Analysis Environment for Safety Assessment of Launch and Re-Entry Vehicles

Juan J. Alonso and Francisco Capristan
Department of Aeronautics & Astronautics
Stanford University

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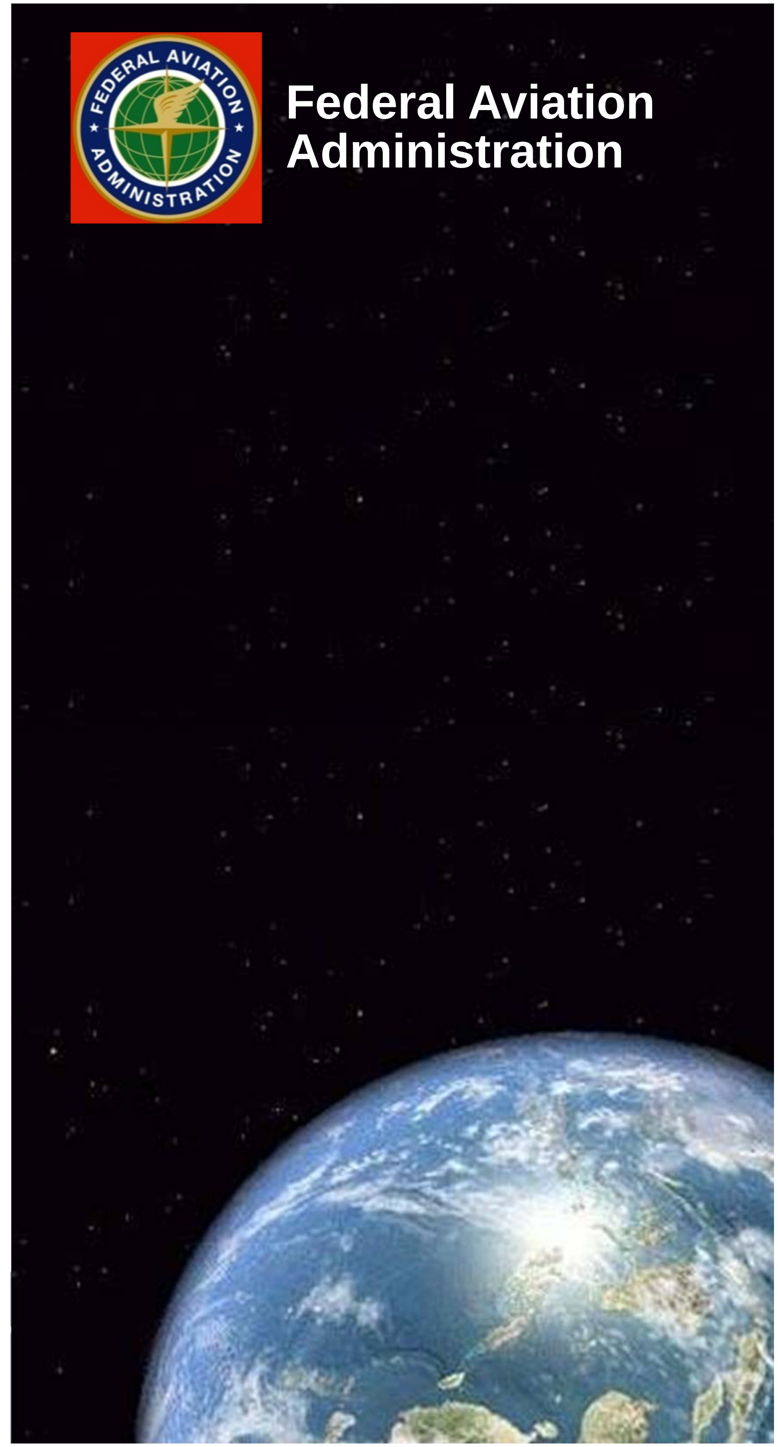


Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results / Progress to Date
- Next Steps

Team Members

- PI: Juan J. Alonso, Aero & Astro
- Francisco Capristan, Aero & Astro, Graduate Student

- Exploratory discussions with:
  - ULA
  - Boeing
  - SpaceX

Purpose of Task / Goals

- To provide the FAA and the community with an independent multi-disciplinary analysis capability based on tools of the necessary fidelity.
- To develop and establish quantitative safety metrics appropriate for commercial space transportation (launch and re-entry).
- To validate the resulting tool with existing and proposed vehicles so that the resulting tool/environment can be confidently used.
- To increase the transparency of the safety assessment of future vehicles via a common analysis tool that is entirely open source and, thus, streamline the licensing process for a variety of vehicle types

Research Methodology

- Currently the FAA uses a number of procedures and tools to assess the safety of future commercial launch and re-entry vehicles (including maximum probable loss determination) that are based on traditional launch systems. There are concerns with potential diversity of future systems.

