Human Exploration of Mars: Cost Realities of a First Mission

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11:00 Paper 2
13 minute oral

Adelaide Convention Center
Riverbank 4

WHY should we be concerned?

- Mars Exploration is a priority that predates NASA
- Mars Sample Return is the next scientific step
- Human Exploration of Mars is a human priority encompassing more than “just” science
- In March 2011
  - MEPAG and Planetary Decadal Survey had identified a solid, scientific Mars exploration program
  - NASA announced serious funding problems
- Eleven months later, in February 2012
  - The President’s budget curtailed Mars plans and set back relations with the European Space Agency – the U.S. “partner for Mars”
- YET NASA is still talking about human missions “to Mars”
  - Where is the money for going to come from?
  - The answer is feared to be from - and at the expense of - the science program

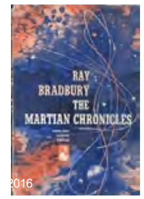
Mars Human Exploration (HE) Perspectives

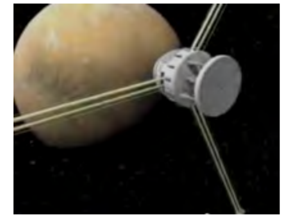
- Science fiction
- Theoretical studies
- Robotic scientific exploration
- Technical challenges
- Funding
- International collaboration

Barsoom (1911 – 1919)

Mars at the Movies (1959 – 1990)

Novels to computer animation…the public loves Mars

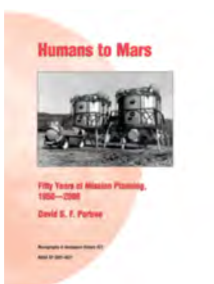




http://www.youtube.com/watch?v=V1vKMTYa40A
http://www.youtube.com/watch?v=-5lviadEChM

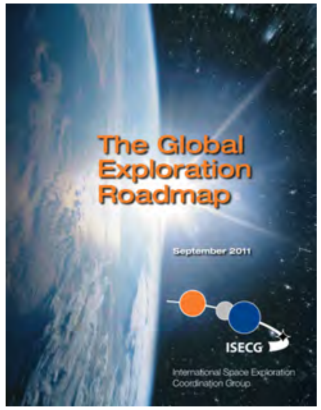
http://www.youtube.com/watch?v=5cqe9Wq9gqo&feature=related
http://www.youtube.com/watch?v=NDuuVo7lVW0&feature=relmfu

NASA Studies Abound

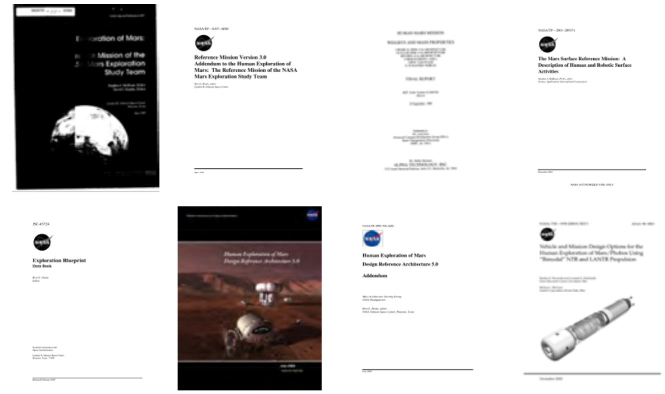


Policies and Policies… Domestic…

…and International



NASA Architectures for Mars



Recent Plans for Launch Vehicles for Human Exploration

Robotic Explorations Successes

- NASA has been riding high on the excitement of the scientific missions across the Science Mission directorate
  – Hubble Space Telescope, Discovery, New Frontiers, Mars missions, Living with a Star, Solar Terrestrial, Explorers, Terra, Aqua, Aura, and the list goes on
- Robotic missions have been “the jewels in the crown” of space exploration and discovery

HE's Future (?)

- Spectacular success of the ISS
  - Fantastic international collaboration
  - Myriads of mundane engineering problems solved
  - Human weightlessness research, etc.
  - What it takes to build structures in space
- What are the long term plans for ISS?
  - Assembly point for human interplanetary spacecraft?
  - Testbed for human deep-space missions?
  - (When will the money run out?)

