Mission to Mars

Harvard Business School Case Study

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Overview

- Brief history
  - NASA
  - JPL
- Early Mars missions
  - Viking
  - Mars Observer
- Faster, better, cheaper
  - Pathfinder
  - Mars Global Surveyor
- Mars 1998
  - Mars Climate Orbiter
  - Mars Polar Lander
- Aftermath
- Way ahead
- Discussion

NASA

- "An Act to provide for research into the problems of flight within and outside the Earth's atmosphere, and for other purposes"
  - 1 October 1958
  - One year after the launch of Sputnik
- Absorbed National Advisory Committee for Aeronautics (NACA)
- Originally started with
  - 8,000 employees
  - $100 million budget
  - Multiple research centers

  absorbed in succession.

NASA logo removed due to copyright restrictions.

JPL

- Federally funded R&D center funded by the California Institute of Technology
- Originated from work by Von Karman for the US Army in World War II
  - Rocket engines, guidance and control
- NASA's center of excellence for planetary exploration
  - Lead many explorations including Ranger, Surveyor, Pioneer, Viking, Voyager, Magellan, Galileo, and Ulysses

FORMATION TIMELINE

1. 1936: Von Karman tested early rocket engines in the wilderness area of Arroyo Seco
2. 1943: He received funding during WW2 to analyze the German V2 control missiles program. JPL was an Army facility operated under contract by Caltech.
3. 1954: Teamed up with Von Braun's Army Ballistic Missile Agency
4. February 1958: JPL and ABMA launched Explorer 1
5. October 1958: Transferred to NASA.

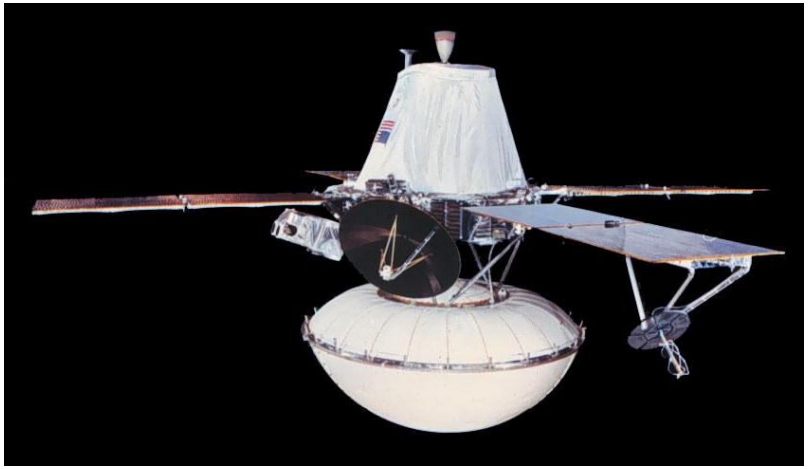
Early Mars Missions

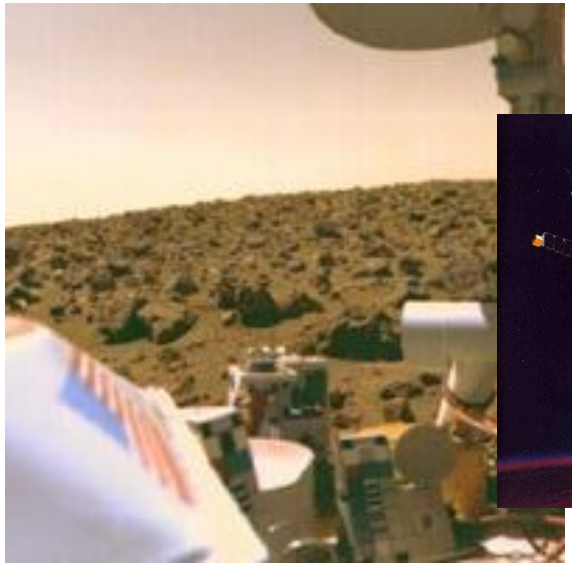
•1877: Italian astronomer Schiaperelli identified channels through his telescope, called them canali, people mistook that for ancient water canals and harbored the possibility of aliens.

