Federal Aviation Administration

COE CST Second Annual Technical Meeting:

Task 185: Unified 4D Trajectory Approach for Integrated Traffic Management

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October 31 2012

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Overview

- **Team Members**
- **Brief overview of the aviation/space transportation conflict**
- **Research Methodology**
- **Results**
- **Next Steps**
- **Conclusions**

Outline

- **Brief overview of the aviation/space transportation conflict**
- **Research: Propose architectures for aircraft safety during launch/re-entry and analyze them using compact 4D envelopes**
- **Results**
  - **Propagate Uncertain Trajectories and Debris**
  - **Generate compact 4D envelopes**
  - **Counting SUA “piercings” with FACET**
  - **Rerouting aircraft with FACET**
- **Concluding thoughts and directions**

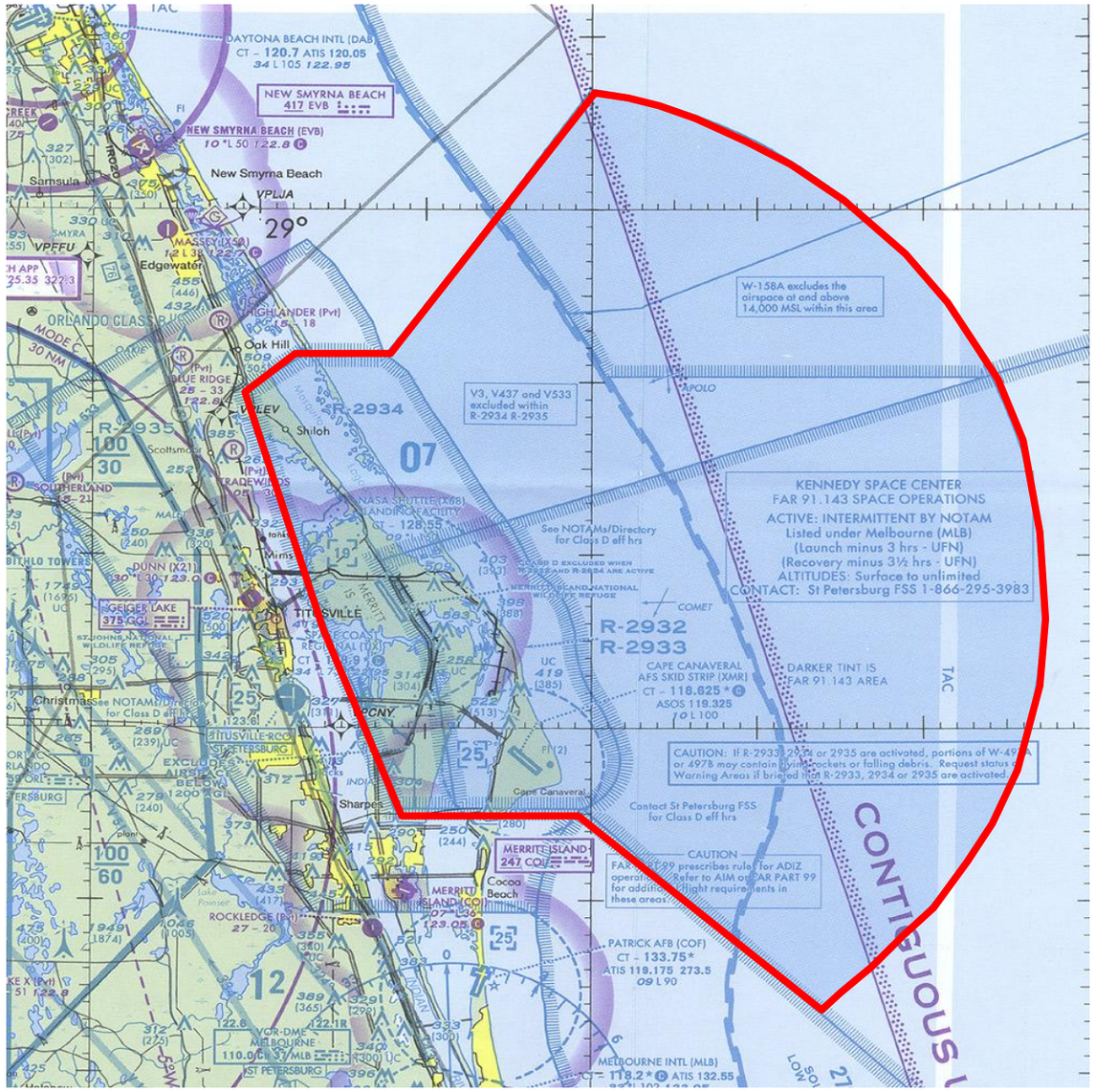
Team Members

- **Principal Investigator**
  - **Juan Alonso - Stanford University**
- **Graduate Student**
  - **Thomas Colvin - Stanford University**
    - **Ph.D Candidate in Aeronautics and Astronautics**

- **Special Thanks**
  - **Dan Murray - FAA AST**

What's The Problem?

- **Safely and fairly sharing the NAS**
  - **Need launch architectures to ensure all NAS users are safe**
  - **Current method uses SUAs**
  - **No formal quantitative framework for creating SUAs, thus they tend to be overly conservative**
  - **Commercial space traffic in rising volume and launching from new ranges will require new ATM architectures**
  - **Can advancements in NextGen be leveraged?**



Source: 45 SW Eastern Range: Special Use Airspace, PPT Presentation by Art Ladd

What's Needed?

- **Airspace Management Architectures For Launch**
  - **Procedures governing how the airspace will be handled / partitioned to keep aircraft and space vehicles safe**
  - **Specific to each vehicle's mission and quantifiably safe**
- **Examples**
  - **Proactive: No-fly zone is established encompassing entire potential danger area for launch until successful staging**
  - **Reactive: No-fly zone bounds nominal trajectory only. In the event of off-nominal event, SUA is dynamically created and enforced**

Purpose of Task

- **Development of requirements, architecture and prototype implementations of simultaneous air/space traffic management procedures for commercial space transportation. Leverage projected improvements derived from NextGen.**
- **Develop and analyze plausible architectures for an Integrated Airspace Management System (IAMS)**
- **Research and develop the foundation of IAMS based on 4D, time-space probabilistic trajectories and safety assessments**

