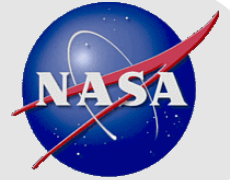


# **AutoORSAT Parametric Studies: a Step Toward Incorporating Uncertainty into Reentry Simulation**

**Presenter: Benton R. Greene**

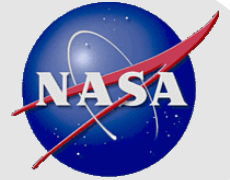
**Co-authors: Jack B. Bacon, Chris L. Ostrom**

**NASA Orbital Debris Program Office**



# Introduction

- **ORSAT: Object oriented approach to reentry casualty risk**
  - Spacecraft is modeled as a collection of nested shape primitives
  - Each object is released and begins aerodynamic heating when its container fully demises
- **AutoORSAT: Python wrapper for ORSAT to extend object nesting and parametric study functionality**
  - Allows arbitrary number of nesting levels
  - Parametric study of an arbitrary number of variations in an arbitrary number of input variables
  - Output to CSV files and to a SQLite3 database file for simple cross-referencing of variables



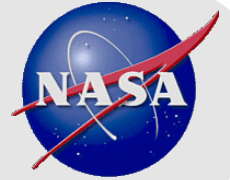
## Questions

- **How much is demisability affected by (realistic) initial conditions?**
- **How much does the change in demisability realistically affect the total Debris Casualty Area (DCA) and Expectation of Casualty ( $E_c$ )?**
- **Which initial conditions affect the DCA and  $E_c$  the most?**
- **How best to interpret a Monte Carlo analysis of the range of realistic entry conditions?**



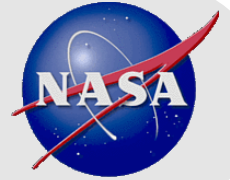
Parameter Space Study

# **REPRESENTATIVE COMPONENTS**



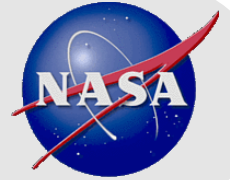
## Parameter Space

- **Each spacecraft component can have up to 65 independent parameters**
  - Geometry
  - Initial trajectory
  - Materials
  - Computation model flags
- **To study the effect of  $n$  variations in all parameters of  $m$  components of a spacecraft requires  $m * 65^n$  separate ORSAT runs**
- **Some of these variables have a greater impact on the demise of a given component than others**



## Parameter Space Study

- **Design limited parameter space study to relative influence of parameters**
  - Restrict inputs to realistic values
  - Components represent typical components of a spacecraft
  - Measure outcome as Demise/Survive Only/Survive with Casualty
- **Parameters Studied**
  - Initial trajectory
  - Shape
  - Dimensions
  - Mass

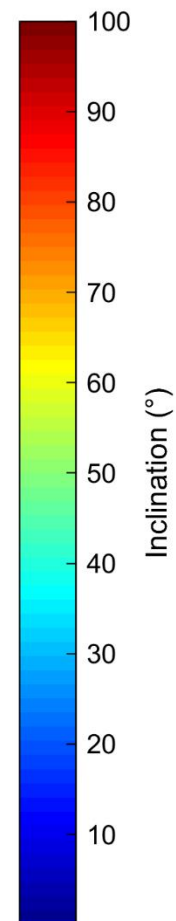
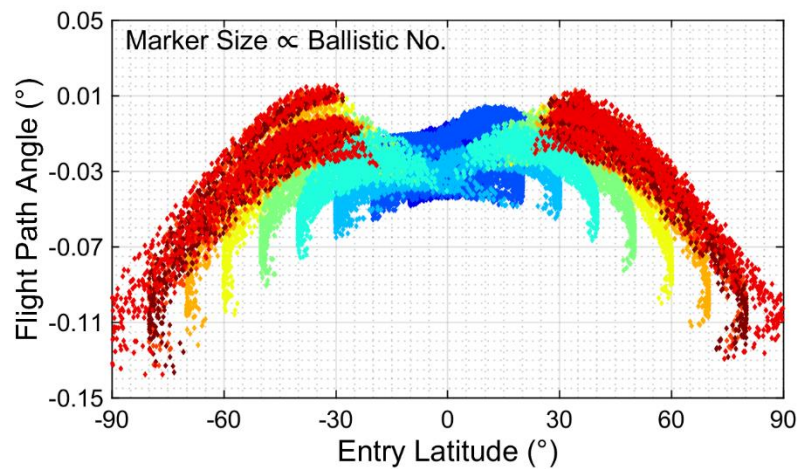
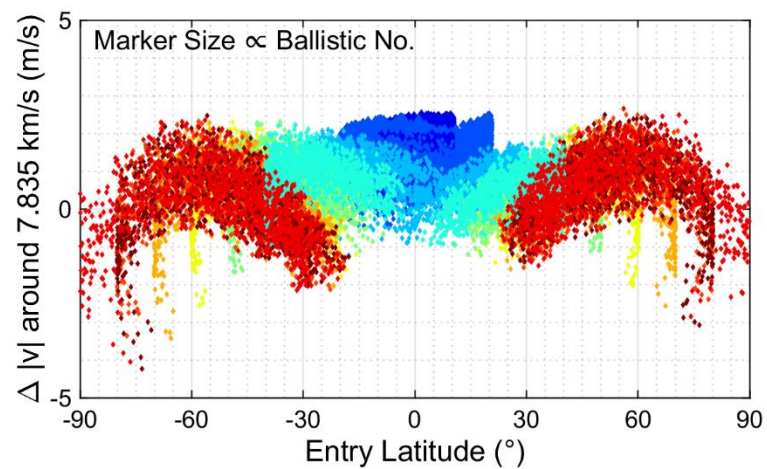
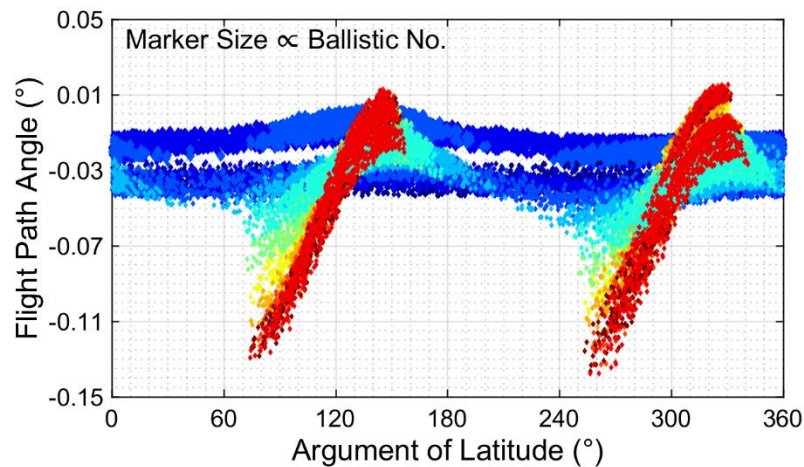
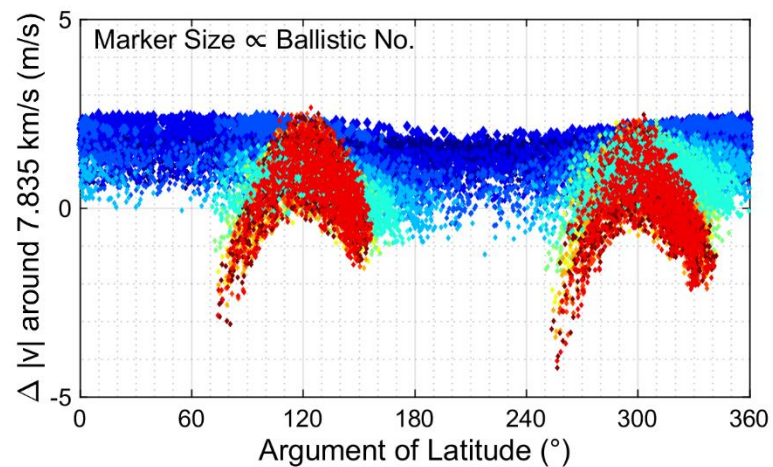


