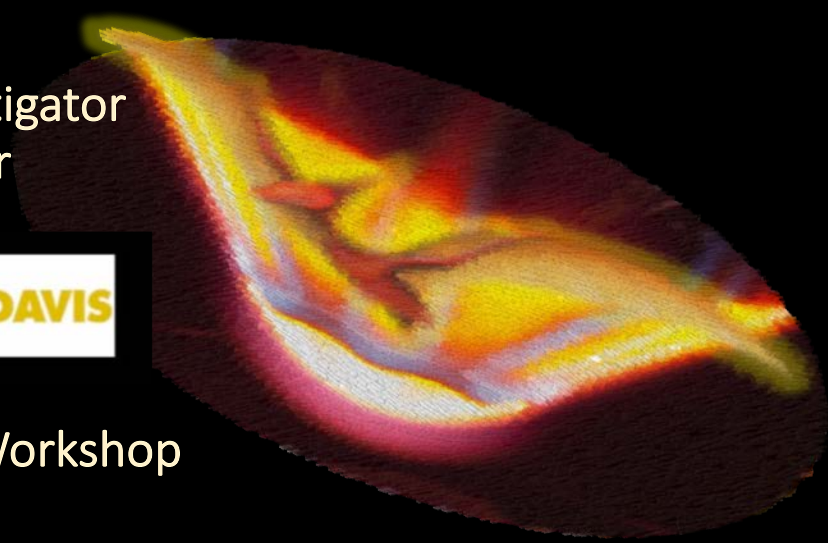
# **Pterodactyl:** Integrated Control Design for Precision Targeting of Deployable Entry Vehicles

Dr. Sarah D’Souza, Principal Investigator
NASA Ames Research Center



15th International Planetary Probe Workshop
June 12, 2018

# Background

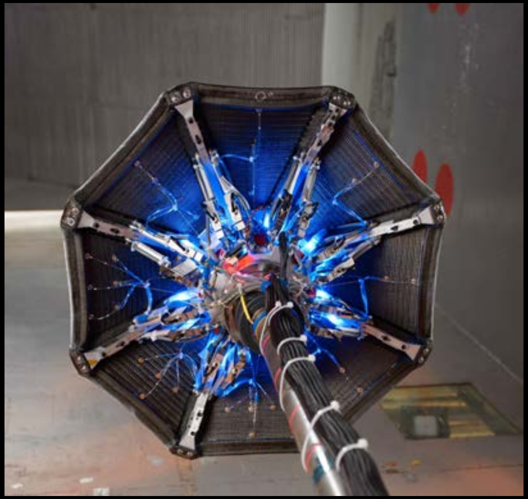
- Funded by NASA's Space Technology Mission Directorate as part of the Early Career Initiative program


- Goal is to grow early career employees while advancing NASA's mission

# What is Pterodactyl?

A design, build, and test capability for finding optimal, scalable Guidance & Control (G&C) solutions for Deployable Entry Vehicles (DEVs) to enable precision targeting

# Large to Small Mass Missions are driving the development of DEVs!



Adaptable, Deployable Entry Placement Technology (ADEPT)

Hypersonic Inflatable Aerodynamic Decelerator (HIAD)

