Jet Propulsion Laboratory
California Institute of Technology

Validation of the Mars 2020 DSENDS Simulation of Entry, Descent, and Landing Using MSL Reconstruction Data

P. Daniel Burkhart, Seth Aaron, and Clara O'Farrell
Jet Propulsion Laboratory, California Institute of Technology
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Overview

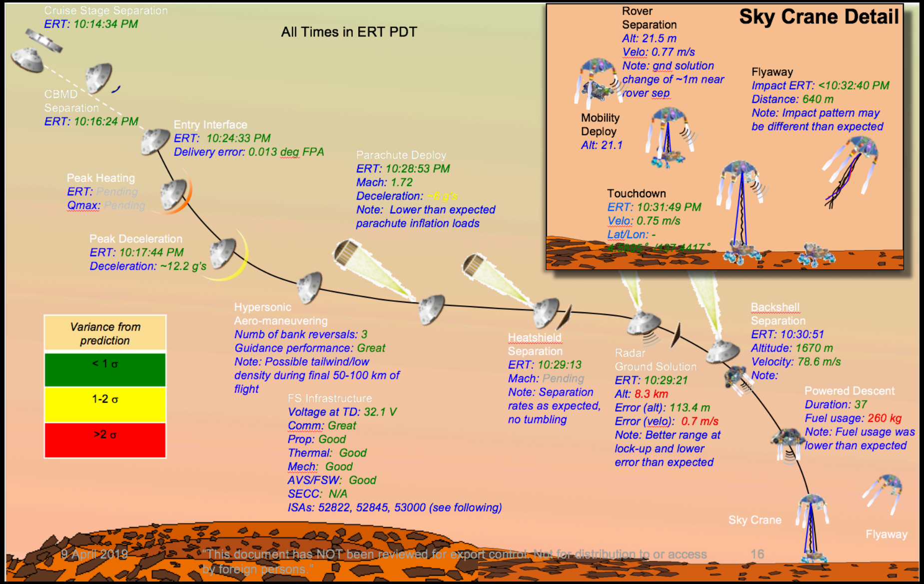
- Motivation: Why are we making this simulation?
  - Simulation is the only end-to-end representation of EDL other than actual EDL. We can't test end-to-end EDL
  - EDL will have more than one complete end-to-end simulation (Mars program requirement)
    - POST2 (LaRC) provides official project performance results for Mars 2020
    - DSENDS is used for targeting and independent V&V of POST results
- Agenda
  - Overview of MSL EDL and DSENDS models required
  - MSL Reconstruction and comparison with expected results
  - Summary and conclusions

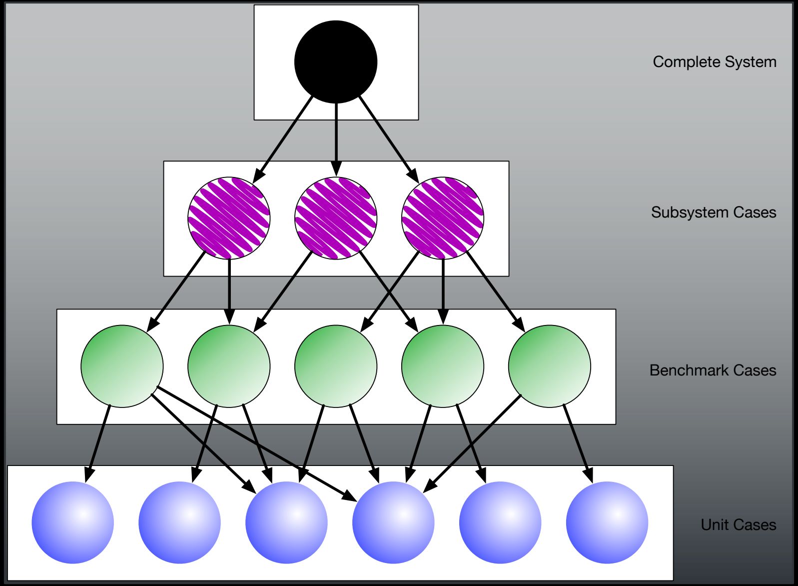
What is DSENDS?

