HRET Human Adaptation and Habitability

Countermeasure Research and Medical Care

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MARS Design Reference Mission

Assumptions

- Mars Design Reference Mission Requires Utilization of Novel Technologies for Human Adaptation to Interplanetary Space Travel and Planetary Habitation
- The Medical/Physiological Challenges Associated with Interplanetary Space Travel will Depend upon Mission Duration or Type of Propulsion System
- Integration of Human and Robotic Activities Will Be A Critical Determinant of the Success of Planetary Exploration

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 EVA, 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

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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 EVA
- dust, suit design, serviceability

Radiation Effects
- carcinogenesis, damage to CNS, fertility, sterility, heredity

Human Performance
- psychosocial, workload, sleep

Medical Care

Environment & Technology

Human Behavior & Performance

Human

Health &

Performance

Risk Elements & Categories (continued)

Bone Loss
- fractures, renal stones, osteoporosis, drug reactions

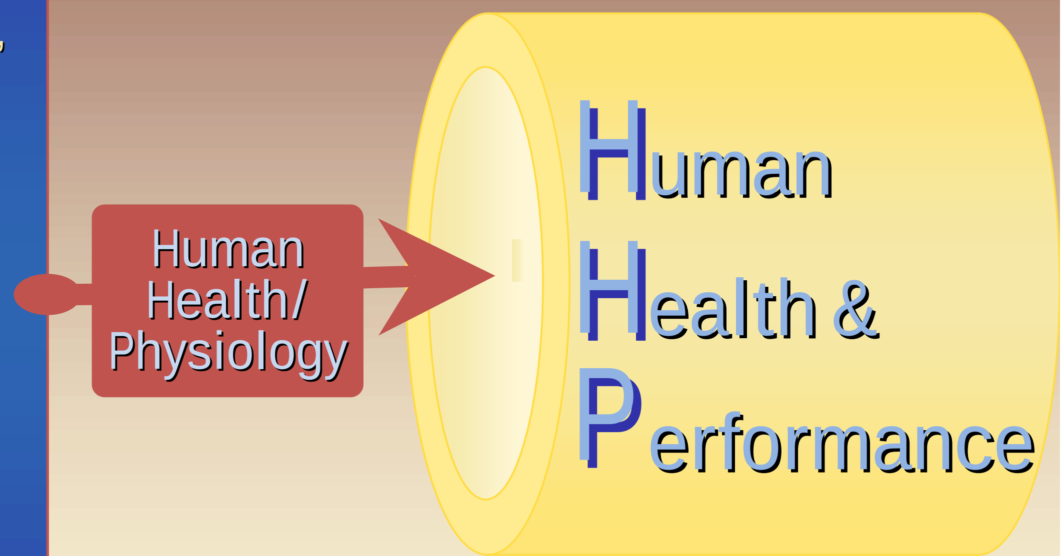
Cardiovascular Alterations
- dysrhythmias, orthostatic intolerance, exercise capacity

