DRAGONFLY

A relocatable lander to explore Titan's prebiotic chemistry and habitability

Assessing Huygens Probe Entry, Descent, and Landing at Titan Simulation using Dragonfly Atmosphere Model

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Overview

Background

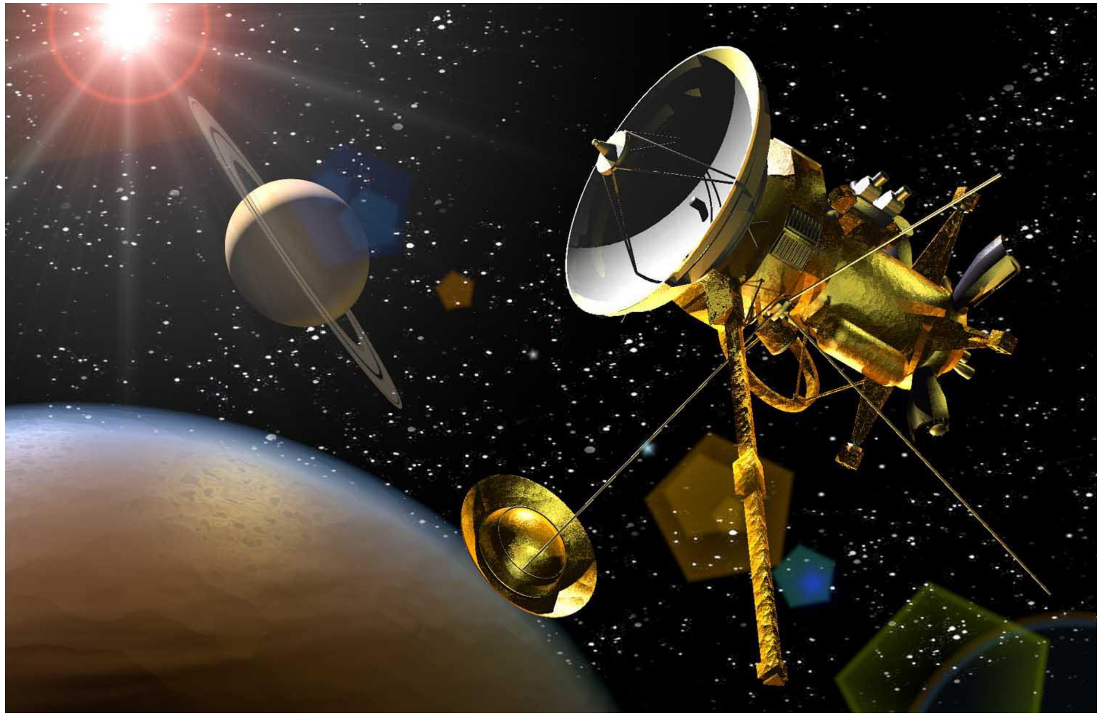
- Dragonfly is a New Frontiers Program mission that will deliver a rotorcraft lander to Saturn’s moon, Titan
  - First landing since Huygens Probe in 2005
- Dragonfly will enter the Titan Atmosphere at a comparable latitude and near-identical season as Huygens
- A new atmosphere model has been developed that builds on the Huygens atmosphere model and has been updated with data collected since Huygens landed

Purpose of this study?

- The purpose of this study was to create a 6 Degree-of-Freedom (6DOF) Entry, Descent, and Landing (EDL) simulation of Huygens probe descent to assess the dynamics using the newer atmosphere model developed for validation

Outline

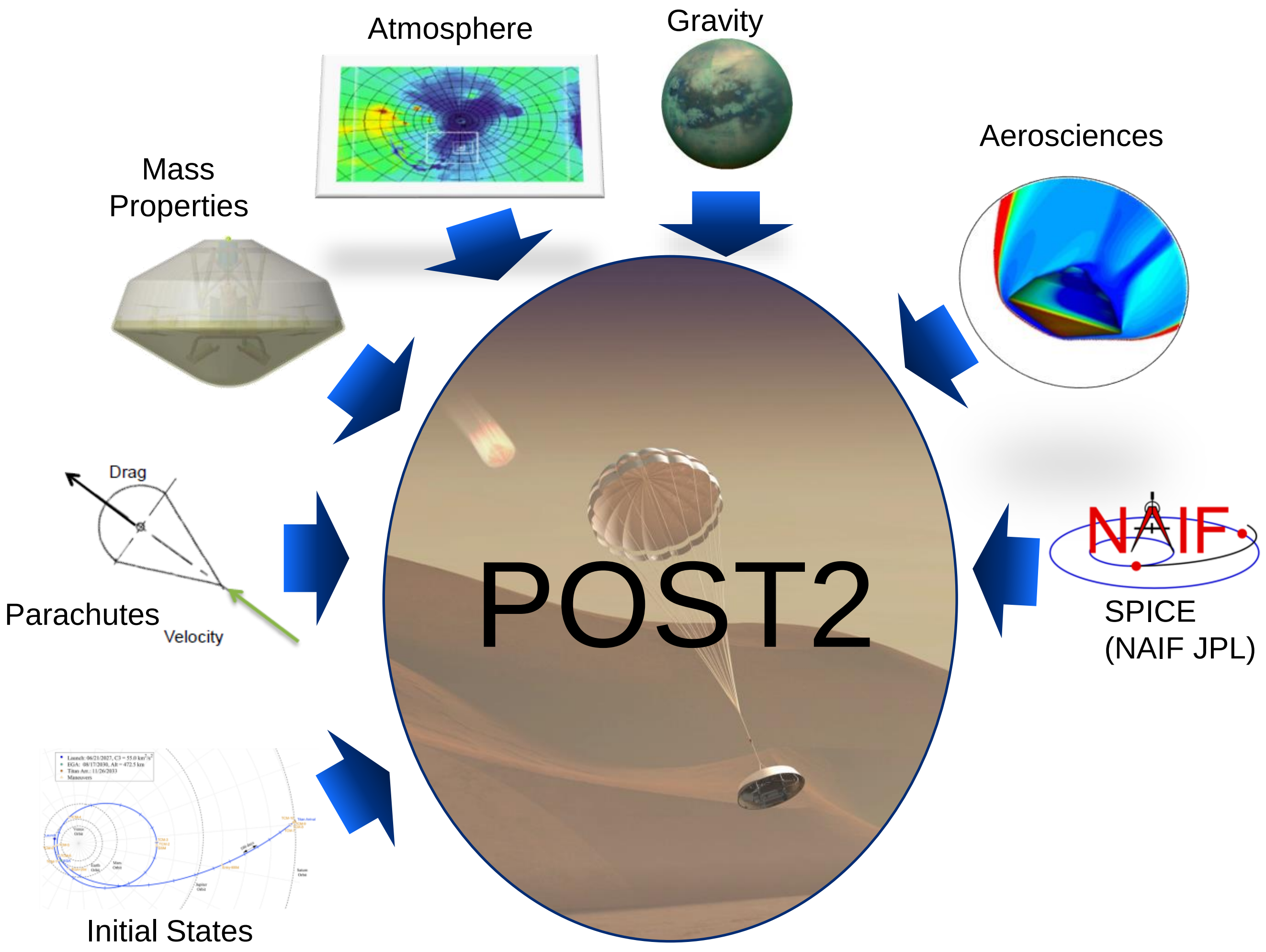
- Developing the simulation
  - Modeling & Simulation Overview
  - Huygens EDL Sequence
  - Atmosphere Models
  - Parachute Model
- Assessing the impact of new atmosphere model
  - Simulation Results Comparison
- Conclusion and Future Work



