Mars Pathfinder
Mars Exploration Rovers in test with 1997 Sojourner rover
Geologist:

Experimentalist:
Pathfinder / Sojourner (1997)

Geochemist:
Curiosity (2012)

10.5 kg ➔ 174 kg ➔ 900 kg
But how do you get it there?
Huge airbags?

Mars Pathfinder Airbag Configuration

Mega Rover Airbag Configuration
On a Pallet?
2003: The Skycrane maneuver is born
MSL Spacecraft Major Elements

- Cruise Stage
- Backshell (EDL)
- Descent Stage
- Rover
- Heatshield with MEDLI (EDL)
- Backshell Interface Plate (BIP)
- Parachute Support Structure (PSS)
- Parachute (EDL)
- Bridle & Umbilical Device
- Separations & Pyros
Parachute Testing @ Ames
Rover System Thermal Testing
Launch date: Nov. 26, 2011
Cape Canaveral, Florida
The mission ....
Landing Accuracy

2012 Curiosity 12 x 4 mi
2008 Phoenix 62 x 12 mi
2004 Opportunity & Spirit 93 x 12 mi
1997 Pathfinder 125 x 44 mi
1976 Viking 174 x 62 mi

Surface Elevation (mi)

September 27, 2012
Mars Exploration Family Portrait

Failed: 24
Succeeded: 15

31: Mars Climate Orbiter
   December 11, 1999
   Crashed due to imperial/metric unit mixup

32: Mars Polar Lander
   January 3, 1999
   Crashed on surface

33: Mars Odyssey
   March 7, 2001
   Orbiting Mars

34: Mars Express / Beagle 2 lander
   June 3, 2003
   Orbiting Mars, Beagle lost after separation

35, 36: Mars Exploration Rovers Spirit and Opportunity
   June 10 / July 7, 2003
   Both landed on surface, Opportunity still in operation

37: Mars Reconnaissance Orbiter
   August 12, 2007
   Orbiting Mars

38: Phoenix
   August 4, 2007
   Landed, dug for water

39: Phobos-Grunt
   November 8, 2011
   Stranded in Earth orbit

40: Mars Science Laboratory Curiosity
   November 26, 2011
   Mission to Gale Crater

1, 2: MARS 1M No. 1 / MARS 1M No. 2
   October 10 / October 14, 1960
   Both destroyed during launch

3, 4, 5, 8: MARS 2M-4 No. 1 / Mars 1 / Mars 2M-3 No. 1 / Zond 2
   October 24 / November 1 / November 4, 1962 / November 30, 1964
   Broke up in Earth orbit / Radio failure en route / Stranded in Earth orbit / Radio failure en route

6, 7: Mariner 3 / Mariner 4
   November 5 / November 28, 1964
   Payload fairing failed to open / First flyby and picture return

9, 10: Mariner 6 / Mariner 7
   February 5 / March 27, 1969
   Both flew by, returned pictures

11, 12: Mars 1969 A / Mars 1969 B
   March 27 / April 2, 1969
   Both destroyed during launch

13, 17: Mariner 8 / Mariner 9
   May 8 / May 30, 1971
   Destroyed during launch / First probe to orbit Mars

14, 15, 16: Cosmos 419 / Mars 2 / Mars 3
   May 10 / May 19 / May 28, 1971
   Failed in Earth orbit / Lander crashed / Lander failed

18, 19, 20, 21: Mars 4 / Mars 5 / Mars 6 / Mars 7
   July 21 / July 23 / August 5 / August 9, 1973
   Missed planet / Orbitied planet / Lander failed (6 and 7)

22, 23: Viking 1 / Viking 2
   August 20 / September 9, 1975
   Both landed on surface, returned data

24, 25: Phobos 1 / Phobos 2
   July 7 / July 12, 1988
   Lost communication en route / Lost communication near Phobos

26: Mars Observer
   September 25, 1992
   Landed on surface, deployed Sojourner rover

27: Mars Global Surveyor
   November 7, 1996
   Orbited and returned data

28: Mars 96
   November 16, 1996
   Destroyed during launch

29: Nozomi
   July 4, 1998
   Missed planet

30: Mars Pathfinder
   December 4, 1996
   Landed on surface, deployed Sojourner rover

