Design and Technology Maturation of the Stratospheric Projectile Experiment of Entry Dynamics (SPEED)

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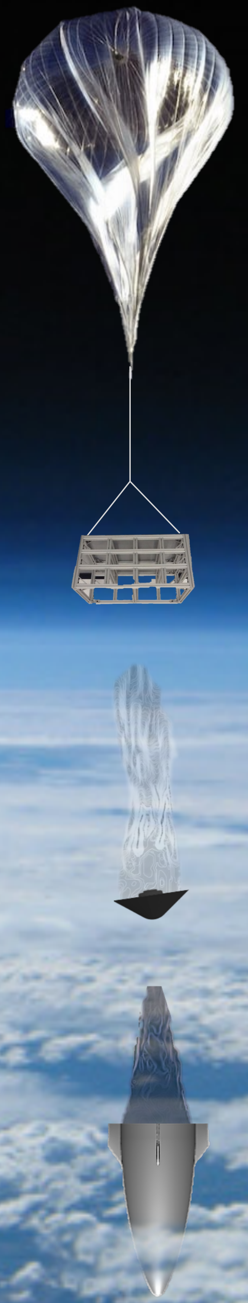


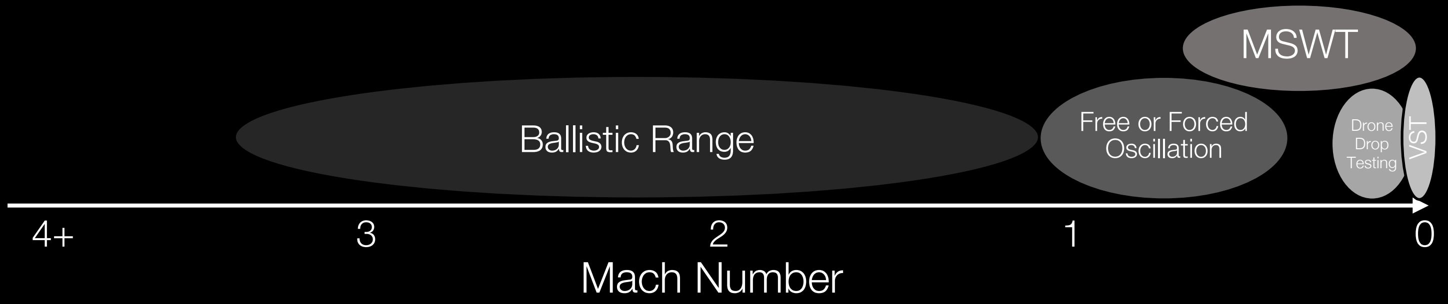
The Need for A Novel Dynamic Test Architecture

SPEED is a technology development and demonstration project at NASA Ames

- Objective: Deliver a free-flight dynamics test architecture to provide rich, flight-like data to complement existing test capabilities
- Funded by Ames IRAD, MSR, Dragonfly, ESM, and NASA STMD
- Will be ready in late 2024 for mission applications following upcoming helicopter and balloon demonstrations

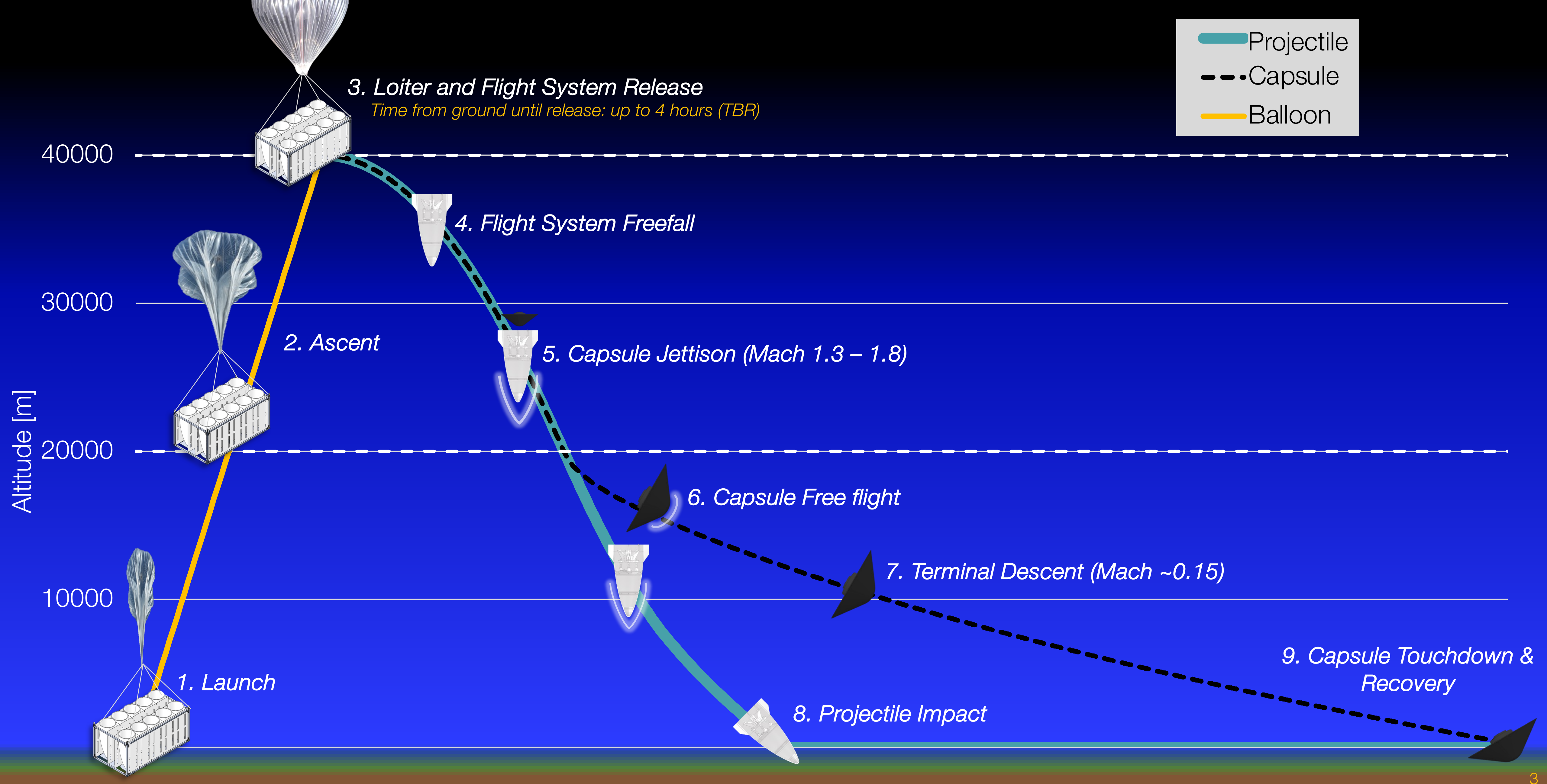
Why do we need SPEED?

