



Deorbit, Descent, and Landing Simulations

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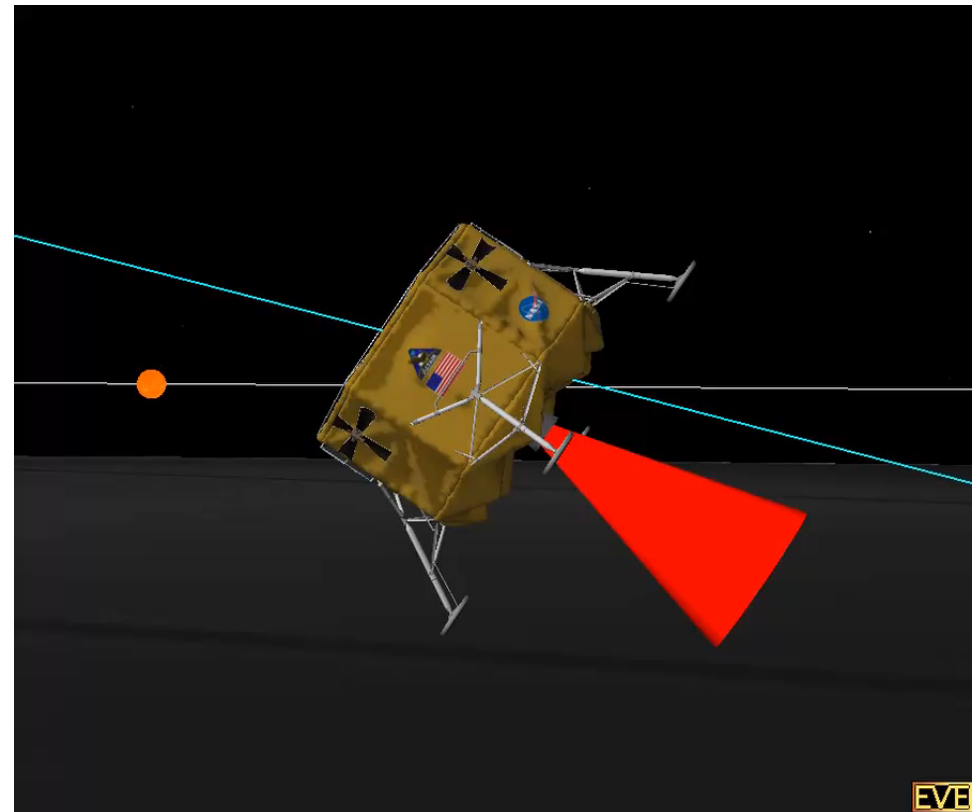
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Introduction