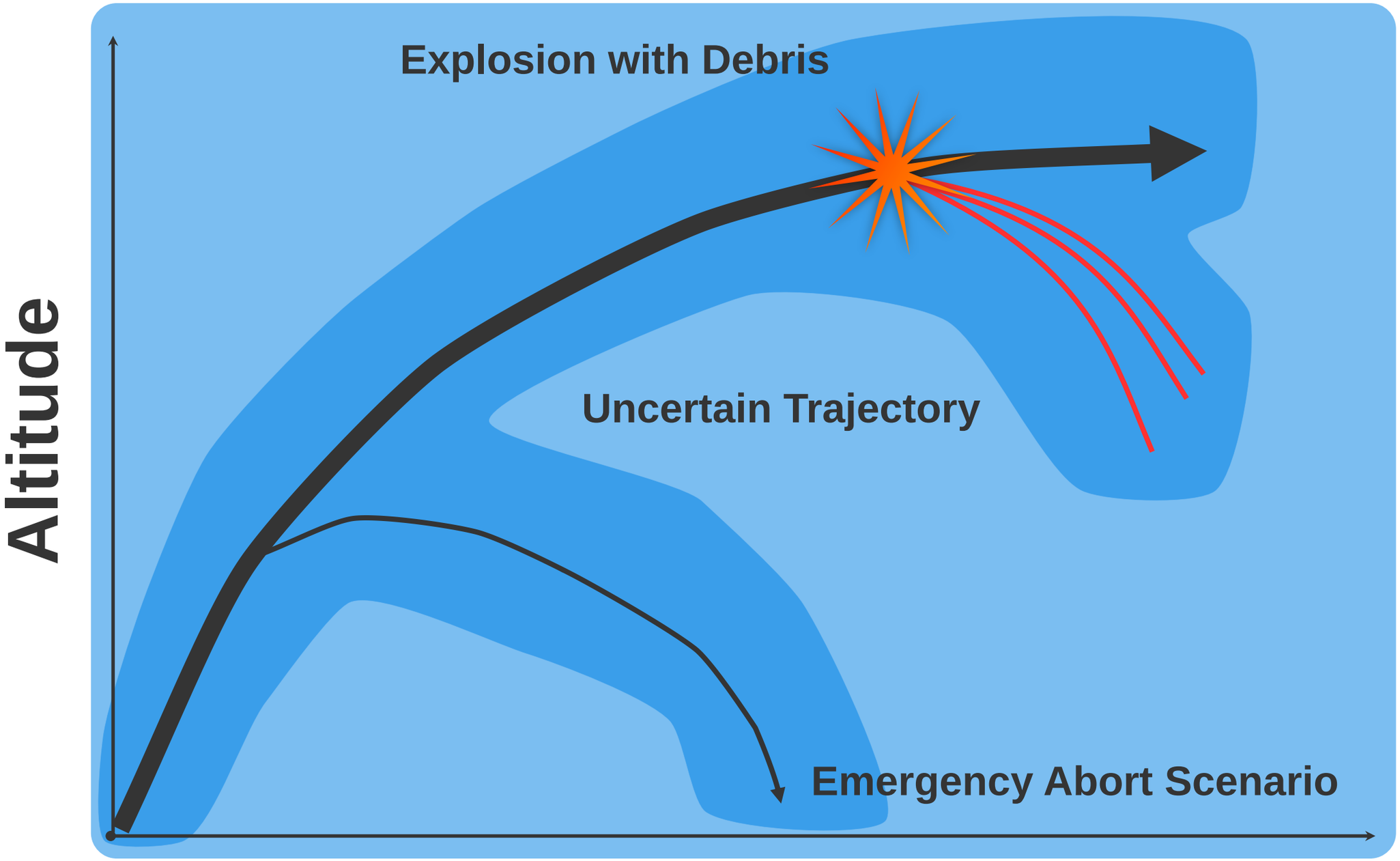
Research Methodology

- **Develop mathematics and software environment to propagate trajectories under uncertainties in 4D (timing, location, “unscheduled” events, weather, system uncertainties, ...)**
- **Develop a way to bound the trajectories, to a “dialed-in” level of safety, within compact 4D envelopes**
- **Use these tools to construct potential architectures, then evaluate and compare their impact on the NAS with FACET**
- **Key metric: shared costs to airlines and launch providers, public at large**

Calculating Trajectories

- **Long-term:**
  - **Given a nominal trajectory or envelope, along with vehicle and mission parameters, create a PDF of the possible rocket and debris locations using advanced Uncertainty Quantification techniques**
  - **Use this PDF to generate a physical (x,y,z,t) boundary, corresponding to a given level of safety, that can be analyzed with ATM software**
  - **Investigate optimization of probabilistic trajectory envelopes to minimize NAS impact**
- **Near-term:**
  - **Use Monte Carlo simulation to approximate the rocket location PDF, sampled at many points**
  - **Bound the trajectories into 4D compact envelopes and quantify their impact on the NAS**

Compact Envelope Concept



How To Measure NAS Impact?

- **Further develop existing ATM simulation software: NASA FACET.**
- **NASA Ames has provided Tom Colvin with access to the FACET source code (on site) to make necessary modifications**
- **Currently can measure impact by counting how many aircraft pierce the compact envelope**
- **Working on rerouting aircraft trajectories to measure**
  - **increased flight time / passenger hours**
  - **increased fuel burn and cost**
  - **impact on airline flight schedules due to these diversions**

Results

- **We have an environment ready to begin analyzing ATM architectures for launching commercial space missions**
  - **Propagate Uncertain Trajectories and Debris**
  - **Generate compact 4D envelopes**
  - **Automated interface with FACET**
  - **Counting aircraft / launch vehicle conflicts with FACET**

