BIOMEDICAL ASPECTS OF EARLY MARS EXPEDITIONS

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This paper will describe the current planning for exploration-class missions, emphasizing the medical and human factors aspects of such expeditions. The details of mission architecture are still under study, but a typical Mars design reference mission comprises a six-month transit from Earth to Mars, eighteen months in residence on Mars, and a six-month transit back to Earth. Physiological stressors will include environmental factors such as prolonged exposure to radiation, weightlessness in transit, and hypogravity and a toxic atmosphere while on Mars. Psychological stressors will include remoteness from Earth, confinement, and potential interpersonal conflicts, all complicated by circadian alterations. Medical risks including trauma must also be considered. Results of planning for assuring human health and performance will be presented.

Human Health & Performance Aspects of the Mars Design Reference Mission

as interpreted and expanded upon by

John B. Charles, Ph.D.

for Human Space Life Sciences Programs Office (HSLSPO)

NASA JSC

Design Reference Mission

Bibliography

Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team (Stephen J. Hoffman and David I. Kaplan, eds.) NASA Special Publication 6107, July, 1997.

The author has augmented the information in the primary source with insights from many formal briefings, informal conversations, and personal musings, some of which are based on the following works:

Oberg, James E. *Mission to Mars : Plans and Concepts for the First Manned Landing.* Harrisburg, PA: Stackpole Books, 1982.

Collins, Michael. *Mission to Mars: An Astronaut's Vision of Our Future in Space.* New York: Grove Weidenfeld, 1990.

Zubrin, Robert. *The Case for Mars: The Plan to Settle the Red Planet and Why We Must.* New York: The Free Press, 1996.

Human Space Life Sciences Programs

JSC is NASA's Lead Center for human operations in space and oversees these human research functions:

- Space Medicine
- Biomedical Research and Countermeasures
- Advanced Human Support Technologies
  - Advanced Life Support
  - Advanced Human Engineering
  - Advanced Environmental Monitoring and Control
  - Elements of Advanced Extravehicular Activity (EVA)

Human Space Life Sciences Program Office (HSLSPO) coordinates these critical support functions for JSC

Background

- **Human Space & Life Sciences Programs Office** identifies critical areas of research and development that will assure human health and performance capability for exploring and developing space.
- The **Mars Design Reference Mission** is a benchmark for determining both the content and direction of mid- and long-term research activities.
- Near-term focus continues to be on tasks and techniques that expand human performance during Space Shuttle and International Space Station missions.

Disclaimer

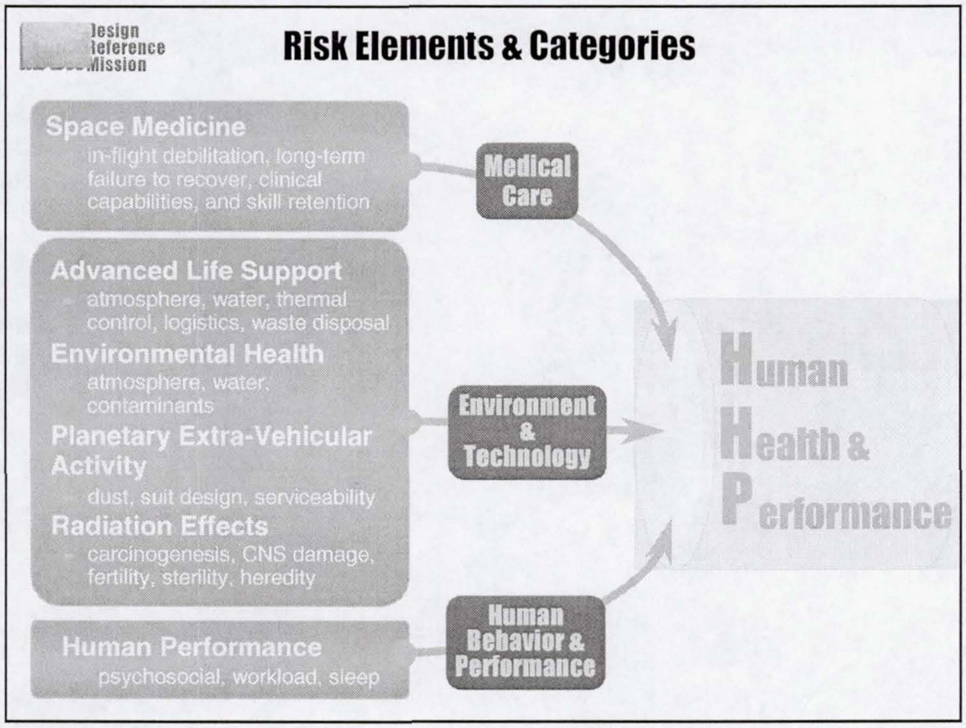
At this time, NASA does not have the authority to undertake a piloted Mars mission. No claim to the contrary can be inferred from this presentation.

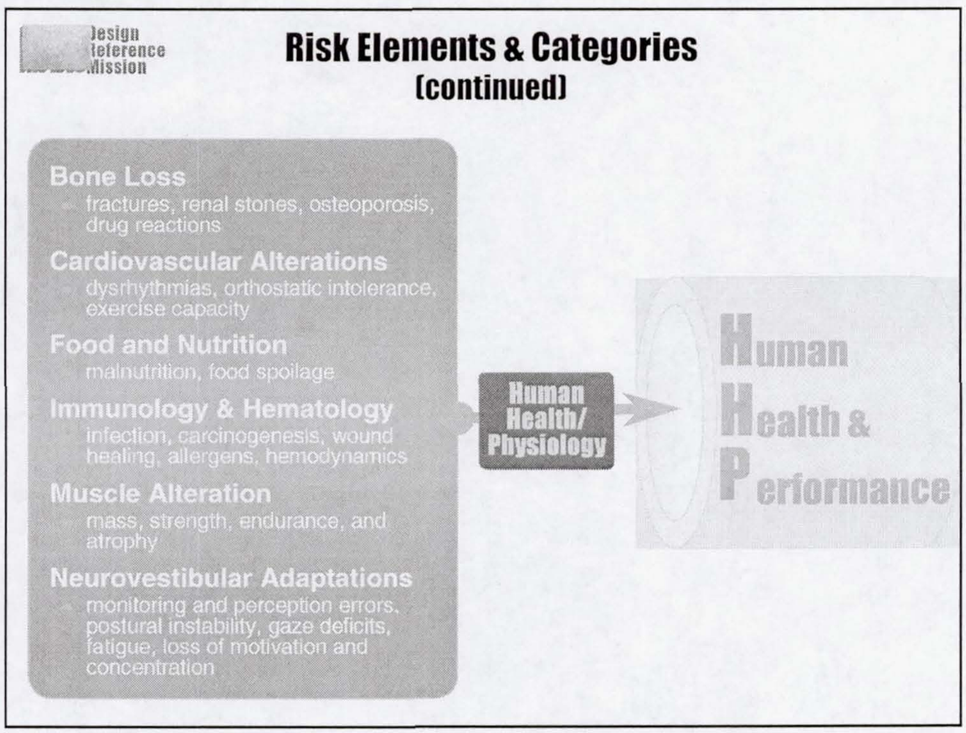
This presentation is based upon the Mars Design Reference Mission (NASA Special Publication 6107, July 1997)and summarizes the work of NASA scientists, engineers, and planners who defined it. This work forms a basis for comparing different approaches and criteria involving new or improved technologies, in order to select from among them at the appropriate time.

