InSight

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16th International Planetary Probe Workshop

InSight EDL Overview and As-Flown Performance

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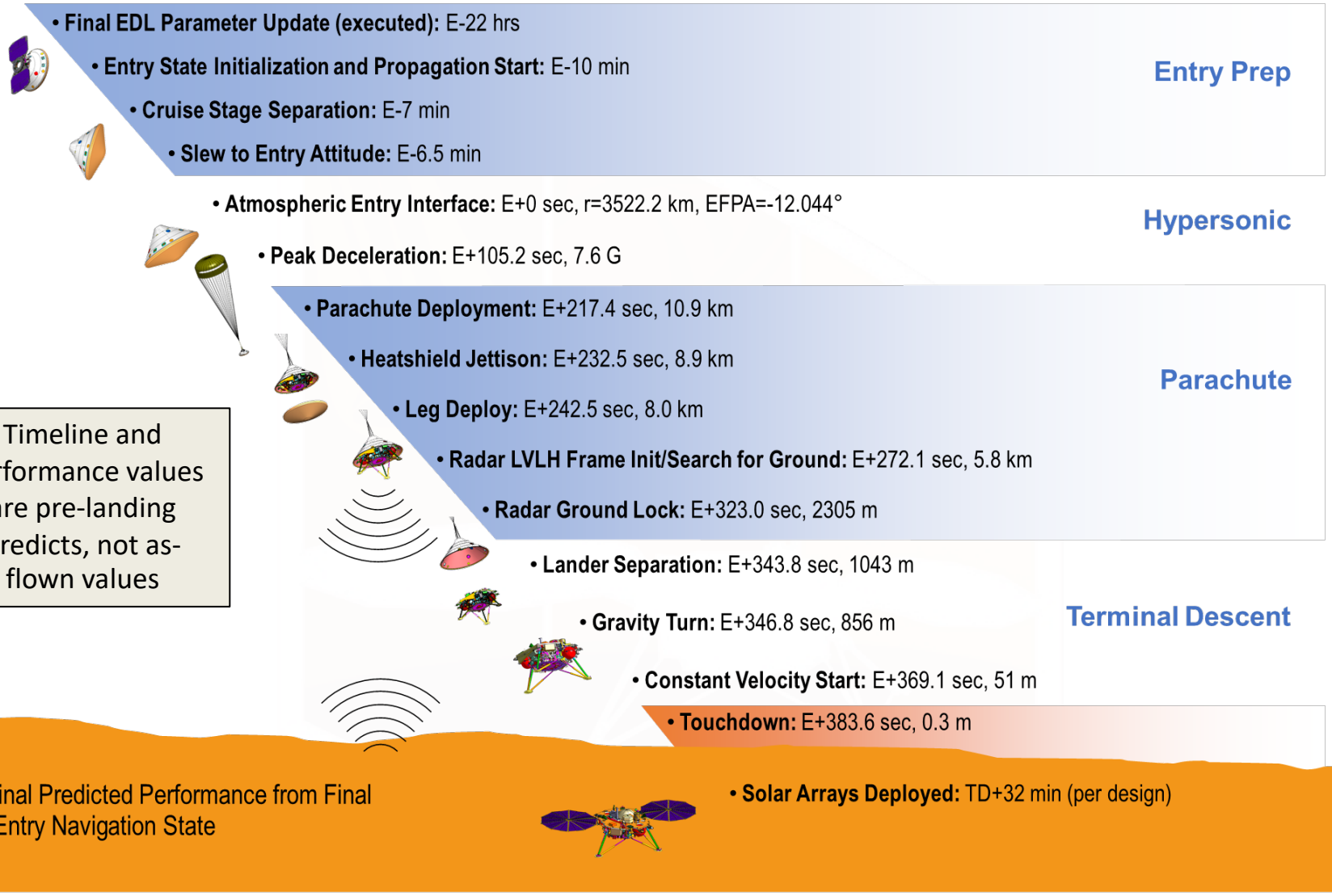
InSight EDL Overview

- InSight EDL system is nearly identical to NASA's Phoenix system that landed in 2008
  - 2.65 m diameter aeroshell flying a ballistic entry
  - Viking heritage 11.8 m DGB supersonic parachute
  - Powered descent under 12 pulse-width modulated descent engines
  - IMU and wide beam Doppler radar for navigation
- Unique challenges to InSight
  - Higher landing site elevation than Phoenix
    - 1.4 km higher so less time/altitude to do EDL
  - Landing during dust storm season
    - Created the need to assess EDL performance against 4 dispersed atmosphere models representing possible environments during EDL
      - Nominal background atmosphere
      - Regional dust storm atmosphere
      - Global dust storm atmosphere
      - Decaying global dust storm atmosphere
    - Multiplied the work load on the EDL team throughout the life of InSight
    - Required extra heatshield TPS to compensate for possible dust abrasion
    - A unique landing point targeting process was developed for operations to compensate for changing atmosphere conditions during approach to Mars