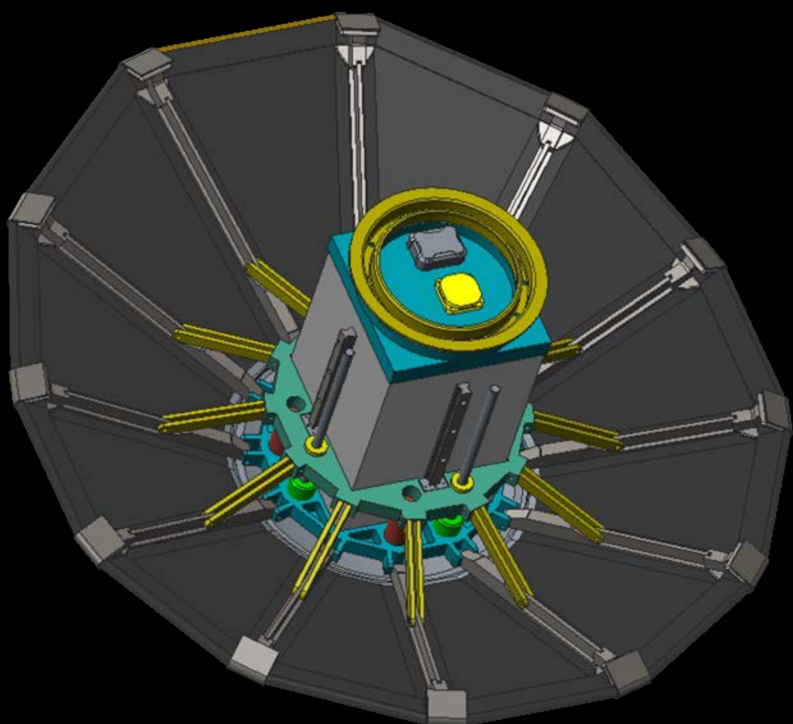
Research Question: What control system will enable steering these vehicles to a location of our choosing, precisely?

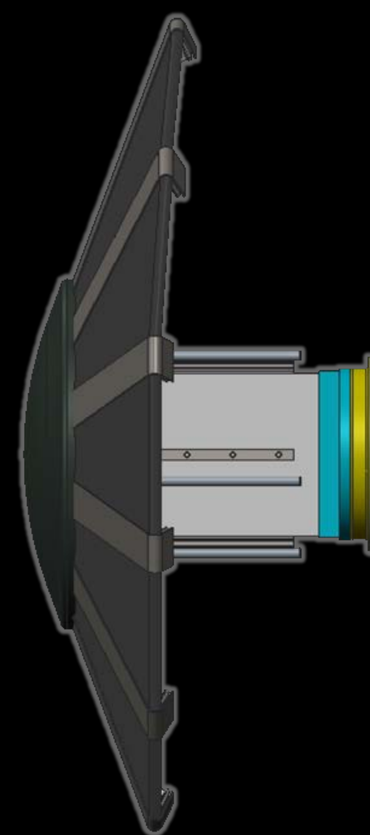
Relevant applications: large mass to Mars, science missions that require timely recovery or arrival at a specific location

# Lifting Nano-ADEPT

Asymmetric, 1+ meter diameter

mass = 55.2 kg, <u>β</u> = 40 kg/m$^2$





# Pterodactyl Mission Roadmap

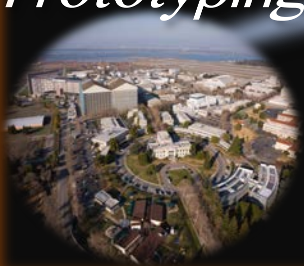
DEV Technology Goals:
*G&C solution that provides precision targeting and scalability*

Then Mars!