A ***deployment*** of the DARTS Lab's DARTS/Dshell multi-mission simulation toolkit

- A high-fidelity, physics-based flight-dynamics system simulation tool in use for EDL (e.g. M2020) and Proximity Operations (e.g. Comet).
- Simulates the multi-body spacecraft's position, attitude, articulation and body flexibility states and the interactions with gravity, atmospheres, terrain, and on-board s/c devices in response to onboard flight-software directed sensing and control actions.
- DSENDS is used for end-to-end simulation and performance evaluation for flight missions, proposal development, internal R&D efforts, mission studies, algorithm & real-time testbeds, EDL targeting and mission operations.

Validation Hierarchies





Reconstruction Description

- MSL day-of-landing setup used. The best prediction before landing of the expected result.
  - 8000-sample Monte Carlo used to compute uncertainty on metrics of interest. Over 100 specific metrics computed.
- Based on the MSL reconstruction work
  - Reconstructed values for metrics of interest computed
  - Explanation of variations relative to expectations gathered, where applicable
- A subset of those metrics is shown here.

Reconstruction Summary

How does the reconstruction compare to the expected values?

- Values from various MSL reconstruction references (see list at the end)
- Entry
  - Higher atmospheric density at guidance start
  - Tail wind from heading alignment start through parachute deploy
- Parachute
  - Deployment and inflation slightly faster than predicted
  - Aeroshell angular rate/accel predicted well within reasonable bounds
- GNC
  - Radar solution at significantly higher altitude than predicted
  - Lower than expected TD velocity

