

Investigation of the Dragonfly Lander, Backshell, Parachute Dynamics through Subscale Drop Tests

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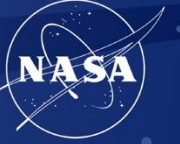
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The Dragonfly Mission

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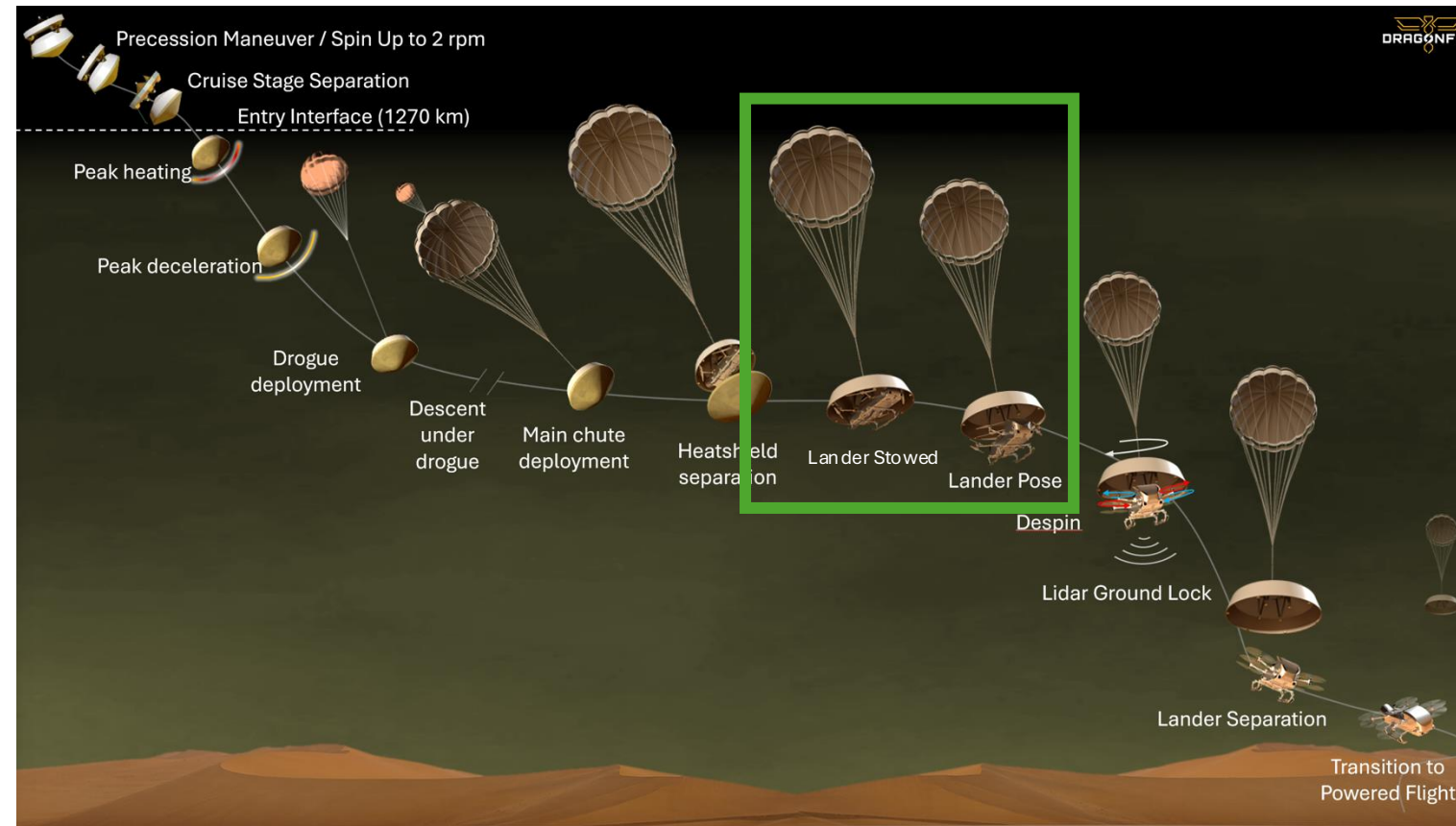
- Dragonfly is a New Frontiers Program mission that will deliver a rotorcraft lander to Saturn's moon, Titan for the first time since Huygens Probe landed in 2005
- Currently set to launch in 2028 and arrive in Dec. 2034
- The entry, descent, and landing (EDL) sequence is approximately 2 hours, with most of it spent under a two-parachute system (drogue and then main)
- This mission is led by The Johns Hopkins University Applied Physics Laboratory (APL) and the EDL Phase is led by NASA Ames and Langley Research Center
- <https://dragonfly.jhuapl.edu>



Credit: APL

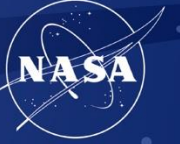
Motivation: Dragonfly Conops

- After descending on the drogue parachute for over 90 minutes, the main parachute is deployed
- The heatshield separates, exposing the lander in the **stowed configuration**
- The lander is lowered to ensure rotors clear the backshell into the **posed configuration**
- Predicting the dynamics of the system without a heatshield remains a critical task to ensure mission success and requires testing for verification



