National Aeronautics and Space Administration

# Supersonic Retropropulsion Flight Test Concepts

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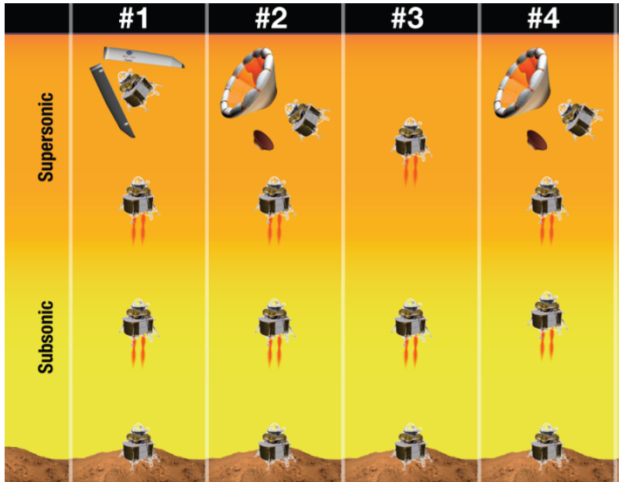
# Introduction

- **Supersonic Retropropulsion (SRP):**
  - Initiation of a retropropulsion phase while the vehicle is traveling at supersonic conditions
  - Advanced entry, descent, and landing (EDL) decelerator technology
  - Potential enabler for high-mass (e.g. human-scale) missions to the surface of Mars
- NASA's Exploration Technology Development and Demonstration (ETDD) Project is investing in the maturation of SRP technologies
  - Computational Fluid Dynamics (CFD) analysis
  - Wind tunnel testing
  - Flight test concept development and systems analysis
  - Roadmapping to mature SRP from ~ TRL 2 to TRL 6
- Flight test concepts have been defined for a proof-of-concept flight test




Reference: NASA EDL-SA Phase 1 Report, NASA TM 2010-216720, 2010.

Reference: NASA ETDD LaRC UPWT FY 10 SRP Test

# Objectives and Mission Requirements

## Objectives

- Demonstrate *proof-of-concept* for SRP in a flight environment
- Replicate *relevant SRP physics* using a *minimally integrated system*
- Collect data during flight within acceptable uncertainties to satisfy relevant TRL achievement criteria
- Demonstrate the ability to design, package, integrate, and test SRP subsystems
- Reduce the risks associated with increasingly complex follow-on flight tests