HE's Future (concluded?)

- Let's go to …
  - The Moon – return is expensive and prejudice is "we've done that"
  - Earth-Sun L2 – JWST post; already harder than Moon with 30-day round trip
  - An Asteroid – test bed for deep-space and Mars – but 6 -12 months (!)
  - Mars moons and/or fly by Mars – looked at in EMPIRE studies; 1000 days (and no landing!)
  - Land on Mars – also 1000 days with prepositioning of masses of hardware and expendables, i.e., lots of "stuff"

HE technical challenges
"Mars is Hard*"

- Time – 3 years is a long time to be away from home; and this is with ~10km/s ΔV: the minimum if the transfer vehicle is reused (!!); long-term storage of liquid hydrogen is mission critical
- Radiation protection – need vault for solar energetic particles and moderate shielding for galactic cosmic rays
- Gravity – artificial? What are the real limits?
- Supplies – Water, air, and food cannot be 100% recylced
- Precision landing is mission-critical for prepositioning of supplies (besides being necessary for safety)
- Backup systems – in-flight repair?

* Mars is Hard - Fred Guterl, Monica Heger / IEEE Spectrum JUNE 2009

Mars Transit Vehicle (MTV) Costs

- The ISS is our solid reference for a human habitat. So:
  - What parts of the ISS do not have to be included in the MTV?
  - What has to be added to the MTV to place it in Mars Orbit?
  - What can be left in Mars Orbit?
  - What has to be added to return to earth orbit?
  - How do we "qualify" it for a two year mission?
- The MTV costs will be >>$100B (ISS cost) because
  - It must be lighter than ISS components
  - Exist without re-supply
  - Include a radiation vault
  - Support the lander
  - Include a repair workshop for unknown problems
  - Be non-claustrophobic (ISS had at least the earth to look at)

Mars HE Cost Reality - $1T?

- ISS (6 crew, 391 mt, 388 m^3 habitable vol., 84 kWe)[1] at ~$150B[2] was not easy…but it was straightforward ($384,000/kg)
- A ~4kg sample robotic return of ~$8.5B[3] scales to ~$850B[4]
  - Humans are "softer" than electronics (to radiation), less acceleration tolerate, and require more expendables (air, food, and water) and liging space – so this is likely a lower limit
- Is "Mars Direct" really feasible at $100B considering all the technical challenges?
  - Our answer is NO! – not if development and all infrastructure costs are included
  - Also the Mars Transfer Vehicle(s) will require ~5 km/s of propulsion each way from Low-Earth Orbit
- To change the speed of 400 mt of an MTV by 7 km/s (assume it is "thrown away" at return requires ~480 mt of LH2 for a nuclear thermal propulsion (NTP) system (900s Isp) or ~1480 mt of LH2 + LOX; at $50k/kg the cost differential alone for launch from Earth is ~10^6 kg x $50k/kg = $50B, but with larger tanks and structure the vehile mass would go up significantly as well
  - Development and forward pre-positioning cost for ISRU production of propellant is unknown
- [1] International Space Station Facts and Figures, NASA, http://www.nasa.gov/mission_pages/station/main/onthestation/facts_and_figures.html
- [2] Costs of US piloted programs, Claude Lafleur, *The Space Review* (2010) http://www.thespacereview.com/article/1579/1
- [3] *Vision and Voyages for Planetary Science*, NAS (2011): summed CATESs for MAX-C descope ($2.4B) + MSR Lander & MAV ($4.0B) + MSR Orbiter & EEV ($2.1 B)
- [4] Orion MPV crew module is 8.8 mt landing weight for crew of 4 and return payload of 100 kg http://www.nasa.gov/pdf/617408main_fs_2011-12-058-jsc_orion_quickfacts.pdf - hence ~400 kg return mass

Mars Is (Really) Hard

Fifty years ago, space experts thought we'd be there by now. Here's why we're not

