ADEPT Sounding Rocket One Flight Test Overview

Alan Cassell
Entry Systems & Vehicle Development Branch
NASA Silicon Valley Ames Research Center

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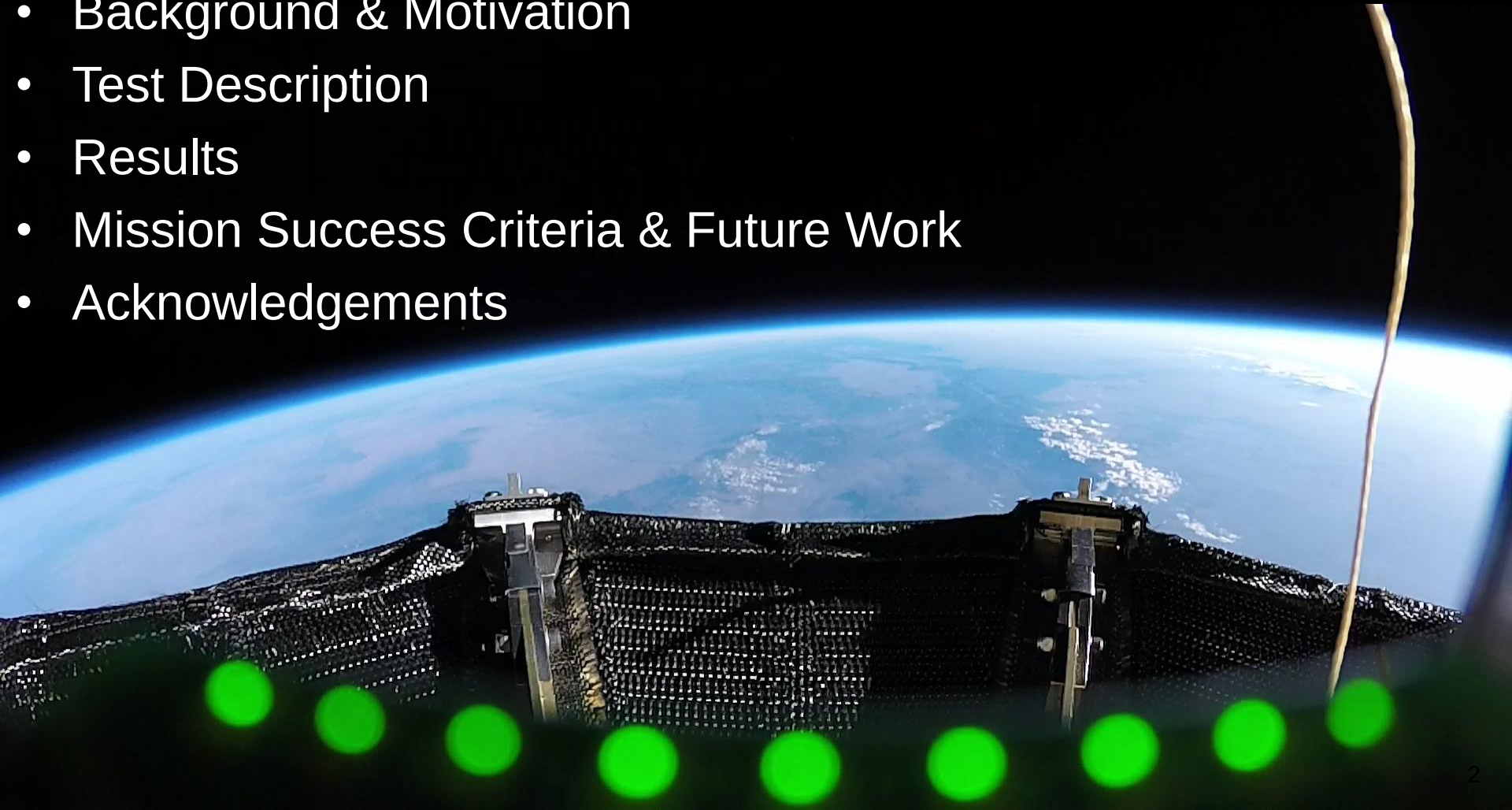
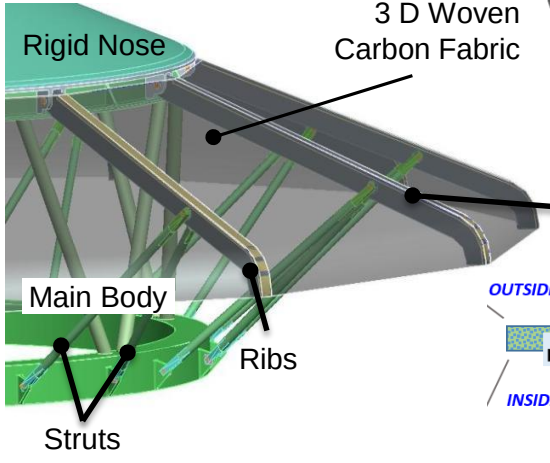
Outline

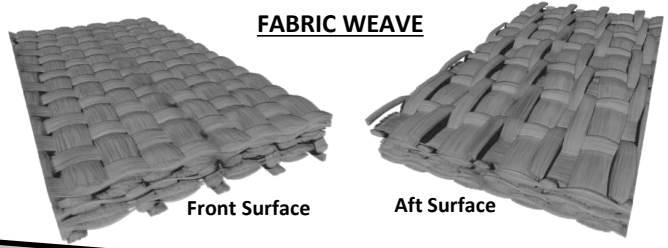
- Background & Motivation
- Test Description
- Results
- Mission Success Criteria & Future Work
- Acknowledgements



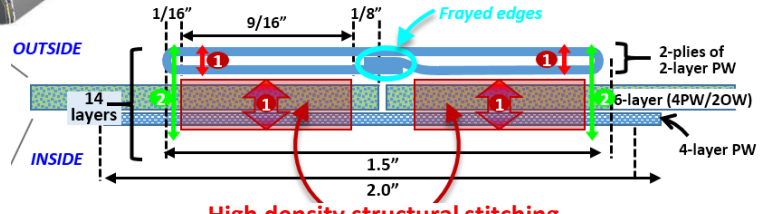
Adaptive Deployable Entry and Placement Technology



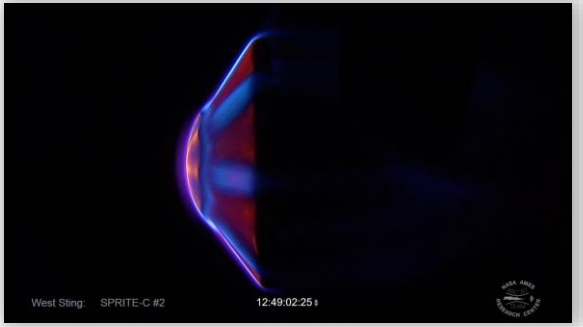
FABRIC WEAVE



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 Time Lapse Video

-Three stage spring-based deployment actuation.