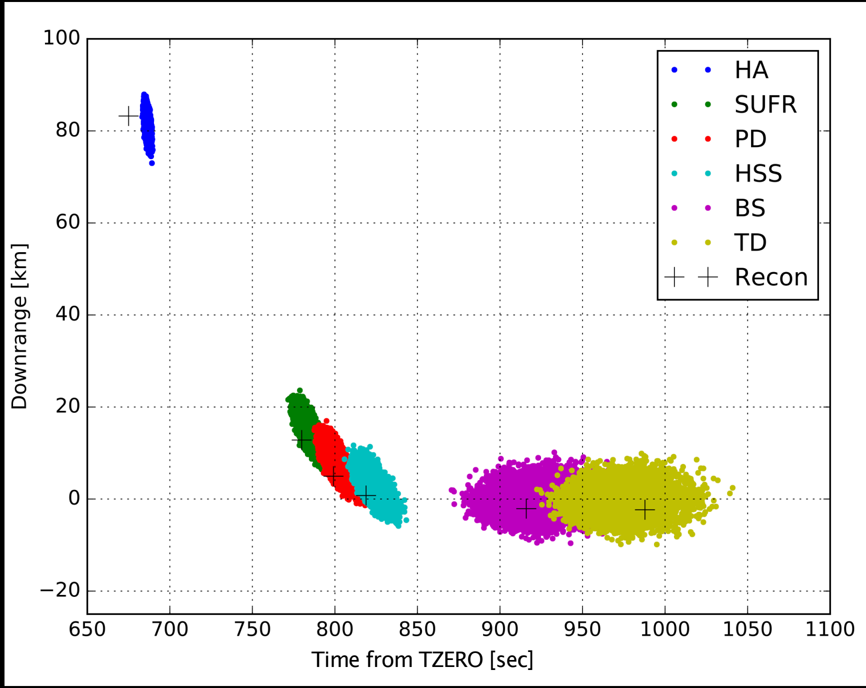
Reconstruction Summary

Score Card Item		DSENDS EDL Simulation Monte Carlo Results			MSL Flight Reconstruction	
Description	Units	1%	Mean	99%	Value	Quantile
Prebank Error	deg	0.05	2.67	8.72	8.595	3.019σ*
Downrange at Heading Alignment	km	76.311	81.452	86.17	83.242	0.780σ
Downrange at SUFR	km	8.249	14.233	20.388	12.819	-0.533σ
Downrange at Parachute Deploy	km	1.534	7.466	13.658	4.966	-0.947σ
Peak Capsule Rates on Chute	deg/s	23.2	47.6	88.3	69.4	1.078σ
Peak Capsule Ang. Accel on Chute	deg/s^2	165	470	1042	625	0.580σ
Altitude AGL at TDS Nav Init	km	5.695	6.729	7.454	8.346	4.164σ
Time in GN&C Mode 21 (Timeline Margin)	s	31.375	43.91	56.192	62.5	3.491σ
Vertical Velocity at Touchdown	m/s	-0.82	-0.75	-0.67	-0.6	-1.465σ
Downrange at Touchdown	km	-6.564	-0.038	6.597	-2.329	-0.783σ
Landing Accuracy	km	0.274	2.666	7.348	2.385	1.139σ*

*Note: One-sided distributions are compared to standard Rayleigh quantiles

Downrange Distance to Target

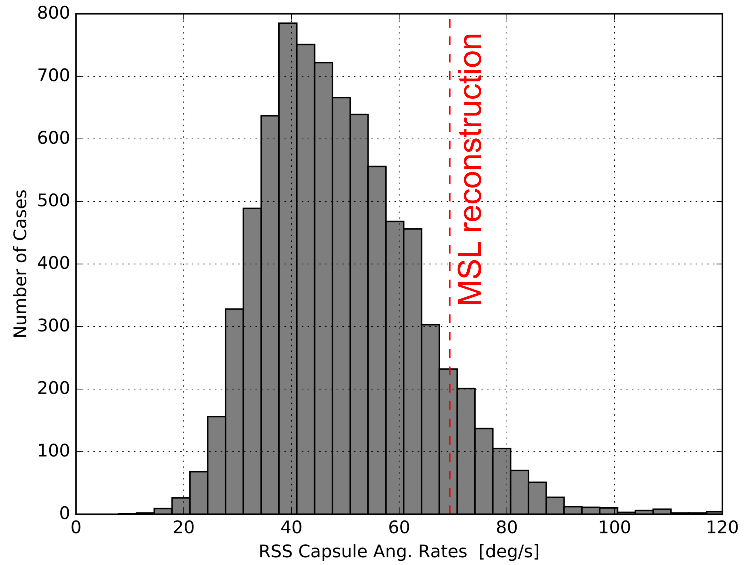
Lower than expected deceleration from heading alignment to parachute deploy



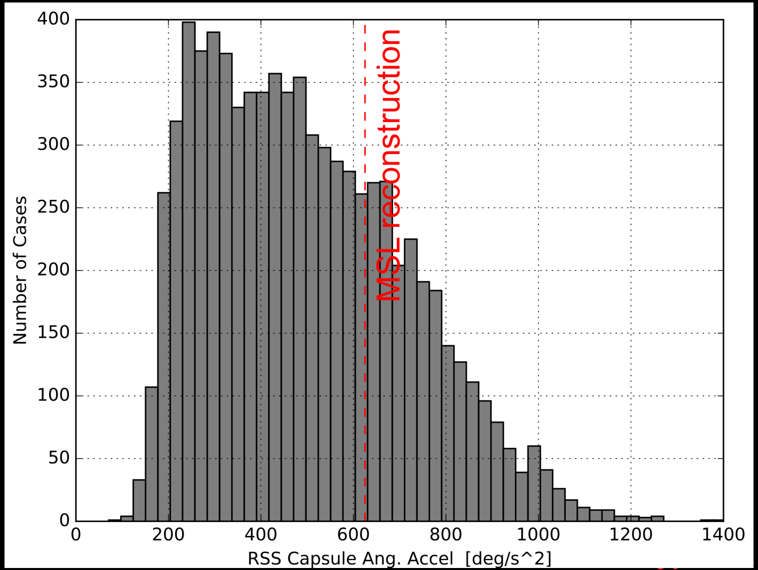
*TZERO is at entry interface minus 9 mins