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



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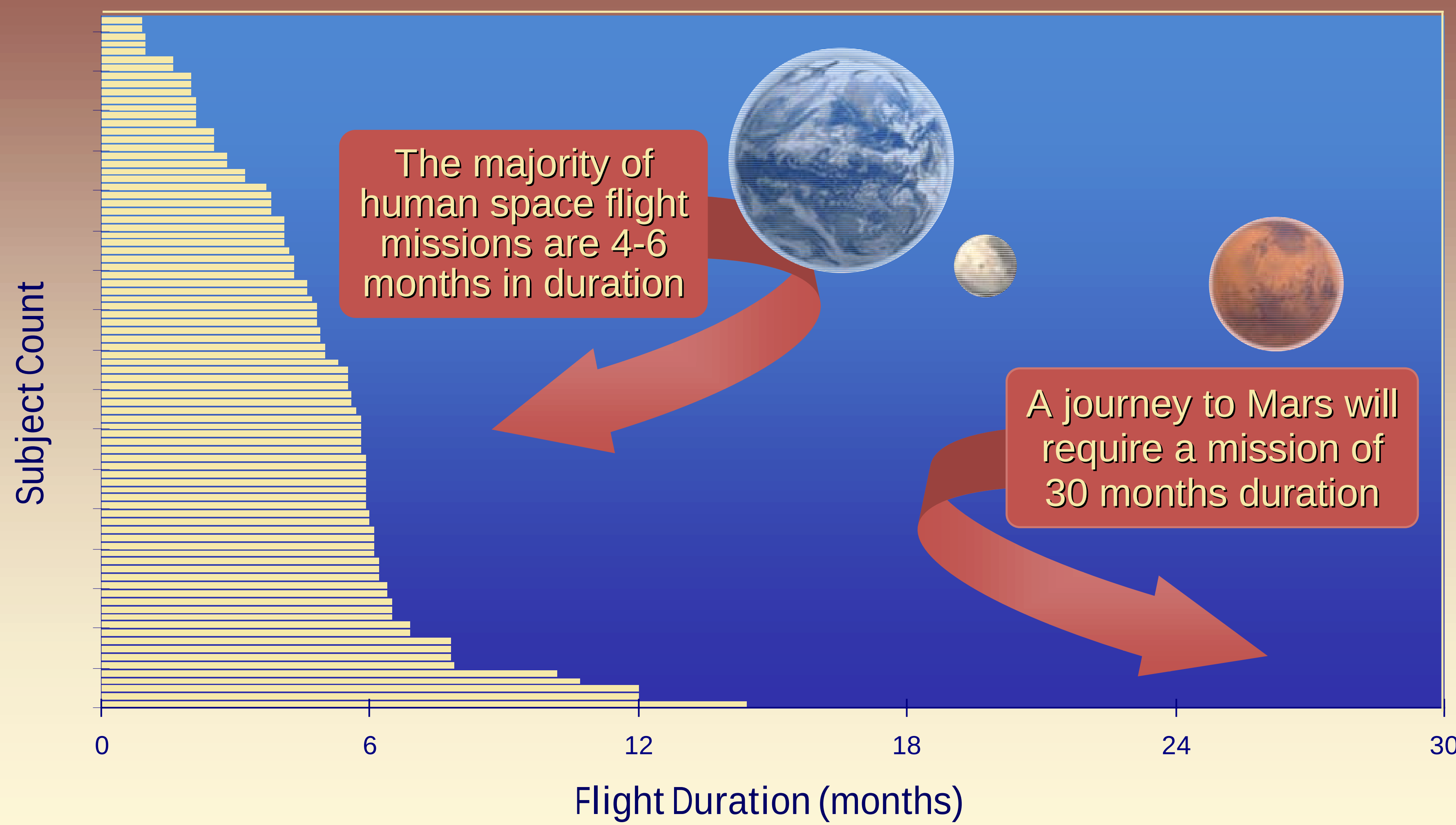
Critical Mission Elements for Medical Care

Novel Evolutionary Mechanism - Survival of the Technologically Adapted

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	2: 1g → 0g; 0g → 1g	4: 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