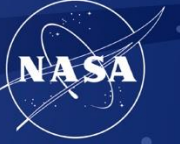
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Test Objectives



- Quantify the dynamics of the backshell, lander, parachute system at 0.8 km Titan altitude in both the stowed and posed configurations
 - Quasi-steady state Euler angles (roll (ϕ), pitch (θ), and nadir (Θ) angles) of the system
 - Quasi-steady state rotation rates (roll (p), pitch (q), and RMS (Ω) rates) of the system

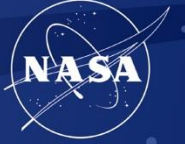
- Build upon previous subscale drop test campaigns to assess the extent to which the dynamics of the system change due to the removal of the heatshield
 - Phase I (Winter 2022): drogue parachute + aeroshell [Cruz et al. AIAA 2024-4329]
 - Phase II (Fall 2023): main parachute + aeroshell [Cruz et al. AIAA 2024-4329]
 - **Phase III (Winter 2025): main parachute + backshell + lander**

Dynamically-Scaled Drop Test



- Dynamic-scaling preserves the ratio of aerodynamic to gravitational forces between the model (M) @ Earth sea-level and full-scale (F) @ Titan 0.8 km
- Given the **environmental** scale factors
 - Density factor, $N_\rho = \frac{\rho_M}{\rho_F}$,
 - Gravitational factor, $N_g = \frac{g_M}{g_F}$
- Choose the **geometric** scale factor $N_L = \frac{L_M}{L_F} = 0.1667$ for this test
- Build to the required **mass** scale factors
 - Mass factor, $N_m = \frac{m_M}{m_F} = N_\rho N_L^3$
 - Inertia factor, $N_I = \frac{I_M}{I_F} = N_\rho N_L^5$

Effects of Dynamic Scaling

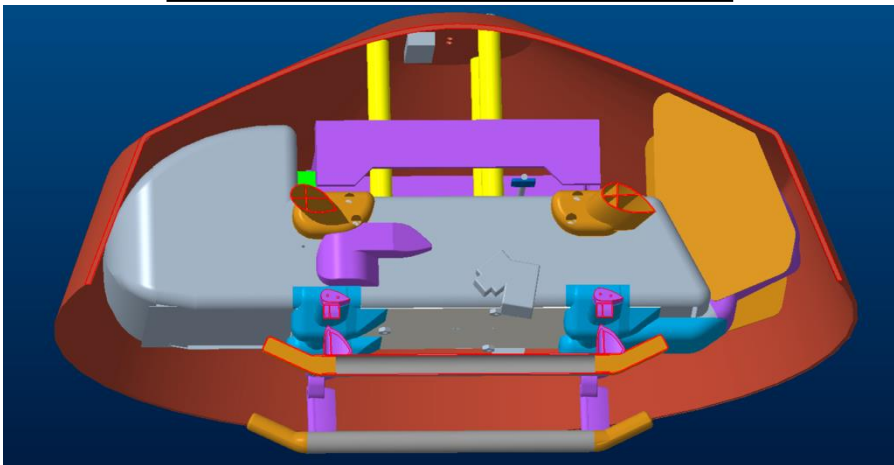


Parameter Type	Scale Factor	Equation	Value	Comment
Geometric	Linear Dimension	$N_L = \frac{L_M}{L_F}$	0.1667	16.67 percent scale model
Environment	Atmospheric Density	$N_\rho = \frac{\rho_M}{\rho_F}$	0.234	$\rho_M = 1.225 \text{ kg/m}^3$ (Earth sea-level) $\rho_F = 5.235 \text{ kg/m}^3$ (Titan at 0.8 km AGL)
Environment	Acceleration of Gravity	$N_g = \frac{g_M}{g_F}$	7.27	$g_M = 9.807 \text{ m/s}^2$ (Earth) $g_F = 1.349 \text{ m/s}^2$ (Titan)
Mass	Mass	$N_m = \frac{m_M}{m_F} = N_\rho N_L^3$	$1.08 \cdot 10^{-3}$	Result from Geometric and Environment
Mass	Mass Moment of Inertia	$N_I = \frac{I_M}{I_F} = N_\rho N_L^5$	$3.01 \cdot 10^{-5}$	Result from Geometric and Environment
Time	Time	$N_t = \frac{t_M}{t_F} = \sqrt{\frac{N_L}{N_g}}$	0.1514	Time is compressed in model scale ($N_t < 1$).
Time	Rotation Rate	$N_\omega = \frac{\omega_M}{\omega_F} = \sqrt{\frac{N_g}{N_L}}$	6.604	Rotation rates of model are larger than full-scale.

