# ADEPT Sounding Rocket One (SR-1) Flight Test

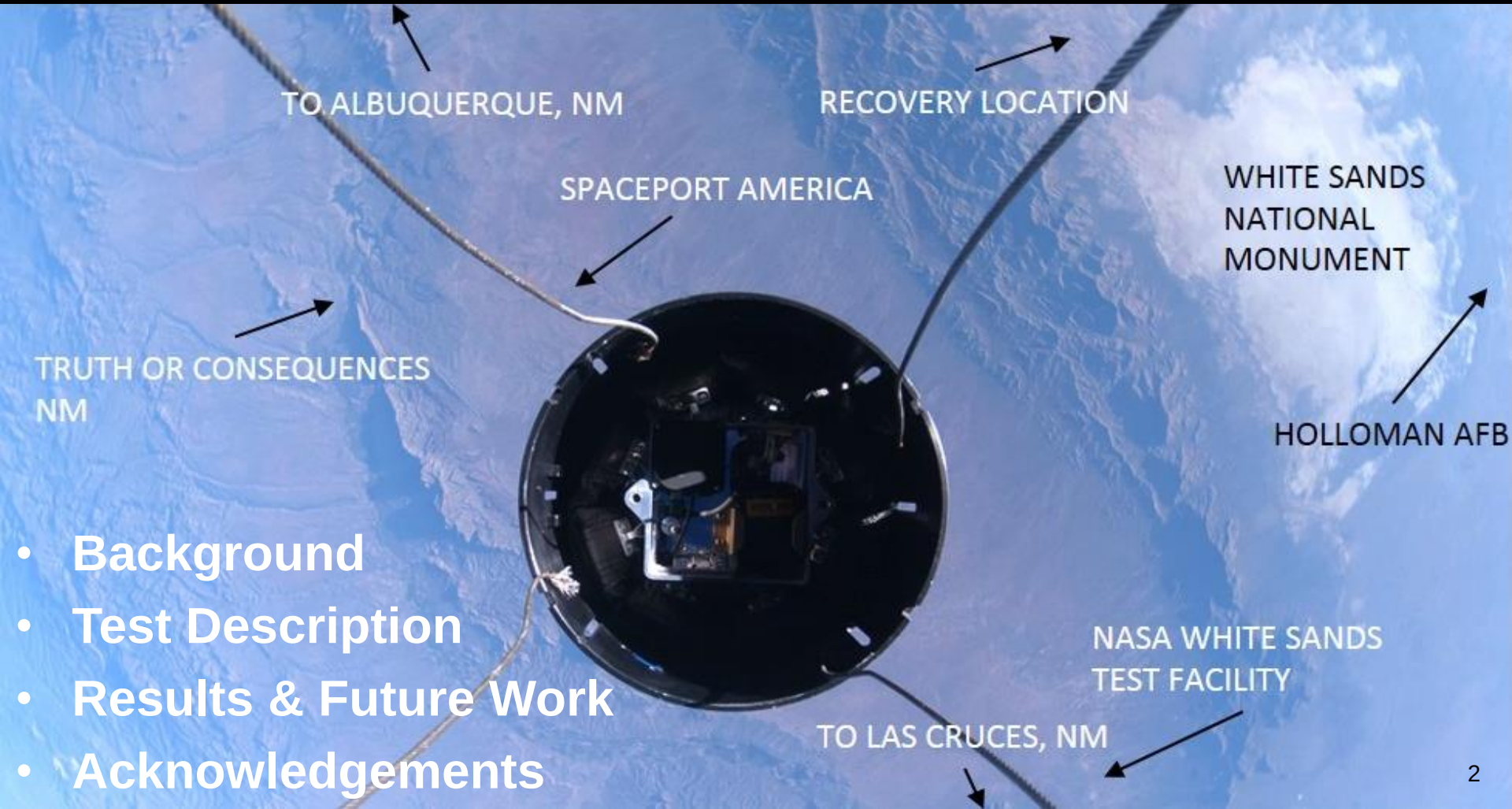
**Alan Cassell, Paul Wercinski, Ethiraj Venkatapathy**

*Entry Systems & Technology Division*

*NASA Silicon Valley Ames Research Center*

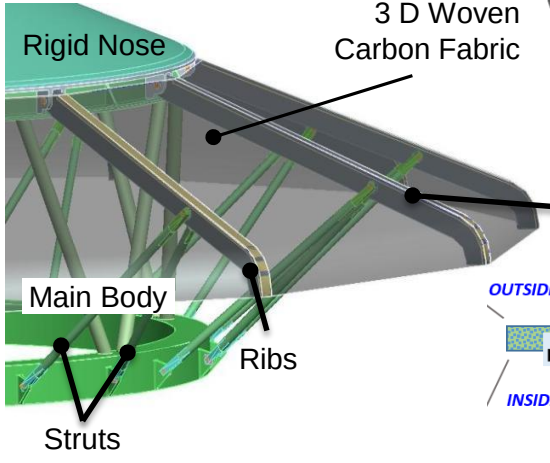
*Moffett Field, California*

# Outline

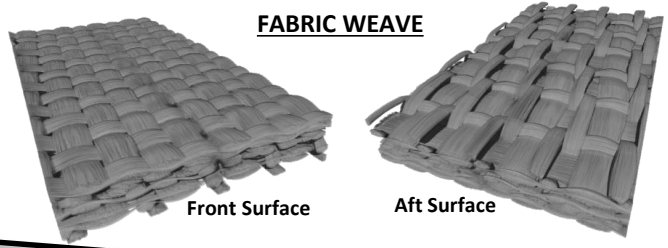



- Background
- Test Description
- Results & Future Work
- Acknowledgements

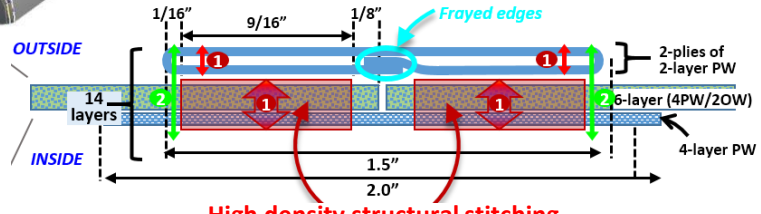
# Adaptive Deployable Entry and Placement Technology



