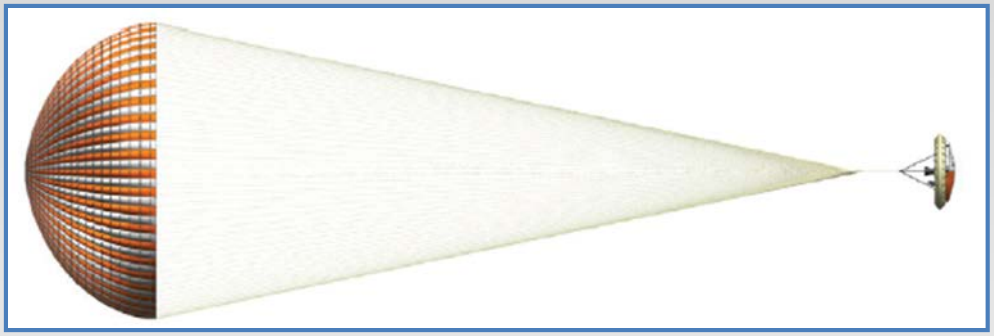
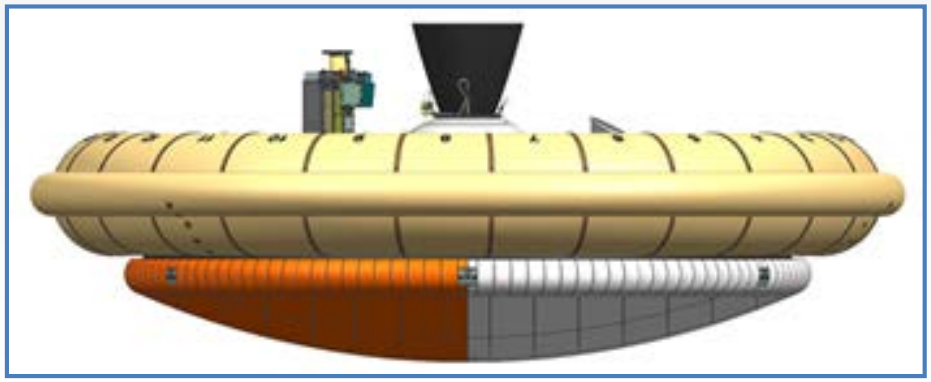


45th International Conference on Environmental Systems

First Test Flight Thermal Performance of the Low Density Supersonic Decelerator (LDSD) Supersonic Flight Dynamics Test (SFDT) Vehicle

A. J. Mastropietro , Jason Kempenaar, Matthew Redmond, and Michael Pauken
Jet Propulsion Laboratory, California Institute of Technology

Walter Ancarrow
WCA Engineering, Inc.



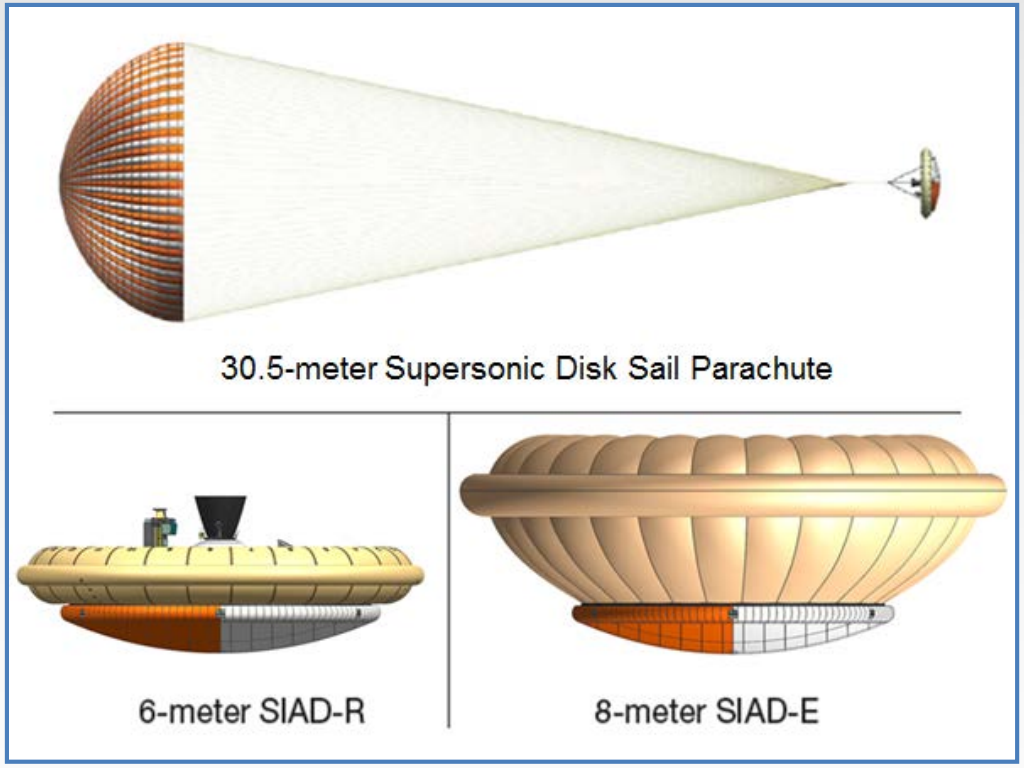
Hilton Bellevue, Bellevue, WA July 12-16, 2015

Agenda

- LDSD Project Overview
- SFDT-1 Objectives
- SFDT Vehicle Description
- SFDT-1 Trajectory and Mission Timeline
- Day of Test Thermal Environment
- Brief Review of SFDT Thermal Model
- SFDT-1 Key Events
- SFDT-1 Thermal Telemetry (Select Components)
- Post-Flight Visual Inspection of the Recovered TV
- Lessons Learned and Conclusions
- Acknowledgements

LDSD Project Overview (1/2)

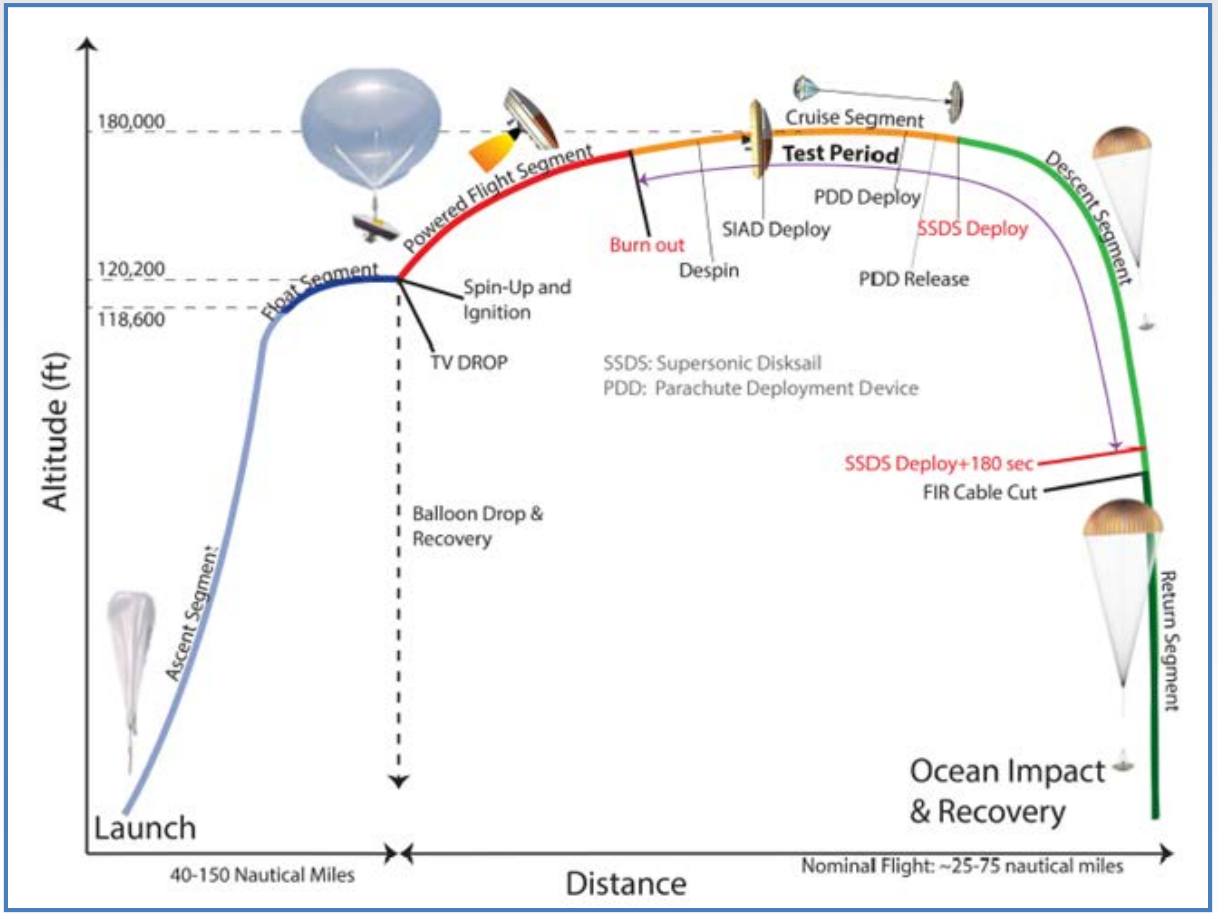
- Charged by NASA's Office of the Chief Technologist to advance the state of the art for Mars EDL
- 3 new EDL technologies under development
  - 30.5 m diameter Disk Sail Parachute
  - Robotic Class SIAD (6 m torus)
  - Exploration Class SIAD (8 m isotensoid)
- Supersonic Flight Dynamics Test (SFDT) Vehicle will provide the experimental platform for testing these new technologies
- Stratospheric tests using helium carrier balloons occurred during the summers of 2014 and 2015 at the PMRF on Kauai, Hawaii