- Industry has asked for further clarity/transparency regarding the necessary proof for obtaining a license

- Safety issues include:
  - Human rating.
  - Acceptable probability of failure.
  - How to account safety risks not associated with component, sub-system, and system failure (unknown unknowns).
  - Reliability does not equal safety: a reliability analysis tool is not sufficient.
  - Mathematical models do not accurately represent reality, numbers obtained are not necessarily indicators of safety

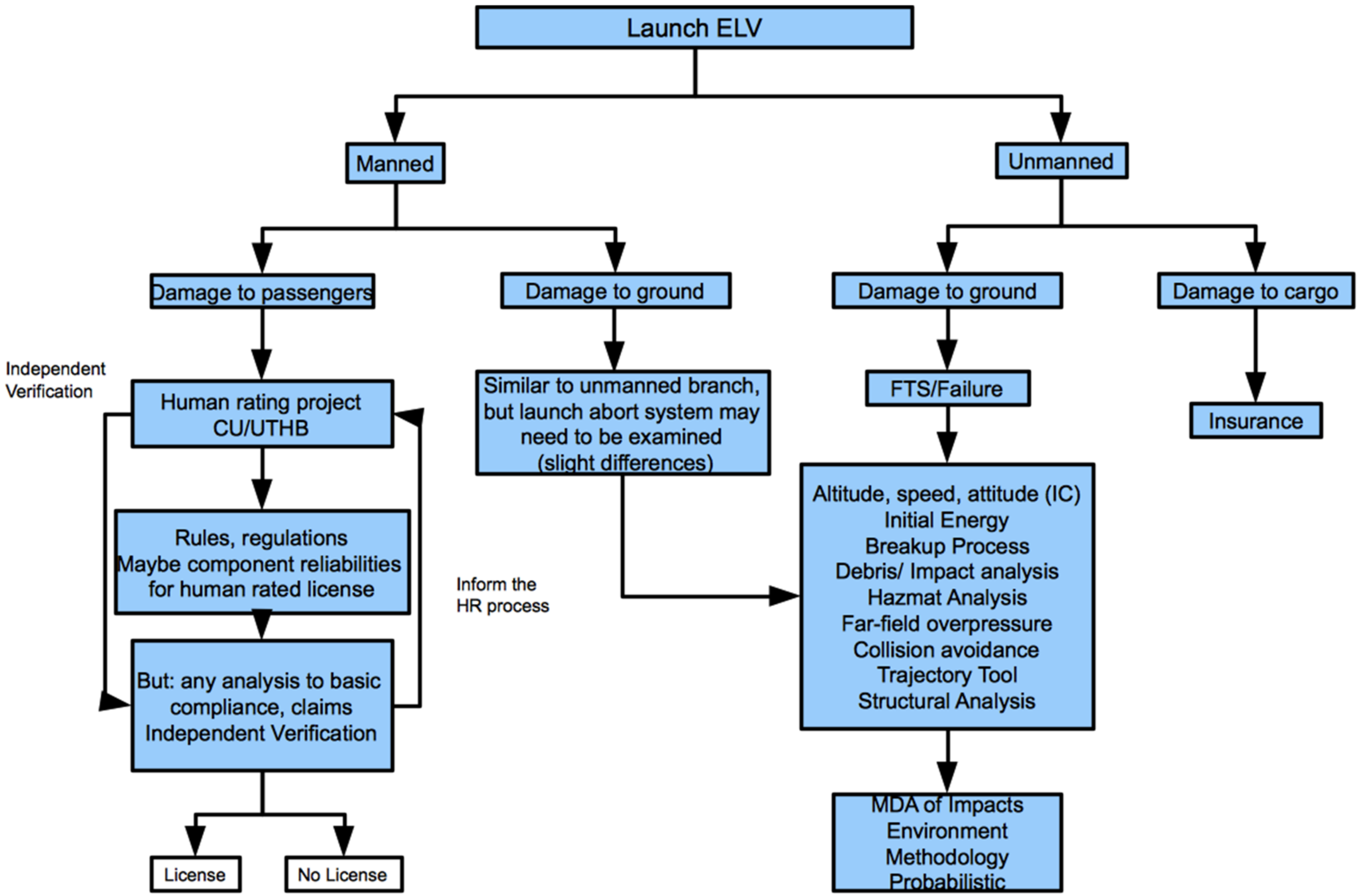
FAA Existing Licensing Requirements

- Mostly based on NASA heritage for ELVs.
- Comprehensive set of flight safety analysis requirements for ELVs:
  - Trajectory Analysis
  - Malfunction Turn Analysis
  - Debris Analysis
  - Flight System Safety Analysis
  - Straight-up Time Analysis
  - Data Loss Flight Time and No Longer Terminate Time Analysis
  - Time Delay Analysis
  - Flight Hazard Area Analysis
  - Probability of Failure Analysis
  - Debris Risk Analysis
  - Toxic Release Hazard Analysis
  - Far-Field Overpressure Effects Analysis
  - Collision Avoidance Analysis
  - Overflight Gate Analysis and Hold and Resume Gate Analysis