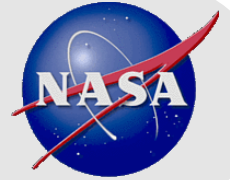
# Realistic Initial Trajectory

- **Assumptions:**
  - Spacecraft starts at a 300 km circular orbit
  - A random reentry could occur at any RAAN, at any time of year, and will be uniformly distributed along the mean anomaly
- **Use the NASA General Mission Analysis Tool (GMAT) to simulate trajectories from 300 km altitude to the standard ORSAT 122 km entry altitude**
  - Uniform distribution of initial RAAN
  - Uniform distribution of entry day of year
  - Uniform distribution of entry argument of latitude
- **Use the final trajectory at 122 km as the ORSAT input trajectory**
- **Generate entry trajectories for**
  - 10 orbit inclinations between  $10^\circ$  and  $100^\circ$
  - 2 spacecraft ballistic numbers:  $50 \text{ kg/m}^2$  and  $150 \text{ kg/m}^2$



# Initial Trajectories





# Components

- **Screws**
  - M6 and M8 size
  - 15 mm to 40 mm long
  - Aluminum, Steel, and Titanium
- **Magnetorquers**
  - Copper windings
  - Iron cores
- **Structural Panels**
  - 1 m and 0.5 m square
  - Aluminum and Steel
- **Spherical Tanks**
  - 0.2, 0.5, and 1m
  - 5 mm – 25 mm thick
  - Aluminum, Steel, Titanium, Carbon Overwrapped Titanium
- **PCBs**
  - Fiberglass
  - 3mm thick
  - 25, 50, and 100 mm square



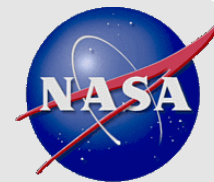
## Unchanged Outcomes

### Always Demised

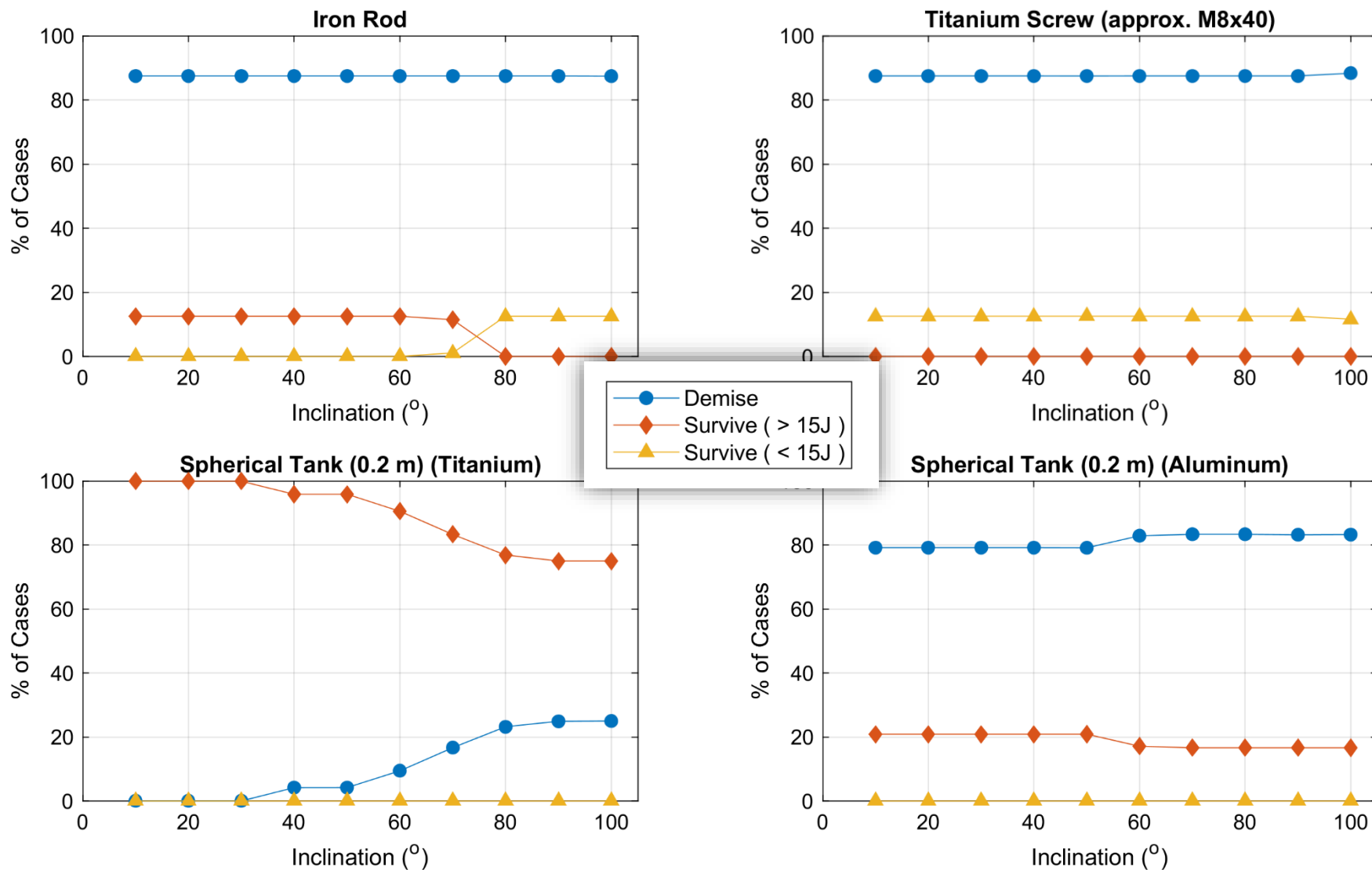
- **25 mm and 50 mm PCB**
- **All magnetorquer copper windings**
- **M8 aluminum screws**
- **15 mm and 25 mm long M8 steel screws**
- **25 mm long M8 titanium screws**

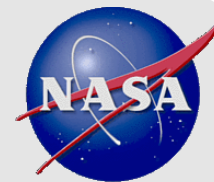
### Always Survived

- **Steel structural panels**
- **1 m titanium spherical tank**
- **1 m carbon overwrapped titanium tank**

