concept have been outlined:
  - Ground-based system provides 4D conflict free trajectories to equipped aircraft via data link
  - TSAFE provides separation assurance advisories to pilots via data link and protects against certain types of failures
  - Controller performs strategic control tasks and handles unequipped aircraft
- TSAFE has potential to reduce operational errors in current system
- Evaluation of concept will focus initially on determining capacity of en route transition airspace using fast time simulation

System-Wide Optimization of the NAS

Matt Jardin

Banavar Sridhar

Automation Concepts Research Branch

NASA Ames Research Center

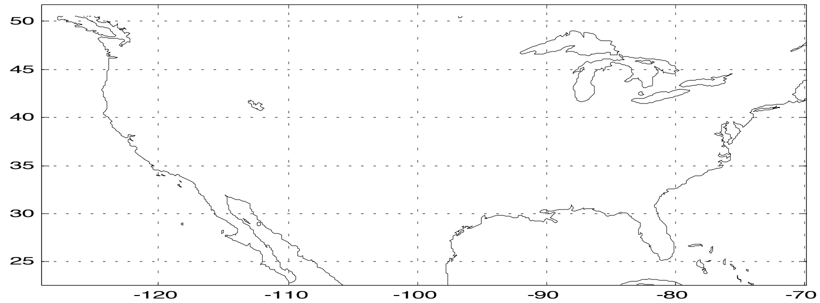
VAMS Technical Interchange Meeting #3

14-15 January, 2003.

Outline

1. **Problem Scope & Objectives**
2. **Core Ideas**
3. **High-Level System Concept**
4. **Core Idea Descriptions**
   - Sequential Optimization
   - Neighboring Optimal Wind Routing (NOWR)
   - Conflict Grid (Conflict Detection)
   - Conflict Resolution (Perturbation NOWR)
5. **Analysis & Simulation Results**
6. **Scenario Development**
7. **Roadmap**
8. **Conclusion**

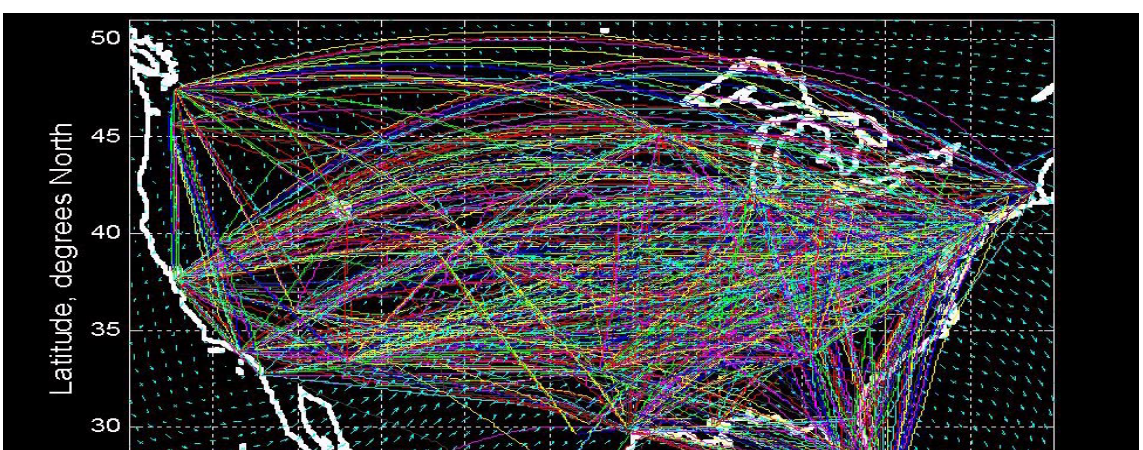
Problem Scope: Class A Airspace Over U.S.



- Area: .... 3 million nmi^2
- Daily Flight Ops above 18000 feet: 38,000
- Peak Traffic Load: ....3000 Aircraft
- Peak Load at Busiest Flight Level:............................500 Aircraft
- Unique Airports Supporting High-Altitude Traffic:................200

Objective

Develop a Practical Real-Time Method to Optimize and Deconflict Enroute Trajectories of All Aircraft on a Continental Scale



Quantitative Goals

- Reduce Direct Operating Costs by 4.5%
- Save Over 500 Hours of Flight Time Each Day
- Achieve Potential Savings of Nearly $1 Million per Day ($360 Million/Year)
- Increase Capacity while Maintaining Safety

Core Ideas:

Sequential Trajectory Optimization & Conflict Resolution

- Reduce NP-hard Problem to a Polynomial-Time Problem
- Achieve Measurable Near-Optimum Solutions

Neighboring Optimal Wind Routing (NOWR)

- Free Flight Routes are Wind Optimal, *NOT GREAT CIRCLE!*
- Computational Primitive: Algorithm Must be *FAST!*
- NOWR Easily Adapted for Conflict Resolution

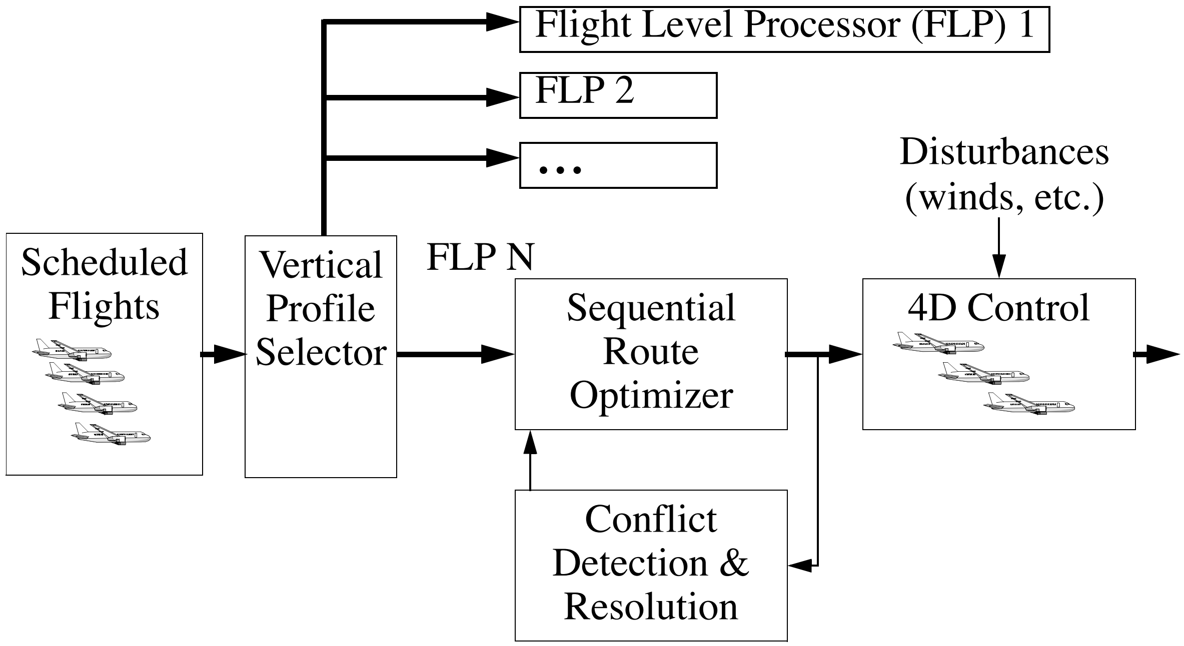
Conflict Grid for Conflict Detection

- Virtually Computationally Free Conflict Detection
- Generalized Conflicts (other aircraft, Weather Cells, SUA, etc.)

