COE CST Sixth Annual Technical Meeting

Task 331: Advanced 4D Special Use Airspace Research

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Aeronautics & Astronautics

Center of Excellence for Commercial Space Transportation

aerospacedesignlab

Team Members

- Stanford University
  - Juan J. Alonso, PI
  - Dr. Thomas J. Colvin, Graduate Student
  - Dr. Francisco Capristan, Graduate Student

- Organizations
  - FAA: Drs. Paul Wilde & Dan Murray
  - FAA SVO: Mr. Kevin Hatton (now w/ SpaceX)
  - FAA Tech Center

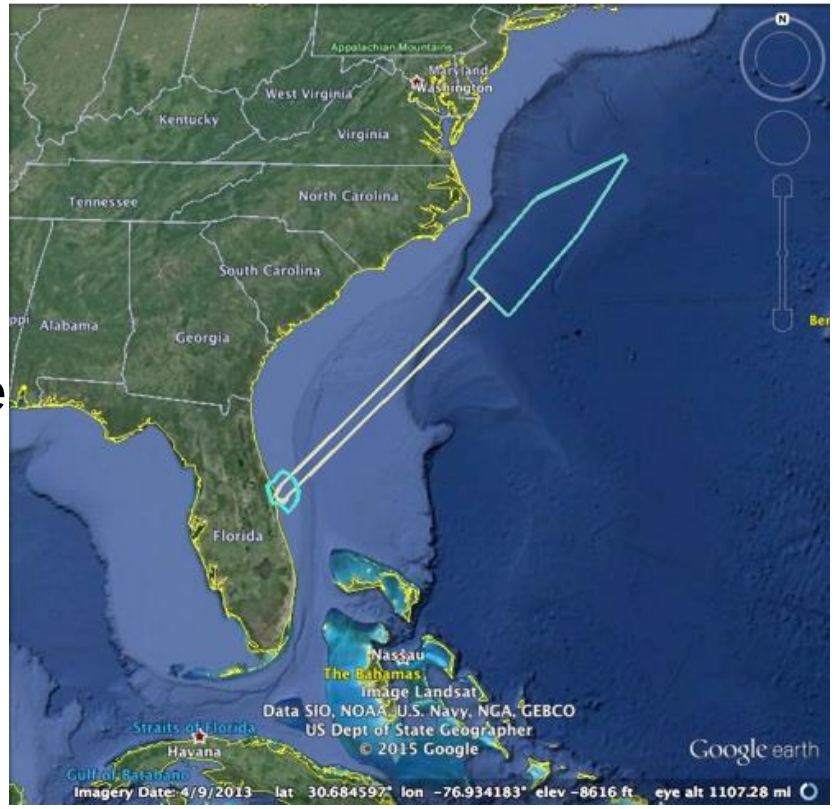
Agenda

- Disruption to Air Traffic from Space Vehicle Operations
- 4D Compact Envelopes
- An Open-Source Tool to Calculate Risk to Aircraft
- Demonstration of Near-Elimination of Airspace Disruption
- Conclusions & Future Work

Today: Space Operations Disrupt the NAS

- Need To Ensure Safety
- Three Problems
  - Proprietary Software
  - Conservative, Generic
  - Static
- Too much space, too much time
- Reroutes are costly to airlines
- Added distance, fuel burn, and flight time
- This particular launch: 200 aircraft
  - 25nm / aircraft
- **What will happen when CST operations are commonplace? Multiple operations / day? Geographically distributed spaceports?**