- At start of heading alignment reconstructed downrange distance to target > prediction
- Lower supersonic deceleration between HA and parachute deploy → downrange distance to target decreases faster than prediction
- Touchdown 2.329 km downrange of target

On-Parachute Dynamics



- Max. capsule angular rates & angular accelerations (RSS) during the parachute phase are within bounds of expectation



- MSL reconstruction provided additional data point for model parameter tuning for M2020

Summary

- A DSENDS end-to-end simulation of EDL has been developed for Mars 2020.
- This simulation has been verified by comparison with MSL reconstruction
- Future Work
  - Update the setup as necessary to match the latest Mars 2020 models and configuration.
    - Final model integration and test is nearly complete
  - Perform analysis as needed for simulation V&V
  - Perform additional analyses as requested by Mars 2020.

References

1. Burkhart, P.D. et al, “DSENDS Simulation of Mars 2020 Entry, Descent, and Landing”, IPPW-2018. [link]
2. Papers from Journal of Spacecraft and Rockets, Vol. 51, No.4, July-August 2014
   a. Mendeck, G and McGrew, L, “Entry Guidance Design And Postflight Performance for 2011 Mars Science Laboratory Mission,” pp1094 - 1105
   b. Chen, A. et al, “Reconstruction of Atmospheric Properties from Mars Science Laboratory Entry, Descent, and Landing,” pp1062 – 1075
   c. Schoenenberger, M. et al, “Assessment of the Reconstructed Aerodynamics of the Mars Science Laboratory Entry Vehicle,” pp1076 - 1093
   d. Cruz, J. et al, “Reconstruction of the Mars Science Laboratory Parachute Performance,” pp1185 – 1196
   e. Sell, S. et al, “Powered Flight Design and Performance Summary for the Mars Science Laboratory Mission,” pp1197 - 1207
   f. Baker, R. et al, “Mars Science Laboratory Descent-Stage Integrated Propulsion Subsystem: Development and Flight Performance,” pp1217 – 1226
   g. Steltzner, A. et al, “Mars Science Laboratory Entry, Descent, and Landing System Development Challenges ,” pp994 – 1003
3. Way, D. et al, “Assessment of the Mars Science Laboratory Entry, Descent, and Landing Simulation,” AIAA/AAS Space Flight Mechanics Meeting, American Astronautical Society Paper 2013-420, Feb. 2013