Supersonic **I**nflatable **A**erodynamic **D**ecelerator (SIAD)

LDSD Project Overview (2/2)

Proposed Flight Profile for High Altitude LDSD Tests using the SFDT Vehicle



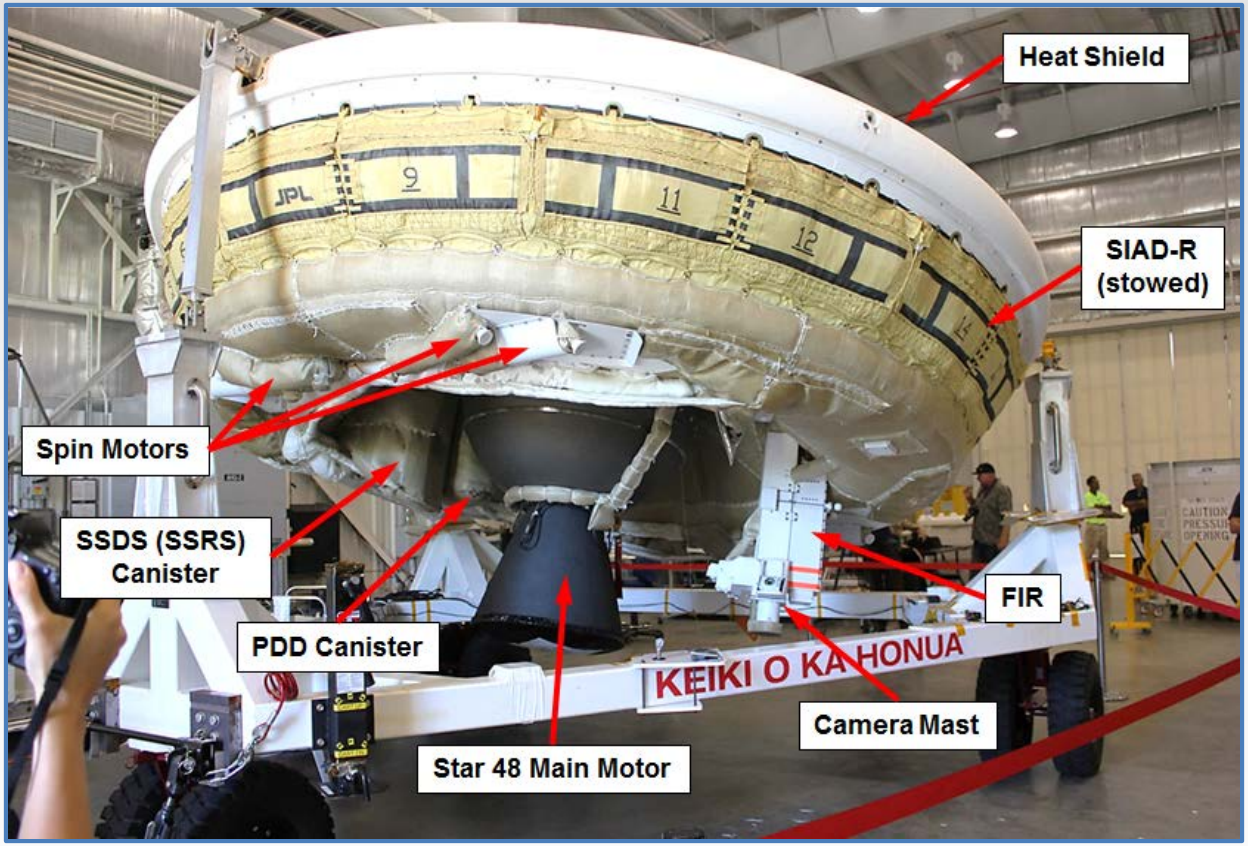
SFDT-1 Objectives

1. Launch the SFDT vehicle with a Star 48 on a balloon from PMRF to float altitude.
2. Conduct a powered flight, demonstrating the ability to target Mars analogous Mach numbers and dynamic pressures.
3. Collect real-time telemetry from the test vehicle sufficient to assess the powered flight objective and to demonstrate the operation of all radio links.
4. Recover the balloon from the ocean for disposal.

Since the first SIAD-R and SSDS elements were ready ahead of time enabling integration with SFDT-1, *secondary goals* were established as the following:

- Deploy and collect data on the operation and dynamics of the SIAD-R.
- Deploy and collect data on the operation and dynamics of the SSDS parachute.
- Fly the camera mast assembly and other SIAD and SSDS sensors.
- Recover the test vehicle and/or flight image recorder from the ocean.

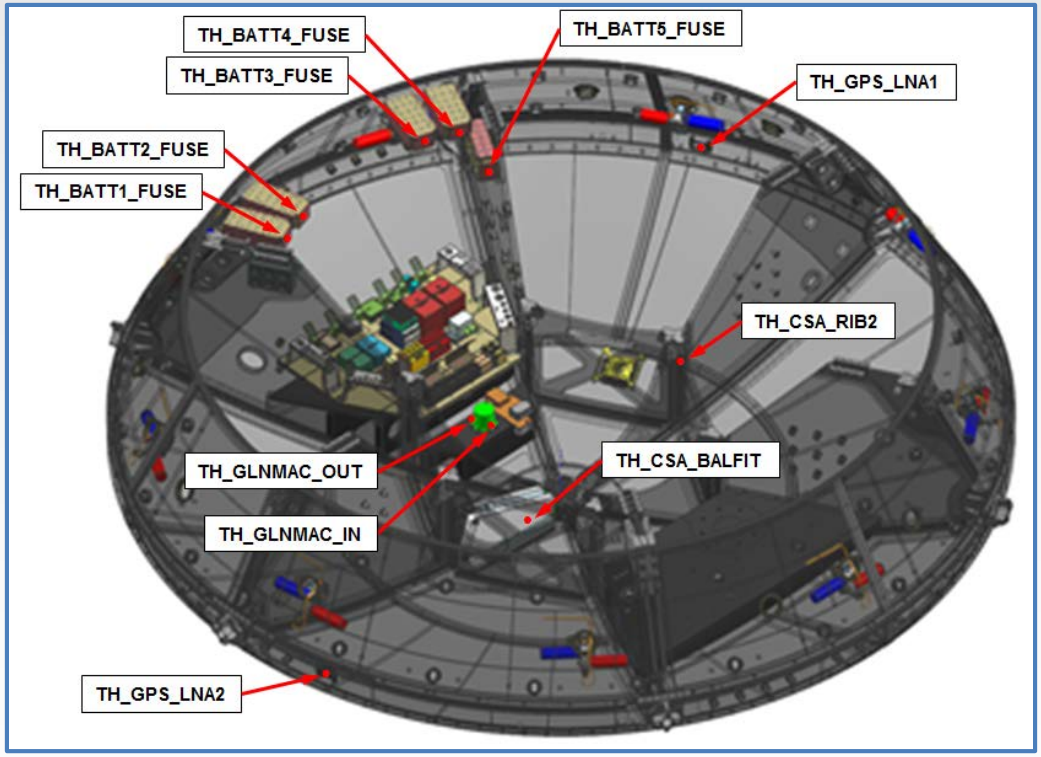
SFDT Vehicle Description (External)