Failed 24
Succeeded 15

28
August 5, 2012 – Landing Day!
Before

After

(photos taken by Mars Reconnaissance orbiter)
First Images from Mars
Looking North to Crater Rim
The Landing Site

Clay Minerals and Sulfate Salts
Clay Minerals
Dark Sand
Crater Floor
Direction of Traverse
Among Curiosity’s tools are 17 cameras, a laser to zap rocks, and a drill to collect rock samples.
SEES BRITAIN IS HOSTING THE OLYMPICS
LANDS ON MARS
What’s under the Hood

- Spacecraft Computers
- Rover Motor Controller
- UHF Radio
- Thermal Fluid Loop
- Batteries
- Power Electronics
- X-Band Radio
- Instruments
EEE Parts Program

Part quality level
• Flight System
  – EEE INST-003 Level 1 parts for single string elements, Level 2+ parts for redundant elements
• Payload
  – EEE INST-003 Level 2 parts for all instruments

The part count for the Spacecraft and Rover consists of more than 6000 line items.
### So many parts, so many problems...

<table>
<thead>
<tr>
<th>Part type</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actel RTAX FPGA rework</td>
<td>Design changes required replacement of 624-pin CGA packages on flight boards. Extensive CGA rework qualification was performed to ensure reliable process.</td>
</tr>
<tr>
<td>DC/DC Converter failure</td>
<td>Failure occurred during constant acceleration testing. Root cause: The supplier of a transformer used internal to hybrid changed to Pb-free lead finish, resulting in excessive stress on solder joints.</td>
</tr>
<tr>
<td>SDRAM SEFI</td>
<td>A spacecraft using memory similar to what is used on MSL experienced multiple bit errors, resulting in extensive testing to determine impact to MSL design.</td>
</tr>
<tr>
<td>SRAM timing issues</td>
<td>SRAM Single Bit Errors at low temperatures. Screening approach used to validate part performance at temperature not the same as flight application. Parts replaced with new versions that have improved cold temperature performance</td>
</tr>
<tr>
<td>Hybrid module failure</td>
<td>TRM failure traced to presence of metallic shards on chip capacitors used in hybrid module. Shards were created during part manufacturer and not detected in standard visual inspection. Rework required on all flight TRMs to identify and remove additional shards.</td>
</tr>
</tbody>
</table>
DAN (Dynamic Albedo of Neutrons), an instrument contributed by the Russian Federal Space Agency, contains a pulsing neutron generator used to detect water ice below the soil through neutron activation measurements. DAN generates 14 MeV neutrons, which is not a typical radiation environment found in space.

Characterization testing was performed using 14 MeV neutron beam on various part types to determine sensitivity of microelectronics to single event effects (SEE). The test results showed the effects of 14 MeV neutrons were comparable to background Galactic Cosmic Rays (GCR).
Cold Encoder Electronics

The Cold Encoder controls the actuators at each motor location outside of the Warm Electronic Box, so the electronics were limited by two primary constraints:

• Reduced form factor
• Exposure to temperature cycling from -130°C to +85°C on surface of Mars

These unique environmental and packaging requirements resulted in:

• Qualification of COB (Chip on Board) packaging to define optimal board material, solder type, and conformal coating.
• Large Sample Characterization for each lot of parts from +125°C to -135°C to establish performance over temperature to support worst case analysis.
• Burn-in of active devices at die level to ensure acceptable performance and reliability prior to board assembly.
MSL DLI Capacitor Failures

System-level failure in RF Module occurred due to short as a result of termination material flaking off of commercial DLI capacitor.

- Parts had all been screened by the manufacturer to mil specs.
- Inherent problem with design of capacitor resulting in need for extensive inspection and special handling requirements with no guarantee that shards will be eliminated.
- **Corrective action:** All capacitors inspected within modules to fullest extent possible and replaced if necessary.

Gold shard can create short.
“If anybody has been harboring doubts about the status of U.S. leadership in space, well, there’s a one-ton, automobile-size piece of American ingenuity, and it’s sitting on the surface of Mars right now.”

-- John P. Holdren, president’s science adviser
Rover Family Portrait