*Lunar Return Mission*

**Currently funded**

FY18 - FY20
*Ground Testing and Prototyping*



FY20+
*Earth Flight Test*

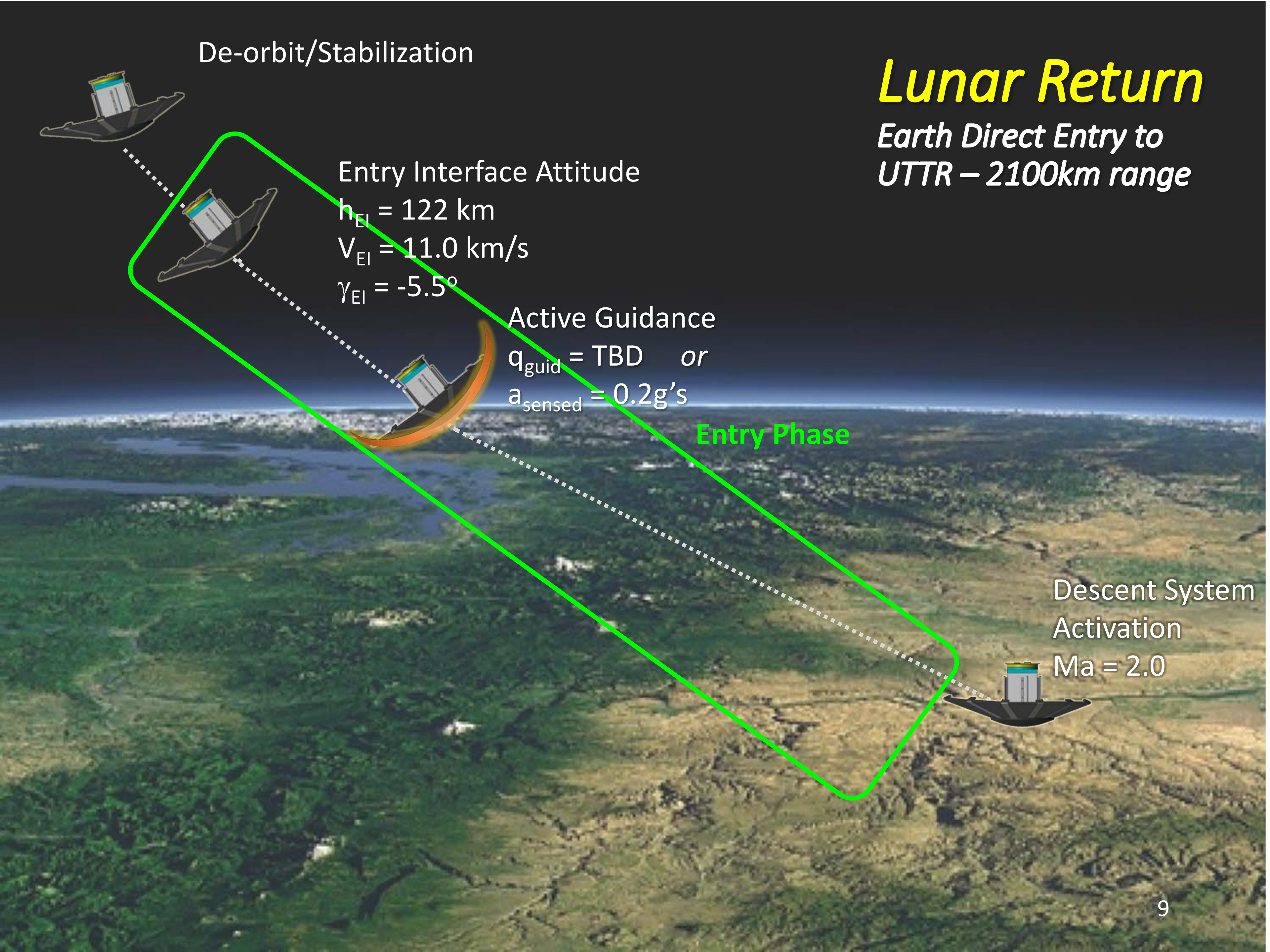
# Pterodactyl Design Overview

## ”Stepping Stone” Approach

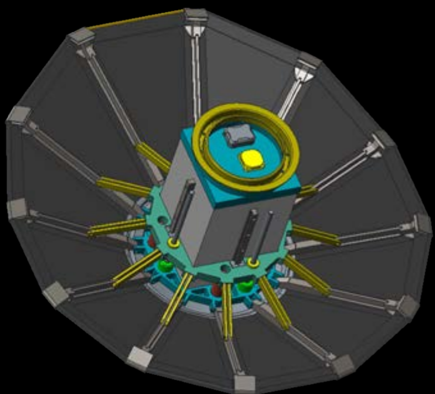
POINT OF DEPARTURE: Design feasible G&C solutions with a notional ConOps

| **Planet** | **Earth** |
|---|---|
| Entry Type | Direct, high speed (> 9 km/s) |
| Mission | NASA missions used as analogs to stress design for scalability and precision targeting |
| Justification | High entry velocity results in high aerodynamic and heat loading impacts G&C design |