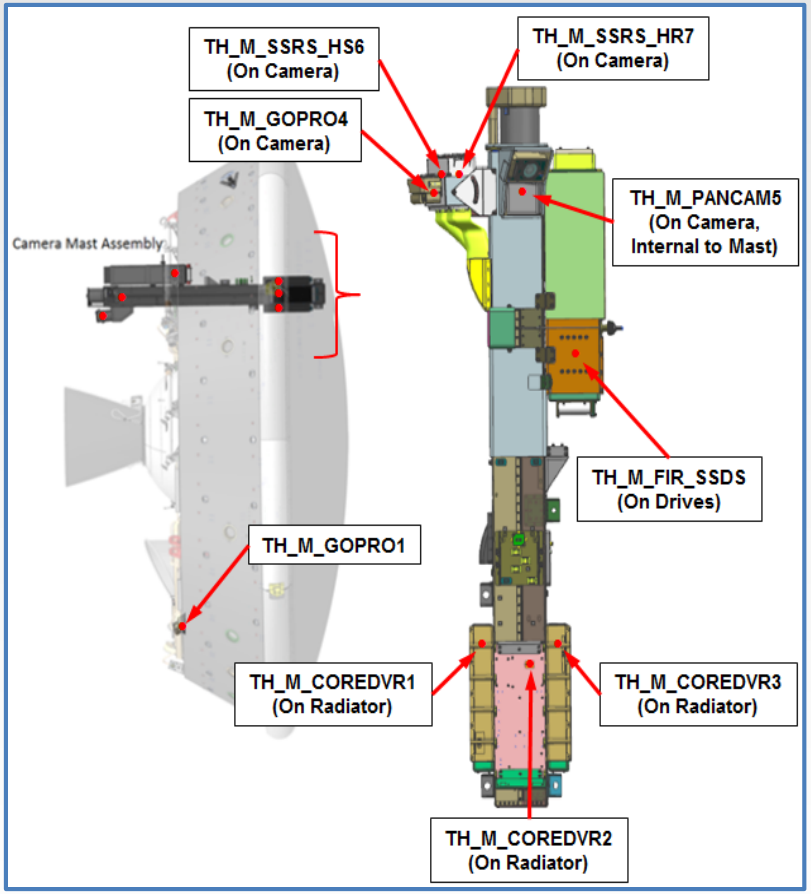
Note 4 major thermal challenges: 1. Star 48 plume heating, 2. Star 48 soakback heating, 3. Spin Motor plume heating, and 4. Spin motor soakback heating

SFDT Vehicle Description (Internal)

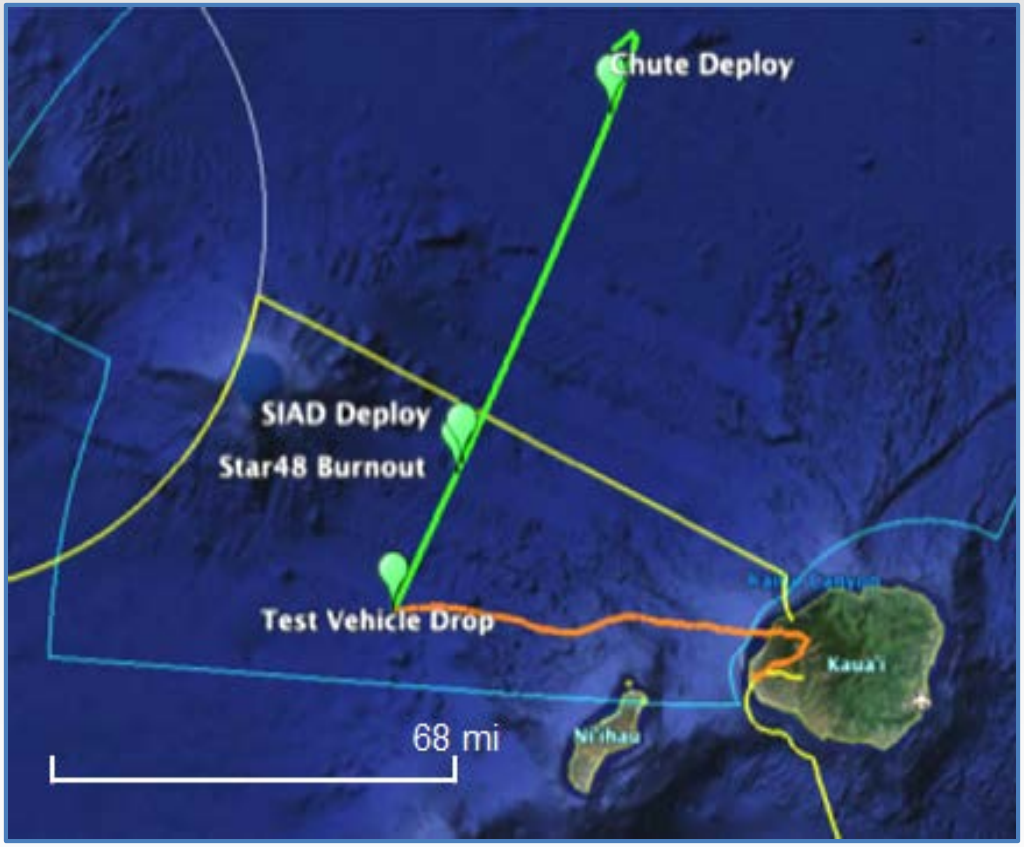
Avionics Pallet and GLNMAC



Camera Mast Assembly

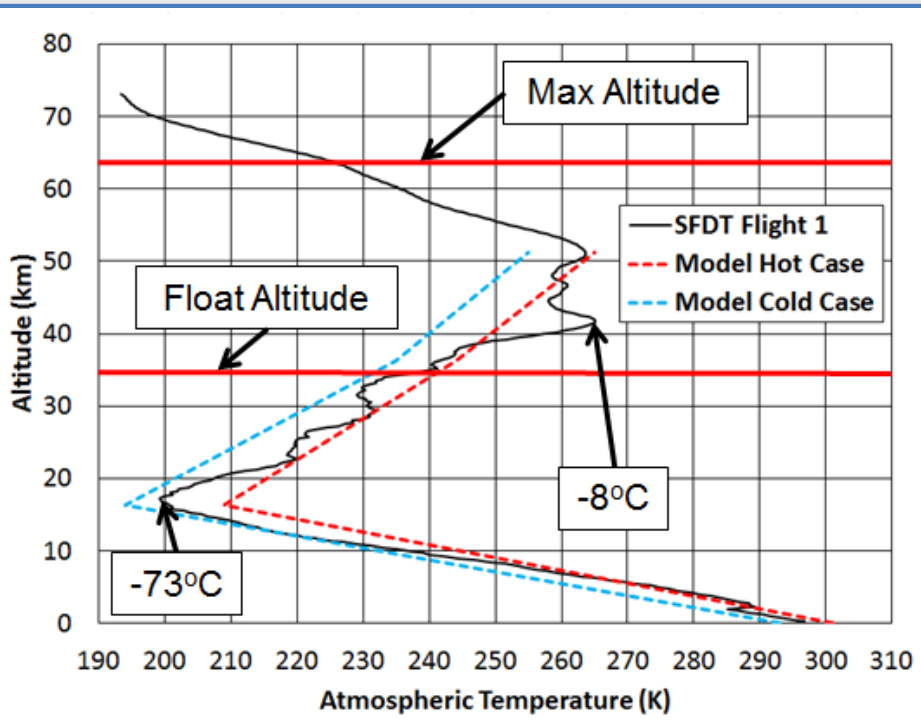


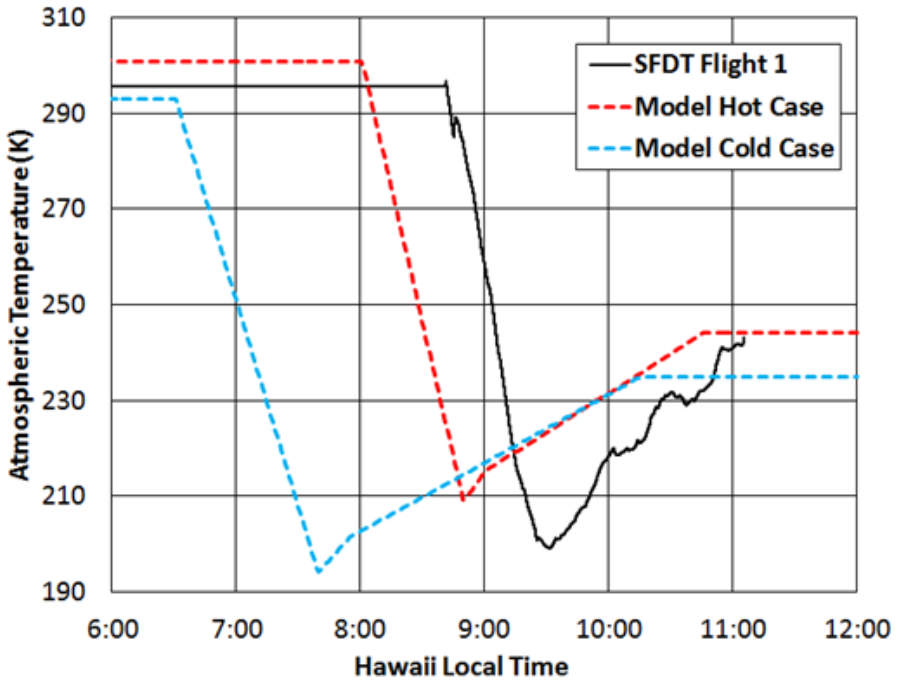
SFDT-1 Trajectory and Timeline – June 28, 2014