•1965: Mariner 4 returned 21 photos that showed that atmosphere was thin, too much CO2, no signs of life.

•1971: Mariner 9 returned 7329 photos showing craters, lava flows.

•1975: Viking 50k+ photos. NO SIGNS OF LIFE – thus public attention stunted and no Mars mission was sent in the next 15 years.





Photos from jpl.nasa.gov

Early Mars Missions

- Viking Mission (1975)
  - Goal to look for evidence of life
  - $1 billion ($4 billion in 2000 USD)
  - Two spacecraft, each with orbiter and lander
  - Orbiter
    - “high resolution” photos
    - Water vapor measurements
    - Thermal mapping
  - Lander
    - Photos
    - Soil Samples
    - Temperature and wind data
- Mars Observer (1992)
  - Goal to study geoscience and climatology of Mars over a two year span
  - $813 million ($1.13 billion in 2000 USD)
  - >10 years to build.
  - One orbiter, eight instruments
    - $22 million camera
    - Laser altimeter for topography
    - Gamma ray spectrometer
    - Flux capacitor…
  - Lost comms three days prior to orbit
    - Likely caused by fuel rupture in propulsion system

Faster, Better, Cheaper

- Revolutionary new program approach
  - NASA Admin Dan Goldin
  - Small and medium-sized robotic spacecraft to planets, moons, asteroids
  - Build assembly-line style
  - Restrictions
    - Cost (~$150 million)
    - Payload (launched by Delta II
  - Could tolerate more risk
    - Less expensive per craft

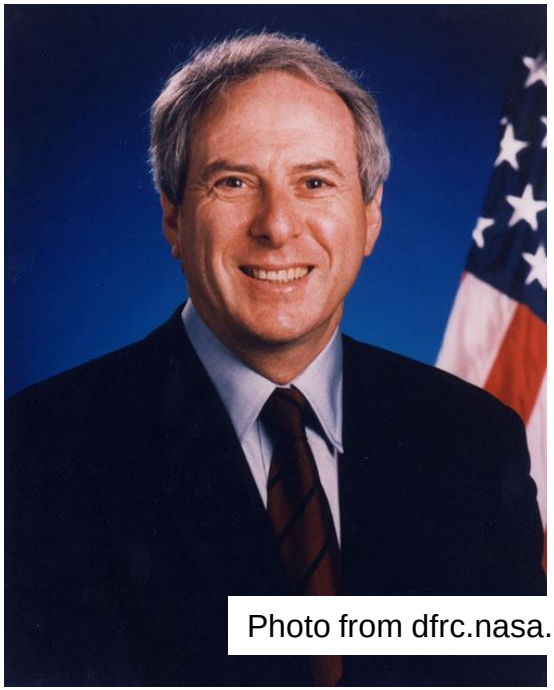


Photo from dfrc.nasa.gov

"The book is not working so don't use the book – try something new and then write a new book".

".. So if we lose a few due to riskier nature of high technology, it won't be the scientific disaster or blow to national prestige …"

Faster, Better, Cheaper

System description

- Cost (10-100million instead of billions of dollars)
  - Size/Mass (from 1000s of pounds to 100s)
  - Technology (commercial instead of completely developed in-house, new radical ones instead of decade old ones, piggy backing on used parts of other missions)
  - Smaller team **(**One specialist, single owner concept**)**
- Time (deploy in months instead of decades)