Artist rendition of Cassini and Huygens
Credit: NASA

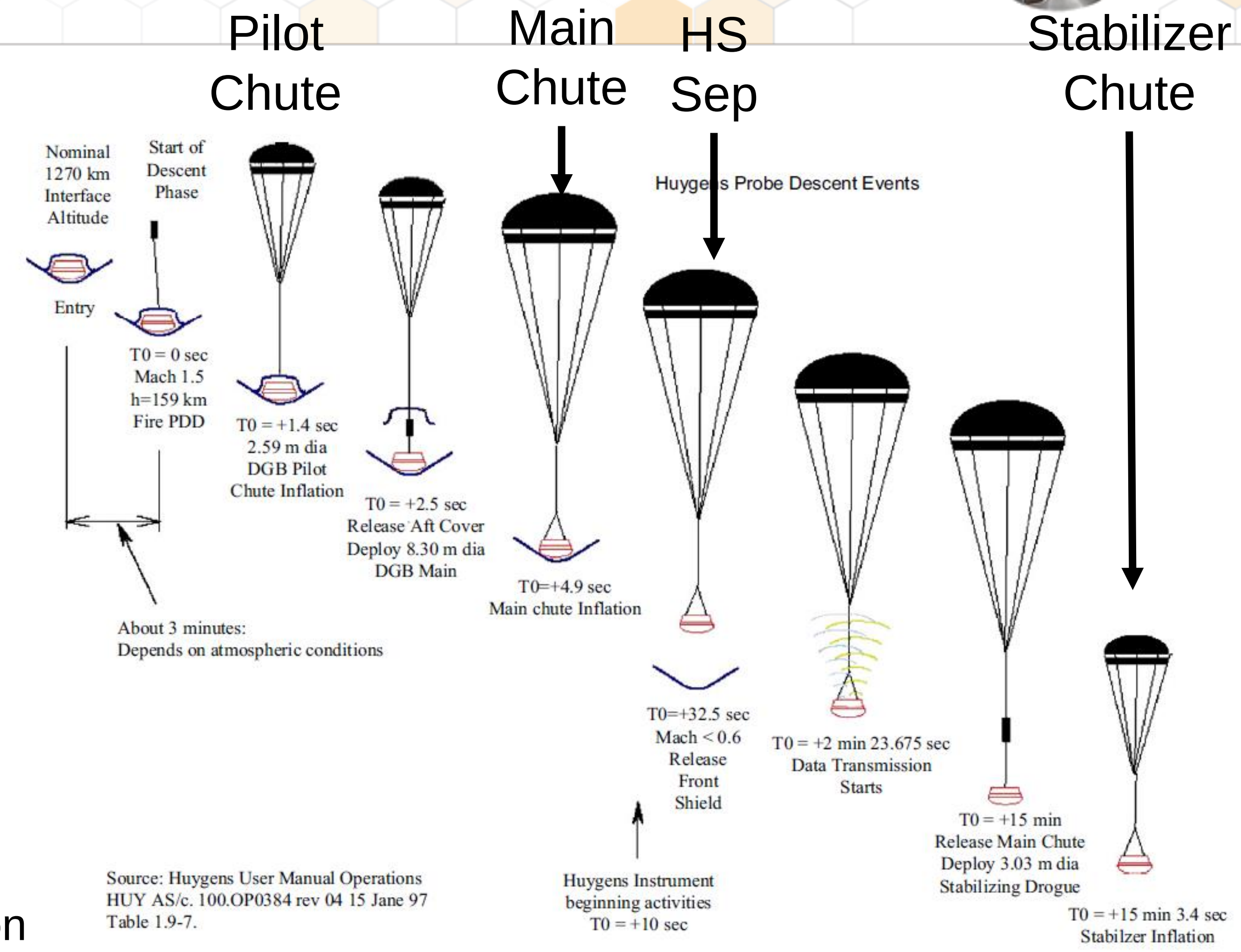
Modeling and Simulation Overview

- The EDL sequence was modeled using Program to Optimize Simulated Trajectories II (POST2)
  - Prime EDL simulation tool for NASA Planetary missions since Pathfinder
- Leveraged the same infrastructure used to model the Dragonfly EDL sequence
- Compiled the subsystem models used in Huygens reconstruction efforts
- The only model that varied was the atmosphere model for the purpose of this study



