Application of a Six Degrees-of-Freedom Drag Model for Small Satellite Mission Development

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Introduction

- The early stages of mission development can be challenging at the university level
  - Often limited resources available
  - Difficult to scope appropriately
  - Algorithm development
- For satellites in LEO, atmospheric drag is a critical mission consideration
  - Attitude and operational lifetime considerations
- Six degrees-of-freedom orbit model with drag perturbations developed
  - Applied to the MR & MRS SAT mission

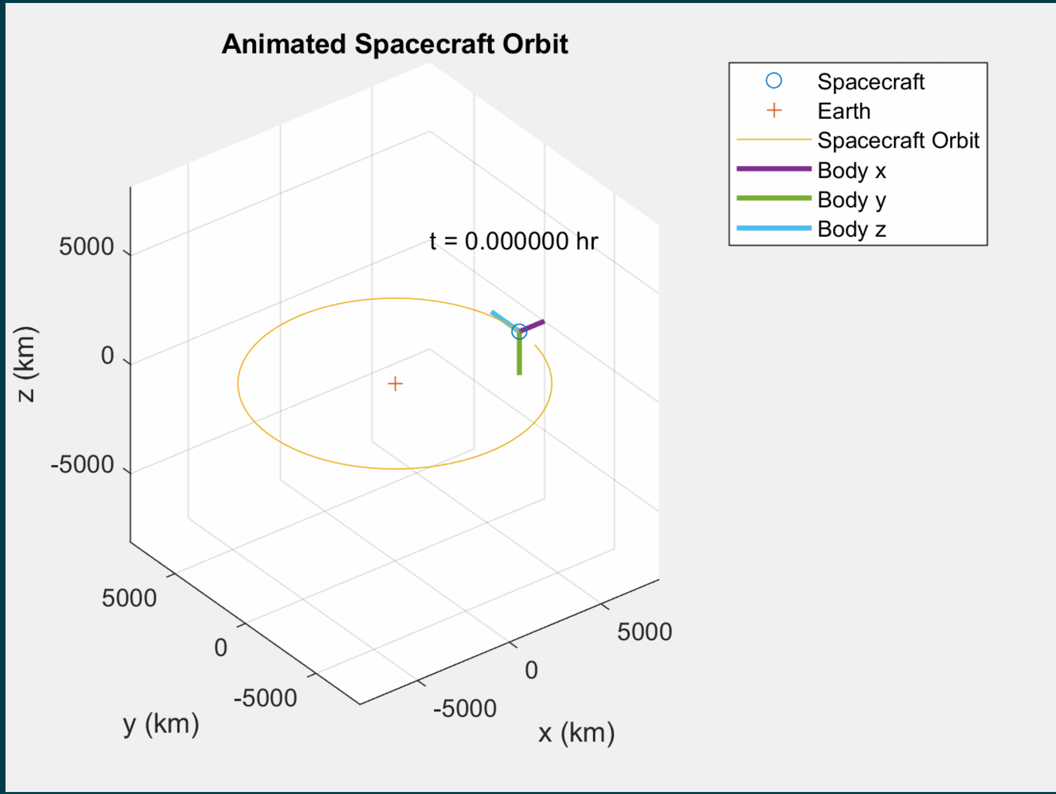
Motivation

- Early design often done in MATLAB
  - STK/MATLAB MEX connection
- For early stages of mission development, high fidelity is not necessary
  - Preliminary spacecraft and orbit design
  - Algorithm testing
- Provides a verified model and prevents repeating unnecessary work

MATLAB Propagator	STK
• Algorithm development • Early mission planning • Quick prototyping and testing	• High-fidelity orbit propagation • Final mission V&V • Power and communications

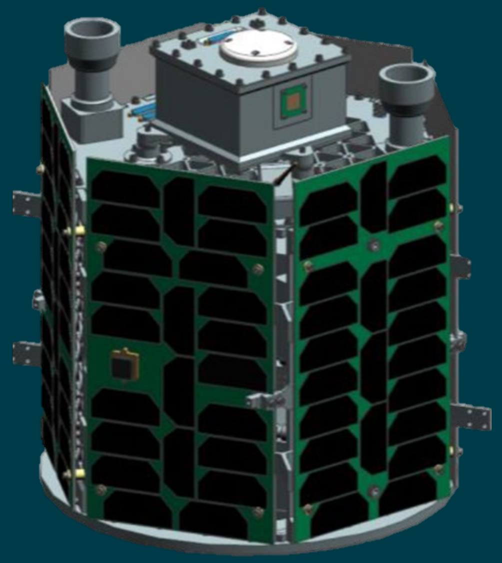
Simulation Framework

- Orbit propagated with drag perturbations using MATLAB *ode113*
  - 1976 Standard Atmosphere table lookup
  - Atmosphere rotates with Earth
  - WGS84 Earth model
- Simple, object-oriented design interface
  - Operates as a script, function, or stand-alone force model
  - Easily configurable
  - Offers a debugging interface