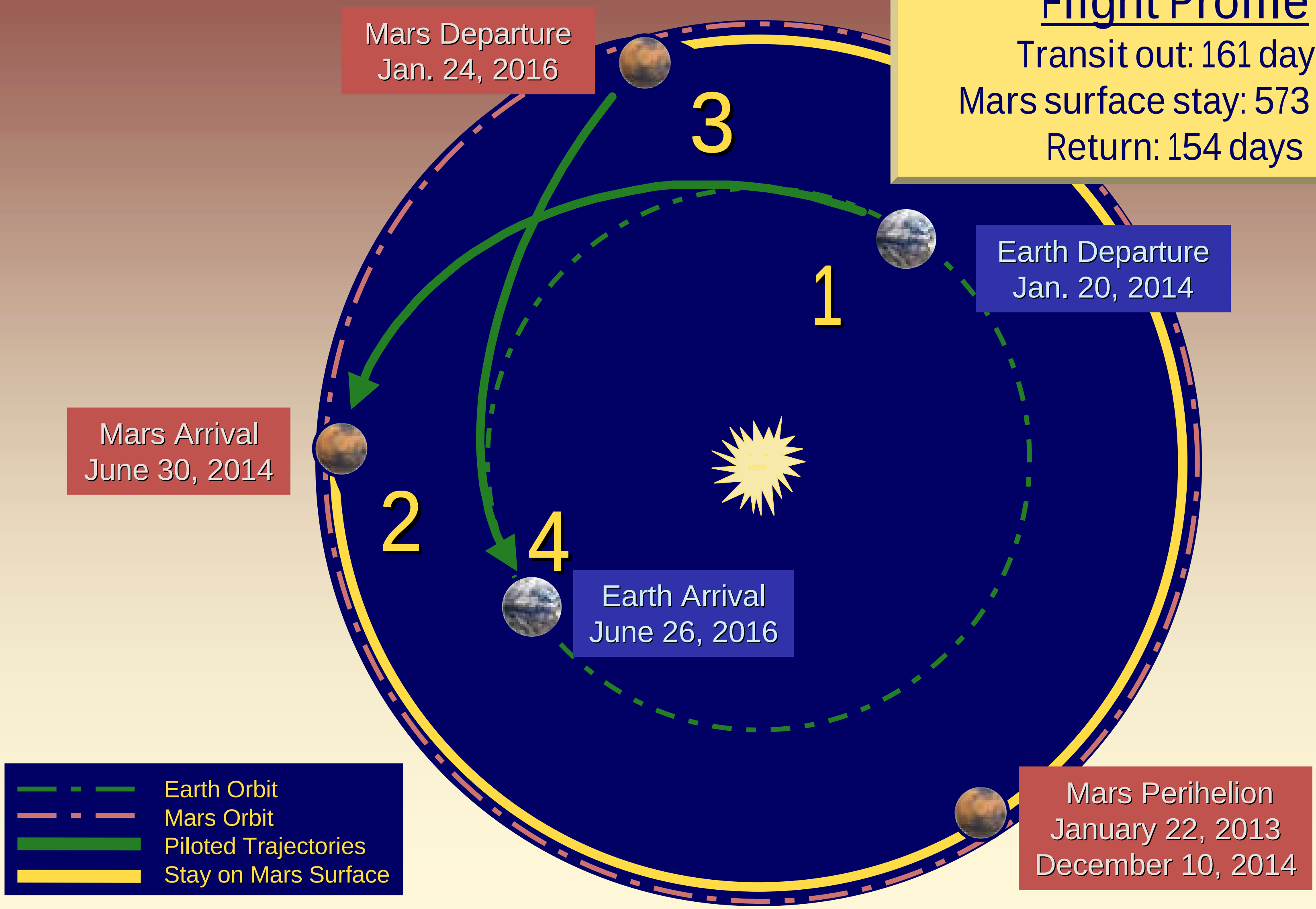
Human Space Flight Experience

(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



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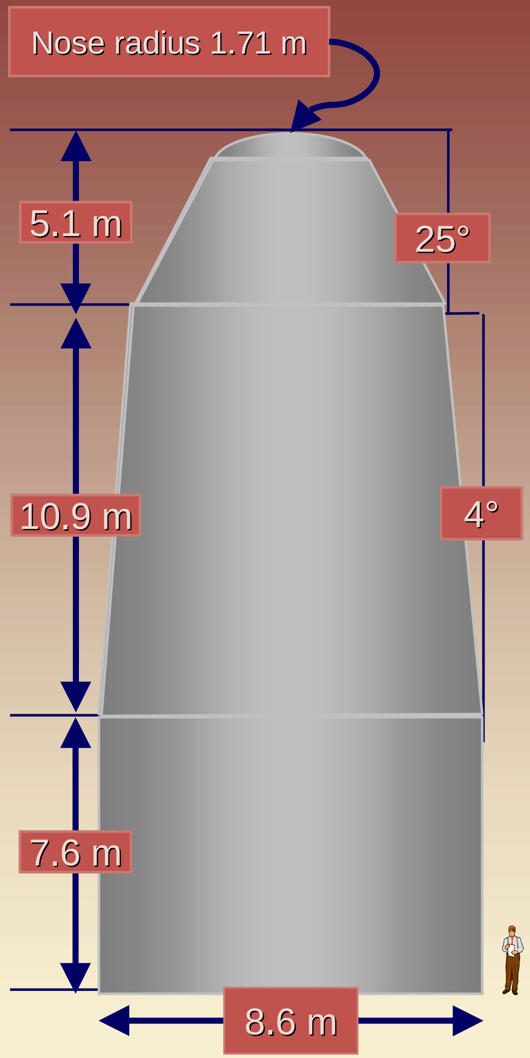
Vehicle Concepts