Huygens EDL Sequence

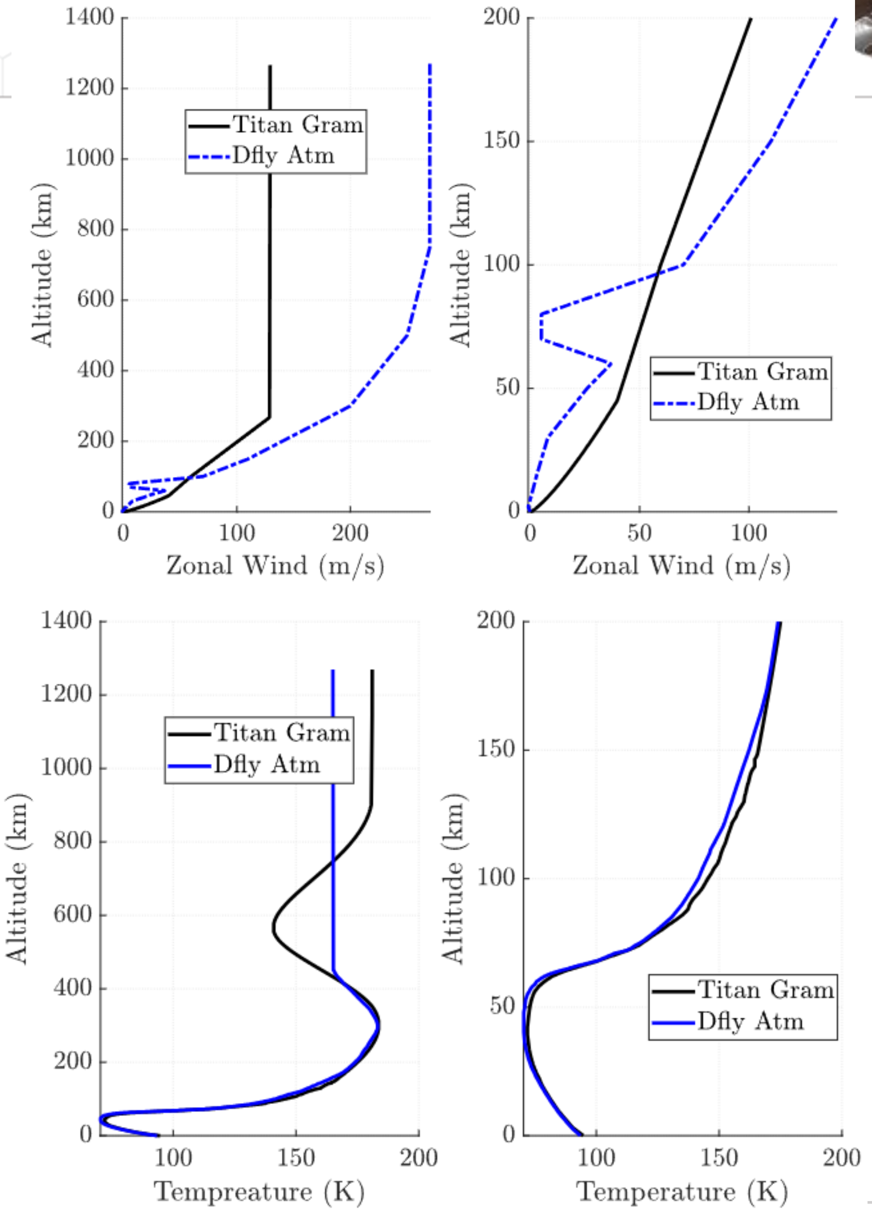
- Same event structure in simulation
  - Instantaneous change in mass properties and parachute inflation
- Event sequence is based off two timers
  - Acceleration trigger timer to determine mortar fire
  - Total descent time on parachute
    - Determines timings of EDL sequence post-pilot deploy
- Descent module
  - 2.75 m diameter heatshield
  - 60 deg sphere-cone design
- Probe
  - Effect of spin vanes modelled post-heatshield jettison



EDL Sequence Stages – Kazeminejad, B., et. al. (2007). Huygens' entry and descent through Titan's atmosphere – methodology and results of the trajectory reconstruction. *Planetary and Space Science, 55*(2007), 1845-1876.

Atmosphere Models

- Impacts several aspects of the descent
  - Peak heating, aerodynamics, parachute release conditions, dynamics of the vehicle, etc.
- Atmosphere Models
  - TitanGRAM 2004 – Huygens Atmosphere Model
    - An update to TitanGRAM to incorporate updates is in work
  - Dragonfly Atmosphere
    - Formulation through 2022 specified in Lorenz et al. Dragonfly: A rotorcraft lander concept for scientific exploration at Titan
    - More details will be published by R. Lorenz
- Overview of Differences
  - Large changes to zonal winds updated through Doppler observation
  - Temperature at high altitudes (deviations from a constant value measured have been classified as local and transient)
  - Density profile adjusted based on reconstruction
  - Large change in how wind dispersions are handled between models (particularly the meridional winds)