InSight EDL Architecture: Pre-Landing Predicted



InSight Landing Day Team – Two Main Locations

InSight EDL Team Orgs

- Jet Propulsion Lab
- Lockheed Martin Space
- NASA LaRC
- NASA ARC

Team at Jet Propulsion Lab in Pasadena, California

Photo courtesy of Jet Propulsion Laboratory

Team at Lockheed Martin Space in Littleton, Colorado

Photo courtesy of Lockheed Martin Space

High Level Summary of EDL Event

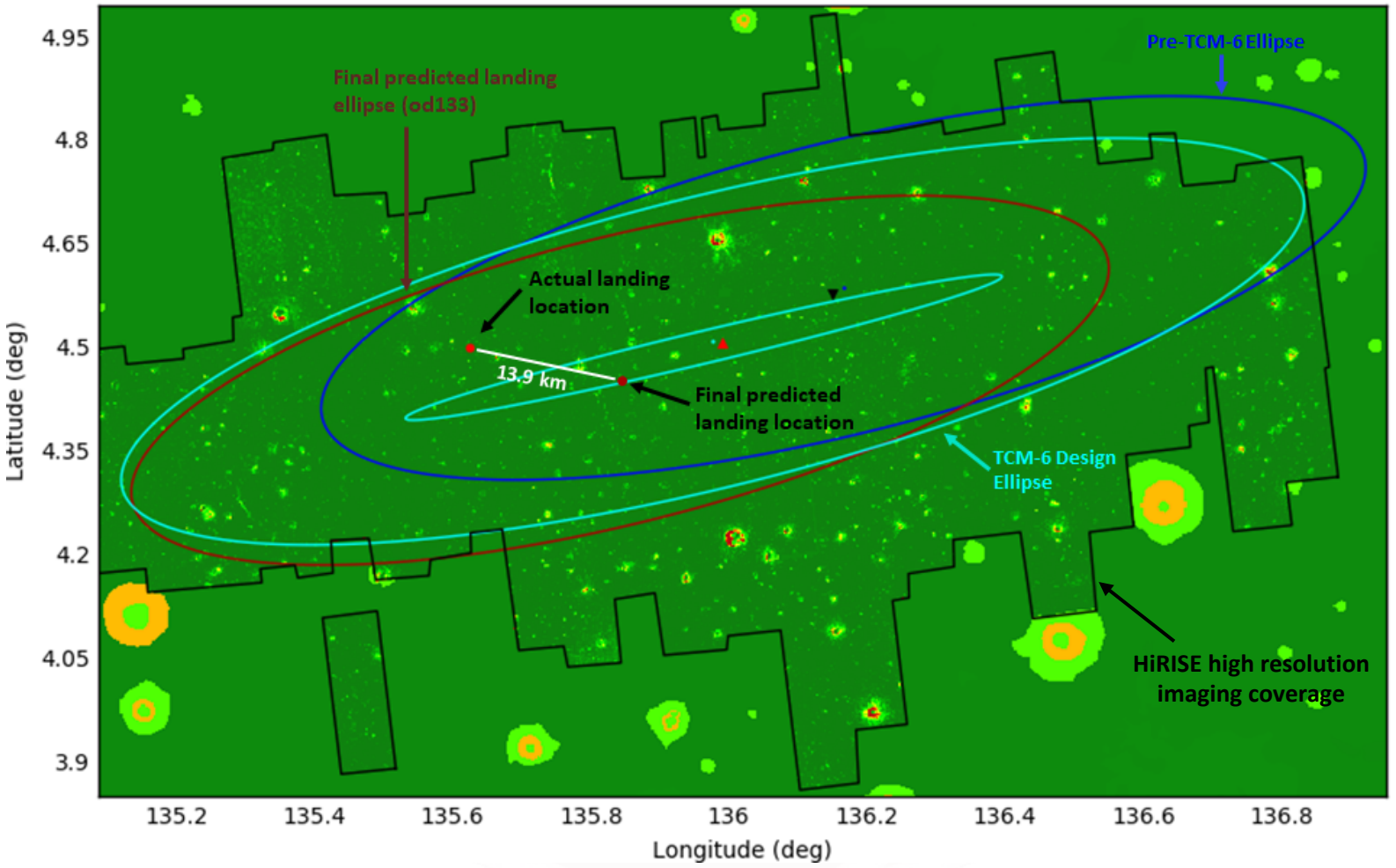
- After a smooth approach to Mars, InSight successfully touched down on November 26, 2018
- The spacecraft was delivered to entry interface with an entry flight path angle (EFPA) of -12.046°, well within the required corridor of ±0.21° centered on -12.0°
- The spacecraft performed nominally and as designed throughout EDL
- While the spacecraft performed nominally, there were a number of indications the trajectory flown was not down the middle of predicts