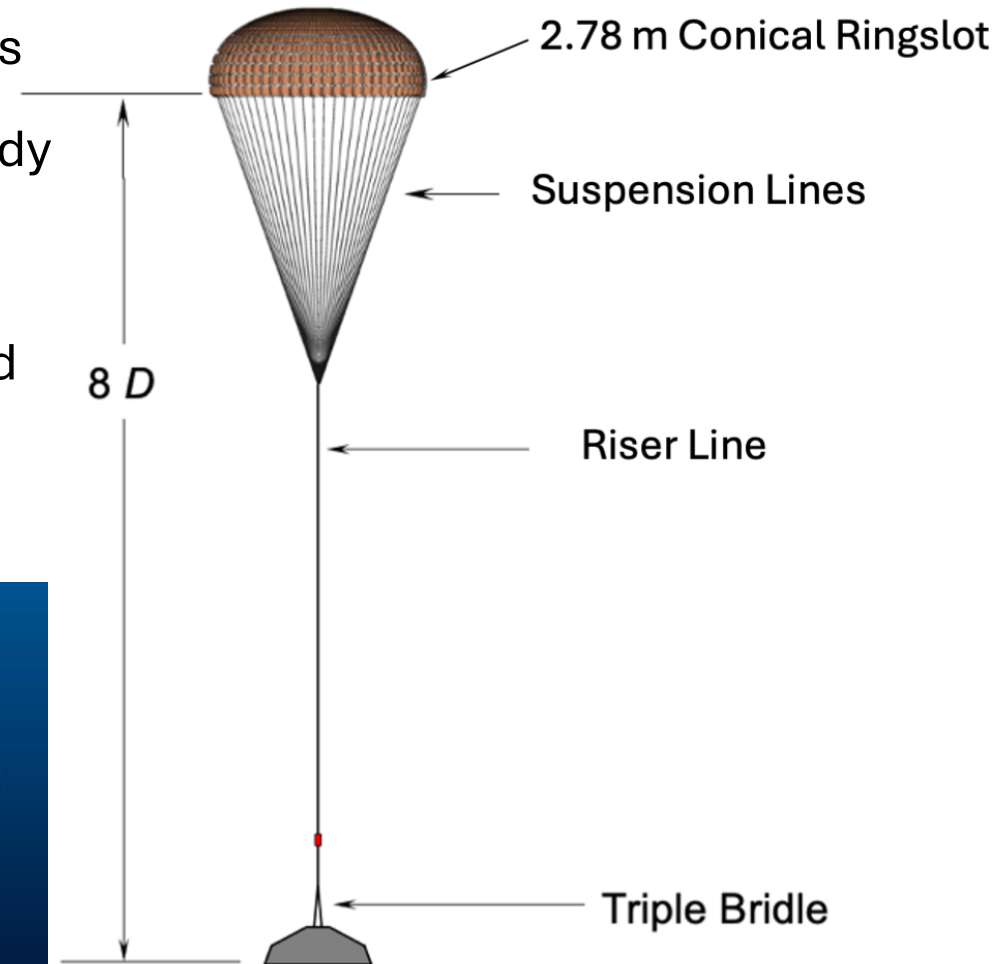
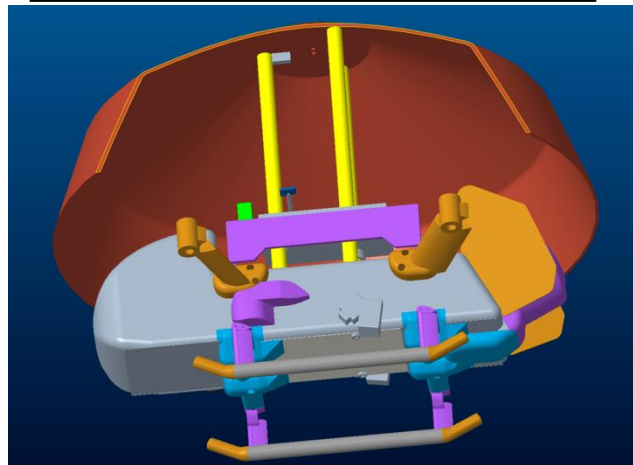
Drops Test Configurations

- 2.78 m Conical Ringslot canopy
 - Geometrically scaled triple bridle, riser, and suspension lines
- 0.75 m diameter, Genesis-derived Kevlar aeroshell with forebody removed
- 3D-printed stowed and posed lander bodies
 - Contain sufficient details to capture geometrically induced aerodynamics