BY FRED GUTERL, MONICA HEGER / IEEE Spectrum JUNE 2009

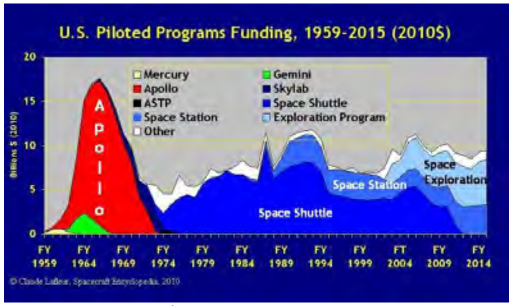
- "Spooked by those numbers back in 2007, when a trillion dollars still seemed like a ridiculous amount of money for even the U.S. government to spend, Congress stipulated in a NASA appropriations bill that 'none of the funds...shall be used for any research, development, or demonstration activities related exclusively to the human exploration of Mars.'"

http://spectrum.ieee.org/aerospace/space-flight/mars-is-hard/1

Funding Reality

- NASA's budget (we hope) is flat at about $20B
- If half the budget goes to Mars HE, then it would take 100 years to invest (i.e., spend) $1T
- Solutions:
  1. Increase NASA budget to $50B/yr and get there in 25 years ("double the budget")
  2. Find a magical solution to do it cheaply
  3. Continue with robotic exploration until our austerity era ends

Option 1: Increase Funding



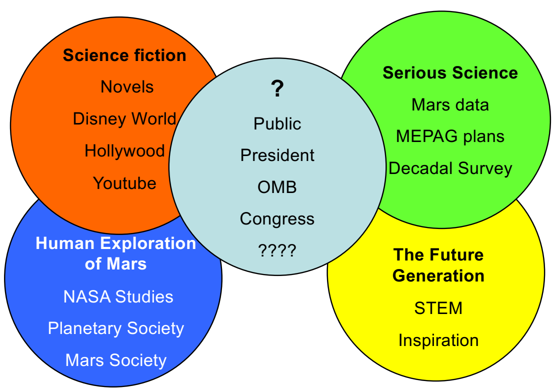
- The US has spent $486 billion over 57 years on human spaceflight, an average of $8.3 billion a year
- Mars is even harder…and can be done with $$$$s

Option 2: Magical Solution

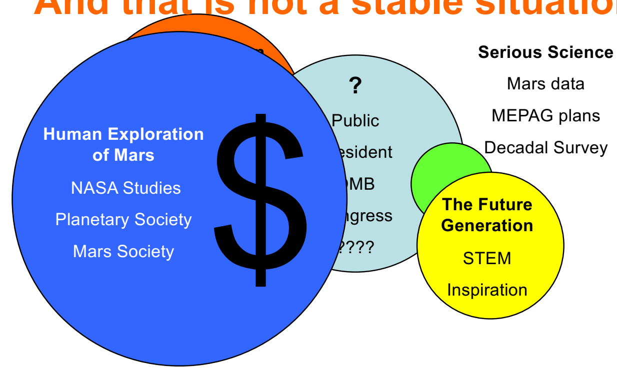
- "So I call these things cargo cult science, because they follow all the apparent precepts and forms of scientific investigation, but they're missing something essential, because the planes don't land."
  - R. Feynman (1974)

Option 3: Continued Progress

The root cause of the dilemma – Confusion amongst the stakeholders



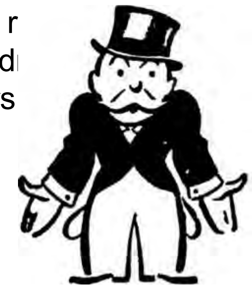
Cost Reality in a Zero (or less!) sum game makes HE resource intensive
And that is not a stable situation



International Collaboration

- While the US may bear most of the cost, International partners are essential for Mars HE.
- The current ExoMars situation suggests that NASA is not interested in being a strong international partner.