Current Approach

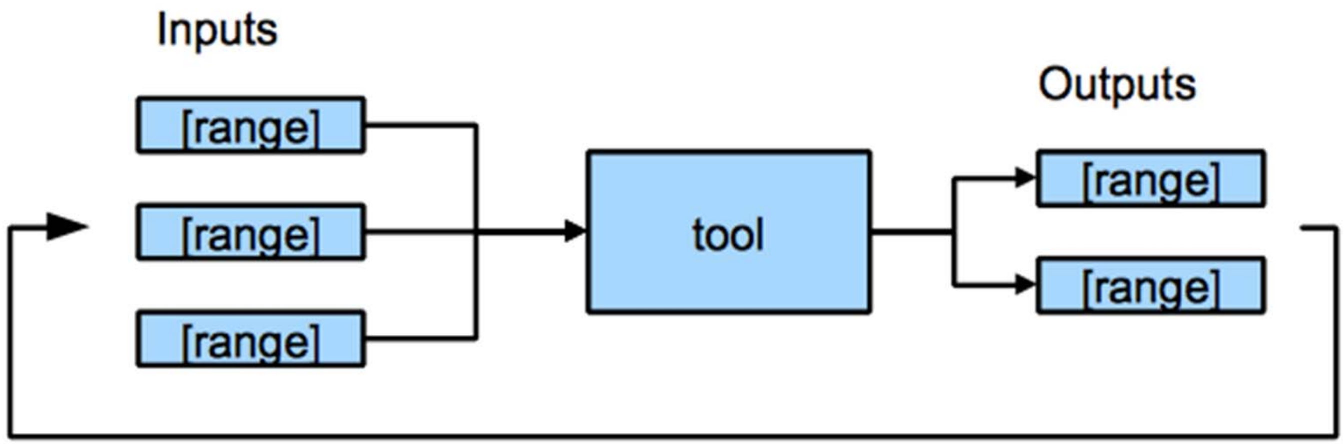
- Long term goal is to look at all possible licensed activities (in the following order):
  - ELV
  - Suborbital
    - Single craft
    - Multi craft
  - RLV
    - SSTO
    - TSTO
    - Various options
- Develop safety metrics.
- Not looking at certification, only licensing.
- Not trying to solve design practices (existing standards must be followed).
- We are trying to answer big picture questions about safety assessment of current and future launch and re-entry systems. How can we set appropriate safety levels rationally?

Current Approach



Current Approach

- Typically deterministic inputs result in a deterministic output. We are considering outputting ranges and understanding the input parameter combinations that lead to worst case scenarios (tails of distribution)
- Results obtained by solving the reverse problem could be used to inform licensing restrictions, or influence designs.