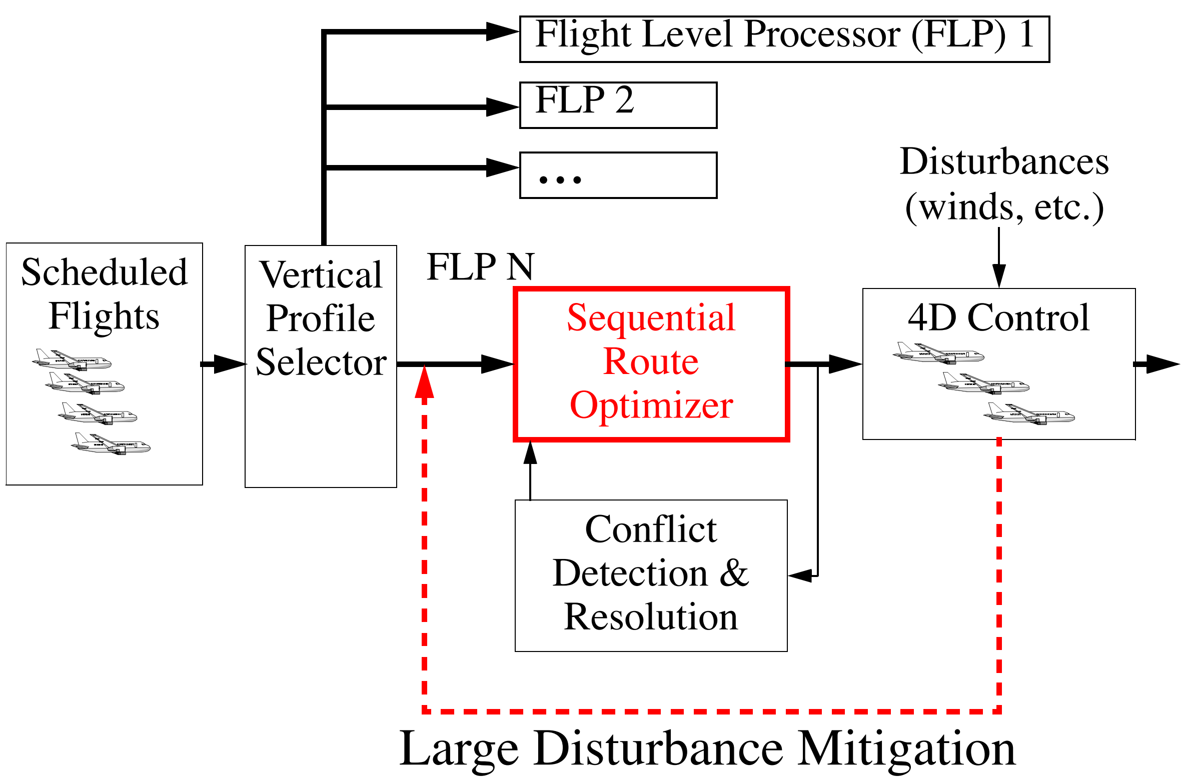
Enhanced 4-Dimensional (4D) Flight Plans