March 1st 2013
Three Hazard Areas
Falcon 9 from Cape Canaveral



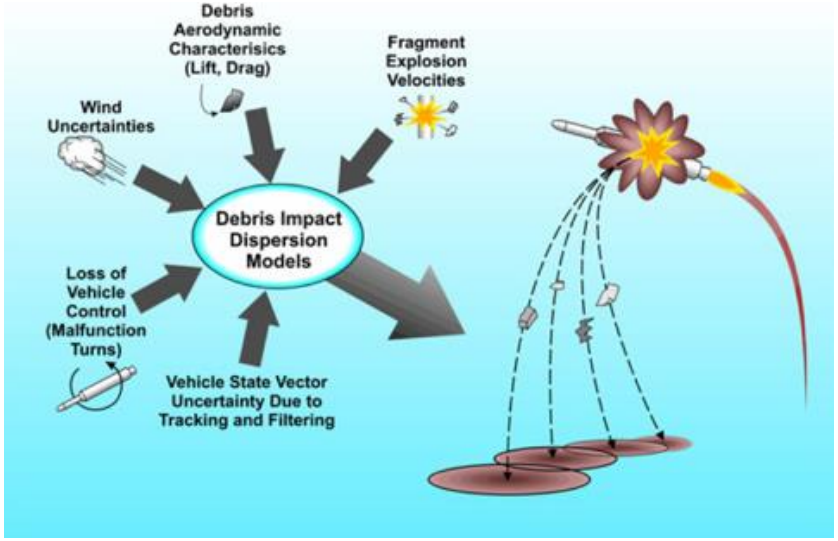
4D Compact Envelopes: A New Approach

- **4D Compact Envelopes**: New framework for calculating and protecting against the probabilistic risk to aircraft from space vehicle debris.
- **Provably safe**: to a regulator-specified safety threshold.
- **NextGen**: incorporates many advances in the capabilities of the modern national airspace. Reaction times and dynamicity.
- **Open-source**: tool to calculate the risk to aircraft from space vehicle operations and necessary compact envelopes.
- **Near-elimination of disruption**: Airspace disruption can be reduced by two orders of magnitude. Virtual elimination of conflicts.

Risk-Based Analyses

Probabilistic Uncertainties

- Probability of Failure
- Failure time distribution
- State vector
- Number of pieces generated
- Imparted velocities
- Aerodynamic properties
- Wind speed and direction
- Atmospheric density