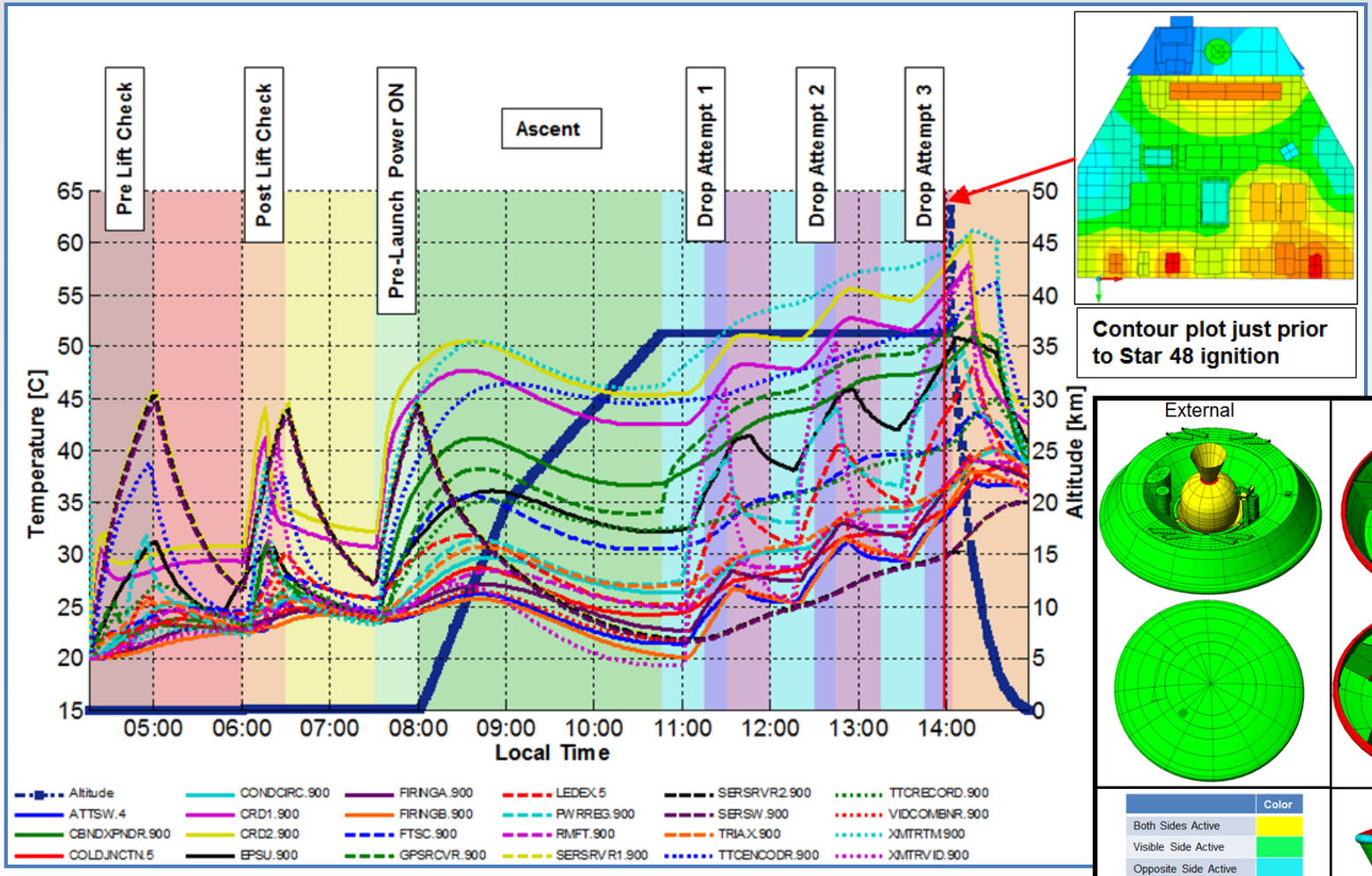
Critical Event	UTC	HST
Pre-Lift Check Begins	12:02:00	2:02:00
Pre-Lift Check Complete	12:32:00	2:32:00
Post Lift Check Begins	15:47:00	5:47:00
Post-Lift Check Complete	16:05:00	6:05:00
Pre-Launch Power ON	18:00:00	8:00:00
Balloon Launch	18:40:51	8:40:51
Balloon Rotator ON	20:05:53	10:05:53
Balloon Rotator Set	20:18:59	10:18:59
TV Block 1 Power ON	20:25:10	10:25:10
TV Block 2 Power ON	20:30:07	10:30:07
TV Block 3 Power ON	20:35:37	10:35:37
TV Block 4 Power ON	20:50:14	10:50:14
Float Achieved	21:02:47	11:02:47
GLNMAC Init	21:03:01	11:03:01
Drop	21:05:00	11:05:00
Spin Up	21:05:00	11:05:00
Star 48 Ignition	21:05:02	11:05:02
Star 48 Burnout Detected	21:06:11	11:06:11
Spin Down	21:06:12	11:06:12
SIAD Deploy	21:06:22	11:06:22
PDD Mortar Fire	21:07:41	11:07:41
SSDS Full Inflation	21:07:49	11:07:49
FIR Cable Cut	21:10:53	11:10:53
EPSU Altitude Switch Closure	21:19:20	11:19:20
All Buses Powered OFF	21:19:32	11:19:32