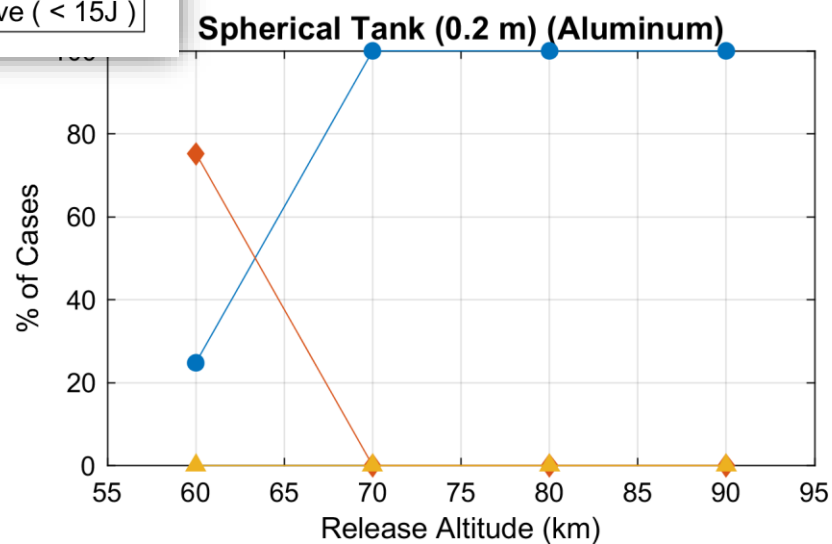
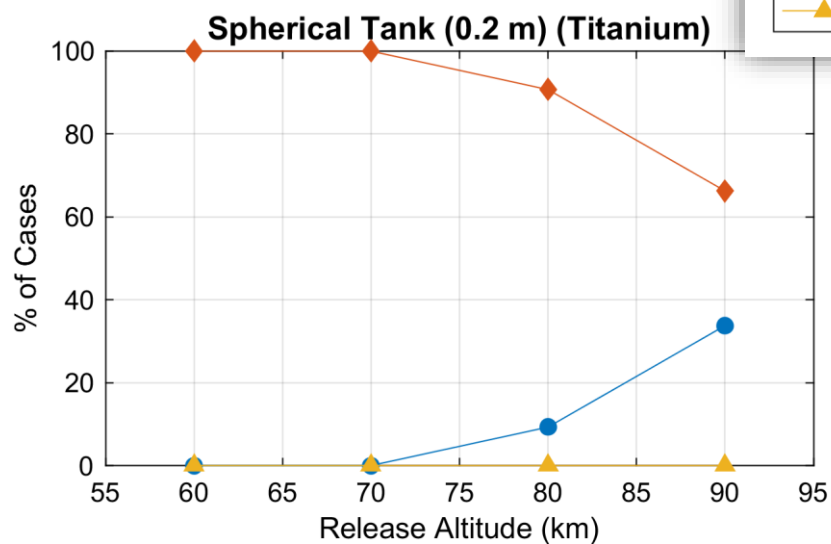
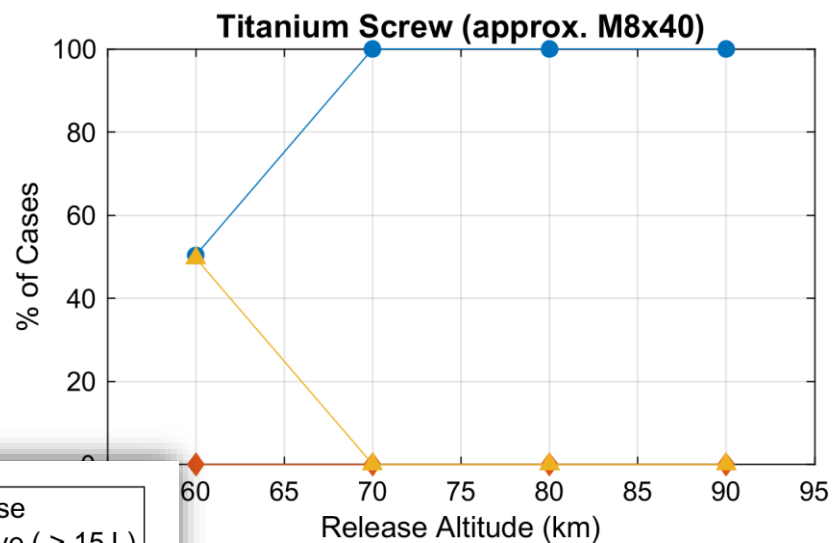
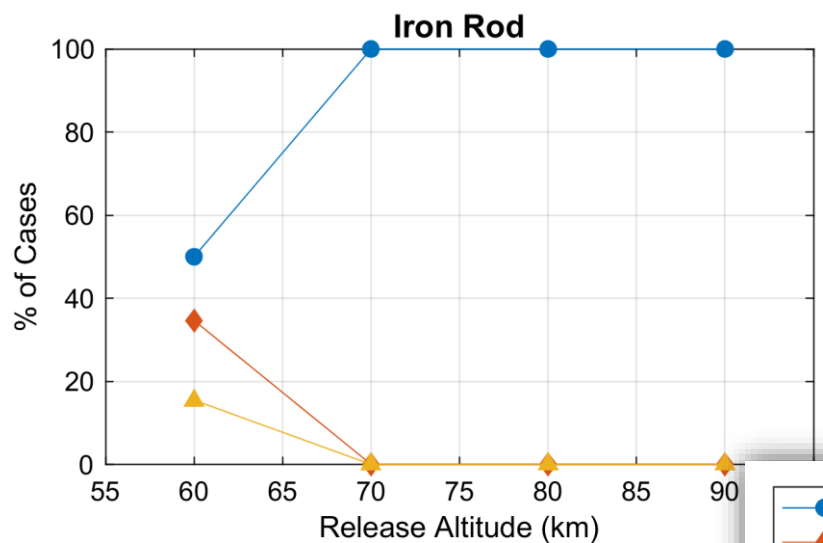