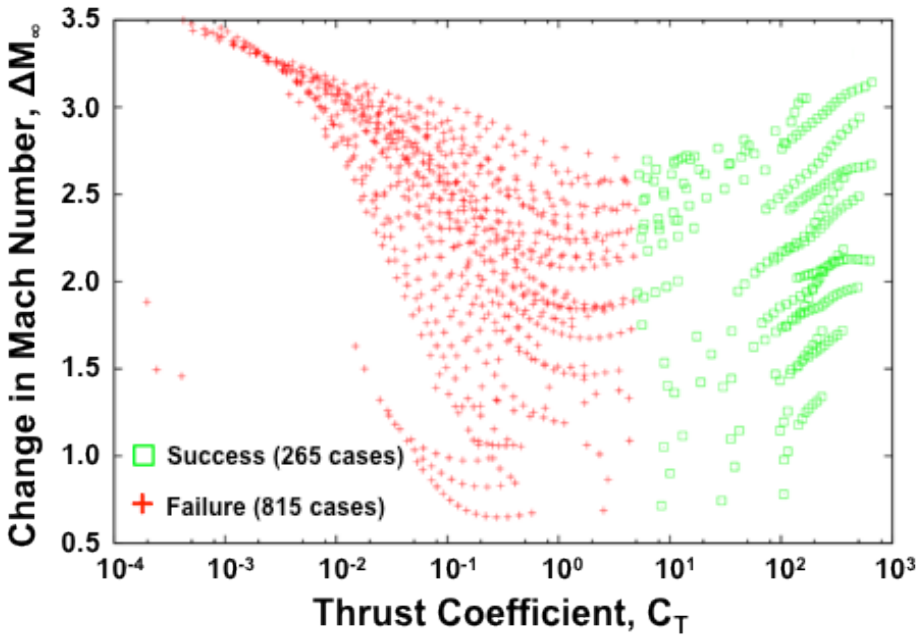
## Mission Requirements Summary

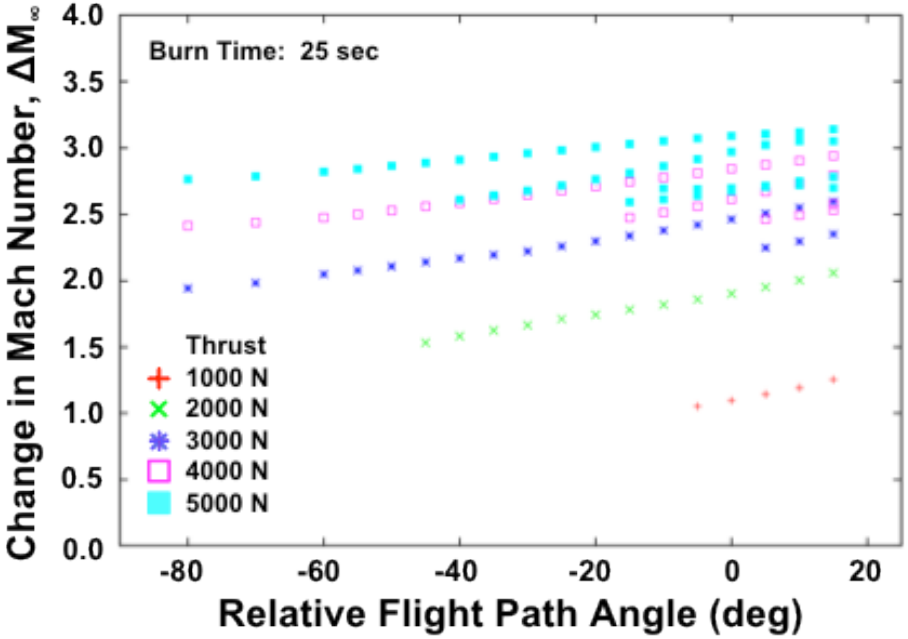
- Achievement of SRP ("hot", propulsive jet flow against a supersonic freestream)
- Ballistic and stable flight throughout entire mission trajectory
- Utilization of existing components for launch system and test article
- Collection and analysis of data required for post-flight reconstruction, including:
  - Atmospheric characterization
  - 6-DOF vehicle state
  - Propulsion system performance and state
  - In-situ surface pressure and temperature

| **Test Phase Requirements** | |
|---|---|
| Duration | > 15 sec |
| $M_\infty$ at initiation | > 2.0 |
| $C_T$ | > 5.0 |