- Rigorous 4-D Trajectory-Based Approach to ATC

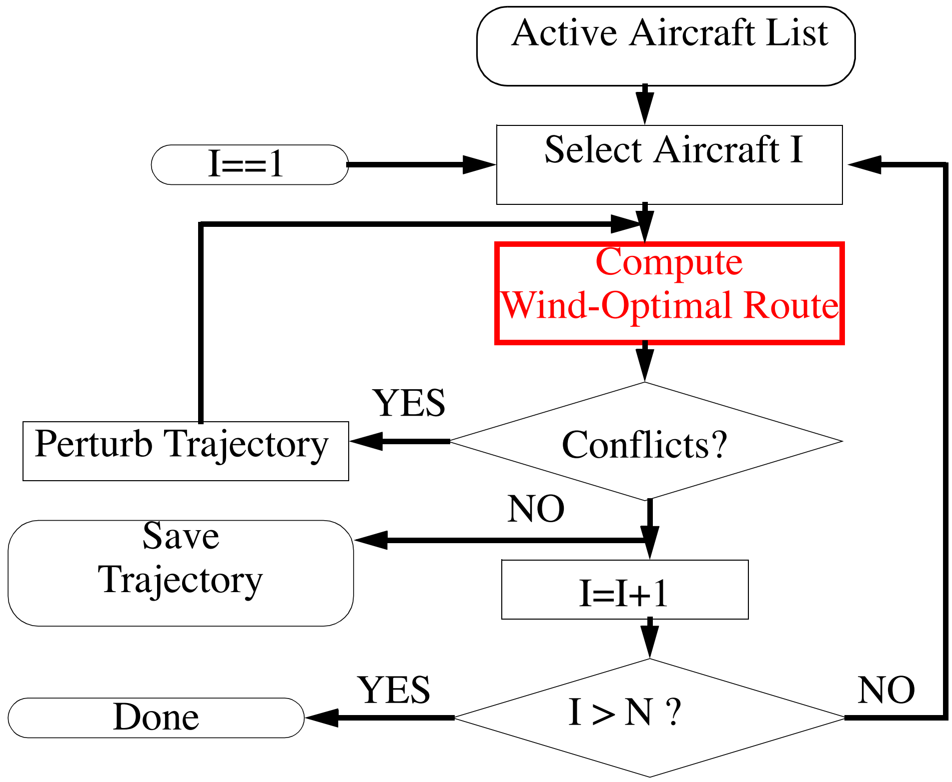
High-Level System Concept



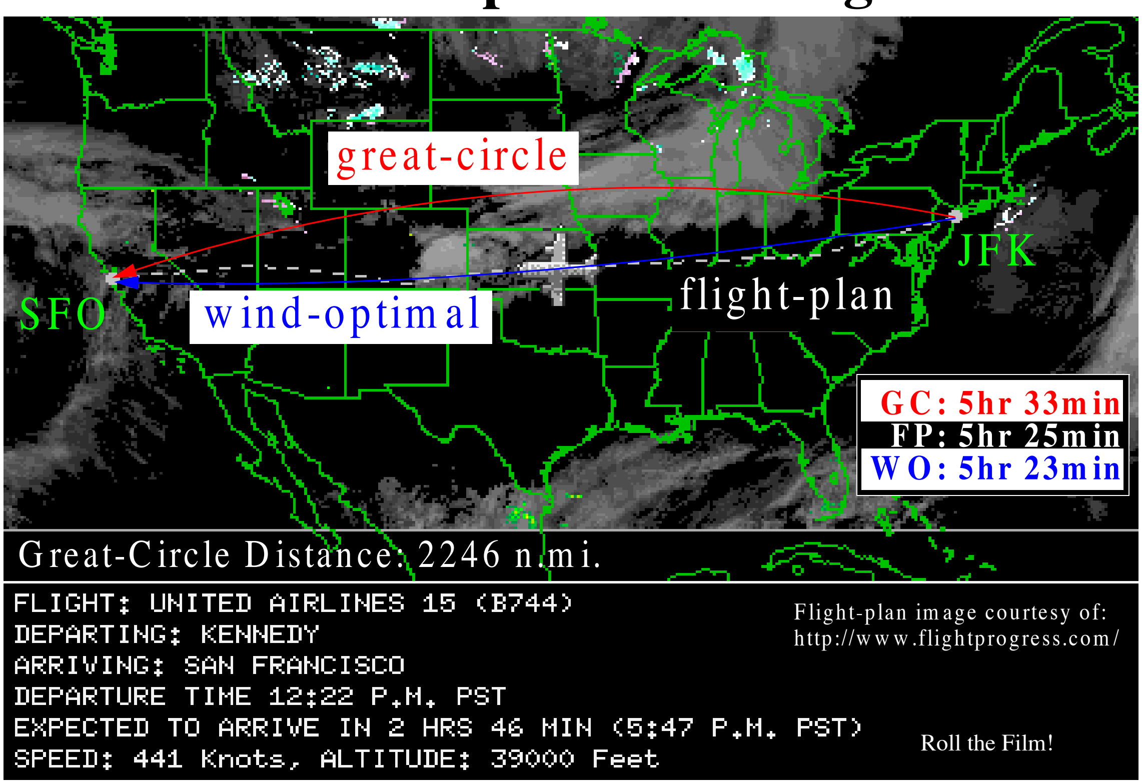
High-Level System Concept



Sequential Optimization

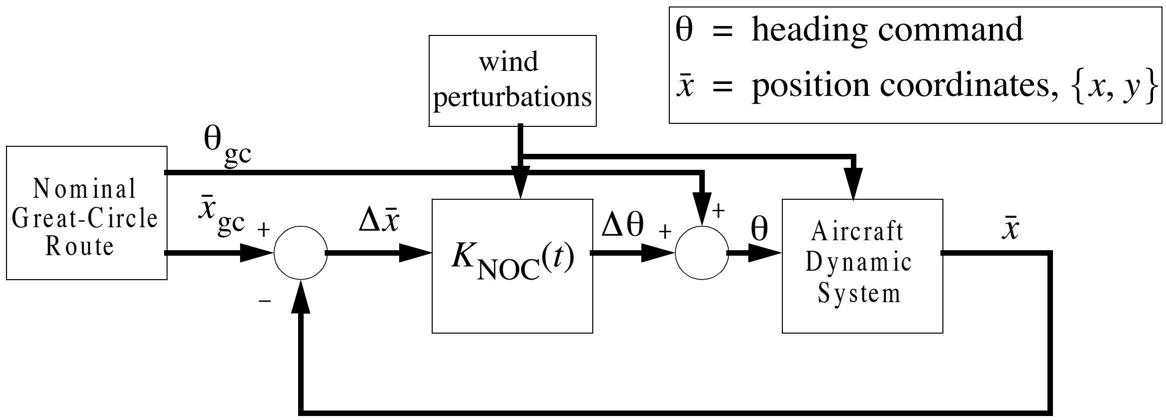


Wind Optimal Routing



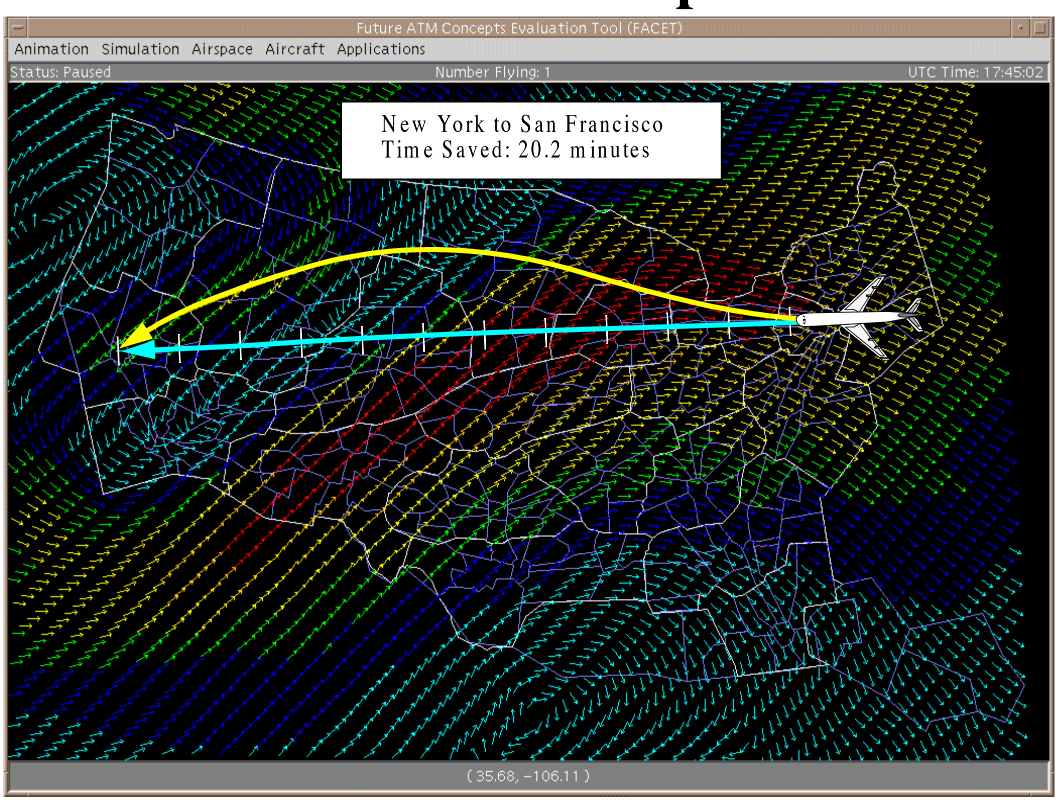
Neighboring Optimal Wind Routing

- Feed forward nominal great-circle heading commands
- Feedback perturbations in the winds and aircraft position
- Compute NOC gains: $K_{\mathrm{NOC}}(t) = -H_{uu}^{-1}[(H_{ux} + f_u^T(\bar{S} - \bar{R}\bar{Q}^{-1}\bar{R}^T))]$