# Marginal Outcomes





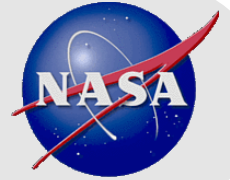
# Marginal Outcomes





Parameter Space Study

# **REPRESENTATIVE SPACECRAFT**

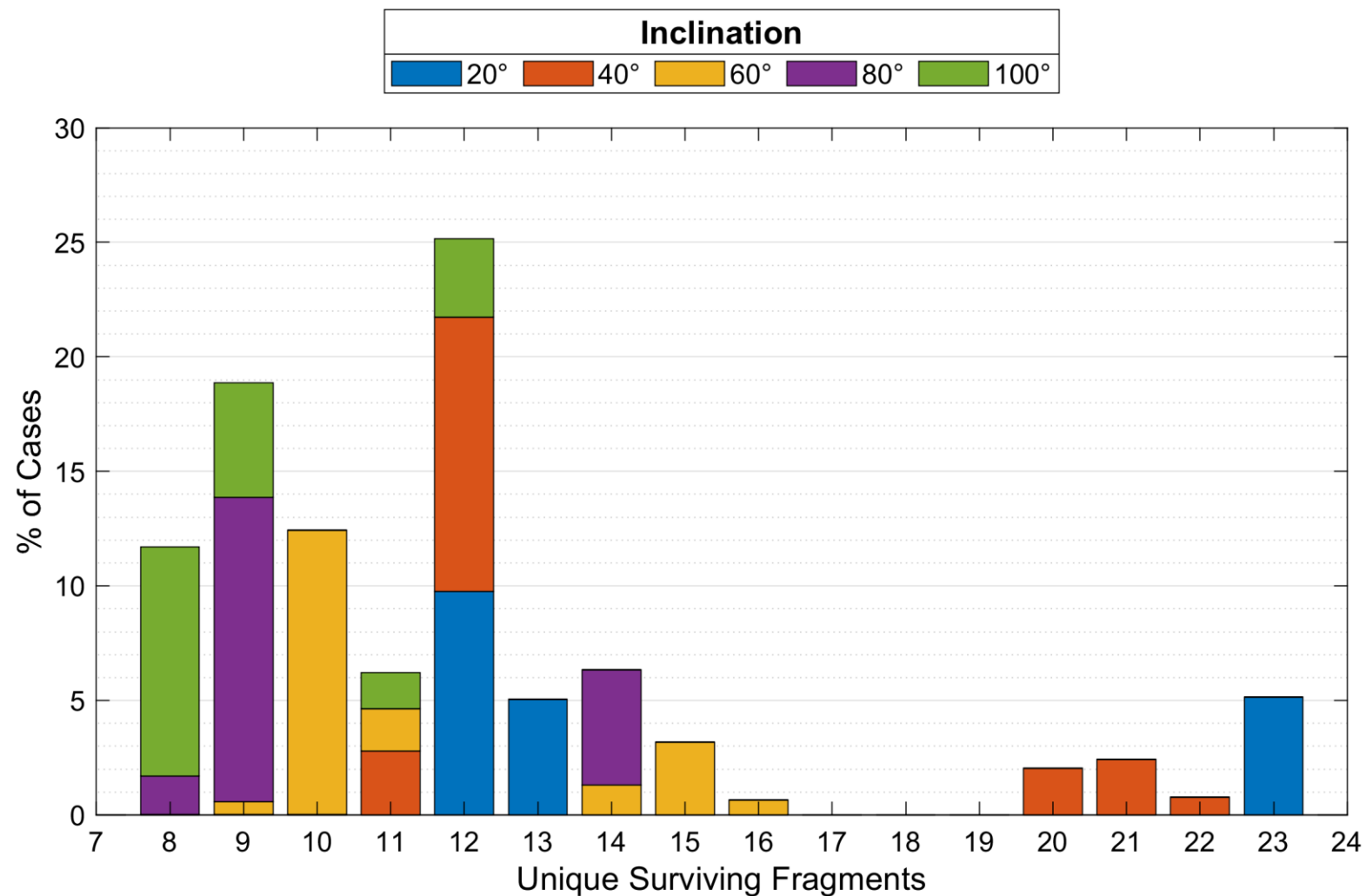


## Representative Spacecraft

- **Hypothetical 2100 kg Spacecraft**
  - Carbon fiber solar array substrate
  - Aluminum structural panels
  - Magnetorquer, reaction wheels
  - Propulsion system & tank
  - Communication antennas
  - Telescope
  - 18650 Li-ion battery pack
  - Various sizes of printed circuit board
- **Variation in demise altitude of parent spacecraft between 74 km and 82 km**