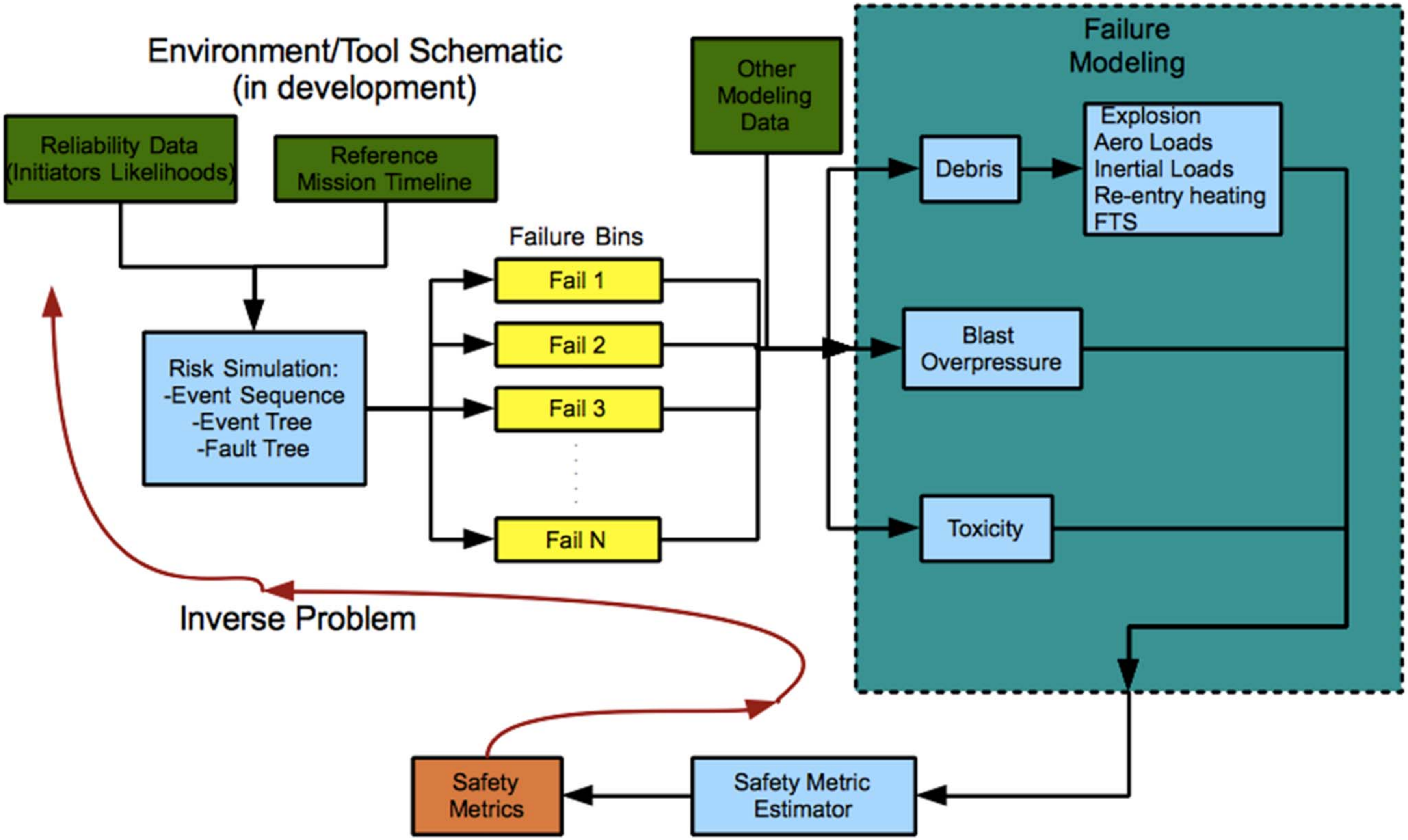


High Level Environment Representation

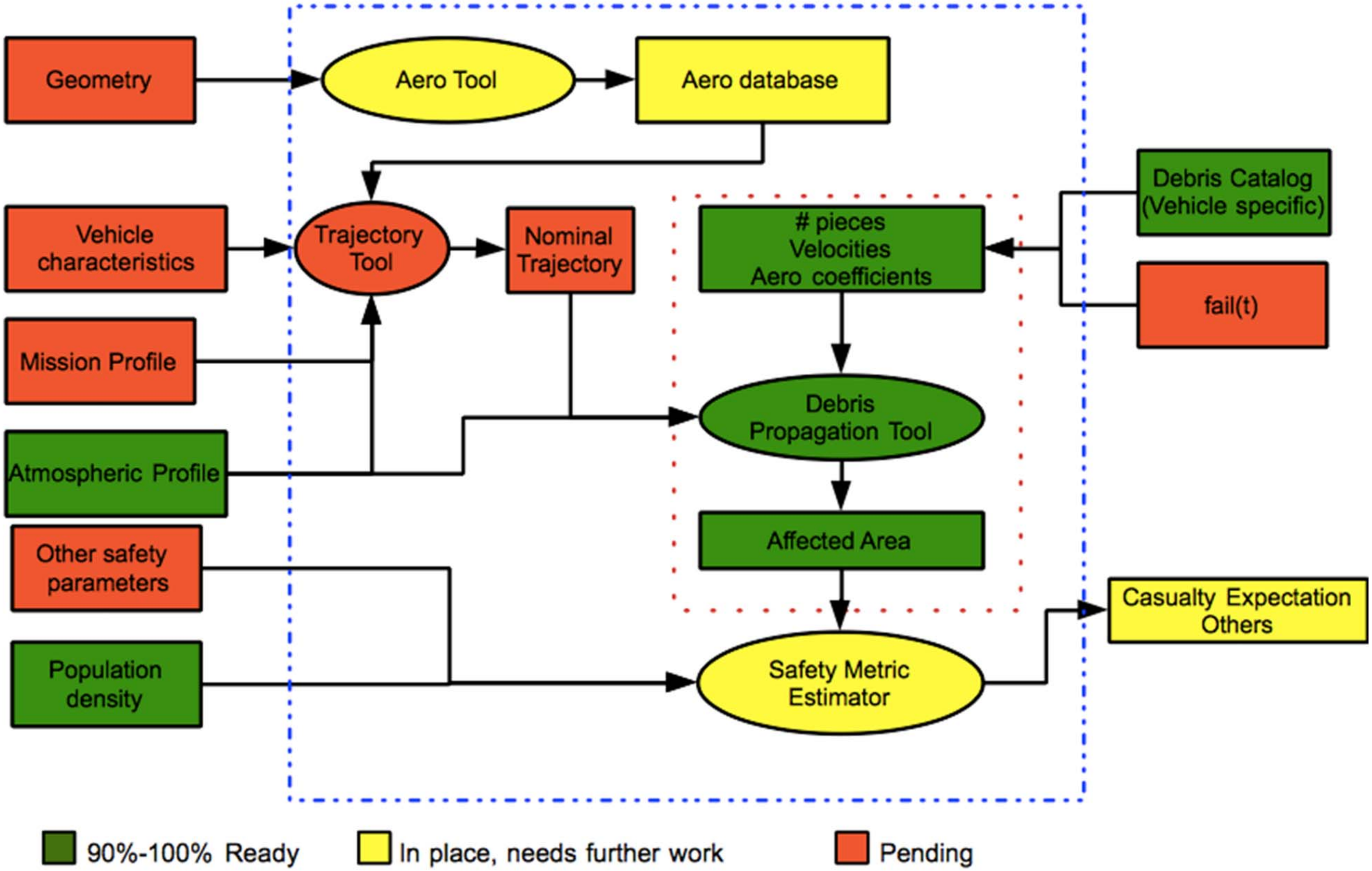
Research Questions

- What are the operating margins?
- How large can the epistemic uncertainty intervals be before losing confidence in safety estimates?
- What is the risk of affecting the surrounding population/protected area?
- How much data of each kind (simulation, experimentation, flight) is needed to guarantee accuracy of safety assessment to a certain degree in a certain envelope?
- By solving the reverse problem, what are the licensing requirements that help obtain the desired outputs/safety metrics?