based on the Triconic Aeroshell

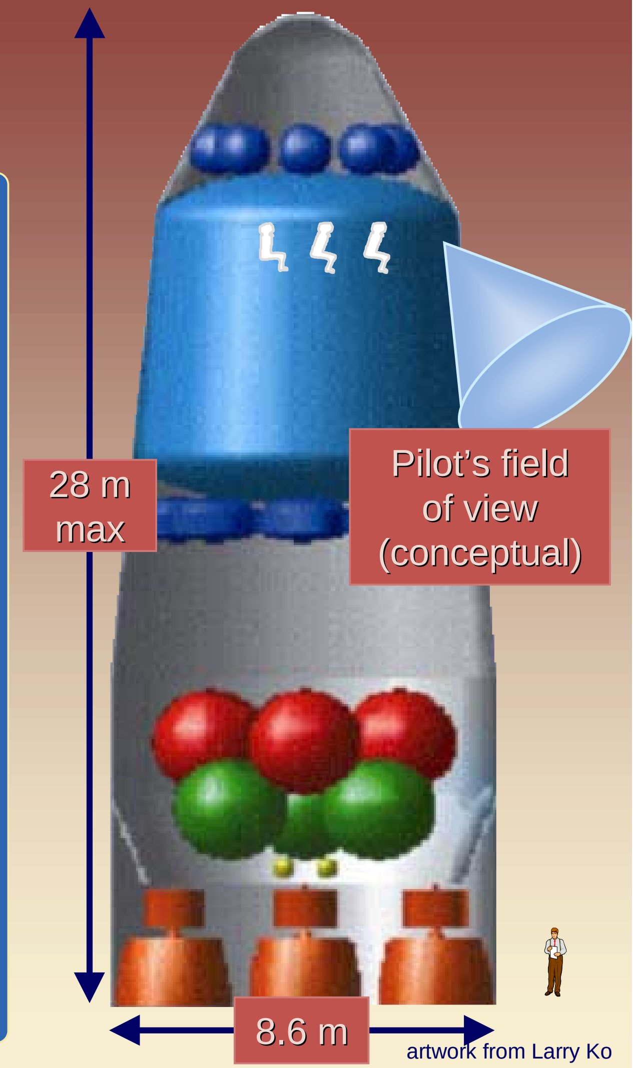


Vehicle Components & Functions:

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



artwork from Larry Kos and Paul Wercinski

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

Physiological Adaptation to Physical Challenges

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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

Cardiovascular alterations

- pharmacological treatments for autonomic insufficiency

Muscle atrophy

- resistive exercise under evaluation

Neurovestibular adaptations

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

Artificial Gravity (AG)

What is required to certify AG as a valid countermeasure to extended weightlessness?

(per Artificial Gravity Working Group, January 1999)

- **Comprehensive ground research program**
- **Flight research program**
  - ISS
  - STS

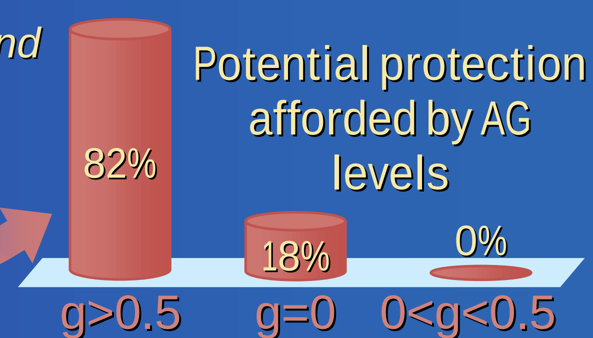
- **Focus on the following research priorities**
  - What are the optimal prescriptions for intermittent AG
  - Identify G threshold values needed to maintain HHP (including 1/3 G exposure for 18 months)
  - Determine optimal AG characteristics (e.g., radius and angular velocity)

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 3/8 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 3/8 g
  - continue studies on optimal angular rate:



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

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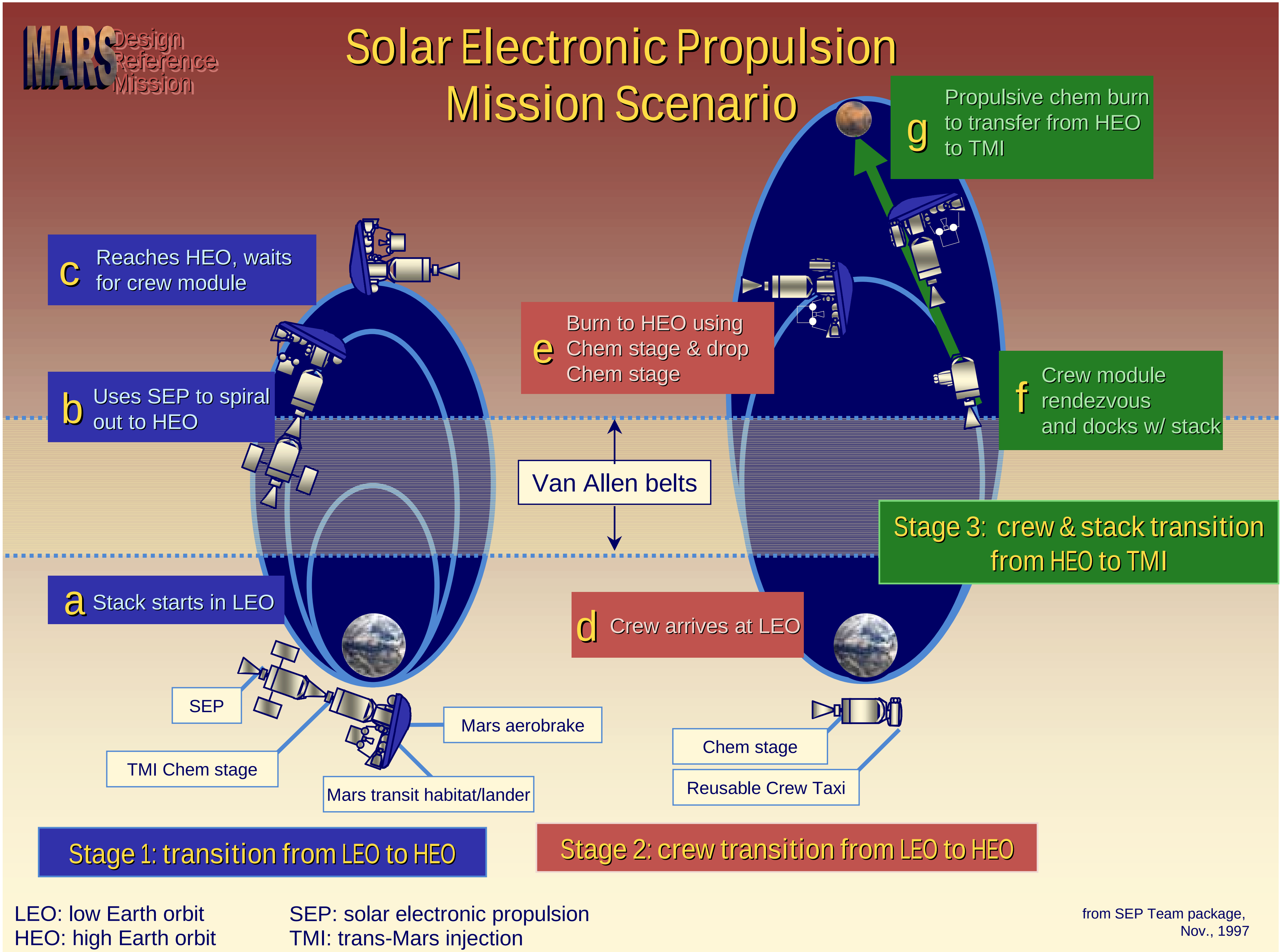
Physical Challenges

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: solars electric propulsion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Solar Electronic Propulsion Mission Scenario
c Reaches HEO, waits for crew module
b Uses SEP to spiral out to HEO
a Stack starts in LEO
e Burn to HEO using Chem stage & drop Chem stage
Van Allen belts
d Crew arrives at LEO
g Propulsive chem burn to transfer from HEO to TMI
f Crew module rendezvous and docks w/ stack
Stage 3: crew & stack transition from HEO to TMI
SEP
TMI Chem stage
Mars aerobrake
Mars transit habitat/lander
Chem stage
Reusable Crew Taxi
Stage 1: transition from LEO to HEO
Stage 2: crew transition from LEO to HEO
LEO: low Earth orbit
HEO: high Earth orbit
SEP: solar electronic propulsion
TMI: trans-Mars injection
from SEP Team package, Nov., 1997

Mars Transit Requirements

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

Health care facilities

- Nutrition
- Exercise
- Psychological support
  - planned activities
    - entry/landing simulations
    - housekeeping
    - refresher training
    - cruise science (microgravity, astronomy, biomedical, etc.)
  - communications
    - reliable contact with mission control, family, & friends
- Health Care
  - autonomous care
  - telemedicine