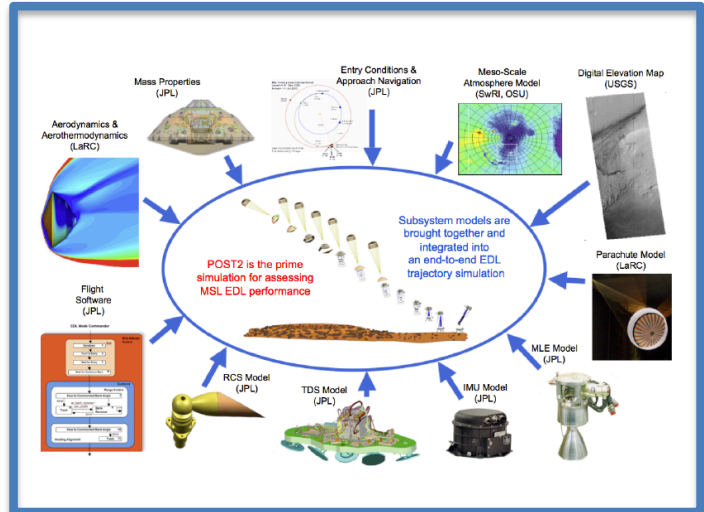
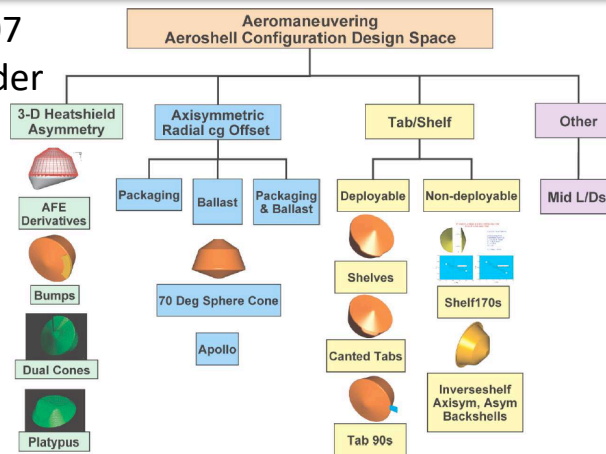
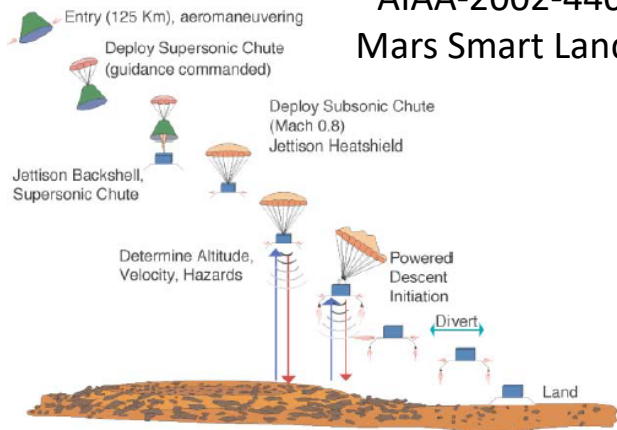
- **Led trajectory simulation for NASA Lunar Human Landing System**
 - Deorbit, Descent, and Landing concept of operations
- **Trajectory Visualization**
- **Develop missions from concept to flight**
- **Perform integrated vehicle design (3-, 6-, and multi-DOF)**
- **End-to-End performance assessments**
- **Independent Verification and Validation (IV&V)**



Concept to Flight: Mars Science Laboratory

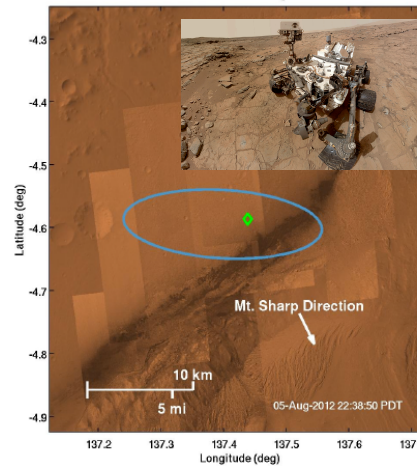
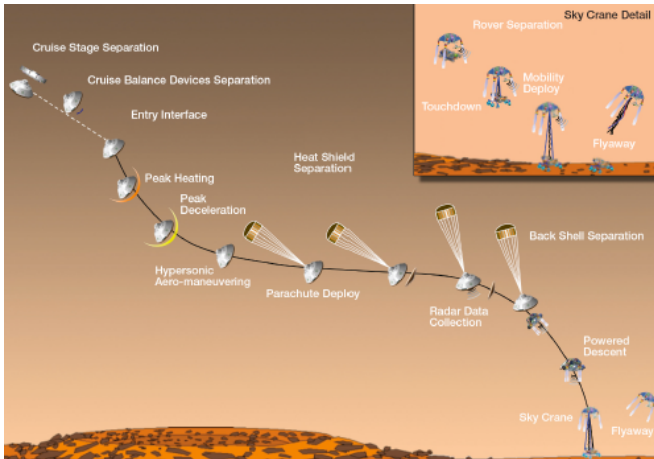