- Blunt-body capsules are subject to dynamic instabilities at low-supersonic and transonic Mach numbers
- Current entry missions have dynamics challenges which are driving new testing needs:
  - MSR EES: dynamics during terminal descent drive impact angle which is key for containment
  - Dragonfly: coupled capsule-chute dynamics drive risk during long descent and Lander separation
- Dynamic stability typically characterized via experiment: forced-, free-oscillation, ballistic range, and VST
  - These methods have a long pedigree of estimating pitch damping for missions
  - Each method has drawbacks resulting in uncertain predictions
  - Little to no overlap in transonic Mach number coverage with existing facilities



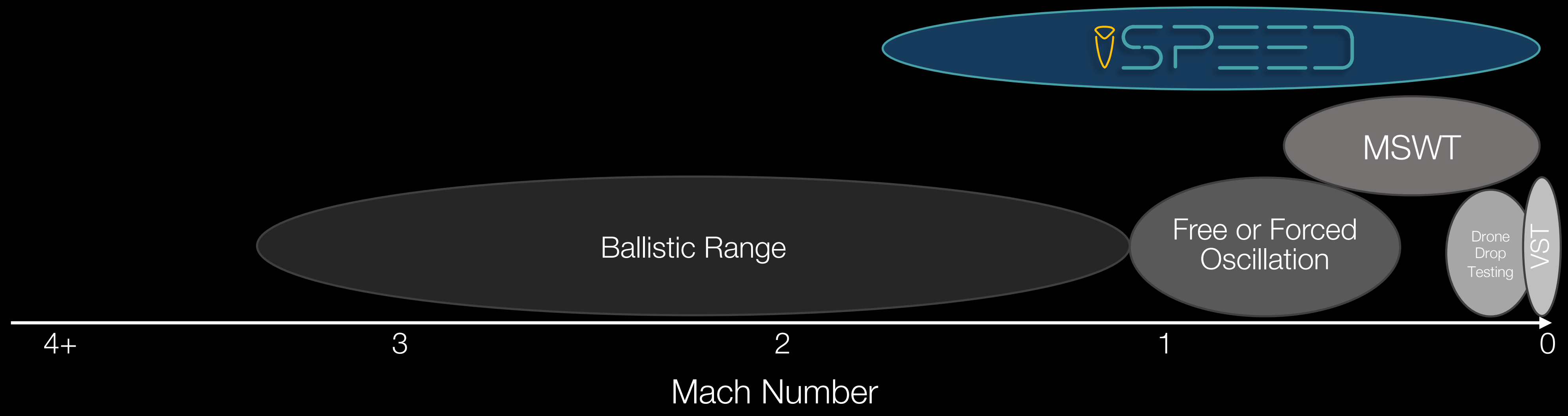
Genesis Capsule

iSPEED ConOps



Value Proposition:

- Most flight-like method for obtaining rich, dynamically scaled data
- Several vehicles per flight allows for statistical understanding of vehicle behavior and A/B testing
- Provides coverage over most critical and most difficult to test Mach regime
- Independent data source for comparing predictions from different test facilities and from CFD
- Low-cost and tailorable test capability to complement future aerodatabase generation