ADEPT Mission Applicability

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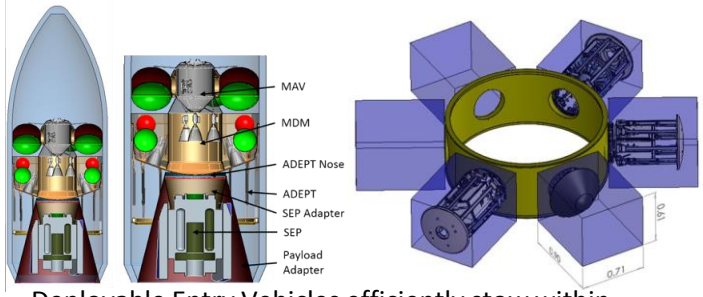
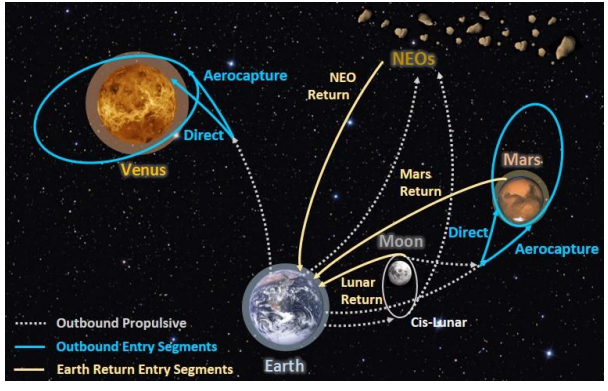
LAUNCH VEHICLE PACKAGING

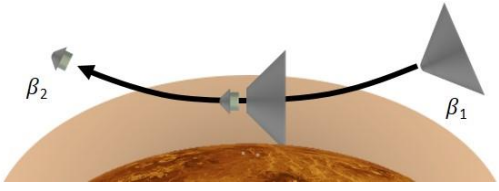


Deployable Entry Vehicles efficiently stow within launch vehicle primary or secondary volume. Once deployed, high drag area reduces entry loads over conventional rigid aeroshells.

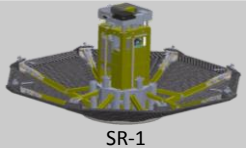
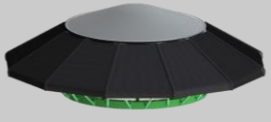
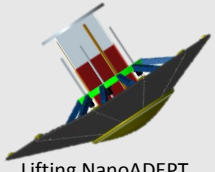
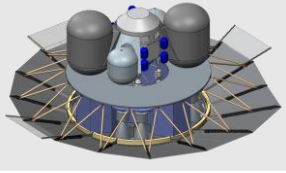
RELEVANT MISSION CONCEPTS



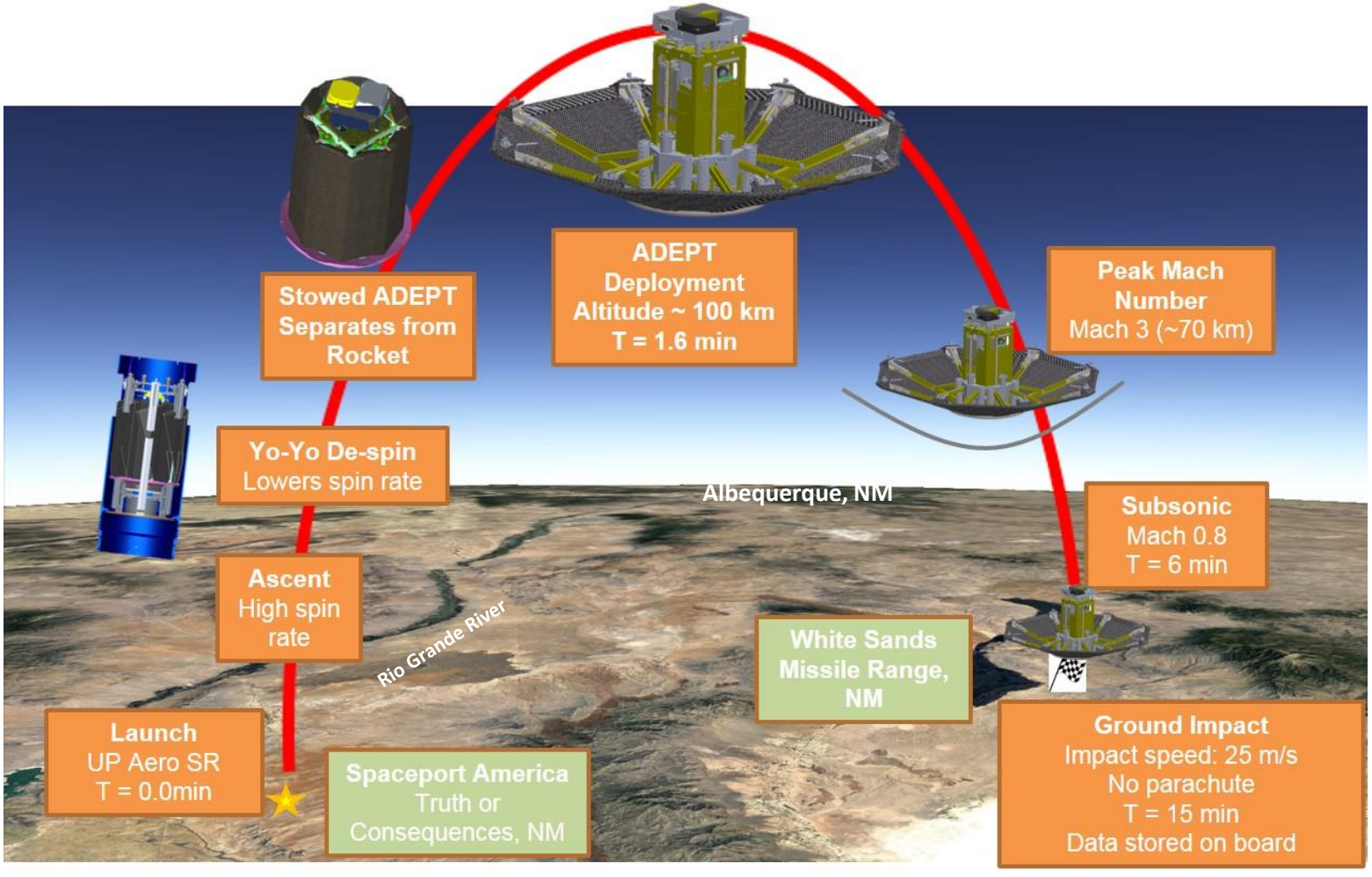
DRAG MODULATED AEROCAPTURE



ADEPT is being considered for Aerocapture missions to Mars & Venus for Small Satellite class payloads.