AIAA-2002-4407 Mars Smart Lander



AAS 13-420

Curiosity Best Estimate Landing Location -4.58° Latitude, 137.44° Longitude

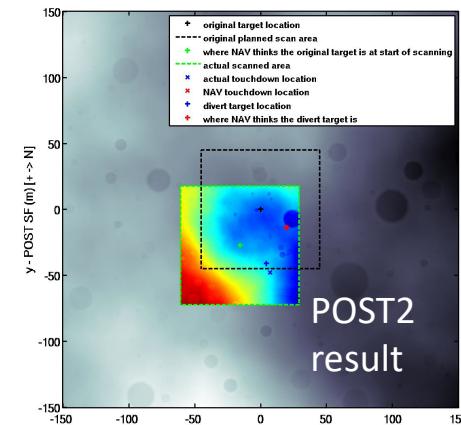
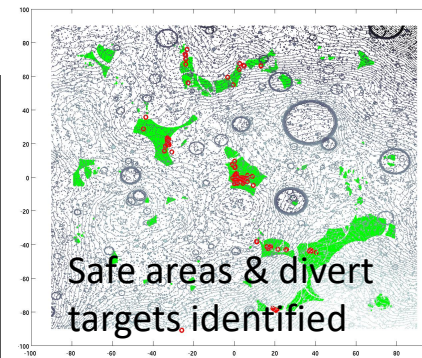
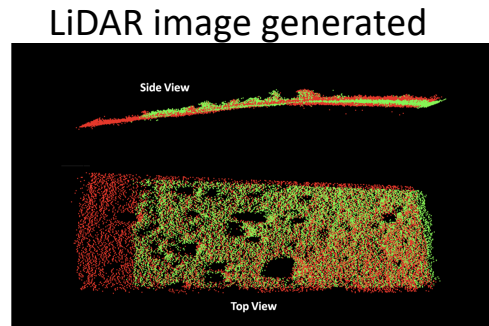


Integrated Vehicle Design: Navigation Sensors