Each iteration (stepping stone) of the design becomes more specific to a particular mission on the Pterodactyl Technology Roadmap

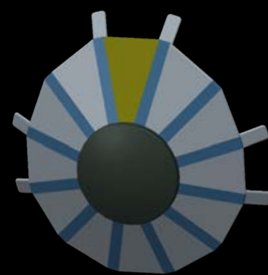

De-orbit/Stabilization
Lunar Return
Earth Direct Entry to
UTTR – 2100km range
Entry Interface Attitude
$h_{EI}$ = 122 km
$V_{EI}$ = 11.0 km/s
$\gamma_{EI}$ = -5.5°
Active Guidance
$q_{guid}$ = TBD *or*
$a_{sensed}$ = 0.2g's
Entry Phase
Descent System
Activation
Ma = 2.0

# Pterodactyl Design Process Overview



**Lifting Nano-ADEPT**
Asymmetric, 1+ meter diameter

**Identify Potential Control Systems**
Tabs, RCS, etc.



- CAD Models
- Aerodynamics
  Aerothermodynamics
- Guidance & Control
- Structures Analysis
- TPS Sizing

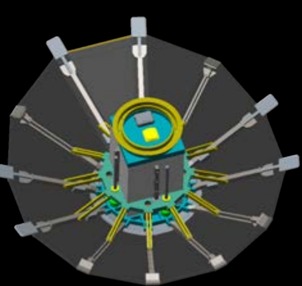
**Develop Vehicle and Control System Simulations**
Varied Fidelity

**Integrate Models into MDAO Framework**
Multi-disciplinary, Design, Analysis and Optimization

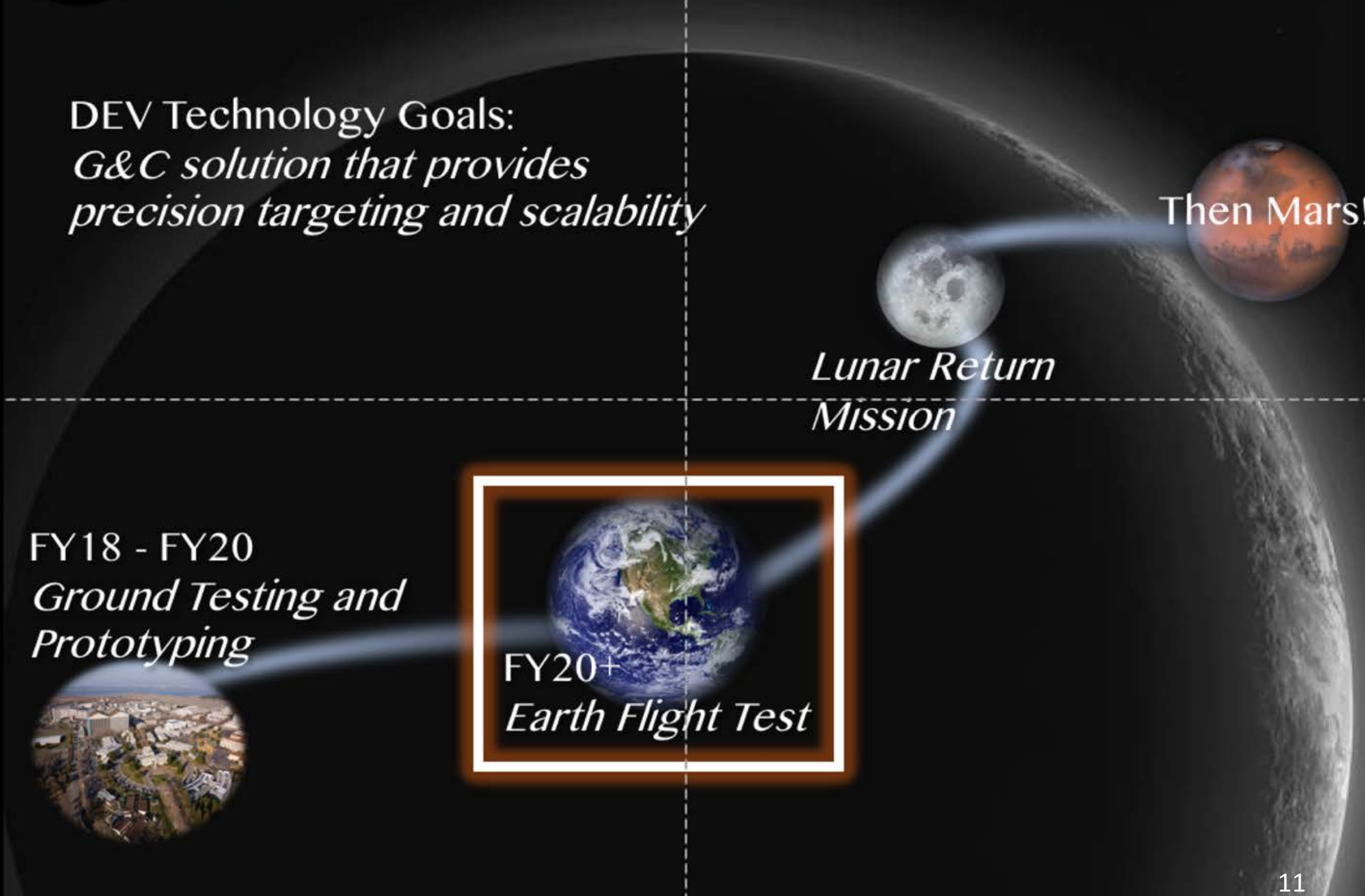
***COBRA-Pt**
**Optimizes control system mass and target ellipse**