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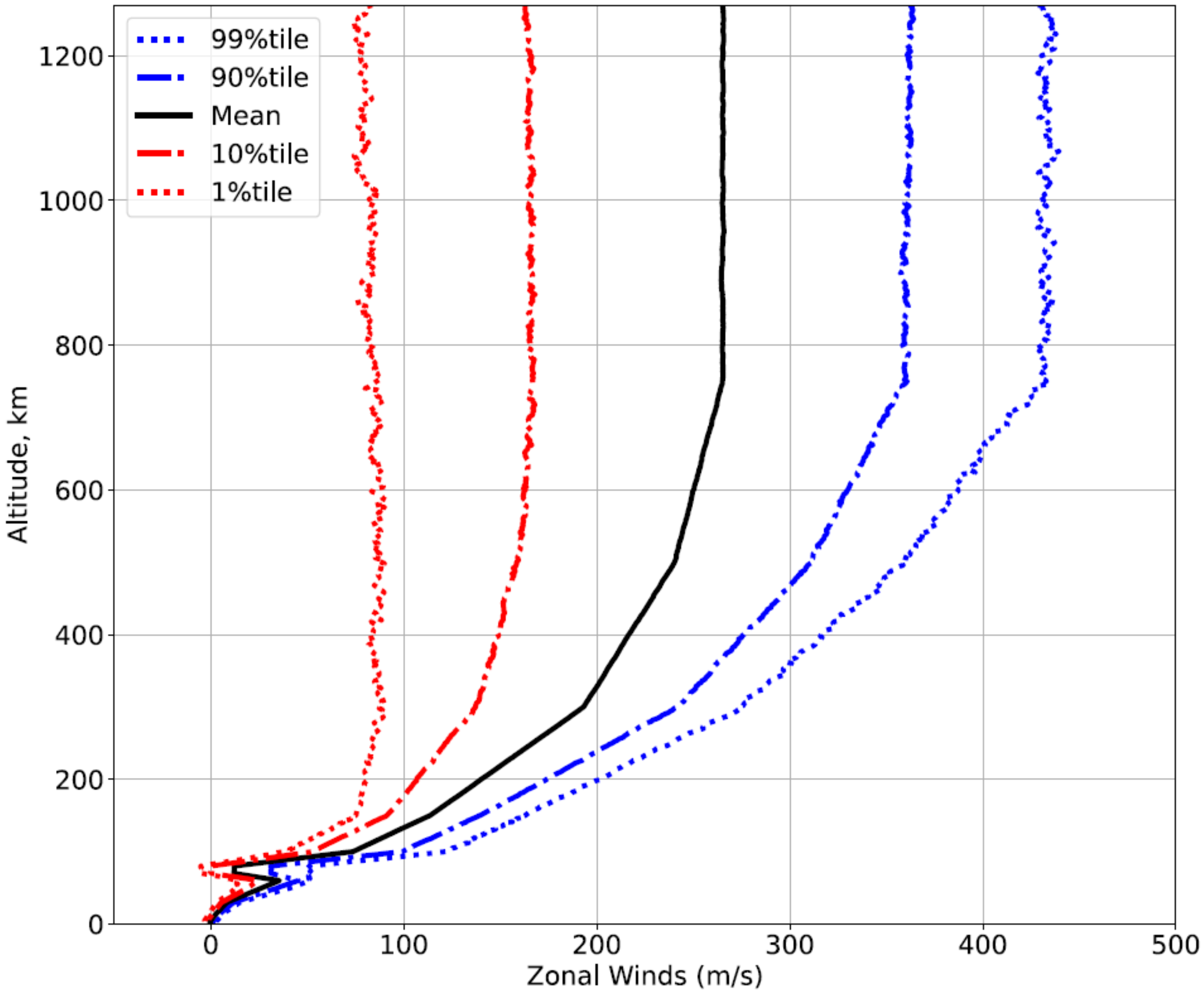
Dragonfly Atmosphere Model

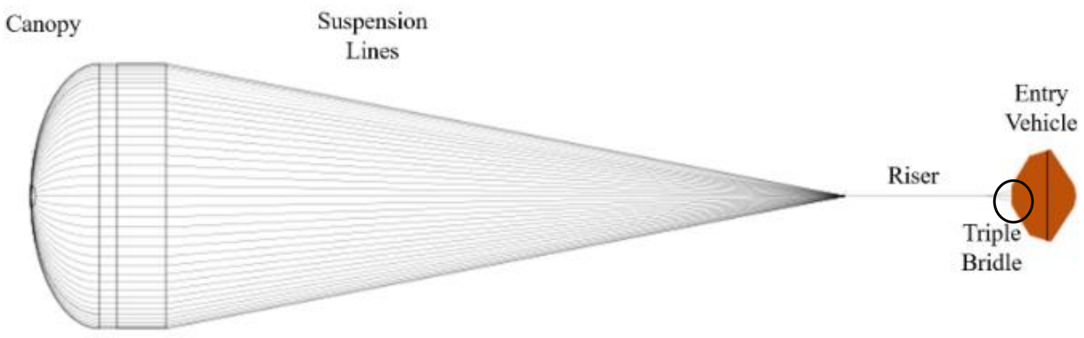
- A significant effort has been made to reevaluate the atmospheric dispersions for the simulation using data collected since Huygens
  - Atacama Large Millimeter Array (ALMA)
  - Re-evaluating Cassini radio occultation
  - Reconstruction efforts evaluated from Huygens

- The dispersion profiles leverage the spatial and temporal similarities to Huygens rather than global atmosphere reference



Parachute Model

- Modelled as a drag force applied at confluence point of bridle
- Huygens used 3x Disk-Gap-Bands (DGB) parachutes to ensure vehicle stability, descent rates, and minimize recontact risk