Summary

- Cost reality is the r  lars HE and the key players need to ad emselves and to the other stakeholders

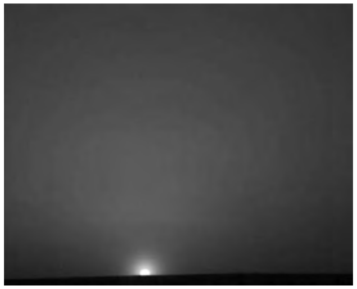
Recommendations

1. Get ExoMars back on track to rebuild international relations
2. NASA request the Space Studies Board/NAS/NAE to sponsor a cost-reality conference to establish a way forward to Mars HE.
3. Follow the Decadal Survey as funds allow
4. Seriously use the ISS as human, expendables, radiation, and hardware qualification facility for deep-space flight by humans
5. Explore Phobos and Deimos for a "basecamp" and ISRU source for human trips to the surface of Mars

The Risk: *Kejserens nye Klæder* (The Emperor's New Clothes)

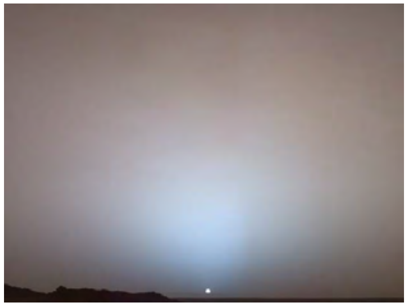
… which we *CANNOT* afford – the stakes are simply too high…

There can be a rising Sun…



Sunrise at Phoenix

…or a setting Sun…



Sunset at Gusev crater

The Future is Up To Us

Backups

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[4] Humans to the Martian System Preliminary Summary of Strategic Knowledge Gaps P-SAG (jointly sponsored by MEPAG and SBAG) May 1, 2012
[5] F.A. Cucinotta, M.-H.Y. Kim, R. L., Managing Lunar and Mars Mission Radiation Risks, Part I. Cancer Risks, Uncertainties, and Shielding Effectiveness, in, NASA Center for AeroSpace Information, Hanover, MD, 2005, pp. 44.
[6] Friedlander,A.L, Niehoff, Byrnes, Longski, "Circulating Transportation Orbits Between Earth And Mars" AIAA Paper No 86-47905
[7] T.P. Stafford, R.C. Seamans, G.W.S. Abbey, S.M. Armstrong, J.L. McLucas, L.T. Silver, America at the Threshold: Report of the Synthesis Group on America's Space Exploration Initiative, U.S. Governement Printing Office, Washington, D.C., 1991.
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[10] W. Von Braun, The Mars Project, Univ. of Illinois Press, Urbana, IL, 1991.
11] R.L. McNutt, Jr., Solar system exploration: A vision for the next 100 years, Johns Hopkins APL Tech. Dig., 27 (2006) 168-181.
[12] Wikipedia, Ming Dynasty, in, 2008

Qualification Ideas for Mars HE

- Demonstrations before people leave LEO for Mars
  - Pinpoint landing of a large (people size) mass on Mars
  - Simulation of the Mars trip at an ISS module
    - 3 to 6 people for 200 days outbound, 30 days return to earth and the same people 200 days inbound
  - Repair workshop evaluation for random single point failures
  - Long term life testing of all components for the mission

Advantages of Humans over Robots

- Human eye is directly connected to human computer (the brain)
- Senses of sound and smell help diagnose problems
- Fear is a great motivator for problem solving i.e. Apollo 13.
- Human can ignore (question) stupid commands

Robots lie in our future

- Asimov's "I Robot" is just around the corner
- Robots:
  - Are expendable (just like test pilots in the 1950's)
  - Only need power and programs
  - Can be put into hibernation
  - Can give people the virtual experience of being there
  - Are low cost
- Mars HE needs supporting Robots

The Footprint Mission

- Goal is to place a footprint on the surface and leave as soon as is safe.
- Crew of 3
- Landing in an extremely safe place
- No in situ emergency ascent vehicle
- Only one person lands (Solves the Armstrong/Aldrin problem – the one landing takes all the risk so gets credit)
- Prepares the way for Mars exploration – radiation protection, long-term boredom, reliability, etc
- Maybe within reach of chemical propulsion