MR & MRS SAT Mission

- Autonomous proximity operations technology demonstration mission
  - MR SAT inspector satellite, ~50 kg
  - MRS SAT noncooperative resident space object, ~5 kg
  - Spacecraft pair separate on-orbit
  - MR SAT performs autonomous circumnavigation about MRS SAT
- Differential drag/collision analysis
- Ballistic coefficient estimation



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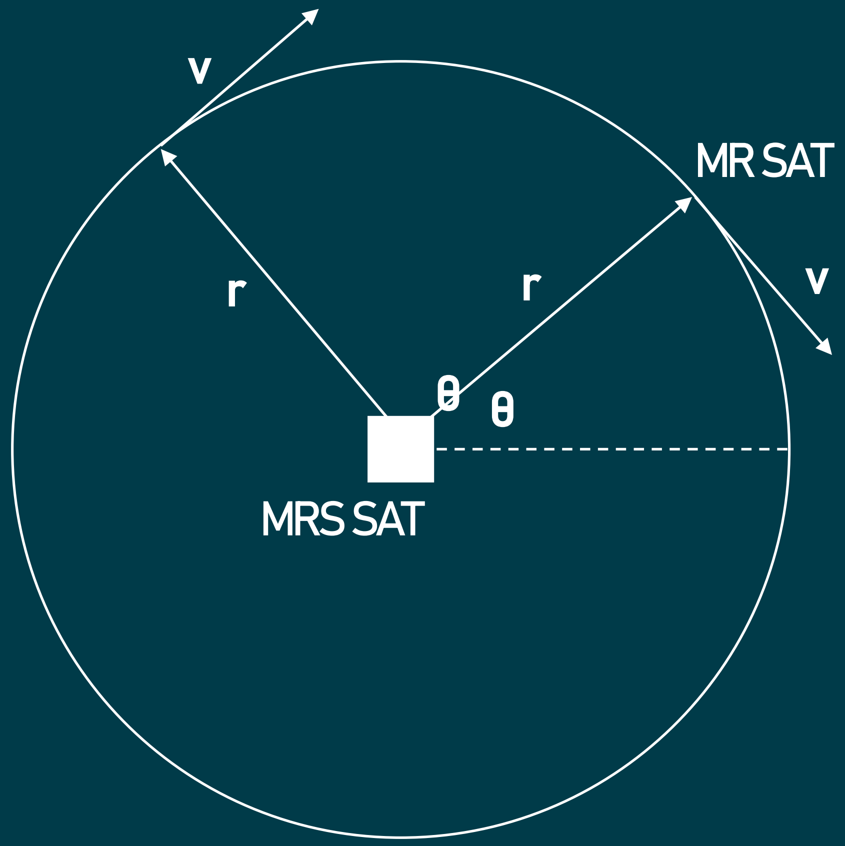
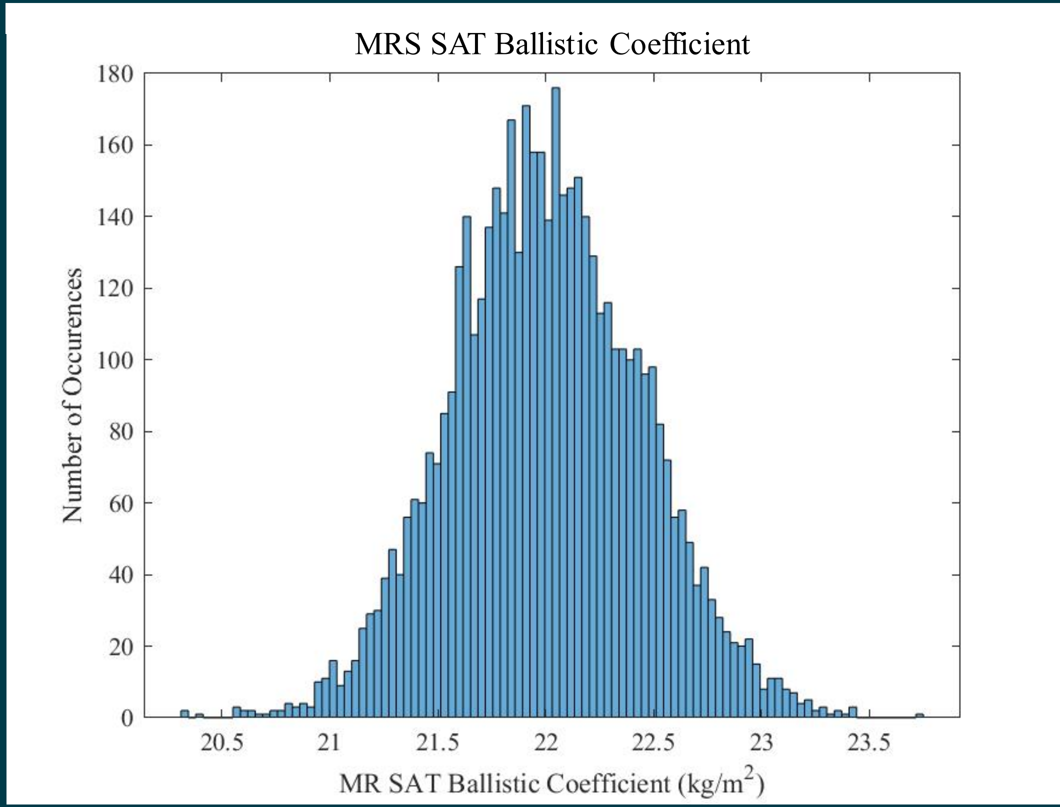
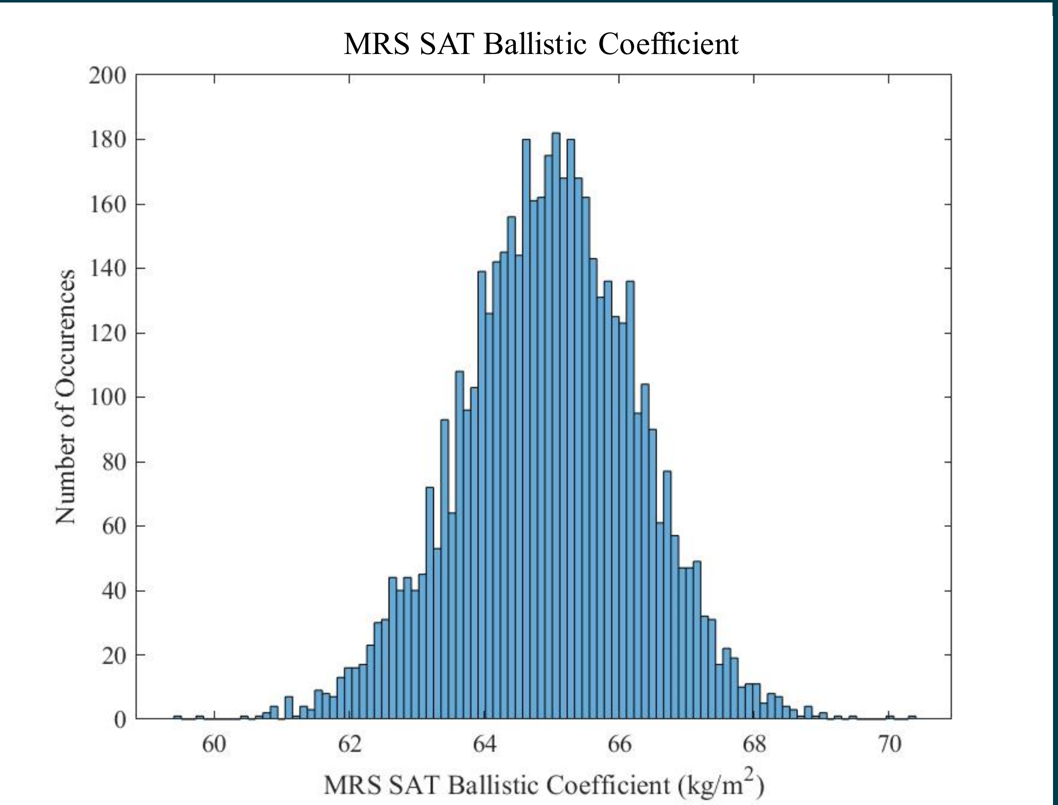
Differential Drag Analysis

