Mars Exploration Rover
Primary Payload Design and Verification

June 17, 2003
Spacecraft & Launch Vehicle Dynamics Environment
Workshop Program

Darlene S. Lee
## MER Acronym List

<table>
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADAMS</td>
<td>Automatic Dynamic Analysis of Mechanical Systems</td>
</tr>
<tr>
<td>BIP</td>
<td>Backshell Interface Plate</td>
</tr>
<tr>
<td>CEM</td>
<td>Cruise Electronics Module</td>
</tr>
<tr>
<td>CLA</td>
<td>Coupled Loads Analysis</td>
</tr>
<tr>
<td>DOF</td>
<td>Degrees of Freedom</td>
</tr>
<tr>
<td>DRL</td>
<td>Descent Rate Limiter</td>
</tr>
<tr>
<td>FDLC</td>
<td>Final Design Load Cycle</td>
</tr>
<tr>
<td>FLL</td>
<td>Flight Limit Load</td>
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<tr>
<td>HGA</td>
<td>High Gain Antenna</td>
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<tr>
<td>I/F</td>
<td>Interface</td>
</tr>
<tr>
<td>IVSR</td>
<td>Integrated Pump Assbly, Vent, Shunt Limiter, Radiator</td>
</tr>
<tr>
<td>LEM</td>
<td>Lander Electronics Module</td>
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<tr>
<td>LVA</td>
<td>Launch Vehicle Adapter</td>
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<tr>
<td>MAC</td>
<td>Mass Acceleration Curve</td>
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<tr>
<td>MEOP</td>
<td>Maximum Expected Operating Pressure</td>
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<tr>
<td>MER</td>
<td>Mars Exploration Rover</td>
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<tr>
<td>MMAC</td>
<td>Modal Mass Acceleration Curve</td>
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<tr>
<td>PAF</td>
<td>Payload Attach Fitting</td>
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<tr>
<td>P DLC</td>
<td>Preliminary Design Load Cycle</td>
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<td>PDM</td>
<td>Power Distribution Module</td>
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<td>PMA</td>
<td>Pancam Mast Assembly</td>
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<td>PSA</td>
<td>Pyro Switching Assembly</td>
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<tr>
<td>RAD</td>
<td>Rocket Assisted Deceleration</td>
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<tr>
<td>RED</td>
<td>Rover Equipment Deck</td>
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<tr>
<td>REM</td>
<td>Rover Electronics Module</td>
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<tr>
<td>RPM</td>
<td>Revolutions per minute</td>
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<tr>
<td>RSS</td>
<td>Root Sum of the Squares</td>
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<td>SA</td>
<td>Solar Array</td>
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<td>SSE</td>
<td>Sun Sensor Electronics</td>
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<tr>
<td>TIRS</td>
<td>Transverse Impulse Rocket System</td>
</tr>
<tr>
<td>VLC</td>
<td>Verification Load Cycle</td>
</tr>
<tr>
<td>WEB</td>
<td>Warm Electronics Box</td>
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</table>
Mars Exploration Rover S/C
Delta II 7925 w/3717 PAF
June 2003

Delta II 7925 or 7925H
with 2.9m Payload Fairing

3717C PAF
(Payload Attachment Fitting)

100in (254cm)
Recommended usable S/C Envelope
(Boeing) 281.9cm
Reduced 1-1/2in Acoustic Blanket
(normal: 3in blanket)

Alignment Feducials

Stayout Envelope
Design and Verification of the MER Primary Payload

• **Launch** – Time = 0
  Loads: 2.0g’s X-Dir; 1.9g’s Y-Dir; 3.7g’s Z-Dir
  Mass = 1077.0 kg

• **3rd Stage Burn** – Time = Launch + 1963.9 Sec
  Loads: 0.4g’s X-Dir; 0.4g’s Y-Dir; 6.6g’s Z-Dir

• **Cruise** – Time = Launch + 17 Days

• **Approach** – Time = Launch + 174 Days

• **Entry Turn** – Time = Launch + 219 Days – 70 Min

• **Cruise Stage Separation** – Time = Launch + 219 Days – 15 Min
  Loads: 0.25g’s X-Dir; 0.25g’s Y-Dir; 8.0g’s Z-Dir
  Mass = 841.9 kg