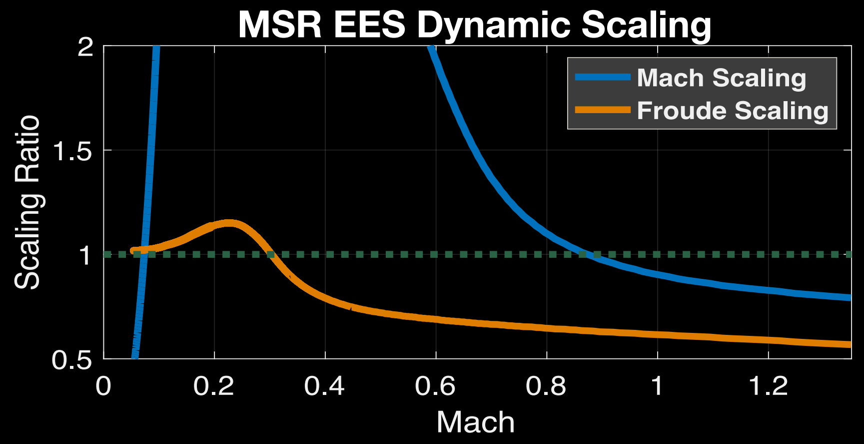


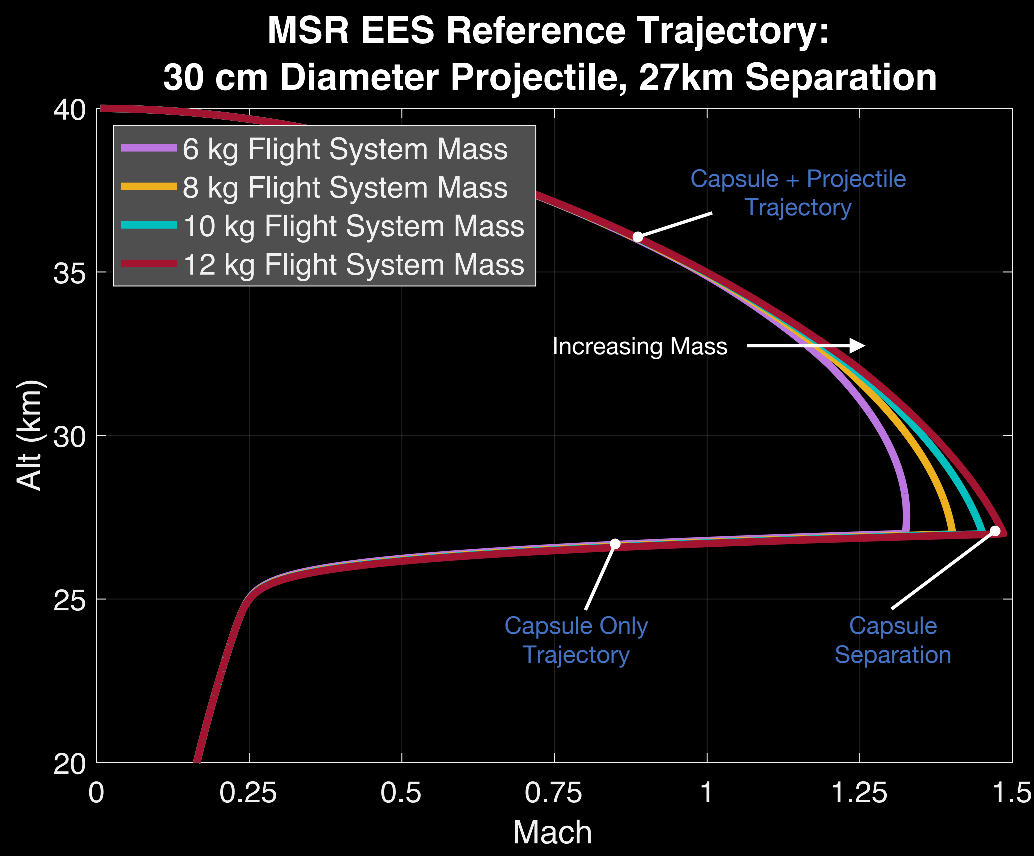
Nominal Trajectory and Dynamic Scaling

- Architecture can be tailored to meet scaling requirements for most missions (Titan, Mars, Earth) by changing mass properties and separation altitude
- Trade between starting altitude, individual flight system mass, peak Mach number, and number of total payloads that can be flown

Capsule	Drop Alt	Separation Alt	Peak Mach	Flight System Mass	Capsule Diameter	Capsule Mass
MSR EES	40 km	27 km	1.35	6.5 kg	0.25 m	0.7 kg
Dragonfly	40 km	23 km	1.60	6.5 kg	0.17 m	1.3 kg

- Dynamic scaling can be closely matched across the regime of interest
  - Mach scaling within ±20% from Mach 1.7 – Mach 0.7
  - Froude scaling within ±20% Mach 0.4 – Terminal Velocity
  - Meets or exceeds capability of ambient ballistic range testing

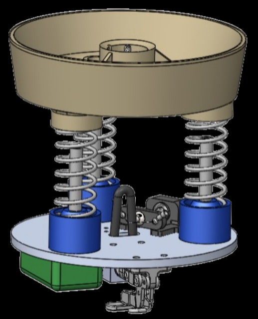


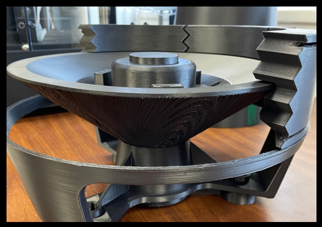


Development Path

Basic concept development and component testing with

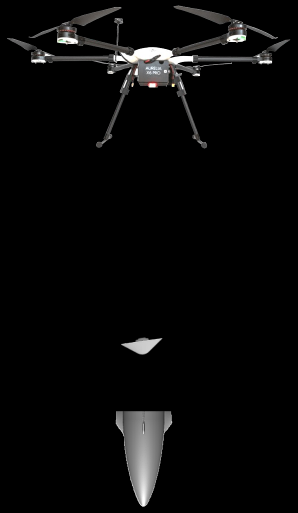
MSR EES Point Design





Drone drop testing of single flight system

(100m starting altitude)



