Status of the Mars Entry Atmospheric Data System (MEADS) Hardware and Flight Data Reconstruction Effort

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Acknowledgements

- Team Members (and coauthors, in **bold**) contributing to the MEADS flight data reconstruction effort:
  - **Mark Schoenenberger (Lead)**
  - **Chris Karlgaard (simulation)**
  - **Prasad Kutty (simulation)**
  - **John Van Norman (aerodynamics)**
  - **Jeremy Shidner (trajectory)**
  - **Noah Favareh (aero testing)**
  - Robert Blanchard
  - **Rafael Lugo (Aberdeen testing, Monte Carlo methods)**
  - Robert Tolson
  - Sean Commo
  - Scott Striepe
  - **Chris Kuhl (MEDLI Chief Engineer)**
  - **Alan Little (MEDLI PM)**

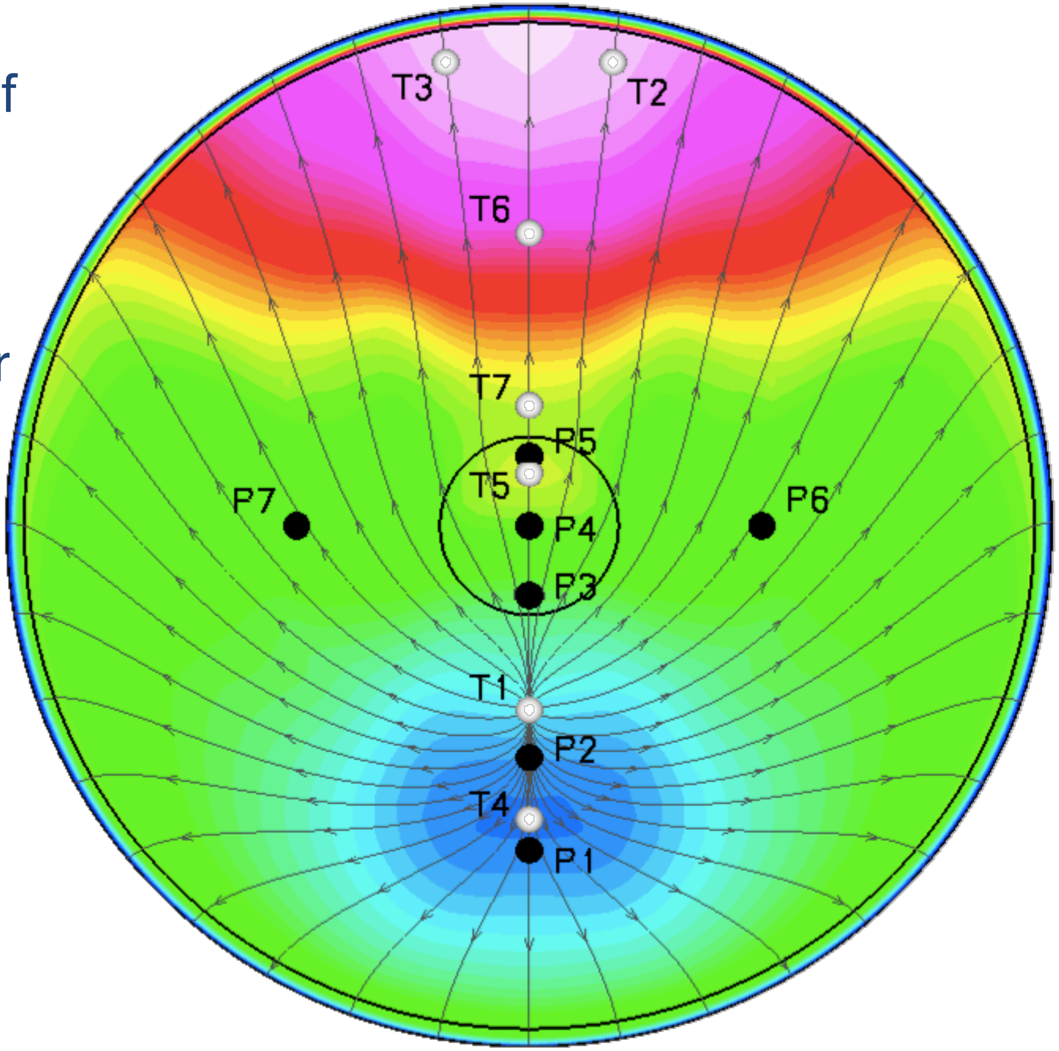
MEDLI System Objectives

Aerodynamics & Atmospheric

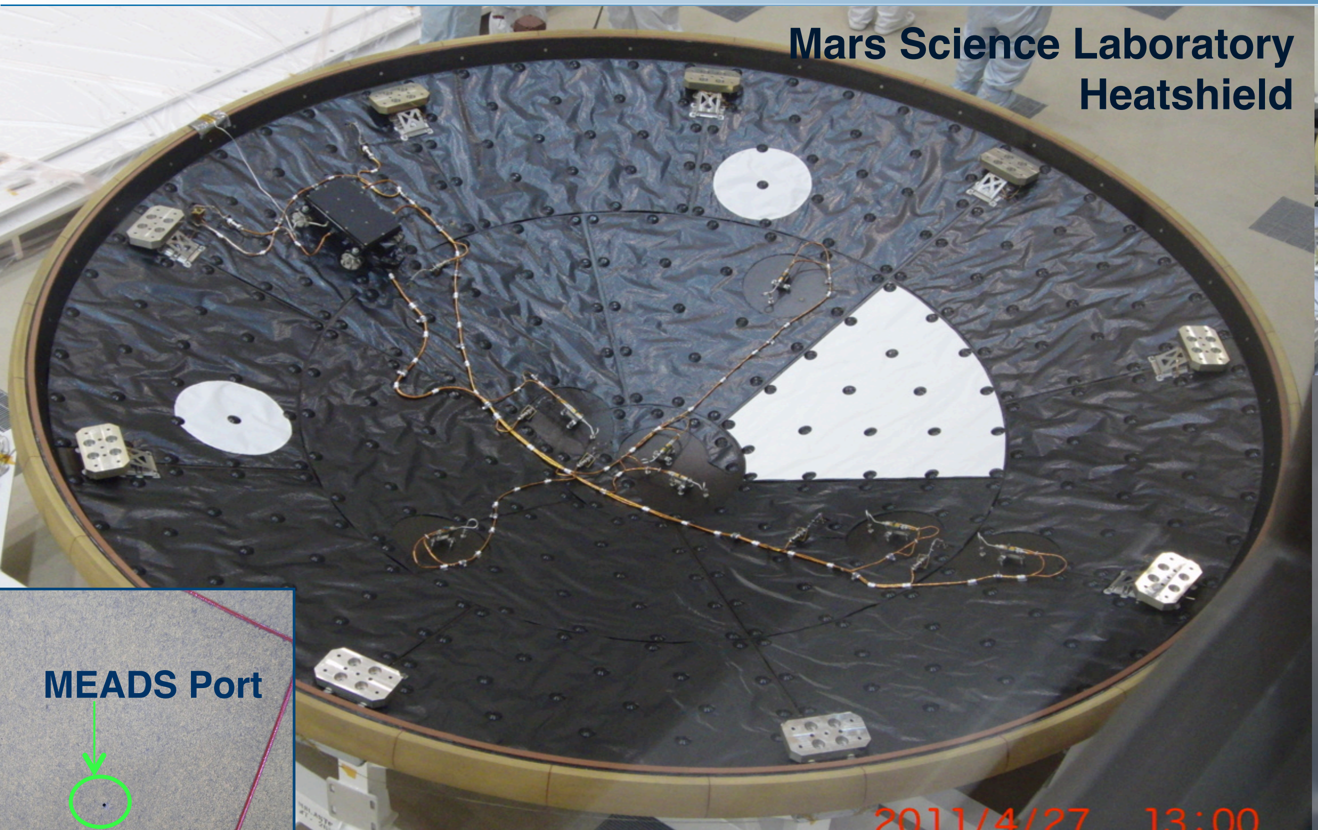
- Confirm aero at high angles of attack
- Separate aerodynamics from atmosphere
- Determine density profile over large horizontal distance
- Determine wind component