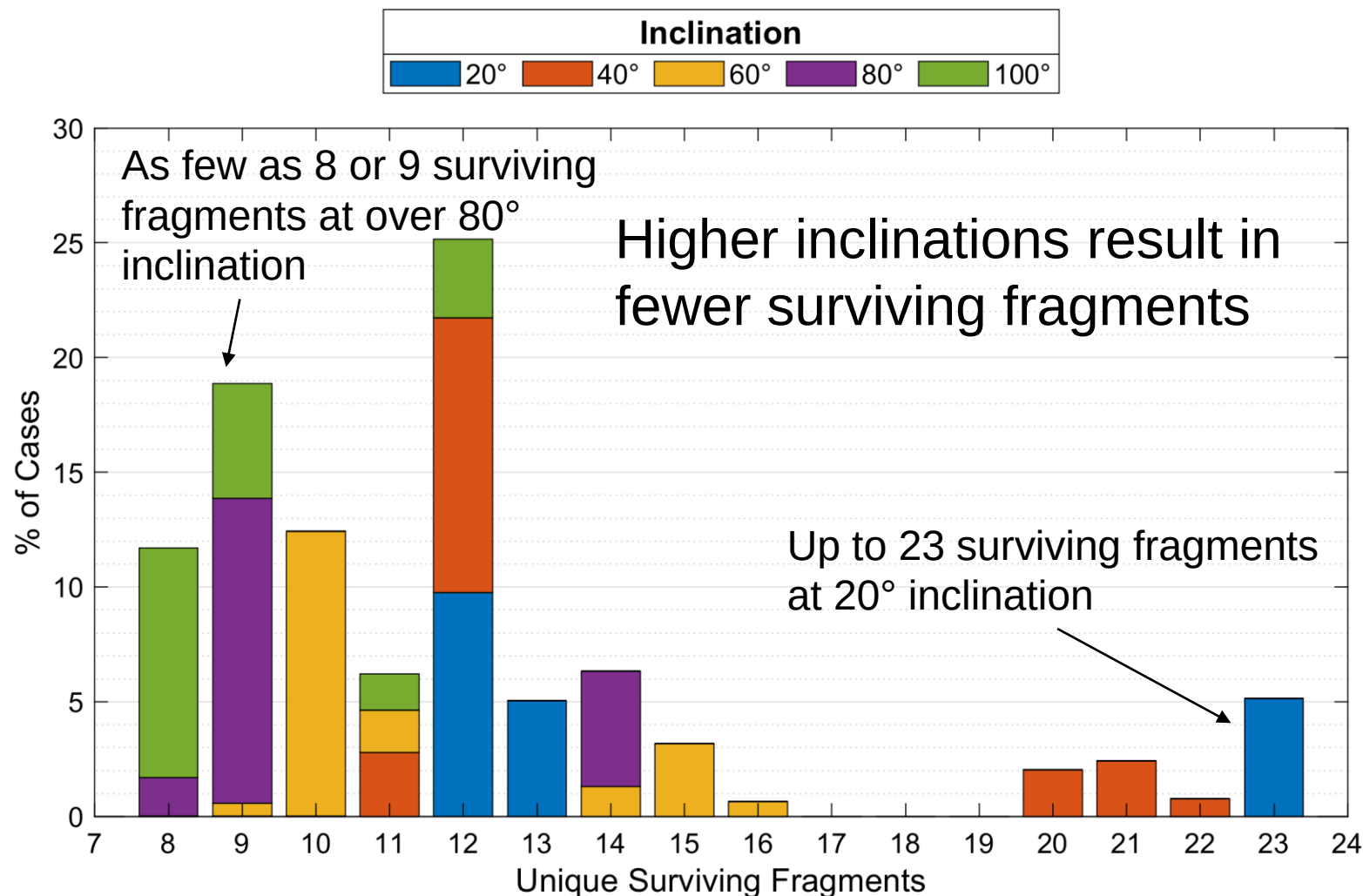


# Effect on DCA of Representative Spacecraft



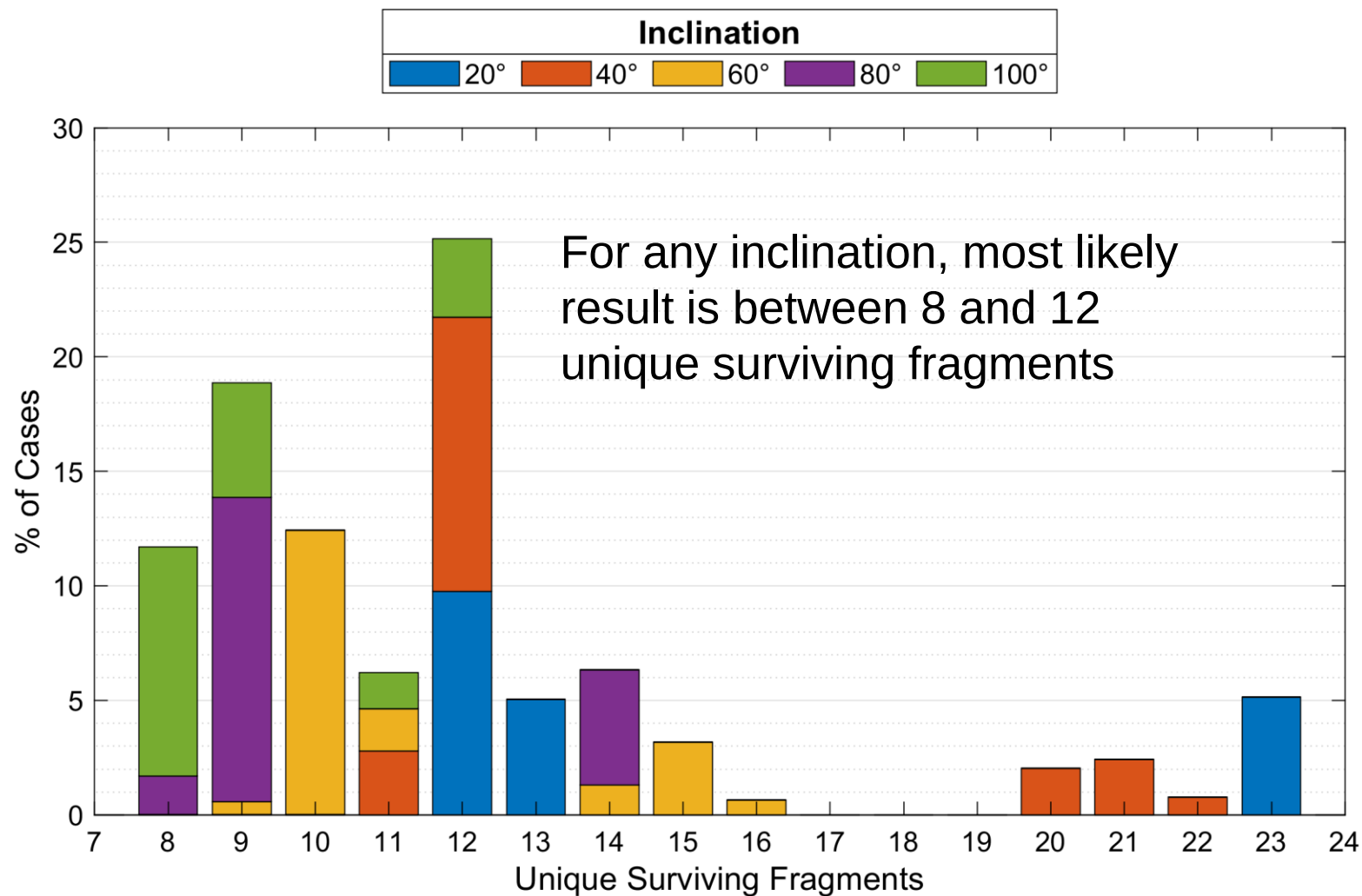


# Effect on DCA of Representative Spacecraft



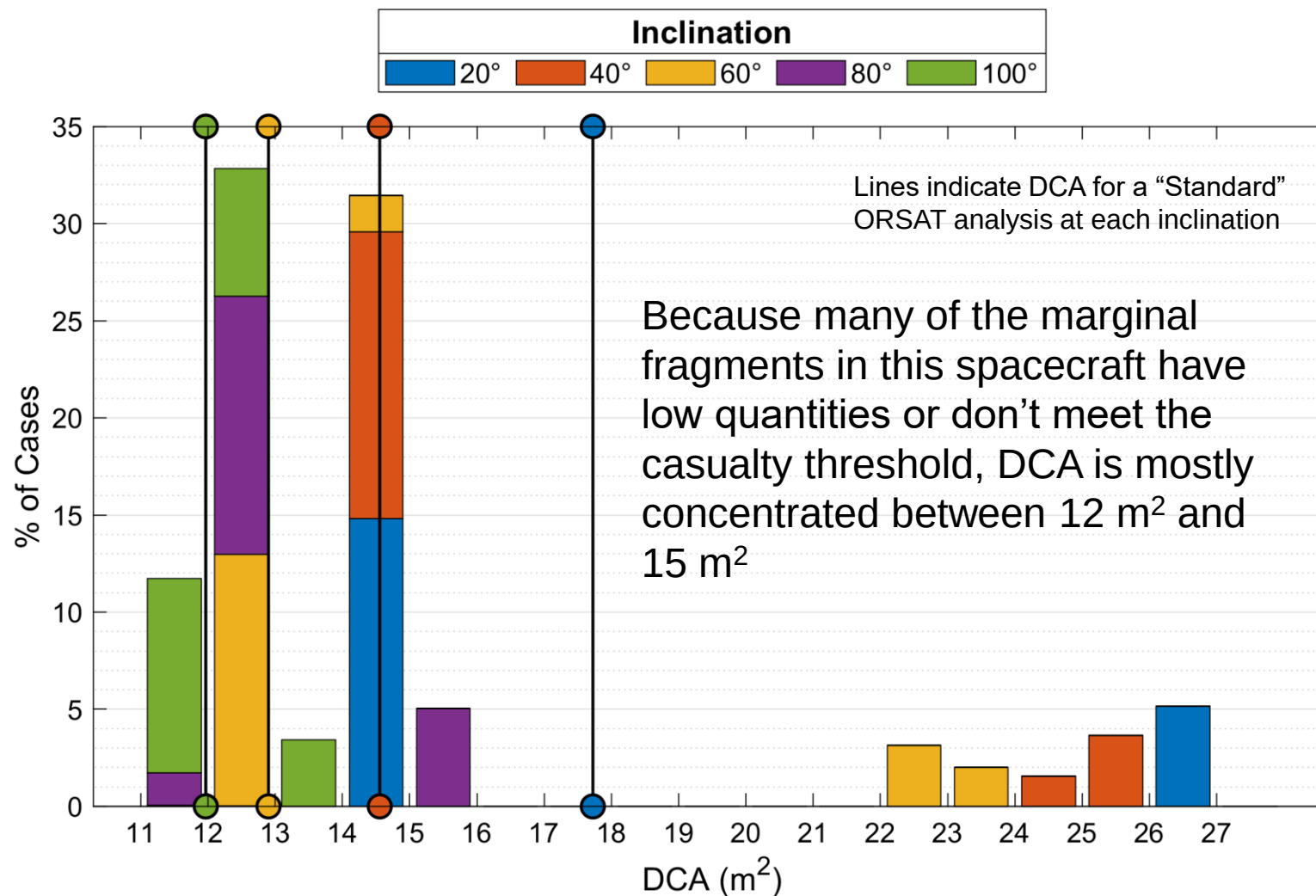


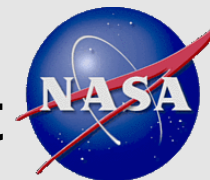
# Effect on DCA of Representative Spacecraft