Helicopter drop testing with full fidelity drop + flight system

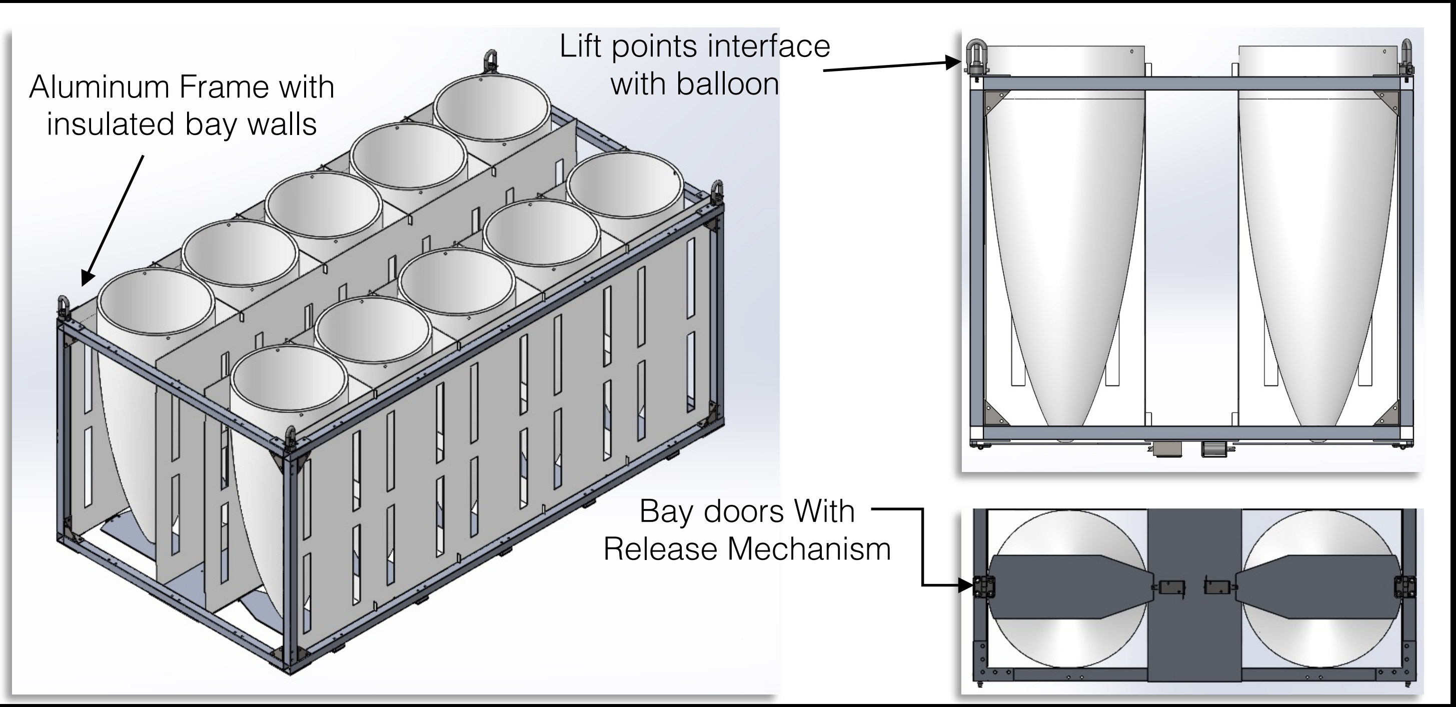
(600m starting altitude)

First stratospheric balloon demonstration

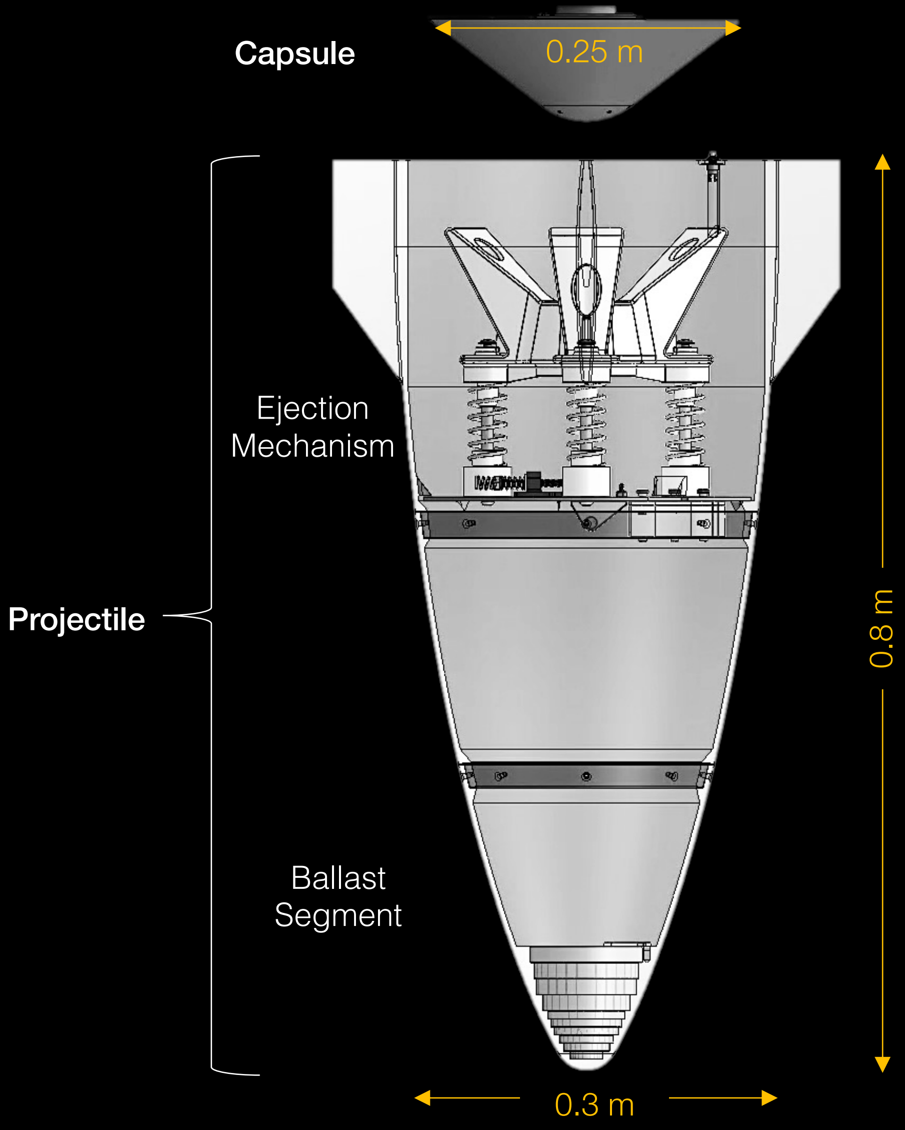
(40 km starting altitude)