Stowed Configuration

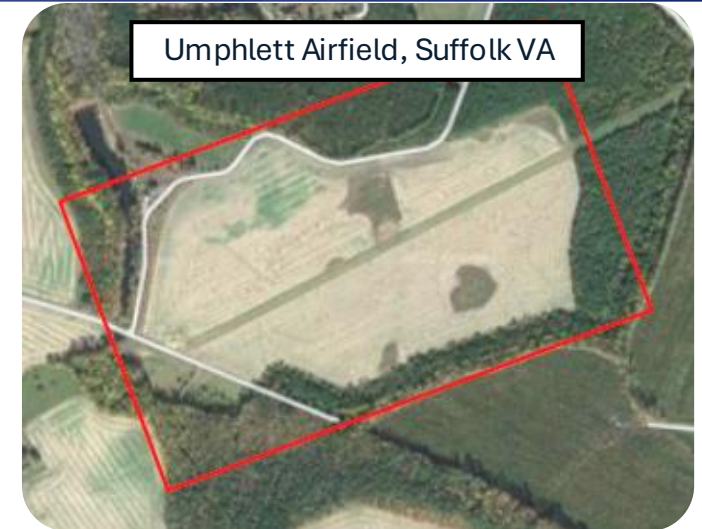


Posed Configuration



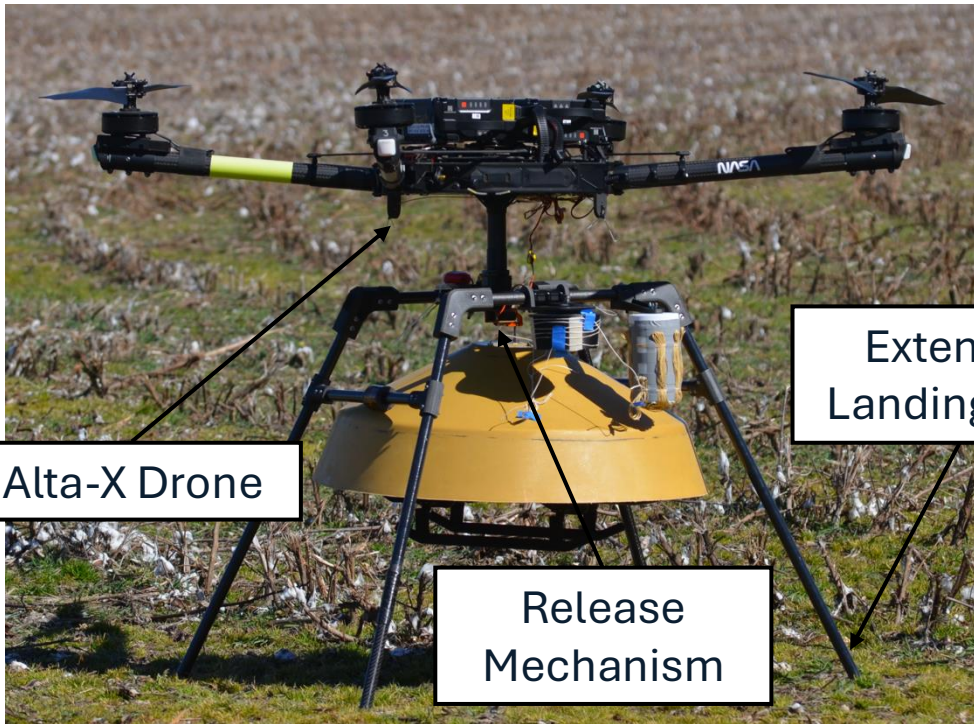
Test Plan

- Dynamically scaled drone drop test of the system at a 200-acre field near NASA Langley Research Center
- Alternate between the stowed and posed configurations
- Mount the system onto an Alta-X drone with a purpose-built container that stages the parachute as the aeroshell drops
- Release the aeroshell at an altitude of 150 m
- Backshell w/ lander descends
- ~ 80 s of quasi-steady flight per drop
- Onboard IMUs and GPS record quantities of interest to capture dynamics
- 12 drops in the stowed, 12 drops in the posed configurations