Day of Test Thermal Environment

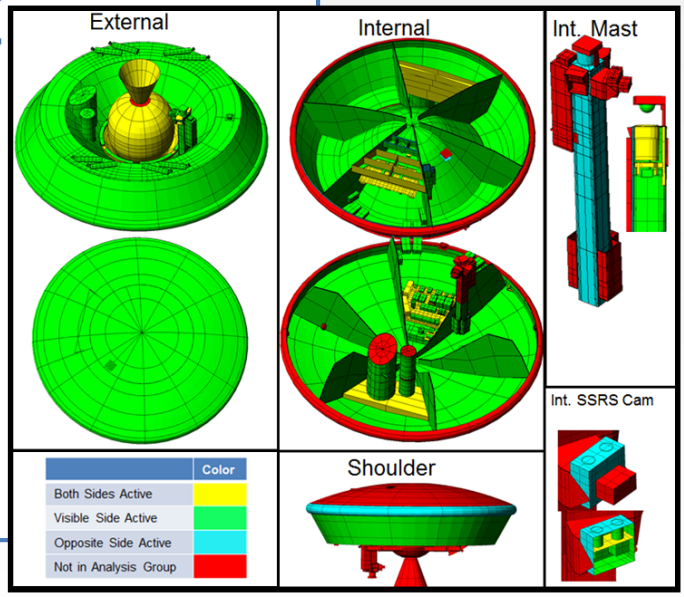




Brief Review of SFDT Thermal Model

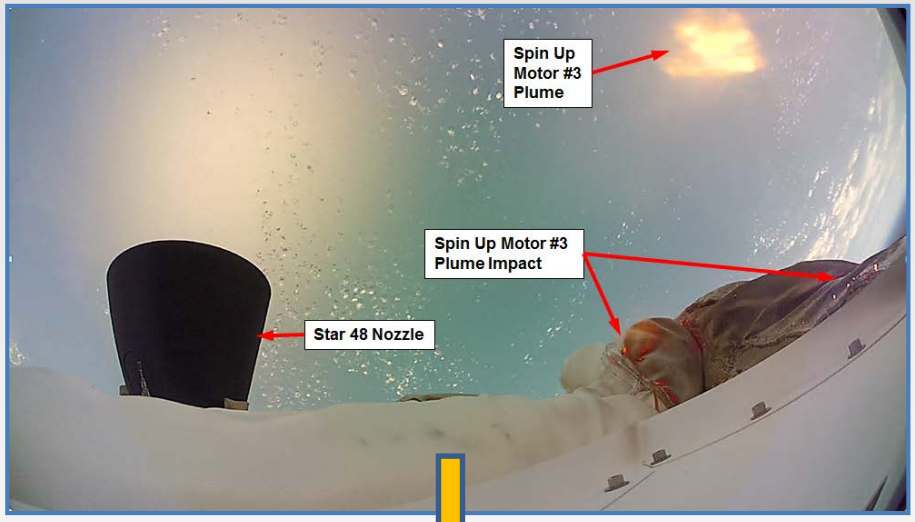


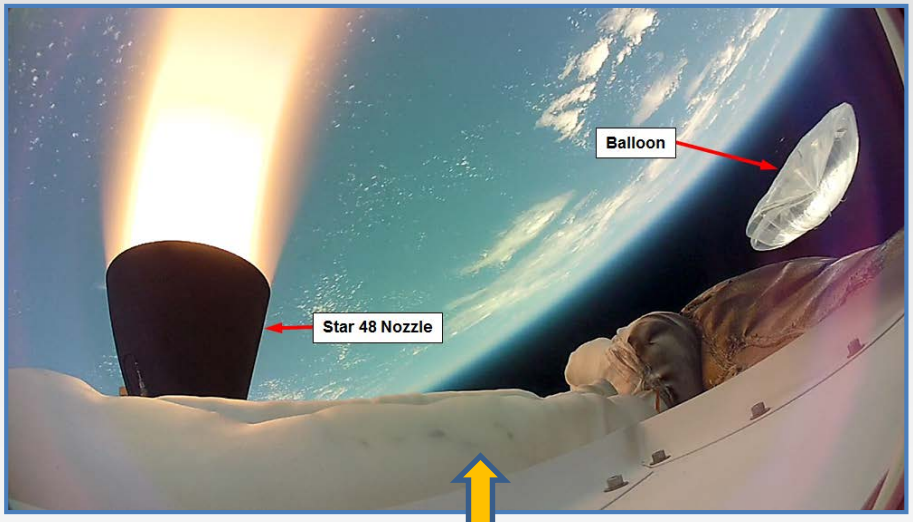
Contour plot just prior to Star 48 ignition

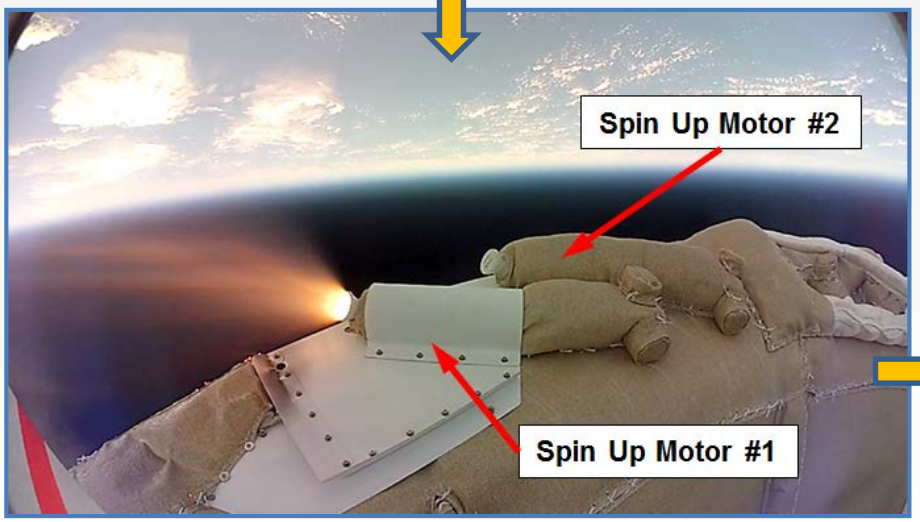


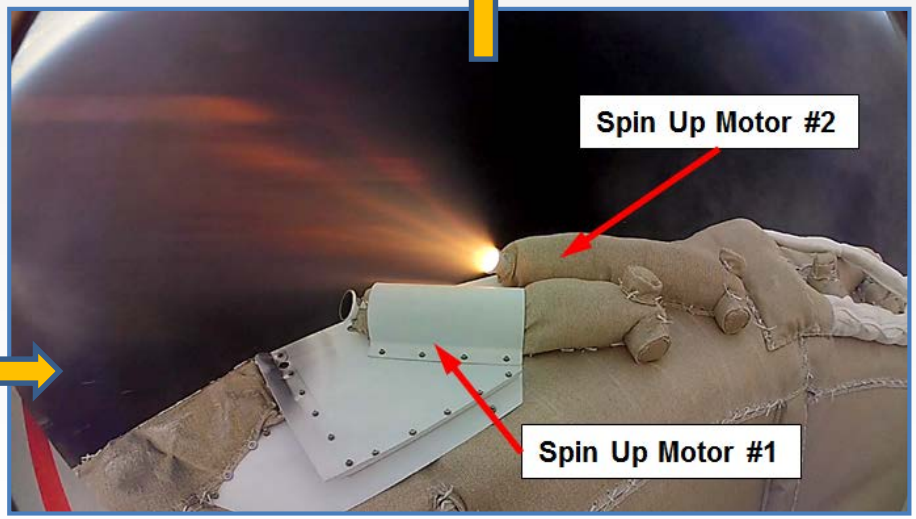
Mastropietro, A. J., et al., "*Thermal Design and Analysis of the Supersonic Flight Dynamics Test Vehicle for the Low Density Supersonic Decelerator Project*," AIAA-2013-3348, 43rd International Conference on Environmental Systems, Vail, CO, 2013.

SFDT-1 Key Events (1/2)