SN1

First Program : DISCOVERY

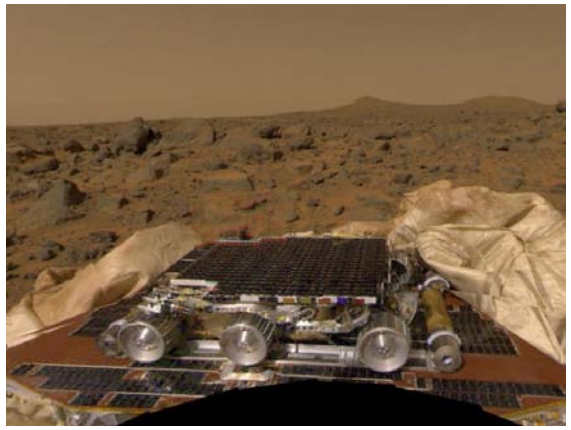
- Guidelines were:
  - Must be launched on a Delta II or smaller rocket
  - Development + operations + launch < $240 million (1992 USD)
  - Total development time from conception through launch < 36 months.
  - Exceeding budget by > 15% could lead to mission cancellation by Review Board!

Faster, Better, Cheaper

- Pathfinder (1996)
  - Part of Program Discovery. First in MESUR series of missions .
  - Goal to study soil composition of Mars
  - $265 million

"We were being asked to do a major NASA mission for the cost of a Hollywood movie. Well, at least our ending will be better."

- One spacecraft and one rover
  - X-ray spectrometer
  - Lots of Testing (Airbag draping over story)
  - Parachutes and airbags instead of retro rockets
    - Bounced 15 times, 50 feet high
- Major differences
  - People: 300 versus 2,000 for Viking
  - One specialist, single owner concept. A-team was on Cassini anyway.
  - Red team which conducted 25 reviews over a two year span (three reviews is the norm)
  - Spare parts from Cassini, commercial motors from Maxon (lovely story on Pg 21), commercial radio modems, own cameras from a few chips.
- Success of Pathfinder brought in more funding from Congress, almost doubling the Mars exploration budget



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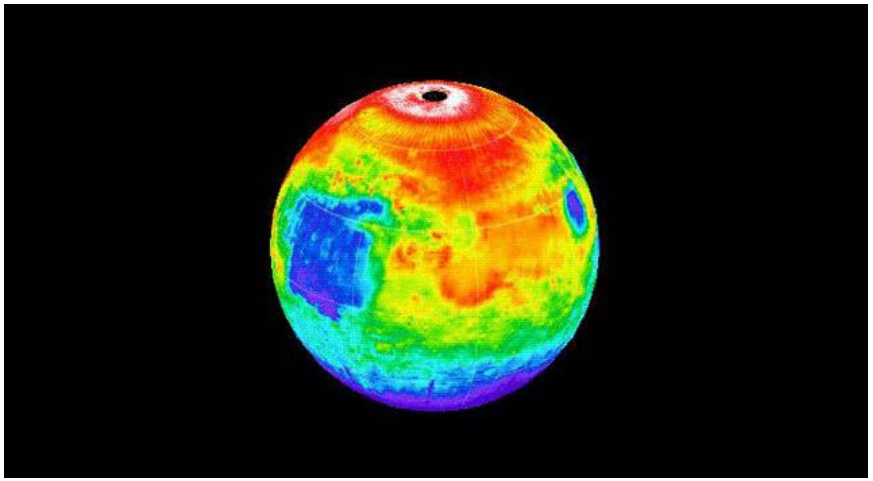
Faster, Better, Cheaper

- Mars Surveyor Program Systems approach: Small orbiters/landers (size constraint) launched every 26 months i.e. at every opportunity (time constraint) and ~ $100 million (cost constraint).
- Mission Mars Global Surveyor (1996)
  - Map the Martian surface in greater detail than before
  - $131 million
- Single spacecraft
  - Used aero-braking instead of retro rockets
    - 700 pounds of fuel vs. 3,175 pounds for MO

Courtesy of NASA/JPL-Caltech. Used with permission.