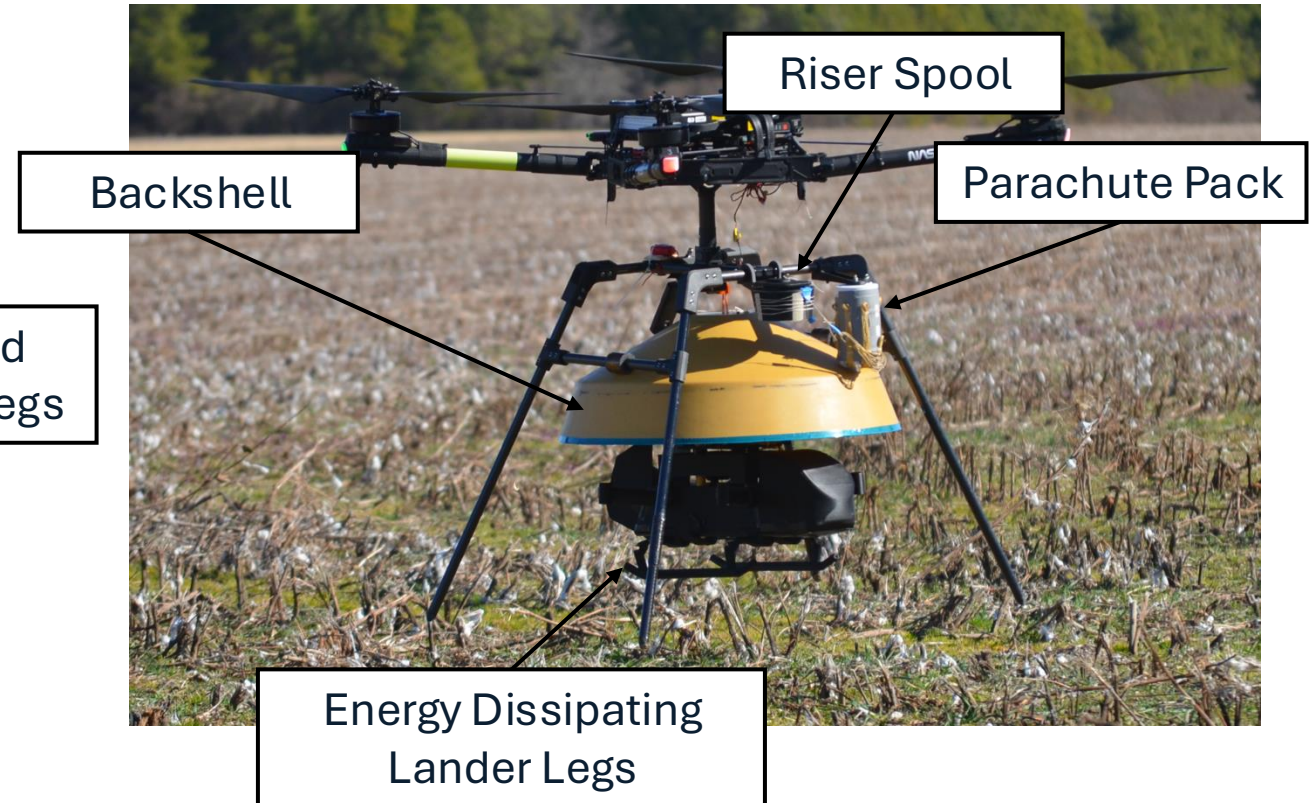


Test Operations: Mounting Payload

Stowed Configuration

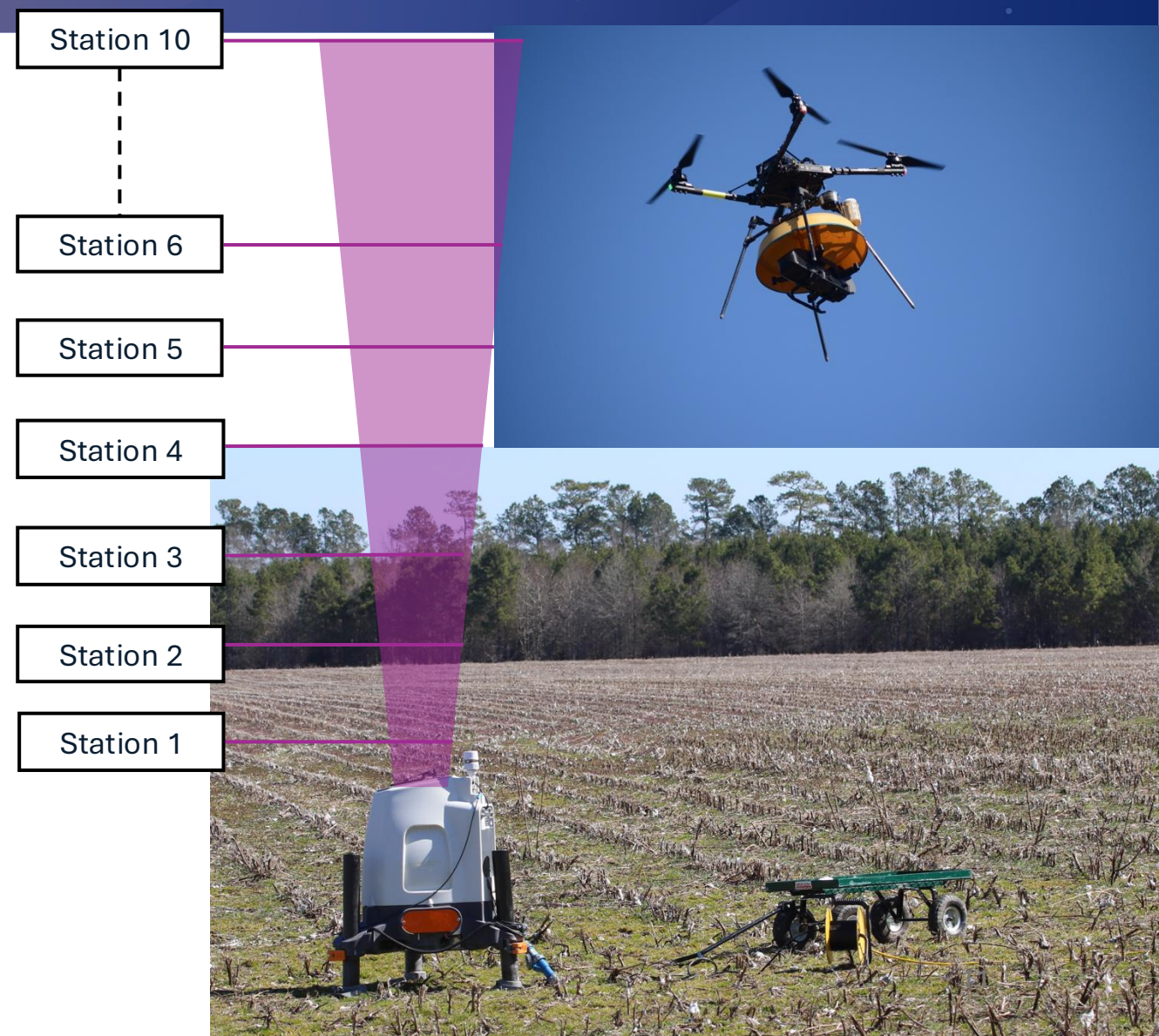


Posed Configuration



Test Operations: Release Location

- Ground-based LiDAR continuously monitored real-time winds at various altitudes to guide payload release coordinates
- Once at payload release coordinates, Alta-X entered “Fixed Position” mode
 - Attitude states from onboard IMU verified LiDAR wind direction predictions
- Ensured payload landed within the bounds of the test field