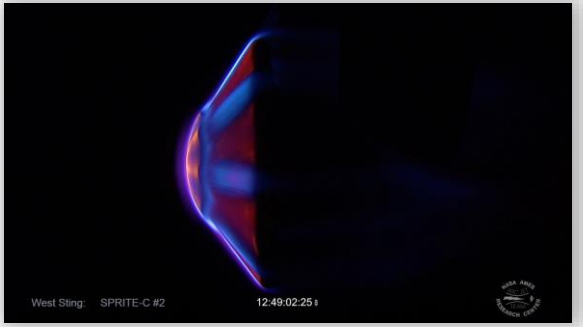

**FABRIC WEAVE**




**FABRIC JOINT DESIGN**




**System Level Aerothermal Testing**




Dual use **3d woven carbon fabric** TPS/structural membrane. 12-layer fabric demonstrated for high heat load entries. Fabric tested to 250 W/cm$^2$ (2100 °C).

**2 m Deployment Prototype Time Lapse Video**

-Electrically driven actuators achieve high fabric pre-tension

**SR-1 Deployment Test Video**

-Three stage spring-based deployment actuation.

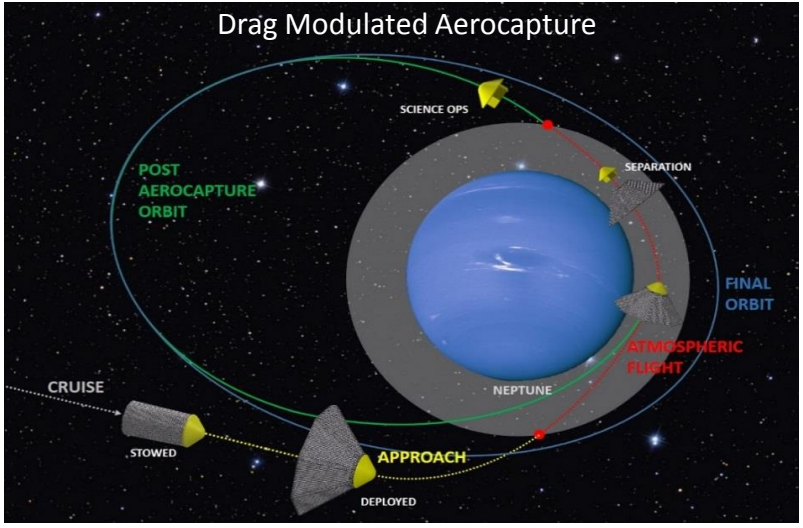
# ADEPT Mission Applicability

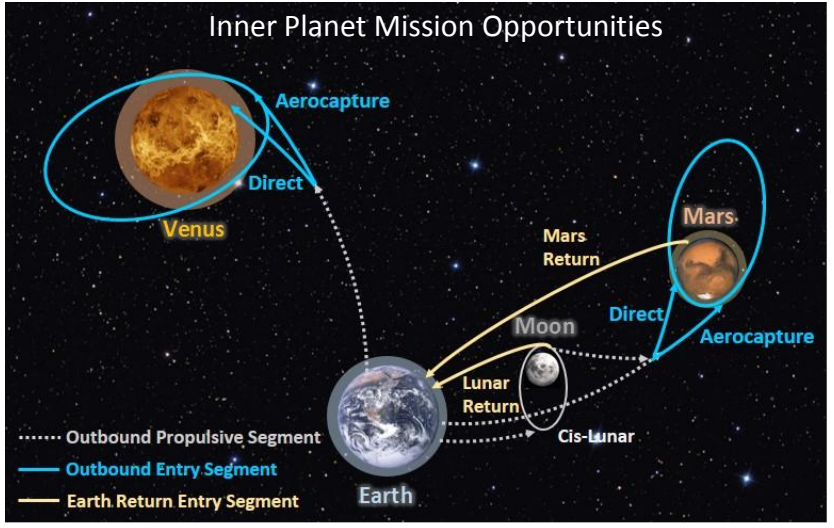
## ➢ Science & Exploration Applicability

- (< 2 m) Small Satellite mission designers can utilize ADEPT for direct entry and/or aerocapture.
- (> 10 m) Human Mars exploration class missions require large drag area decelerators capable of precision targeting/landing.
- Guidance and control system integration with ADEPT enables precision targeting and landing. Project Pterodactyl technology development ongoing.

## ➢ Mission Opportunities

- Investigating robotic sample return capability for cis-Lunar exploration applications.
- Drag-Modulated Aerocapture at Venus, Mars & the Ice Giants.
- Robotic & Human Exploration at Mars. Enhanced hypersonic drag capability and precision targeting.