- Examined nominal "loss of control" scenario
- Monte Carlo simulation varied initial relative position and ballistic coefficients of the two satellites
  - Inspector relative position and velocity coupled in circumnavigation orbit
- Recorded separation data after 1, 3, and 10 hours
  - Checked for collision between spacecraft



Differential Drag Analysis - Inputs





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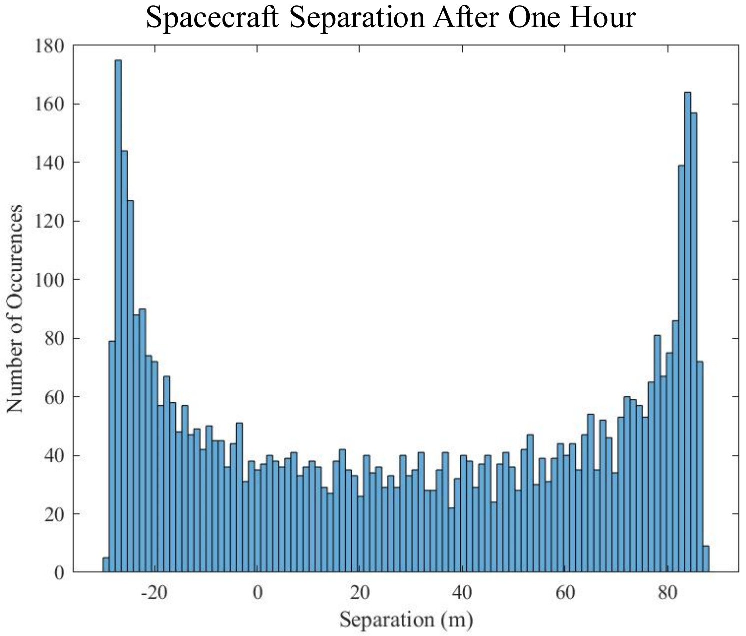
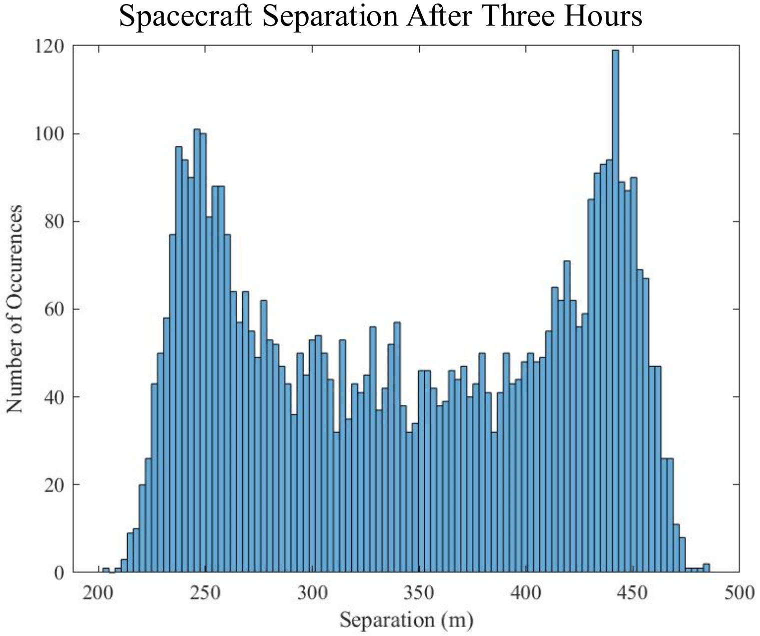
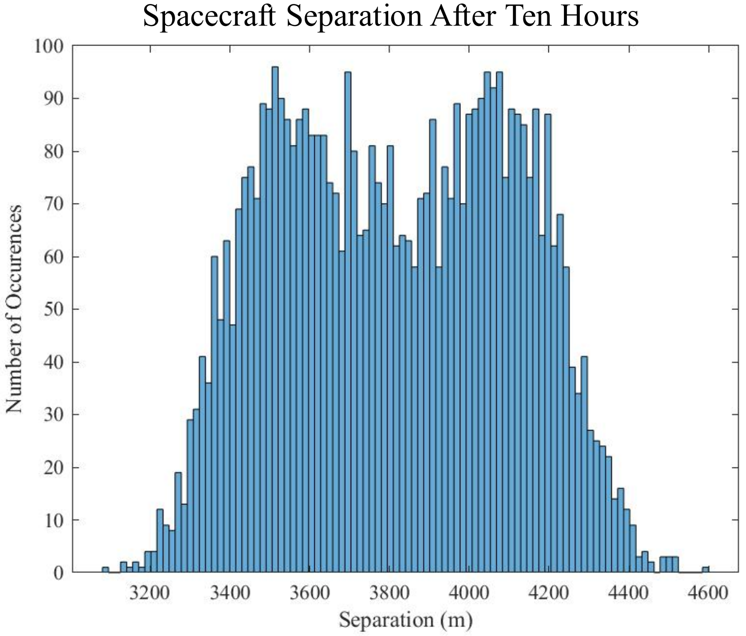
Differential Drag Analysis - Outputs