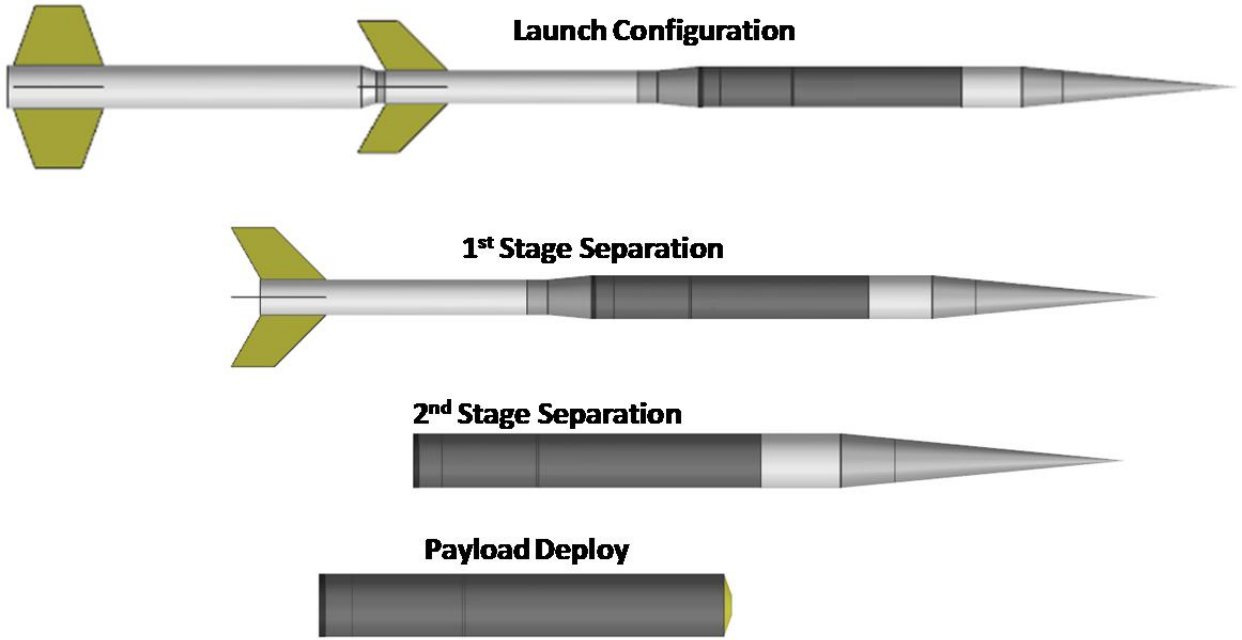
# Initial Trade Study

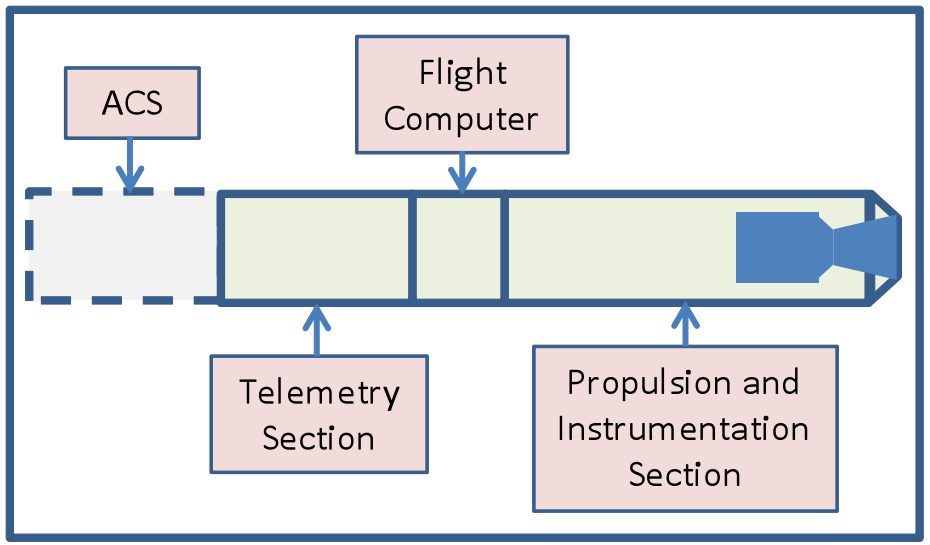
- Objective:
  - Determine if a typical sounding rocket trajectory is a viable option for FT1
- Constraints:
  - $C_T > 5.0$
  - SRP initiation at Mach 3.5