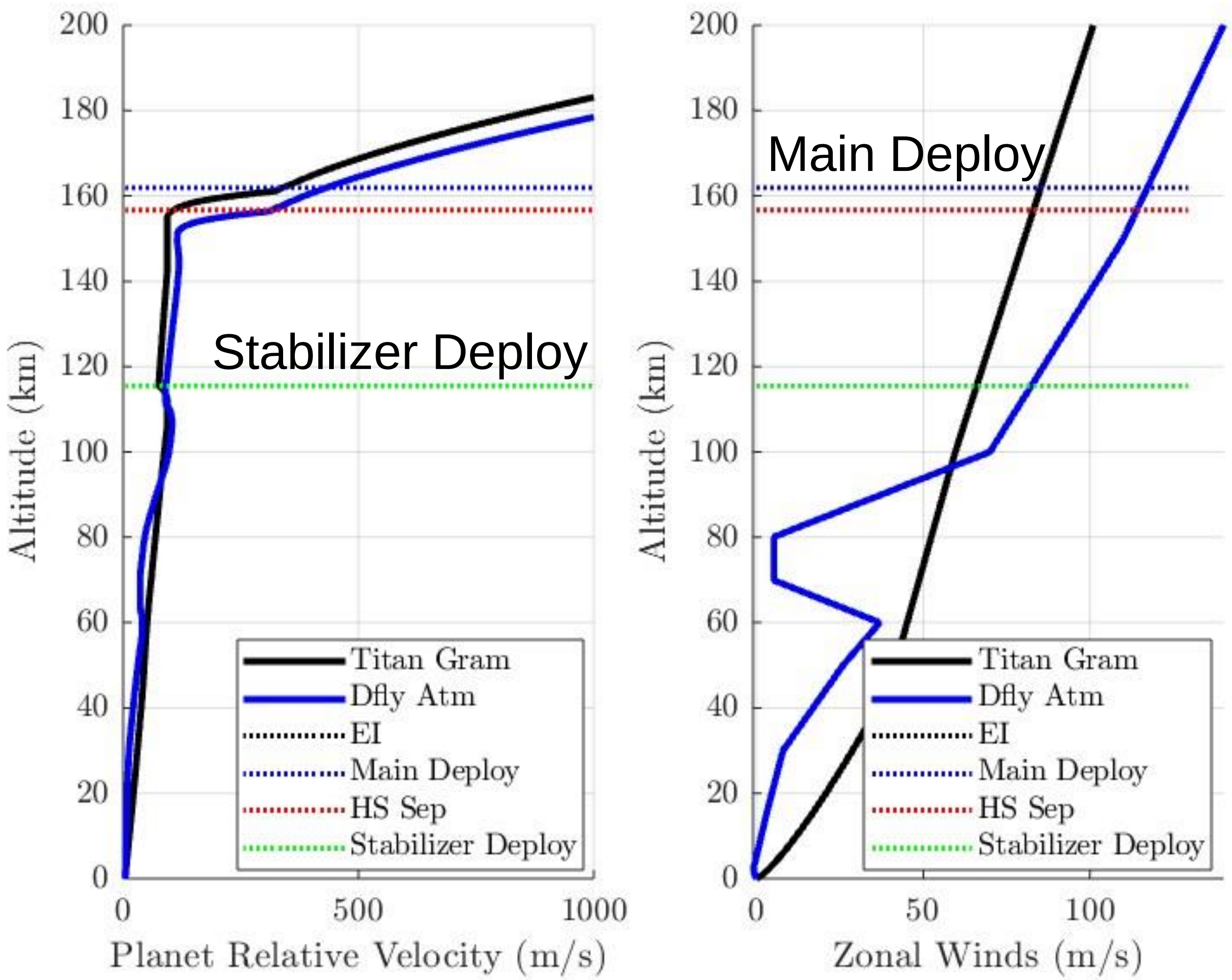


Parachute	Type	Diameter (m)	Geometry Porosity (%)
Pilot	Disk-Gap-Band	2.59	13.1
Main	Disk-Gap-Band	8.30	22.4
Stabilizer	Disk-Gap-Band	3.03	22.4

Parachute	Bridle Attachment (m)	Bridle Height (m)	Bridle Confluence Point in Huygens Frame (m)
Pilot	0.5572	0.53	1.09
Main	0.4468	3.88	4.33
Stabilizer	0.3755	3.88	4.26

Results – EDL Overview

- Nominal profiles using both atmospheres are comparable
- Differences in the density profiles impact the initial pilot chute deployment and the descent rate
- The larger zonal winds in the Dragonfly atmosphere model inject more dynamics