• **Peak Heating** – Time = Launch + 219 Days + 102 Sec

• **Parachute Deployment** – Time = Launch + 219 Days + 242 Sec
  Loads: 0g’s X-Dir; 0g’s Y-Dir; 15.3g’s Z-Dir
  20000 lbs Cord load

• **Heatshield Separation** – Time = Launch + 219 Days + 262 Sec
Design and Verification of the MER Primary Payload

- Lander Separation – Time = Launch + 219 Days + 272 Sec
- Bridle Deployment – Time = Launch + 219 Days + 282 Sec
  Loads: 0.0g’s X-Dir; 0.0g’s Y-Dir; 3.0g’s, 3667 lbs Single Bridle Load
- Radar Ground Acquisition – Time = Launch + 219 Days + 311 Sec
- Airbag Inflation – Time = Launch + 219 Days + 339 Sec
- Rocket Firing – Time = Launch + 219 Days + 341 Sec
  Loads: 1950 lbs per Rocket (3), 7900 lbs Single Bridle Load
- Bridle Cut – Time = Launch + 219 Days + 344 Sec
- Landing with Bounces – Time = Launch + 219 Days + 347 Sec
  Loads: \( a_{cg} = 21.2 \text{ g’s} \), \( a = 31.2 \text{ g’s} \)\( (50\text{cm}) \)
  \( a_{cg} = 26.4 \text{ g’s} \), \( a = 35.0 \text{ g’s} \)\( (50\text{cm}) \)
  Mass = 554.4 kg
- Deflation/Latch Firing – Time = Launch + 219 Days +101 Min + 47 Sec
- Rover Egress – Time = Launch + 222 Days
  Loads: \( a=3.4\text{g’s}, \alpha=82.0 \text{ rad/sec}^2 \)
  Mass = 180.1 kg
### MER Spacecraft Masses

**Rover**
- Rover WEB: 145.6 kg
- Rover Mobility: 34.5 kg

**Lander**
- Lander Structure: 252.6 kg
- Bridle (on Lander): 10.6 kg
- Air Bags and Covers: 111.1 kg

**Landing**
- Total Lander Mass: 554.4 kg

**Aeroshell/BIP**
- Heatshield: 84.0 kg
- Backshell & Equipment: 81.3 kg
- RAD/TIRS & Mounting: 68.5 kg
- BIP, SepNuts, Sirca, etc.: 27.3 kg
- Parachute, canister, mortar: 26.4 kg

**Entry**
- Cruise Stage: 235.1 kg
- LVA, SepNuts, etc.: 33.5 kg

**Total**
- Total Mass: 1077.0 kg

\[ Z_{cg} = 829.5 \text{ mm} = 32.66" \]
Launch Loads

- **JPL in-house Modal MAC design loads for sizing (April 26, 2001)**
  - Model consistent with PDLC model
- **Launch Vehicle Coupled Loads Analyses**
  - Three Spacecraft System Coupled Loads Analyses performed
    - Preliminary Design Load Cycle (June 2001)
    - Final Design Load Cycle (Jan 2002)
    - Verification Load Cycle (Jan 2003)
- **JPL adds mid-frequency loads to Boeing CLA to account for structure-borne vibroacoustics**
  - Boeing CLA includes modes to 50 Hz
  - JPL adds loads from 60 to 90 Hz for Liftoff and 50 to 90 Hz for Airload events
  - MECO evaluation: add .5 g axial sinusoidal base-drive from 80 to 130 Hz, no results exceeded previous launch events
- **Stage 3 Burn**
  - Performed at 6.5 g’s static thrust with 75 RPM spin rate and 10 rad/sec² angular acceleration
Landing Loads Definition