Habitat facilities & functions

Exercise & conditioning for Mars surface activities

Recreation & privacy

Maintenance & housekeeping (including workshop)

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

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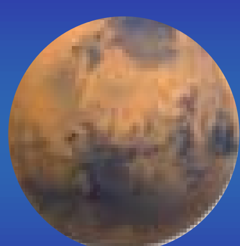
Abort Scenarios for Design Reference Mission

"Abort to Earth" options are very limited

- Trans-Mars Injection (Earth-departure maneuver)
  - Option 1: nuclear thermal propulsion (or other impulsive maneuver) makes "abort-to-Earth" progressively more difficult after first hours-days post-TMI
  - Option 2: solar electronic propulsion (or other low-thrust, long-duration maneuver) uses limited spacecraft maneuvering fuel and requires long time period
- Missed Mars orbit insertion or direct entry
  - Mars flyby <u>may</u> result in 2-year return to Earth that is not very different from completed 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)

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Peak Physical Challenges

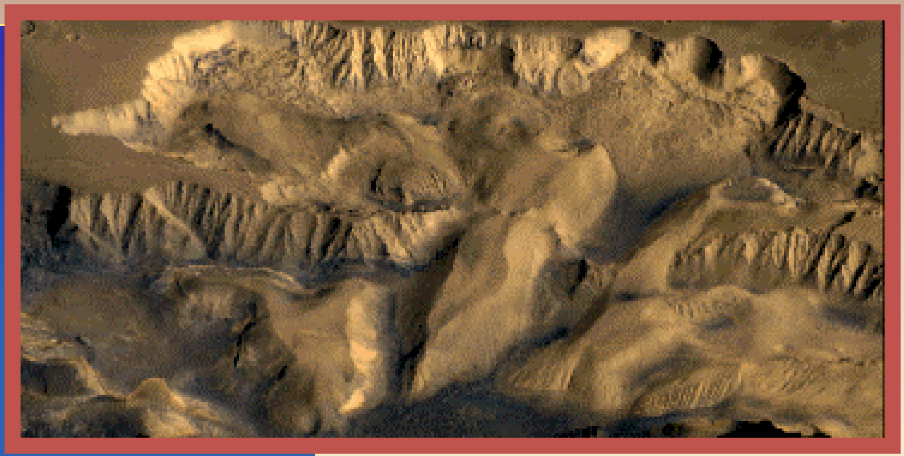
Mars Surface Phase
(post-landing through pre-launch)

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: extravehicular mobility unit
MCC: Mission Control Center

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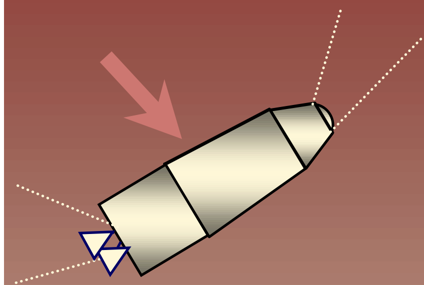
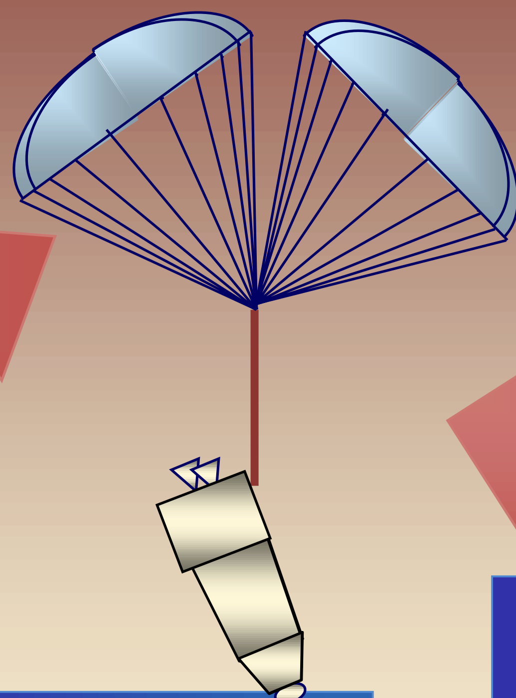
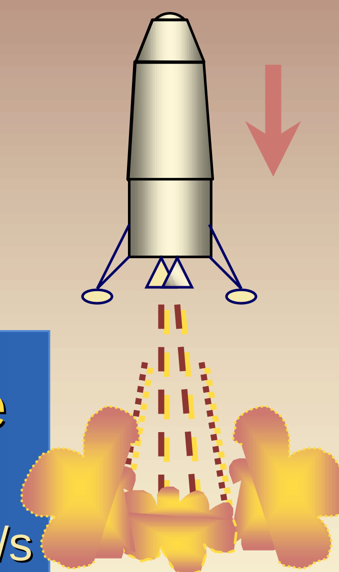
Possible
Mars Landing Sequence