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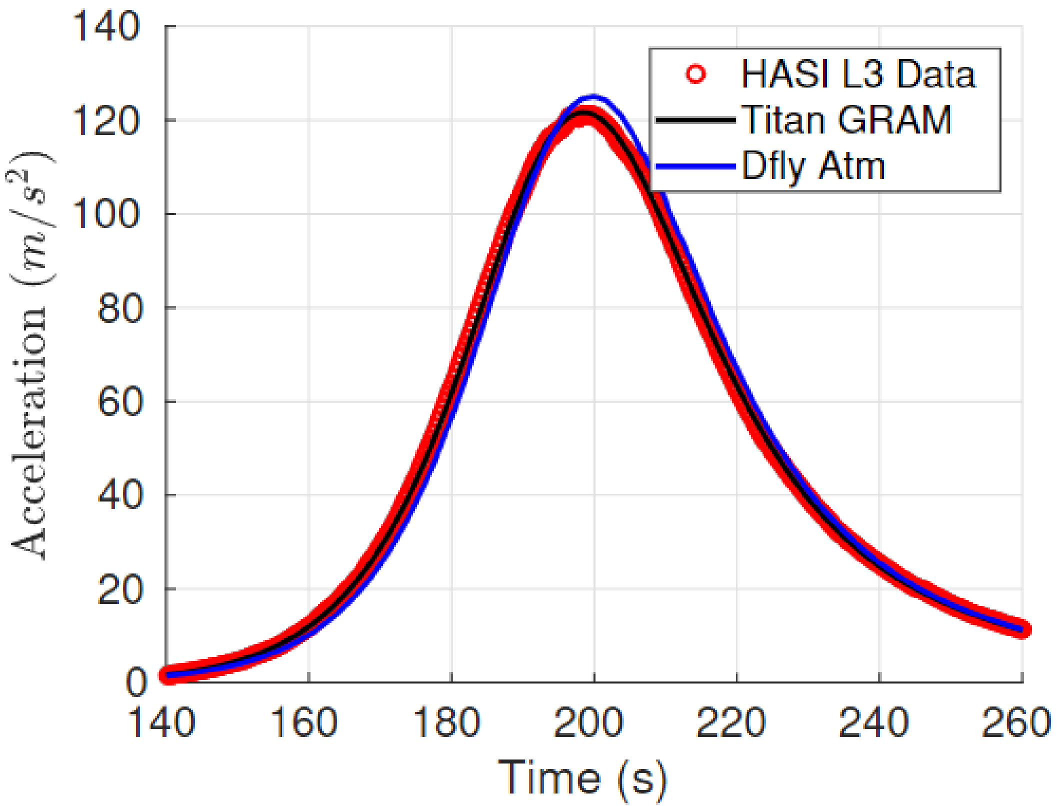
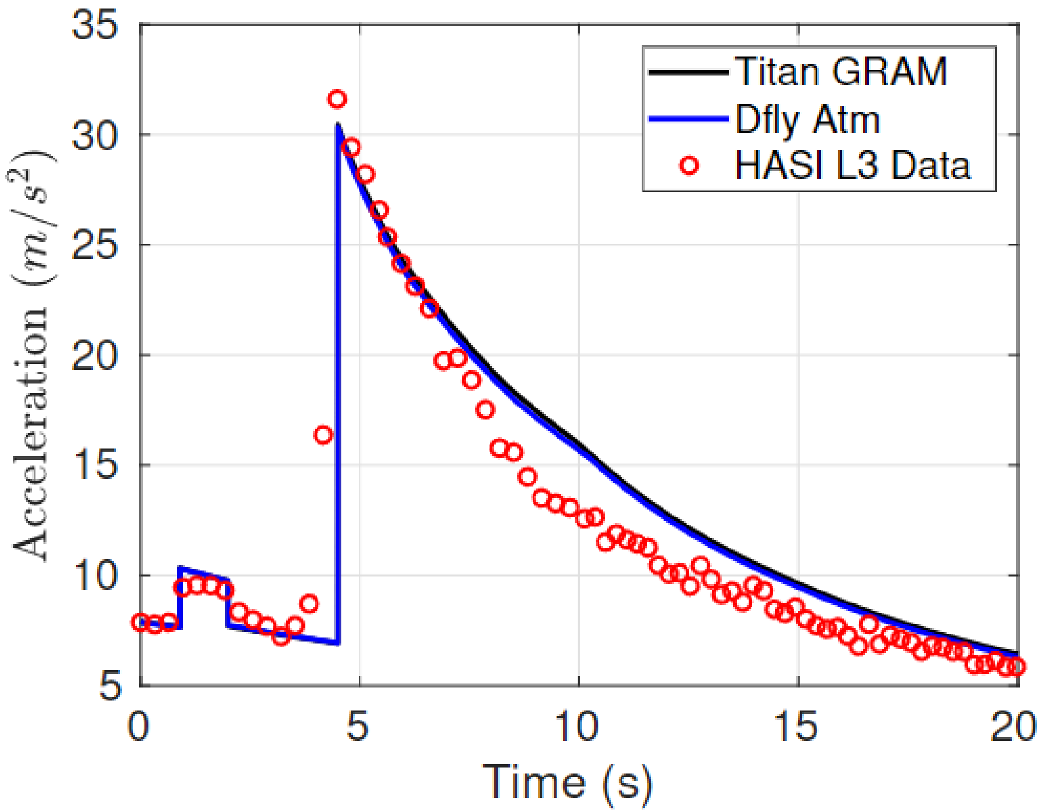
Results – Acceleration Time Histories

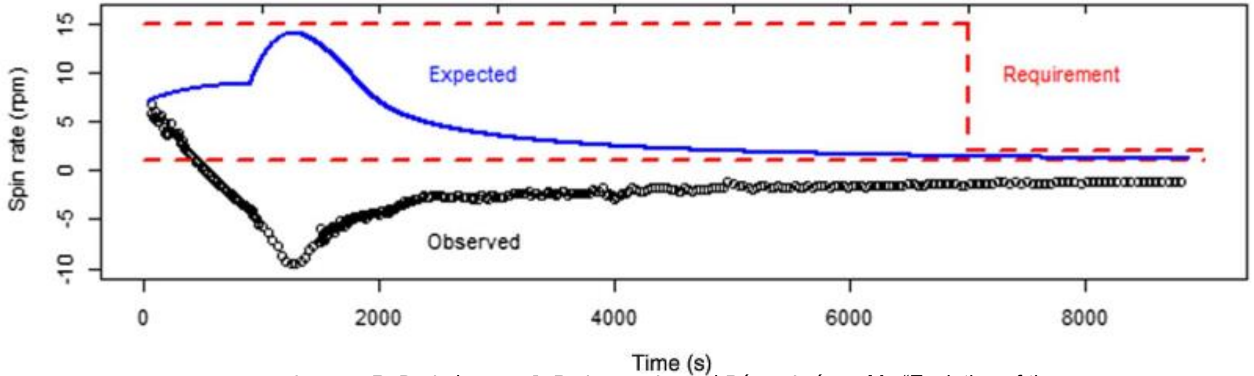
- Flight data (HASI L3) compared to both simulations
- Simulation shows good agreement with flight data
  - Acceleration at entry and from mortar fire through main parachute deploy