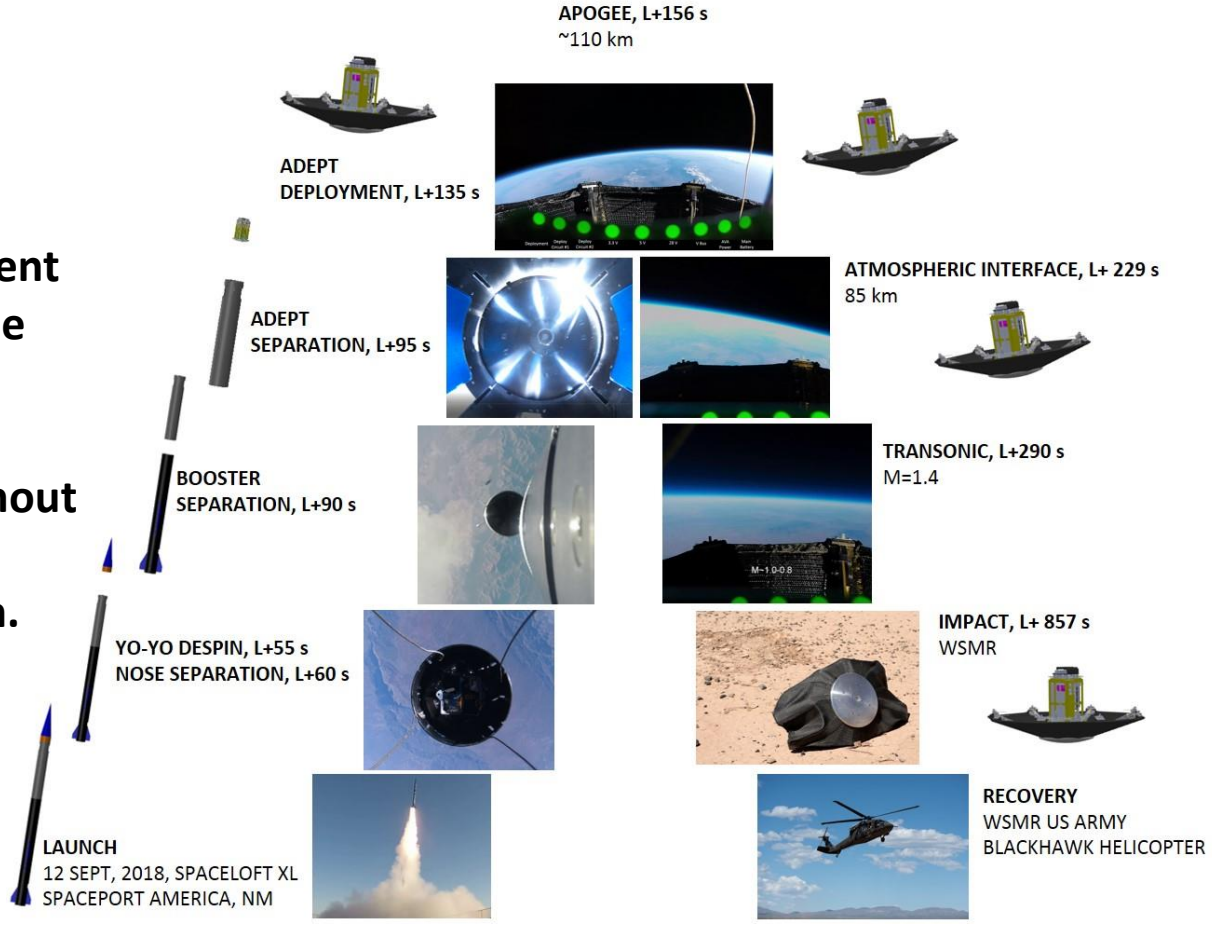



# Operations Timeline

## Key Performance Parameters

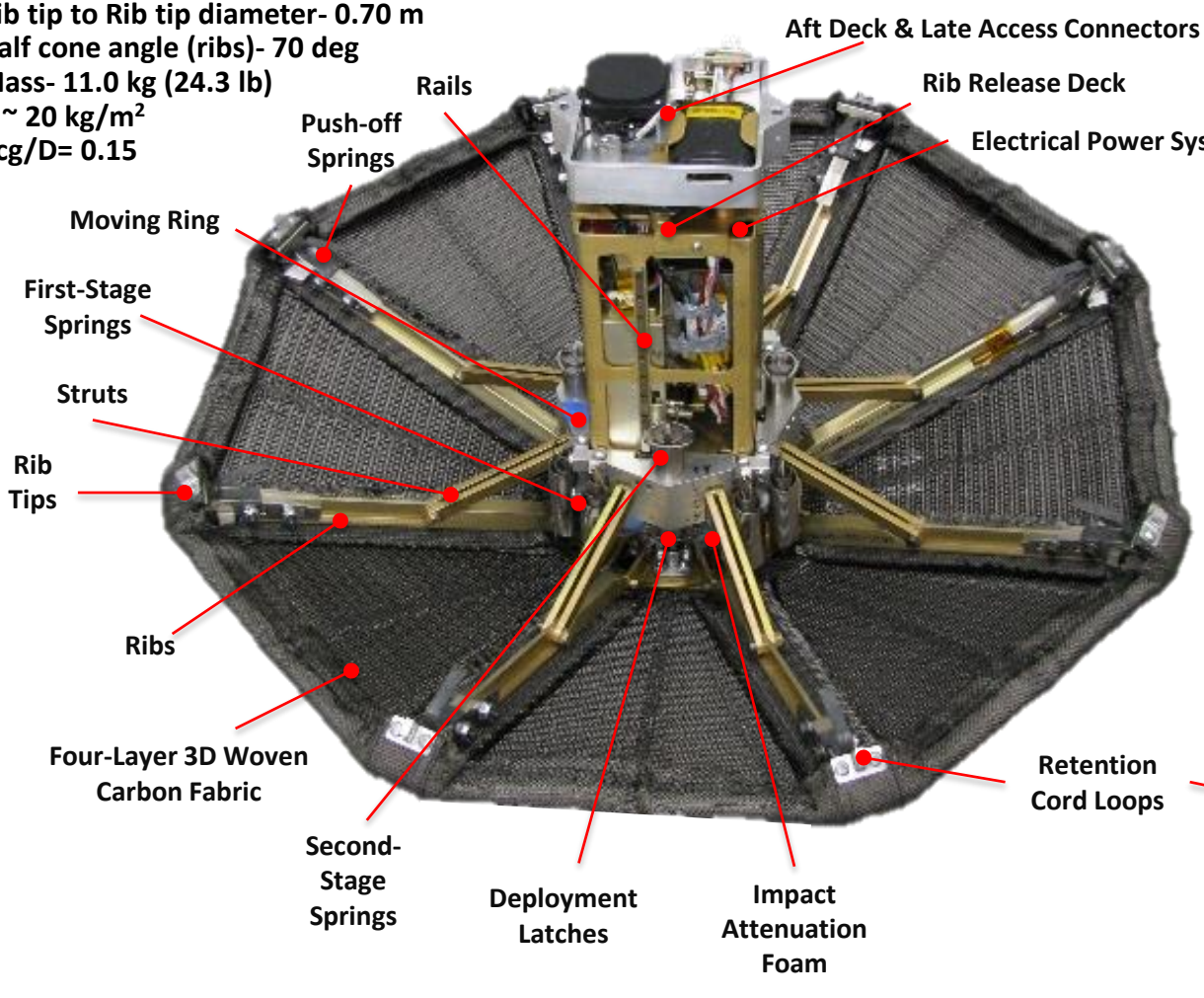
**#1- Exo-atmospheric deployment to an entry configuration of the 1m-class ADEPT.**