Medical Requirements

Human Health & Performance during interplanetary space flight

- **Basic Elements**
  - Nutrition (adequate, appropriate, appealing)
  - Rest (avoid chronic fatigue)
  - Exercise (fitness, recreation, motivation)
  - Human Performance (psychosocial, workload, human-robotic interface, & circadian factors)
- **Habitability** including extra-vehicular activity, advanced life support, & environmental health
- **Countermeasures & preventive measures** for deleterious physiological effects
- **Diagnosis** of new or pre-existing conditions
- **Treatment** subsequent to diagnosis
- **Research** directed towards fulfilling all of the above


Design Reference Mission
Risk Elements & Categories
Space Medicine
in-flight debilitation, long-term failure to recover, clinical capabilities, and skill retention
Advanced Life Support
atmosphere, water, thermal control, logistics, waste disposal
Environmental Health
atmosphere, water, contaminants
Planetary Extra-Vehicular Activity
dust, suit design, serviceability
Radiation Effects
carcinogenesis, CNS damage, fertility, sterility, heredity
Human Performance
psychosocial, workload, sleep
Medical Care
Environment & Technology
Human Behavior & Performance
Human Health & Performance


Design Reference Mission
Risk Elements & Categories (continued)
Bone Loss
fractures, renal stones, osteoporosis, drug reactions
Cardiovascular Alterations
dysrhythmias, orthostatic intolerance, exercise capacity
Food and Nutrition
malnutrition, food spoilage
Immunology & Hematology
infection, carcinogenesis, wound healing, allergens, hemodynamics
Muscle Alteration
mass, strength, endurance, and atrophy
Neurovestibular Adaptations
monitoring and perception errors, postural instability, gaze deficits, fatigue, loss of motivation and concentration
Human Health/ Physiology
Human Health & Performance

Design Reference Mission

Why Mars?
from the life sciences perspective

The Mars DRM is a "strawman" chosen to represent exploration-class missions because it requires a rigorous life sciences critical path.

Long Duration Experience	14 months Longest flight; 3-6 months ISS tours	30 months Mars round trip
Episodes of Hypergravity	1.5-2.0g Earth aerobraking	peak 3-5 g, peak 3-5 g Earth & Mars aerobraking
G Transitions	1g → 0g 0g → 1g	1g → 0g 0g → 1/3g 1/3g → 0g 0g → 1g
Physical Demands	Current: infrequent orbital EVAs with regular daily exercise	**Mars:** frequent Mars surface EVAs, possibly daily
Toxin Exposure	Current: spacecraft & terrestrial toxins only	**Mars:** spacecraft, terrestrial, & <u>extraterrestrial</u> toxins

Design Reference Mission

Possible Future Mission Scenarios: Low Earth Orbit, Lunar, and Planetary

	In Space	Planetary Surface
100 Days	LEO: STS, ISS Libration Points	Moon
1000 Days	Libration Points	Mars, asteroids, comets

Design Reference Mission

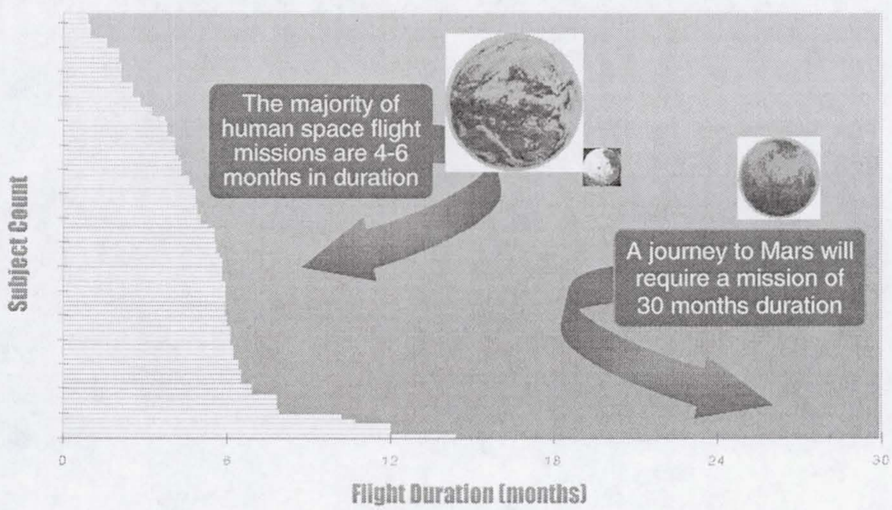
Possible Future Mission Scenarios: Low Earth Orbit, Lunar, and Planetary