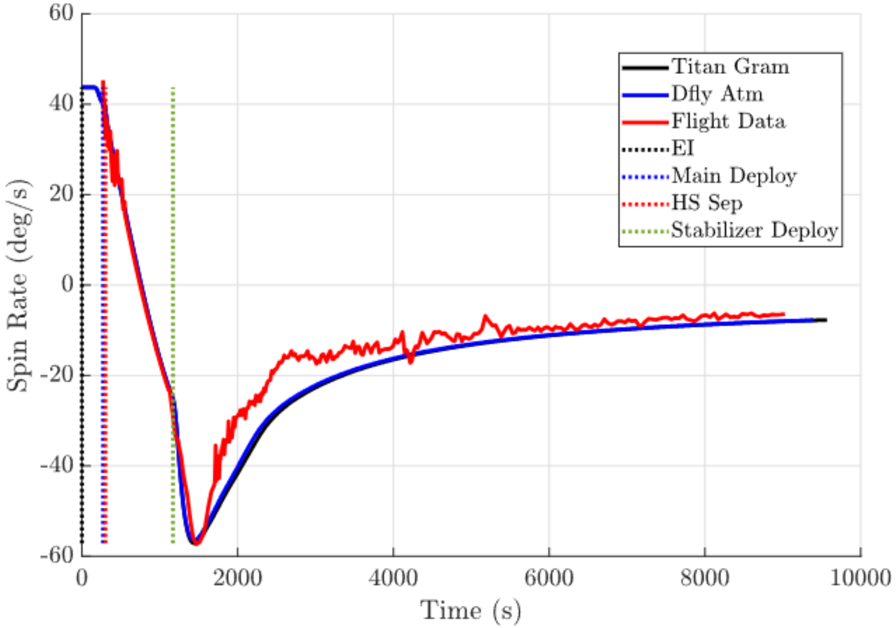


Results – Spin Rate

- Huygens Probe spun in the wrong direction
  - Interaction between booms and instruments with the spin vanes led to delta in behavior
  - Original testing was with a "clean" configuration of the probe
  - New aero-database was tuned to match the as-flown spin direction
    - Lebreton et al. wind tunnel testing with instrumentation and booms added
    - Test results for roll moment coefficients were tuned and a roll damping model was added
- Results are comparable using both atmosphere models and match flight data
  - Both simulations use the new additions to the aero model
- Future work is needed to characterize the differences in the spin rate after the peak

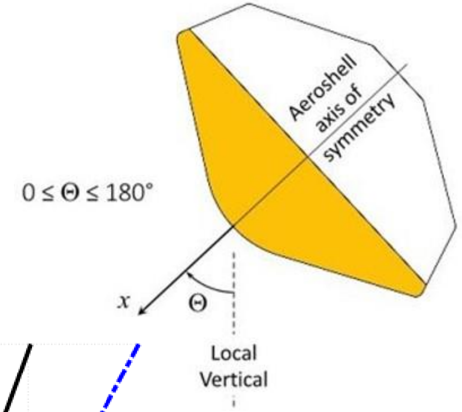


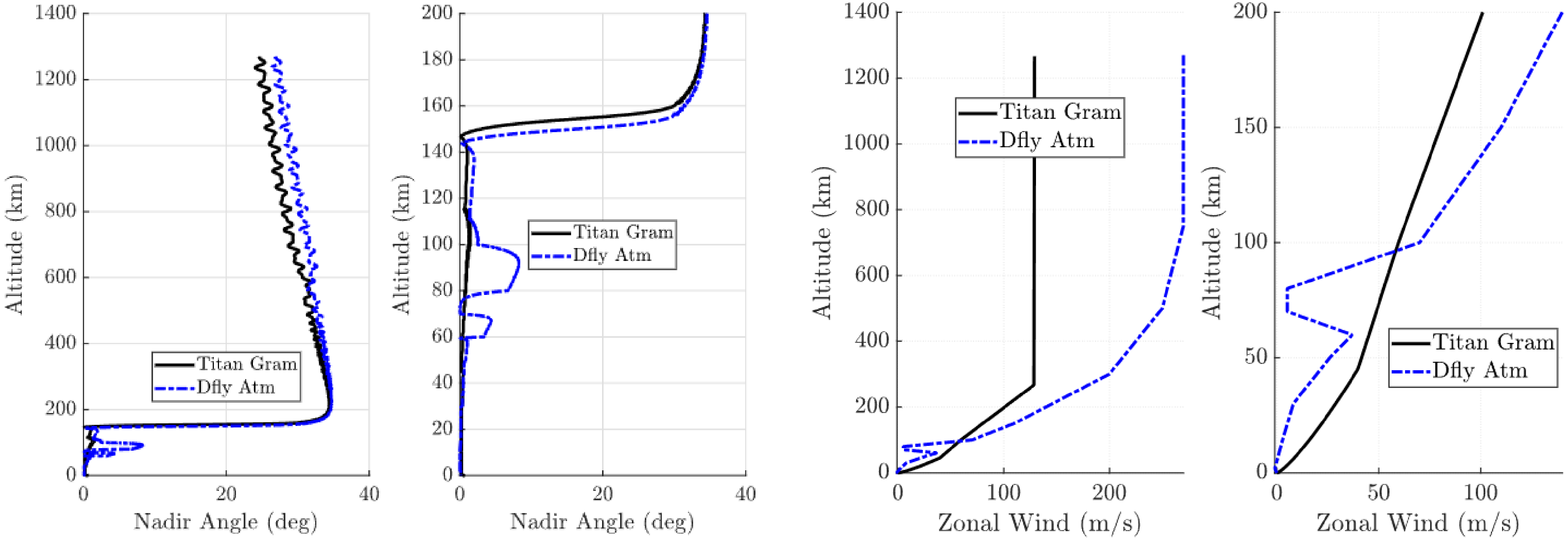
Lorenz, R. D., Lebreton, J.-P., Leroy, A., and Pérez-Ayúcar, M., "Evolution of the Huygens Probe Spin During Parachute Descent," Journal of Spacecraft and Rockets, Vol. 58, No. 3, 2021, pp. 609–618.