**#2- Aerodynamic stability without active control of the 1m- class ADEPT in a flight configuration.**

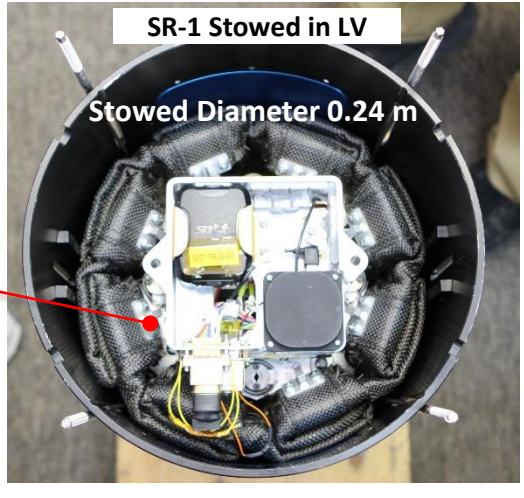


# SR-1 Flight Article Description

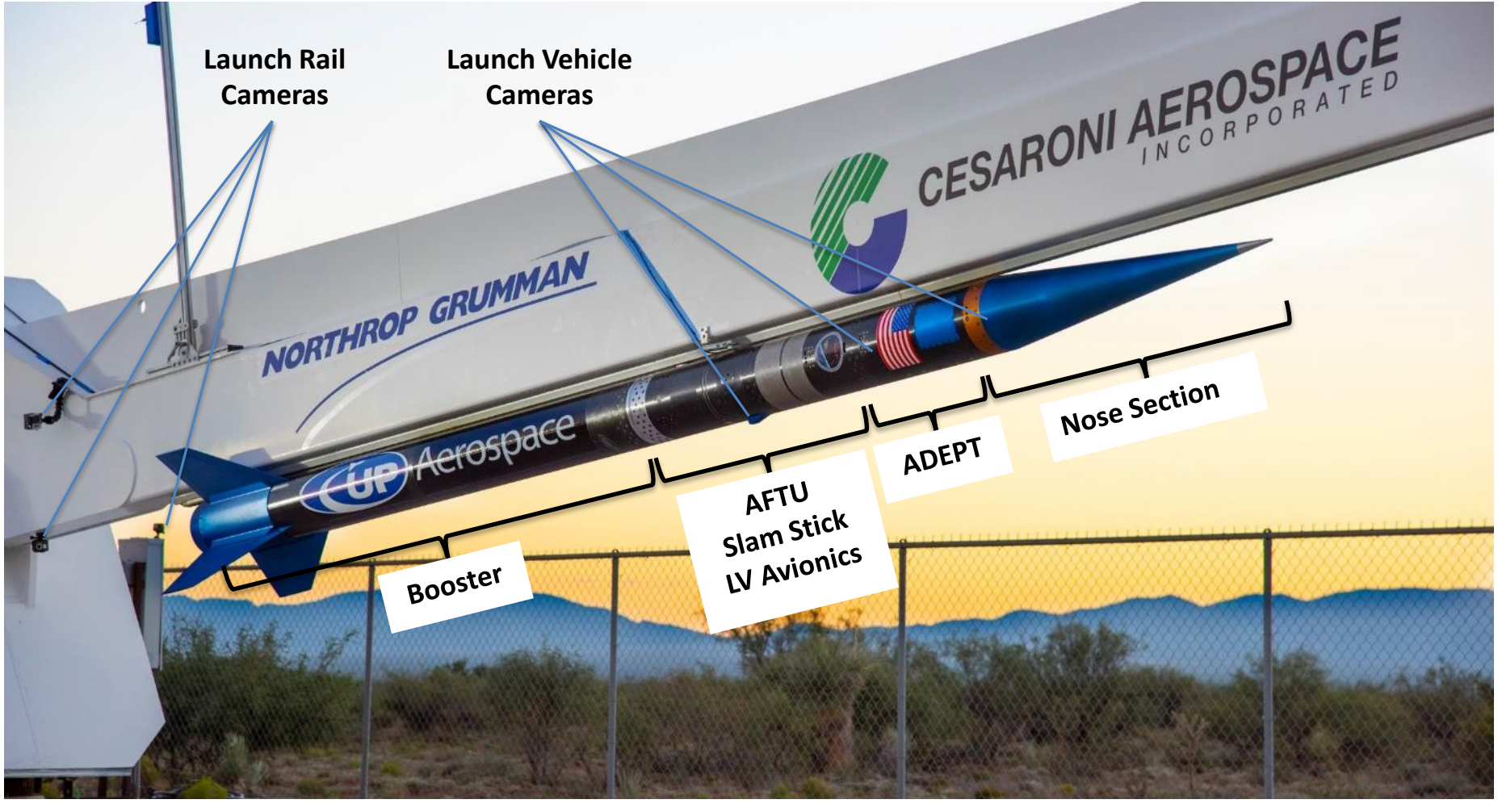
- Rib tip to Rib tip diameter- 0.70 m
- Half cone angle (ribs)- 70 deg
- Mass- 11.0 kg (24.3 lb)
- $\beta$~ 20 kg/m$^2$
- Xcg/D= 0.15




| Instrumentation | Data/Function |
|---|---|
| AVA | Accelerometers, Rate Gyros, Magnetometer, GPS Tracking |
| NGIMU | Accelerometers, Rate Gyros, IMU Board Temp Sensors |
| LED Indicator Board | System Health Indicator Status |
| GoPro Video | 1080p, 60 fps video |
| C-Band Transponder | WSMR Radar Tracking |
| SPOT Trace | GPS Recovery Tracker |
| Separation Sensors | Power-on signal for deployment timer, C-Band & GoPro |
| Deployment Switch | Indicates full deployment |