System Overview

- Three major elements: Drop Platform, Projectile, Capsule
  - Low-cost materials and fabrication (~$25k for full system with 10 payloads)
- Architecture allows for easy tailoring to different vehicle configurations
  - 3D printed capsule geometries (OMLs, surface features)
  - Initial angle of attack, Mach, altitude
  - Could be reconfigured to test other systems (e.g. parachutes)



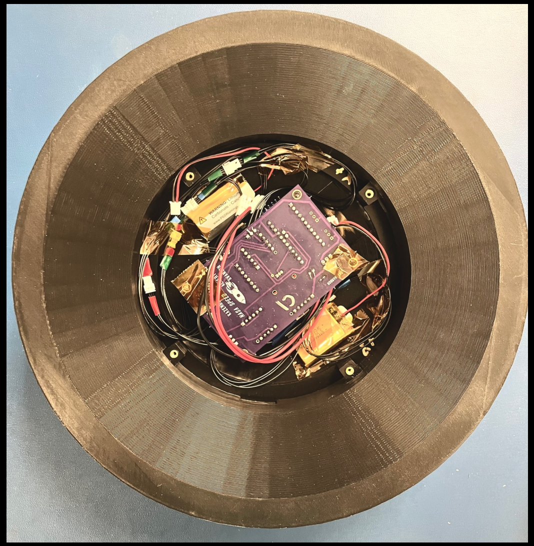
Drop Platform



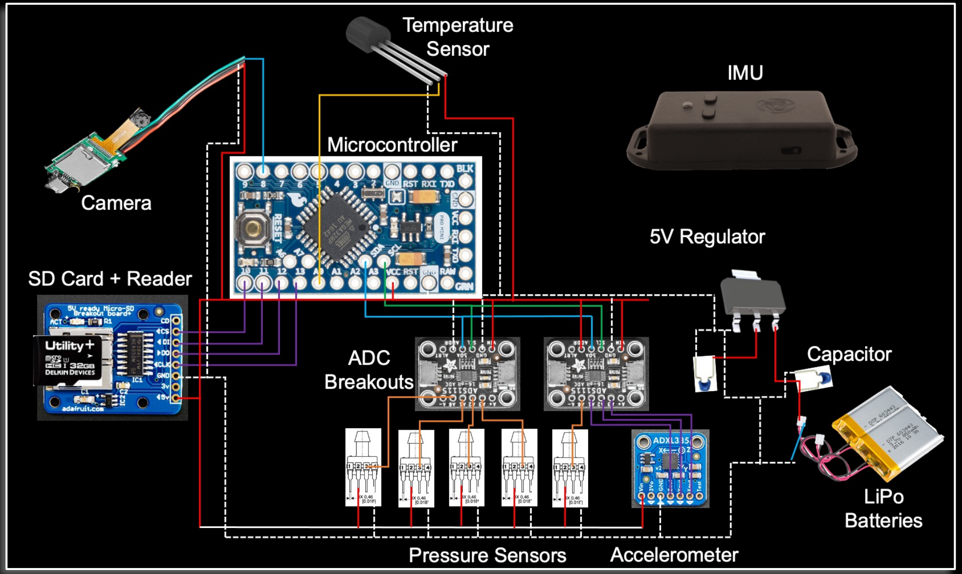
Flight System for MSR EES Point Design

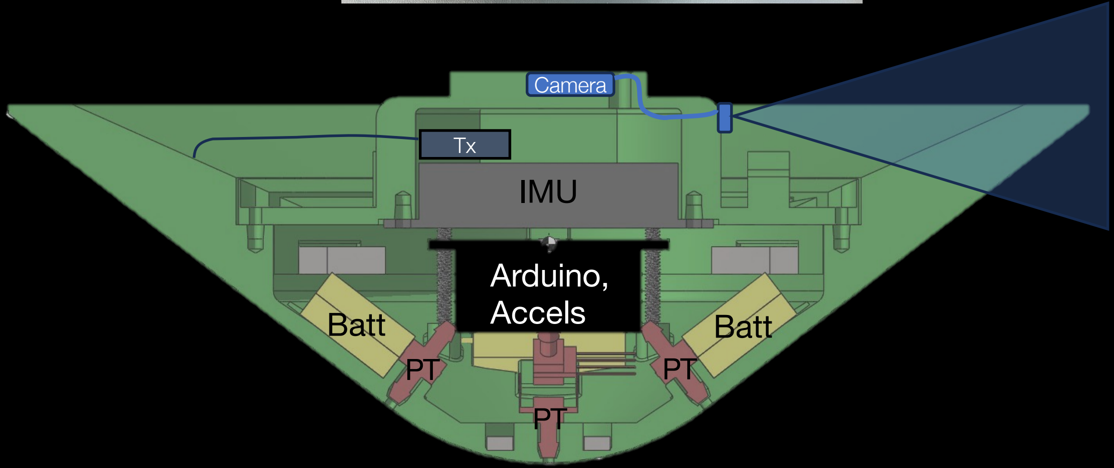
Avionics

- Avionics perform critical functions on each major element in the system
  - Drop Platform: Receive drop signal from balloon and send signal to drop mechanisms in sequence to initiate freefall
  - Projectile: Sense conditions that indicate we are at the desired experimental altitude and initiate capsule ejection
  - Capsule: Measure vehicle and environmental state for downstream data reduction
- Capsule is highly instrumented to provide rich dataset for characterizing flight performance
  - Pressure transducers (stag, cruciform, optional Kulites on aftbody)
  - 200 Hz IMU, Magnetometer
  - Camera
  - Recovery aids
- SD cards on board will be recovered for data extraction and analysis