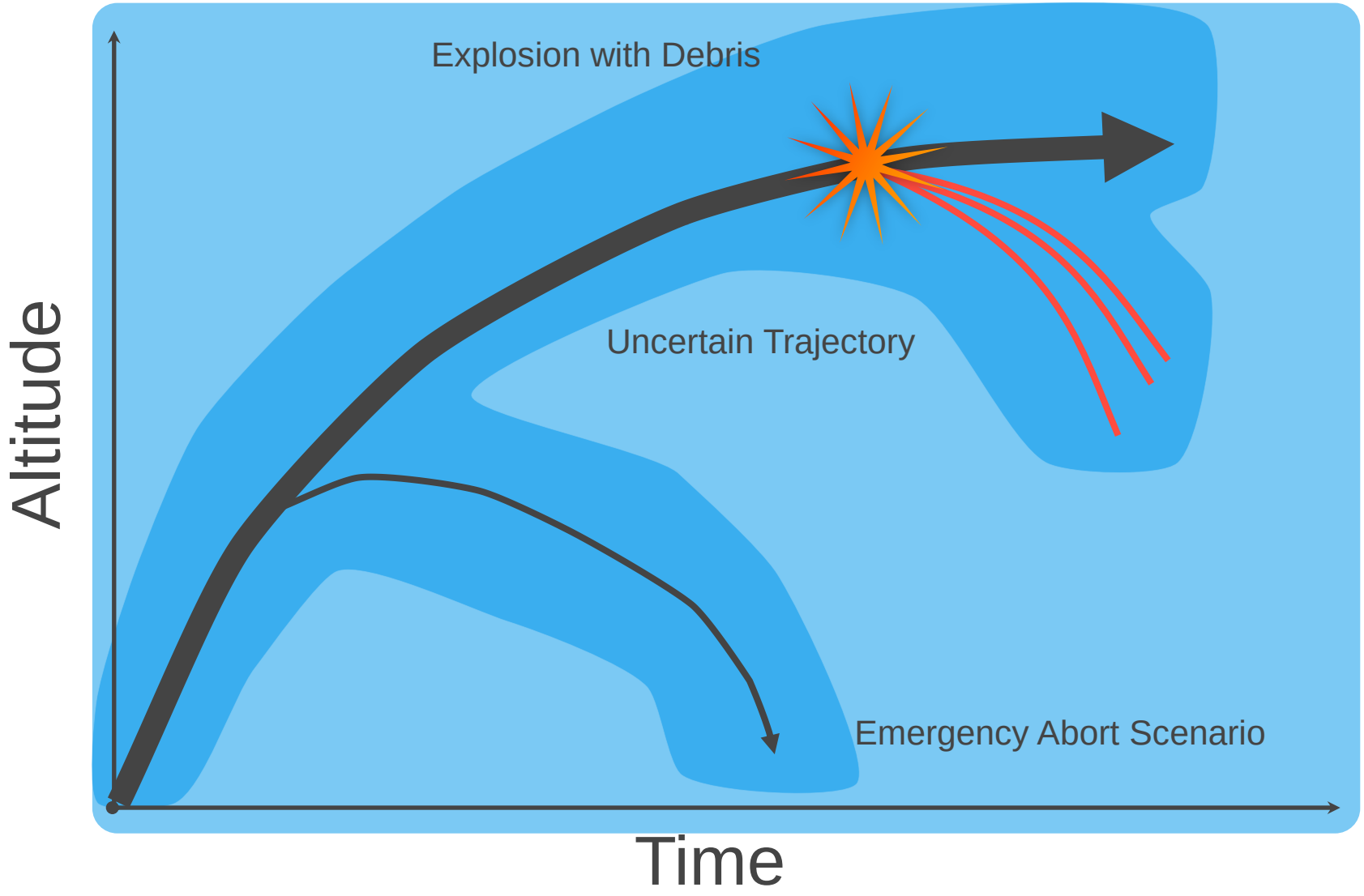


Source: FAA Flight Safety Analysis Handbook

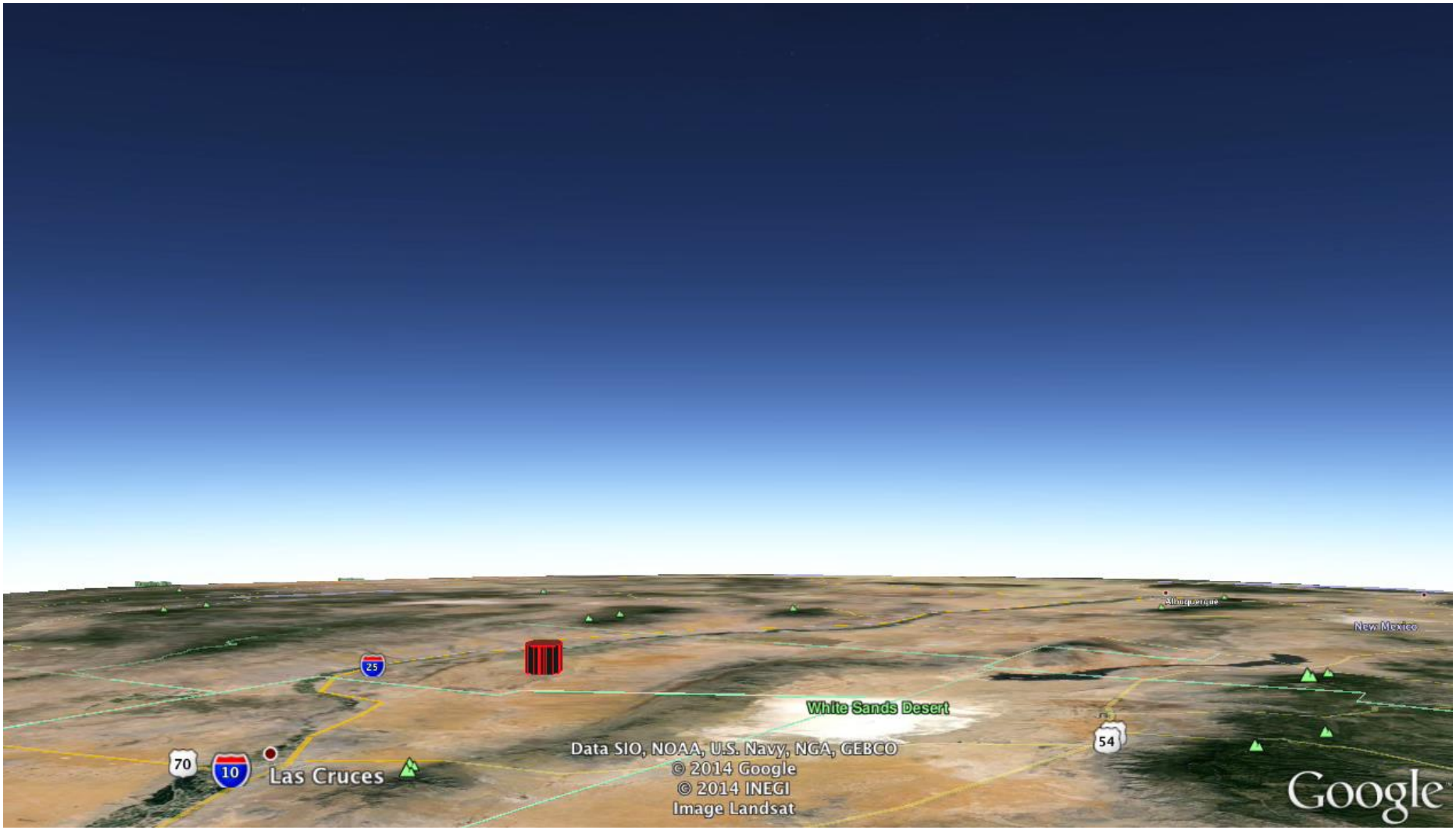
$$\xi^d(\mathbf{r}, t)$$

Probability density that