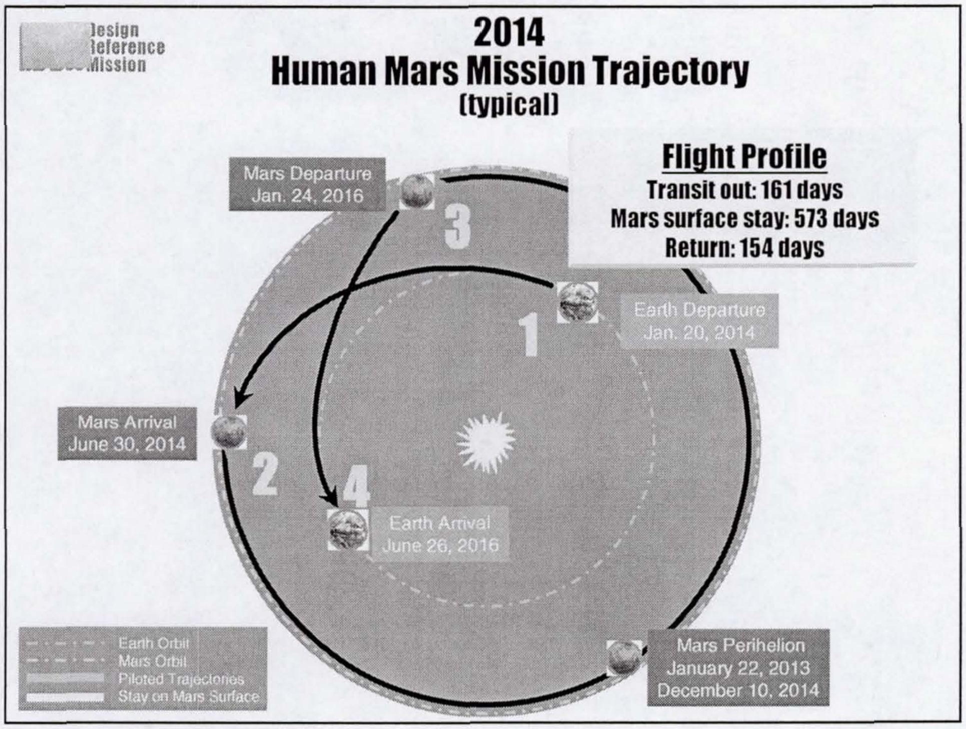
	Shuttle	ISS	Moon	L-1 Point	Mars	Asteroids, Comets
Duration	up to 18 days	3-6 months	Up to 100 days		Up to 1000 days	
G-Transitions	2		4	2	4	2
Hypogravity	0		1/6 G	0	1/3 G	0
Artificial Gravity	No				Possible	
Radiation Environment	Shielded by Van Allen Belts		Some shielding by Moon's mass	Unshielded	Some shielding by Mars mass and atmosphere	Unshielded
Abort to Earth Time	Hours		~4 days		Months	
Rescue Options	Minimal	Possible			Minimal	
Potential Toxins	off-gassing, leaks, etc.		+ local materials	off-gassing, etc.	+ local materials, biohazards	
Trauma Potential	+	+	++	+	++	+