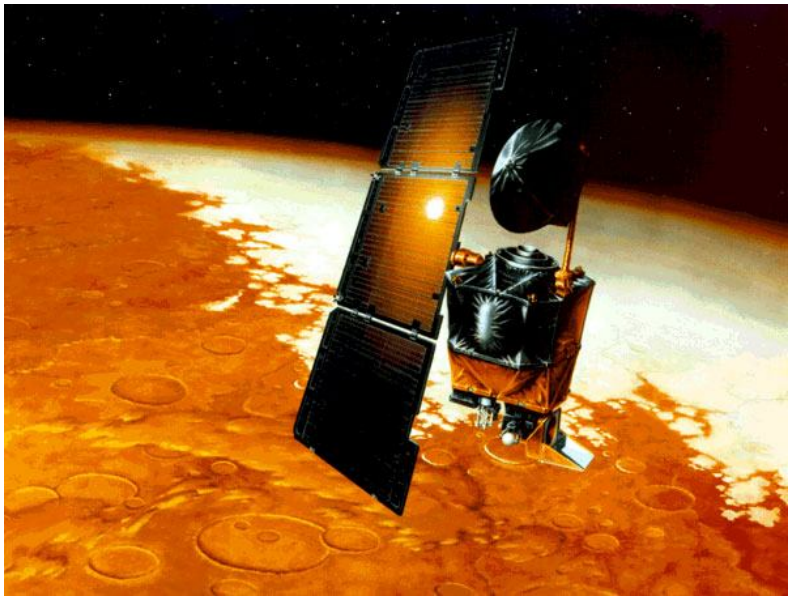
This image shows the Martian nighttime temperatures measured by the Thermal Emission Spectrometer instrument on the Mars Global Surveyor wrapped on to a globe. The coldest temperatures (shown in purple) are -120 degrees Celsius (-184 degrees Fahrenheit) and the warmest temperatures (shown in white) are -65 degrees Celsius (-85 degrees Fahrenheit). From: NASA/JPL

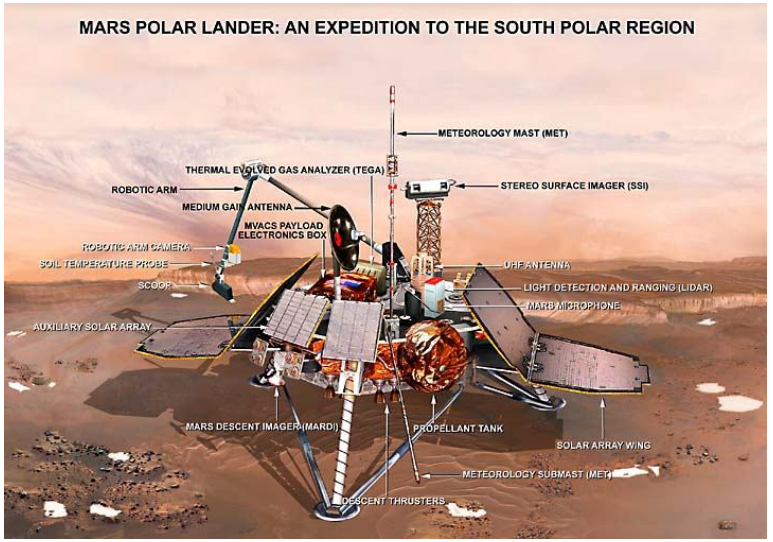
Courtesy of NASA/JPL-Caltech. Used with permission.

Photos from jpl.nasa.gov

Mars 1998

- 1998 Missions began in 1995
  - Goal to develop both orbiter and lander for less than $100 million each
  - Mission was to study Martian weather, water, carbon dioxide and search for long-term climate changes
- Mars Climate Orbiter
  - Entered orbit 20 miles lower than intended
    - Caused by English versus Metric units
  - Burned up in atmosphere and crashed into surface
- Mars Polar Lander
  - Lost comms during descent, never regained
  - Premature shut-down of engine
    - Deployment of spacecraft legs registered as landing deceleration and the engine was cut out
  - Spacecraft fell the last 130 feet and was destroyed on impact





Photos from jpl.nasa.gov

Aftermath – What went wrong?