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

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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

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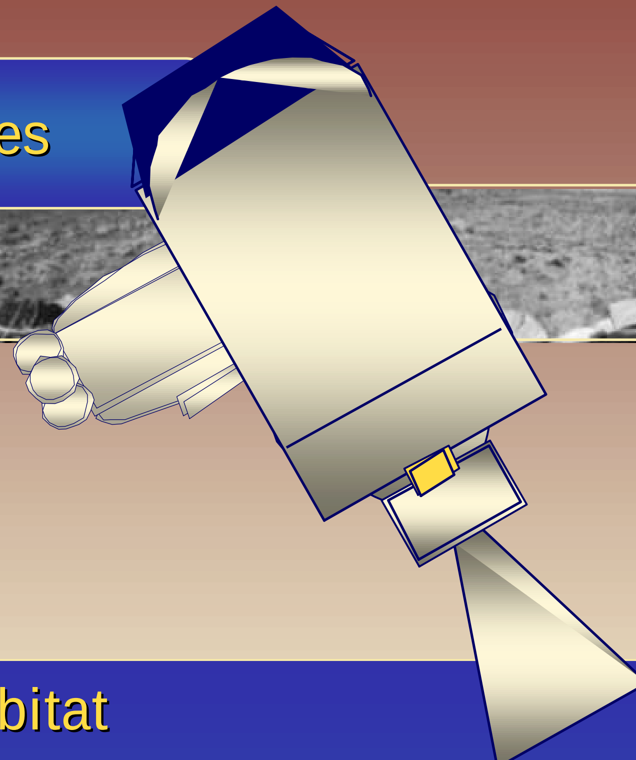
Mars Surface Stay Requirements

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, TEI, contingencies
    - progressive debriefs, sample processing, etc.
    - housekeeping
  - communications capability

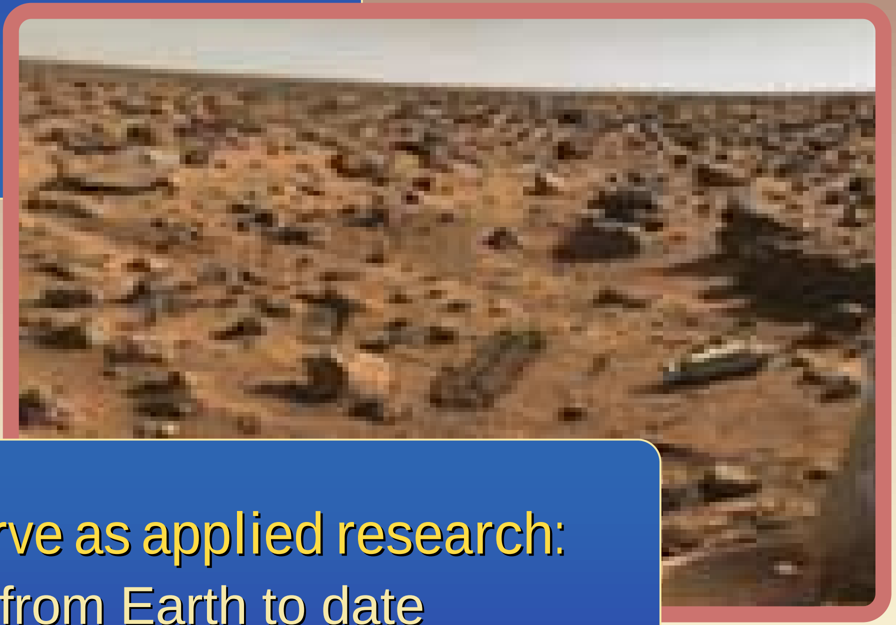
Habitat

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

Life Sciences on the Martian Surface

Periodic 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

Autonomous Clinical Care

Crew Health Care Facility:

- non-invasive diagnostic capabilities for medical/surgical illnesses, SMART systems
- non-invasive imaging capabilities
- definitive surgical therapy - robotic surgical assist devices, surgical simulators
- blood replacement therapy
- laboratory support

Telemedicine:

- preventive health care
- consultative diagnostic/therapeutic capabilities

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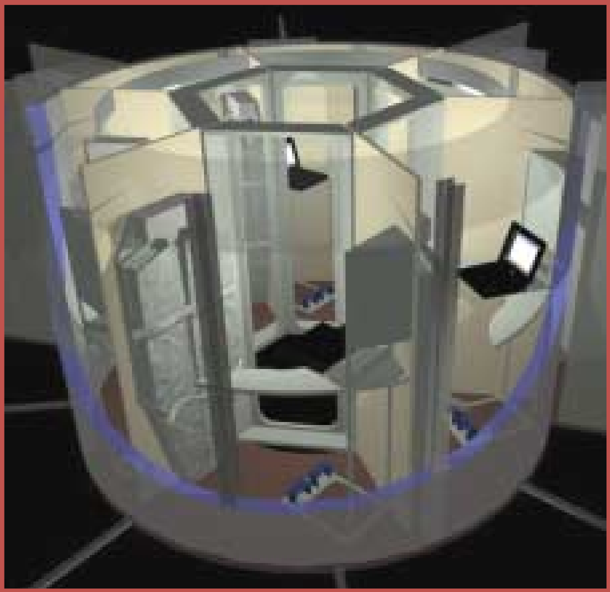
Earth Return Transit Requirements



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

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Space Medicine Issues

Projected rates of illness or injury

Past Experience

0.06 person/year

Mars DRM

0.90 person/mission

Based on U.S. and Russian space flight data, U.S. astronaut longitudinal data, & 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

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.

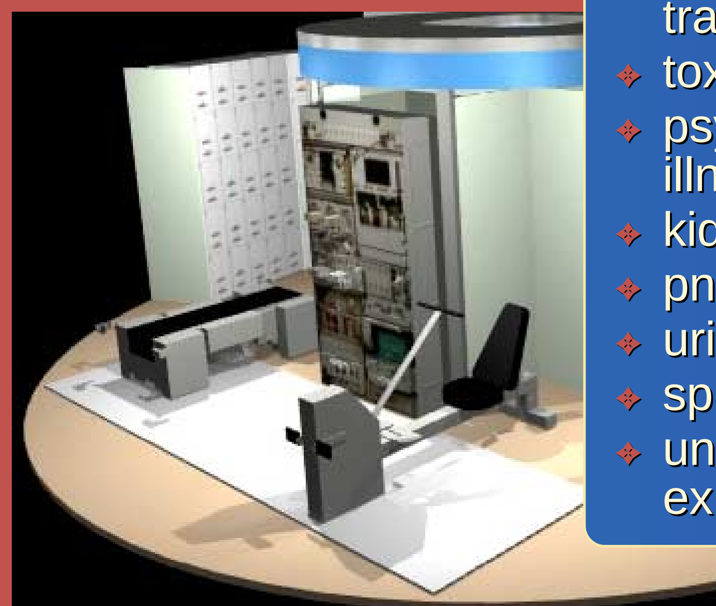
Data from R. Billica, January 1998, and D. Hamilton, June 1998

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 Kris Kennedy for the JSC TransHab Team

Human Factors and Habitability

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

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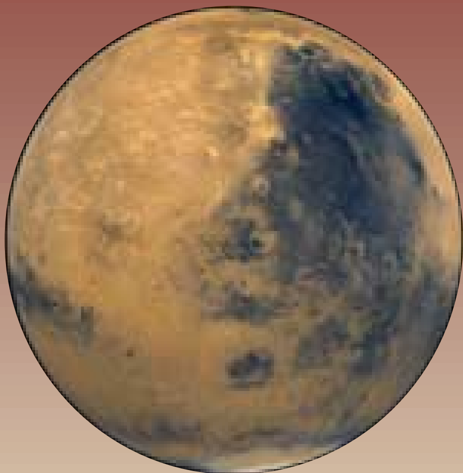
Conclusions



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 critical

Critical Roadmap Research Path required for issues that may be show-stoppers (bone, radiation)

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