- **Objectives**
  - Empirically determine Landed Mass Center of Gravity acceleration and angular velocity and acceleration vectors
  - Measure Lander tendon pin loads
- **Data Reduction/Analyses (Total of 45 drop tests)**
  - Recorded Accelerometer data was processed using a least squares algorithm
  - Statistical Analyses used to determined expected worst case acceleration environment
  - Impact Velocity (normal to surface) was 12 m/sec
  - Ramp angle varied from 0, 45, 60 degrees (measured from horizontal)
    - 60 degrees critical for primary impact
    - 0 degrees used for second impact
  - Airbag pressure varied from .85 to 1.25 psi → 1 psi is the FLT airbag pressure
    - 4 Airbags
    - 6 Lobes per Airbag (diameter = 1.8 m)

Upon release, gravity and a cluster of bungee cords accelerate the airbag/lander mass to the desired impact velocity. After impact with the rock-populated ramp, a large net catches the airbag.
Design and Verification of the MER Primary Payload

- **Objectives**  
  - Predict impact velocity to define landing loads drop test condition  
  - Verify Descent Rate Limiter (DRL) and Bridle loads  
  - Evaluate parachute cannister roller loads and clearance loss during lander separation  

- **Analyses – ADAMS multi-body dynamic model**  
  - Scope of Analysis: parachute deploy to ground impact  
  - Includes RAD/TIRS firing algorithm  
  - Conduct Monte Carlo dynamic simulations (500 each landing site)  

- **General Configuration**  
  - RAD located inside of Aeroshell Backshell used for descent deceleration  
    - Three RAD’s equally spaced around the Backshell  
    - Oriented 28.65 degrees from vertical  
  - TIRS located outside of Aeroshell Backshell used to null out RAD-induced horizontal velocity  
    - Three TIR’s equally spaced around Backshell  
    - Oriented such that thrust vector coincides with Backshell center of gravity  
  - Triple Bridle attached to 3 places on backshell and on Lander side petal (FLL = 7900 lbs for Single Bridle)  
  - DRL attached to Backshell Interface Plate (BIP) and Lander side petal (DRL FLL = 603 lbs)
Mobility Loads Definition

- **Objectives**
  - Compute maximum wheel impact loads and suspension system station cut loads for design
  - Compute loads at deployed appendages

- **Analyses – ADAMS transient analyses**
  - Scope of Analysis: includes all reasonable egress and surface mobility cases
  - Assume maximum wheel drop of 25 cm in 3/8 Mars gravity field
  - Assume $\mu_s = .2$, $\mu_d = .4$ between wheel and infinitely stiff ground
  - Assume wheel stiffness is 2500 lbs/in

- **General Configuration**
  - Deployed appendages and suspension system elements modeled to achieve frequency characteristics of detailed Finite Element Model
    - PMA – 4.5 Hz Lateral
    - HGA – 20 Hz Torsion, 25 Hz Lat
    - Solar Arrays – 8.3 Hz, 13 Hz, and 14 Hz bending
    - IDD – 11.6 Hz, 20.2 Hz
    - Suspension System – 4 Hz

- **Model Validation**
  - verified with drop testing and static testing of DTM unit: measured suspended mass CG accelerations to within 20% of model prediction
    - Fundamental $f = 4$ Hz (lab linoleum surface conditions)
Design and Verification of the MER Primary Payload

Mobility Loads Definition

- **ADAMS model**: Total Mass = 185 kg, 718 Degrees of Freedom
  - Plots show transient simulation of Forward Wheel 25 cm Drop Case AB

![Diagram showing rover with labeled components and forces](image)

![Graphs showing force and acceleration](graphs)

- +Y Fwd Rocker Wheel Impact
- Rover CG Z Acceleration
ADAMS Output

- Appendage Acceleration Loads
- Station Cut Forces
- CG acceleration and displacement
- Wheel Impact (600 lbs)
Design and Verification of the MER Primary Payload

Loads Environment Summary

- **Launch:** Minimum Design Load is Verification Load Cycle Results w/o mid-frequency augmentation
  - S/C acceleration: 2 g’s lateral with 3.7 g’s vertical
  - Rover Acceleration: 4.9 g’s lateral with 5.1 g’s vertical
  - Maximum component level acceleration: 17.6 g’s for 17.8 kg IVSR on Cruise Stage