*Garcia et al., AIAA 2010-5052

**Select Optimal Design**
MDAO output, SMEs

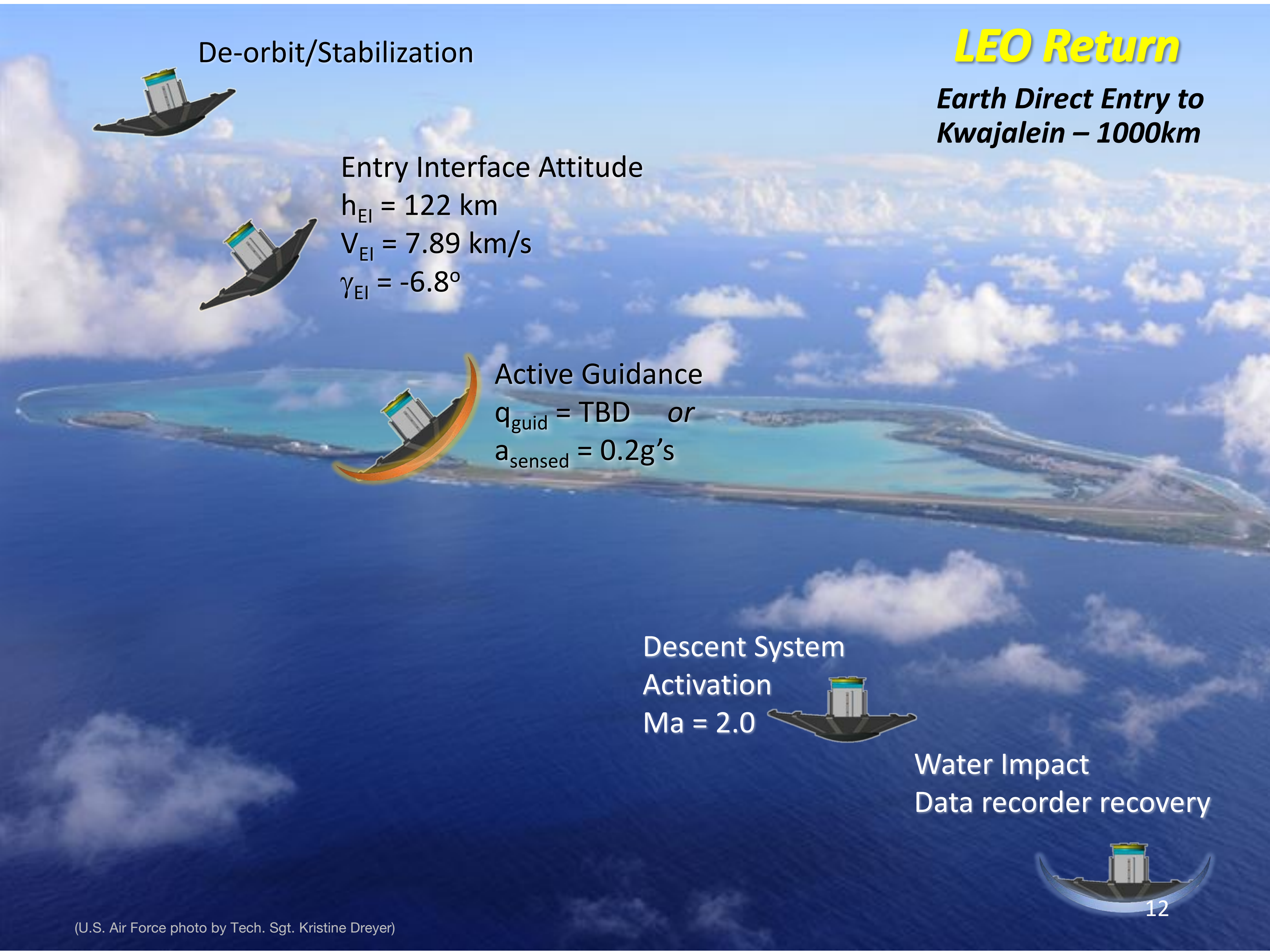


# Pterodactyl Mission Roadmap



# LEO Return

***Earth Direct Entry to Kwajalein – 1000km***




(U.S. Air Force photo by Tech. Sgt. Kristine Dreyer)

# Pterodactyl Testing Plan Overview

| | Test | Requires G&C Algorithms | Pterodactyl Testing Timeline | Purpose |
|---|---|---|---|---|
| FUNDED | ***6DOF Simulation*** | ✓ | ***FY19*** | ***G&C logic development, System performance predictions, Monte Carlo analyses*** |
| FUNDED | ***Bench Tests of Hardware*** | | ***FY19-20*** | ***Validate simulation hardware and hardware interfaces to software*** |
| FUNDED | ***Hardware in the Loop Tests*** | ✓ | ***FY19-20*** | ***Validate compiled software operation on the flight processor, computational loading, and timing to/from hardware*** |
| TBD | Vertical Motion Simulator | | Optional | Validate navigation algorithms/sensors given physical motion |
| TBD | Captive Flight Tests | ✓ | if necessary | Validate flight software & mission states, navigation software in flight, telemetry collection |
| TBD | Flight Tests | ✓ | Notionally FY22-23 | Validate hardware & environment models, software executing a mission, system performance predictions |

