Red Rover, Red Rover: Landing Rovers on Mars

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Overview

- Introduction
  - Overview of Jet Propulsion Laboratory
- Why go to Mars
- Mars Exploration Rover (MER)
  - Overview
  - Entry, Descent & Landing
  - Landing Data from Mars
- Mars Science Laboratory (MSL)
  - Overview
  - Skycrane Descent & Landing Concept
- Working at JPL
- MER Pictures
Introduction

- The mission of the Jet Propulsion Laboratory (JPL) is the robotic exploration of the solar system
  - Owned and managed by the California Institute of Technology (Caltech)
  - Under contract to NASA
- Located in the foothills of the San Gabriel Mtns. in Pasadena, CA
- Employs ~4900 staff and ~600 contractors

JPL

- Why is it called the “Jet” Propulsion Laboratory?
  - The Caltech group that would eventually become JPL designed the first jet-assisted take-off (JATO) rockets for the US Army Air Corps, circa 1940.
- At the time, “rockets” were considered science fiction, the domain of Flash Gordon and Buck Rogers
  - “Jet” was politically correct

First U.S. Jet Assisted Take-Off
March Field, California on August 12, 1941
JPL Missions Today

- JPL is involved in 20 missions in orbit about the Sun, Earth, Mars, and beyond. A sampling...

Voyagers 1 and 2
Cassini
Mars Odyssey

In 300,000 years, Voyager 1 will pass by Sirius, brightest star in the sky

The Huygens probe will detach and land on Titan, a moon with clouds and organic compounds

Discovered soil at high latitudes of Mars is more than 1/3rd water ice

Mars Rovers

- NASA Vision:
  To improve life here,
  To extend life to there,
  To find life beyond.

- Liquid water is necessary for life (as we know it)
  - "Follow the water!"

- Rover missions conceived to be robotic geologists
  - Confirm or refute liquid water in Mars past

- Rover Missions
  - Mars Pathfinder - 1996
  - Mars Exploration Rovers (MER) - 2003
  - Mars Science Laboratory (MSL) - 2009
MER Overview

- Two solar-powered rovers, Spirit and Opportunity
  - Each can travel ~40 m a day
- Robotic arm with three instruments and an abrader
- Stereoscopic camera with “eyes” at human height
- Opportunity found conclusive evidence of liquid water in Mars’ past
- Both still running strong, 200 “sols” past warranty

Outcrop on Meridiani Planum where Opportunity discovered evidence of liquid water

MER Spacecraft

Flight System

Cruise Stage

Backshell

Heat Shield

Rover

Lander

1.7 m

2.65 m
Three Rover Mission Phases

- Launch & Cruise
- Entry, Descent & Landing (EDL)
- Egress & Surface Operations

MER Mission Animation

- Animation of MER mission
  - Launch
  - Mars Transfer Orbit Injection
  - Abbreviated Cruise
  - Entry, Descent and Landing (EDL)
  - Rover Egress
  - Surface Operations/Example science
- Mars looks like a hot desert, but highs just reach freezing and lows can be \(-150^\circ\text{F}\)
MER Mission Animation

- Animation of MER mission
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And I’m Learning this Because?

- Intermediate Dynamics
  - First year grad course
  - Culminates in dynamics of rigid bodies
    - Spacecraft – rigid body
    - Stability of spinning bodies
  - Attitude Representations
    - Euler Angles
    - Rotation Matrices
    - Quaternions
Entry, Descent & Landing Timeline

- Entry Turn & HRS Freon Venting: E+ 90m
- Cruise Stage Separation: E+ 15m
- Entry: E- 0 s, 125 km, 6.7 km/s (20,000 km/hr)
- Parachute Deployment: E+ 295 s, 11.8 km, 430 m/s (1500 km/hr)
- Heatshield Separation: E+ 315 s, L - 105s
- Lander Separation: E+ 325 s, L - 95 s
- Bridle Deployed: E+ 335 s, L - 85 s
- Radar Ground Acquisition: L - 30 s, 2.4 km, 75 m/s (270 km/hr)
- Airbag Inflation: 355 m, L - 6.5 s
- Rocket Firing: L- 6 s, -110 m, 70 m/s (250 km/hr)
- Bridle Cut: L- 3 s, 0 m/s, 12 m
- Bounces: L - 420 s
- Roll-Stop L+2 min
- Airbag Retracted: L+74 min
- Petals & SA Opened: L+90 min

EDL Movie

MER Entry

- Need to enter atmosphere at 11° else will burn up or skip
- Begins at atmosphere interface, ~3400 km from Mars
- Ends at parachute deployment
**MER Descent**

- Parachute deploy based on accelerometer reading
  - Pop chute a set time after peak accel

- MER based on Pathfinder
  - But MER twice as heavy!