- **Entry, Descent, Landing**
  - Aerobraking: .25 g’s lateral with 8 g’s vertical
  - Parachute Inflation: 15.3 g’s vertical (20,000 lbs cord load)
  - RAD/TIRS Deceleration: 1950 lbs per RAD with 7900 lbs max single cord load (~6.5 g’s)

- **Landing Impact**
  - 1st Bounce: $a_{cg} = 21.2$ g’s, $\alpha = 39.1$ rad/sec$^2$, $\omega = 13.8$ rad/sec (or 31.2 g’s at 50 cm)
  - 2nd Bounce: $a_{cg} = 26.4$ g’s, $\alpha = 0.0$ rad/sec$^2$, $\omega = 13.0$ rad/sec (or 35.0 g’s at 50 cm)

- **Mobility Loads**
  - 25 cm wheel drop cases: $a$ (suspended mass) = 3.4 g’s with $\alpha = 82$ rad/sec$^2$
Design Load Summary

- **Launch Environment Critical Structure** (2 g’s lateral, 6.6 g’s vertical)
  - Cruise Stage/LVA, Backshell Interface Plate (BIP)

- **Entry & Descent Critical Structure**
  - Aerobraking (.25 lateral, 8 g’s vertical): Heatshield
  - Parachute Inflation (15.3 g’s vertical): Parachute Assembly, BIP beams
  - Bridle End Snap (3 g’s vertical): Descent Rate Limiter (Mar’s gravity 3/8 g’s)
  - RAD firing: Backshell, Bridle Assembly

- **Landing**: 26.4 g’s + $\omega$ of 13 rad/sec (30.7 g’s when 25 cm from c.g.)
  - Lander, Rover Assembly, Wheel Restraint System

- **Surface Traverse**: 1.9 g’s drive, .19 g’s lateral, 3.0 g’s vertical at Rover CG ($\alpha = 76$ rad/sec$^2$) – Case AB w/1.25 loads uncertainty factor
  - Mobility System, Wheels
  - Deployed Solar Arrays & Deployed PMA

Note: Mass of 10 kg corresponds to 30 g’s by the MAC method
Definition of Flight Limit Load

- Critical Environment is Landing (Launch g's ~7.7 from Jan. '02 FDLC)
  - March '01 Landing g's = 31.4 g's with 224.6 rad/sec²
  - Jan. '02 Landing g's = 21.2 g's with 207 rad/sec²
- Proper Design Load Methodology
  - Must account for effect of distributed mass system on structural loading in angular acceleration field
  - Must account for multi-directional nature of loading

→ For each load component (tension, shear, etc) for each structural element, there will be a unique load vector to develop its maximum design load

- Developing Flight Limit Load - two options
  - RSS of load components due to 3 orthogonal translational accelerations, RSS of load comp due to 3 ortho rotational accelerations about landed mass CG, then sum the two RSS values
  - RSS of load components due to 3 orthogonal translational accelerations where g level represents extreme boundary of assembly

→ Both methods will be conservative (probably not more than 10%)
Design and Verification of the MER Primary Payload