## Pterodactyl Team

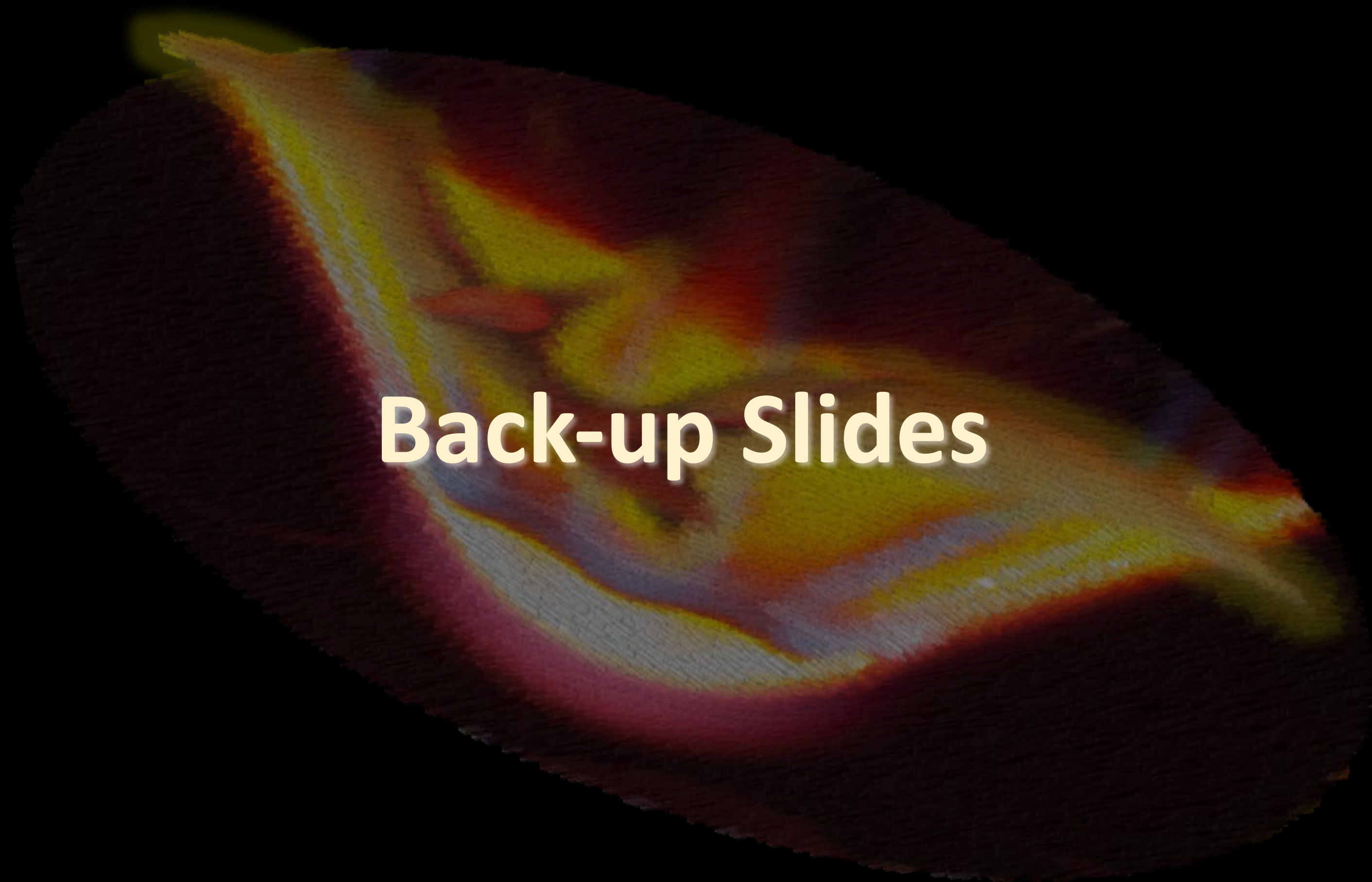
Dr. Wendy Okolo, Brandon Smith, Ben Nikaido,
Dr. Alan Cassell, Bryan Yount, Xun Jiang
NASA Ames Research Center

Breanna Johnson
NASA Johnson Space Center

Ken Hibbard, Jeff Barton, Gabe Lopez, and Andrew Sanders
Space Exploration Sector
JHU Applied Physics Laboratory

Dr. Steve Robinson
Center for Human-Systems Engineering
University of California at Davis