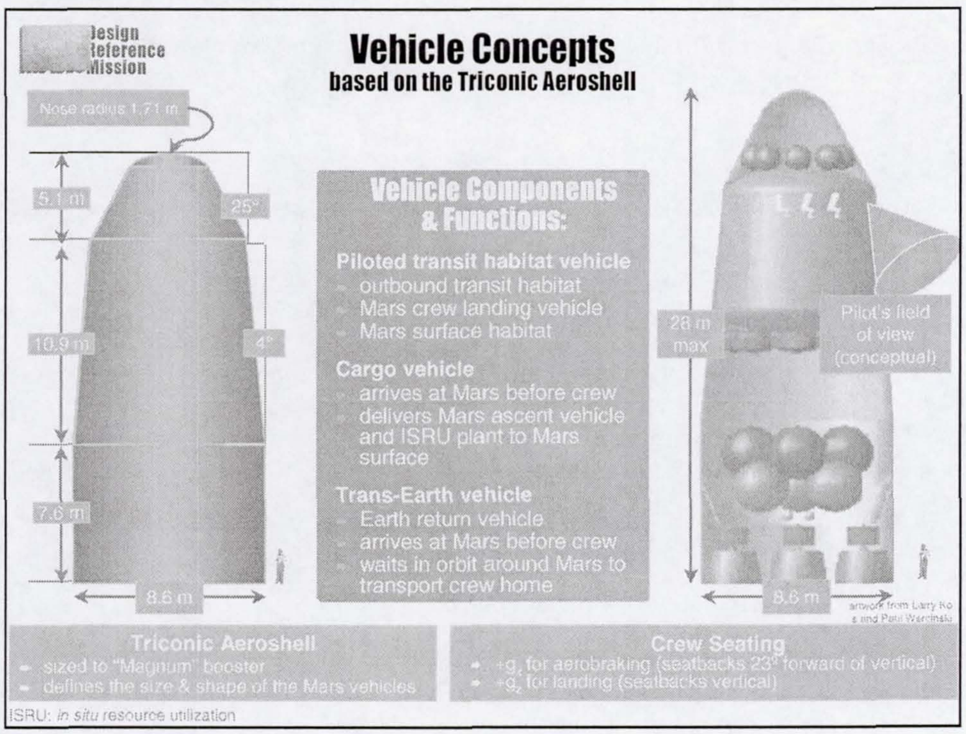
Design Reference Mission

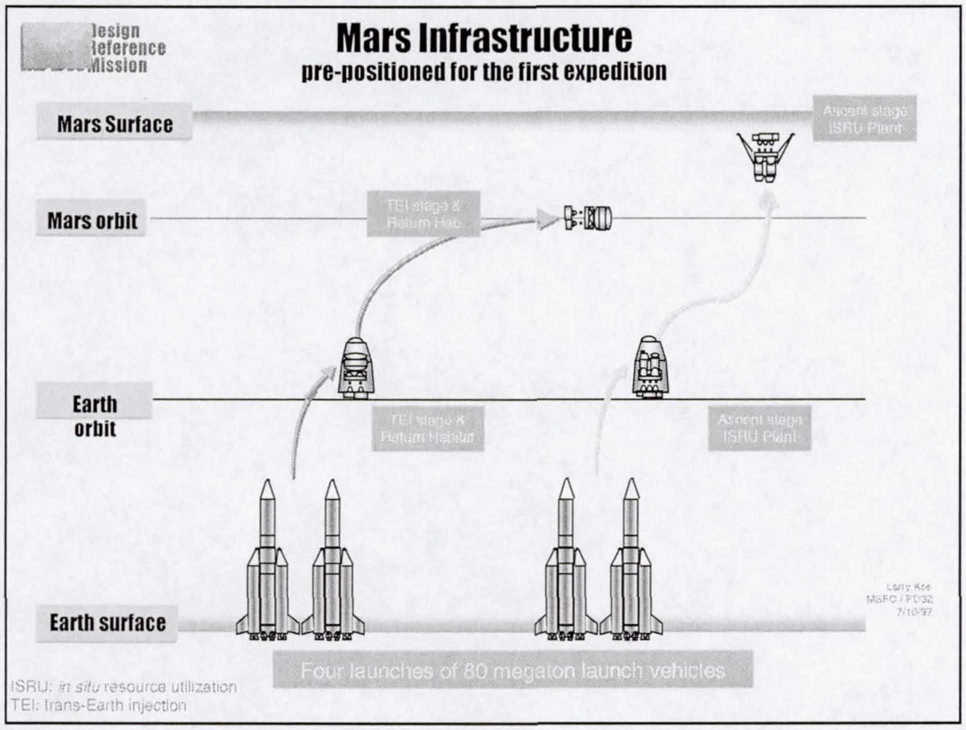
Human Space Flight Experience

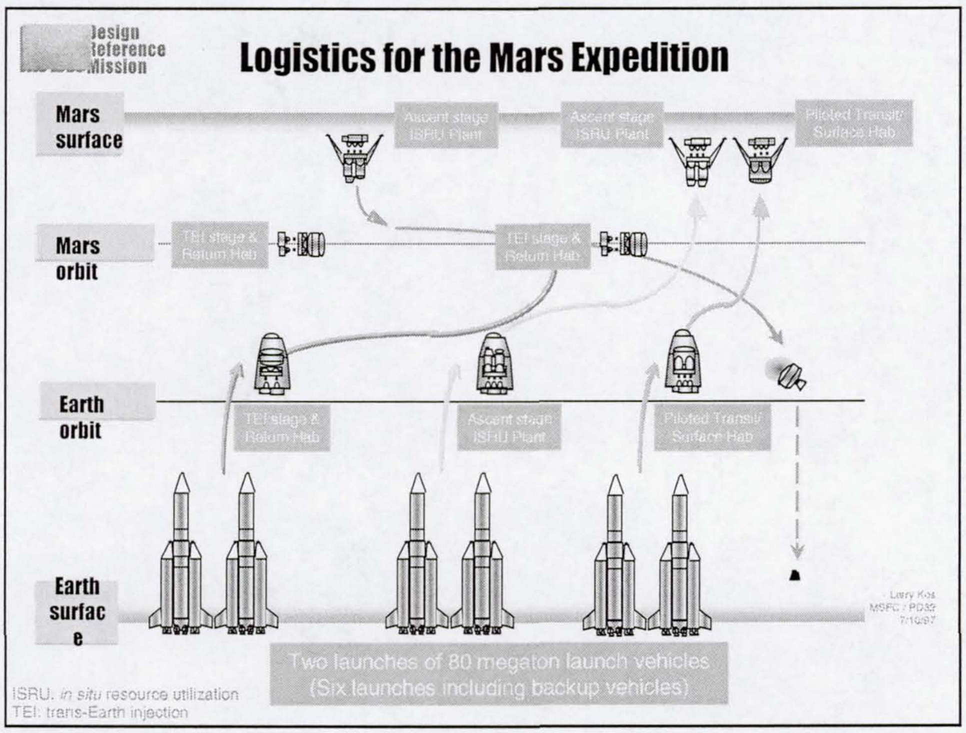
(Includes flights longer than 30 days as of April 1999)



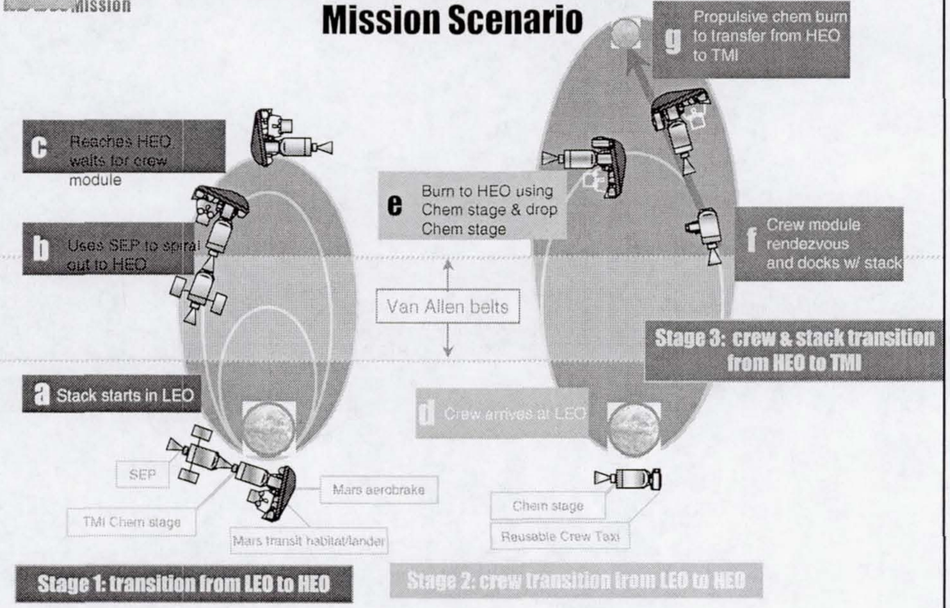

2014
Human Mars Mission Trajectory
(typical)
Flight Profile
Transit out: 161 days
Mars surface stay: 573 days
Return: 154 days
Mars Departure
Jan. 24, 2016
3
Earth Departure
Jan. 20, 2014
1
Mars Arrival
June 30, 2014
2
4
Earth Arrival
June 26, 2016
Earth Orbit
Mars Orbit
Piloted Trajectories
Stay on Mars Surface
Mars Perihelion
January 22, 2013
December 10, 2014


Vehicle Concepts
based on the Triconic Aeroshell
Nose radius 1.71 m
5.1 m
25°
10.9 m
4°
7.6 m
8.6 m
Vehicle Components & Functions:
Piloted transit habitat vehicle
- outbound transit habitat
- Mars crew landing vehicle
- Mars surface habitat
Cargo vehicle
- arrives at Mars before crew
- delivers Mars ascent vehicle and ISRU plant to Mars surface
Trans-Earth vehicle
- Earth return vehicle
- arrives at Mars before crew
- waits in orbit around Mars to transport crew home
28 m max
Pilot's field of view (conceptual)
8.6 m
Triconic Aeroshell
- sized to "Magnum" booster
- defines the size & shape of the Mars vehicles
Crew Seating
- $+g_x$ for aerobraking (seatbacks 23° forward of vertical)
- $+g_z$ for landing (seatbacks vertical)
ISRU: *in situ* resource utilization