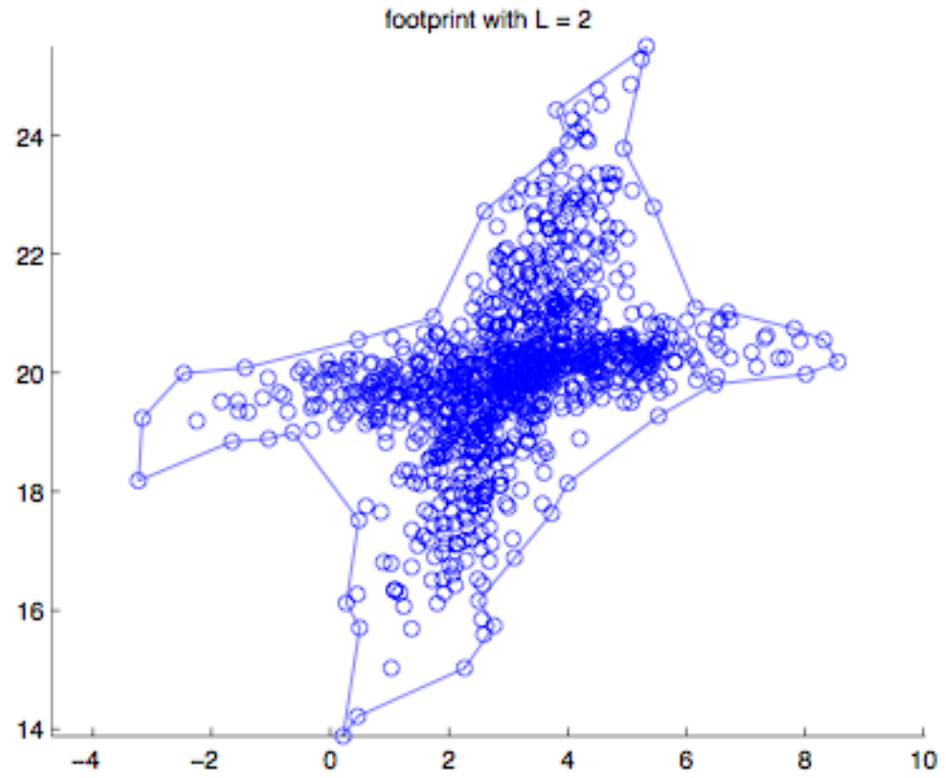
Results: Propagation Code

- **Monte Carlo software framework that accepts arbitrary:**
  - **Thrust profiles (TVC, etc)**
  - **Weather profiles for wind and temperature, with uncertainty parameters for each**
  - **Failure parameters and distributions**
  - **Debris model**
  - **Leverages work in Project 258**
- **Outputs:**
  - **Collection of (x,y,z,t) points which represent all places a vehicle or its debris may be found from a MC simulation**

Results: Characterize Trajectories

Difficult Test Shape: No Physical Meaning

- **Trajectories as points in space and time**
- **How do we turn this set of trajectories into something useful?**



Results: Compact 4D Envelopes

- **With reasonably realistic mission plans and probabilistic trajectories, can create dynamic 4D compact envelopes**
- **Analyze with existing ATM software: FACET**