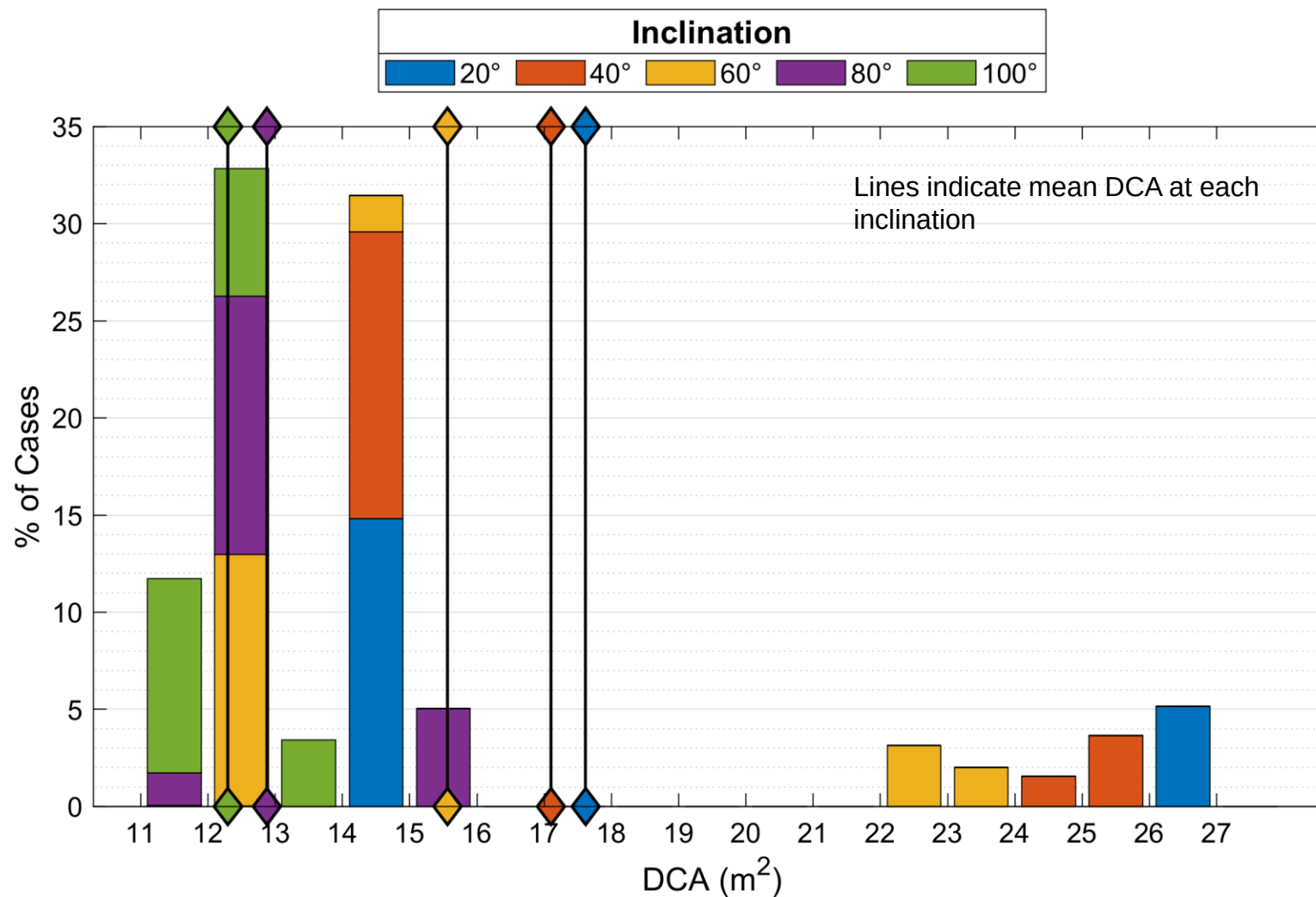


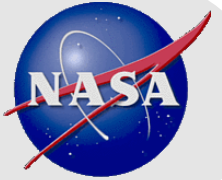
# Effect on DCA of Representative Spacecraft





# Effect on DCA of Representative Spacecraft

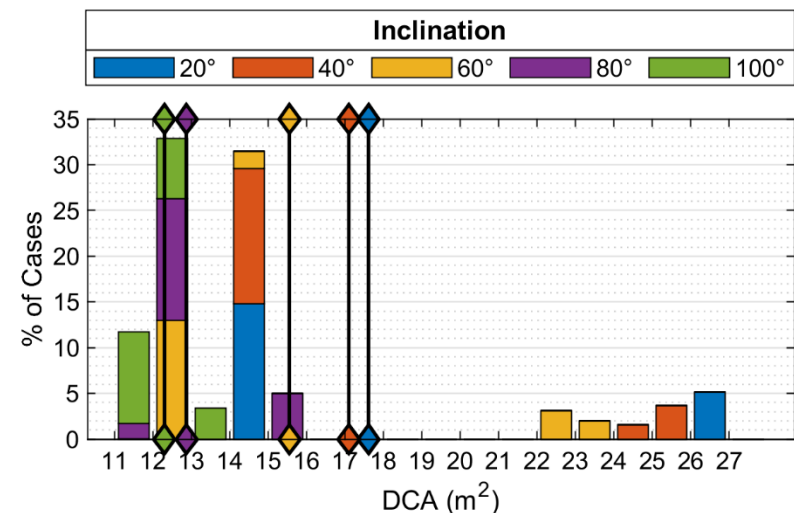


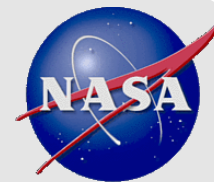


# Effect on DCA of Representative Spacecraft

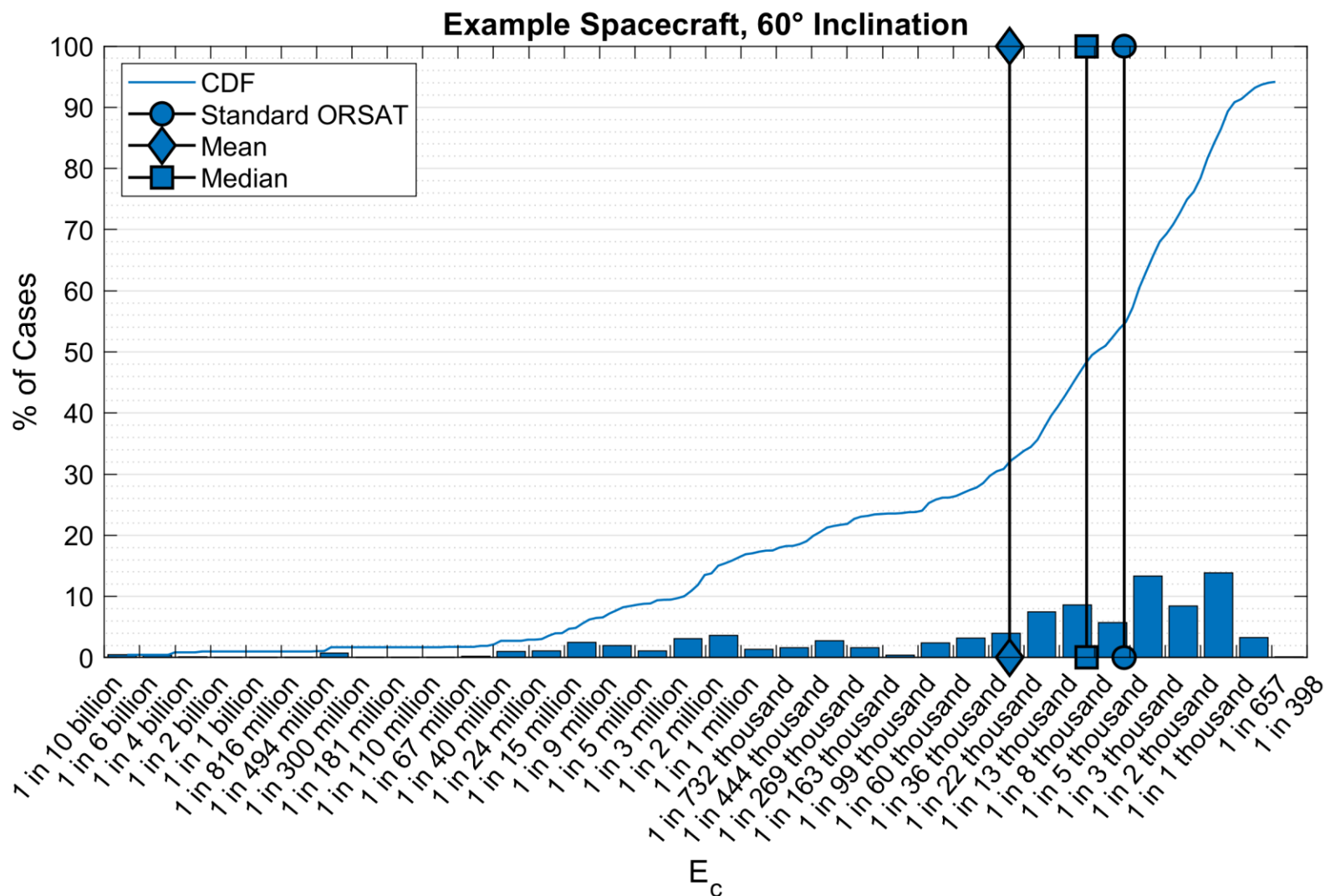
- **“Standard” ORSAT analysis:**
  - Altitude: 122 km
  - FPA:  $-0.1^\circ$
  - Breakup: 78 km
- **Standard ORSAT less conservative than mean**
- **Usually aligns with highest-count bin**