piece of debris d is found at location r at time t

4D Compact Envelopes Concept



Example


Albuquerque
New Mexico
White Sands Desert
25
70
10
Las Cruces
54
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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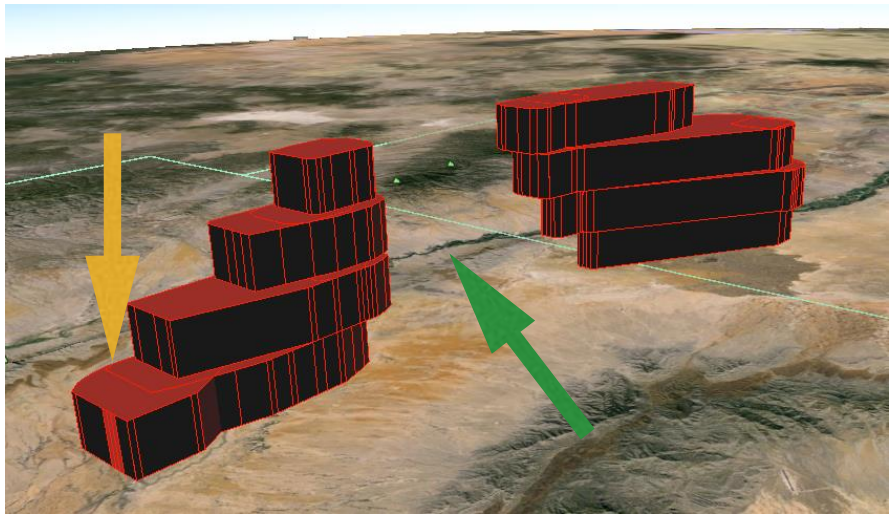
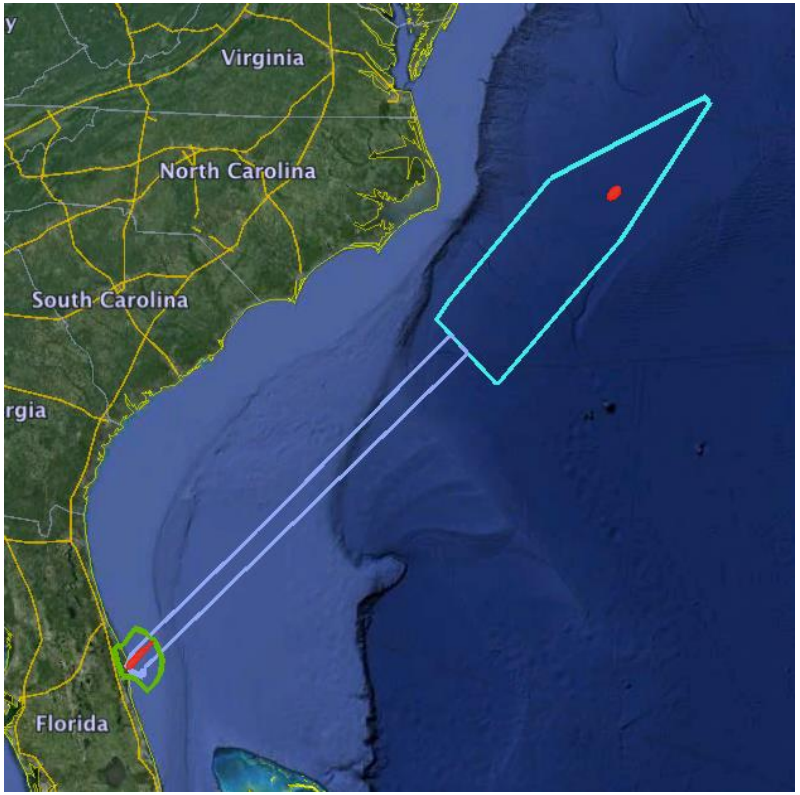
Some Implications