ADEPT Designs	SmallSat Class (Tech Demo or Secondary Payload)	Robotic Class (Discovery)	Flagship or New Frontiers Class	Exploration Class (Human Mars)
Ballistic Concepts	 SR-1  Aft Drag Skirt	**Design Trades Underway**	 ADEPT VITaL	
Lifting Concepts	 Lifting NanoADEPT  Project Pterodactyl	**Design Trades Underway**	**Design Trades Underway**	
Diameter Range	**< 3 m**	**2-6 m**	**6-10 m**	**>16 m**

ADEPT SR-1 Operations Concept



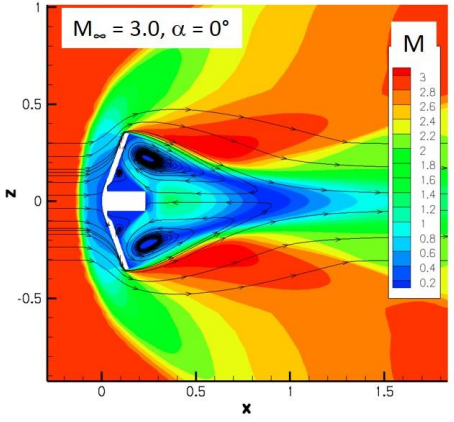
Test Objectives & Success Criteria

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 forebody 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.
B	ADEPT does not re-contact any part of the launch vehicle after separation.
C	ADEPT reaches an apogee greater than 100 km.
D	ADEPT achieves fully deployed and locked configuration prior to reaching 80 km altitude.
E	Obtain on-board video of deployed ADEPT to observe fabric response and flight dynamics during entry.
F	Obtain data necessary to reconstruct ADEPT 6 DOF descent trajectory to ***required accuracy below*** with 95% confidence from Mach 3.0 while decelerating to ground impact: a. Mach number: 0.1 b. Drag coefficient: Larger of 5% or 0.005 c. Total angle of attack: 2 deg (if not tumbling) d. Sign of pitch damping sum

SR-1 Development Campaign Highlights

AERODYNAMICS DATABASE DEVELOPMENT



- Static and dynamic aerodatabase predictions were used to perform preflight trajectory analysis of vehicle performance and helped inform risk and safety management.
- Details in upcoming talk entitled: "**Aerodynamics for the ADEPT SR-1 Experiment**" presented by Ashley Korzun.

FREE-FLIGHT DYNAMICS TESTING

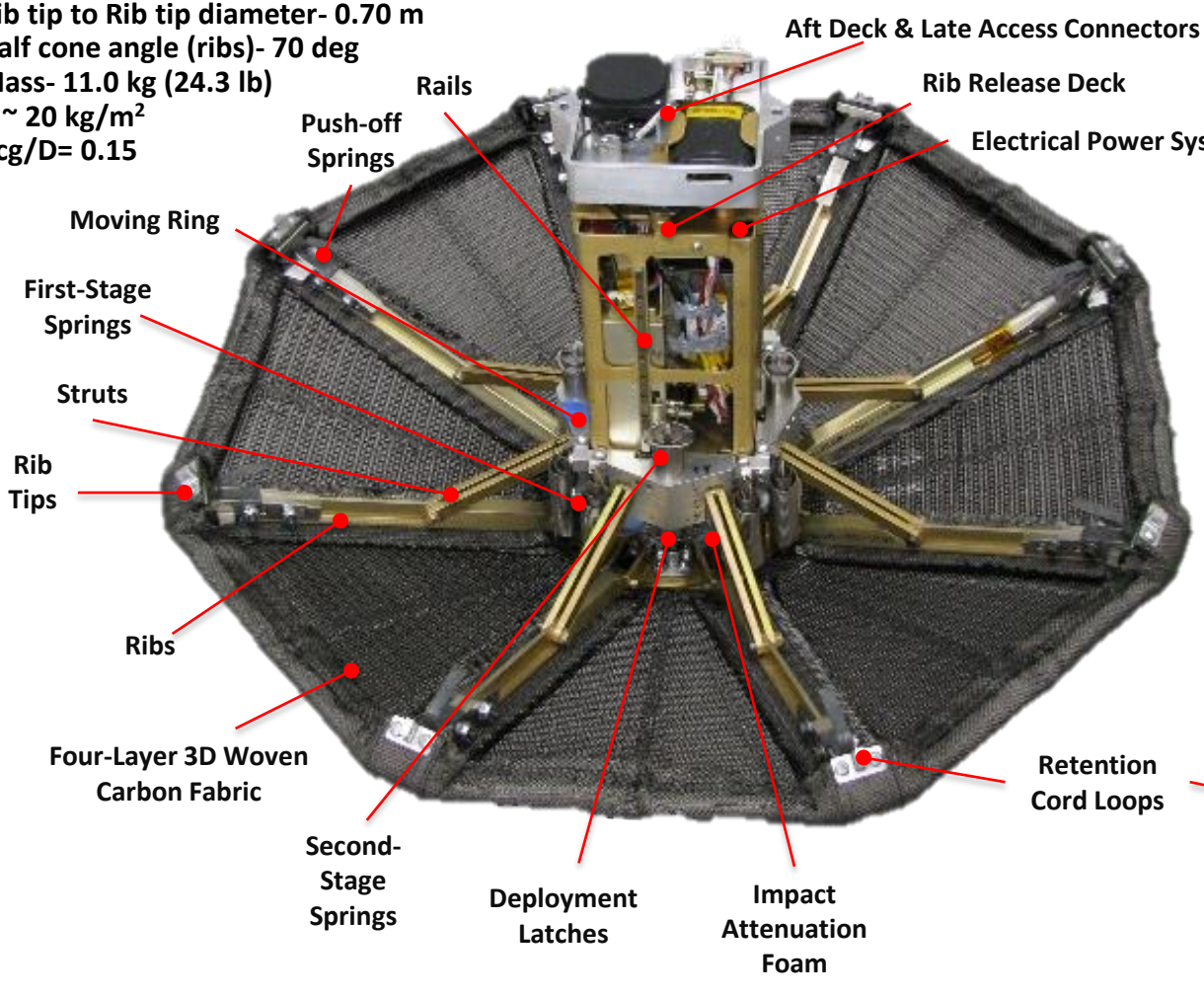
- Assessed the dynamic behavior of ADEPT SR-1 at sub-sonic speeds, and aided in the selection of center of mass location to maximize likelihood of nose first impact. Testing performed in the Langley Vertical Spin Tunnel.
- "**Subsonic Dynamic Testing of a Subscale ADEPT Entry Vehicle**" presented by Justin Green.