- **ALHAT 2008-2011**

- Established end-to-end simulations including high fidelity engineering models of the ALHAT systems (GN&C, and sensors) and Lunar environment

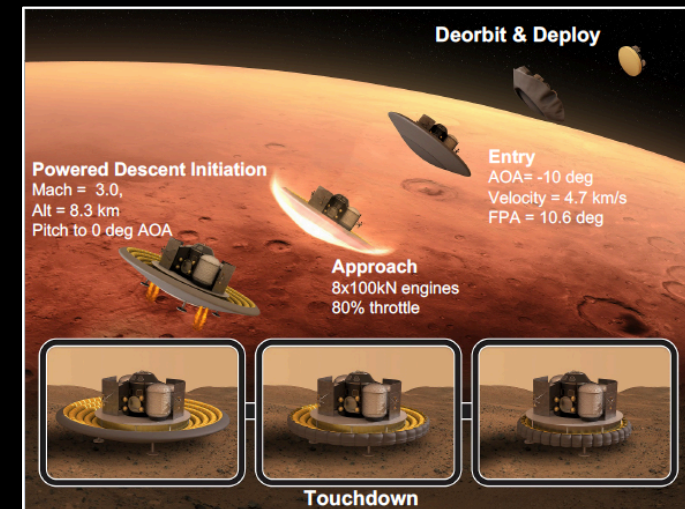
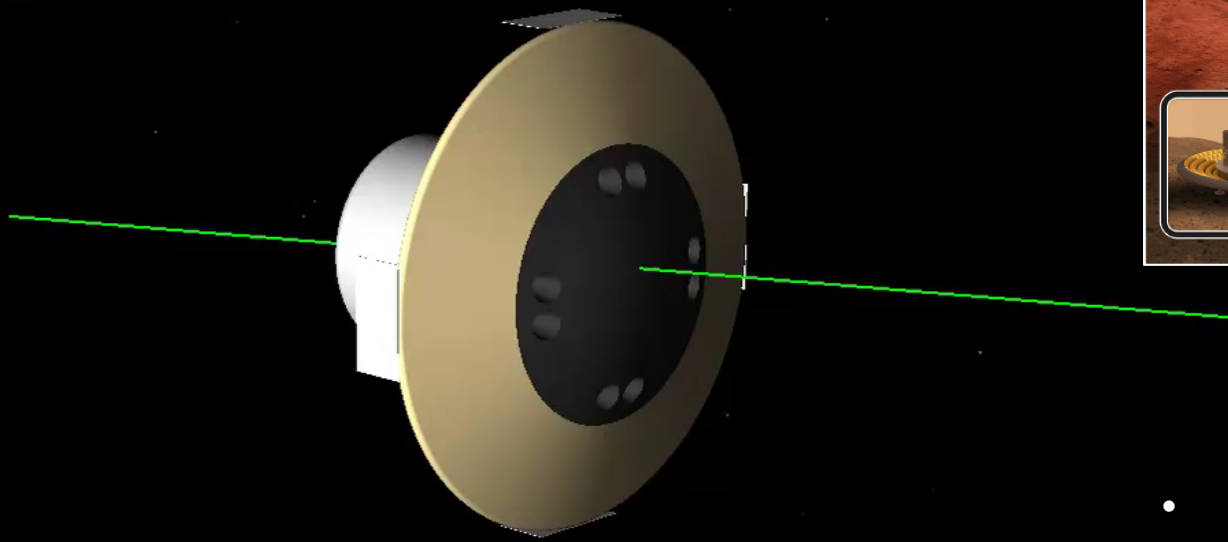


