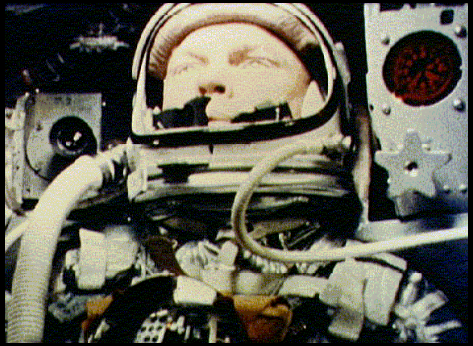
Life in Space…

Leslie Wickman, Ph.D.

First Men and Women in Space

- 1961: First manned spacecraft, *Vostok 1*, takes Yuri Gagarin into orbit.
- 1961: First American in space, Alan Shepard, flies aboard *Freedom 7* in a 15+ minute suborbital flight.
- 1962: John Glenn orbits the earth aboard *Friendship 7.*
- 1963: USSR's Valentina Tereshkova becomes first woman in space with 48 orbits around the earth in *Vostok 6*.



The First Space "Walks"

- 1965: Alexei Leonov performs first space walk.
- 1965: Ed White performs first EVA by an American during *Gemini 4* flight.

On to the Moon: the Apollo Program

- 1968: *Apollo 8* US astronauts orbit the Moon.
- 1969: US astronauts Armstrong and Aldrin become first humans to walk on the Moon during *Apollo 11* mission.
- 1972: *Apollo 17* is the sixth and last US manned lunar mission.

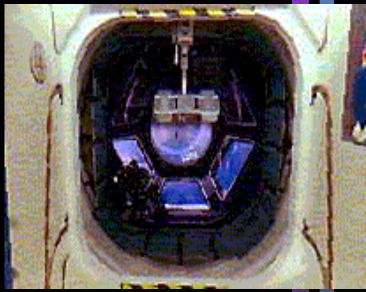
Early Space Stations

- 1971: First orbiting station, USSR's *Salyut 1,* is launched.
- 1973: *Skylab,* first US station, is launched.

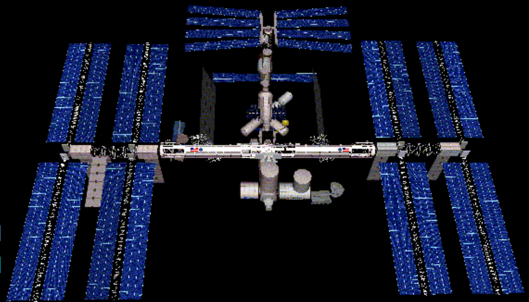
Shuttle Flights

- 1981: Launch of US space shuttle *Columbia,* first reusable spacecraft.
- 1984: Manned Maneuvering Unit used by US astronaut Bruce McCandless to fly independently from parent craft.
- 1986: US shuttle *Challenger* explosion kills crew of 7, halts program for almost 3 years.
- 1988: Launch of shuttle *Columbia* resumes US space shuttle program.
- 2003: Space Shuttle Columbia and crew of 7 lost on re-entry.
- 2011: Space Shuttle is retired.

International Space Station



- 1998: First two elements of ISS are launched (Zarya Control Module in November, and Unity Node in December).
- An international crew of up to seven live and work on the Space Station for typically about three to six months. Crew return vehicles (such as the Russian Soyuz) will always be attached to the Space Station to ensure the safe return of all crew members in the event of an emergency.



Life Science Issues

Special conditions of spaceflight:

- **microgravity**
- **radiation**
- **vacuum**
- **temperature variations**
- **isolation**
- **confinement**

Produce various physiological and psychological effects:

- space adaptation syndrome (SAS)
- reduced stimulation of taste and olfactory receptors
- body mass loss
- body fluid upward shift and loss
- cardiovascular deconditioning
- muscular atrophy
- bone demineralization
- electrolyte imbalance
- nasal congestion
- cellular damage
- psychosocial manifestations

Space Flight Physiological Issues

- Phases of Flight (launch, transit, return)
- Environmental Considerations:
  - Atmospheric Conditions
    - Near Vacuum (no measurable pressure)
    - Extreme temperatures (-100 to +120 degrees C)
  - Radiation

    (LEO shuttle ~250 times average terrestrial exposure!)
    - High velocity charged particles
    - High frequency electromagnetic waves
  - Reduced gravity
    - Micro (on-orbit) or Partial (moon or Mars)

Launch: Acceleration

- **FRONTAL** (G_x - eyeballs in): up to 40 g's survivable for ~10 seconds
- **LATERAL** (G_y - eyeballs left/right): unknown/ untested
- **VERTICAL** (G_z - eyeballs down): 2 g's intolerable after ~12 minutes

Launch: Vibration

- If in-phase with natural frequencies of various body components --> large amplitude resonance
  - Imperceptible to voluntary tolerance limits
  - Biomechanical damage

Launch: Noise

- 85 dB ~ threshold of exposure without damage
- 120 dB ~ threshold of discomfort
  - Space Shuttle flight deck ~120 dB
  - Payload Bay ~ 160 dB