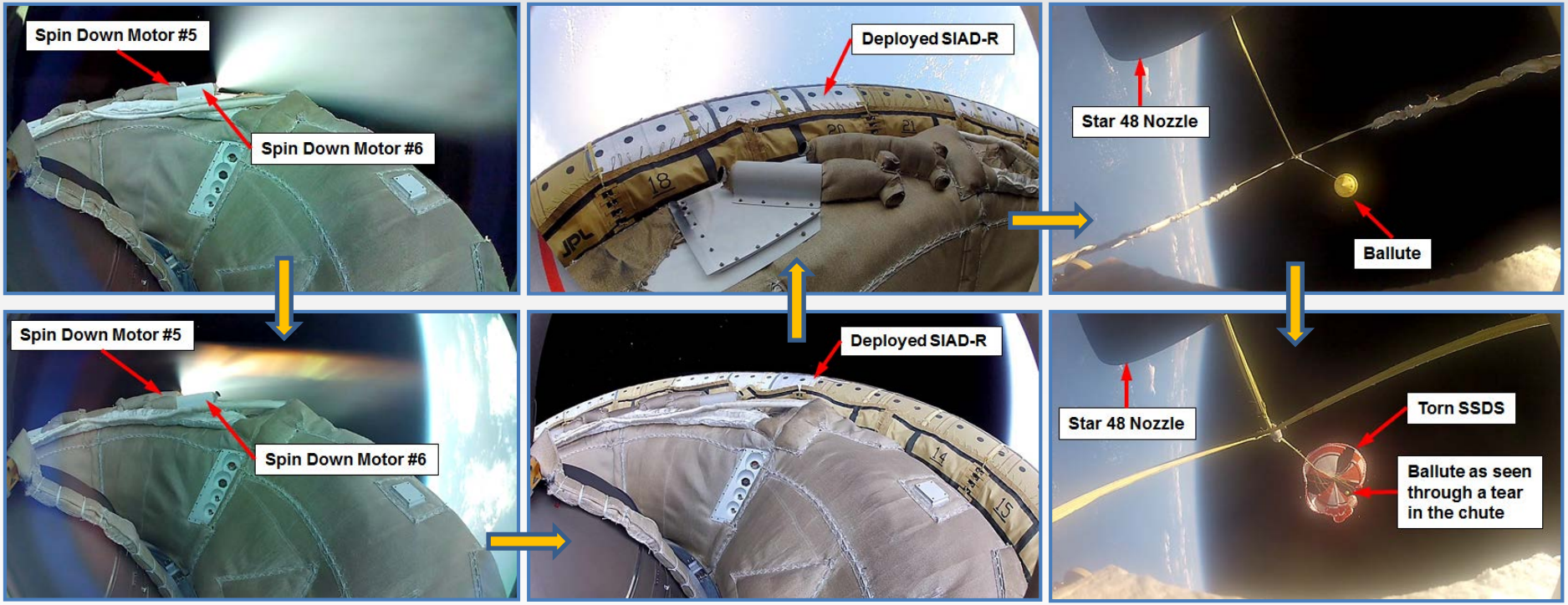




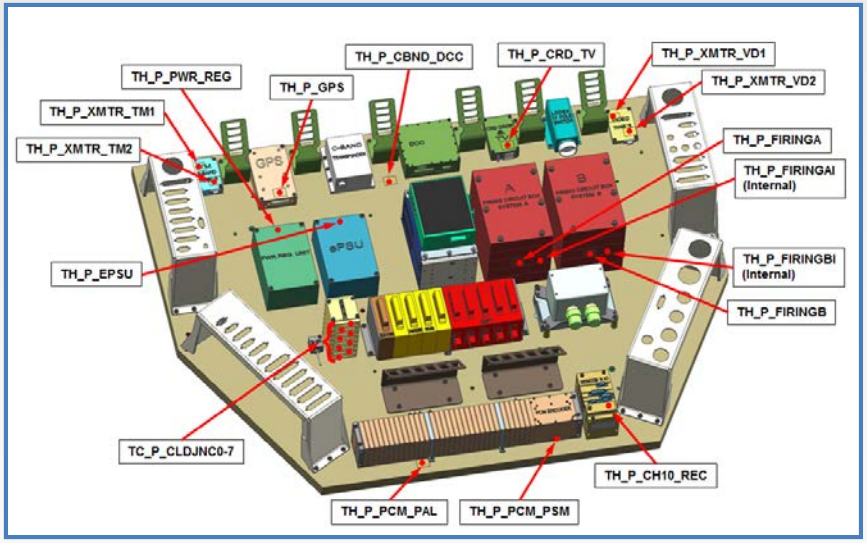


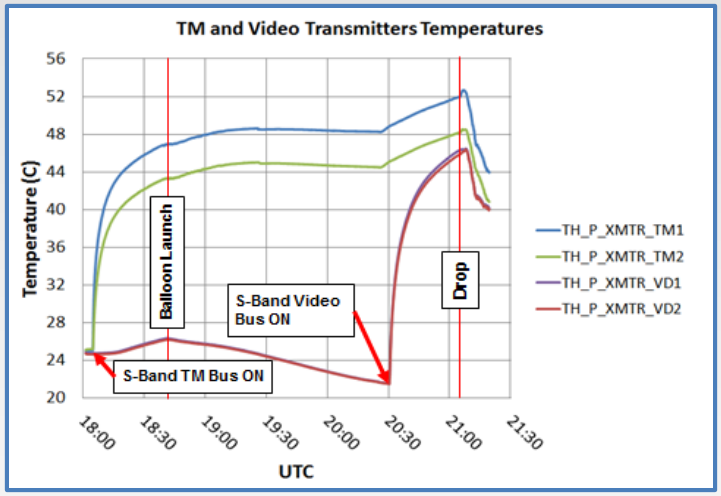


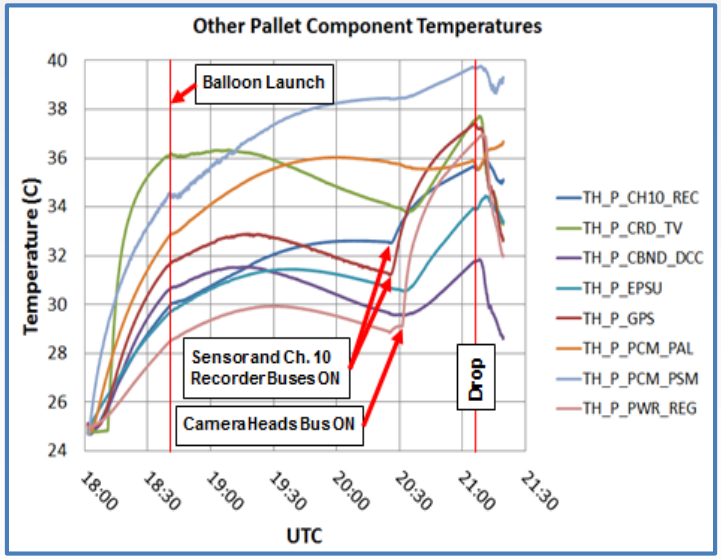
SFDT-1 Key Events (2/2)



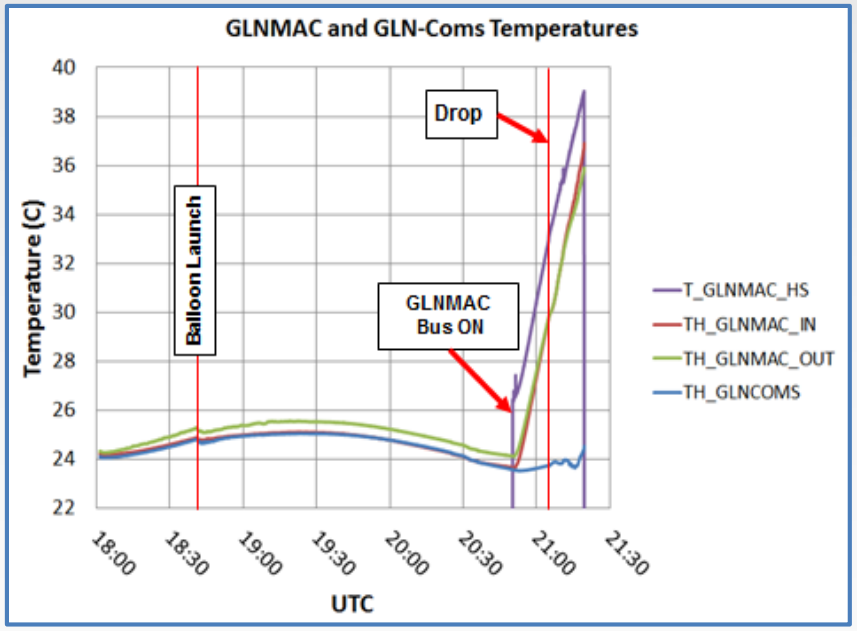
SFDT-1 Thermal Telemetry – Avionics Pallet