IMPACT TESTING

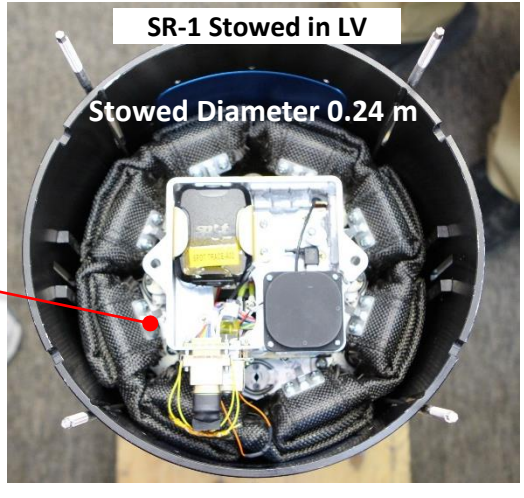
- Drop testing enabled testing of various impact attenuators, characterization of impact load and demonstrated survivability of the on-board memory cards and battery design robustness.
- Impact testing also enabled battery safety procedures to be rehearsed in the event of severe damage to the rechargeable lithium-ion batteries upon impact.

SR-1 Flight Article Description

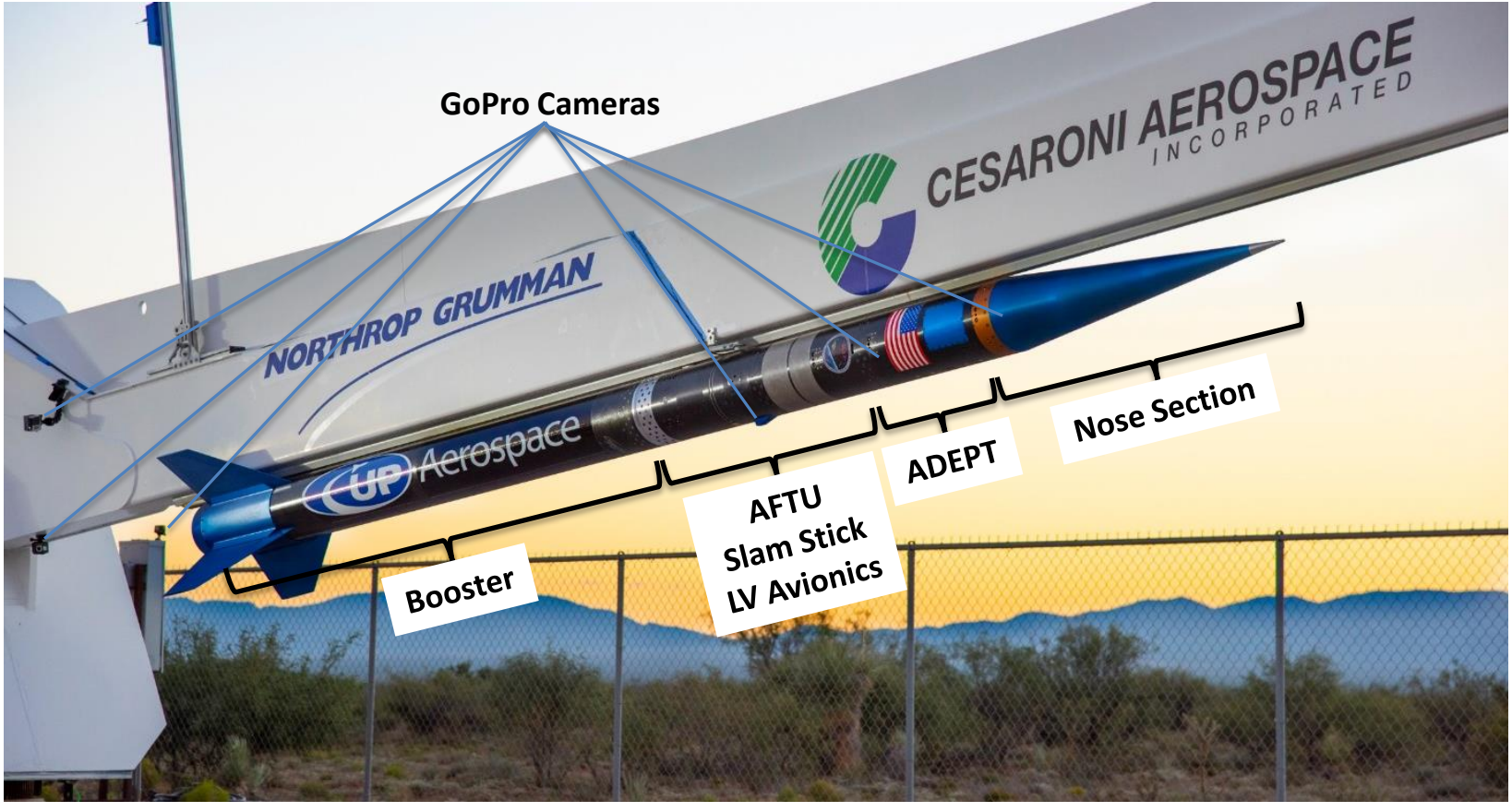
- Rib tip to Rib tip diameter- 0.70 m
- Half cone angle (ribs)- 70 deg
- Mass- 11.0 kg (24.3 lb)
- β~ 20 kg/m^2
- Xcg/D= 0.15