- **Safe & Precision Landing Integrated Capabilities Evolution (SPLICE) 2017-19**

- Updated end-to-end simulations and sensor models
- Considering precision landing concepts of operations at **multiple destinations** (Moon, Mars, Europa) and **classes of missions** (robotic and human scale)
- Evaluating **classes of sensors** (high, medium, and low quality)

Identifying sensors that enable safe and precise landing at multiple destinations to inform NASA investments

Integrated Vehicle Design: 6DOF Human Mars Landers

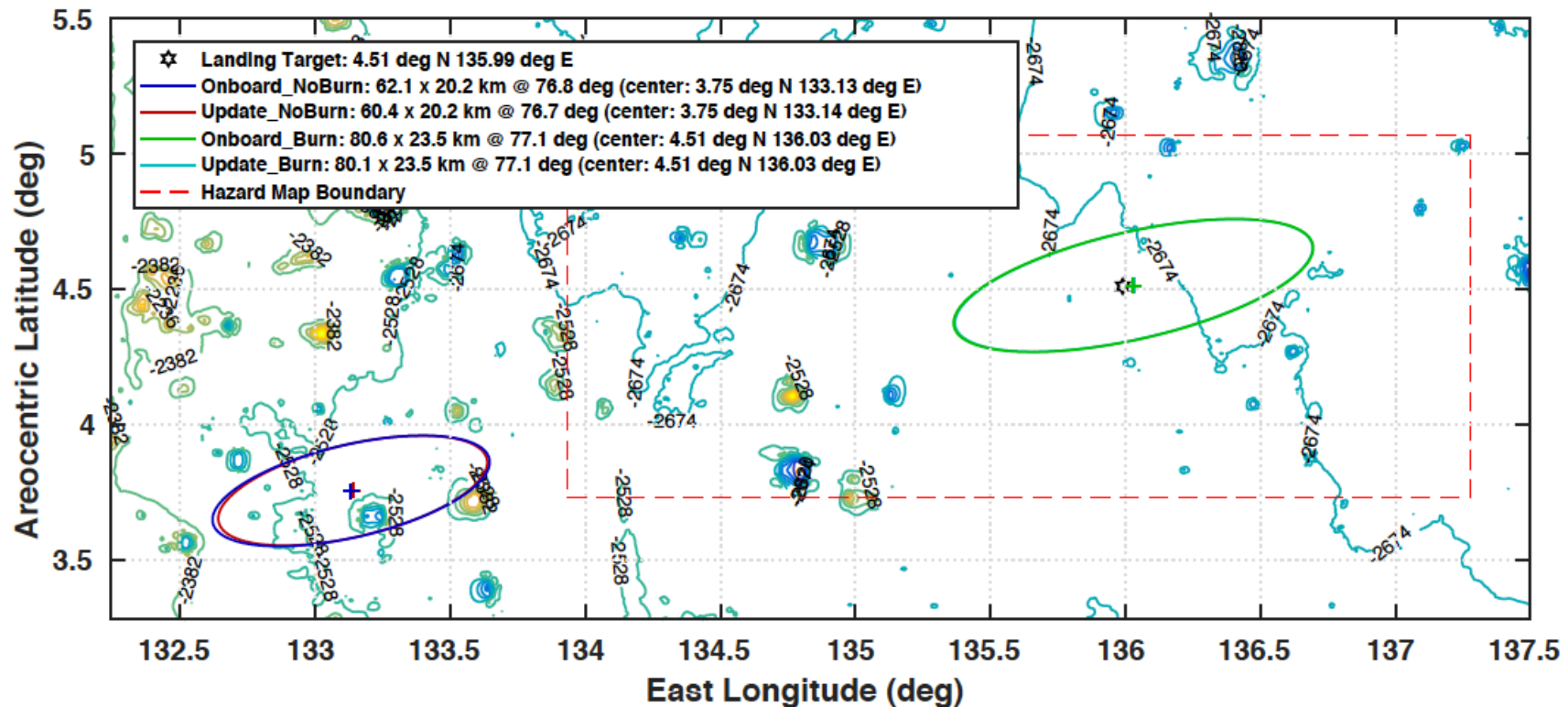


- 16 m diameter inflated forebody
- Visualization running at 4x speed
- Numerical predictor-corrector guidance
- EKF Navigation Filter & SPLICE Sensor Suite
- RCS and main engine thrust controllers (differential throttling)
- 6DOF aerodynamics (flaps, SRP interference)
- **EVE** Full Monte Carlo dispersion analysis
- Assess landing footprints, propellant usage, etc.

Performance Assessments: Mars InSight EDL Ops



- November 26, 2018: InSight Landed on Mars
- On November 8, analyzed the need to perform burn to retarget landing
- Ran 4 – 8000 case Monte Carlos to inform the decision