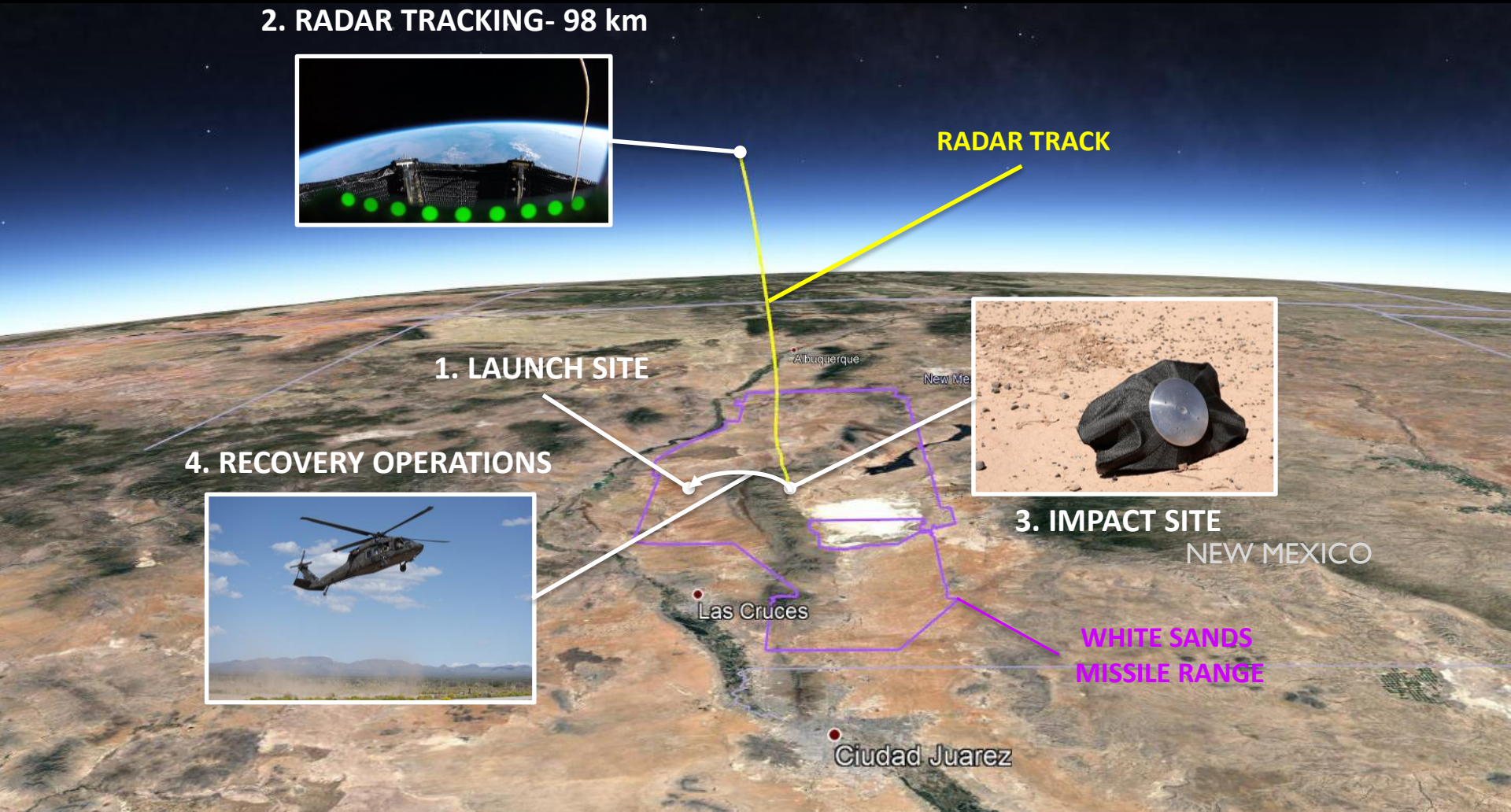


# Launch Vehicle

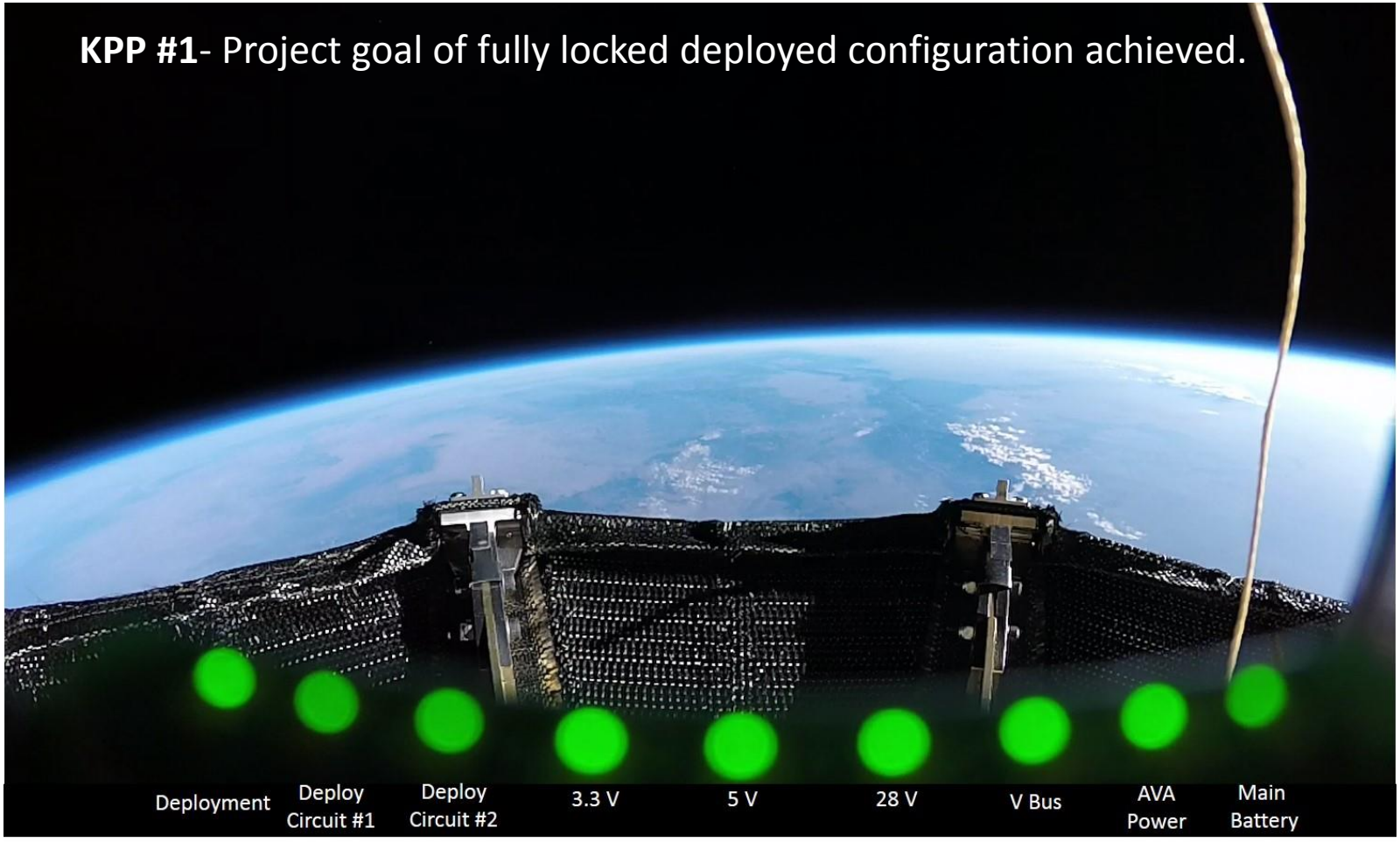


# Launch & On-board Video

# Results- Radar Tracking & Vehicle Recovery



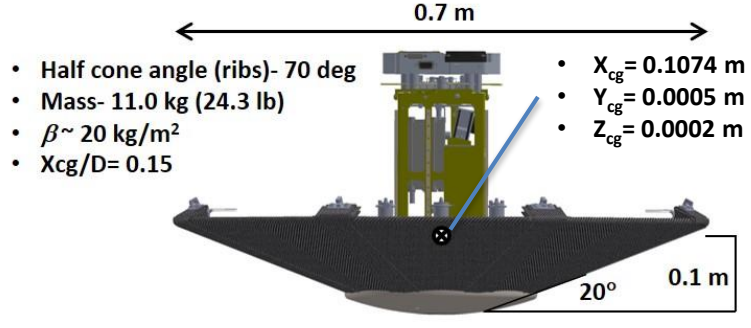
# Results- Full Deployment & Health Status