- Parachute design is an art
  - Early test
  - Near-final test

- Retro-rockets fire
  - 110 m, 190 mph, L -6 s
  - 12 m, 0 mph, L -3 s

**MER Landing**

- MER landing system based on Pathfinder system
  - Three story drop onto airbags

- Why three stories?
  - Accuracy of inertial navigation system (~5 m)
  - Margin

- MER heavier by ~20%
  - Need to retest airbags

- Pathfinder airbag design not sufficient

- Test new designs at Plum Brook
  - Initial test
  - Exploratory test
  - Near-final test
MER Landing Data - Inertial Navigation

- Spacecraft lands autonomously
  - Roundtrip light-time was 20 minutes
  - EDL takes 6 minutes
- How does lander know where it is?
  - Inertial Navigation
  - Radar altimetry
- Inertial Navigation
  - Position
    - Measure translational acceleration with accelerometer
    - Add in gravity
    - Integrate twice
  - Attitude
    - Measure rotational velocity with gyroscopes
    - Integrate once (to get quaternion)
Spirit Landing Reconstruction (from Mars)

- Telemetry from landing radioed back to Earth
- Engineer simulations used to visualize telemetry
- Descent
  - Inertial Navigation estimates of backshell and lander attitude
  - Inertial Navigation estimates of backshell and lander position and velocity
  - Estimates of chute angle
- Landing
  - Accelerometer records bounces
  - Inertial Navigation estimates of lander position and attitude

Opportunity’s Hole-in-One
MSL

MER and Pathfinder have three main drawbacks
- Limited lifetime due to decrease in effectiveness of solar panels
- Limited landing accuracy: landing ellipses ~100x20 km
- "Straight-in" landers: cannot avoid unsafe slopes, rocks or craters

Mars Science Laboratory (MSL)
- A roving science lab, approx. the size of a Mini Cooper
- Powered by RTGs (nuclear decay) like Voyager and Cassini

Smart Lander Concept
- Senses landing area
- Selects safe landing site
- Maneuvers lander to new site
  all autonomously

Planned to launch in 2009

MSL Skycrane EDL Concept
MSL Simulation

- Powered Descent Phase *engineering* simulation
  - Validate guidance, estimation and control algorithms
  - C-based simulation testbed currently with rigid body models
  - Extensive use of (you guessed it) quaternions

Practical Constraint

- JPL does world-renowned work
- Guidance & Control Analysis Group
  - 70% PhDs
  - 27% Masters
  - 3% Bachelors (getting Masters)
- To design
  - A guidance algorithm for landing a rover on Mars
  - An attitude control system for a Europa probe
  - You need a graduate degree
  - Each JPL spacecraft is one-of-a-kind
- Cannot speak for industry, other areas of JPL
  - Mechanical, electrical design
  - Industry route: hands-on more quickly with repeat products
Me & MER Engineering Model in Mars Yards

MER #1, MER #2, & Sojourner Spare Rovers
JPL, February 10, 2003
Stowed Rover and Lander

Integrated Lander
On the Third Stage

Spirit in the Fairing
MER Launch - KSC

MER ACS Ops Team Waiting for Signal
Usual Suspects

In 41 attempts by space-faring nations, 26 missions have failed.
27 orbiters,
12 landers &
2 probes.
No mission has brought back samples and no one has been to Mars.
Old meets new...

Flying to Mars - it's a long trip

MER-A Open
Launch 30 May 2003
Arrival 4 Jan 2004

7 months!
Mars Missions: 2001-2009

2001: NASA Mars Odyssey

2003: ESA Mars Express

2005: NASA Mars Reconnaissance Orbiter (Italian SHARAD)

2007: MARVEL

2009: NASA Telesat

Science pathways responsive to discovery

NASA Mars Exploration Rovers

NASA Mars Science Laboratory

The rovers listen and speak to Earth with their communications antennas.

Low Gain Antenna

UHF Antenna

High Gain Antenna
Rover Deployed on Mars

- 179 kg
- 1.54 m from ground to Pancam eye level

My Story

- At 10, a dynamical mind?
  - When passing a truck slowly, can not tell that you are both going over 60 mph
  - Snow falls off a speeding car backwards, but then moves forward when it hits the street

- Watched Voyager flyby of Uranus when I was 12
  - Project Manager was from JPL

- 17 years of school later...
  - Univ. of Minnesota BS Aerospace
  - Univ. of Michigan MS & PhD Aerospace
  - Intern at JPL

- Now at JPL working on formation flying
Spirit's Sky Observations

Spirit snapped a picture of Earth from Mars and watched the sky at night with its panoramic camera.

Mars — a bitter history
(stats as of 2002)

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Japanese Hozumi spirit hit the ground after flight anomaly in 1998 forced it to go the long way round. She's shown but not yet out.

** Mars 3 in 1971 apparently transmitted for 20 sec after landing but no significant information was returned.
Spirit imaged the stars in the upper part of the constellation Orion, including the bright shoulder star Betelgeuse and Orion's three-star belt.

It's a Bird, It's a Plane, It's a... Spacecraft?

Observing the sky with a green filter, Spirit came across a surprise streak!

The leading theory is that the Unidentified Flying Object is the inactive Viking 2 orbiter sent to Mars in the 1970's.
The dips of fine layers at angles to each other are telltale signs that water flowed from left to right in this rock.

Goodbye To Eagle Crater