Rover Loads Summary

Note: Output coordinate system is S/C

<table>
<thead>
<tr>
<th>Rover Component</th>
<th>Mass (kg)</th>
<th>Design Load, g's</th>
<th>VLC CLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Rover Web</td>
<td>145.6</td>
<td>41.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Y Rover Web</td>
<td>41.0</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Z Rover Web</td>
<td>41.0</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>X Accel REM CG</td>
<td>46.2</td>
<td>33.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Y Accel REM CG</td>
<td>33.9</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Z Accel REM CG</td>
<td>33.9</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>X Accel BATTERY CG</td>
<td>9.6</td>
<td>40.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Y Accel BATTERY CG</td>
<td>40.0</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Z Accel BATTERY CG</td>
<td>40.0</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>X Accel MINI-TES CG</td>
<td>2.8</td>
<td>39.7</td>
<td>4.4</td>
</tr>
<tr>
<td>Y Accel MINI-TES CG</td>
<td>39.7</td>
<td>3.3</td>
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</tr>
<tr>
<td>Z Accel MINI-TES CG</td>
<td>39.7</td>
<td>6.8</td>
<td></td>
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<tr>
<td>X Accel PMA MDD</td>
<td>10.4</td>
<td>41.3</td>
<td>5.0</td>
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<td>Y Accel PMA MDD</td>
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<td>6.1</td>
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<tr>
<td>Z Accel PMA MDD</td>
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<tr>
<td>X Accel HGA Dish</td>
<td>113.0</td>
<td>50.9</td>
<td></td>
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<tr>
<td>Y Accel HGA Dish</td>
<td>113.0</td>
<td>14.8</td>
<td></td>
</tr>
<tr>
<td>Z Accel HGA Dish</td>
<td>113.0</td>
<td>31.4</td>
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<tr>
<td>X Accel HGA Gimble</td>
<td>6.35 total</td>
<td>43.1</td>
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<tr>
<td>Y Accel HGA Gimble</td>
<td>43.1</td>
<td></td>
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</tr>
<tr>
<td>Z Accel HGA Gimble</td>
<td>43.1</td>
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<tr>
<td>X Accel IDD, note CLA is 30 degrees from s/c</td>
<td>42.0</td>
<td>14.8</td>
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<td>Y Accel IDD</td>
<td>42.0</td>
<td>17.0</td>
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<tr>
<td>Z Accel IDD</td>
<td>42.0</td>
<td>20.0</td>
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<tr>
<td>X Accel WEB/RED Aft-Top, MAC=20 g's</td>
<td>31.4+244.6 rad/sec²</td>
<td></td>
<td></td>
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<tr>
<td>Y Accel WEB/RED Aft-Top</td>
<td>31.4+244.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z Accel WEB/RED Aft-Top</td>
<td>31.4+244.6</td>
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<tr>
<td>Lift Mechanism</td>
<td>3.88</td>
<td>49.0</td>
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<tr>
<td>+Y Solar Array</td>
<td>16.5</td>
<td>33.5</td>
<td>33.5</td>
</tr>
<tr>
<td>Right, Fwd wheel, vertical DOF</td>
<td>1.1</td>
<td>37.0</td>
<td>7.9</td>
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</table>
Stowed and Deployed Rover

- **Structural Concept (DTM tested to 33 g's in Centrifuge)**
  - Rover Warm Equipment Box (WEB) supported to Base Petal with 7 DOF constraint
    - 3 "Bipods" and 1 "Monopod"
  - Suspension System: 6 aluminum wheels, 6 drive actuators, 4 steering actuators (turn in place) with titanium rockers and bogies
    - Wheel Restraint System: 4 radial restraints reacts 5 DOF with surface friction providing 6th DOF rotational restraint (Cable Cutter Assbly)
  - Solar Arrays: 3 Primary Arrays with 2 Secondary Arrays preloaded against +Y Primary Arrays
    - Each Primary Array attached to Rover Equipment Deck (RED) in two places (3 DOF at motor, 2 DOF at hinge
    - Three Primary to Primary 3 DOF Ball in Cup Joints (Cable Cutter Assbly)
Design and Verification of the MER Primary Payload

Warm Electronics Box (WEB):
Shear Panel construction with Rover Equipment Deck (RED) providing structural close-out

- **Design Loads**
  - Mass = 145.6 kg (Rover w/o Suspension System)
  - Landing Design Load = 41.0 g's (Landing)
  - Temperature = -55 C
  - MAC Design Load = 10 g's (VLC = 9.1 g's)

- **Panel Geometry**
  - M55J/BTCY: \([45/0/-45/90]\)s layup, \(E = 14.2 \text{ msi}\)
  - B-basis allowables: \(F_{tu} = 79 \text{ ksi}, F_{cu} = 36 \text{ ksi}\)
  - Local Doublers and Core Fill used as required
  - Astroquartz softening layer used at bonded titanium fittings to reduce bondline peaking stresses