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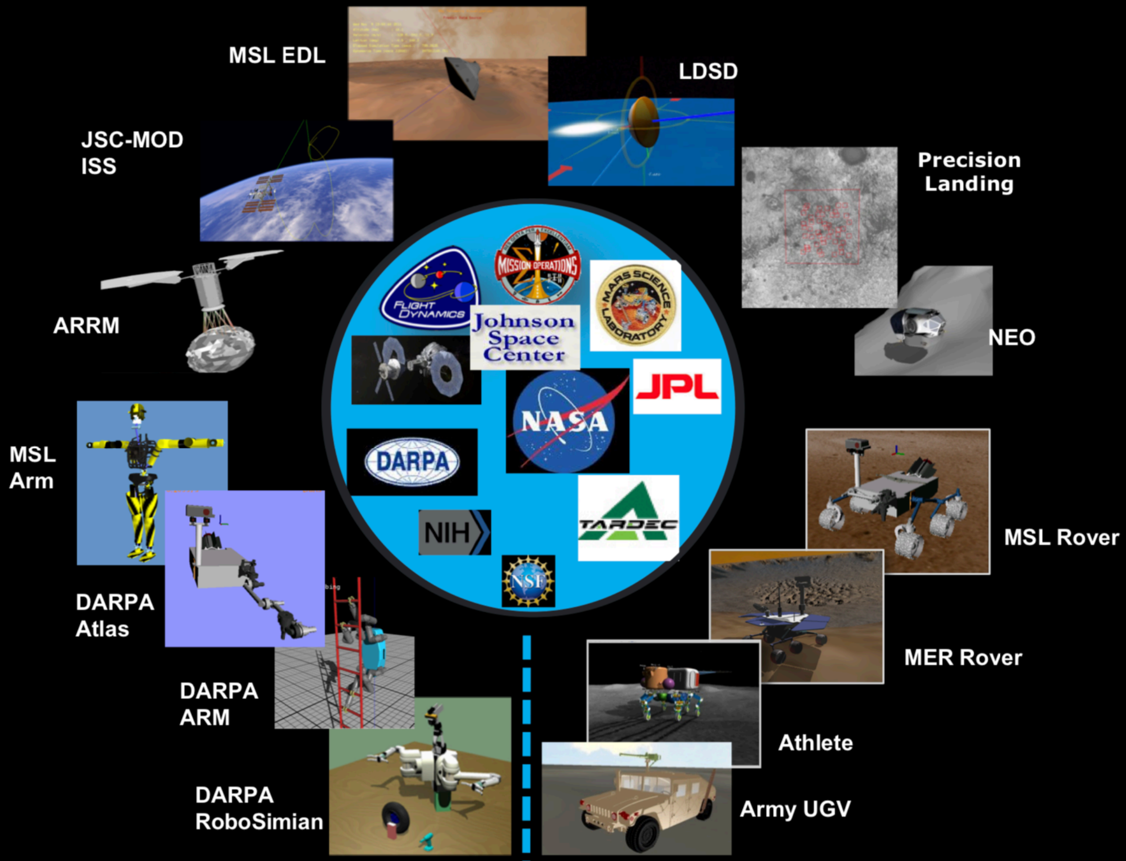