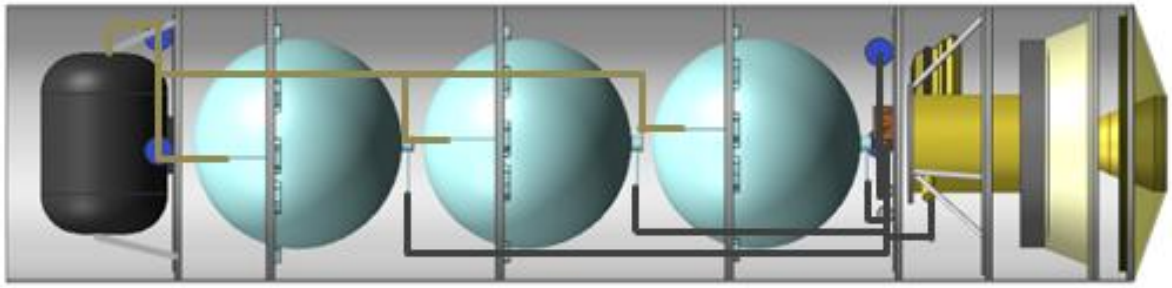



# Generalized Flight Test Article

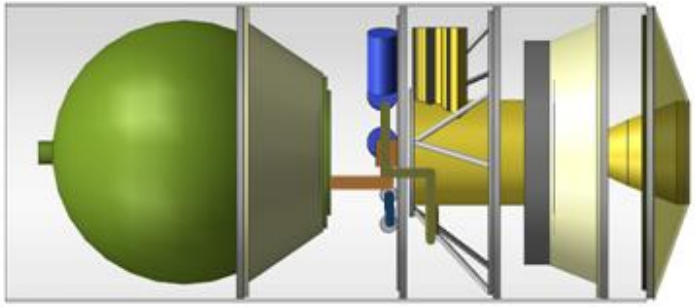


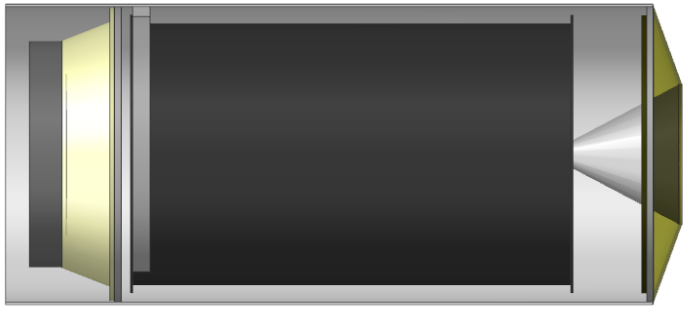
# Concept Specific Packaging Study



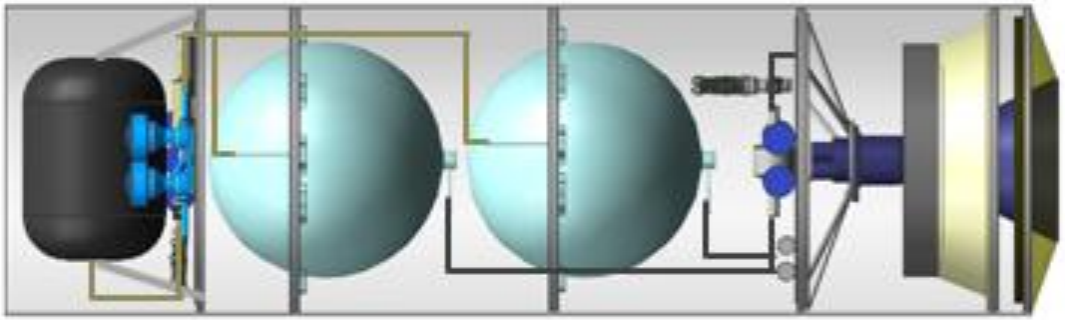
Pressure-Fed Monopropellant



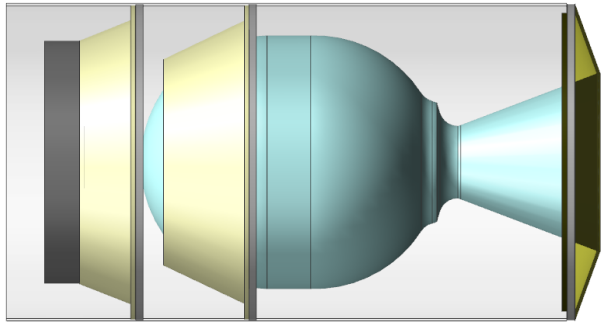
Blow-Down Monopropellant



STAR 15G SRM

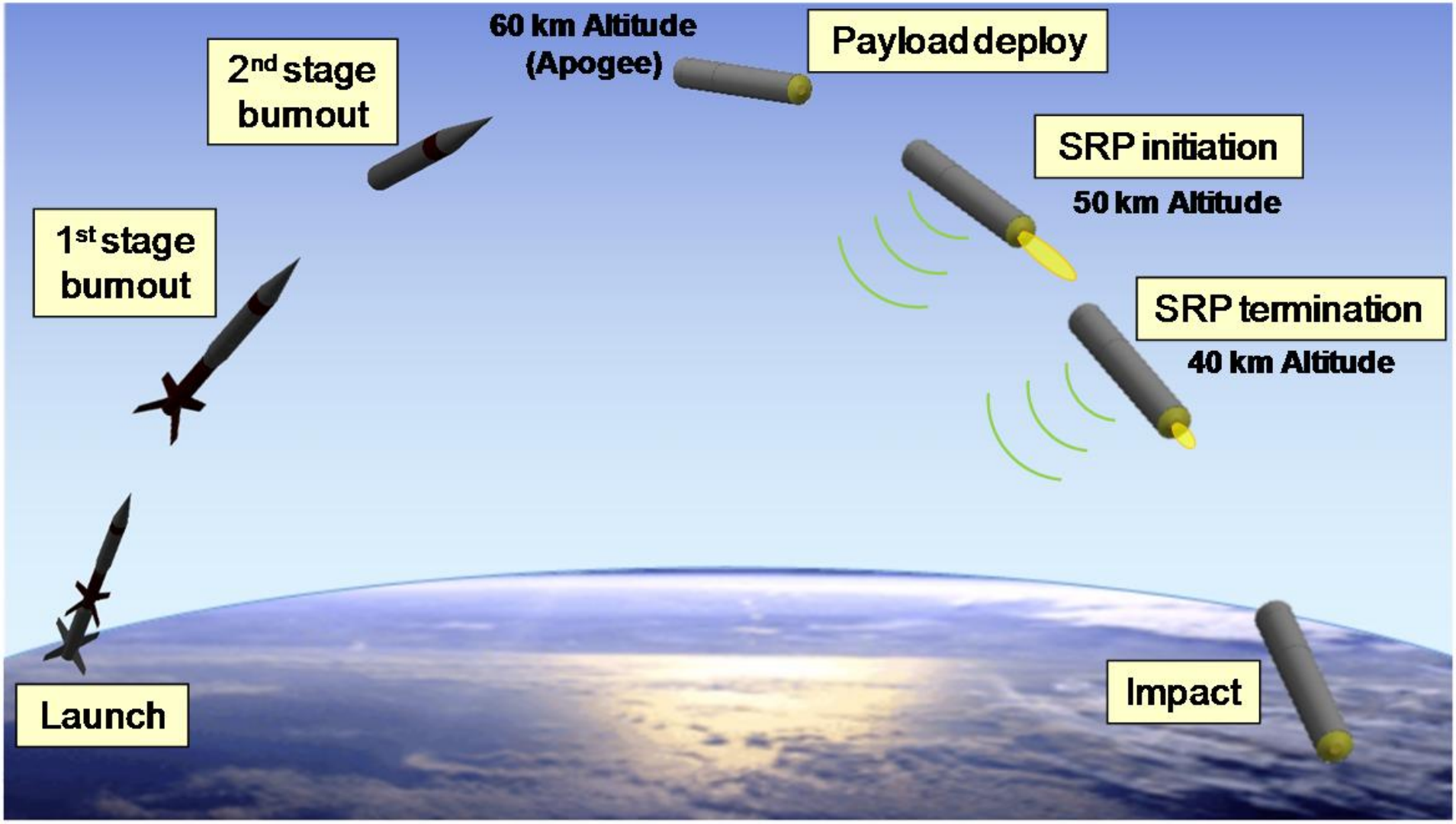


Pressure-Fed Bipropellant



STAR 13B SRM

# Concept of Operations



# Concept Specific Trade Study

- Objective:
  - Examine 5 FT 1 concepts using 3 different propellant types and explore the test space for each
- Trade Variables:
  - Propellant type
  - Packaging configuration
- Constraints:
  - $C_T > 5.0$
  - Post-shock stagnation pressure less than the nozzle exit static pressure ($p_{02} < p_e$)
- Trajectory based on Terrier-Improved Orion launch vehicle with test initiation at:
  - 50 km altitude
  - Flight path angle = -30.3°
  - Velocity = 871 m/s

# Trade Study Results

| Concept | Propellant Type | Burn Time (sec) | Thrust (N), max/min | $C_{T,min}$ | $p_{02,max} / p_e$ (< 1.0) | $\Delta M_\infty$ |
|---|---|---|---|---|---|---|
| 1 | $N_2O_4$ / MMH | 30.0 | 4003 / 4003 | 8.0 | 0.680 | 0.85 |
| 2 | Hydrazine (Pressure-fed) | 35.0 | 3100 / 3100 | 4.2 | 1.170 | 0.40 |
| 3 | Hydrazine (Blow-down) | 24.0 | 3100 / 800 | 2.0 | 0.950 | 0.02 |
| 4 | Solid (STAR 13B) | 15.6 | 9643 / 6007 | 75.0 | 0.104 | 1.40 |
| 5 | Solid (STAR 15G) | 36.4 | 12460 / 1744 | 80.0 | 0.144 | 2.10 |

# Status and Forward Work

- **Gathering information to focus the effort**
  - Options
    - Launch platforms
    - Test vehicle architectures