Design Reference Mission
Mars Infrastructure
pre-positioned for the first expedition
Mars Surface
Ascent stage ISRU Plant
Mars orbit
TEI stage & Return Hab
Earth orbit
TEI stage & Return Habitat
Ascent stage ISRU Plant
Earth surface
Larry Kos MSFC / PD32 7/10/97
Four launches of 80 megaton launch vehicles
ISRU: *in situ* resource utilization
TEI: trans-Earth injection


Design Reference Mission
Logistics for the Mars Expedition
Mars surface
Ascent stage ISRU Plant
Ascent stage ISRU Plant
Piloted Transit/ Surface Hab
Mars orbit
TEI stage & Return Hab
TEI stage & Return Hab
Earth orbit
TEI stage & Return Hab
Ascent stage ISRU Plant
Piloted Transit/ Surface Hab
Earth surfac e
Larry Kos MSFC / PD32 7/10/97
Two launches of 80 megaton launch vehicles
(Six launches including backup vehicles)
ISRU: *in situ* resource utilization
TEI: trans-Earth injection

Solar Electronic Propulsion Mission Scenario



LEO: low Earth orbit
HEO: high Earth orbit

SEP: solar electronic propulsion
TMI: trans-Mars injection

from SEP Team package, Nov., 1997

Abort Scenarios for Design Reference Mission

"Abort to Earth" options are very limited

- Trans-Mars Injection (Earth-departure maneuver)
  - Impulsive propulsion (nuclear-thermal, chemical) may prohibit abort within hours or days of TMI
  - Low-thrust propulsion (solar-electric, plasma) ***if available after TMI*** may permit abort, but only with long return time lasting weeks or months
- Missed Mars orbit insertion or direct entry
  - Mars flyby may result in multi-year return to Earth that is similar in duration to nominal mission

"Abort to Mars" options

- Life support and other resources already deployed
- Mars environment provides the most safety after Earth (offers radiation shield and partial gravity)

Physical Challenges

Gravity ······ **Acceleration**

	Earth Launch	Transit	Mars Landing	Mars Surface	Mars Launch	Transit	Earth Landing
G-Load	up to 3 g	0 g	3-5 g	1/3 g	TBD g	0 g	3-5 g
Notes	boost phase (8min); TMI (min)	4-6 months	aerobraking (min); parachute braking (30s); powered descent(30s)	18 months	boost phase (min); TEI (min)	4-6 months	aerobraking (min); parachute braking (min)
Cumulative hypo-g	0		4-6 months		22-24 months		26-30 months
G transition	1 g to 0 g		0 g to 1/3 g		1/3 g to 0 g		0 g to 1g

TMI: trans-Mars injection
TEI: trans-Earth injection

Impacts of Extended Weightlessness

Physical tolerance of stresses during aerobraking, landing, and launch phases, and strenuous surface activities

Bone loss
- no documented end-point or adapted state
- countermeasures in work on ground but not yet flight tested

Muscle atrophy
- resistive exercise under evaluation

Cardiovascular alterations
- pharmacological treatments for autonomic insufficiency

Neurovestibular adaptations
- vehicle modifications, including centrifuge
- may require auto-land capability

Design Reference Mission

Artificial Gravity (AG)

What steps are required to certify AG as a valid countermeasure to extended weightlessness?
(per Artificial Gravity Working Group, January 1999)

- **Begin a comprehensive ground research program immediately**
- **Begin a parallel flight research program as soon as possible**
  - The ISS small-animal centrifuge will *not* be available before CY2003
  - A larger centrifuge is currently not planned at all!
- **Focus on the following research priorities**
  - Minimize physiological effects by developing optimal prescriptions for intermittent AG
  - Identify g threshold values needed to maintain HHP (including 1/3 g exposure for 18 months)
  - Determine optimal AG characteristics (e.g., radius and angular velocity)

Design Reference Mission

Artificial Gravity (AG)

What steps are required to certify AG as a valid countermeasure to extended weightlessness?
(per Artificial Gravity Working Group, January 1999)

- **Establish a comprehensive ground research program**
- **Implement a flight research program**
  - International Space Station
  - Space Shuttle
- **Focus on the following research priorities**
  - Determine optimal characteristics for intermittent AG
  - Identify g threshold values needed to maintain HHP (including 1/3 g exposure for 18 months)
  - Determine optimal AG characteristics (e.g., radius and angular velocity)

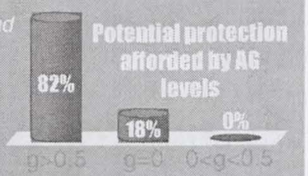
Design Reference Mission

Artificial Gravity Considerations

Can artificial gravity preserve physiological function during long-duration missions?

Actions needed to accomplish Mars mission transit

- **Vigorously investigate** AG to reach a consensus about AG for Mars mission
- **Explore current approach**: AG may be used to pre-adapt crew to Mars gravity (outbound) and re-adapt to Earth gravity (inbound):
  - provides extended physiological protection from 1 g
  - eases transition throughout 1/3 g exposure
  - requires AG capability of 1 g outbound and *inbound*
- **Define parameters** for optimal g level
  - initiate benchmark studies based on best guess
  - evaluate protective effects (if any) of 1/3 g
  - continue studies on optimal angular rate:
    - few problems if $\omega < 1$ rpm
    - some problems if $1 > \omega > 6$ rpm
    - more problems if $6 > \omega > 10$ rpm
    - no data if $\omega > 10$ rpm



Note: no consensus currently exists on AG levels needed for exploration missions

Design Reference Mission

Physical Challenges

Radiation

	Earth Launch	Transit	Mars Landing	Mars Surface	Mars Launch	Transit	Earth Landing
Source	van Allen belts (trapped radiation)	GCR (quiet sun); SPE (active sun); nuclear power reactor		GCR (quiet sun); SPE (active sun); nuclear power reactor		GCR (quiet sun); SPE (active sun); nuclear power reactor	
Exposure	SEP option: 3 passengers or more	4-6 months		18 months: shielded by Mars' bulk & atmosphere		4-6 months	
Cumulative Exposure	hours-days		4-6 months		22-24 months		26-30 months