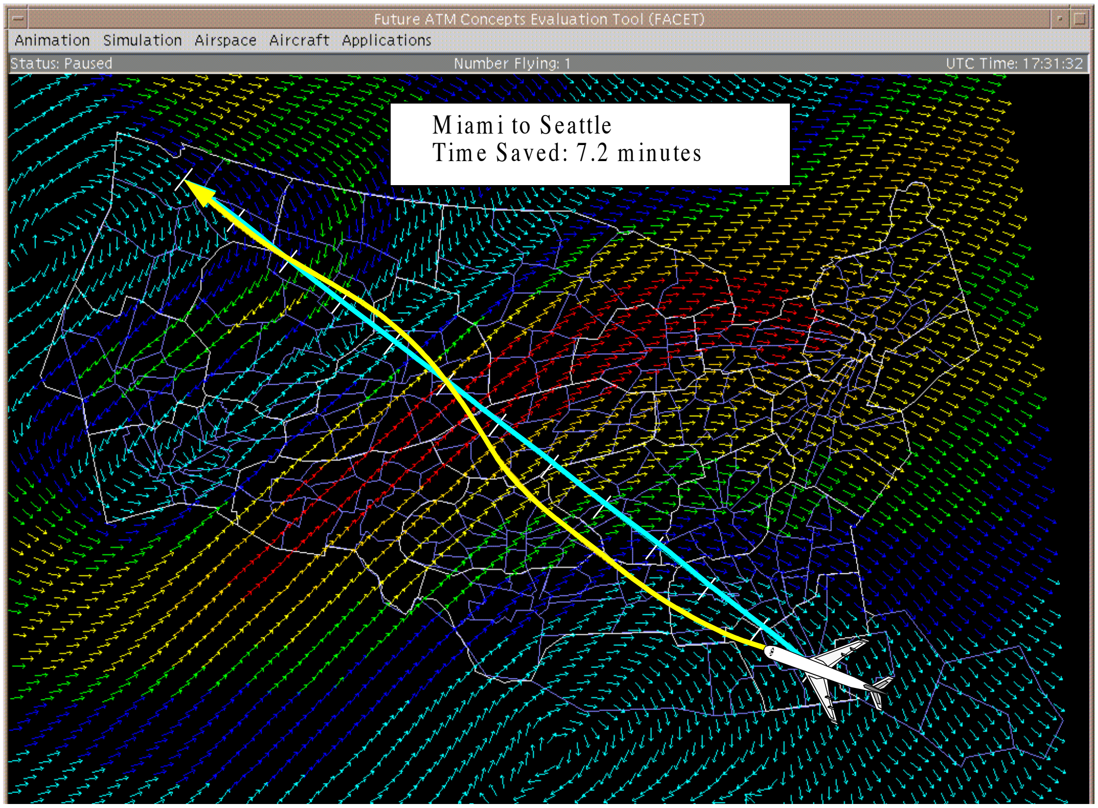


- See Journal of Guidance, Control, & Dynamics, Vol. 24, No. 4.

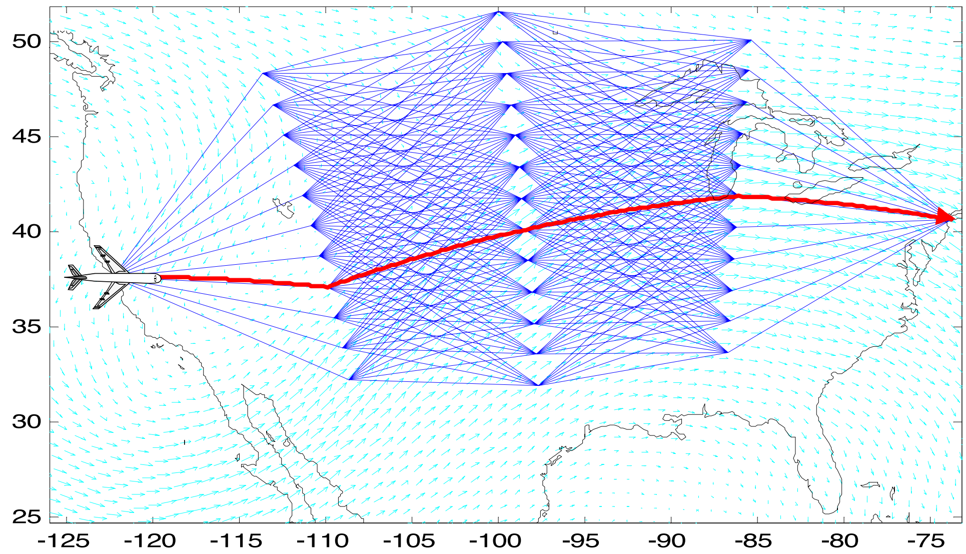
NOWR Example



NOWR Example #2



Dynamic Programming



- Search a Discrete Grid for Minimum-Time Route
- Apply Simplifications to Reduce Computation Time
- Trade-off Between Computation Speed and Optimization Performance

NOWR Performance

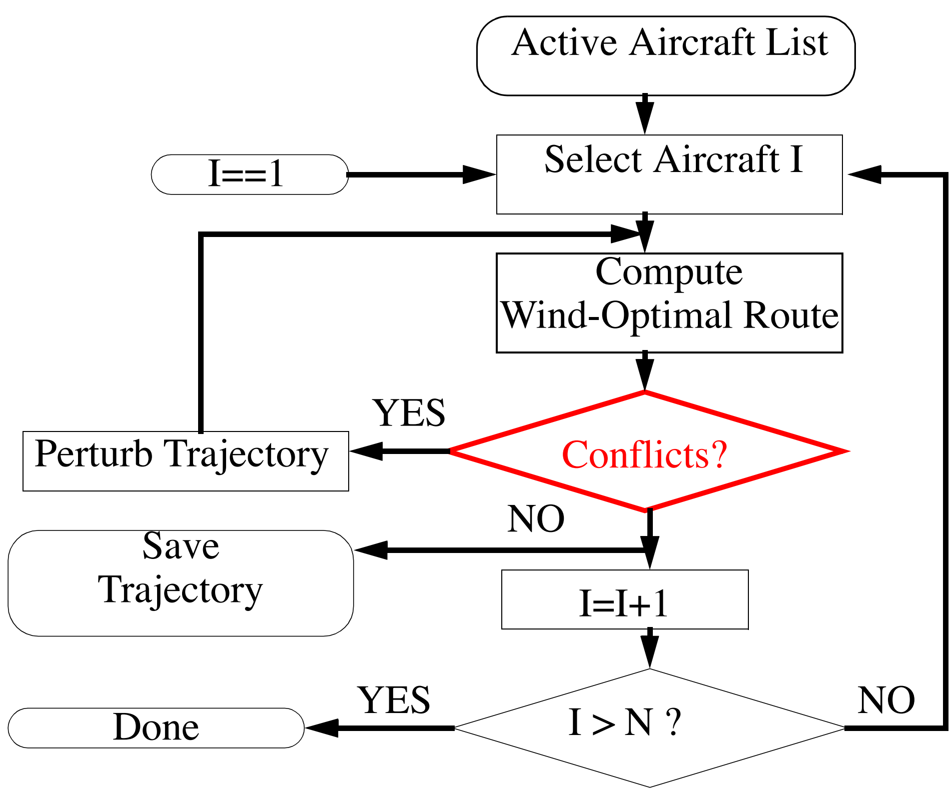
Dynamic Programming Solution Comparisons