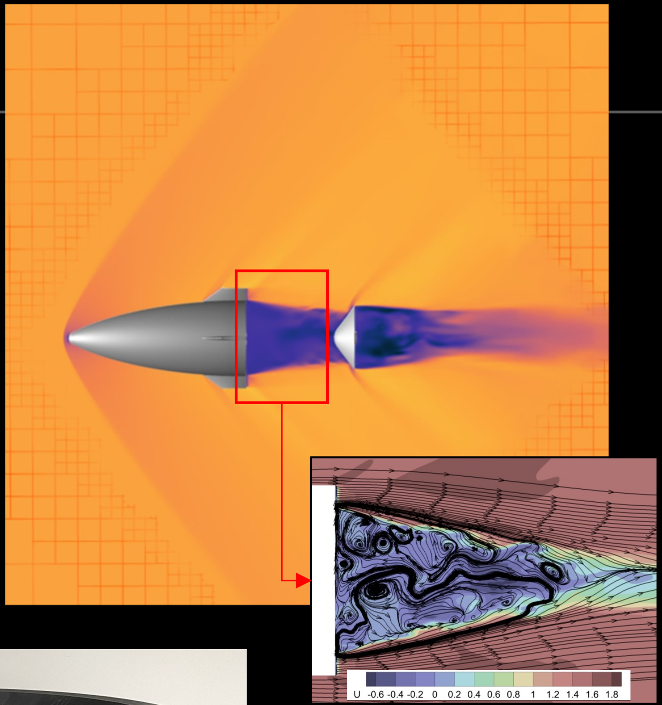
Capsule Avionics

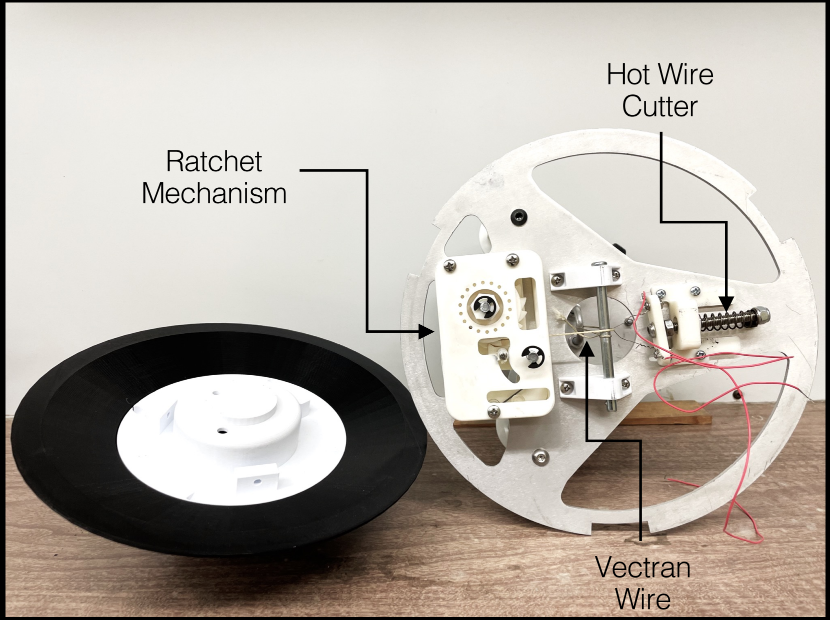


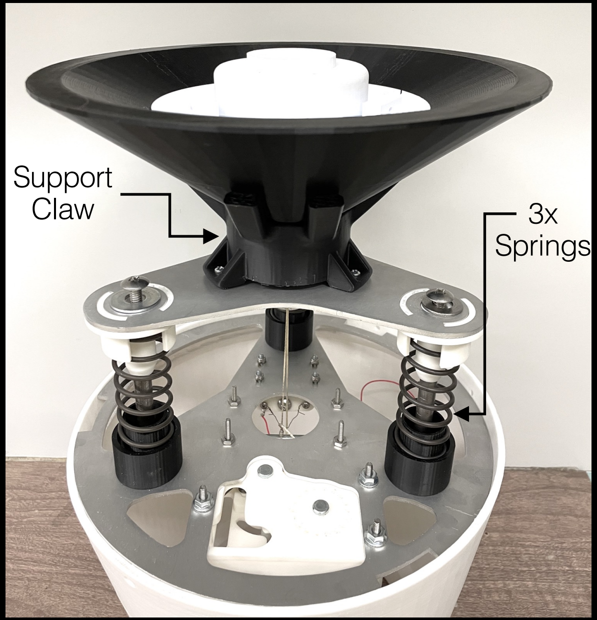


Separation Event

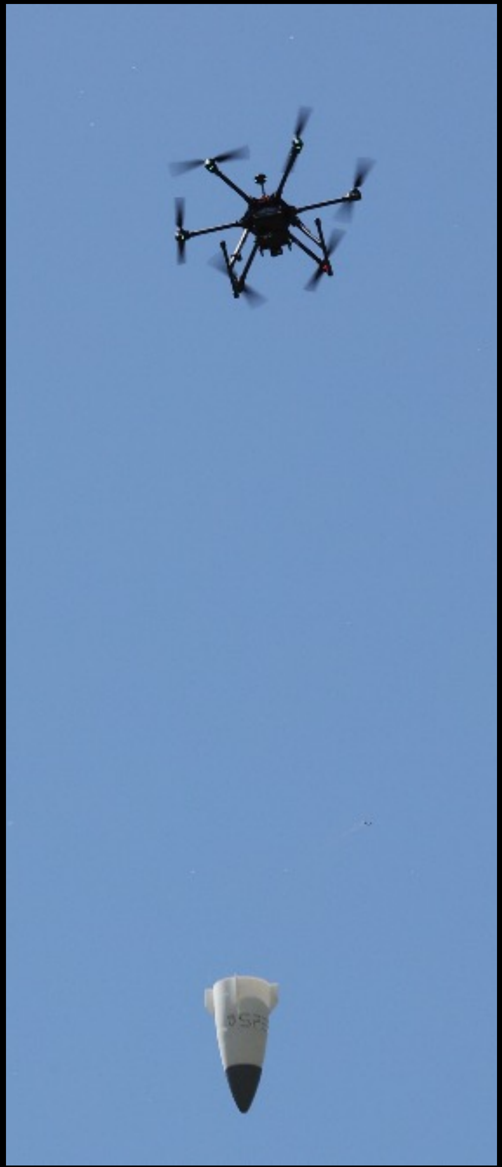
- Avionics detect separation conditions and power a hot-wire cutter that initiates a spring driven separation
- Key open question: How long after separation is the capsule in a representative free-flight environment where data is valid?
- Two-body static CFD assessment indicates capsule aero asymptotes after getting ~2 projectile lengths behind projectile
- Capturing relative dynamics of the capsule and projectile during the separation will be assessed in maiden flight