- Suborbital missions may have corridors that are always safe.
- Launch site overflight permitted

- Falcon 9 envelopes much smaller
- Generally, first stage event can be handled reactively

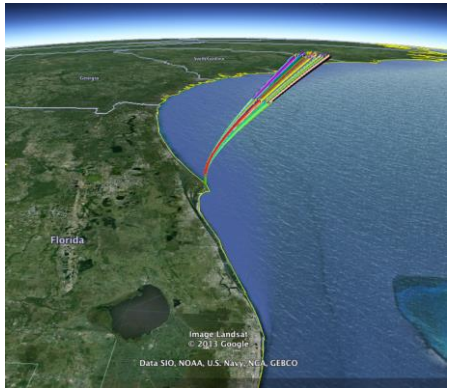


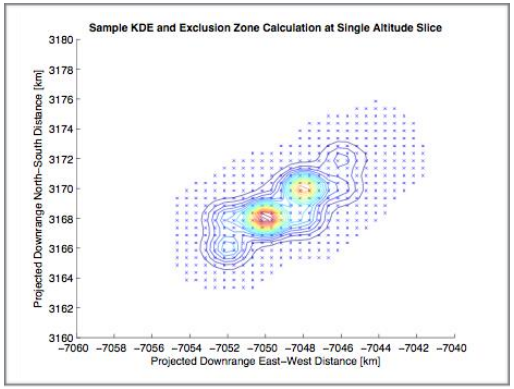
SU-FARM

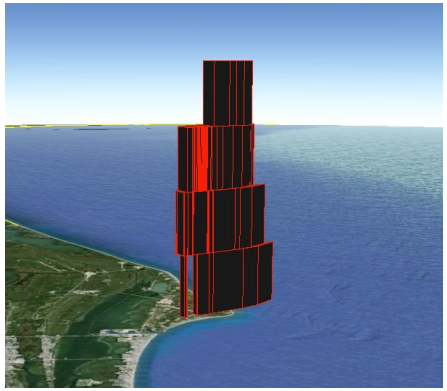
Stanford University Framework for Aircraft Risk Management

- Calculate the risk to aircraft from space vehicle operations
- Mitigate that risk through the use of 4D Compact Envelopes
- Written in C++, Python
- Open Source, available on github