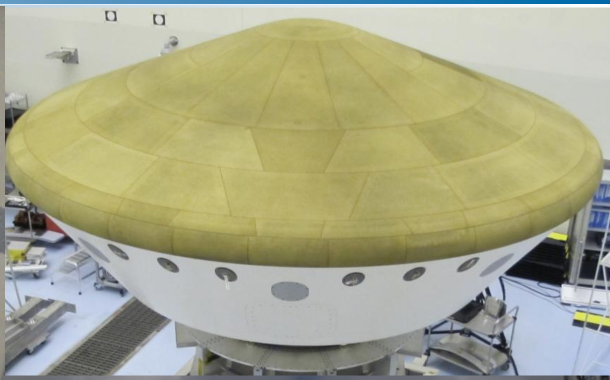
Aerothermal & TPS

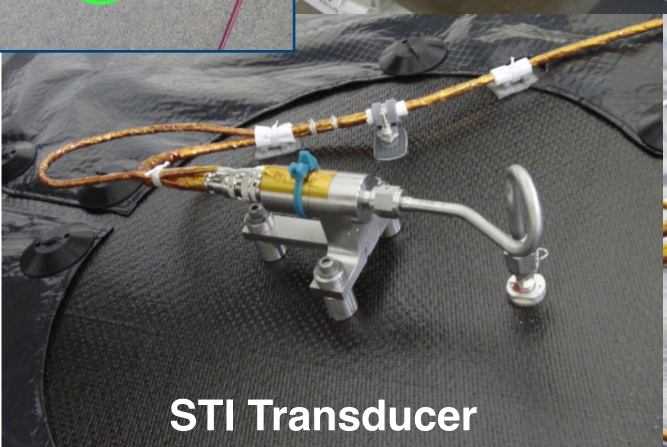
- Verify transition to turbulence
- Determine turbulent heating levels
- Determine recession rates and subsurface material response of an ablative heatshield at Mars conditions

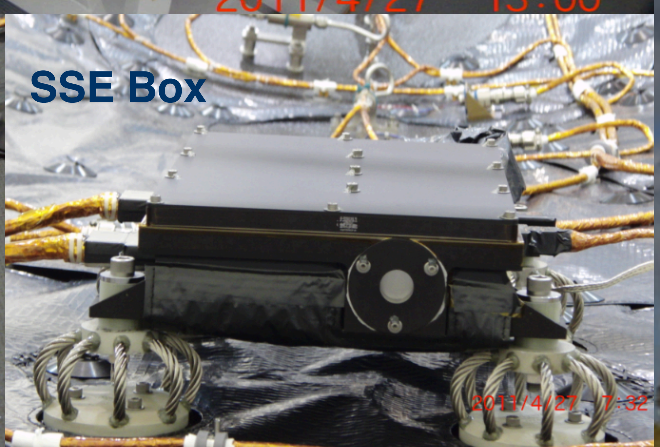


On Our Way to Mars!



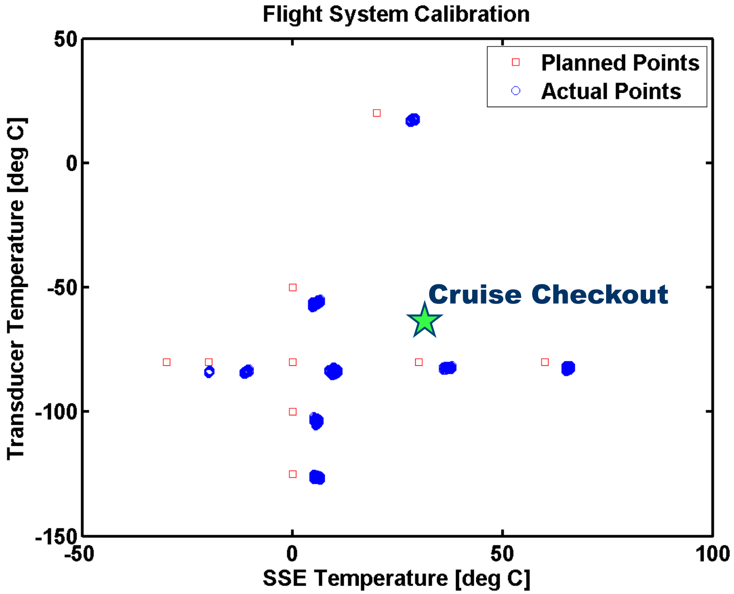






MEADS Pressure Data (In-Flight Zero)

- MEDLI Cruise Checkout in March
- All sensors functioning
  - Average MEADS Transducer Temperature = -65°C
  - Thermally stable SSE Temperature = +35°C