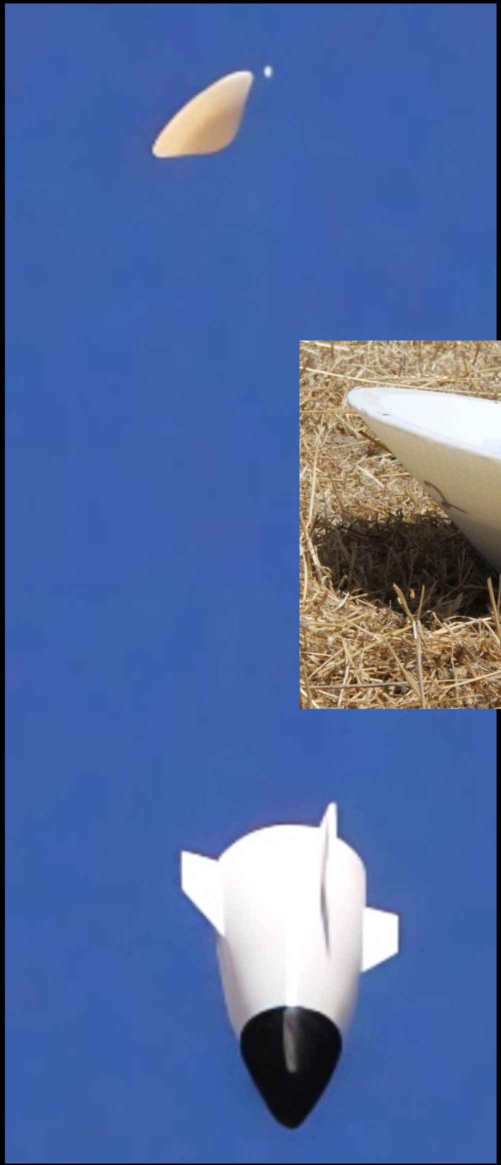




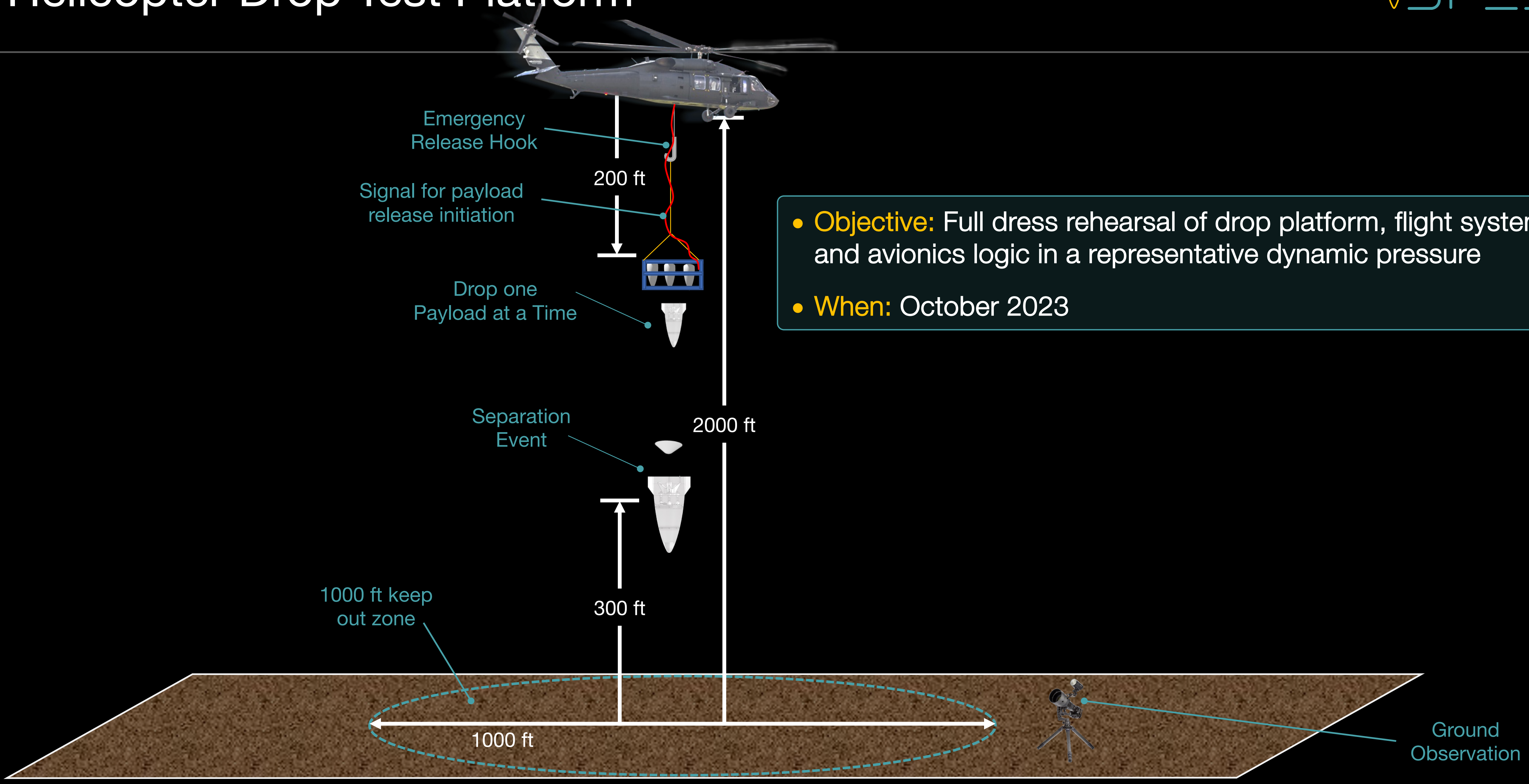


Drone Testing





Helicopter Drop Test Platform

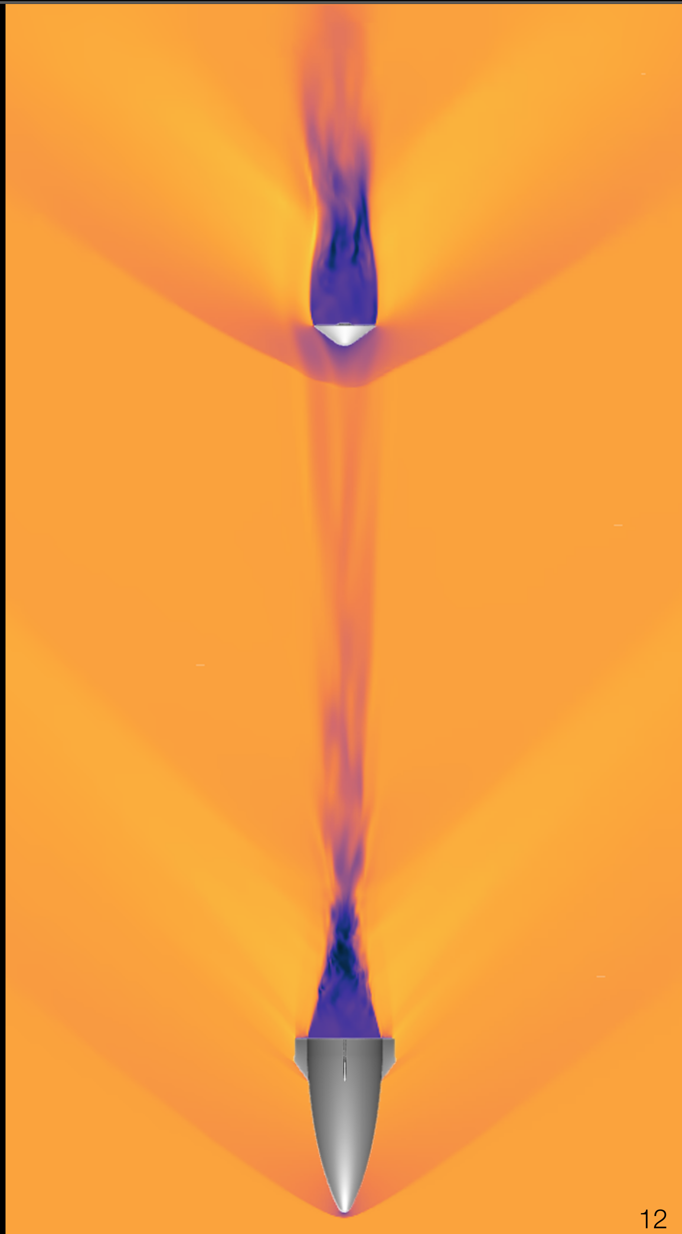


- **Objective:** Full dress rehearsal of drop platform, flight system, and avionics logic in a representative dynamic pressure
- **When:** October 2023

Summary

- New balloon-delivered, stratospheric dynamic test architecture is in development (“SPEED”)
- Two-stage, ballistically accelerated, 3D-printed payload delivers a dynamically scaled entry capsule to flight-relevant conditions up to ~Mach 1.8
- Heavily instrumented capsule records vehicle state for trajectory reconstruction
- Architecture can be tailored to match conditions either for capsule alone or for under drogue parachute
- Provides most flight-like validation of vehicle dynamics
- Open Risks: relative dynamics during ejection, thermal environments
- Demonstration balloon flight planned for March 2024
  - Flying 4x MSR EES capsules and 4x Dragonfly
- Architecture can be customized to pursue various mission specific or scientific objectives
  - Parachute dynamics, influence of roll rate, etc

Following demonstration flight in Spring of 2024, SPEED test architecture will be ready for deployment for mission use



SPEED