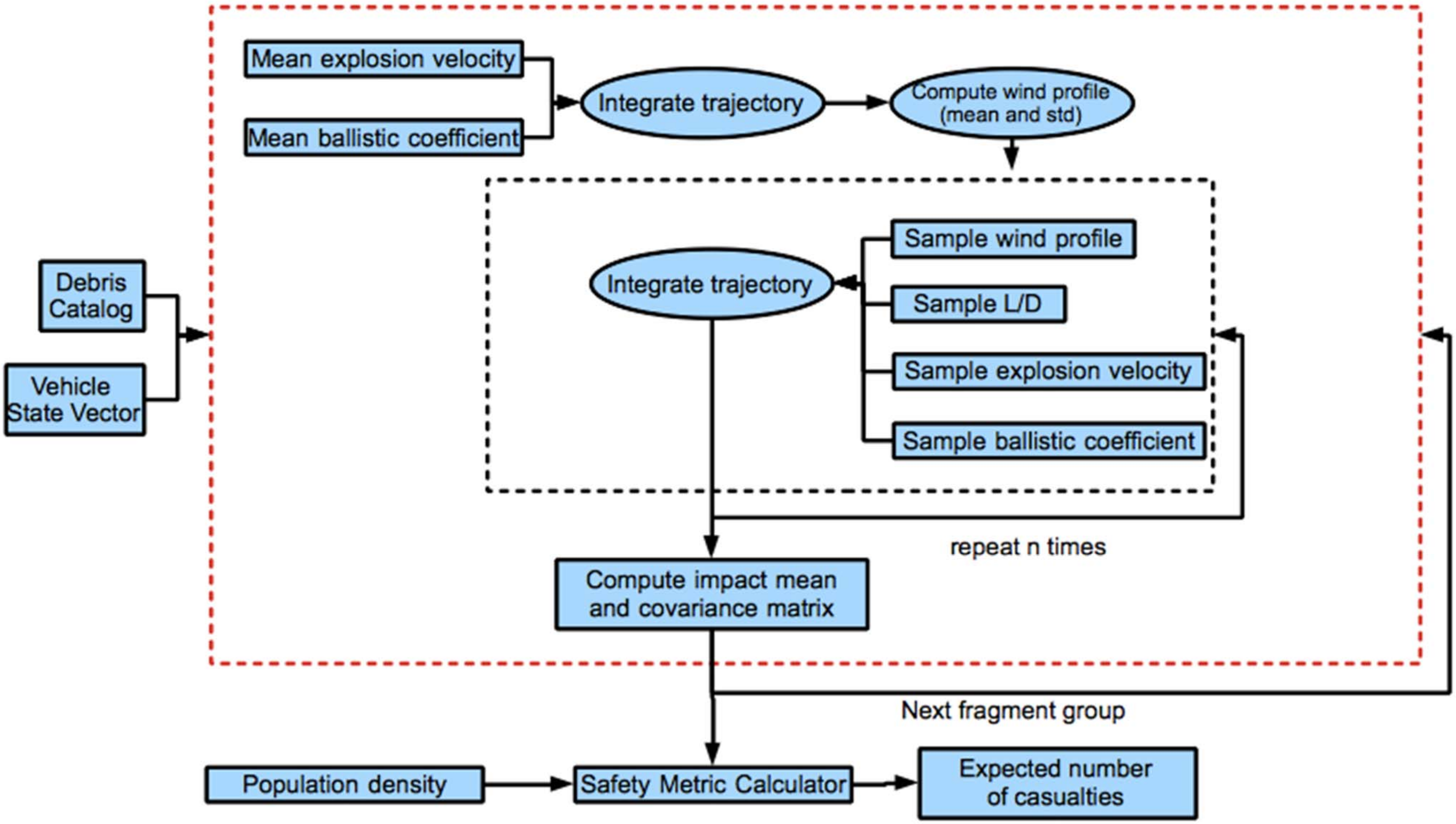
Analysis Environment



Analysis Environment: Debris Propagation

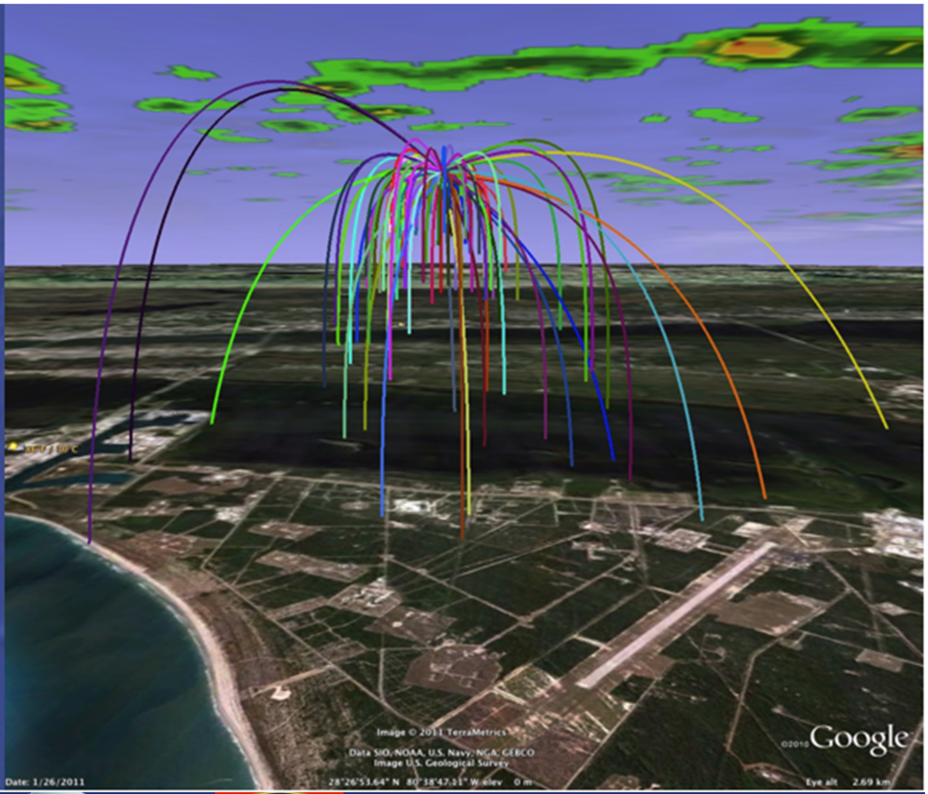


Debris Propagation Details



Debris Propagation Results

- Debris simulation for fictitious launch vehicle of approximately the size of a Falcon 9
- Randomly generated debris catalog. Probabilistic CD and initial velocities
- Intent was to verify trajectory and debris propagation portion of environment



Sophisticated Debris Models

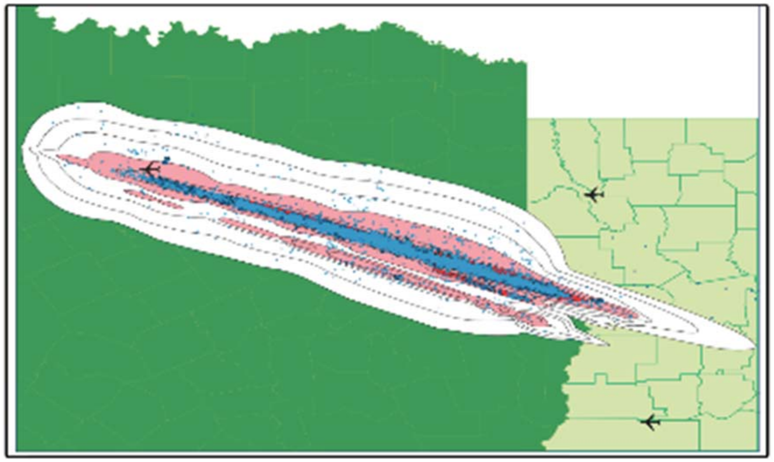
- Prior work includes LARA (USAF) and CRTF (ACTA) with many needed components. Attempting to improve on these models by including uncertainty directly in the modeling and ensuring open access
- Assumptions in new debris dispersion tool :
  - Spherical rotating Earth.
  - Debris pieces are not allowed to change mass or collide during propagation.
  - Debris pieces treated as point masses.
  - Lift and drag coefficients constant throughout all speed regimes.
  - Explosion effects simulated by giving impulse velocities to the debris.
  - Wind effects in all 3 orthogonal directions are considered.
  - Malfunction turns not implemented yet.

Sophisticated Debris Models (II)

- Assumptions in the Expected Casualty (safety metric #1) calculation:
  - No sheltering.
  - A normal bivariate distribution assumed for the affected areas.
  - Population divided in square grid cells, and uniformly distributed within a cell.
  - All debris (regardless of size or kinetic energy) consider lethal.
  - Debris pieces assumed to reach the ground at their terminal speed.
  - No bouncing or explosive debris considered.