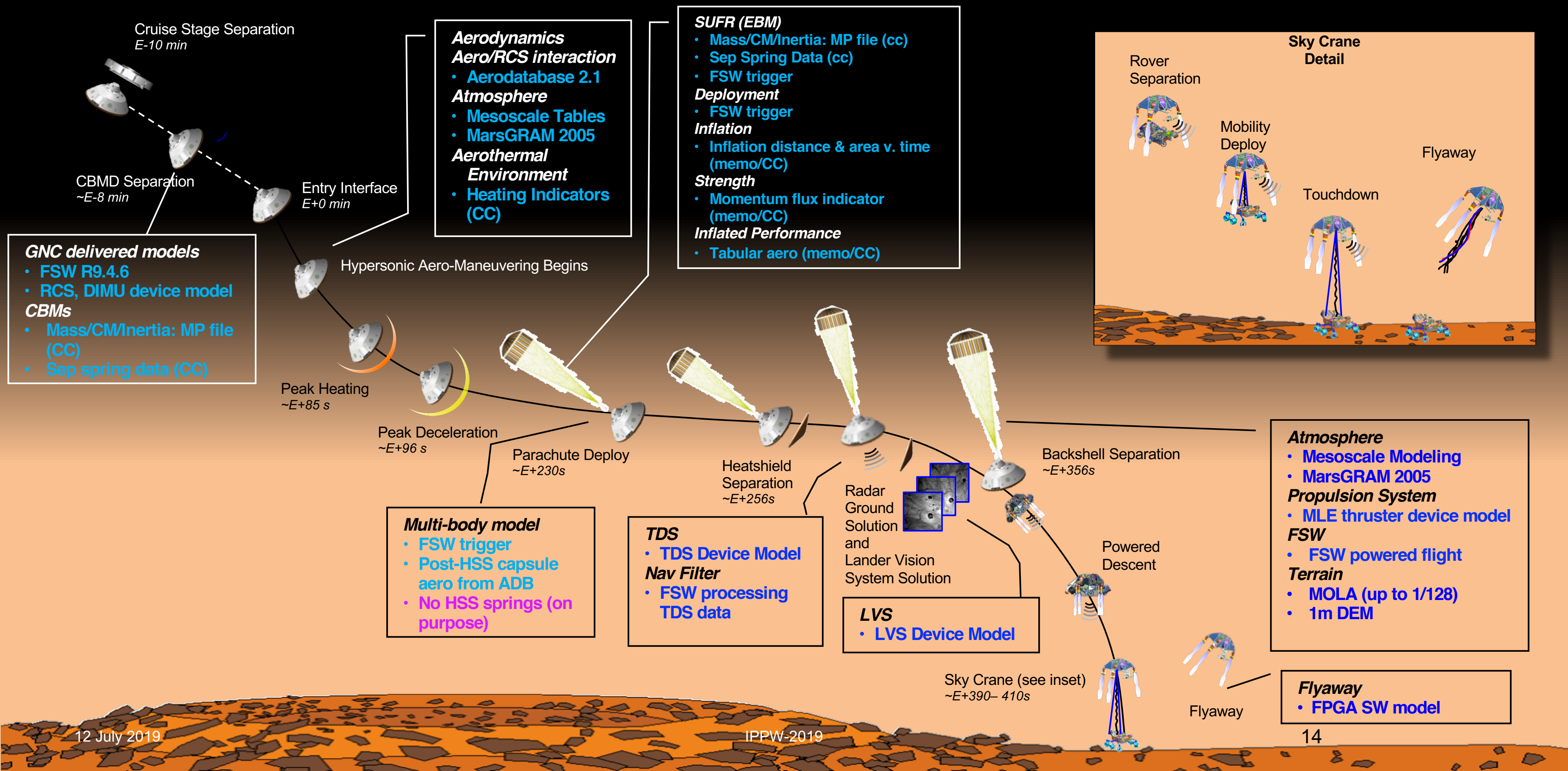
DARTS/Dshell Simulation