    - Propulsion systems
  - Performance criteria include $C_T$, range of Mach number
    - Small perceived benefit to test initiation at $M_\infty > 2$
    - Deceleration through the transonic regime viewed as strongly beneficial

- **View of test as proof-of-concept allows for de-emphasis on some performance differences between architectures, providing that:**
  - Test phase is initiated at supersonic conditions
  - $C_T > 5$ is maintained over majority of test phase

- **Evaluating important cost factors**
  - Sounding rocket costs less than Viking BLDT type platform
  - Determine costs of actively controlled vs. passively stabilized test vehicle
  - Compare hard costs and schedule costs of viable test vehicle engine options
    - Long lead time (years) and other availability issues with some motors
    - Opportunities to obtain left-over RCS engines from Space Shuttle
    - Opportunities to use industrial grade engines/tanks
    - Opportunities to partner with engine developers ($LOX/CH_4$)

# Summary

- Sounding rocket identified as a viable platform for a proof of concept flight test of SRP
  - Identified a large range of trajectories capable of satisfying test phase requirements
- Five flight test concepts were considered
  - Demonstrated ability to package concepts on a sounding rocket
  - Additional cost information to be gathered for each concept
- Identified two Concept of Operations that satisfy test phase requirements
  - Trajectories and ConOps will be optimized following down-selection of flight test concepts

# Acknowledgements

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