Columbia Accident Simulations

- More than 80 000 debris pieces recovered over more than 10 counties.
- 11 debris groups considered.
- There is a considerable amount of uncertainty in the input parameters, for example:
  - Number of debris pieces
  - Main vehicle's state vector
  - Impulse velocities due to explosions
  - Lift to drag ratio



Recovered Debris location. From CAIB report Volume II Appendix D.16

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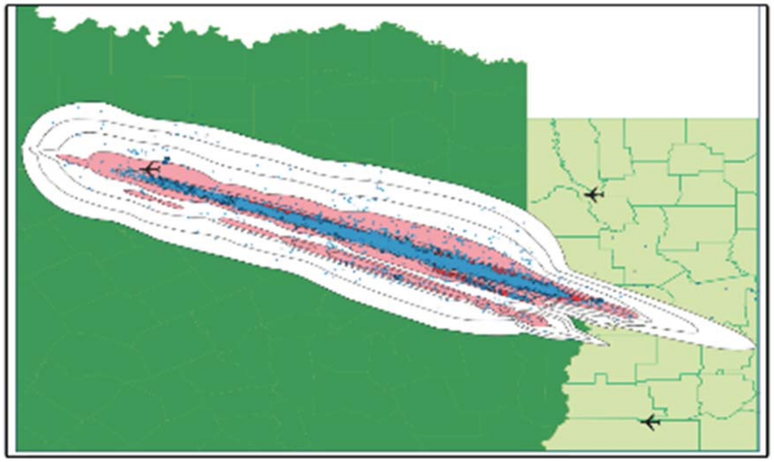

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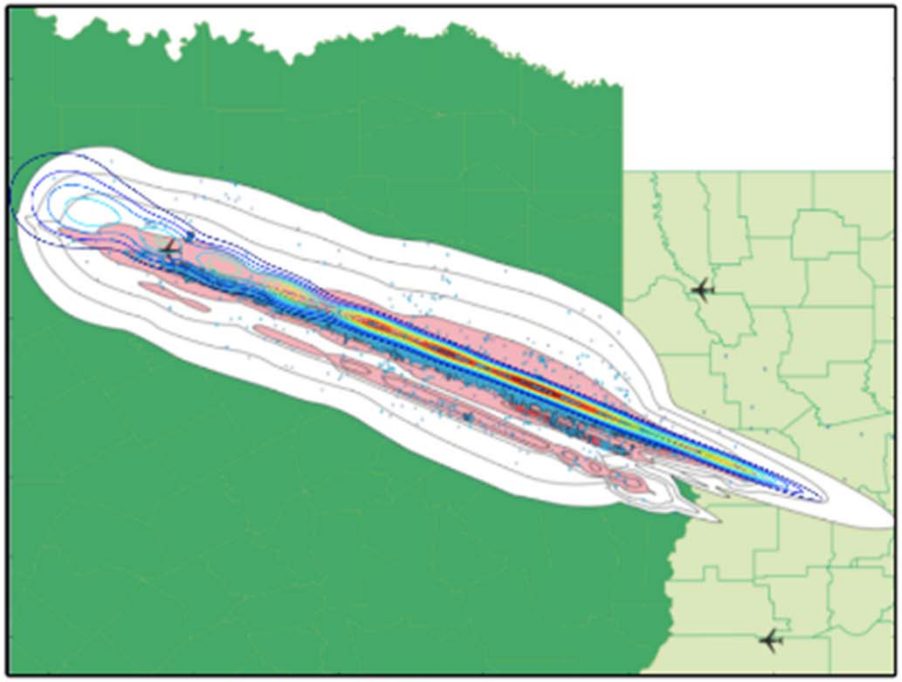
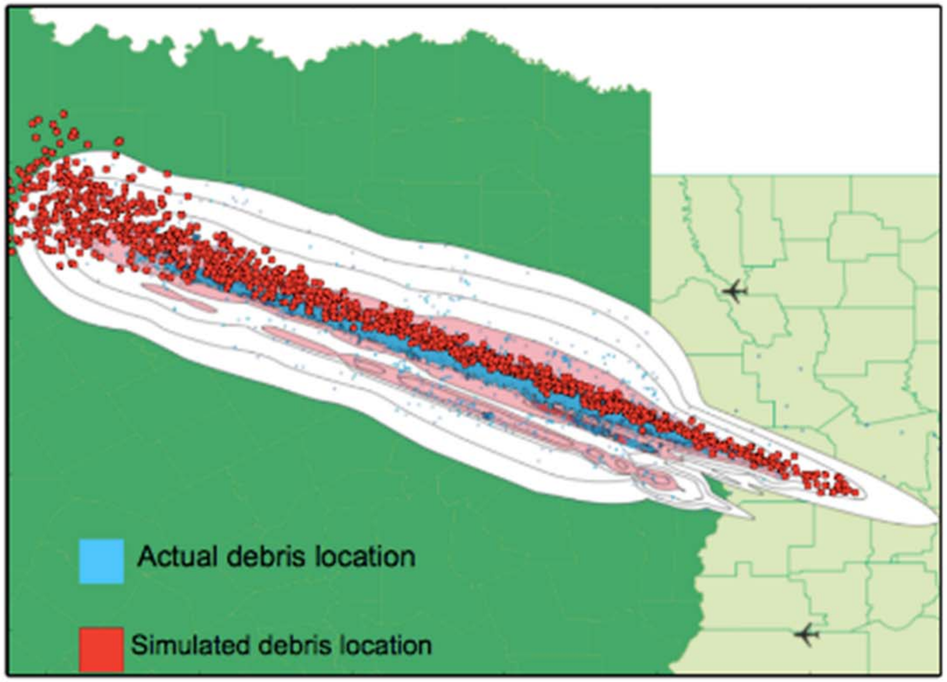
Columbia Accident Simulations