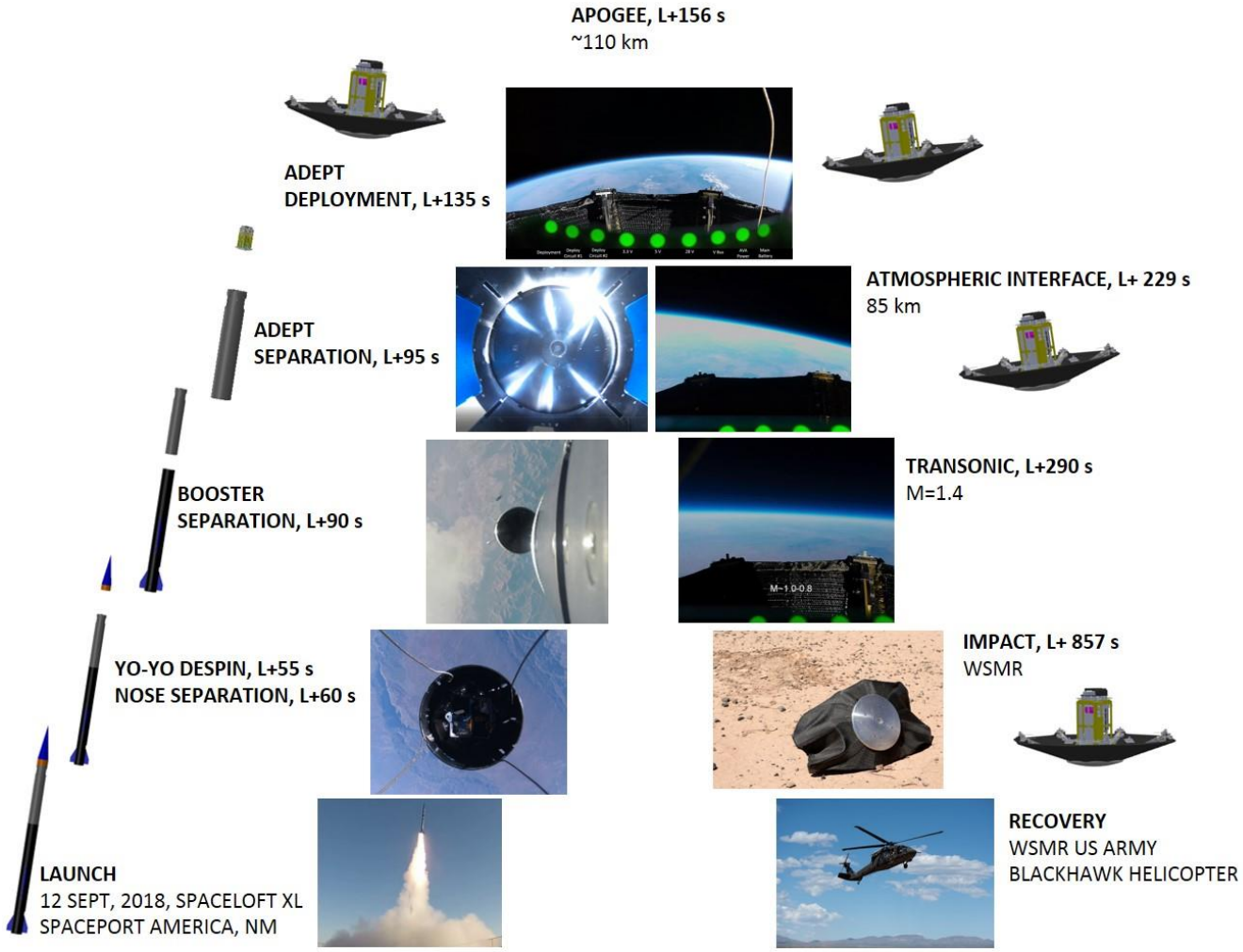
Instrumentation	Data/Function
AVA	Accelerometers, Rate Gyros, Magnetometer, GPS Tracking
NGIMU	Accelerometers, Rate Gyros, IMU Board Temp Sensors
LED Indicator Board	System Health Indicator Status
GoPro Video	1080p, 60 fps video
C-Band Transponder	WSMR Radar Tracking
SPOT Trace	GPS Recovery Tracker
Separation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