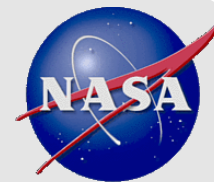
| Inclination | Standard ORSAT DCA  | Mean DCA            |
|-------------|---------------------|---------------------|
| $20^\circ$  | 17.7 m <sup>2</sup> | 17.6 m <sup>2</sup> |
| $40^\circ$  | 14.6 m <sup>2</sup> | 17.2 m <sup>2</sup> |
| $60^\circ$  | 12.9 m <sup>2</sup> | 15.6 m <sup>2</sup> |
| $80^\circ$  | 12.0 m <sup>2</sup> | 12.9 m <sup>2</sup> |
| $100^\circ$ | 12.0 m <sup>2</sup> | 12.3 m <sup>2</sup> |



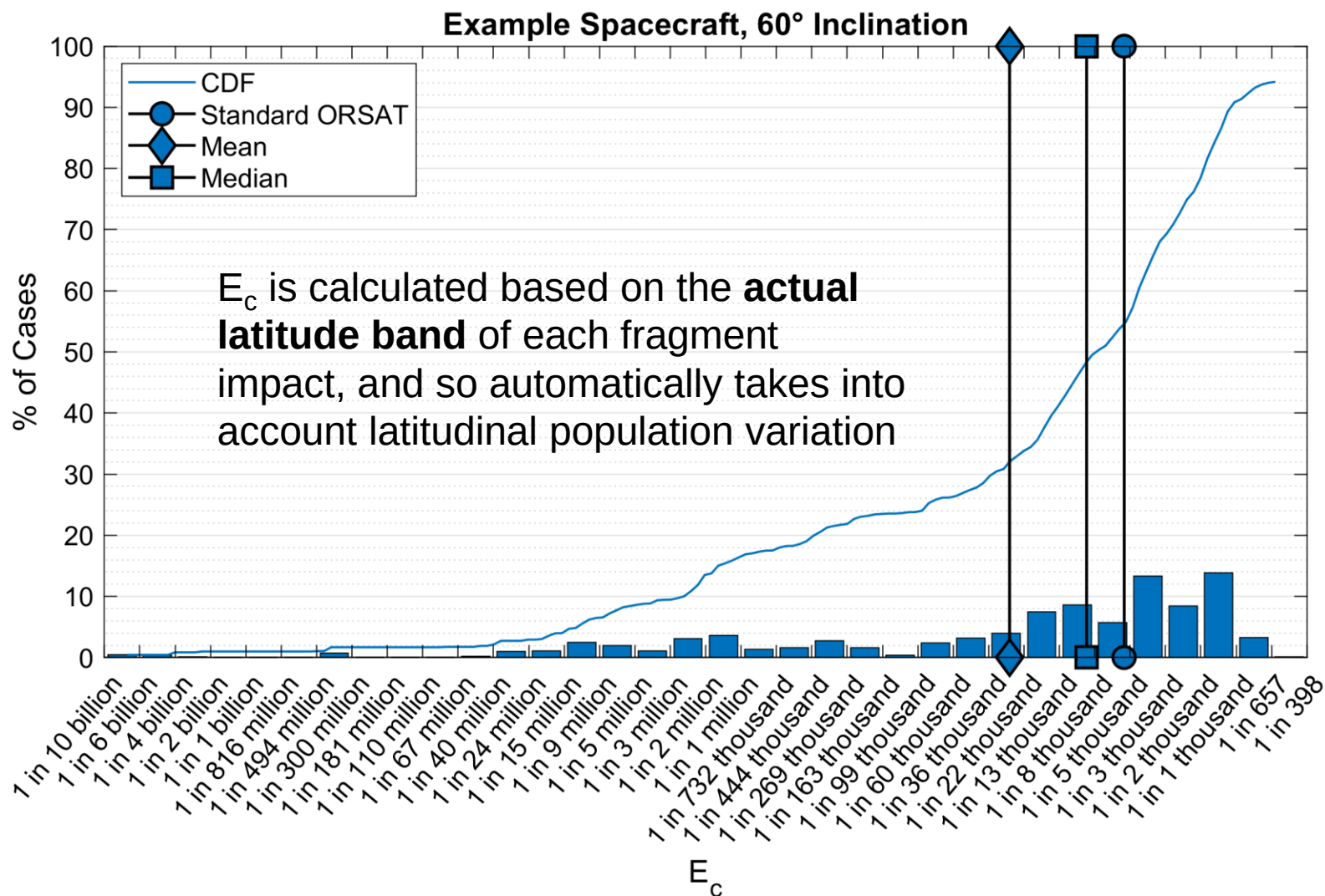


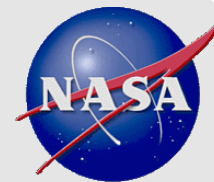
# Effect on Expectation of Casualty ( $E_c$ )