SU-FARM Typical Scenario

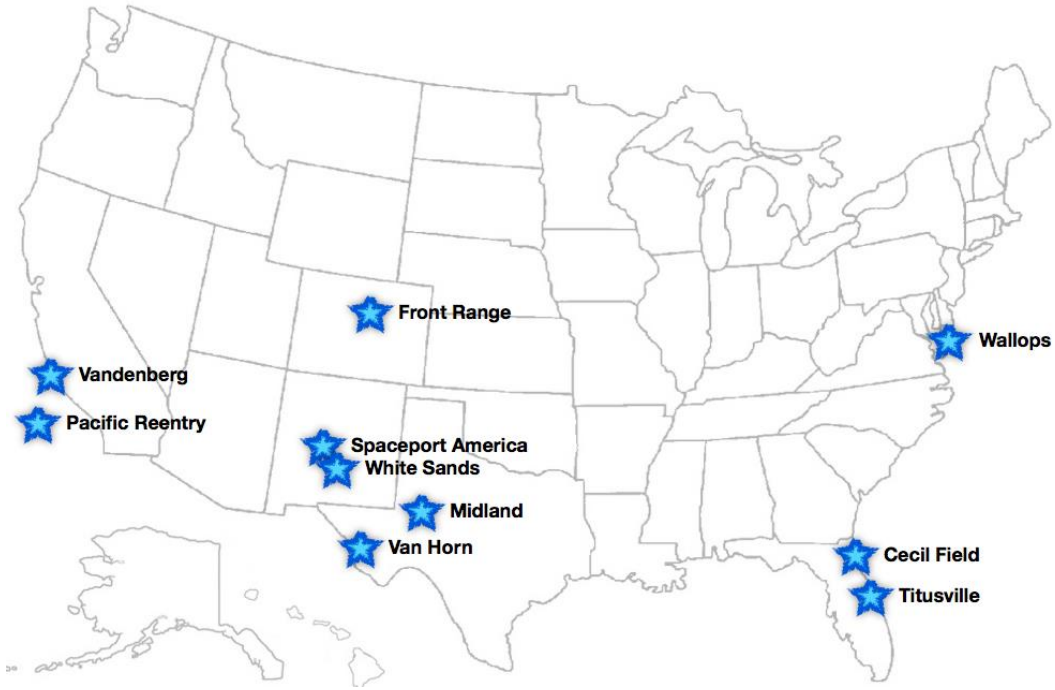




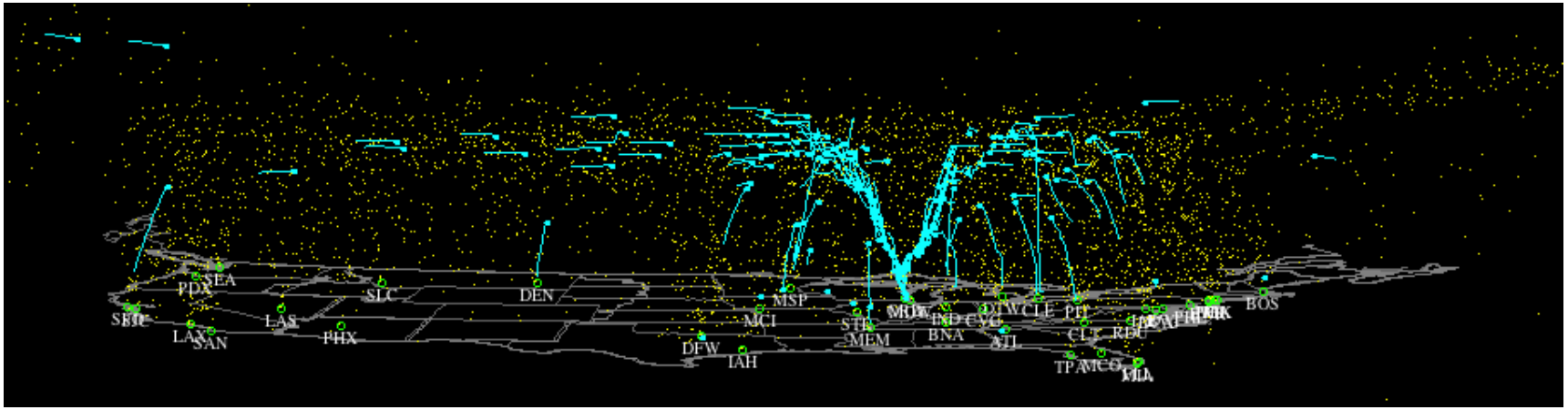


Case Study: Airspace Disruption

- Quantify the efficiency of compact envelopes
- 8 vehicles, 10 locations, 14 missions
- Traditional hazard area vs compact envelopes
  - Five minute reaction time
  - Simulate 90 days
- Compare disruptions
- Collaboration with FAA NextGen, Tech Center, and Commercial Space



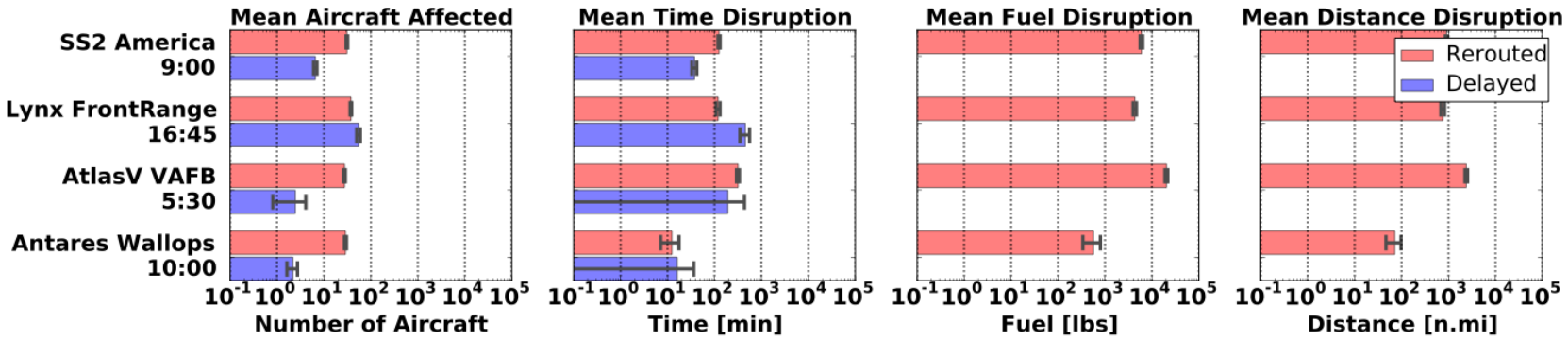
FACET to Measure Disruption



- Future ATM Concepts Evaluation Tool (NASA Ames)
- Simulation environment for preliminary testing of advanced ATM concepts over continental United States
- Uses aircraft performance profiles, airspace models, weather data, and flight schedules, etc.
- Models trajectories for the climb, cruise, and descent phases of flight for each aircraft in the NAS

Results (Traditional Approach)