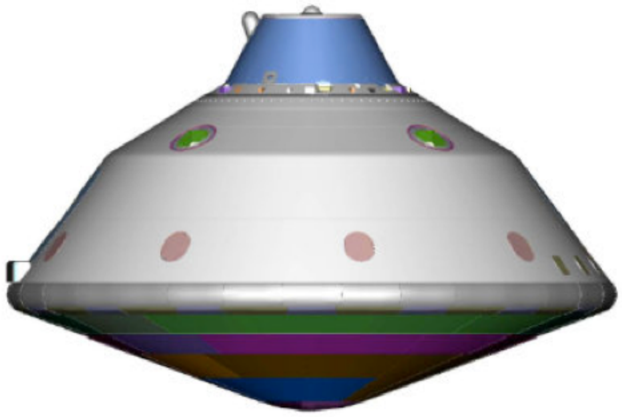


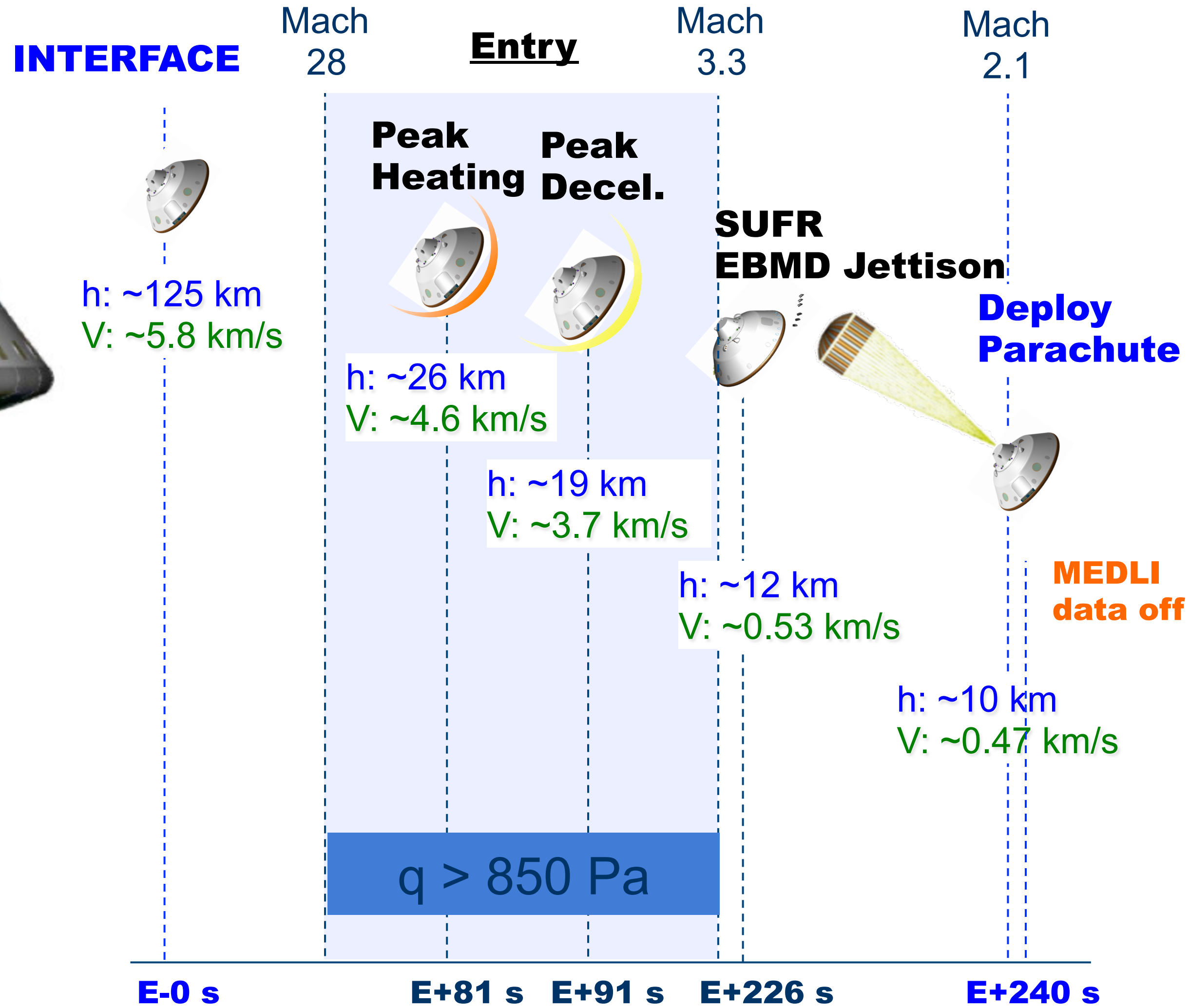
MEAD S/N	Calibration Model (from thermal vac) (mV)	In-Flight Zero (mV)	Difference
022	-0.37	**-0.27**	0.1
025	-0.48	**-0.39**	0.09
029	-0.75	**-0.70**	0.05
021	-0.52	**-0.39**	0.13
032	-0.15	**-0.08**	0.07
023	-0.70	**-0.70**	0.0
024	-0.90	**-0.81**	0.09

Note: In-flight zero data will be used to update the calibration model prior to entry