GCR: galactic cosmic radiation
SPE: solar particle events
SEP: solar electric propulsion

Mars Transit Requirements

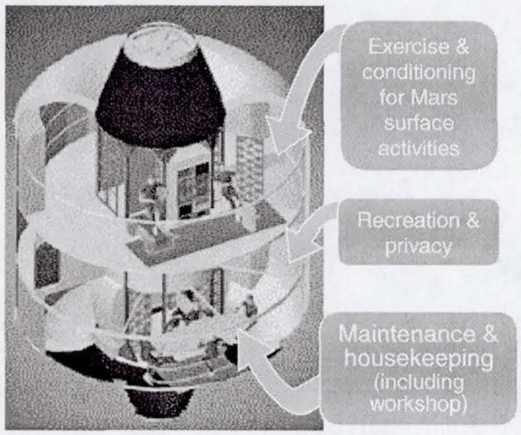
Design Reference Mission

Facilities must be mostly autonomous
(one-way Earth-Mars communications time is 3-22 min.)

Health care functions

- Nutrition
- Exercise
- Psychological support
  - planned activities
    - entry/landing simulations
    - housekeeping
    - refresher training
    - cruise science (rover operations/site preparation, microgravity, astronomy, and biomedicine)
  - communications
    - reliable contact with mission control, family, & friends
- Health Care
  - autonomous care
  - telemedicine

Habitat facilities



artwork from Constance Adams and Kris Kennedy for the JSC TransHab Team

Human Factors and Habitability

Design Reference Mission

The following require engineering solutions:

- air purifier
- water purifier
- particulate analyzer
- microbial analyzer
- waste manager/recycling
- food storage
- food processor
- clothing manager (e.g., washing machine)
- lighting levels
  - intensity (threshold level)
  - periodicity (circadian rhythmicity)

Optimal
Human
Health &
Performance

Design Reference Mission

Peak Physical Challenges

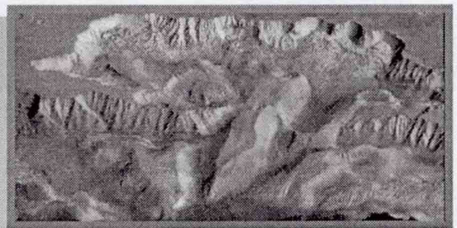
Mars Surface Phase
(post-landing through pre-launch)

Assumptions about Mars surface gravity

- Too *LOW* to be beneficial (for preserving bone integrity, etc.)
- Too *HIGH* to be ignored (for avoiding g-transition & vestibular symptoms)

Challenges

- Physical
  - g-transition (first few days only?)
  - prolonged exposure to 1/3 g
  - high-intensity surface activity
  - EMU hypobaric environment
  - 70 kg EMU (partially self-supporting)
  - surface trauma risk
- Communications - no real-time MCC support (one-way communications: 3-22 min.)
  - crew highly autonomous
  - Earth monitoring for trend analysis only



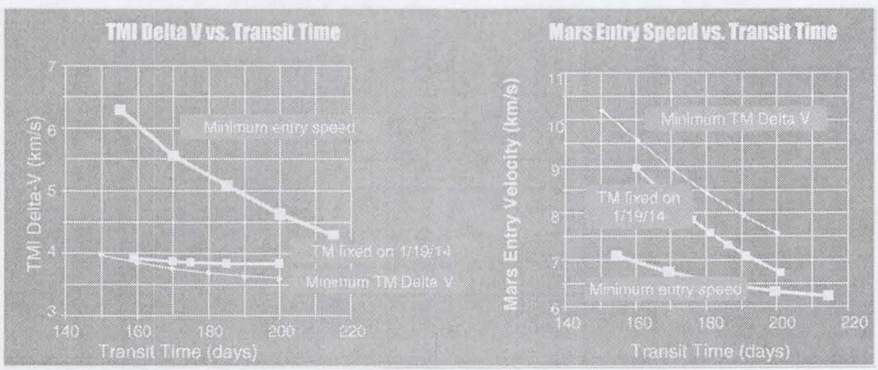
EMU: extra-vehicular mobility unit
MCC: Mission Control Center

Design Reference Mission

Interplanetary Trajectory Trades

Key Parameters Affecting Aeroassist: DRM V3.0

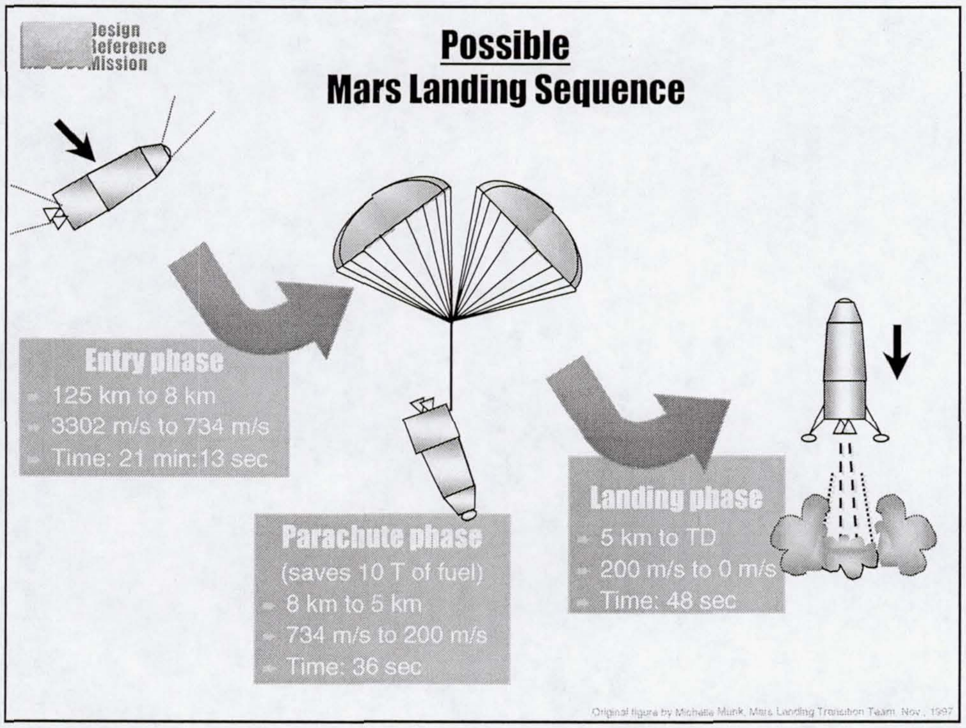
Earth-Mars 2014 Opportunity Crewed Launch