**Side walls (M55J/BTCY)**
- Honeycomb Construction
- \(t_t = 15 \text{ mm (}.59\")\)
- \(t_{fls} = 1 \text{ mm (.04")}, 8 \text{ plies}\)
- \(h_c = 13 \text{ mm (.51")}\)
- 5056 Al core (3.1 pcf)
- 1 mm doublers around -X sep. fitting

**Bottom Wall (M55J/BTCY)**
- Honeycomb Construction
- \(t_t = 10 \text{ mm (}.39\")\)
- \(t_{fls} = 1 \text{ mm (.04")}, 8 \text{ plies}\)
- \(h_c = 8 \text{ mm (.31")}\)
- 5056 Al core (3.1 pcf)
- 1 mm doublers in +X section
Design and Verification of the MER Primary Payload

Warm Electronics Box (WEB)

- **Joints**
  - Two Types – 90° and 60° Joints
  - Tested to demonstrate moment capability

- **Bonded Joints**
  - HYSOL 9309 Adhesive
    - $E=3.0\times10^5 \text{ psi}; \ G=1.3\times10^5 \text{ psi}$
  - Nominal Bond Strength = 1143 psi at $-60^\circ\text{C}$
  - Equivalent Peak Stress Allowable = 4870 psi
  - Peak Stress based on Volkerson Equations

- **Interfaces – Titanium Fittings**
  - Lander Interface (4 Sep-Nuts)
  - Differential Interface (Housings)
  - REM Struts (6 Struts)
  - Lift Mechanism Interface (Fitting in WEB)
  - Battery Interface (Fittings)
  - RED Interface (Inserts)
  - IDD Fitting (Invar)
Design and Verification of the MER Primary Payload

WEB/ Lander Separation Joint

- **Design Features:** "U joint" - coplanar two axis pivot, designed as bipod or monopod
- Provides ± 2 degrees of rotation and ± 2 mm of translation
- Capable of transferring high loads in compact space (2"x3" by 1" depth)
- Interference fit between Axle pin and Rover Yoke
- Interference fit between Bushing & Spider and Bushing & Lander Yoke
- Interface to Rover Yoke is 45 degree cup/cone interface with 17,000 lbs preload
Mars Exploration Rover Structural Verification Review

WEB/Lander Separation Joints

- **Design Loads**
  - Mass = 145.6 kg (Rover w/o Suspension System)
  - Design Load = 41.0 g's (Landing)

<table>
<thead>
<tr>
<th>1/2 in Bolt</th>
<th>Forward Bipod</th>
<th>Aft Bipod</th>
</tr>
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<tbody>
<tr>
<td>P = 6839 lbs</td>
<td>P = 1170 lbs</td>
<td>P = 6839 lbs</td>
</tr>
<tr>
<td>V = 6055 lbs</td>
<td>V = 7851 lbs</td>
<td>V = 6055 lbs</td>
</tr>
<tr>
<td>T = 1821 in-lbs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Statically Tested to 17,000 lbs (12,000 Tension and 12,000 Shear)**

- **Materials**
  - Vascomax 300 Properties
    - $F_y = 270$ ksi
    - $F_{ult} = 280$ ksi
    - $F_{brg 	hinspace yd} = 380$ ksi
    - $F_{brg 	hinspace ult} = 400$ ksi
  - ½” MP35N Bolt
    - $F_y = 230$ ksi
    - $F_{ult} = 260$ ksi

**Units are inches**
Design and Verification of the MER Primary Payload

RED/WEB Development Testing

Achieved 16 g's lateral, 30 g's vertical

Criteria: Mimic the critical landing environment

- Test in -35 C temperature environment (not achieved)
- Structural loads distribution is produced from a long duration impulse - static event

Types of Tests

- Traditional Static Pull - difficult to load structure due to system mass distribution
- Sine or Random Vibe - risk of exciting modes of appendages w/o generating proper load distribution
- Centrifuge Test - cleanliness issues, cannot be done at cold temperature, off site logistics (schedule, handling fixtures, transportation, etc.)