MSL EDL Timeline

MEDLI data on E – 10 min





MSL Entry Vehicle

4.5 m diameter
70 deg sphere-cone

Entry Mass: 3200 kg

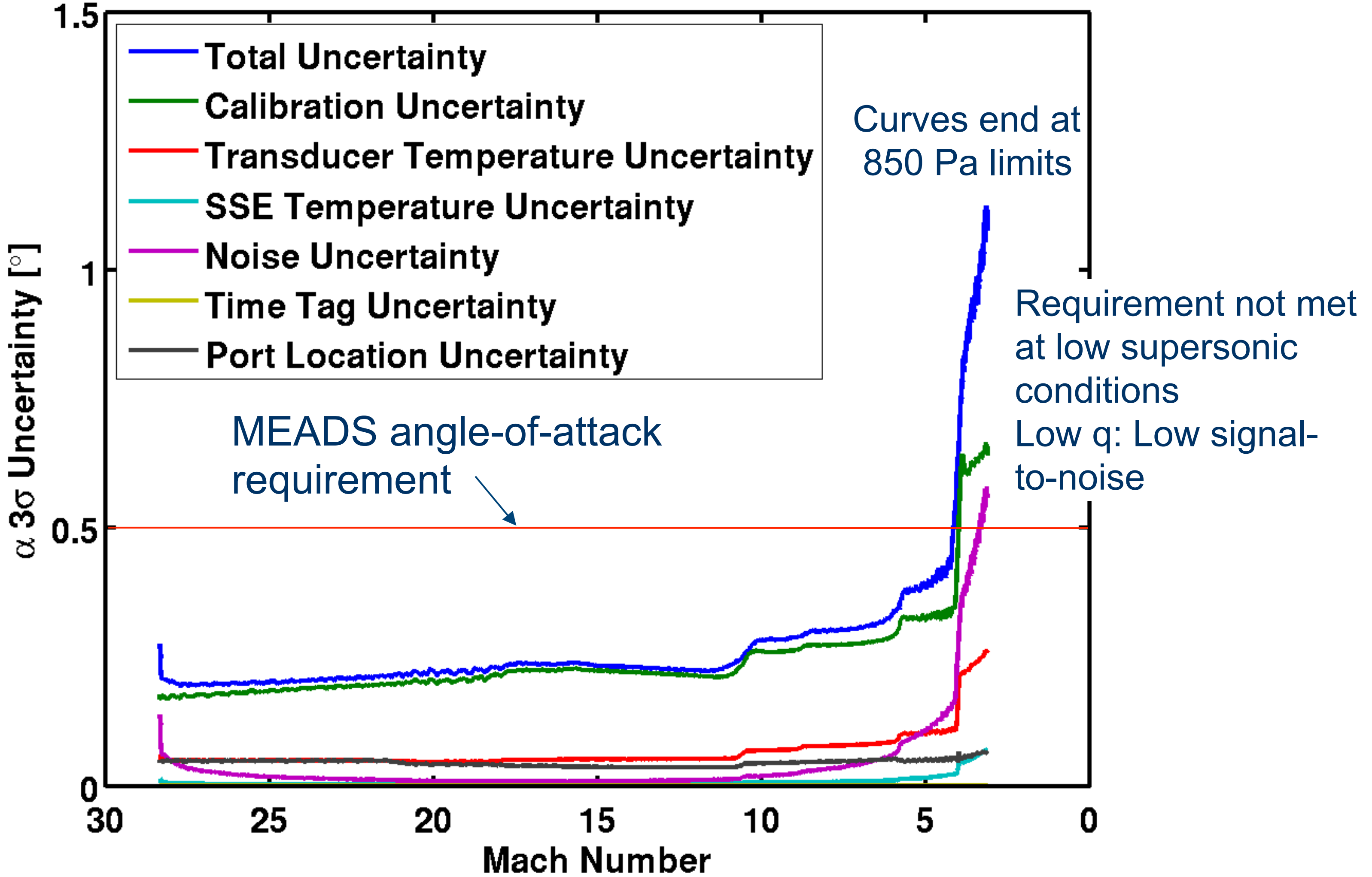
Hypersonic L/D: 0.24

Trim AoA: 17 – 20 deg

MEADS Science Objectives

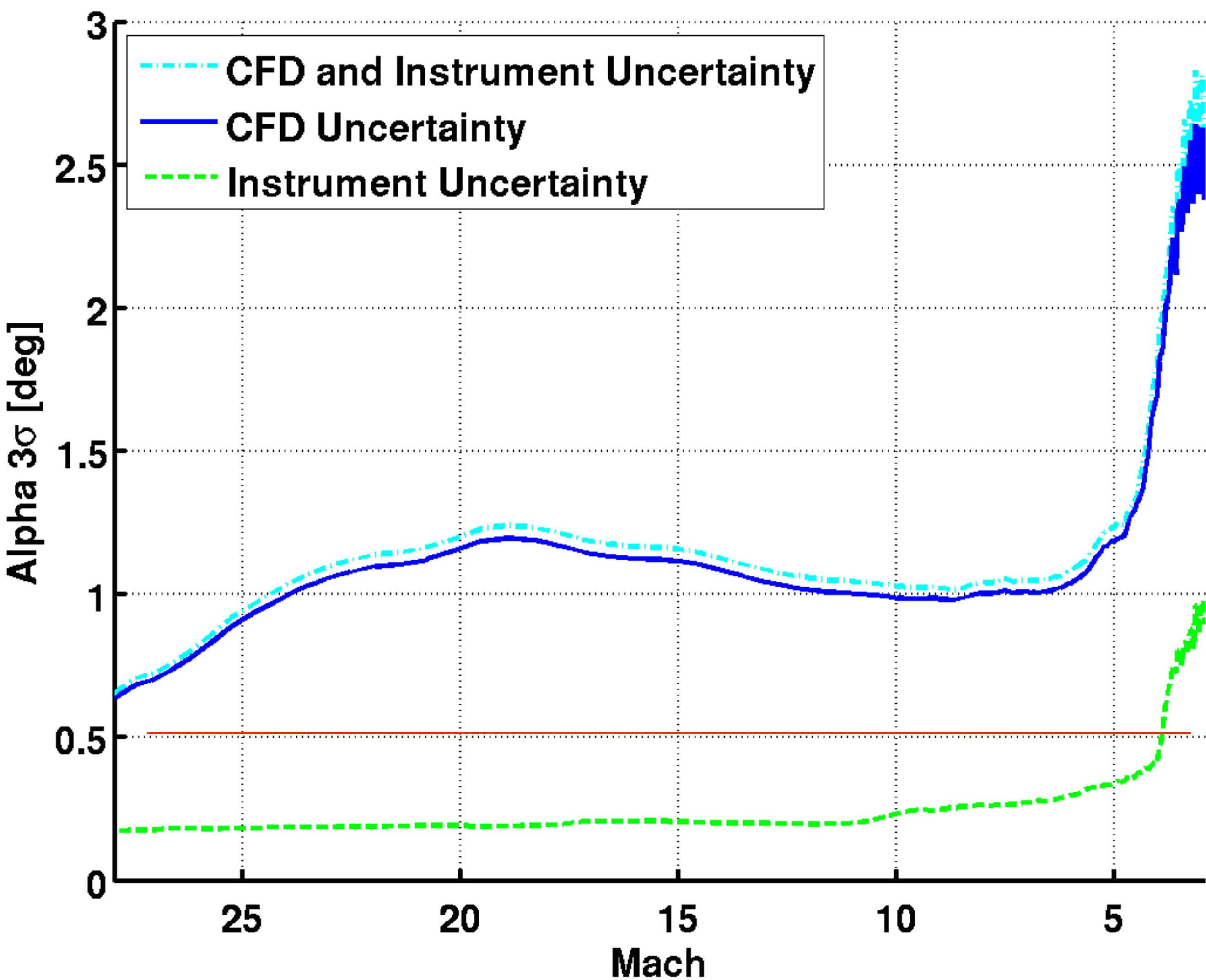
Level 2 Requirement	Objective	Accuracy
PS-371	Reconstruct basic surface pressure	None specified
PS-372	Reconstruct Angle of Attack	$\pm$ 0.5° when P > 1750 Pa
PS-373	Reconstruct Angle of Sideslip	$\pm$ 0.5° when P > 1250 Pa
PS-374	Reconstruct dynamic pressure	$\pm$ 2% when P > 850 Pa