- Directed Graph Search for Optimal Trajectories
- Varying Grid Resolutions
- 6 Different Real Wind Conditions
- 42 Different Cross-Country Flight Routes
- Compute Average Floating-Point Operations (FLOPs)
- Compute Average Total Flight Time Across All Simulations

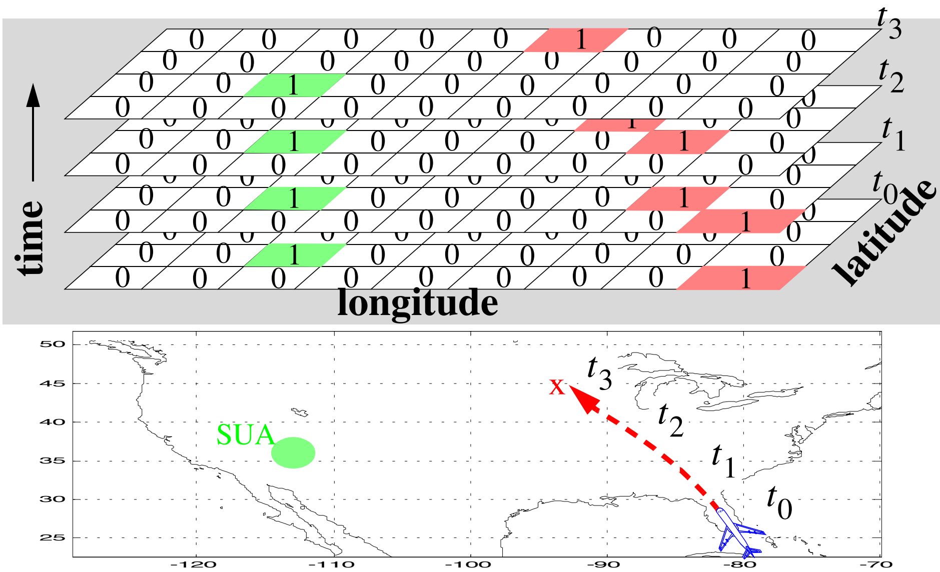
Results

- 40 milliseconds per NOWR computation (450 MHz Sun Ultra)
- NOWR solution within 0.25% of Optimum on Average
- Fastest DP solution took 5 times longer than NOWR
- DP solutions very coarse