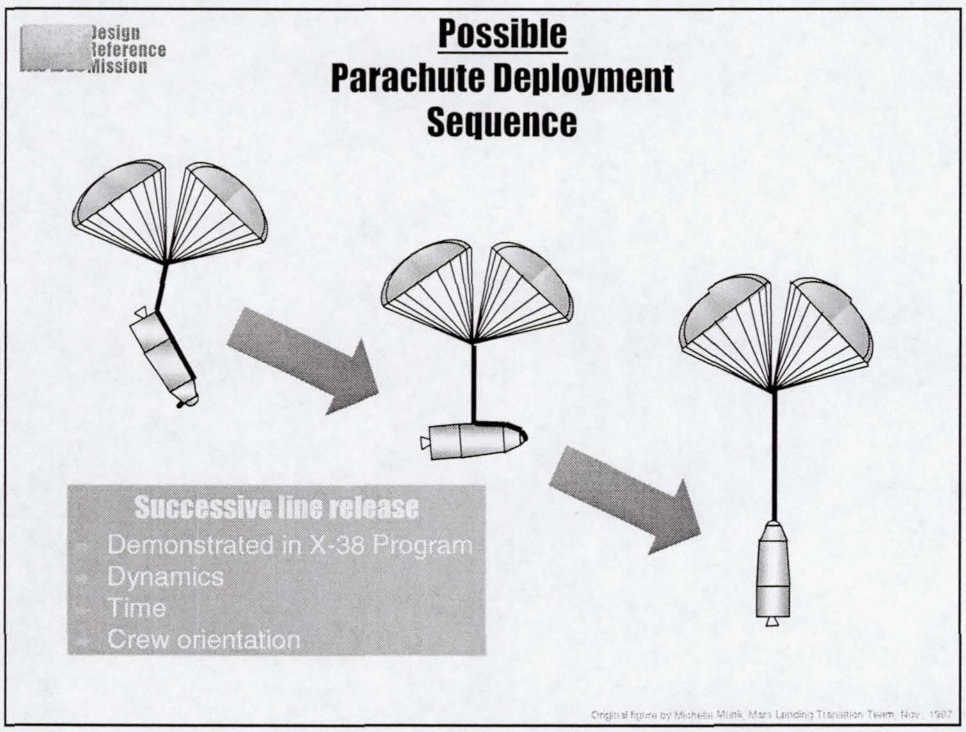


- Choice of launch date and trip time have significant impact on TMI DV and V_e at Mars
- Non-optimum TMI DV trajectories can reduce Mars entry velocity 0.7-1.2 km/s with 2-6% increase in TMI DV

POC: E. Lyne (U-Tenn), M. Munk (JSC)

Data from Jim Arnold, Dec. 16, 1997


Design Reference Mission
Possible
Mars Landing Sequence
Entry phase
125 km to 8 km
3302 m/s to 734 m/s
Time: 21 min:13 sec
Parachute phase
(saves 10 T of fuel)
8 km to 5 km
734 m/s to 200 m/s
Time: 36 sec
Landing phase
5 km to TD
200 m/s to 0 m/s
Time: 48 sec
Original figure by Michelle Munk, Mars Landing Transition Team, Nov., 1997


Design Reference Mission
Possible
Parachute Deployment
Sequence
Successive line release
Demonstrated in X-38 Program
Dynamics
Time
Crew orientation
Original figure by Michelle Munk, Mars Landing Transition Team, Nov., 1997

Design Reference Mission

Peak Physical Challenges

Strategy for Mars Surface Operations

Background → Anecdotal evidence suggests only ~50% of Russian *Mir* crewmembers are ambulatory *with assistance* immediately after landing, increasing to nearly 100% within hours

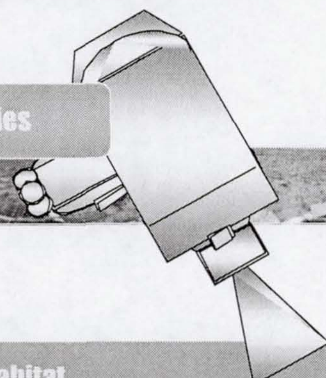
Assume → Only 3 out of 6 Mars crewmembers are ambulatory immediately after landing

Strategy → Start with passive tasks inside vehicle and progress to strenuous tasks on surface

- **First 1-3 days** activities limited to reconfiguration of lander/habitat and surface reconnaissance
- **Then**, conduct first Mars walk(s) in vicinity of lander (umbilical instead of backpack?)
- **Next,** use unpressurized rover for early, shorter excursions
- **After a week or more**, extended excursions are possible

Design Reference Mission

Mars Surface Stay Requirements



Autonomous facilities

Crew health care

- Radiation Protection
- Medical Surgical care
- Nutrition - Food Supply
- Psychological support
  - meaningful work
    - surface science
      - planetary
      - biomedical
    - simulations of Mars launch, trans-Earth injection, and contingencies
    - progressive debriefs, sample processing, etc.
    - housekeeping
  - communications capability

Habitat

- Maintenance/housekeeping
  - workshop with HRET capabilities
- Exercise supplemental to Mars surface activities
- Recreation
- Privacy

HRET: human-robotic exploration team

Design Reference Mission

Life Sciences on the Martian Surface

Periodic (monthly?) health checks for:

- bone integrity
- cardiovascular/cardiopulmonary function
- musculoskeletal fitness
- hematological parameters

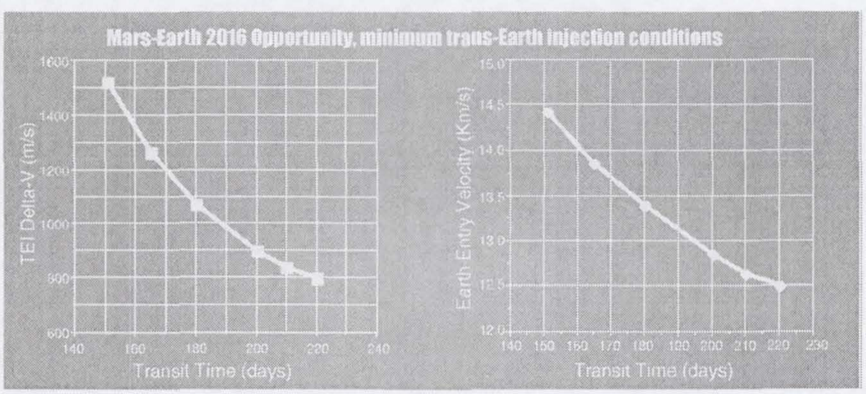
Health assessments will also serve as applied research:

- probably longest period away from Earth to date
- probably longest exposure to hypogravity (1/3 g) environment to date

Design Reference Mission

Interplanetary Trajectory Trades

Key Parameters Affecting Aeroassist: DRM V3.0



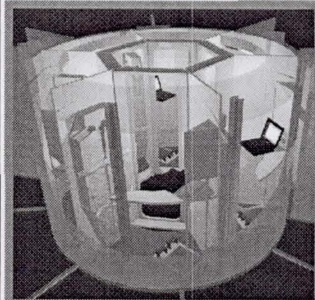
- Choice of launch date and trip time have significant impact on TEI DV and Ve @ Mars
- Increasing trip time reduces both TEI DV and Earth entry velocity
- DRM conditions -> 13.0 - 13.5 Km/s entry velocity
- Further analysis needed to look at synodic period effects on Earth entry velocity

POC: E. Lyne (U-Tenn), M. Munk (JSC)

Data from Jim Arnold, Dec. 16, 1997

Design Reference Mission

Earth Return Transit Requirements



Conceptualization of crew quarters

Autonomous Facilities

(one way Earth-Mars communications time is 3-22 min.)

- **Crew health care**
  - Nutrition
  - Psychological support
    - meaningful work
      - simulations of Earth aerobraking, contingencies
      - debriefs, reporting, & consultation with primary investigator
      - housekeeping
      - cruise science
        - Mars sample analysis?
        - microgravity, astronomy, other?
    - communications capability
- **Habitat**
  - Maintenance/housekeeping
    - workshop
  - Exercise - supplemental to Mars surface activities
  - Recreation
  - Privacy

artwork from Constance Adams and Kris Kennedy for the JSC TransHab Team

Design Reference Mission

Space Medicine Issues

Projected rates of illness or injury

Past Experience

0.06 person/year

Based on U.S. and Russian space flight data, U.S. astronaut longitudinal data, and submarine, Antarctic winter-over, and military aviation experience:

- Incidence of *significant* illness or injury is **0.06 per person per year**
  - as defined by U.S. standards
  - requiring emergency room visit or hospital admission

Mars DRM

0.90 person/mission

Expected incidence for a DRM of 6 crewmembers and 2.5 year mission is **0.90 person per mission,** approximately one person per mission

- Subset of injuries or illness requiring intensive care support is 0.02 per person per year
  - Expected incidence is 0.30 per person per year, about **once per three missions** (~80% of intensive care support lasts only 4-5 days)

Note: any such occurrences will also preoccupy onboard care-giver.

Data from R. Billica, January 1998, and D. Hamilton, June 1998

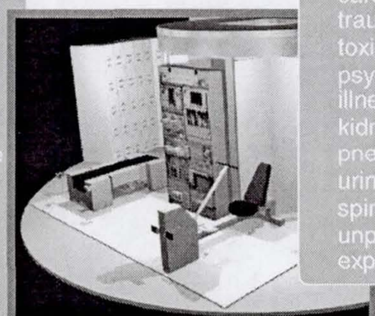
Design Reference Mission

Space Medicine Issues

Reports of illness and injury during space flight

Incidence Common [>50%]

- skin rash, irritation
- foreign body
- eye irritation, corneal abrasion
- headache, backache, congestion
- gastrointestinal disturbance
- cut, scrape, bruise
- musculoskeletal strain, sprain
- fatigue, sleep disturbance
- space motion sickness
- post-landing orthostatic intolerance
- post-landing neurovestibular symptoms



Conceptualization of crew healthcare & exercise facilities

Incidence Uncertain

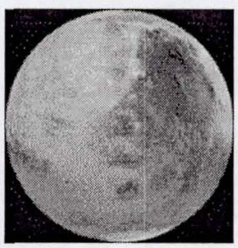
- infectious disease
- cardiac dysrhythmia, trauma, burn
- toxic exposure
- psychological stress, illness
- kidney stones
- pneumonitis
- urinary tract infection
- spinal disc disease
- unplanned radiation exposure

Data from R. Billica, Jan. 8, 1998

artwork from Constance Adams and Kriss Kennedy for the JSC TransHab Team

Design Reference Mission

Autonomous Clinical Care



Crew Health Care Facility

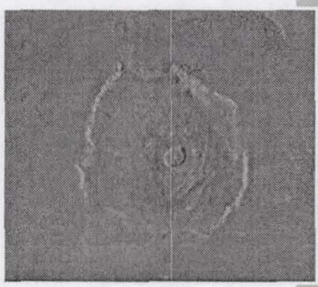
- non-invasive diagnostic capabilities for medical/surgical care
  - "smart" systems
  - non-invasive imaging systems
- definitive surgical therapy including robotic surgical assist devices and surgical simulators
- blood replacement therapy
- laboratory support

Telemedicine

- preventive health care
- diagnostic/therapeutic capabilities from ground-based consultants

Design Reference Mission

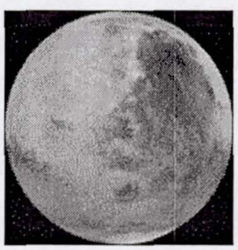
Assumptions



- **Mars Design Reference Mission** requires utilizing novel technologies that allow human adaptation to:
  - interplanetary space travel
  - planetary habitation
- The medical and physiological challenges associated with interplanetary space travel will depend upon
  - mission duration
  - type of propulsion system
- The integration of human and robotic activities will be a critical determinant of the success of planetary exploration

Design Reference Mission

Conclusions



- The human element is the most complex element of the mission design
- Mars missions will pose significant physiological and psychological challenges to crew members
- Human engineering, human robotic/machine interface, and life support issues are critical
- The Critical Roadmap Research Path is required for issues that <u>may</u> be show-stoppers (bone, radiation)
- The ISS platform must be used to address exploration issues before any "Go/No Go" decision
- A significant amount of ground-based and specialized flight research will be required - the Critical Path Roadmap project will direct our research toward exploration objectives