MEADS: Angle of Attack Uncertainty*



***Perfect CFD assumed**

MEADS: Angle of Attack Uncertainty

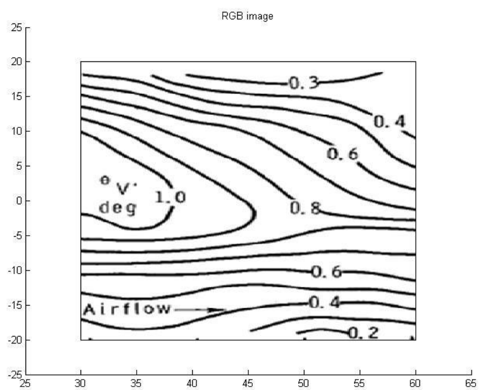


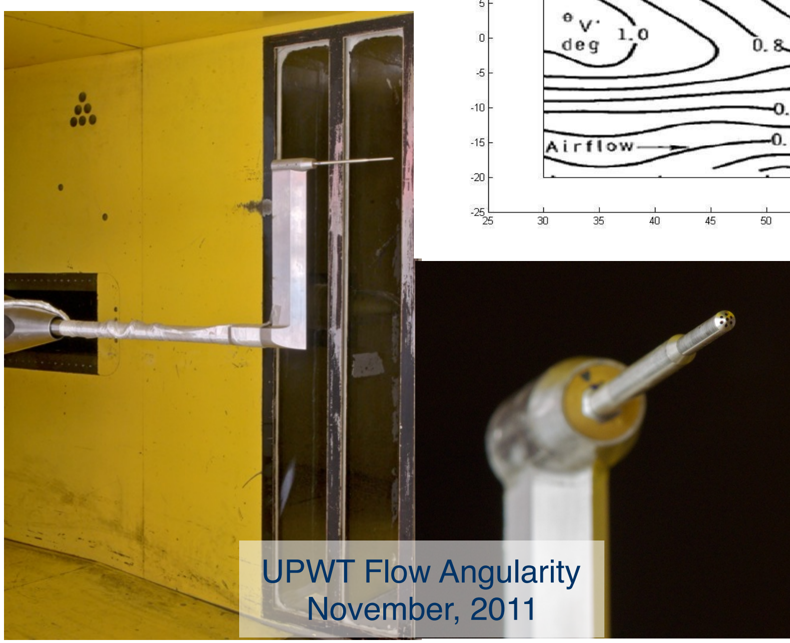
MEADS alpha requirement

Curves end at 850 Pa limits

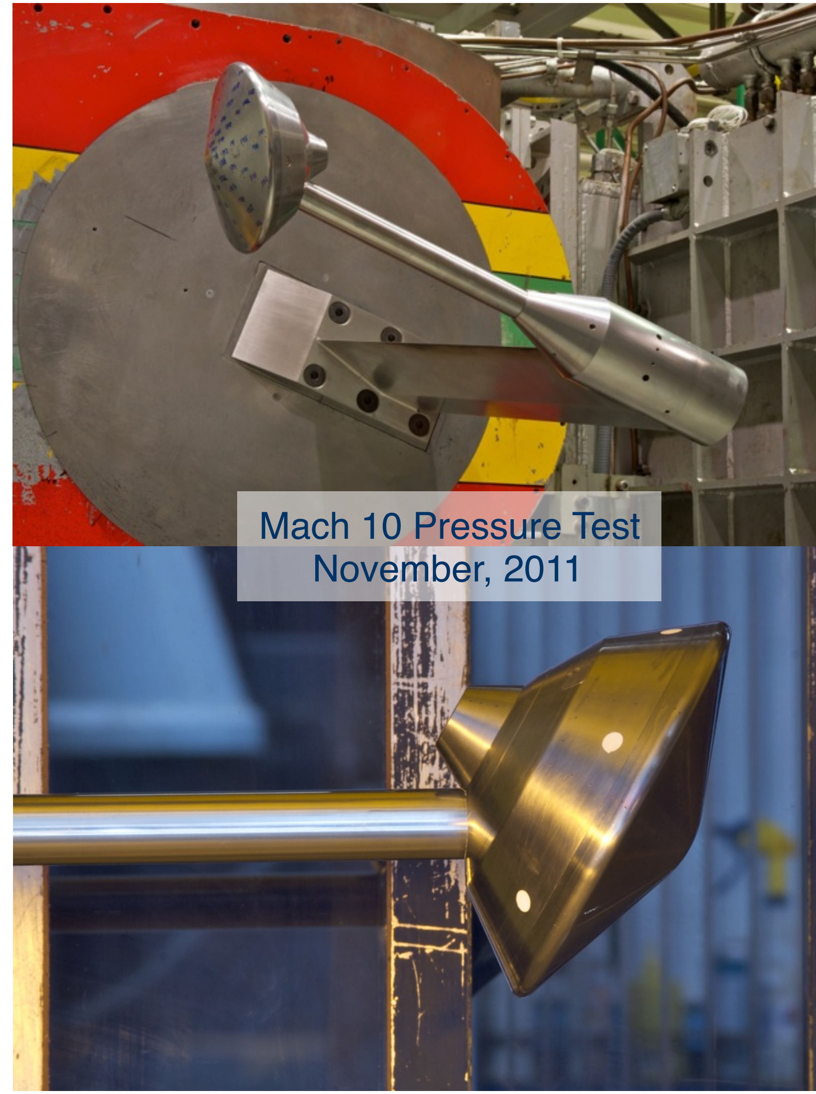
CFD Uncertainty and Calibration

CFD V&V Test Facilities:
- LaRC UPWT
  - Mach 2.5, 3.5, 4.5 Pressure model
  - Flow Angularity survey
- LaRC 31” Mach 10
  - Pressure model



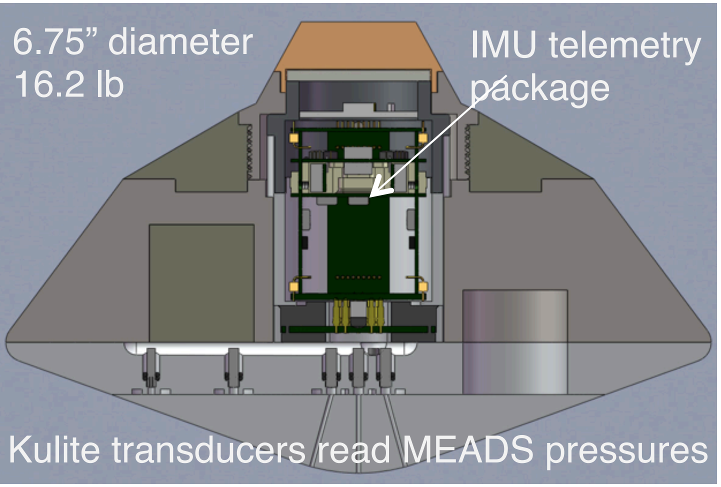


UPWT Flow Angularity
November, 2011



Mach 10 Pressure Test
November, 2011

Aberdeen Proving Grounds Ballistic Range Test

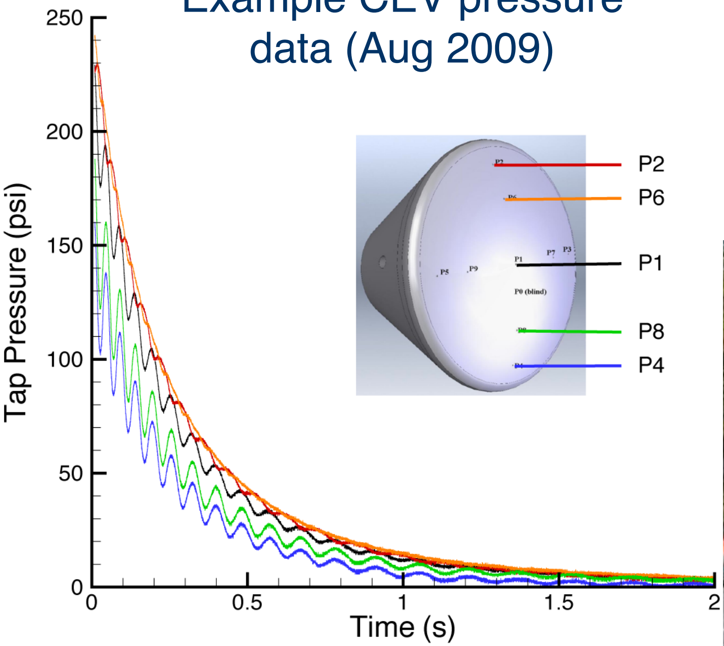


A series of ballistic range tests were conducted to demonstrate and refine the reconstruction approaches.