Sequential Optimization

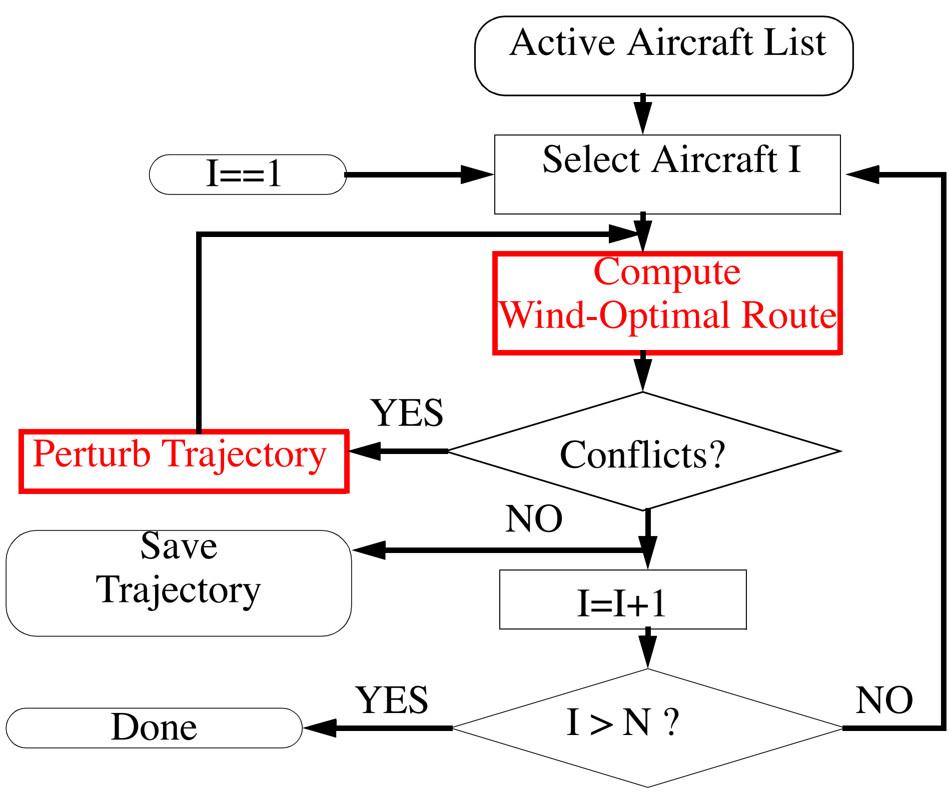


Conflict Grid

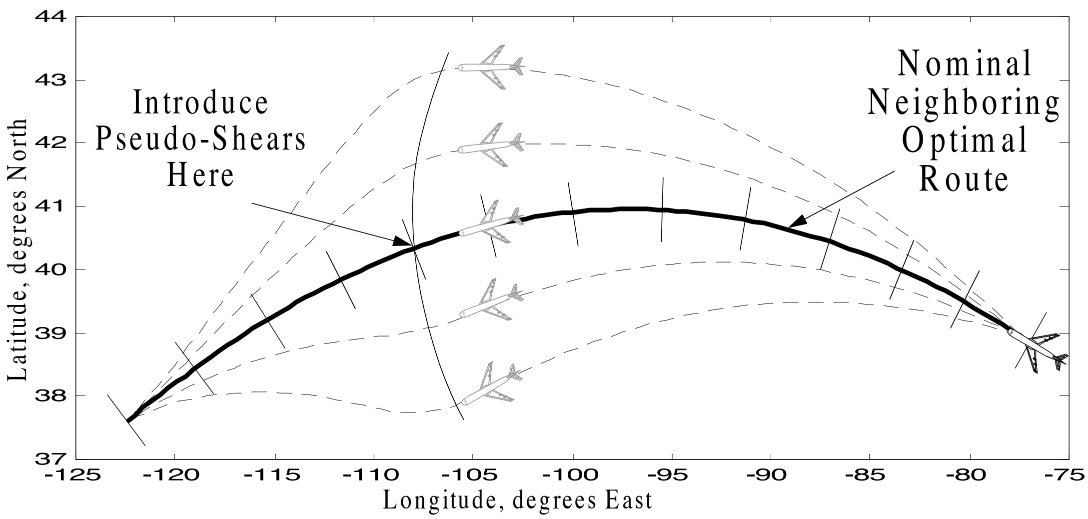


- {Lon, Lat, Time} maps to unique grid cell
- Spacing: {5nmi x 5nmi x 30 seconds}
- Up to 7hr “Rolling” time grid
- Memory (for 1 FL): 300 x 500 x 840 bits (16 Mbytes)
- Aircraft in cell? ==> set bit to ‘1’
- No aircraft in cell? ==> set bit to ‘0’
- Bad Wx in cell, or SUA? ==> set bit to ‘1’
- *Virtually free conflict detection!* $O(0)$

Sequential Optimization



NOWR Conflict Resolution



- Modify NOWR for Conflict Resolution: Pseudo Wind Shear
- Resulting Conflict-Free Trajectories Near-Wind-Optimal
- Roll the Animation!

Computational Requirements

Total Number of Expected Operations for N_{AC} Aircraft:

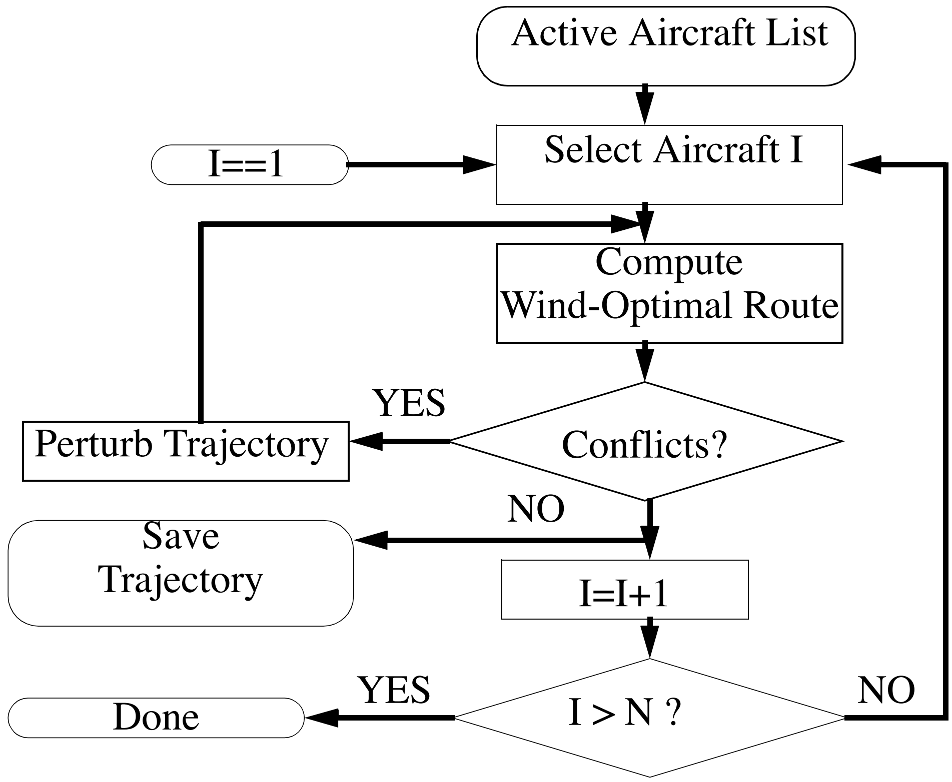
$$\sum_{i=1}^{N_{AC}} E[\xi_i] = \left(\sum_{i=1}^{N_{AC}} E[N_{ci}]\right) \cdot [\bar{\chi}_{\text{wind-opt}} + \bar{\chi}_{\text{conf-detect}}]$$

$N_{ci} \equiv$ number of conflict resolution iterations for aircraft i

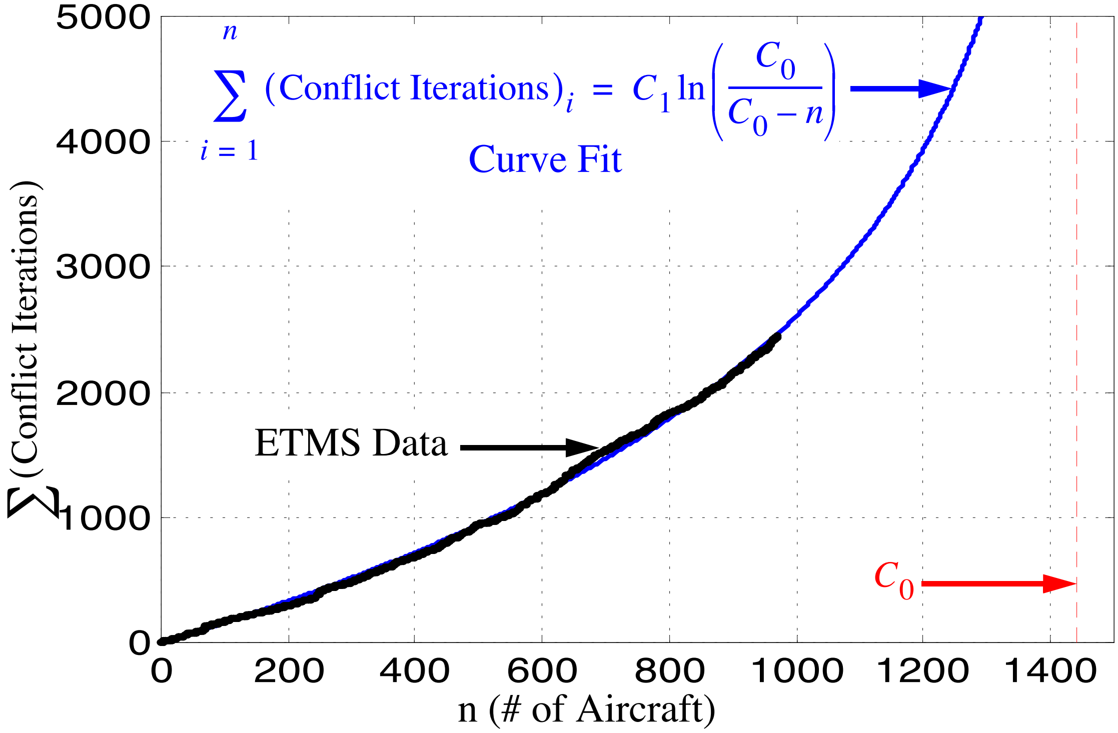
Observations

- $\left(\sum_{i=1}^{N_{AC}} E[N_{ci}]\right) \le \frac{N_{AC}(N_{AC}-1)}{2}$ (A Polynomial-Time Algorithm)
- Wind-optimal computations are a primitive
- Develop physical model, fit parameters with empirical data