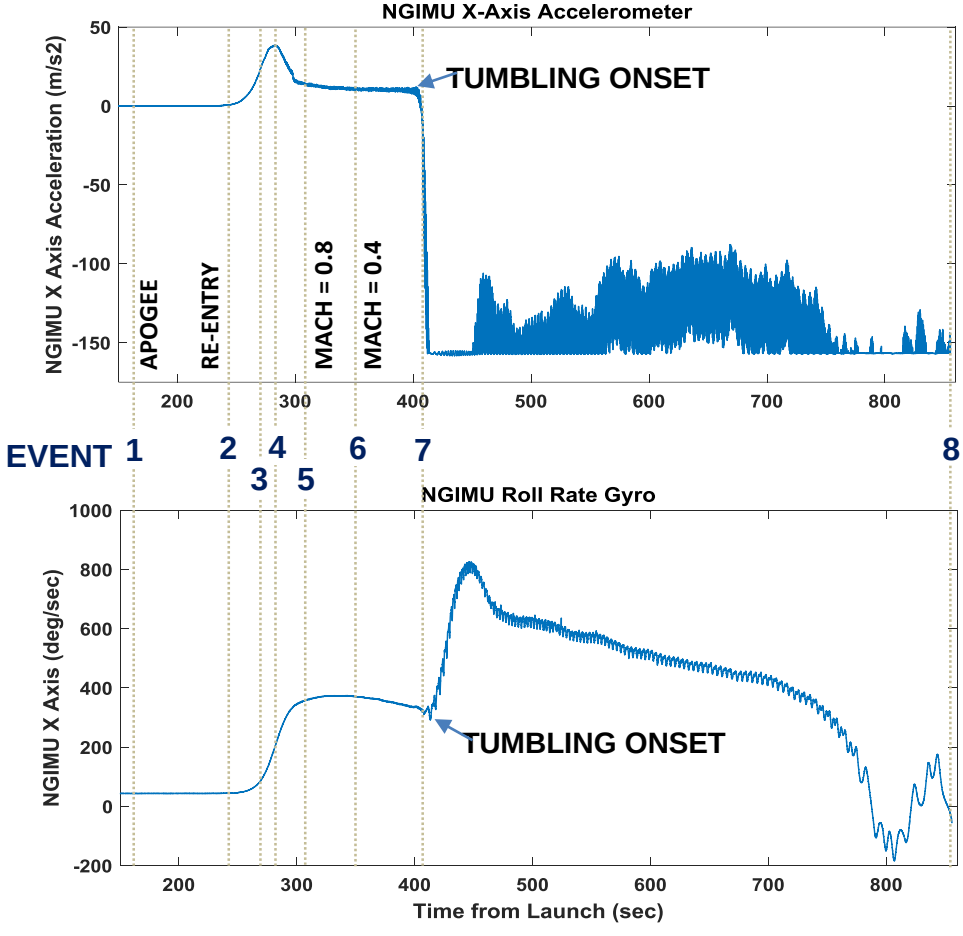


# Results- Reentry, Descent & Impact

**KPP #2**- Project threshold of no tumbling prior to M=0.8 achieved

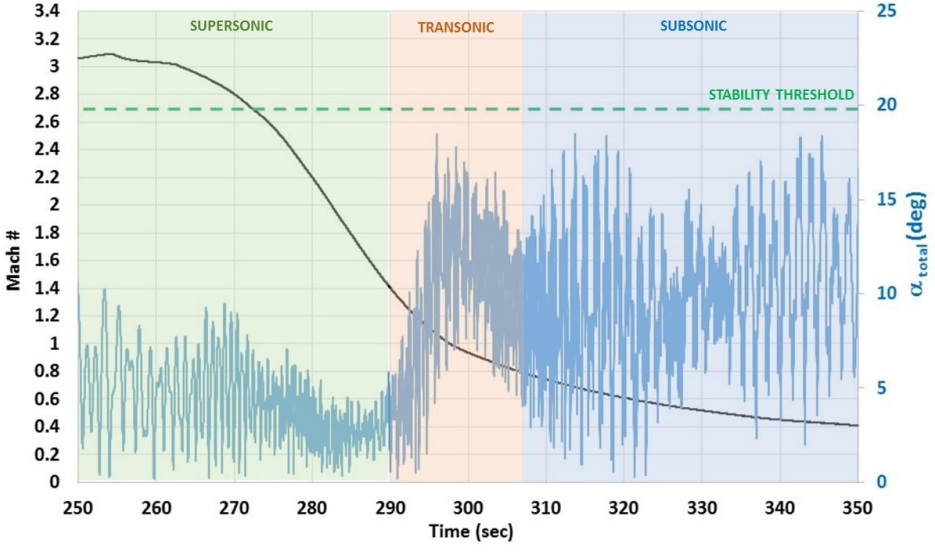
| EVENT # | DESCRIPTION | PREDICTED TIME (SEC) | ACTUAL TIME (SEC) |
|---|---|---|---|
| 1 | APOGEE 110 km | 161 | 156 |
| 2 | ADEPT RE-ENTRY 85 km | 244 | 229 |
| 3 | PEAK MACH 3.2 | 270 | 254 |
| 4 | PEAK DYNAMIC PRESSURE 822 Pa | 294 | 282 |
| 5 | MACH 0.8 | 318 | 307 |
| 6 | MACH 0.4 | 363 | 352 |
| 7 | TUMBLING OCCURED | - | 407 |
| 8 | IMPACT (~25 m/sec) | 879 | 856 |

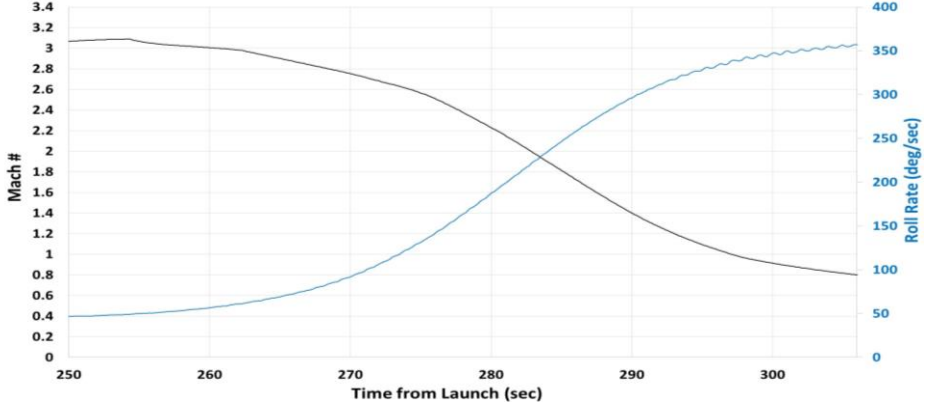


# Results- Trajectory Reconstruction

- Trajectory reconstruction simulated at 100 Hz using LV IMU, AVA IMU, AVA Magnetometer, radar tracking and atmospheric models using an Extended Kalman Filter-Smoother code call NewSTEP. For more details see **“Reconstruction of the ADEPT Sounding Rocket One Flight Test” AIAA Aviation 2019**
- Total angle of attack remains below stability threshold of 20 degrees through M=0.4.
- The spin rate increase through supersonic deceleration was unexpected**.** Post flight analysis is ongoing to determine cause.
- For details on the flight mechanics modeling, see: “**Flight Mechanics Modeling and Post-Flight Analysis of ADEPT SR-1**” **AIAA Aviation 2019**



# Summary

| SR-1 Key Performance Parameters | | |
|---|---|---|
| **Performance Parameter** | **Threshold Value** | **Project Goal** |
| **#1- Exo-atmospheric deployment to an entry configuration of the 1m-class ADEPT.** | **Less than fully locked condition resulting in shape with less than 70-degree fore body cone angle.** | **Full, locked deployment before reaching 80 km altitude on descent, to 70-degree fore body cone angle achieving 6x greater drag area.** |
| **#2- Aerodynamic stability without active control of the 1m- class ADEPT in a flight configuration.** | **Does not tumble prior to M=0.8 while decelerating from peak Mach # (when Mach number is decreasing after passing through peak Mach number).** | **ADEPT does not tumble* before ground impact; Sign of pitch damping coefficient (Cmq) is determined; FF-CFD simulation tool is validated** |