Landing Day Indicators	
Peak Deceleration	Peak-g reached 8.13 g while 99% high predict was 8.14 g
EDL Duration	Time from Entry to Touchdown was 35.5 s faster than predict, and near the predicted lower limit
Landing Location	Vehicle landed 12.3 km uptrack, with a 6.1 km crosstrack error, or 13.9 km from the center of the final predicted landing ellipse

- Subsequent investigations show contributors were atmosphere and vehicle aerodynamics

InSight Landing Location

Landing Location on InSight Landing Hazard Map



PreTCM-6(od115) 92kmX25km
TCM-6(Predicted Ellipse)101kmX25km
Post TCM-6(od133) 86kmX24km

- Final predicted landing location
- Actual landing location

Landing location relative to last predict:
Uptrack distance: 12.3 km
Crosstrack distance: 6.1 km

End-to-End EDL Performance Table

EDL Metric	Reqmt	Units	Flight	Pre-Flight Predicts		
			Reconstructed Value	Nominal	1%-tile	99%-tile
Loads						
Peak Deceleration	< 13	Earth G	8.1	7.6	7.1	8.1
Parachute Inflation Load Indicator	< 15	1000 lbs	10.1	12.0	9.2	14.2
Parachute Deploy State						
Time from Entry	NA	sec	208.4	217.4	204.5	234.7
Deploy Mach	1.1 to 2.1	Mach	1.5	1.7	1.5	1.9
Deploy Dynamic Pressure	300 to 750	Pa	546.0	521.4	477.4	572.0
Total Angle of Attack	< 9.7	deg	3.1	1.6	0.1	6.5
Total Angle of Attack Amplitude	< 9.7	deg	8.5	2.1	0.4	7.7
Altitude at Deploy	NA	km	8.5	10.9	7.8	14.8
Parachute Phase Events						
Attitude Rate Amplitude at Heatshield Se	< 100	deg/s	19.8	49.6	20.4	88.9
Attitude Rate Amplitude at Leg Deploy	< 100	deg/s	27.0	40.9	18.7	72.1
Radar Activation Altitude (MRD_INIT)	2497 to 10051	m	5383	5796	4217.1	8862.2
Lander Separation State						
Time from Parachute Deploy	NA	sec	95.5	126.4	88.3	193.3
Altitude at Lander Sep	NA	m	1257	1046	935.3	1412.1
Attitude Rate Amplitude at Lander Sep	< 60	deg/s	8.5	22.9	14.5	41.3
Touchdown Conditions						
Time from Lander Separation	NA	sec	44.2	39.8	37.7	45.9
Vertical Velocity	1.4 to 3.4	m/s	2.4	2.7	2.0	2.8
Horizontal Velocity	< 1.4	m/s	0.3	0.2	0.03	0.58
Overall Metrics						
Maximum Attitude Rate	< 375	deg/s	105.1	93.1	44.4	175.7
Duration of EDL	NA	sec	348	384	341.5	458.7

- 0.5 g higher peak deceleration
- 9.0 sec early to chute deploy
- 2.4 km low on chute deploy altitude
- 30.9 sec shorter duration on chute
- 4.4 sec longer during terminal descent
- 35.5 sec early to landing

Summary

- The InSight spacecraft performed nominally and as expected
- The trajectory flown resulted in peak deceleration higher than expected, a short EDL duration, and a landing somewhat uptrack and crosstrack of the predicted landing location
  - More details on the factors contributing to the flown trajectory are in IPPW presentations
    - Mars InSight Trajectory and Atmosphere Reconstruction
    - Performance of the InSight Spacecraft During Entry, Descent, and Landing at Mars
    - Comparison of the Reconstructed Entry, Descent, and Landing Phase of the InSight and Phoenix Mars Landers
- Poster session contains additional aerodynamics details, as well as information on parachute, aerothermal, radar, operations, landing safety, and will have an animation of the landing generated from flight data