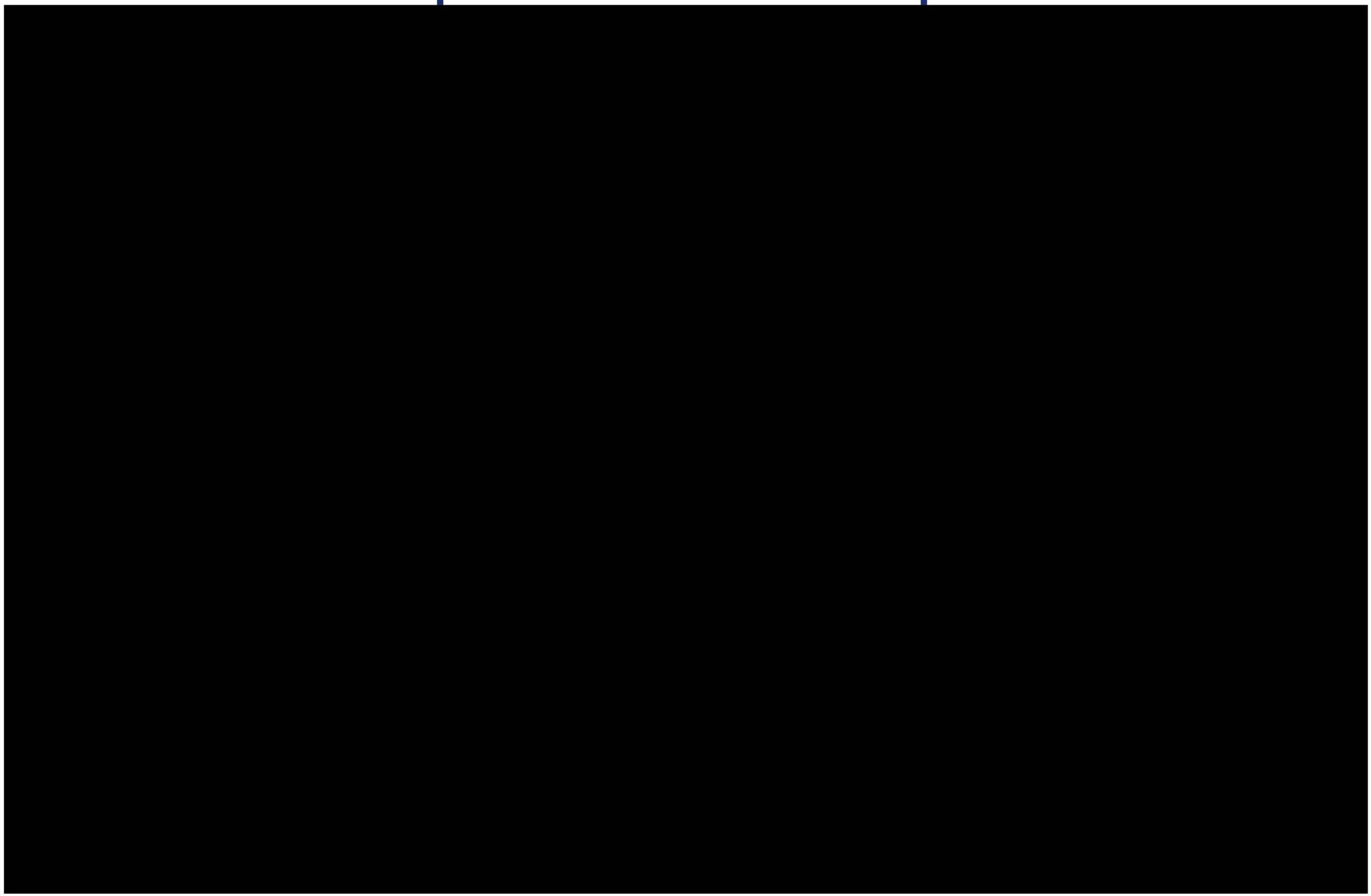
FACET: Intro to the environment

- **NASA Future ATM Concepts Evaluation Tool**
- **Simulation environment for preliminary testing of advanced ATM concepts over continental United States**
- **Award Winning**
  - **NASA's Software of the Year Award 2006**
  - **AIAA Software Engineering Award 2009**
- **Examples of advanced ATC concepts already implemented**
  - **Aircraft self-separation, prediction of aircraft demand and sector congestion, system-wide impact assessment of traffic flow management constraints, wind-optimal routing, etc.**
- **<u>Massive</u> amount of code in C and Java**