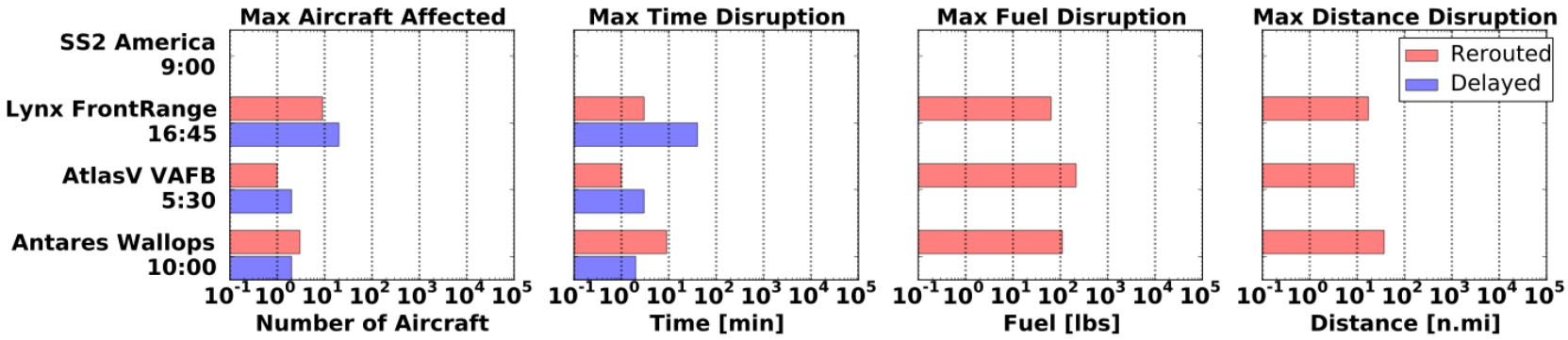
Traditional: Mean Values of Aggregate Impact (N=90)



Mission	Rerouted	Delayed	Flight Delay	Ground Delay	Added Fuel	Added Distance
SS2 America	30.86	6.56	125.79	37.52	5989.59	904.73
Lynx FrontRange	37.53	54.64	119.78	454.16	4324.11	754.88
AtlasV VAFB	27.46	2.46	318.03	193.29	20387.36	2390.38
Antares Wallops	28.76	2.18	12.39	16.14	568.16	71.93
Units	Aircraft	Aircraft	Minutes	Minutes	Pounds	Nautical Miles

Results (Compact Envelopes)

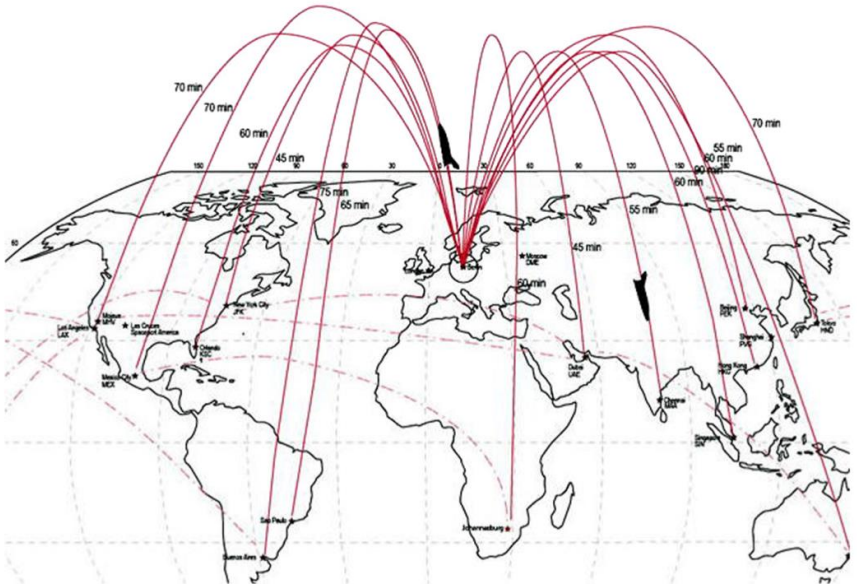
Envelopes: Maximum Values of Aggregate Impact (N=90)



Mission	Rerouted	Delayed	Flight Delay	Ground Delay	Added Fuel	Added Distance
SS2 America	0.00	0.00	0.00	0.00	0.00	0.00
Lynx FrontRange	9.00	20.00	3.00	40.00	63.67	17.32
AtlasV VAFB	1.00	2.00	1.00	3.00	214.36	8.77
Antares Wallops	3.00	2.00	9.00	2.00	110.06	37.18
Units	Aircraft	Aircraft	Minutes	Minutes	Pounds	Nautical Miles

Conclusions & Significance of Work

- Reduced / eliminated aircraft disruption
- Enables high frequency space travel from an ATM perspective
- Spaceports can be collocated with airports
- As airspace capabilities evolve, Compact Envelope framework can handle them



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