## Mission Success Criteria

A. ADEPT separates from the sounding rocket prior to apogee- SUCCESSFUL

B. ADEPT does not re-contact any part of the launch vehicle after separation- SUCCESSFUL

C. ADEPT reaches an apogee greater than 100 km- SUCCESSFUL

D. ADEPT achieves fully deployed configuration prior to reaching 80 km altitude on descent- SUCCESSFUL

E. Obtain on-board video of deployed ADEPT to observe fabric response during entry- SUCCESSFUL

F. Obtain data necessary to reconstruct ADEPT 6-DOF descent trajectory- SUCCESSFUL

# Acknowledgements


- Soumyo Dutta (LaRC, Flight Mechanics Lead)
- Shakib Ghassemieh (Ames, Lead Avionics Systems Engineer)
- Chris Karlgaard (LaRC-TEAMS2, Traj. Reconstruction)
- Ashley Korzun (LaRC, Aerosciences Lead)
- Carl Kruger (Ames, Mechanical Design)
- Ali Guarneros-Luna (Ames, SS & MA)
- Owen Nishioka (Ames, Mechanical Design)
- Brandon Smith (Ames, SR-1 Principal Investigator)
- Paul Wercinski (Ames, Project Manager)
- Joseph Williams (Ames-AMA, Instrumentation and Test)
- Shang Wu (Ames, Electrical Systems Lead)
- Bryan Yount (Ames, Structures and Mechanics Lead
- Steve Battazzo (Ames, AVA Integration)
- Chad Brivkalns (Ames, Mechanical Design)
- Juan Cruz (LaRC, Aerodynamic Testing)
- Neil Davies (Ames, Electrical Technician)
- Dzung Hoang (Ames, Test support)
- Nghia Mai (Ames, Electrical Testing Support)
- Alberto Makino (Ames, Structural Testing and Analysis)
- Mark Mallinson (Ames, Risk and CM Manager)
- Ryan McDaniel (Ames, Aero CFD)
- Matt Padilla (Ames, Electrical Technician)
- Justin Green (LaRC, Traj Reconstruction)
- Jake Tynis (LaRC-TEAMS3, Traj Reconstruction)

**Space Technology Mission Directorate:**

- Game Changing Development Program
- Flight Opportunities Program

**Spaceport America**

**White Sands Missile Range**

**Bally Ribbon Mills**

**Thin Red Line Aerospace**



# Questions?

# References


1. Venkatapathy, E., et al, “Adaptive Deployable Entry and Placement Technology (ADEPT): A Feasibility Study for Human Missions to Mars” AIAA Aerodynamic Decelerator Systems Technology Conference, May 23-26, 2011, Dublin, Ireland. AIAA 2011-2608
2. Arnold, J., et al., “Thermal and Structural Performance of Woven Carbon Cloth for Adaptive Deployable Entry and Placement Technology,” AIAA Aerodynamic Decelerator Systems Technology Conference, March 25-28, 2013, Daytona Beach, FL.
3. Arnold, J., et al. “Arcjet Testing of Woven Carbon Cloth for Use on Adaptive Deployable Entry Placement Technology.” IEEE Aerospace Conference, March, 2013, Big Sky, MT.
4. Yount, Bryan, C., et al. “Structures and Mechanisms Design Concepts for Adaptive Deployable Entry Placement Technology” AIAA Aerodynamic Decelerator Systems Technology Conference, March 25-28, 2013, Daytona Beach, FL.
5. Kazemba, C., et al, “A Versatile 3D-Woven Carbon Fabric for Broad Mission Application of ADEPT” International Planetary Probe Workshop, June 16-20, 2014, Pasadena, CA.
6. Smith, B., et al, “ADEPT for Secondary Payloads” International Planetary Probe Workshop, June 16-20, 2014, Pasadena, CA.
7. Yount, Bryan, C., Kruger, Carl, E., Cassell, Alan, M., Kazemba, Cole, D. “Deployment Testing of the ADEPT Ground Test Article. International Planetary Probe Workshop, June 16-20, 2014, Pasadena, CA.
8. Smith, B. P., Cassell, A. M., Kruger, C. E., Venkatapathy, E., Kazemba, C. D., Simonis, K. R., “Nano-ADEPT: An Entry System for Secondary Payloads,” *IEEE Aerospace Conference*, Big Sky, MT, March 2015.
9. Smith, B., et al “Nano-ADEPT Aeroloads Wind Tunnel Test” IEEE Aerospace Conference, 2016.
10. Cassell, Alan, M., et al. “System Level Aerothermal Ground Testing for the Adaptive Deployable Entry and Placement Technology.” International Planetary Probe Workshop, June 13-17, 2016, Laurel, MD.
11. Cassell, A. M., et al “Human Mars Mission Design Study Utilizing the Adaptive Deployable Entry and Placement Technology” *IEEE Aerospace Conference*, Big Sky, MT, March 2017.
12. Wercinski, P. F. et al., “ADEPT Sounding Rocket One (SR-1) Flight Experiment Overview,” *IEEE Aerospace Conference*, Big Sky, MT, March 2017.
13. Cassell, A. M., et al “ADEPT, a Mechanically Deployabe Re-Entry Vehicle System, Enabling Interplanetary CubeSat and Small Satellite Missions” *SmallSat* 2018, Logan, UT, August 2018.
14. Cassell, A., et al “ADEPT for Interplanetary Small Satellite Missions” Interplanetary Small Satellite Conference, 29-30 April, 2019, San Luis Obispo, CA.
15. Cassell, A. M., et al “ADEPT Sounding Rocket One Test Overview” *AIAA Aviation Conference*, Dallas, TX, 17-21 June 2019.
16. Korzun, A. M., Dutta, S., McDaniel, R. D., Karlgaard, C., Tynis, J. A., “Aerodynamics for the ADEPT SR-1 Flight Experiment,” *AIAA Aviation Conference*, Dallas, TX, 17-21 June 2019.
17. Cruz, J. R., Green, J. S., “Subsonic Dynamic Testing of a Subscale ADEPT Entry Vehicle,” *AIAA Aviation Conference*, Dallas, TX, 17-21 June 2019.
18. Tynis, J. A., Karlgaard, C., “Reconstruction of the Adaptable Deployable Entry and Placement Technology Sounding Rocket One Flight Test,” *AIAA Aviation Conference*, Dallas, TX, 17-21 June 2019.
19. Dutta, S., Green, J. S., “Flight Mechanics Modeling and Post Flight Analysis of ADEPT SR-1,” *AIAA Aviation Conference*, Dallas, TX, 17-21 June 2019.
20. D’Souza, S. D., Johnson, B. J., Okolo, W. A., Nikaido, B. E., Smith, B. P., “Pterodactyl: Developing a Design, Build and Test Capability for Non-propulsive Control Systems for Lifting Nano-ADEPT,” *AIAA Aviation Conference*, Dallas, TX, 17-21 June 2019.