Test Operations: Deployment

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Unstable attitude
upon release



Backshell deploys
packed parachute



Parachute begins to
inflate, stabilizing the
system



Quasi-steady state
reached after
canopy fully
deploys

Test Operations: Drop Videos

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Stowed Deployment

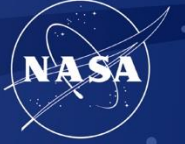


Posed Quasi-Steady



Data Analysis: Individual Drop Data

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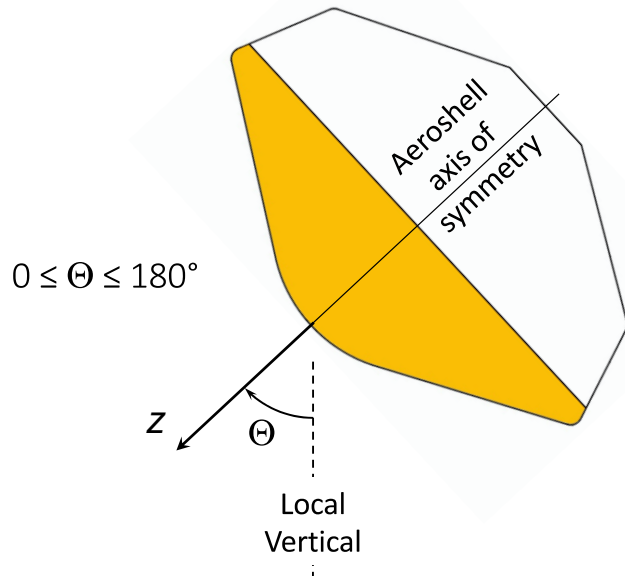
Individual Drop

Appended Drops

Statistics I

Statistics II

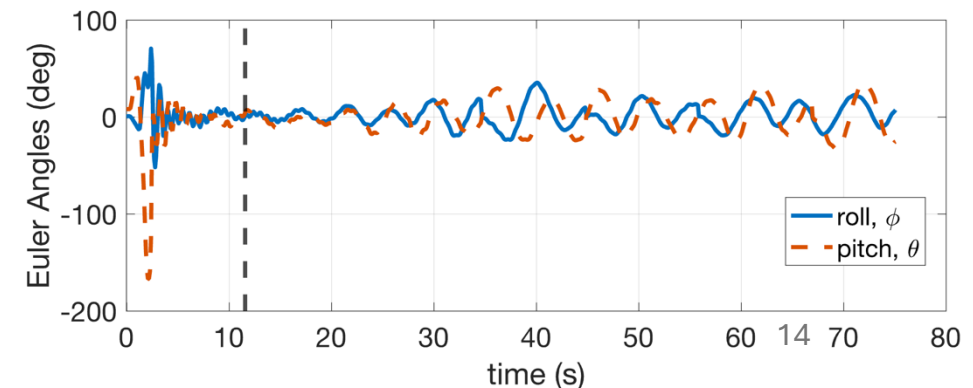
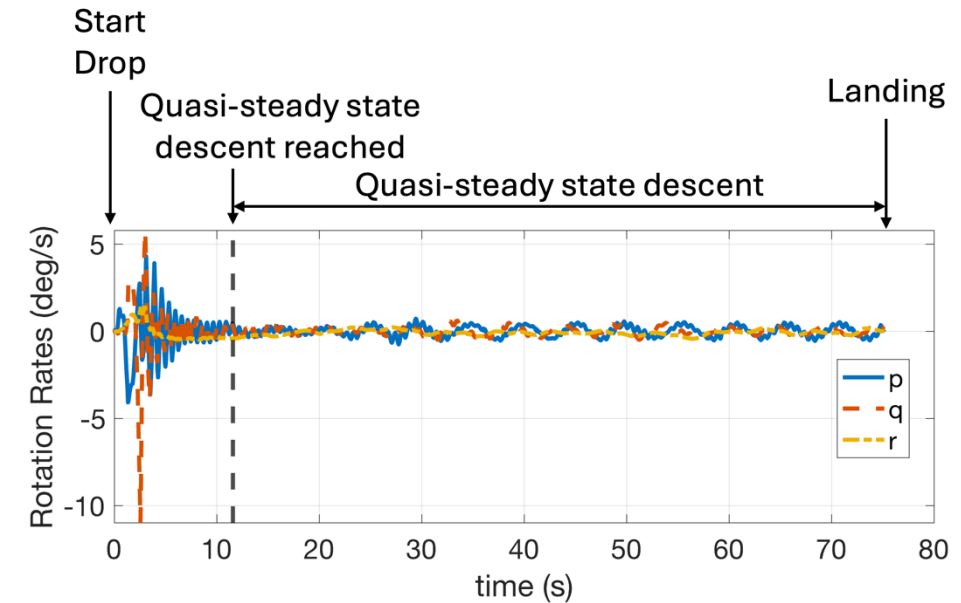
- Initial transients dampened within 12s for all drops
- Data of interest: rotation rates and Euler angles from the quasi-steady state descent of each drop
- The lateral rate and Nadir angle are used as metrics to assess the dynamics