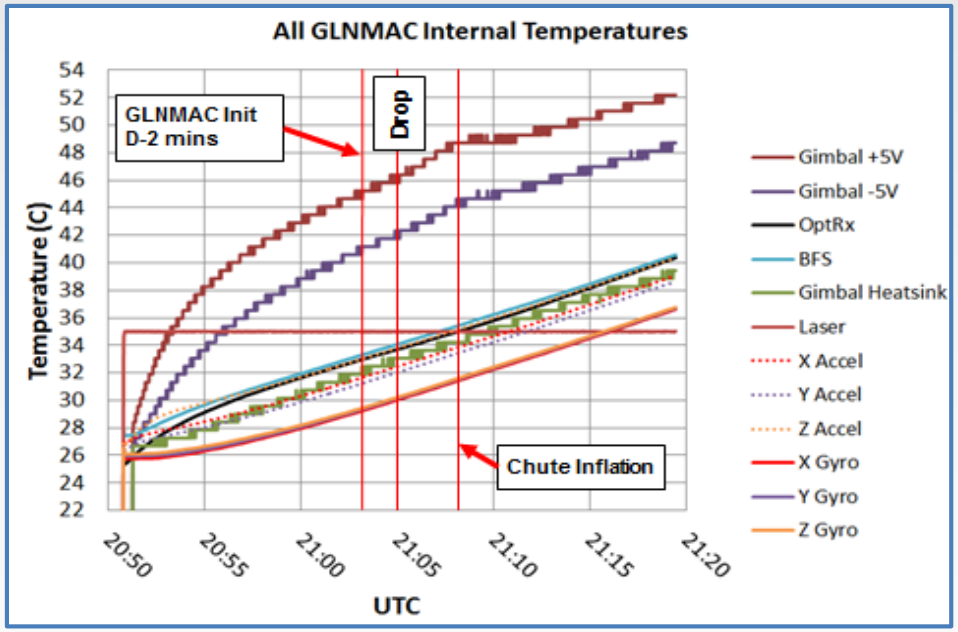




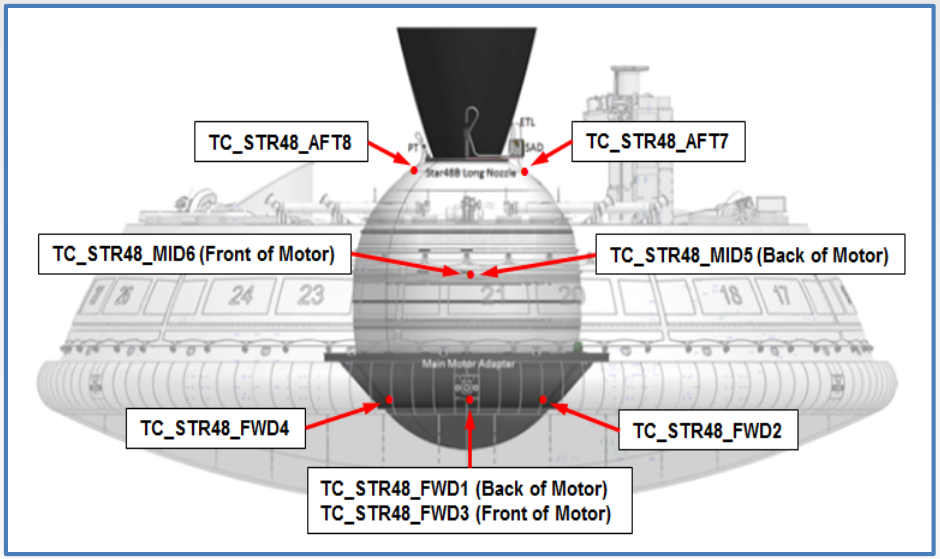


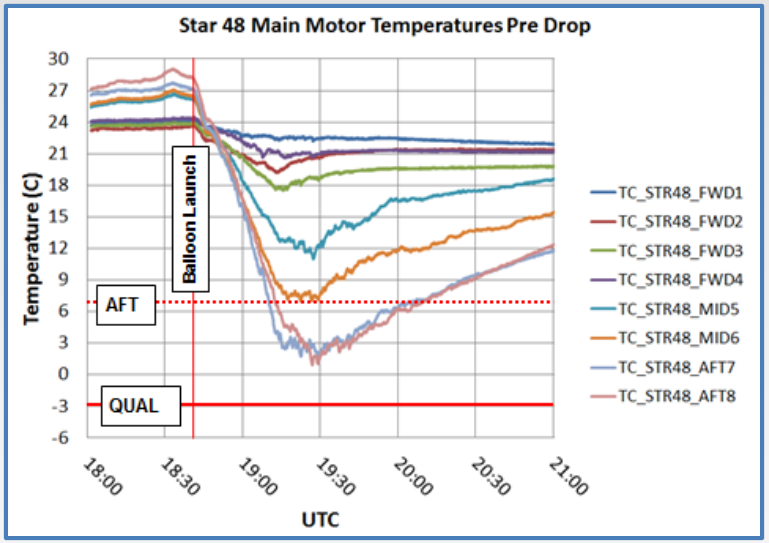
SFDT-1 Thermal Telemetry – GLNMAC

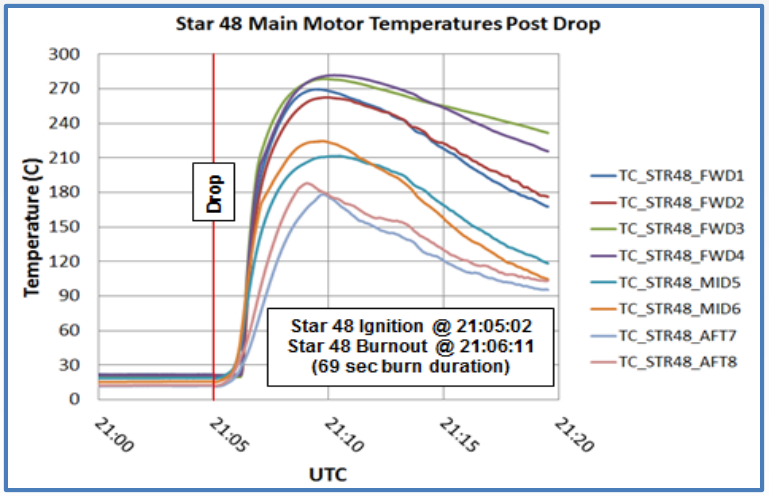




SFDT-1 Thermal Telemetry – Star 48

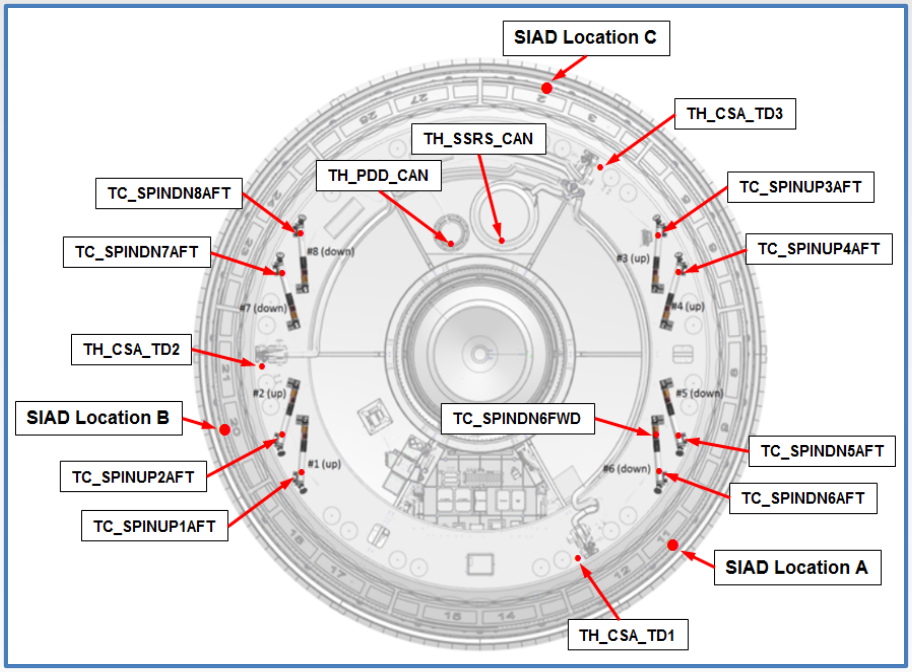


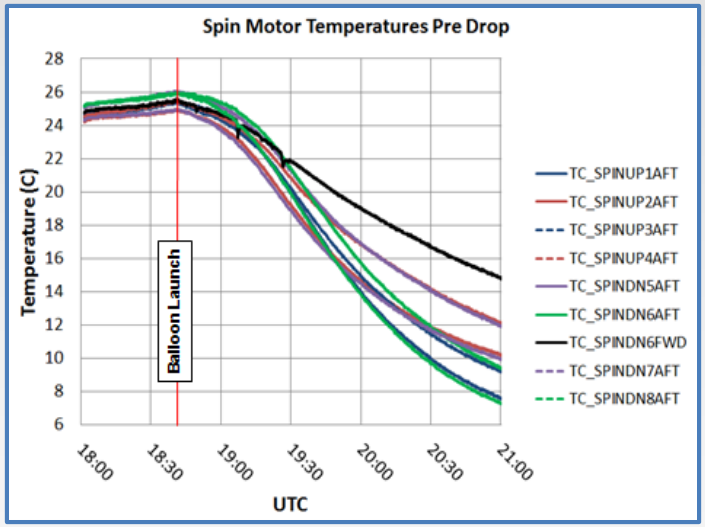


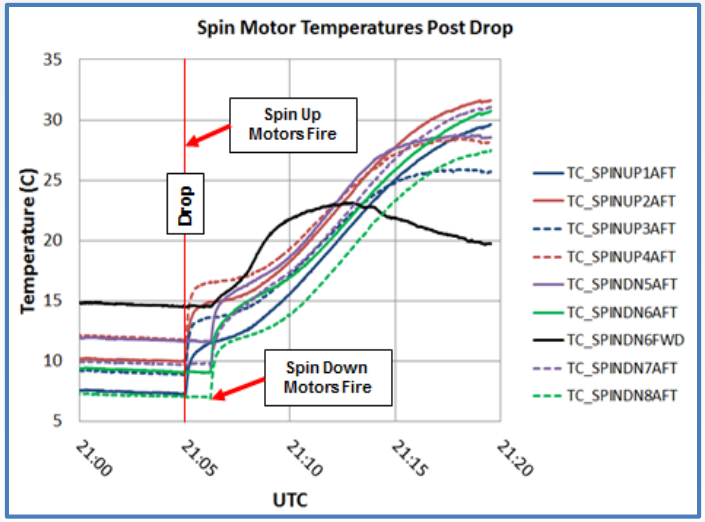


Only 1 AFT violation occurred briefly during the balloon ascent near the nozzle end of the Star 48.