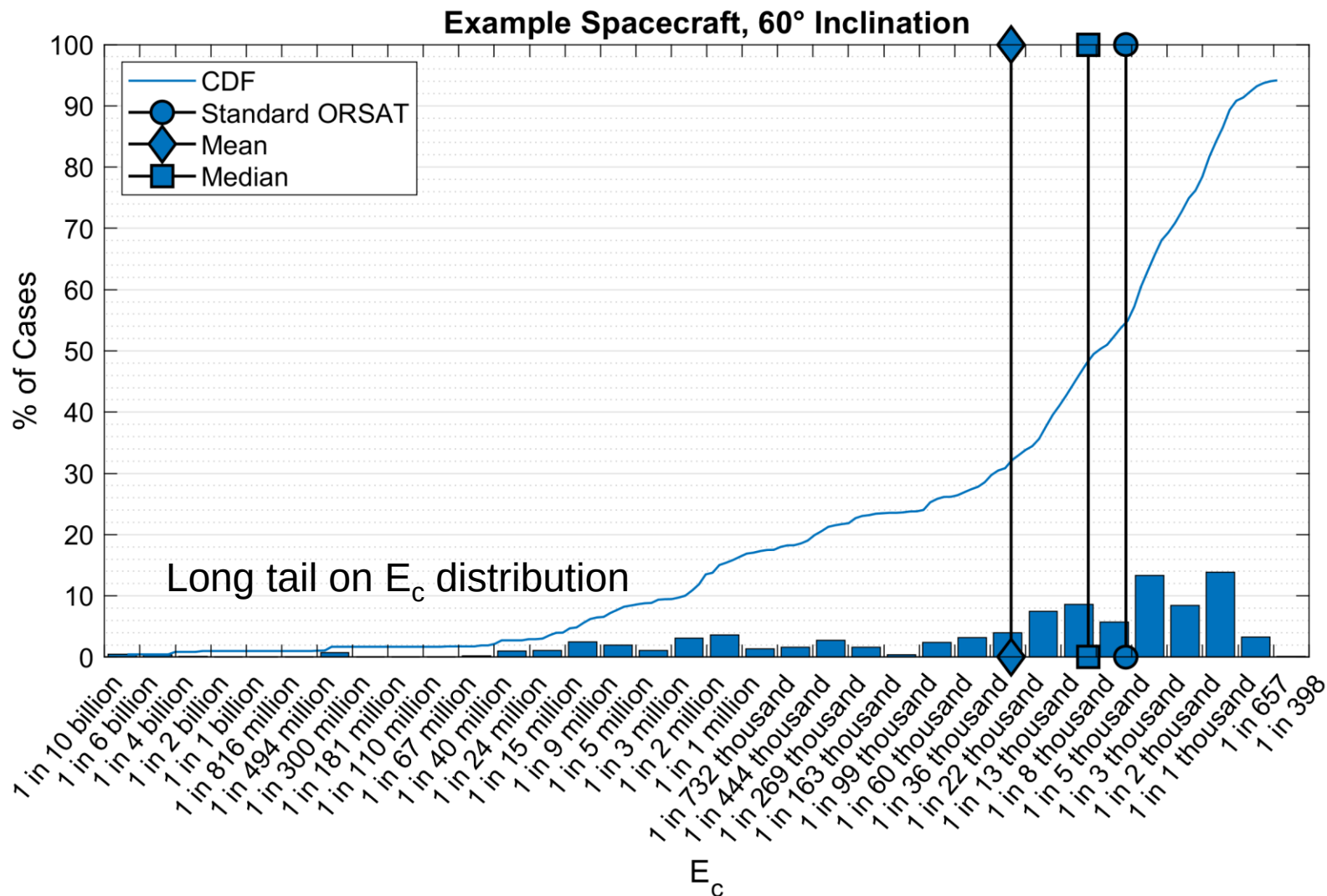


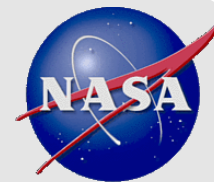
# Effect on Expectation of Casualty ( $E_c$ )



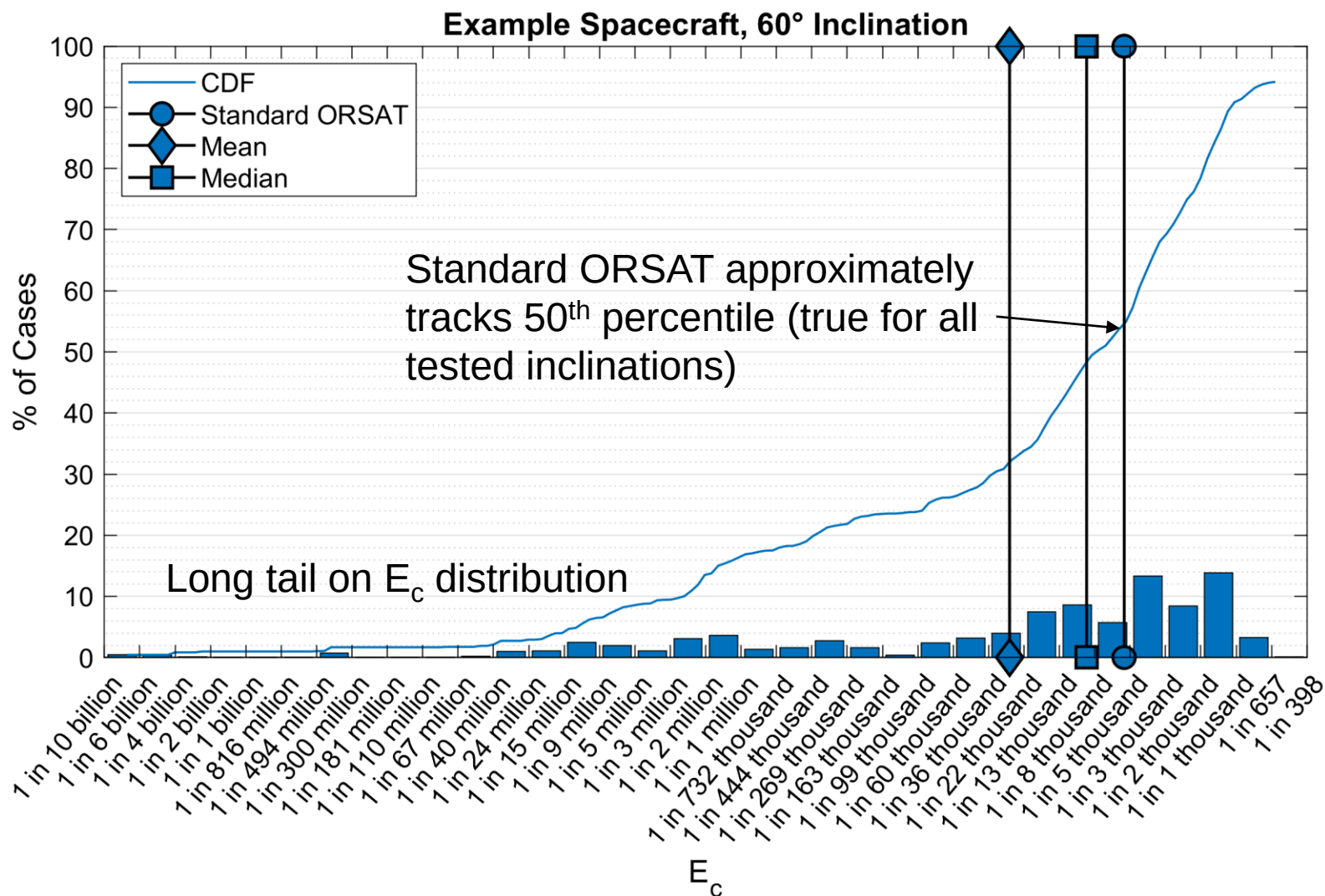


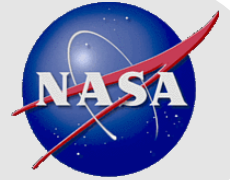
# Effect on Expectation of Casualty ( $E_c$ )





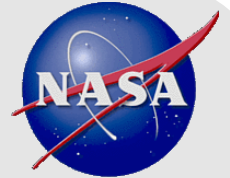
# Effect on Expectation of Casualty ( $E_c$ )





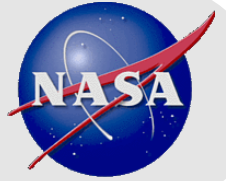
## Conclusions

- **Demisability of many types of components not affected at all by even large changes in initial conditions**
- **Marginally demisable components can have a very large effect on the DCA of a spacecraft**
- **A relatively small parametric study can determine whether any of the components are marginal**
- **The vast majority of variability in DCA comes from**
  - Release altitude of the component (unfortunately also the least well-known input)
  - Inclination of the orbit
- **The vast majority of variability in  $E_c$  comes from variability in impact latitude**



## Future Work

- **Develop statistical model for**
  - Distribution of release altitudes
  - Distribution of initial entry trajectory
- **Implement true Monte-Carlo analysis in AutoORSAT**
  - Likely require fewer ORSAT runs to achieve representative results
  - Mean value of final DCA will be representative of likeliest DCA



# BACKUP SLIDES