Simulation



Conflict Resolution Model



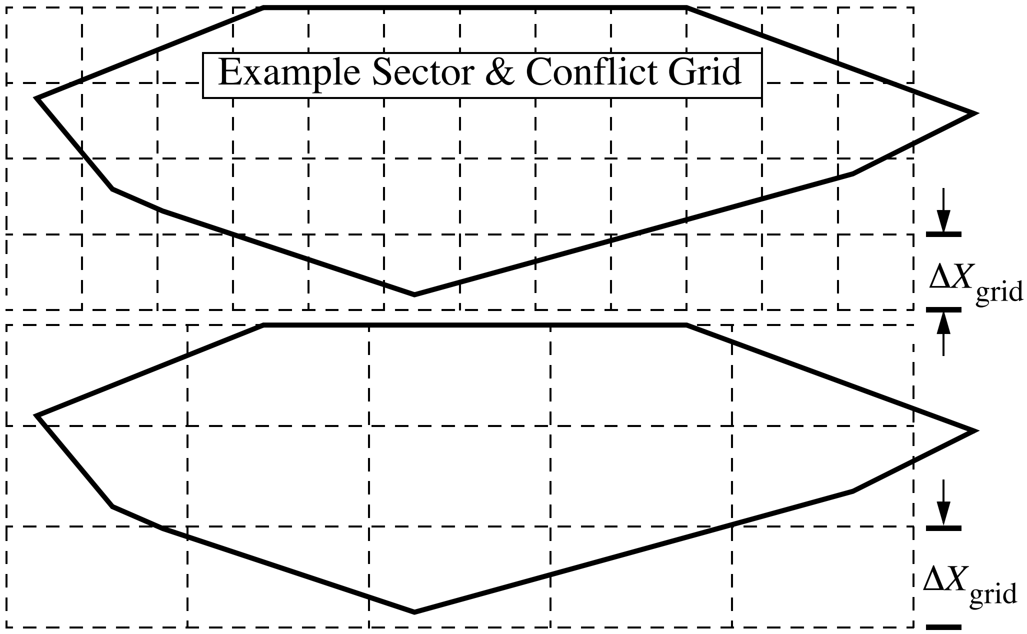
Simulation Description

- Spherical Earth Model
- Horizontal-Plane
- Initialized with ETMS Data or Simulated Traffic
- Rapid Update Cycle (RUC) Winds
- Modeled Weather Cell & Special-Use Airspace
- Modeled Uncertainty in Aircraft & Wx-Cell Positions

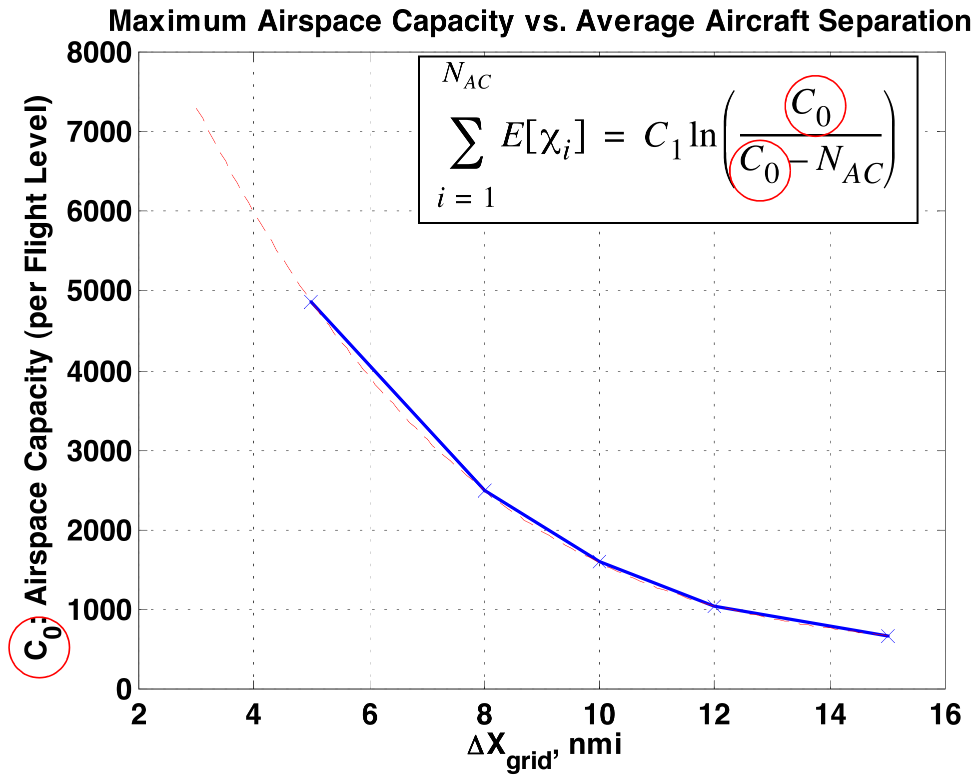
System Simulation Animation

Airspace Capacity Study

- Vary Idealized Sector Loading Constraints
- Use Capacity Model to Measure Predicted Airspace Capacity