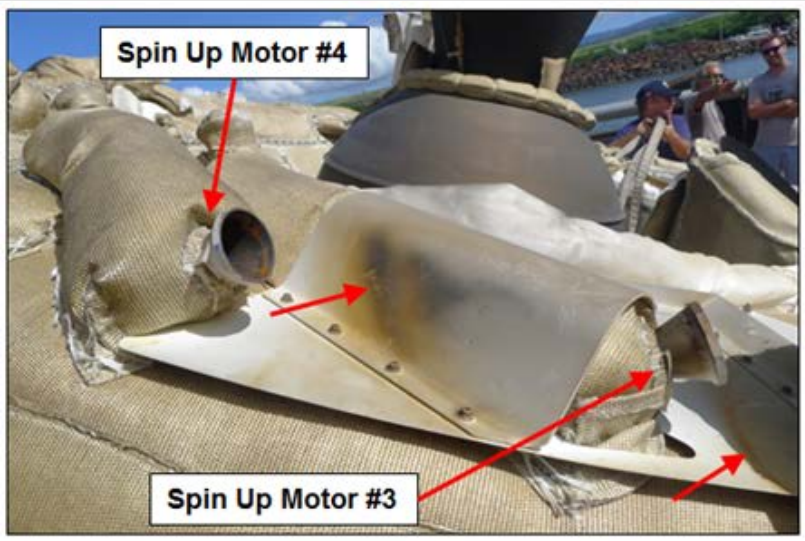
SFDT-1 Thermal Telemetry – Spin Motors



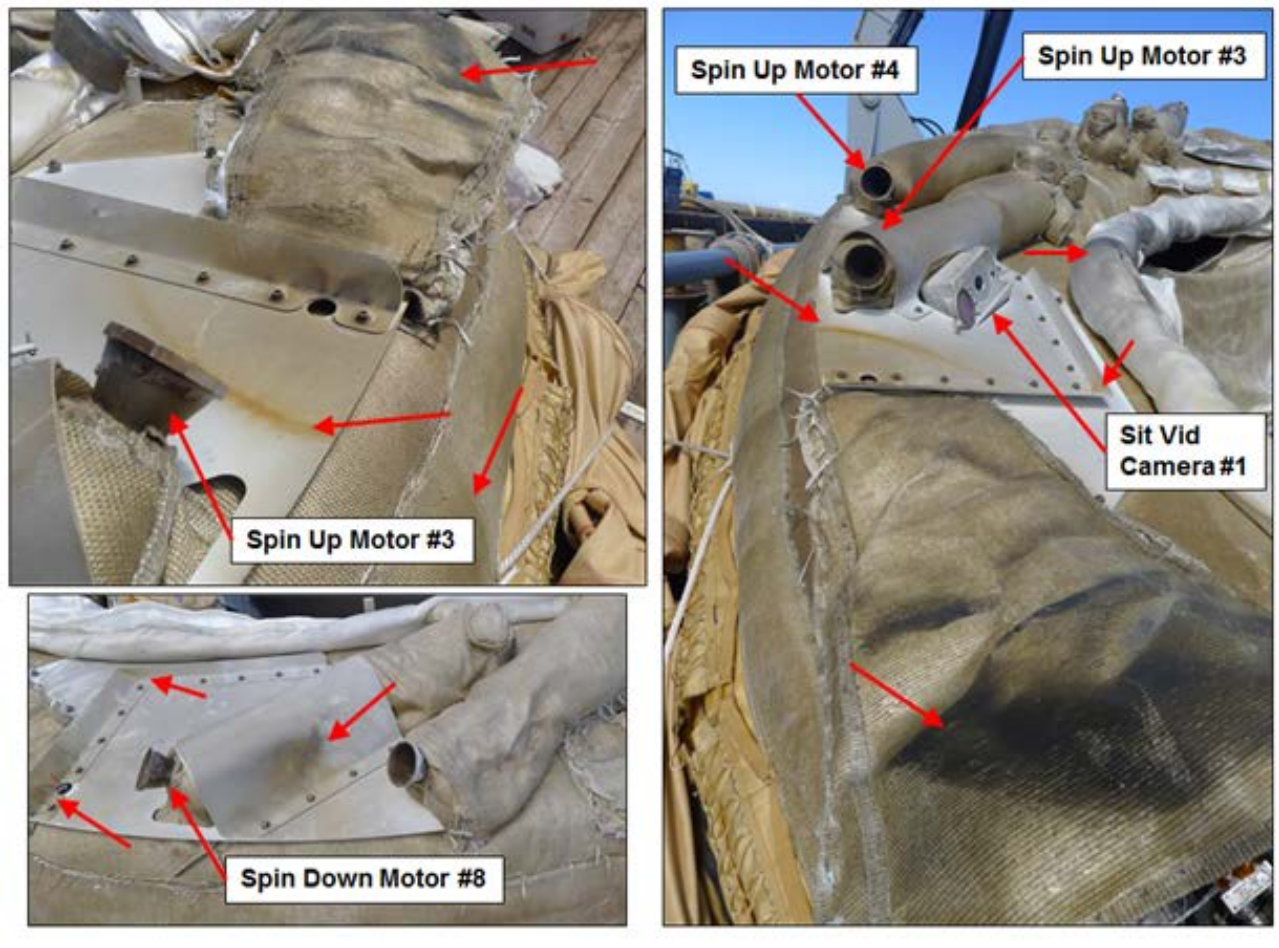




Post-Flight Visual Inspection of the Recovered TV (1/2)



Post-Flight Visual Inspection of the Recovered TV (2/2)

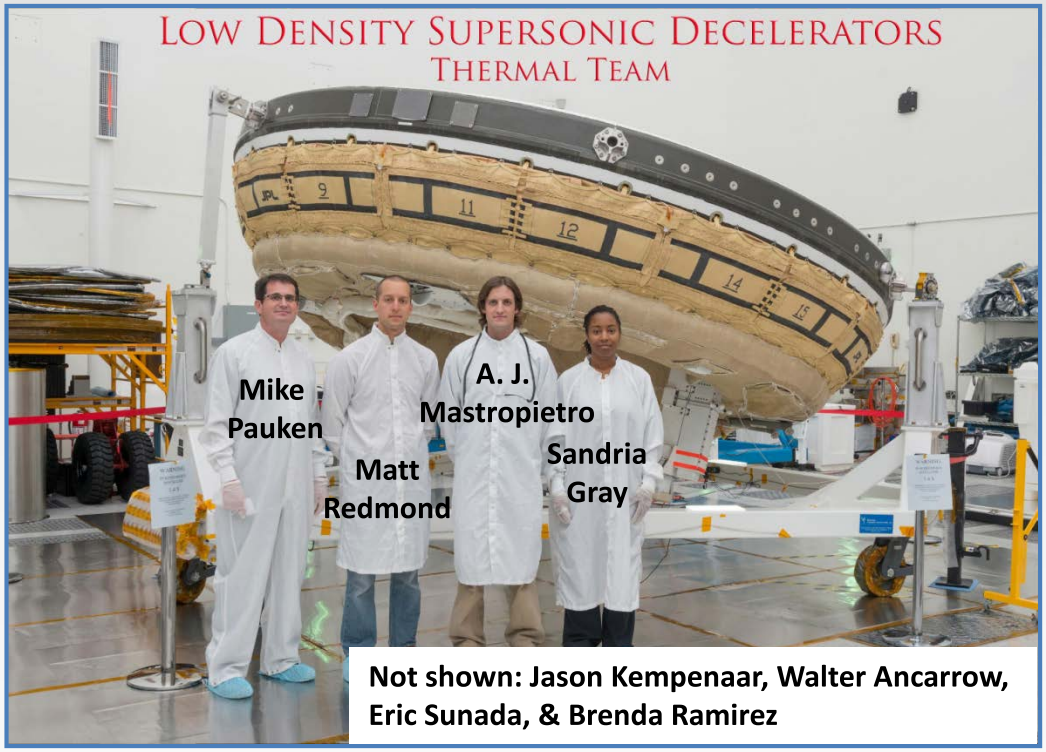


Lessons Learned and Conclusions

- Difficult to predict exactly what the thermal performance of the vehicle was going to be for the first test flight
  - 4 major thermal challenges had to be conservatively estimated
    - Star 48 main motor plume heating
    - Star 48 soakback heating
    - Spin motor plume heating
    - Spin motor soakback heating
- Thermal telemetry and post-flight visual inspection of the recovered TV confirmed that the SFDT vehicle thermal design was robust to the 4 major thermal challenges.
- All components stayed well within their Allowable Flight Temperatures with the exception of the previously noted temporary violation near the nozzle end of the Star 48.

Acknowledgements

The development described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors express their thanks to NASA's Office of the Chief Technologist for supporting this effort and enabling a select few to push the envelope. The authors wish to thank several of their colleagues at JPL who have been instrumental to the successful thermal performance of SFDT-1: Eric Sunada, Sandria Gray, Brenda Ramirez, Brant Cook, Kevin Burke, John Luke Wolff, Gabriel Molina, Steven Schroeder, Jason Gates, Mark Duran, Richard Frisbee, Eric Oakes, George Chen, Grace Tan-Wang, Martin Greco, Steve Sell, Eric Blood, Marc Pomerantz, Thomas Randolph, Carl Guernsey, Mark Yerdon, Morgan Parker, Rebekah Tanimoto, Lou Giersch, John Gallon, Andrew Kennett, Coleman Richdale, Chris Tanner, Erich Brandeau, Paul Lytal, Ban Tieu, Chris Porter, and Rob Manning, as well as Virgil Mireles, Tony Paris, Pradeep Bhandari, and Bob Krylo for serving as the thermal review board members.



Not shown: Jason Kempenaar, Walter Ancarrow, Eric Sunada, & Brenda Ramirez

The authors also wish to thank the following individuals from other NASA Centers including Brian Hall, Brian Abresch, Joel Simpson, Chris Purdy, Scott Hesh, Andrew Owens, Carl Davis, Michael Haugh, Jeff Benton, and Joe O'Brien from WFF and Brandon Mobley (MSFC), Bud Smith (MSFC) and Jay Grinstead (ARC) who provided critical inputs to the SFDT thermal model. Lastly, the authors would like to take this opportunity to acknowledge the LDSD project managers Mark Adler, Jeff Weis, and Principle Investigator, Ian Clark, for supporting the development of this paper.

Backup

SFDT-1 Thermal Telemetry – Cameras