Launch Vehicle Description



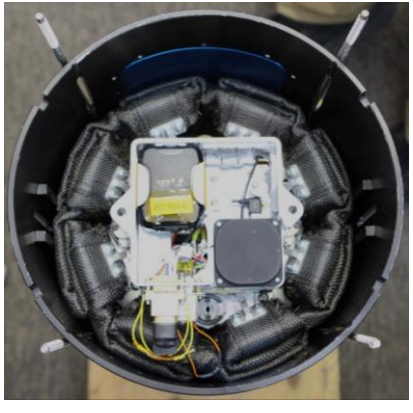
Operations Timeline



Pre-Launch Preparations

9/8/18- Compatibility Check & Vehicle Integration



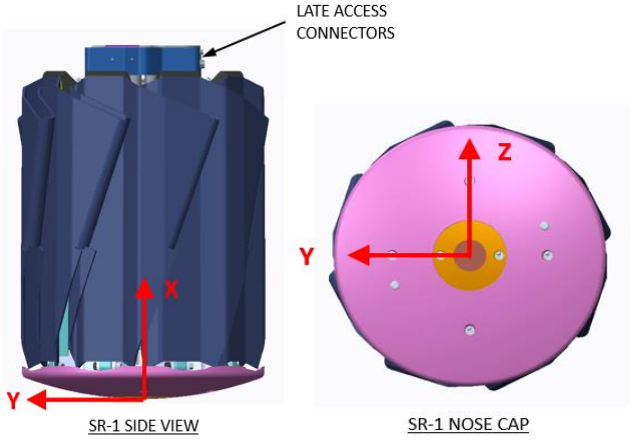



9/11/18- Mission Dress Rehearsal


9/12/18- Launch Day Power-Up Procedures

Launch & On-board Video

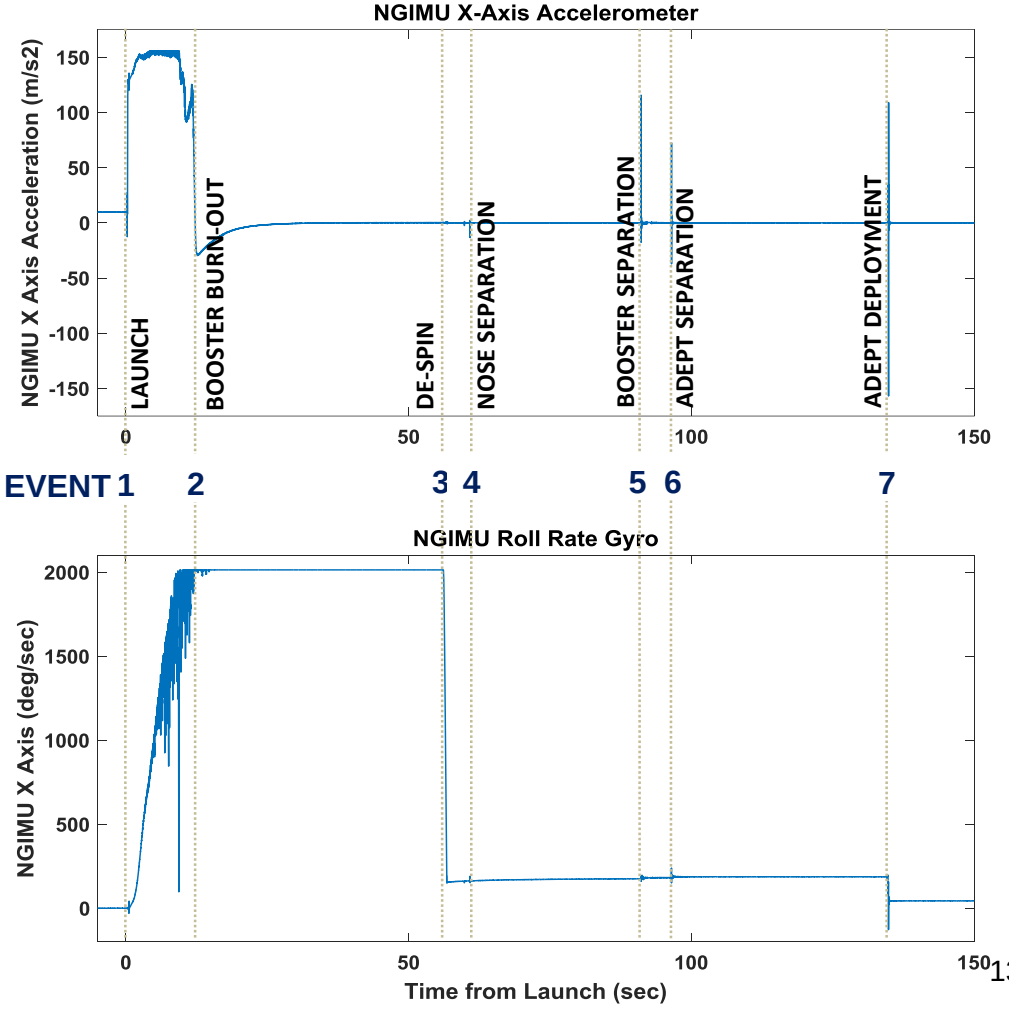
Results- Ascent & Exoatmospheric Deploy



SR-1 SIDE VIEW

SR-1 NOSE CAP

EVENT #	DESCRIPTION	PLANNED TIME (SEC)	ACTUAL TIME (SEC)
1	LIFTOFF	N/A	N/A
2	BOOSTER BURN-OUT*	12	12
3	DE-SPIN DEPLOY*	55	55
4	NOSE FAIRING SEPARATION*	60	60
5	BOOSTER SEPARATION*	90	90
6	ADEPT SEPARATION*	95	95
7	ADEPT DEPLOY*	100	*135*



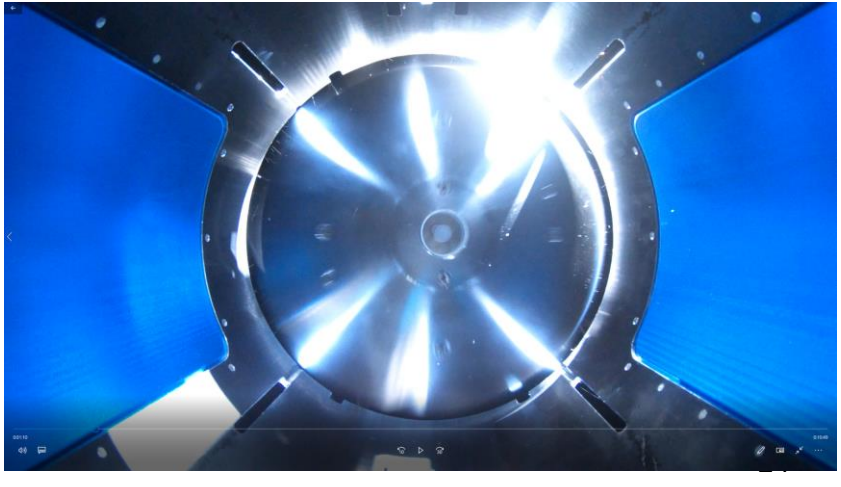
Video Stills- Ascent & Exoatmospheric Deploy

Launch

LV Nose Camera After Separation

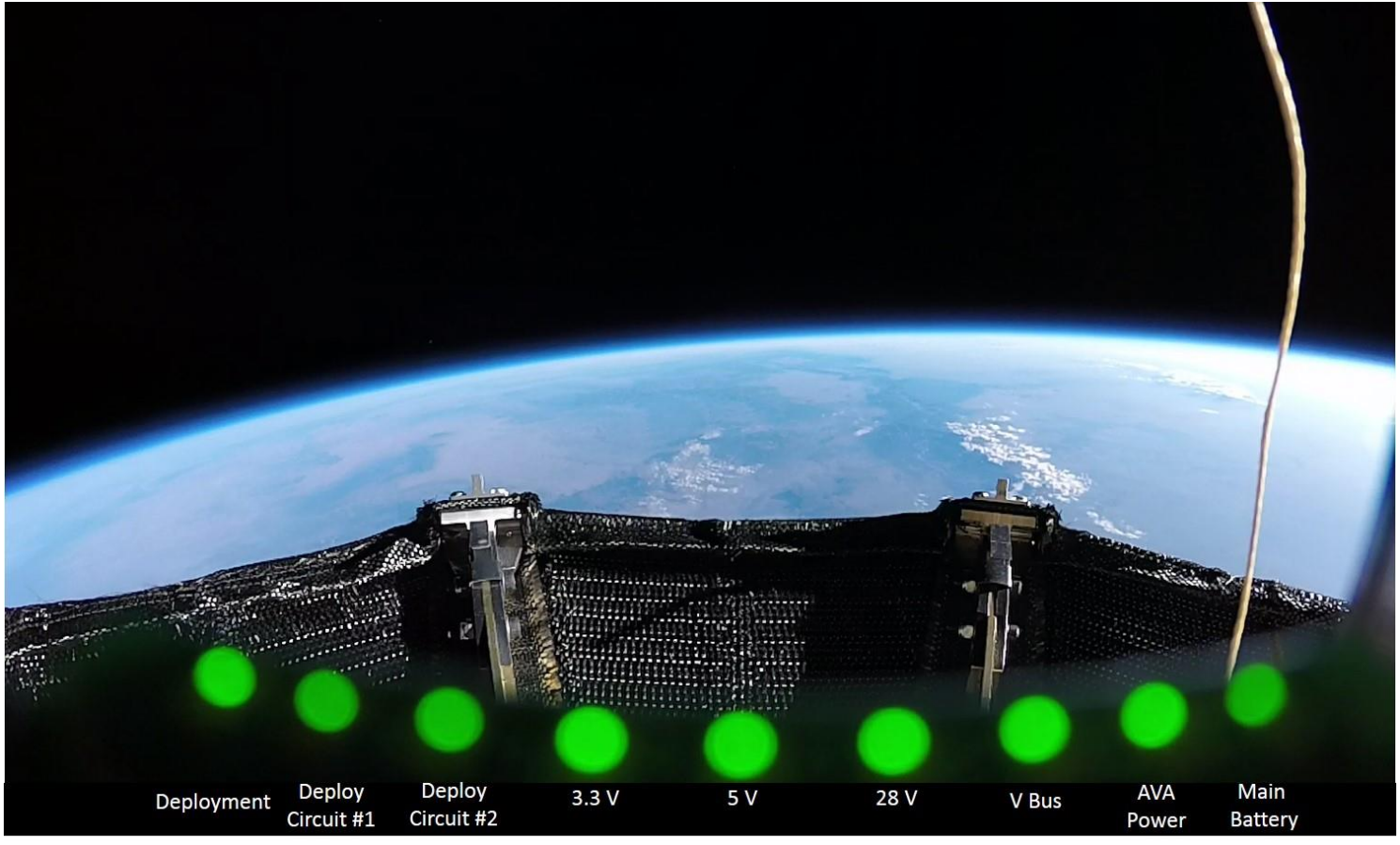
LV Nose Camera Prior to Booster Separation