Independent Verification and Validation



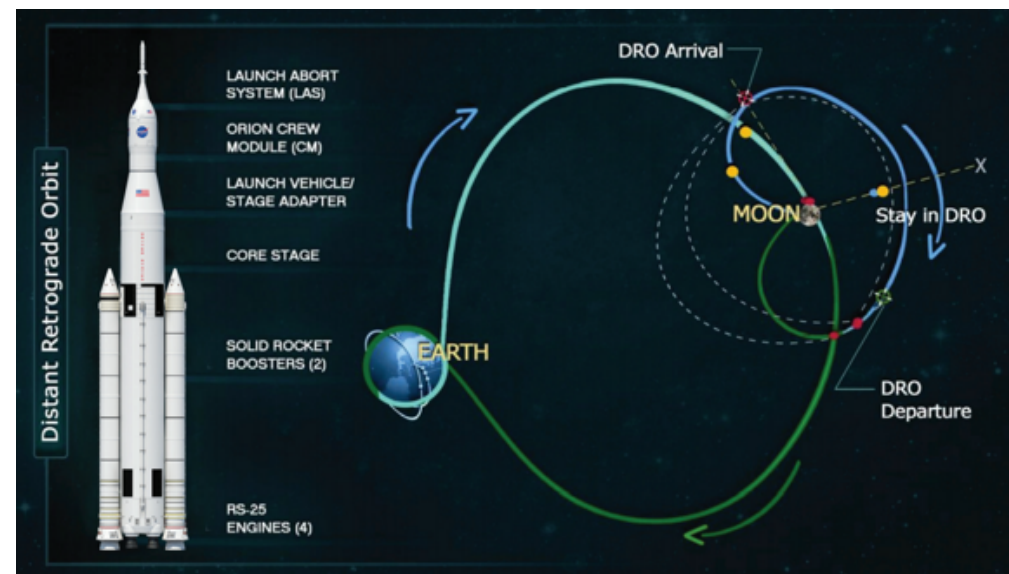
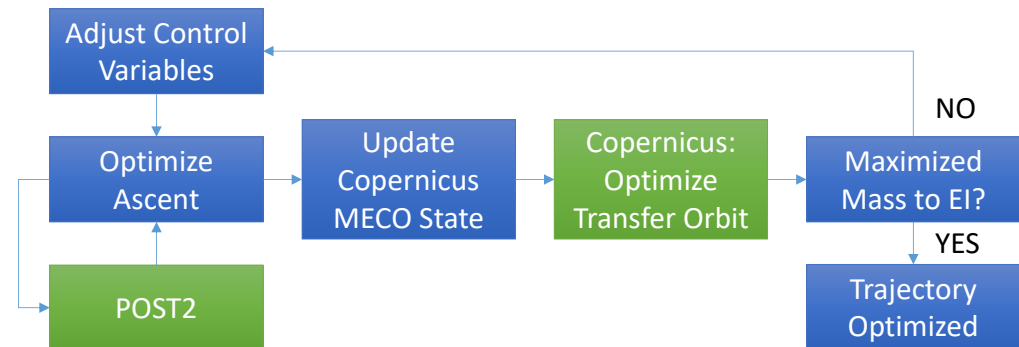
- Serve as IV&V for Commercial Crew Program
- Develop independent multi-degree of freedom flight simulations of commercial vehicles
- Perform flight and aerothermal comparisons with commercial simulations using shootout tools
- Compare with commercial hardware-in/out-the-loop simulations
 - Identify “stress” cases to be evaluated
 - Understand outlying cases
- Shoot-Out Tools

Requirement/Design Constraint	Type	Units	Simulation #1	Simulation #2	Simulation #3	Difference	>, <, =	Flag	Out of Spec	Description	Calculation	Multiplier	Calculation Checked By	Metric Checked By	Flag/Out of Spec Owner
State @ Ignition															
Time from simulation t0	Nominal	sec					>				time_init	1			
Inertial Velocity Magnitude	Nominal	ft/sec					>				veli_init	1			
Planet Relative Velocity Magnitude	Nominal	ft/sec					>				velr_init	1			
Atmosphere Relative Velocity Magnitude	Nominal	ft/sec					>				vela_init	1			
Inertial Longitude	Nominal	deg					>				longi_init	1			
Longitude	Nominal	deg					>				long_init	1			
Geodetic Latitude	Nominal	deg					>				gdlat_init	1			
Geocentric Latitude	Nominal	deg					>				gclat_init	1			
Geodetic Altitude	Nominal	ft					>				gdalt_init	1			
Geocentric Altitude	Nominal	ft					>				altito_init	1			
Planet Relative X Position	Nominal	ft					>				xr_init	1			
Planet Relative Y Position	Nominal	ft					>				yr_init	1			

Other Capabilities



- **Multiple code trajectory optimization**
- **Sensed Force Modeling: Flex, slosh, thrust, sensors, etc.**
- **Inertial Tracking**
- **Communication link tracking analysis**
- **Proximity visualization**



Simulation Heritage



- Mars Odyssey and Reconnaissance Orbiter Aerobraking missions
- Mars Pathfinder, Exploration Rovers, Science Laboratory EDL
- Europa Lander DDL
- Huygens Probe
- X-43 (Hyper-X)
- Genesis and Stardust Earth entry
- Countless Discovery, New Frontier and other proposals and studies

