Mars Science Laboratory Entry Descent and Landing Simulation Using DSENDSS

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Overview

• MSL EDL Overview

• DSEND5 Description

• MSL Specific Models
  – MSL Atmosphere Model
  – MSL Aerodynamics Model
  – Terrain Model
  – MSL Parachute Model
  – MSL Device Models (IMU, RCS, TDS, MLE)
  – MSL Flight Software
  – MSL Telecom Module

• MSL High-Fidelity Simulation
  – Simulation Initialization
  – EDL Trajectory Nominal Runs
  – EDL Monte Carlo Runs

• DSEND5 Independent V&V

• Summary and Conclusions

Topics for this presentation
In paper but not discussed here
Altitude is DIMU altitude above ground.
Velocity is DIMU velocity relative to the ground.
DSEND5 Description

- Dynamics Simulator for Entry, Descent and Surface landing

- Framework for modeling aero-assisted simulations from simple single-body systems to multi-body, flexible systems.

- Extensive library of models for sensors, actuators, environment, environment interaction, and avionics elements.
  - Framework for linking user-supplied code and built-in functions to build a complete simulation.
  - Includes Monte Carlo and parametric simulation capability.

- For MSL, core simulation functions were augmented with project-specific models
MSL Specific Models (1/2)

**GNC delivered models**
- FSW G6.0
- RCS, DIMU device model CBMs
- Mass/CM/Inertia: MP file (CC)
- Sep spring data (CC)

**Aerotherm Environment**
- Heating Indicators (CC)

**TPS Response: N/A**

**Aerodeformation:**
- N/A

**Aerodynamics**
- **Aero/RCS interaction**
  - Aerodatabase 2.1

**Atmosphere**
- Mesoscale Tables
- MarsGRAM 2005

**SUFR (EBM)**
- Mass/CM/Inertia: MP file (cc)
- Sep Spring Data (cc)
- FSW trigger

**Deployment**
- FSW trigger

**Inflation**
- Area scaling vs time (memo/CC)

**Strength**
- Stacked max area/drag for loads

**Inflated Performance**
- Tablular aero (memo/CC)

**Multi-body model**
- FSW trigger
- Post-HGS capsule aero from ADB
- No sep springs (on purpose)

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MSL Specific Models (2/2)

TDS
- Not modeled
- Nav Filter
- Output not used

Trigger
- FSW trigger modeled
- Multi-body model
- No sep aero interaction
- Parachute aero: memo/CC

Subsonic Aero
- " $S&' ()"

Propulsion System
- Lumped thruster model

Atmosphere
- Mesoscale Modeling
- MarsGRAM 2005

Backshell Separation

Powered Descent

Sky Crane

Subsonic Aero
- " $S&' ()"

Propulsion System
- Lumped thruster model

FSW
- FSW Powered flight trajectory profile flown with truth data

Terrain
- MOLA (up to 1/128)
- 1m DEM

Flyaway
- " $S&' (X"

Radar Data Collection

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**Components:** triple bridle, single riser, canopy plus shroud lines

- Each is a rigid body connected to the adjoining body by a ball joint
  - Bodies can rotate in any direction, no relative translation
- Joint between bridle and riser is free to move, all others locked
  - Two rigid bodies: capsule/bridle and riser/parachute
• Built-in components with MSL-specific aerodynamics and mass properties
• Checkout example: compare simulation output aerodynamic axial coefficient with hand-computed values
• RCS stand-alone routine delivered and integrated into DSENDSS
• Checkout example: fire a 1s pulse with a single thruster, compare performance with expected values (thrust, rise time, delay, etc)
**MSL Simulation**

- **Full-fidelity simulation**
  - Single-run nominal cases and Monte Carlo
  - Results compared between POST and DSEND5 at parachute deploy and landing

- **Targeting simulation**
  - 3DOF simulation without closed-loop functionality used for cruise maneuver design and real-time Doppler event detection
  - Entry guidance design using POST was performed using the trajectories from cruise maneuver design
Open-loop comparison: As part of reference trajectory design, compare output from DSEND5 with POST entry guidance design trajectories

Common models: atmosphere and winds, capsule aerodatabase, mass properties
- Monte Carlo comparison at parachute deploy: equivalent modeling in both simulations to this point
- Small (400m) difference in mean values
DSEND5 Independent V&V

- Monte Carlo comparison at landing
- Major modeling differences: parachute model, powered flight
- The MSL project concluded the independent V&V activity was successful.