Payload Separation Section Camera at ADEPT Separation



Results- Full Deployment & Health Status

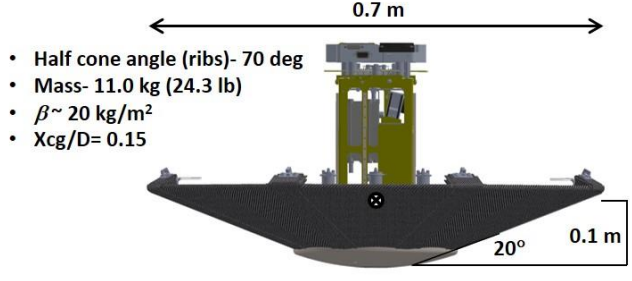
KPP #1- Project goal of full and locked deployment achieved

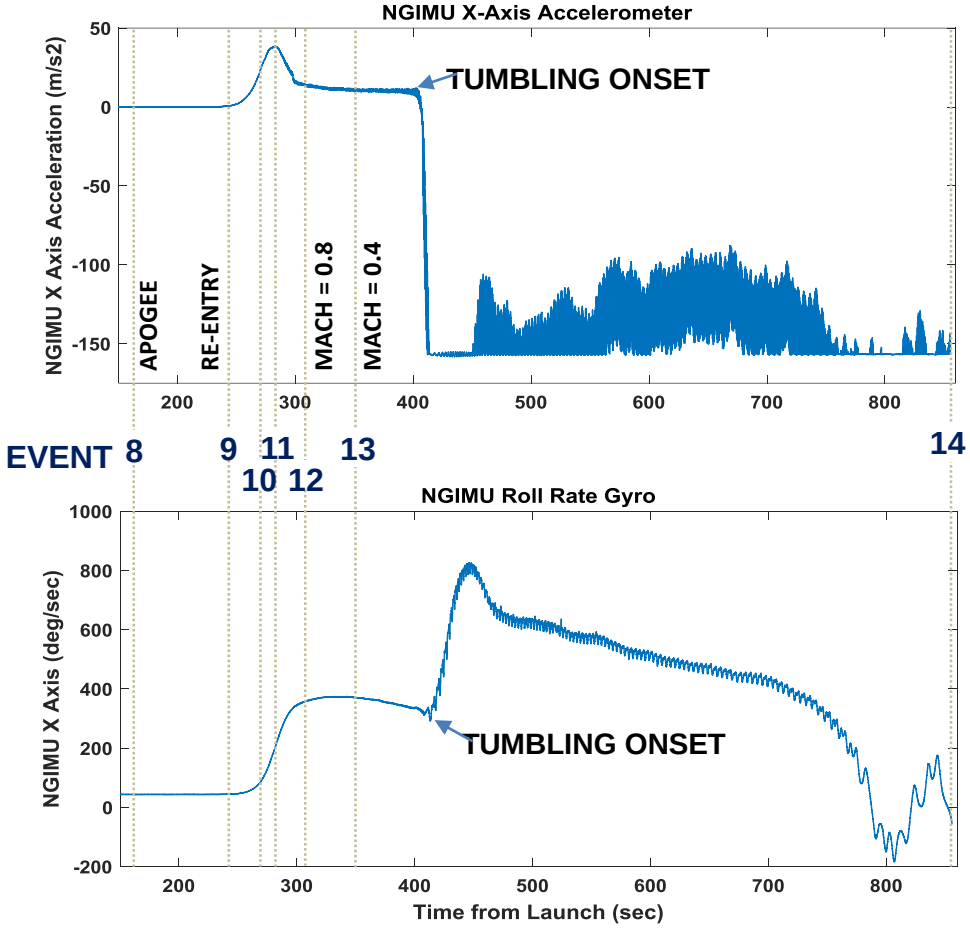


Results- Reentry, Descent & Impact

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

EVENT #	DESCRIPTION	PREDICTED TIME (SEC)	ACTUAL TIME (SEC)
8	APOGEE	161	156
9	ADEPT RE-ENTRY (85 km)	244	229
10	PEAK MACH # (3.2, PREDICTED)	270	254
11	PEAK DYNAMIC PRESSURE (~822 Pa,)	294	282
12	ADEPT MACH 0.8	318	307
13	MACH 0.4	363	352
14	IMPACT (~25 m/sec, NOMINAL)	879	856





Vehicle Recovery

Impact Site

Recovery Procedure

Battery Safeing

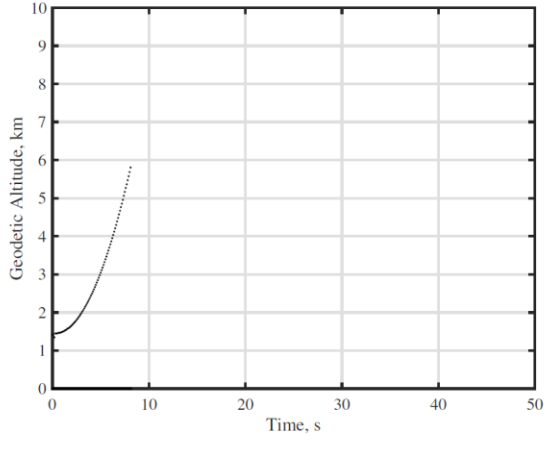
Blackhawk Returns to Launch Complex

Offloading Recovered Components

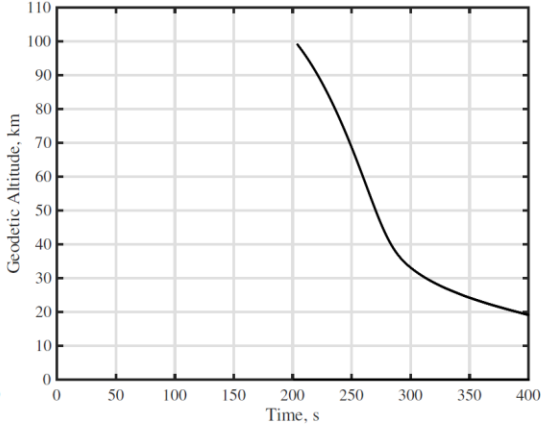
Recovered ADEPT

Data Sources

Data Sources	Status/Notes	Comment
AVA IMU	Utilized in initial trajectory reconstruction	
AVA GPS	Not utilized in trajectory reconstruction	Minimum number of satellites not met
AVA Magnetometer	Utilized in initial trajectory reconstruction	
NGIMU	Utilized in initial trajectory reconstruction	
GoPro Video	Video recorded through launch +595 seconds	GoPro stopped recording below M=0.2, Qualitatively confirmed key data observations.
LV IMU	Utilized in initial trajectory reconstruction	
AFTU GPS	Utilized in initial trajectory reconstruction	
Radar Tracking	Utilized in initial trajectory reconstruction	Data obtained on descent from 99 km altitude