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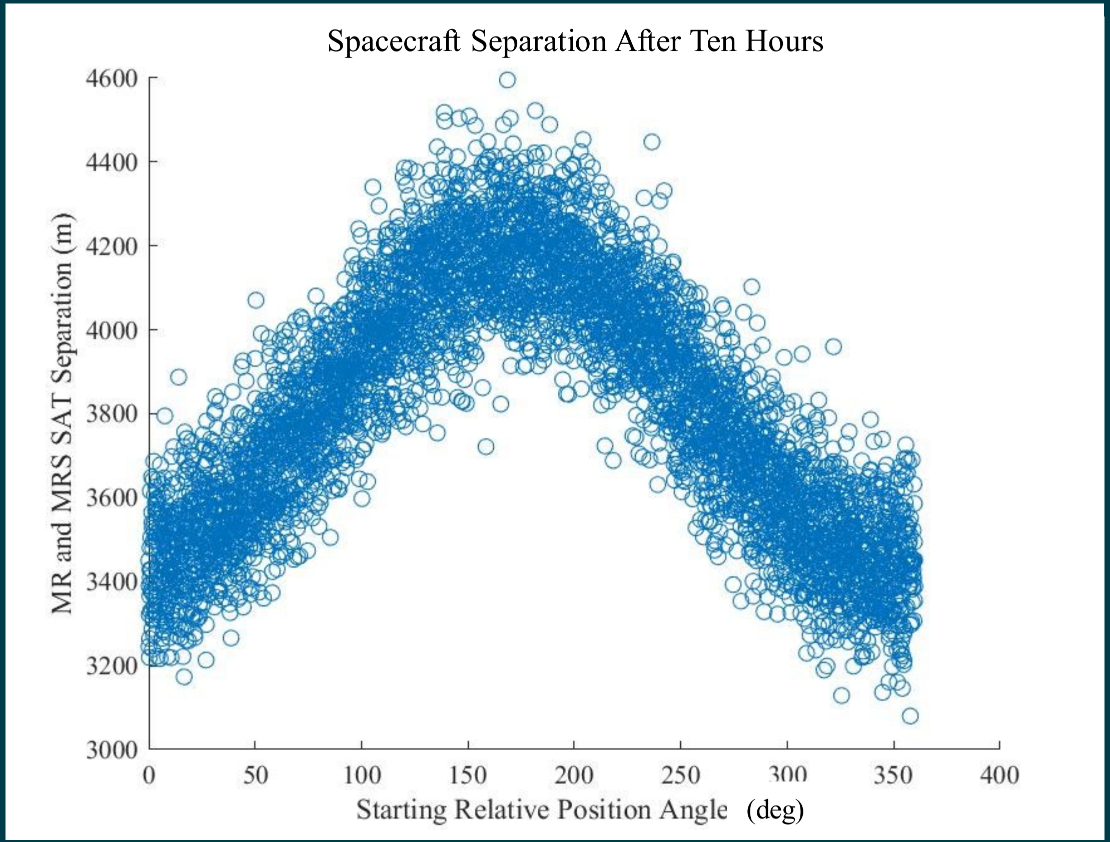
Differential Drag Analysis - Results