Each model telemetered onboard pressure, accelerometer, rate and magnetometer data, and tracked by radar.

- Testing in air makes wind tunnel data directly relevant (no CO_2 vs Air uncertainty)
- RADAR tracking provides inertial trajectory path “truth” to within meters.
- MET data provides Mach measurements with accuracy of RADAR velocity measurements.

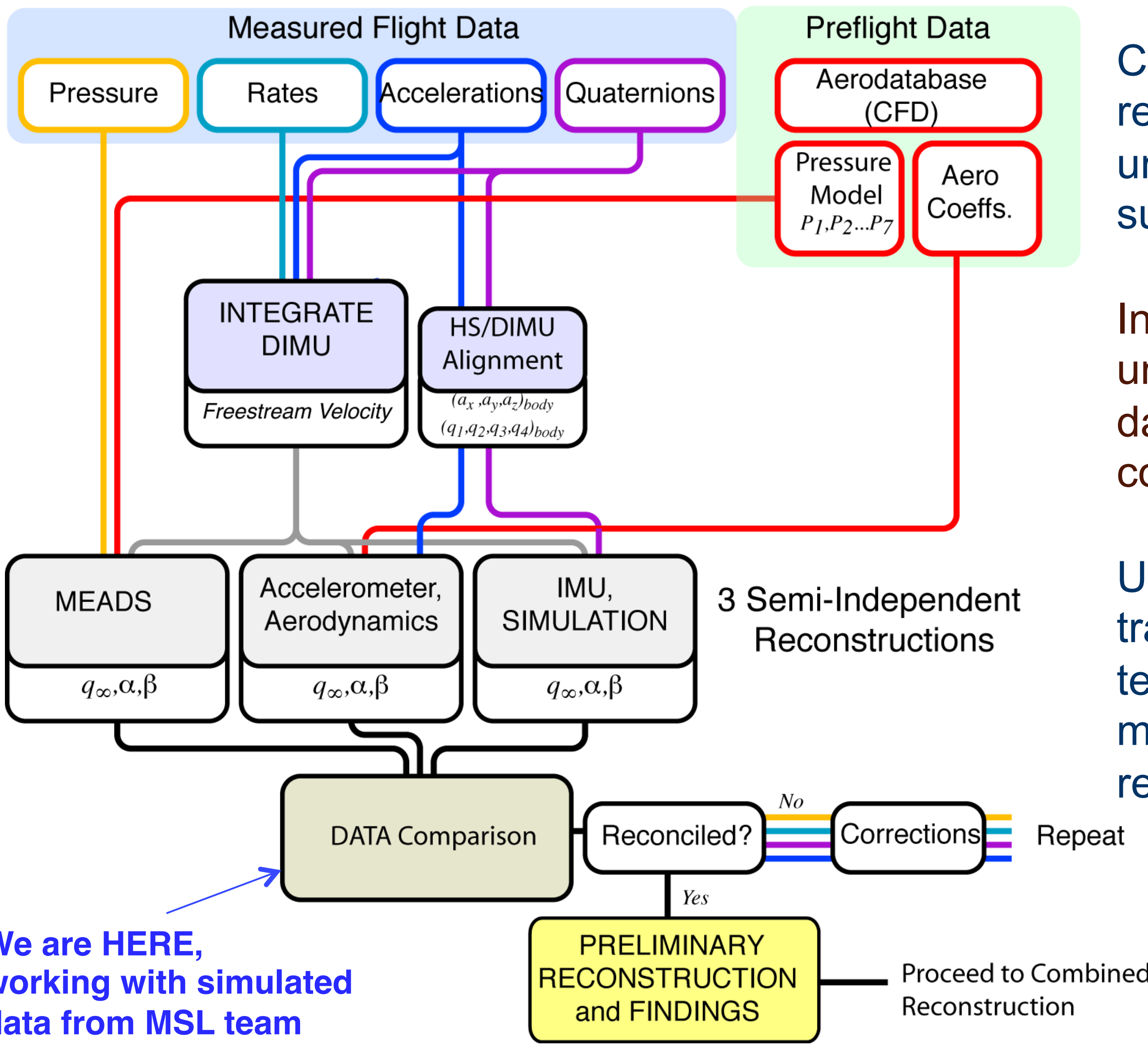
Example CEV pressure data (Aug 2009)



Aberdeen Proving Grounds 7” Gun
Initial Mach: ~3.6
~10 kHz data rate
~10 s flight data

Reconstruction Tool Testing

MSL/MEADS Data Reduction Flow Chart



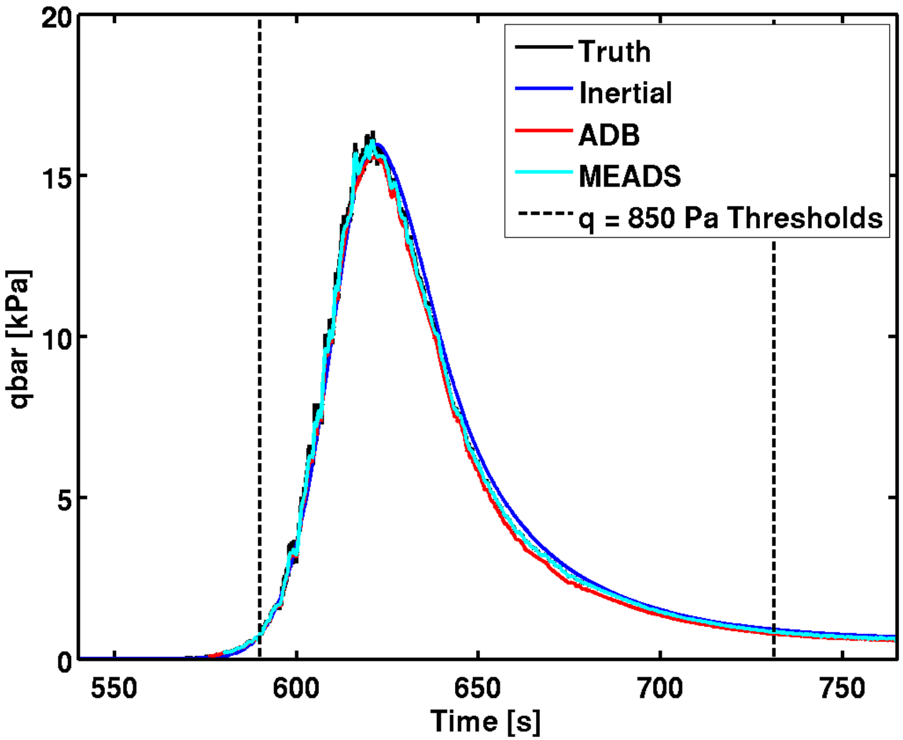
We are HERE, working with simulated data from MSL team