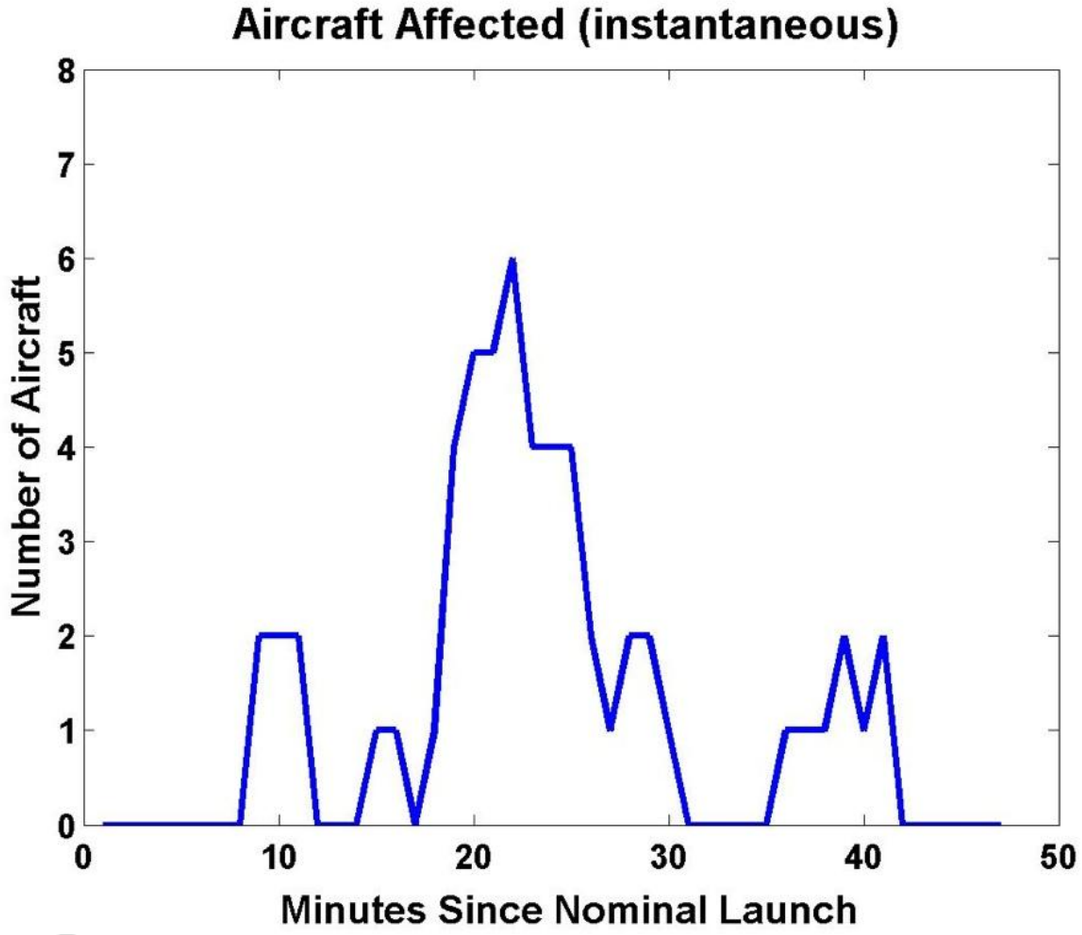
Results: Developing FACET For Our Task

- **Nominal Capabilities**
  - **Specify reasonably complex time-evolving SUAs**
    - **But they were invisible in the GUI, could not turn on/off, etc.**
  - **Count piercings of SUA by aircraft using historical data**
    - **Bugs in determining when multiple are active, overlap, etc.**
  - **Simulate rerouting flights around SUA and compute cost to airlines from this diversion**
- **Issues: SUA aspects less mature than rest of code**
  - **MANY key functionalities for SUAs, including rerouting around them, are only partially developed or buggy**
  - **API exists but does not expose everything needed**