- Initial conditions dominate relative spacecraft dynamics
- The dynamics of circumnavigation orbits tend to drive the inspector and target spacecraft apart
  - No collisions in 5,000 runs



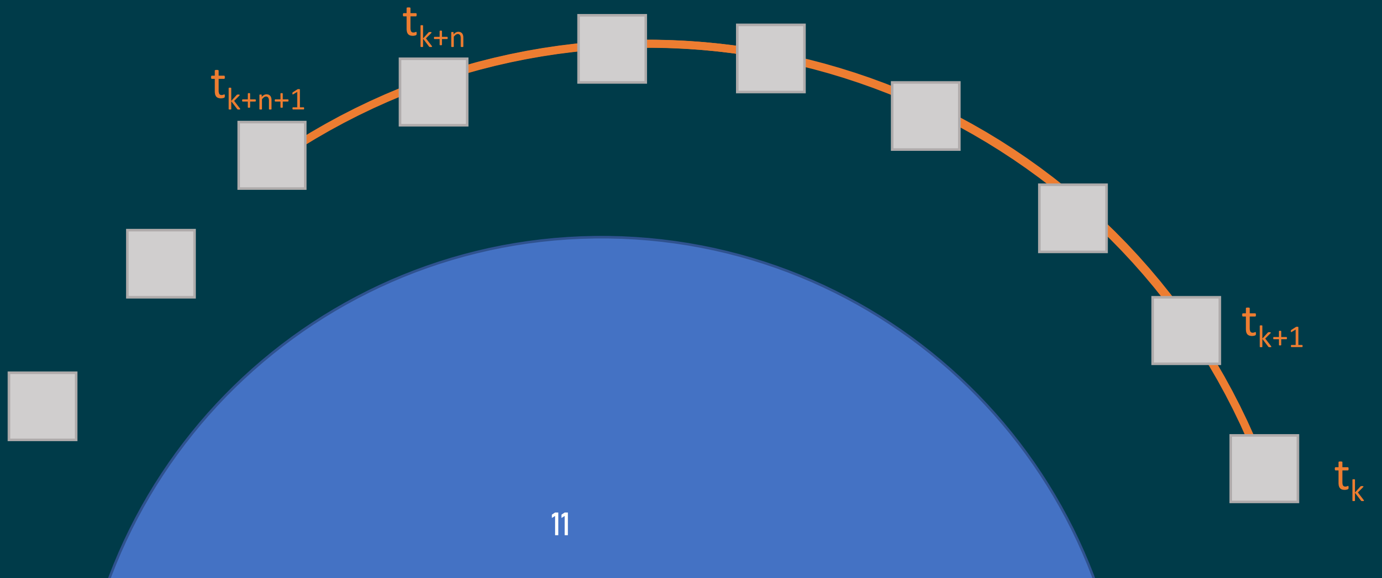
Ballistic Coefficient Estimation

- MR & MRS SAT mission objectives include estimating MRS SAT ballistic coefficient from MR SAT measurements
- MRS SAT relative position data only available for short period (~3 hr)
- Measurements closely spaced (~15 sec apart)

$$\beta = \frac{m}{c_d A}$$

Ballistic Coefficient Estimation

- Method similar to one developed by Saunders et al.
- Calculates change in semimajor axis from measurement data
- Iterates ballistic coefficient and propagates until convergence



Ballistic Coefficient Estimation - Results

Truth (1/β)	Estimated Value (1/β)	Std. Dev. (1/β)	Error (%)
0.0500	0.0510	0.0253	2.00
0.0250	0.0280	0.0275	12.0
0.0167	0.0187	0.0251	11.9

Ongoing/Future Work

- Recent improvements:
  - Simplified user interface and moved to object-oriented design
  - Added J_2 perturbations
  - Improved internal propagation logic for enhanced speed
- Future work:
  - Continue to increase model functionality
  - Refine and further test ballistic coefficient estimation algorithm

Conclusion

- Research tool developed in MATLAB to further enable small satellite mission development
- Differential drag analysis conducted on MR & MRS SAT mission yielded noteworthy results
  - Dynamics of circumnavigation orbit tend to drive inspector and target spacecraft apart, minimizing the risk of collision
  - Initial conditions dominate separation, even after several orbits
- Ballistic coefficient estimation algorithm developed using space-based measurements
  - Early proof-of-concept showed promising results

Acknowledgements

- AFRL University Nanosatellite Program

Questions?