- Sine Pulse - develops proper load distribution, dependent on shaker capability to achieve pseudo static testing

- 10 cycles to ramp up
- 2 cycles at peak
- Shut down within 1 cycle
DTM Rover on Baspeetal Centrifuge Tests

- **Objective:** Test DTM Rover hardware to Landing loads: \(\pm 33\) g's X and \(\pm 33\) g's Y. Note Rover hardware oriented 30 degrees from S/C axes to generate maximum Rover/Lander I/F loads
  - DTM Hardware: WEB, RED, REM struts, MiniTes Struts, Battery struts, Mobility System, Sep/Nut Assbly, Solar Array Substrates, Base Petal w/o LPA's
  - Mass Mockups: PMA, HGA, IDD, REM, MiniTes, Battery
- Note DTM RED/WEB tested to 30 g's Vertical Z-axis during Sine Pulse Test
Design and Verification of the MER Primary Payload

Flight Rover 1 & 2 on Basepetal Random & Sine Pulse Tests (3 Axes)

- **Objective:** Perform Protoflight Landing Level Workmanship Random and Sine Burst Tests (25 msec or 20 Hz)
  - Random: $3.9 \, g_{\text{rms}}$, from 20 to 2000 Hz
  - Sine Pulse: $\pm 14 \, g$'s lateral, $\pm 22 \, g$'s vertical (based on measured Interface force)

- **Rover 1 & 2**
- FLT WEB/RED, FLT PMA, FLT HGA
- FLT IDD, FLT REM, FLT MiniTes
- Substrate Solar Arrays (FLT on Rover 1)
- FLT Mobility Sys, FLT Lift Assy
- MM Battery
- FLT Basepetal w/ FLT LPA's

**Input ASD**
- .02 $g^2$/Hz from 80 to 450 Hz

**Sine Pulse Input:** 11 g's lat, 15 g's vert

![Graph showing sine pulse input](image)
Mobility Loads and Dynamic Testing

ADAMS model:
Total Mass = 180 kg
718 Degrees of Freedom
Simulation of Forward Wheel 25 cm Drop

Flight Mass Testing on Earth w/1.2 Test Factor
Mass of Test Rover = 148.8 kg
Drop Height = 14.2 cm (31.6 cm on Mars)
* Drop height adjusted for reduced mass and Earth gravity affects

<table>
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<th>Test</th>
<th>2.0</th>
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<th>2.0</th>
<th>8.0</th>
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<td>Predicted</td>
<td>1.6</td>
<td>0.6</td>
<td>2.5</td>
<td>7.7</td>
<td>6.5</td>
<td>5.4</td>
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Completed Structural Verification Tests

DTM, FLT Aeroshell Static & Stiffness Test 1/02
FLT Cruise Stage/LVA/Clamp/PAF - Static & Modal Test 3/02
DTM Rover (w/o suspension) Pulse - 16g Lateral & 30g Vertical Input 5/02
DTM Rover/Basepetal – Fixed Base Modal; Random; Basedrive Modal;
  Pulse ~ 14g Lateral* & 22g Vertical* 8/02
DTM Rover/Basepetal – Centrifuge ~ 33g ±X & ±Y Axes 8/02
Rover Suspension (Mars Landing Configuration)
  – DTM Wheel Restraint Static 8/02
DTM Rover Suspension (Mars Traverse Configuration)
  – Rocker/Bogey Static & Stiffness 7/02
  – End to End Suspension Stiffness 8/02
  – Wheels Static Strength & Stiffness 5/02
DTM, FLT Lander Petals
  Basepetal Static & Stiffness 5/02
  Flt. Base & Side Petals (Each) Static & Stiffness 7/02 – 8/02
FLT S/C 1 – Random; Fixed Base Modal; Acoustic 10/02, 1/03
FLT Rover 2 on FLT Basepetal – Random; Pulse (14 g’s lat, 19.3 g’s vert)* 12/02
FLT Rover 1 on FLT Basepetal – Random; Pulse (13.7 g’s lat, 21 g’s vert)* 2/03

Sufficient Static and Dynamic Testing has been completed to verify design
and workmanship of the MER primary payload

* Based on measured interface load