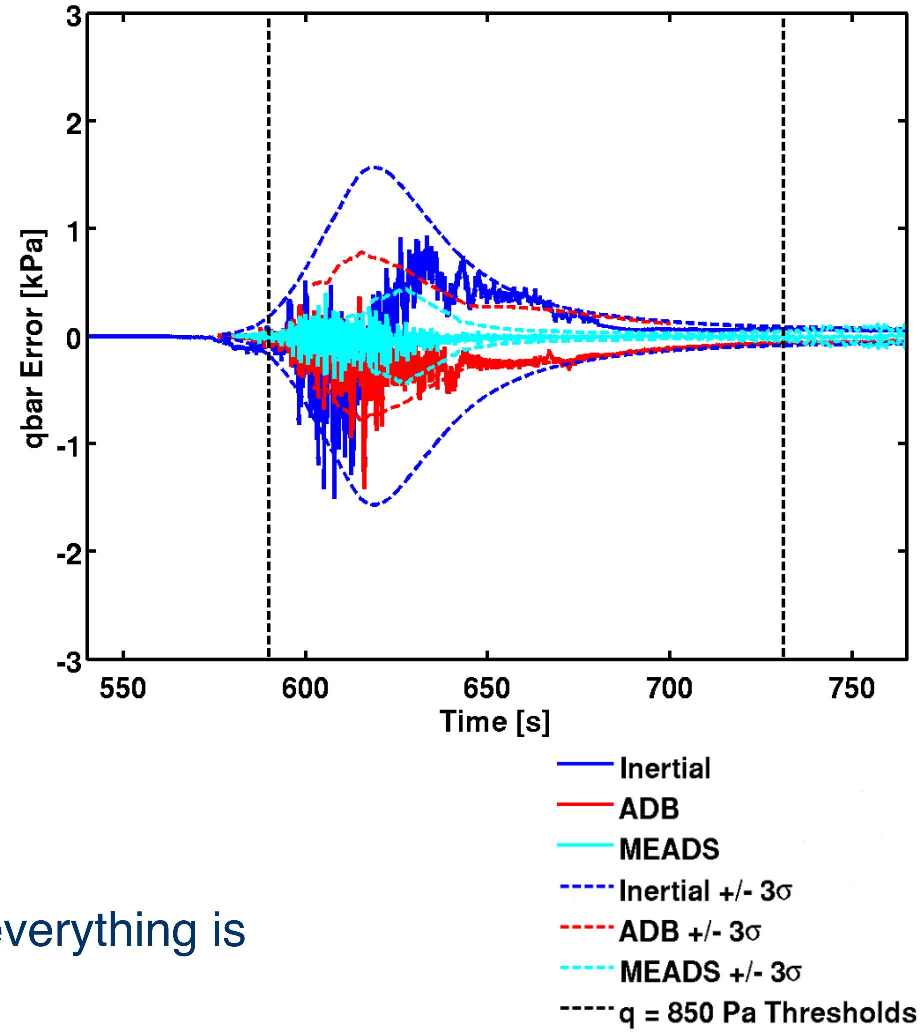
Comparing 3 independent reconstructions with uncertainties identifies suspect data

In addition to MEADS, uncertainty analysis of all data sources is being done concurrently

Using MSL design trajectories with simulated telemetry, run all 3 methods and compare results

Reconstruction Tool Test: Dynamic Pressure (3s low C_A case)





- Inertial reconstruction slightly high
- ADB reconstruction slightly low
- MEADS pressure readings tell us that everything is fine; it's an aero database problem
- ***MEADS data improves observability of the issues***

Additional Reconstruction Work

- **POST-based reconstruction (Striepe and MSL trajectory team)**
  - Extended Kalman filter in POST2 architecture
  - Utilizes MSL flight simulation (best state estimates available for EKF)

  This effort will become an updated version of the MSL trajectory team's reconstruction work done for past Mars Missions.
- **Reconstruction NRA awarded to NIA university team (Robert Blanchard, PI)**
  - Adds statistical uncertainty analysis to existing reconstruction methods

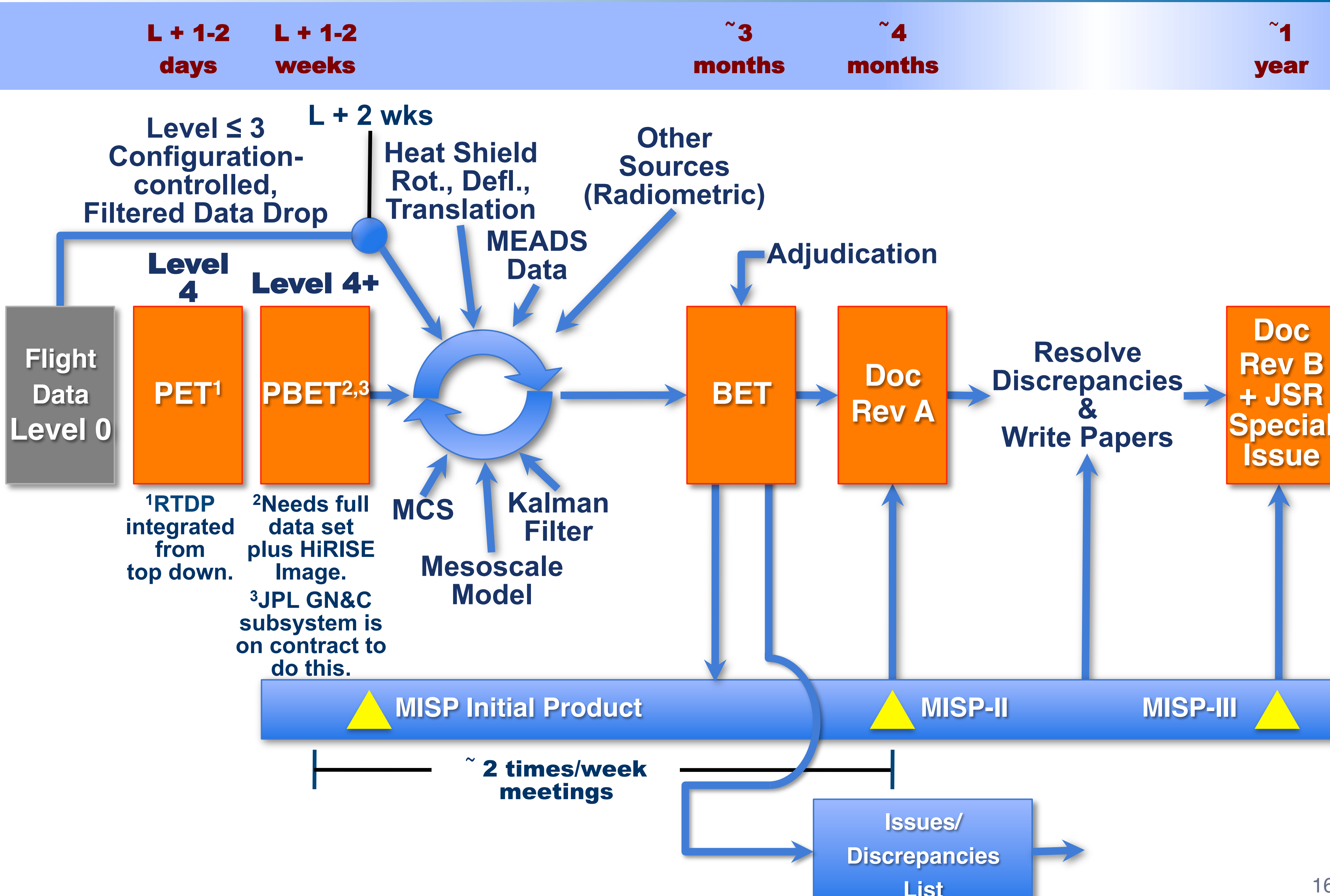
  This effort will add continuity to the independent reconstructions funded by recent Mars missions. New capabilities (and new data) should improve (and better quantify) accuracy.
- **MISP Reconstruction relies somewhat upon reconstruction of MEADS data**