Results – Nadir Angle

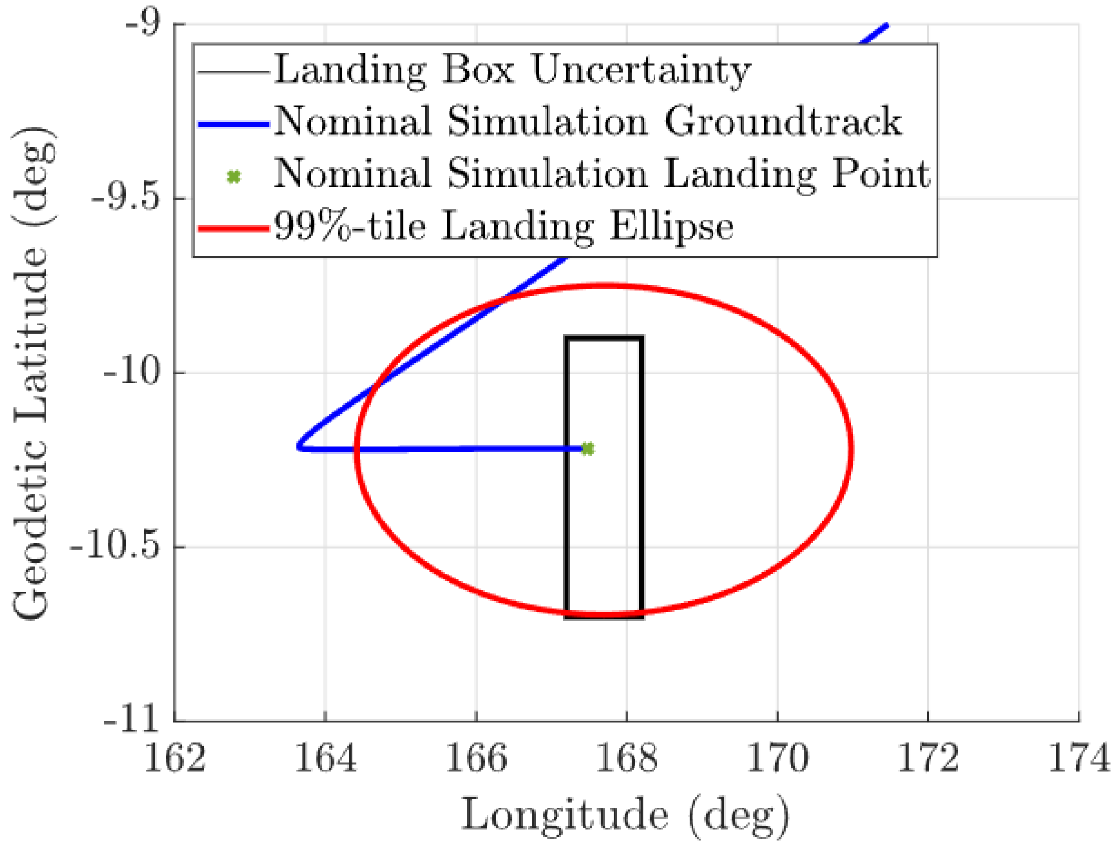
- The angle between the entry vehicle’s body axis and the local vertical is denoted as the nadir angle
- In tandem with the winds, can describe the effect of the atmosphere on the vehicle during the slow descent phase





Results – Landing Impact

- Dispersions applied to Dragonfly sim to compare landing ellipse to touchdown uncertainties
  - Uncertainties based off Lebreton et al. reconstruction efforts
- Ground-track, landing spot, and landing ellipse for the Dragonfly-model based sim
  - Nominal results fall in uncertainty box
  - Landing ellipse encompasses uncertainty bounds
- Current results indicate that the atmosphere model created for Dragonfly can predict the overall trajectory of the Huygens mission



Conclusions and Future Work

- Agreement was shown between the 6DOF simulations that were created and Huygens flight data using the same model inputs that were available for reconstruction efforts
- Atmosphere model created for the Dragonfly mission can be validated using flight data from Huygens
  - Overall trajectory is shown to be a good estimation of the Huygens mission
  - Monte Carlo analysis conducted to conservatively cover off-nominal atmospheric conditions encloses landing box uncertainty
- Future work
  - Limitation identified in attitude analysis due to simple parachute model that is currently implemented
    - Dynamics described by nadir angle can be tracked to wind shifts in magnitude and direction
    - Not seen in the Dragonfly simulation that utilizes a more sophisticated multi-body parachute model
  - Assess the dynamics using a multi-body parachute model
  - Investigate the same areas of concern in the Dragonfly simulation to ensure artificial dynamics are not being introduced