Airspace Capacity



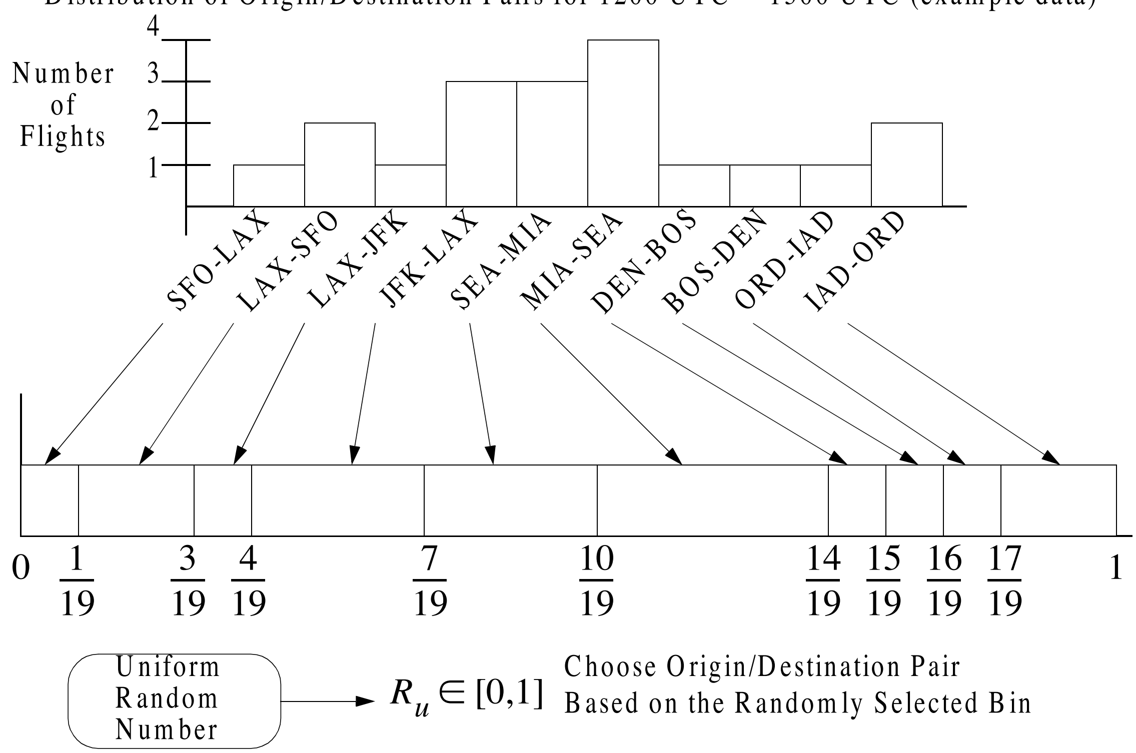
Scenario Development

Realistic Free Flight Scenario Generation

- Begin with Real ETMS Schedule Data
  - Origin Airport
  - Departure Airport
  - Actual Departure Time
- Generate Histogram of # of Aircraft per Route Per Hour
- Create Random Route Generator Based on Histograms
- Utilize Real Wind Data Files
- Utilize Corresponding Weather Data

Scenario Development

Distribution of Origin/Destination Pairs for 1200 UTC -- 1300 UTC (example data)



Roadmap:

2D Algorithm Development in MATLAB Environment

- Perform Basic Computation Timing Analyses
- Examine Effects of Wind Modeling Errors
- Incorporate Weather Cells and Prediction Errors

Port Algorithms to C (or similar) Language

- Software Library Development for VAST & Concept Blending
- Incorporate into FACET for Higher-level Simulations

Extend Algorithms to 3D

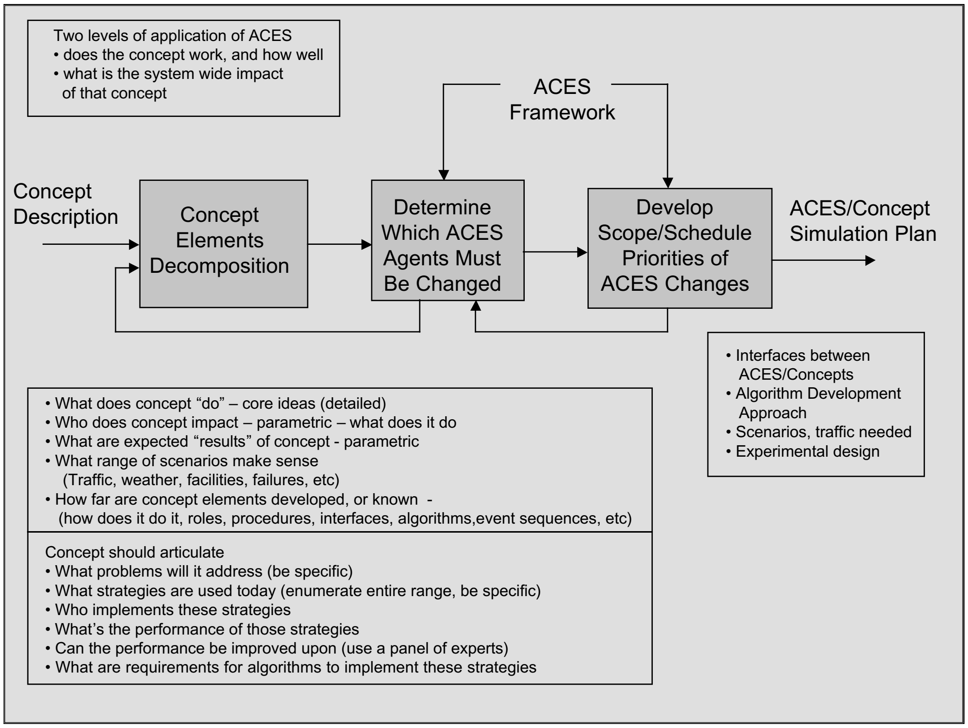
- Requires Greater Amount of Memory than 2D
- Requires Compiled Code Speed

Run Higher-Fidelity Simulation and Analyses

- Sector Load Constraints
- Communications Timing Constraints
- Emergency Procedures
- 4D Control Requirements

Conclusion

- Objective is to Achieve Real-Time Conflict-Free Strategic Trajectory Optimization
- Have Developed Basic Algorithms and Demonstrated in 2D
    - Neighboring Optimal Wind Routing (NOWR)
    - Conflict Grid Conflict Detection
    - NOWR Conflict Resolution
- Component Algorithms will be Useful for VAMS
- Will Extend to 3D and to Higher Fidelity
- Will Port to C and to FACET



Concept should articulate

- what problems will it address (be specific)
- what strategies are used today (enumerate entire range, be specific)
- who implements these strategies
- what's the performance of those strategies
- can the performance be improved (panel of experts)
- what are requirements for algorithms to implement these strategies

TIM #4

August 19-21, 2003

- Concept Self-Assessment
- ACES Build 1
  - Usage
  - Lessons Learned
- ACES Build 2
  - Status
- SEA Evaluation Prioritization

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13. SUPPLEMENTARY NOTES
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14. ABSTRACT
A three day NASA Virtual Airspace and Modeling Project (VAMS) Technical Interchange Meeting (TIM) was held at the NASA Ames Research Center in Mountain View, CA, from January 14 through January 16, 2003. The purpose of this meeting was to continue the information exchange amongst the VAMS Project technical team, concept developers and stakeholders; to descripe the scenario and metric requirements delivered on December 21, 2002 (Milestone 5); to define and begin to address the next steps for this milestone; and to provide updates on the System-Level Integrated Concepts. An overall goal of the VAMS Project is to develop validated, blended, robust and transition-able air transportation system concepts over the next five years that will achieve NASA's long-term Enterprise Aviation Capacity goals. This document describes the presentations, given during the first two days of the TIM, and presents the related questions and answers.

15. SUBJECT TERMS
Air traffic management, Air traffic control, Capacity

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