Quantities of interest:

$$\text{RSS Lateral Rate, } \Omega = \sqrt{q^2 + p^2}$$

$$\text{Nadir Angle, } \Theta = \cos^{-1}(\cos(\theta) \cos(\phi))$$



Data Analysis: Appended Statistics

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Individual Drop

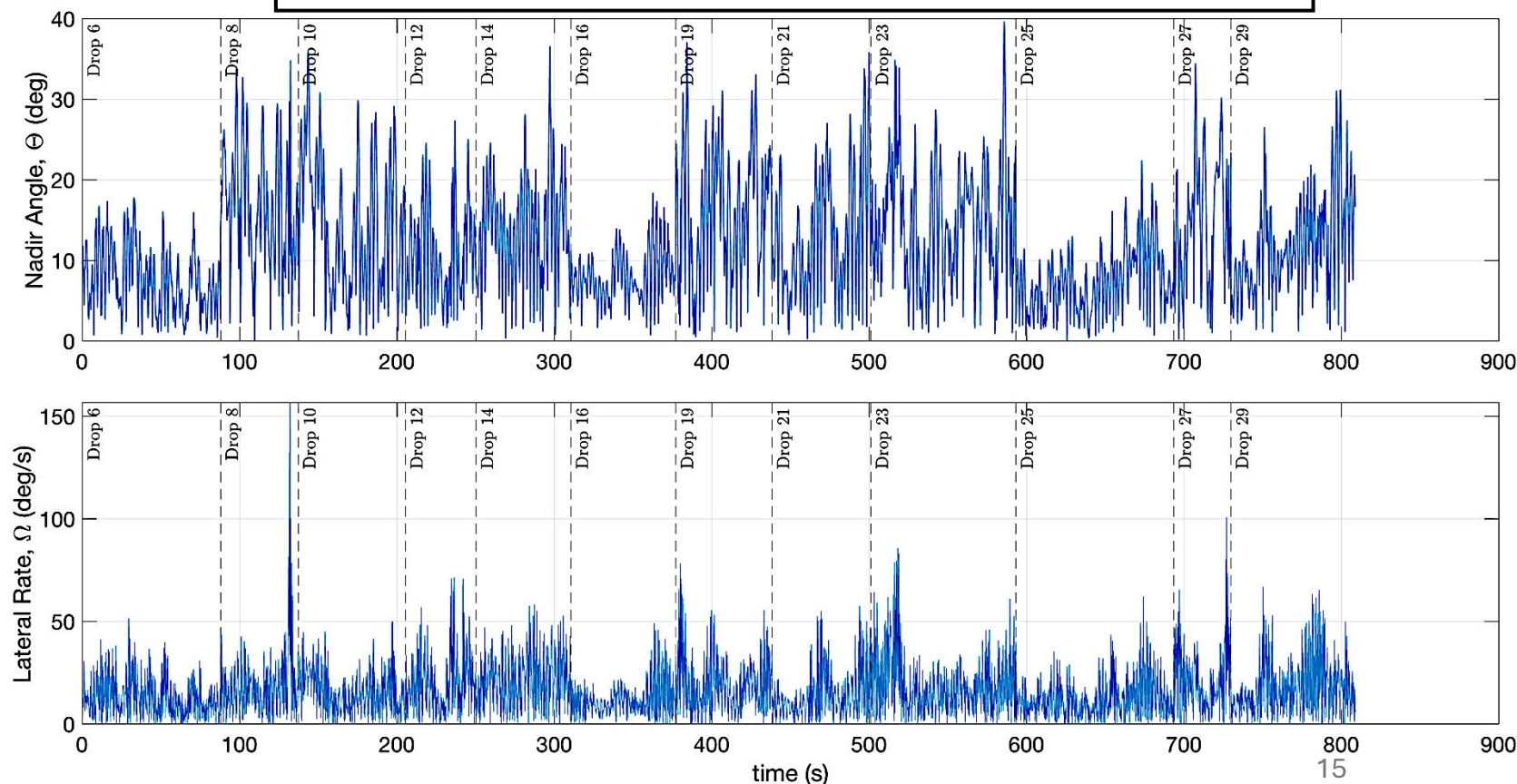
Appended Drops

Statistics I

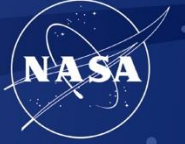
Statistics II

- Append all quasi-steady state dynamics data for each configuration
- ~14 mins of dynamics data for each configuration
- 90+ mins full-scale, Titan time
- 12 drops across 4 test days mitigate day-of wind biases
- Low-altitude turbulence at tree line induce localized high dynamics (observed prior Cruz et al. AIAA 2024-4329)