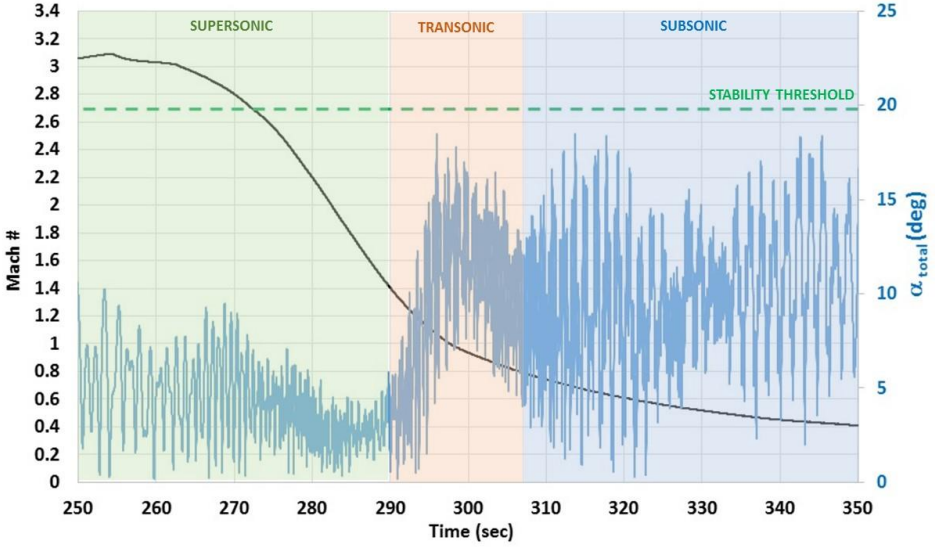
(a) GPS Data.

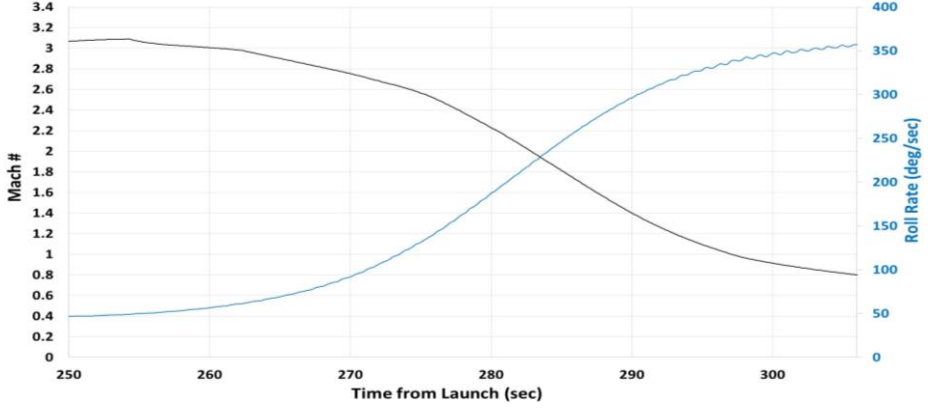


(b) Tracking Radar Data.

Post-Flight Data Analysis

- 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: Soumyo Dutta's paper and presentation "**Flight Mechanics Modeling and Post-Flight Analysis of ADEPT SR-1**"
- Trajectory reconstruction simulated at 100 Hz using LV IMU, AVA IMU, AVA Magnetometer, radar tracking and atmospheric models. For more details see the following paper by Jake Tynis **"Reconstruction of the ADEPT Sounding Rocket One Flight Test"**



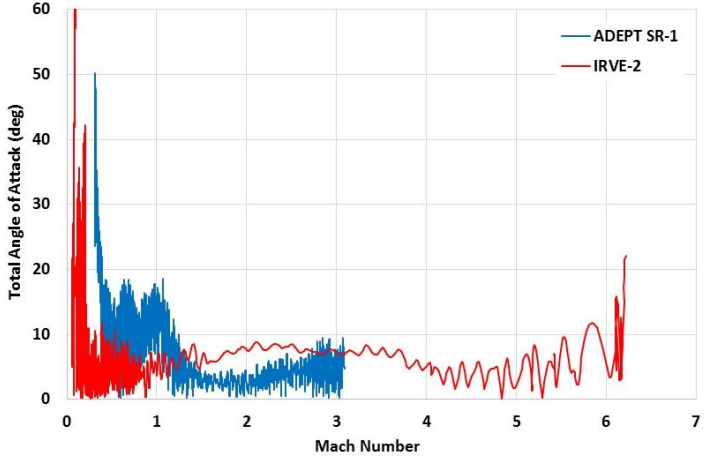


Mission Success Criteria

	Mission Success Criteria	Preliminary Assessment
A	ADEPT separates from the sounding rocket prior to apogee.	***Pass,* confirmed by three independent data sources- Radar, AVA IMU, NGIMU**
B	ADEPT does not re-contact any part of the launch vehicle after separation.	***Pass,* no evidence of re-contact from IMUs and on-board GoPro video cameras**
C	ADEPT reaches an apogee greater than 100 km.	***Pass,* confirmed by radar tracking, launch conductor verbal call was ~115 km**
D	ADEPT achieves fully deployed and locked configuration prior to reaching 80 km altitude.	***Pass,* evidence from on-board GoPro video**
E	Obtain on-board video of deployed ADEPT to observe fabric response and flight dynamics during entry	***Pass,* evidence from GoPro video**
F	Obtain data necessary to reconstruct ADEPT 6 DOF descent trajectory to ***required accuracy below*** with 95% confidence from Mach 3.0 while decelerating to ground impact: a. Mach number: 0.1 b. Drag coefficient: Larger of 5% or 0.005 c. Total angle of attack: 2 deg (if not tumbling) d. Sign of pitch damping sum	***Incomplete- trajectory will be reconstructed, but will not meet desired level of accuracy.***

Summary & Future Work

- **ADEPT SR-1 satisfied both Key Performance Parameters and met 5 out 6 Mission Success Criteria**
- **Noteworthy observations:**
  - **Roll rate increase (from 44 deg/s to 370 deg/s) was observed during supersonic to transonic deceleration**
  - **ADEPT SR-1 is the bluntest (70 deg half cone angle) open back decelerator to be successfully flown.**
  - **SR-1 total angle of attack vs Mach performance compares favorably with inflatable IRVE-2 decelerator.**



Total Angle of Attack Performance Comparison
ADEPT SR-1 (70 deg) & IRVE-2 (60 deg)

- **Aerodatabase Refinements and Free-Flight CFD**
  - **Updates to SR-1 aerodatabase will be incorporated into future trajectory reconstruction efforts.**
  - **Entry Systems Modeling project will utilize FF-CFD analysis tool to further understand SR-1 dynamic behavior.**
- **Development of Guidance & Control Capabilities for ADEPT, Project Pterodactyl**
  - **See paper and presentation by Sarah D'Souza "Developing an Entry Guidance and Control Design Capability using Flaps for the Lifting Nano-ADEPT"**

Acknowledgements

- Soumyo Dutta (LaRC, Flight Mechanics Lead)
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- Owen Nishioka (Ames, Mechanical Design)
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- Matt Padilla (Ames, Electrical Technician)
- Justin Green (LaRC, Traj Reconstruction)
- Jake Tynis (LaRC-TEAMS3, Traj Reconstruction)

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Questions?