Results: Compact 4D Envelopes



Sample Results: Plot Of Aircraft Conflicts



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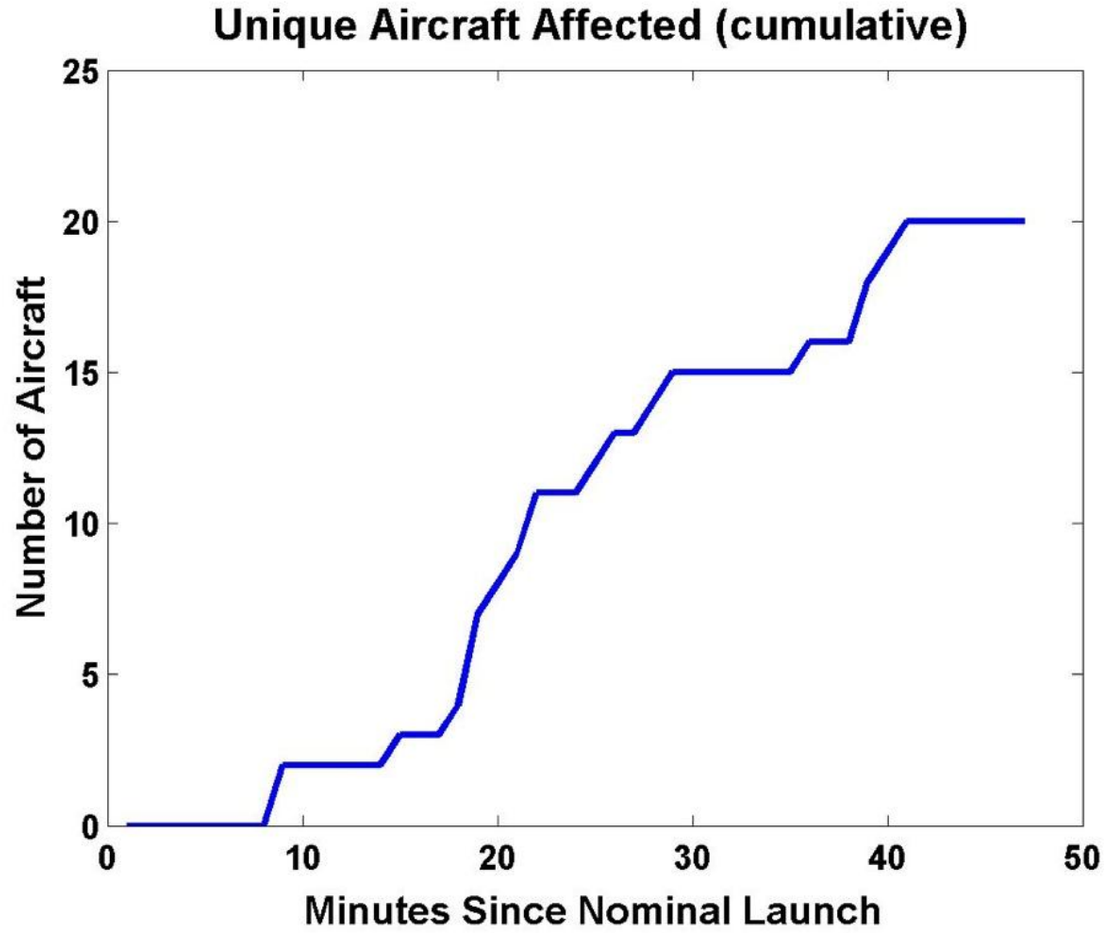

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Ongoing Work

- **Further develop FACET capabilities to reroute aircraft around compact envelopes to calculate added time, fuel burn, and cost to airlines**
- **Collaborate with FAA and launch providers to construct realistic mission profiles**
- **Design ATM architectures based on these mission profiles for use in trade studies**
- **Research techniques to optimization the integrated air-space system given uncertainties inherent to space launch**
- **Eventually will make suggestions to FAA on how to safely and equitably integrate airline and commercial space traffic**

Conclusions

- **In most proposed spaceports (not necessary all), significant conflicts will arise between airlines and launch providers. What is a fair way of utilizing a shared resource: the NAS?**

- **Developing mathematics and software implementations to propagate uncertainties in launch trajectories to construct compact 4D envelopes. Based on STOP (Stanford Trajectory OPtimization) tool and Monte Carlo**

- **Gathering information to construct realistic mission profiles and three separate scenarios (low, medium, high frequencies with varying numbers of launch locations) as a basis to assess potential ATM approaches**

- **Planning to use NASA's FACET to quantitatively analyze impact on NAS**
  - **Working with NASA to ensure FACET has needed capabilities implemented**

TASK 185. Unified 4D Trajectory Approach for Integrated Traffic Management

MAJOR MILESTONES – PAST

- Development of 3D compact envelope techniques
- Initial modifications of NASA FACET tool to enable dynamic Special Use Airspaces
- Development of low-, medium-, and high-traffic scenarios for impact assessments

MAJOR MILESTONES - FUTURE

- Aircraft re-routing capabilities (for dynamic airspaces) in FACET
- Validation of environment capabilities
- Development of plausible architectures for integrated air-space traffic management
- Assessment of integrated air-space traffic management architectures on specific operations
- Development of dynamic techniques for traffic management

SCHEDULE

- Compact envelope techniques/algorithms – Apr 12
- Initial modifications to NASA FACET – Nov 12
- Future traffic scenarios – Dec 12
- Re-routing capabilities in FACET – Apr 13
- Validation of resulting environment – Jul 13
- Development of IASTM alternatives – Apr 14
- Assessment of IASTM alternatives – Sep 15-Feb 15
- Integration of techniques for dynamic management – Jun 15

BUDGET

- FY13 - FY14 - FY15 - FY16 - FY17
- $80K $80K $80K $0 $0K
- Total amounts shown. 50/50 cost share included

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