Appended Dynamics Data of the Posed Configuration



Data Analysis: Statistics I



Individual Drop

Appended Drops

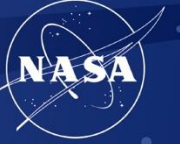
Statistics I

Statistics II

- Stowed and posed configurations have larger Euler angles compared to full aeroshell
- In the posed configuration, asymmetry of the lander body results in higher dynamics in x-direction than the y-direction

	Roll Euler Angle $ \phi $ (deg)			Pitch Euler Angle $ \theta $ (deg)			Nadir Angle Θ (deg)		
Config	aeroshell*	stowed	posed	aeroshell*	stowed	posed	aeroshell*	stowed	posed
50%-tile	2.9	5.8	9.6	3.3	6.2	6.0	5.5	10.4	13.6
90%-tile	8.0	16.3	19.3	7.7	16.4	15.9	10.6	22.1	24.9
95%-tile	9.7	19.9	25.8	9.5	20.3	19.3	12.1	25.3	28.1
99%-tile	13.1	26.6	31.4	12.7	26.8	25.2	15.4	31.2	33.7

Data Analysis: Statistics II



Individual Drop

Appended Drops

Statistics I

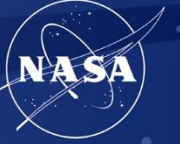
Statistics II

- Stowed and posed configurations have larger rotation rates compared to full aeroshell
- The stowed configuration had larger rotation rates than the posed configuration
- The posed configuration had asymmetric rotation rates compared to stowed and full aeroshell

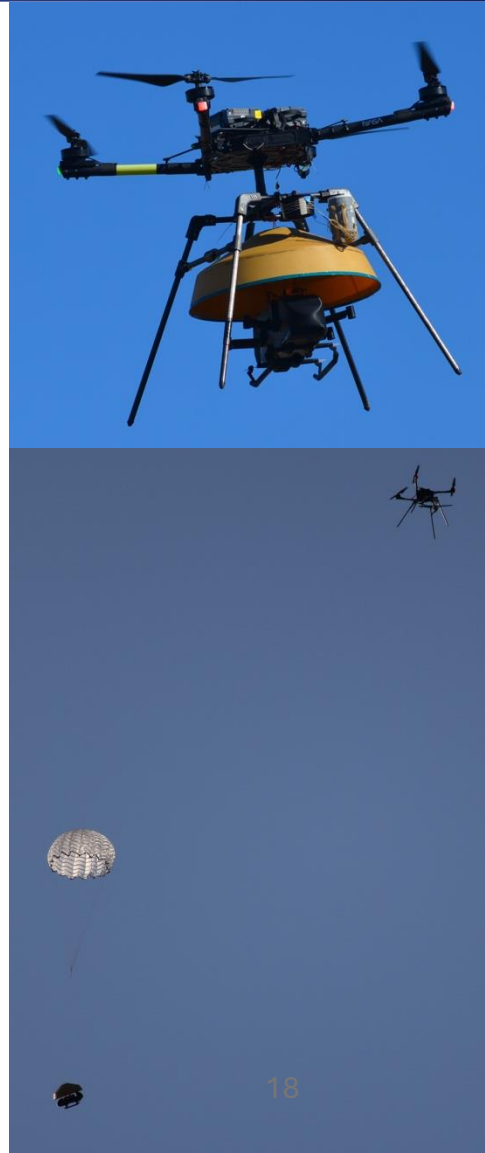
	Roll Rate $ p $ (deg/s)			Pitch Rate $ q $ (deg/s)			Lateral Rate Ω (deg/s)		
Config	aeroshell*	stowed	posed	aeroshell*	stowed	posed	aeroshell*	stowed	posed
50%-tile	0.7	1.2	1.6	0.8	1.3	1.3	1.3	2.2	2.5
90%-tile	1.9	3.3	3.4	1.9	3.7	3.0	2.6	4.8	4.1
95%-tile	2.4	4.2	4.0	2.3	4.6	3.5	3.0	5.8	4.7
99%-tile	3.4	6.2	5.6	3.4	6.9	4.6	4.2	8.1	6.2

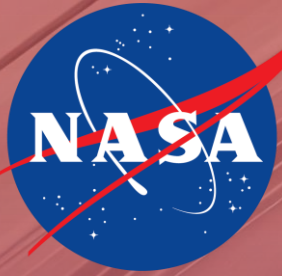
Rates are reported in Full-Scale, Titan time

Findings and Conclusions



- Drop testing from drones provide low-cost solutions to generate informative dynamics data of a parachute systems
- Overall, the observed dynamics of the subscale Dragonfly model are higher in the posed and stowed configurations than with the full aeroshell
- The lateral rates, Ω , nearly doubled from aeroshell to stowed/posed configurations, but remained low amplitude (4 deg/s $\rightarrow$ 8 deg/s at Titan)
- Statistical data is used to validate POST2 flight mechanics simulations of parachute descent
 - Reconstruction: [Williams et al. AIAA 2026-1957]
 - Apparent Mass Model Validation: [G. Guecha AIAA 2026-3845]





Questions?