The combined comparison of all of these reconstructions (each with the benefit of the MEADS data) will provide the best assessment of the MSL trajectory, help understand data from past missions, and yield the most information to assist future missions.

Current Status of MEDLI Project

- 2 Cruise checkouts have occurred (March, April 2012)
  - Full dataset returned for practice with formatting, check against qualification testing ranges, etc.
- Working with JPL and EDL simulation team to determine data flow, products, and timing (first team meeting was 12/14/11)
- All primary MEADS reconstruction codes for processing flight data have been written and checked out
- Held Peer Review of methods in January 2012
- Reconstruction Readiness Review in late July at ARC
- **Entry: August 6, 2012 ~1 a.m. EDT**
  - MEDLI Operations Engineer, Chief Engineer, MEADS Reconstruction Lead will be at JPL for entry
  - "Real-time" data: 16 selected measurements at 1 Hz
  - MEDLI also generates tones during EDL: 5 catastrophic, 3 progressive
  - Anticipate full dataset 1-2 weeks after landing

MSL/MEDLI Reconstruction Process

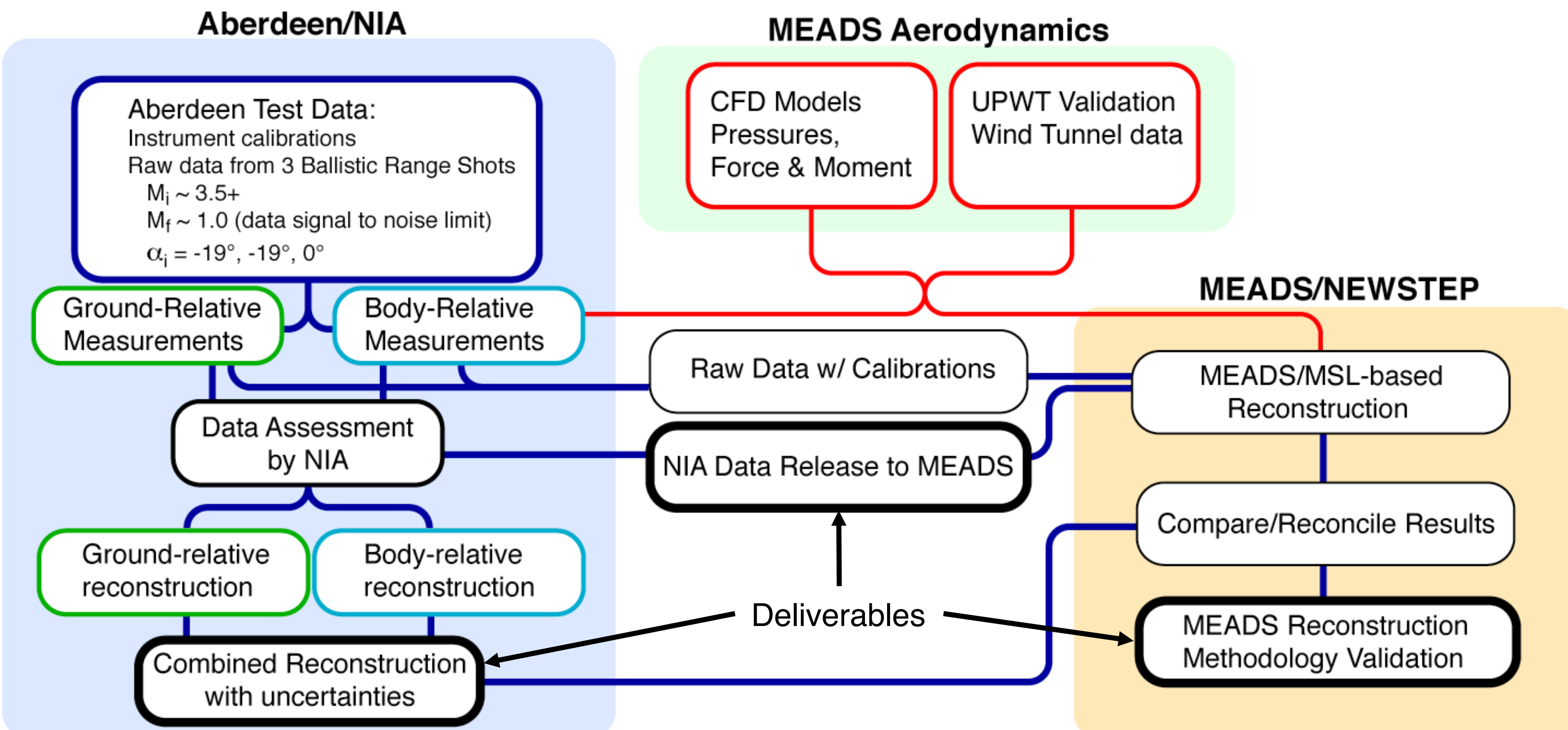


Thank you!

Backup

Motivation and Benefits of Aeroballistic Testing

- Flight data from aeroballistic testing can be used to test various reconstruction techniques (data sources include IMU, pressure taps, and radar)
- Radar tracking data permits comparison to "truth" trajectory solution (inertial position and velocity)
- Other available data: magnetic field vector from magnetometers and MET data



1σ Uncertainty Stackup Example: P1

- Dashed lines show ± 1% bound on averaged experimental data.