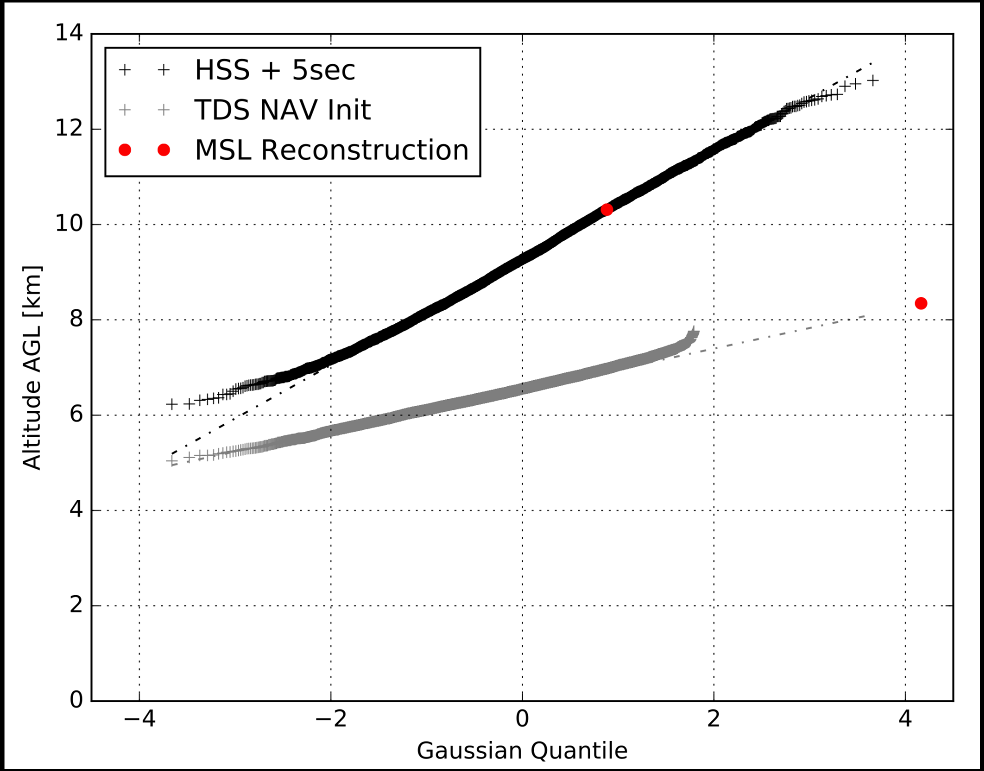
Toolkit usage



EDL Overview – Mars 2020 Models

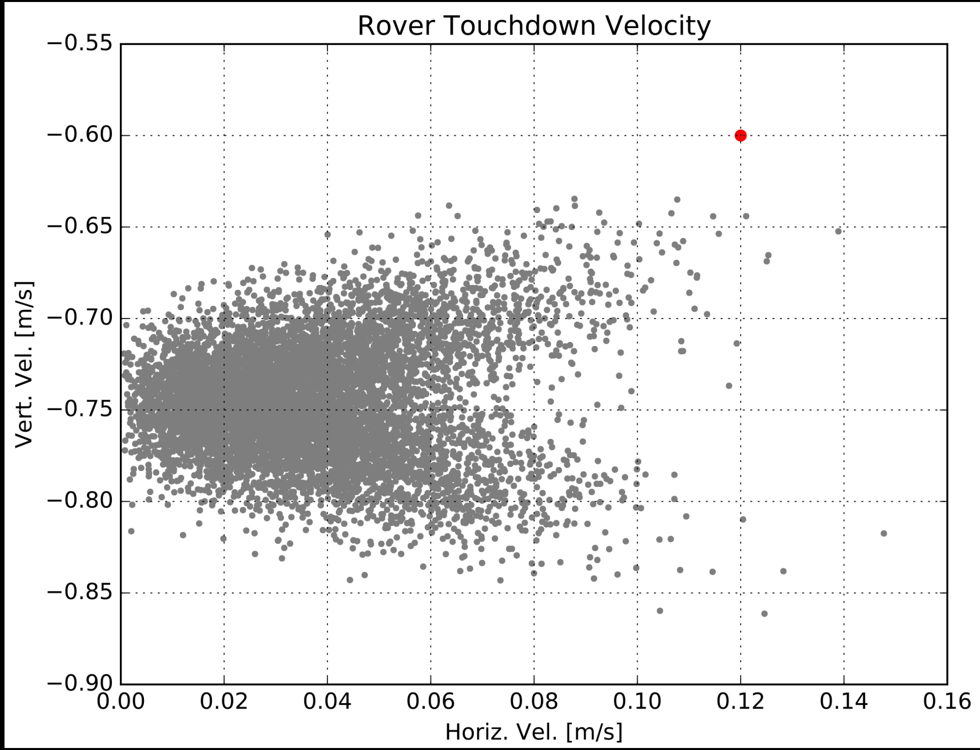


TDS Performance



- Vehicle ready to process TDS data approx. 5 sec after heatshield sep.
- Radar solution obtained at significantly higher altitudes than predicted
- TDS level 1 model was intentionally conservative
- (Slant range measuments > 7km declared invalid)

Touchdown Velocity



- Rover vertical velocity at touchdown was significantly lower than expected
- Caused by a 450 µg error in estimating the local gravity at Gale crater
- Updated local gravity model for Mars2020

Reconstruction summary

- For MSL, how does the reconstruction compare to the expected values?
  - Base this on the various reconstruction papers
- Notes from papers
  - Gavin’s EG paper
    - Higher atmos density at guidance start
    - Tail wind late in guided entry
    - Long SUFR-chute deploy time delta
      - 0.5km downrange due to atmosphere/aero/winds
  - Supersonic atmos data not very good (MEDLI not calibrated here), also adds uncertainty to aero recon
  - Chute paper
    - Deployment and inflation slightly faster than predicted
    - Aeroshell angular rate/accel predicted well within reasonable bounds
  - TDS: measurement start at significantly higher altitude than predicted, in line with HS separation and clear vs the modeled max height constraint based on requirements
  - PD an d prop/thruster papers
    - Higher-than-expected thrust from MLEs
  - Steltzner overview paper
    - Lower than expected TD velocity