- Affected area obtained from debris dispersion tool compared with actual debris field



Contour of affected area



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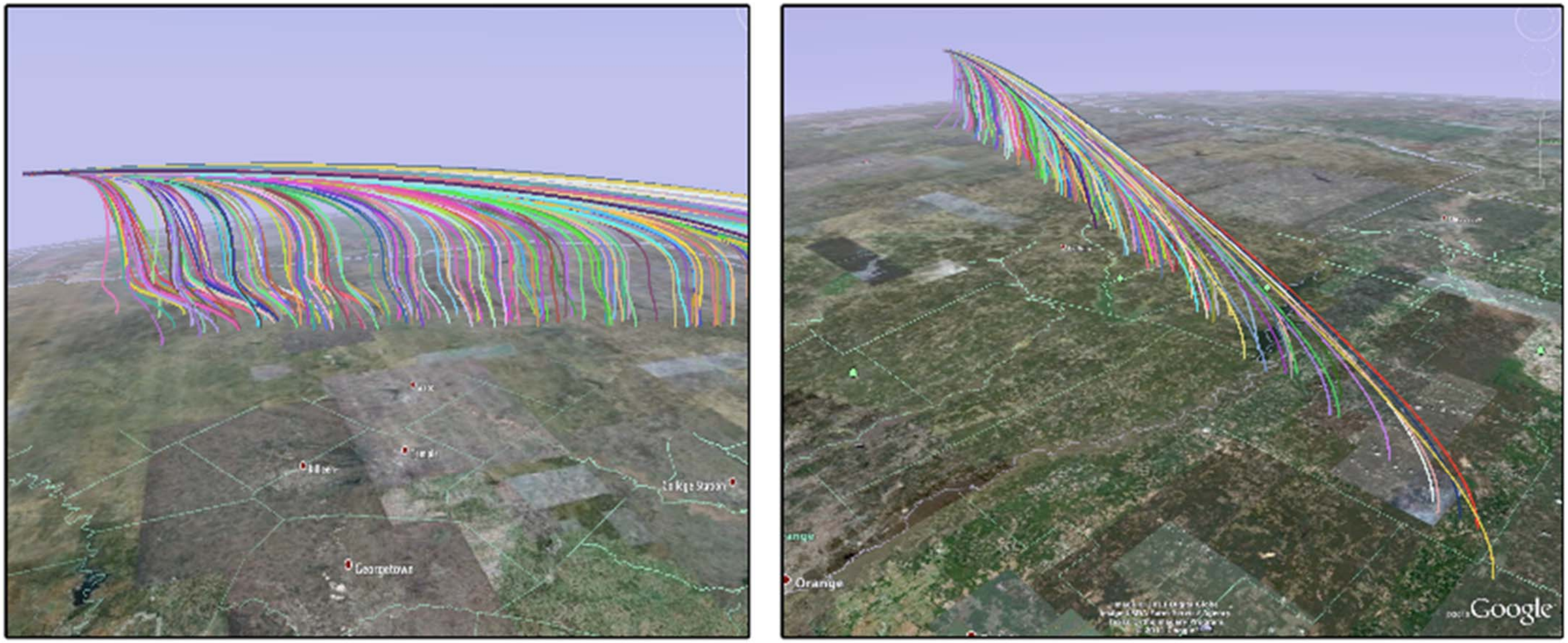

Debris trajectories visualized in Google Earth

Conclusions & Future Work

Conclusions

- Initial framework architecture developed, modular components being added
- Initial focus on damage to the ground on ELV ascent trajectory
- Initial trajectory and debris dispersion tools have been implemented, and successfully automated to generate thousands of Monte Carlo evaluations.
- The current debris dispersion tool seems to capture the basic physical effects of falling debris.
- Despite the considerable amount of uncertainty in the input parameters, the debris dispersion model does an acceptable job in locating the risk areas.

Future work

- Validate the dispersion tool against other well accepted debris analysis tools (help is needed from industry to define realistic debris catalogs).
- Add malfunction turns to the simulation.
- Implement other random distributions (e.g Kernel density estimation) to calculate casualty expectation.
- Begin theoretical development for probabilistic inversion of safety requirements.