NASA FBC task force set up to investigate concluded in 2000

- First generation FBC programs could fit challenging mission scope within cost allowance, second generation programs bar was set too high with less stable funding and escalating requirements
- Increased risk was used as relief valve because cost and schedule were fixed. *"Let's take more risk, do smaller missions and accept there will be some failures as long as we learn from them. But lose $200 million and they go 'gulp', that wasn't meant to happen."*
- Projects were too individually oriented, fragmented program without a clear, cohesive strategy, no single individual in charge of Mars program at JPL or NASA
- Cut-down on tests – unfortunate that the full, continuous landing system had not been tested.
- "*With single specialists on each subsystem, there was no one else to bounce ideas off. Couple that with the fact that most engineers worked 80-hour weeks for months. If there was a failure, it was not recognizing how we were stressing the team*"

Photos from jpl.nasa.gov

Aftermath – Changes to the Program

- Appointed a Mars program director at NASA HQ and JPL
- Revisions made to verification and validation, risk management, and configuration management processes
- Risk assessments for all projects were conducted and a council was created to give authority for each major project to proceed
- Measures implemented to improve NASA's ability to share lessons learned across projects and from completed projects
- Give the science community an opportunity to contribute within the same mission (this could go in your next slide too)
- Infrastructure gets built only inside large projects as only these can pull in funding. Distributed size and scope of missions needed so that the value of whole is more than the sum of its parts. (Programs like Discovery and Pathfinder worked because they relied on Cassini's parts, and Viking's aeroshell design and parachute system)

Way Ahead

- Larger satellites favored in the past
  - Already paying a lot to get there
  - On incremental basis, adding one experiment to a project is less than creating a new project
- Need effective strategy to span all programs
  - Culture at JPL was too focused on individual programs, program managers not looking at the bigger picture
  - Robust enough to be successful across multiple changes of administration
  - Flexible enough to change with new data received from current Mars missions
- All designs were based on FBC strategies contracted to Lockheed --> risk of failure again?
  - Payload ~ 66kg i.e. 3 times that of MPL because science teams wanted to better experiments. Too heavy for Pathfinder landing system.
  - Tests prove that legs deployed actually could cause another crash. (Cancel missions?)
  - Demand for sample return which would need 6 more tech breakthroughs and $1-2 billion.
- More coordination and flexibility required – integrated into one coherent program. *"It seems like we need to draw up a new 10-year plan every 12 months"*

Photo from jpl.nasa.gov

Mars Program Since 1998

2001	Mars Odyssey	US	Success	High resolution images of Mars
2003	Mars Express Orbiter/Beagle 2 Lander	ESA	Success/Failure	Orbiter imaging Mars in detail and lander lost on arrival
2003	Mars Exploration Rover - Spirit	US	Success	Operating lifetime of more than 15 times original warranty
2003	Mars Exploration Rover - Opportunity	US	Success	Operating lifetime of more than 15 times original warranty
2005	Mars Reconnaissance Orbiter	US	Success	Returned more than 26 terabits of data (more than all other Mars missions combined)
2007	Phoenix Mars Lander	US	Success	Returned more than 25 gigabits of data

http://marsprogram.jpl.nasa.gov/missions/log/

Discussion

- In the context of the failures in 1998, what would you have recommended to NASA in order to move on and succeed once again?
- Some parts in an article by the Staff Director at the White House (Pg 5) FBC plus safer. Do you think the FBC missions traded the safety bit for the first three?
- With the years of Mars missions based on FBC (Pathfinder to Mars' 98) → costs of Flight systems increases, Science instrumentation increased but Project management declined → A compromise is seen. Do you feel that it is more important to field multiple, cheap, less capable exploration projects or fewer, expensive, more capable projects. i.e. Pathfinder vs. Viking?
  - Is the right answer a mix of both?
  - Is today's society too risk adverse to continue the FBC strategy, will a relatively small scale program ($100 million) cause enough negativity ?
  - Systems approach on the Mars Science Laboratory?
- Given the recent report from the Augustine Commission, where do you believe NASA should focus in 2010 and beyond?
  - Current funding inadequate, private space, multinational cooperation

Questions

16.842 Fundamentals of Systems Engineering

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