# Questions?



# Back-up Slides

# Deployable Entry Vehicle Technology Challenge Areas

| | TECHNOLOGY DEVELOPMENT | | | TECHNOLOGY DEMONSTRATIONS | | DESIGN REFERENCE MISSIONS | |
|---|---|---|---|---|---|---|---|
| **CHALLENGE AREAS** | **PTERODACTYL** | ADEPT | DESCENT SYSTEMS STUDY | LOW EARTH ORBIT FLIGHT TEST | LUNAR RETURN FLIGHT TEST | LUNAR SAMPLE RETURN MISSION | HUMAN MARS EXPLORATION MISSIONS |
| Guidance Algorithm Validation | ✓ | | | ✓ | ✓ | ✓ | |
| Control Effector Design, Analysis & Characterization | ✓ | | | ✓ | ✓ | ✓ | |
| Static Aerodynamic Database | ✓ | | | ✓ | ✓ | ✓ | |
| Guidance & Control System Validation | ✓ | | | ✓ | ✓ | ✓ | |
| Electro-mechanical Deployment System | ✓ | | | ✓ | ✓ | ✓ | |
| Carbon Fabric Packing & Tension Management | ✓ | | | ✓ | ✓ | ✓ | |
| System Level Aerothermal Analysis | ✓ | | | ✓ | ✓ | ✓ | |
| Scalability | ✓ | | | | ✓ | ✓ | |
| Carbon Fabric Response Model | | ✓ | | ✓ | ✓ | ✓ | |
| System Thermo-structural Performance | | ✓ | | ✓ | ✓ | ✓ | |
| Payload Thermal Control | | ✓ | | ✓ | ✓ | ✓ | |
| ***Safe & Precise Landing Integrated Capability*** | | | ✓ | | | ✓ | |
| ***Propulsive Descent*** | | | ✓ | | | ✓ | |
| ***Control Surface Effectiveness*** | | | ✓ | | ✓ | ✓ | |
| ***Parametric Mass Model*** | | | ✓ | | | ✓ | |

# Pterodactyl Development Roadmap

## LNA Technical Challenge Areas

***Stakeholder Needs & System Design***

1. End-to-End mission concept(s) definition
2. Payload thermal environment management

***GN&C***

3. Guidance algorithm
4. Control effector performance mapping
5. IMU sensor characterization
6. Real-time state estimation (e.g. EKF)
7. GN&C system validation

***Structures and Mechanisms***

8. Control effector design
9. Fabric packing and tension management
10. Electro-mechanical deployment system

***Aero/Aerothermal & Materials***

11. Static aerodynamic performance
12. Mid-fidelity carbon fabric response model
13. System thermo-structural performance

## Test/Analysis Activity Mapping

*CY18-CY19 Pterodactyl (STMD ECI)*

- COBRA-Pt MDAO tool development
- GN&C algorithm development
- GN&C algorithm validation via Monte Carlo simulation AND/OR hardware-in-the-loop test
- IMU requirements development and hardware options identification
- Control effector thermo-structural analysis
- System-level aerothermal analysis (e.g. shock-interaction, wake impingement)
- Mid-fidelity static aerodynamic database development (CBAERO anchored to NS)

*CY19 Pterodactyl (STMD ECI)*

- Deployment system benchtop test
- Control effector performance characterization

*Unplanned, unfunded work*

- Component thermo-structural load testing
- Stagnation and SPRITE-C arc jet testing

***Residual Risks***

## Path to TRL 6

**Flight Test:**
**Guided entry at Earth from orbital velocity**

*Flight Test Objective:*
*Retire residual risks that were not addressed in other test/analysis activities*

# Analog Missions

- Use analog missions to develop a notional Concept of Operations

- Trade between what we want to account for in the design process versus capability at landing site

| Mission | Return From | Entry Trajectory | Guided | Entry Velocity (km/s) | Recovered |
|---|---|---|---|---|---|
| Apollo | Lunar | Direct (some lofted) | Yes | 11.0 | yes |
| Orion EFT-1 | LEO | Direct | Yes | 8.93 | yes |
| Orion EM-1 | Lunar | Skip | Yes | 11.1 | |
| Stardust | comet | Direct | No | 12.9 | yes |
| Genesis | L1 | Direct | No | 11.1 | yes |
| Mars Sample Return | Mars | Direct | ? | 11.-12.0 | |
| MSL | Earth | Direct | Yes | 5.9 | yes |