On-Orbit: Immediate

- Effects occurring within *minutes to hours*… (also quickly reversible)
  - Height increase ~ 1-2 inches due to spinal response
  - Abdominal girth decrease
  - Internal organ shift
  - Posture altered (underwater, neutral, fetal position)
  - Fluid Shift – due to loss of hydrostatic pressure caused by gravity
    - facial puffiness, stuffy head, suppressed smell

On-Orbit: Intermediate

- Effects occurring within ***hours to days***… (with correspondingly longer recovery times)
- **Fluid loss** – due to fluid shift
  - extracellular fluid decreased ~15% by day 2
  - ~3% total body water loss by day 4 or 5
- **Leg volume decrease** – due to fluid shift and later muscle atrophy
- **Vestibular system effects**

  without gravity, motion is perceived differently
  - Perception of motion, spatial orientation, visual and auditory localization
  - SMS/SAS – signal conflict vs. distortion
- **Neuromuscular inhibition**
  - Tactile/cutaneous receptors - skin pressure
  - Proprioceptors – spatial relationship of body parts

On-Orbit: Intermediate, continued

- Effects occurring within ***days to weeks***… (with correspondingly longer recovery times)
- **Blood plasma loss** – due to fluid loss
  - RBC may be reduced disproportionately due to combination of lost RBCs and lower rate of production
  - Mild anemic symptoms
  - Possible post-flight issues
- **Muscular atrophy**, especially of lower limb and postural anti-gravity muscles
  - Slow-twitch anti-gravity muscles convert to fast-twitch fibers
- **Cardiovascular deconditioning** (reduced volume and size)
  - Altered Cardiac SV (increased) and HR (decreased)
  - Result of decreased peripheral resistance

On-Orbit: Longer Term

- Effects occurring within ***weeks to months*** … (with correspondingly longer recovery times)
- **Bone atrophy**
  - microgravity impairs normal bone structure and bone cell function
    - bone formation and resorption
  - back pain
  - fatigue
  - fractures
  - kidney stones

- **Enlargement of some organs**, such as liver and kidney
  - GFR appeared to increase in Skylab and Mir crewmembers

On-Orbit: Longer Term, cont.

- Effects occurring within ***weeks to months*** … (with correspondingly longer recovery times)

- **Immuno-suppression**
  - Red blood cell reduction
  - psycho/social stress adaptation
  - Higher radiation exposure

- **Possible radiation exposure effects**
  (via ionization of biological molecules)
  - Cell death or modification
  - Hair loss
  - Vomiting
  - Infertility/sterility
  - Genetic mutations/birth defects
  - Central nervous system changes
  - Cataract formation
  - Chromosome alterations
  - Tumor induction
  - Death

Re-entry & Post-landing

- **Fluid shift from upper body to leg tissue**
  - orthostatic intolerance
  - leads to anemic-like condition following plasma replacement (RBC dilution)
- **Loss of coordination**
  - Adaptation of neurovestibular & proprioceptive feedback
- **Muscle and bone atrophy**
  - Adaptation to mechanical stress of environment
- **Cardiovascular deconditioning**
  - Adaptation to fluid volume and gravity level

Three big problems…

- Body mass loss
- Bone demineralization
- Psycho-social issues

Body Mass Loss

- Many of the physiological effects previously mentioned contribute to mass loss:
  - **Space Adaptation Syndrome (SAS)**
  - **Body Fluid Shift and Resultant Loss**
  - **Bone Loss**
  - **Muscular Deconditioning**
  - **Reduced Sensitivity of Taste, Olfactory Senses**

Mechanics & Components of Body Mass Loss

- Loss of both fat and lean mass; more than half the loss comes from fat-free mass such as muscle, organs, blood, and bone.
- Protein and bone catabolism increases; protein and bone mineral synthesis decreases.
- Headward fluid shift triggers baroreceptors to initiate diuresis; fluid intake decreases; thirst mechanism altered.
- In-flight energy expenditure is similar; food consumption decreases.

Mass Loss Countermeasures

Focus on restoring function to body's regulatory systems; treat the cause, not just the symptoms.

- Stimulate hunger and thirst.
- Emphasize adequate hydration and electrolyte balance.
- Vigorous exercise program.
- Mechanical body-loading devices.
- Adequate nutrients, especially protein, iron, calcium, calcitonin, potassium, antioxidants, folic acid, copper, zinc, and whole foods.

Space Food...

- lightweight
- small storage space
- safe and nutritious
- convenient to prepare
  - microwave (STS), oven (ISS)
- natural forms
  - crackers, cookies, candy
- thermostabilized
  - tuna, canned fruit
- irradiated
  - meat, bread
- dehydrated
  - drinks, fruits, cereals, eggs, pasta
- refrigerated/frozen (ISS)

Bone Demineralization

PROBLEM:

- Human exposure to weightlessness causes progressive loss of bone mass similar to that observed in disuse osteoporosis, particularly in the bones of the lower limbs.

IMPORTANCE:

For long-duration space travelers (and osteoporosis patients), bone losses may reach detrimental levels, possibly resulting in irreversible damage and/or future recurrences of osteoporosis.

Theoretical Background

- Elimination of muscle forces and weight from bone has long been known to cause loss of bone mineral.
- Changes in mechanical loading stimulate functional adaptation and tissue reorganization - German scientist W. Roux, 1881.
- Bone architecture optimized w.r.t. local stresses so that:

  Stress/Ultimate Strength = Constant throughout Bone

Empirical Findings

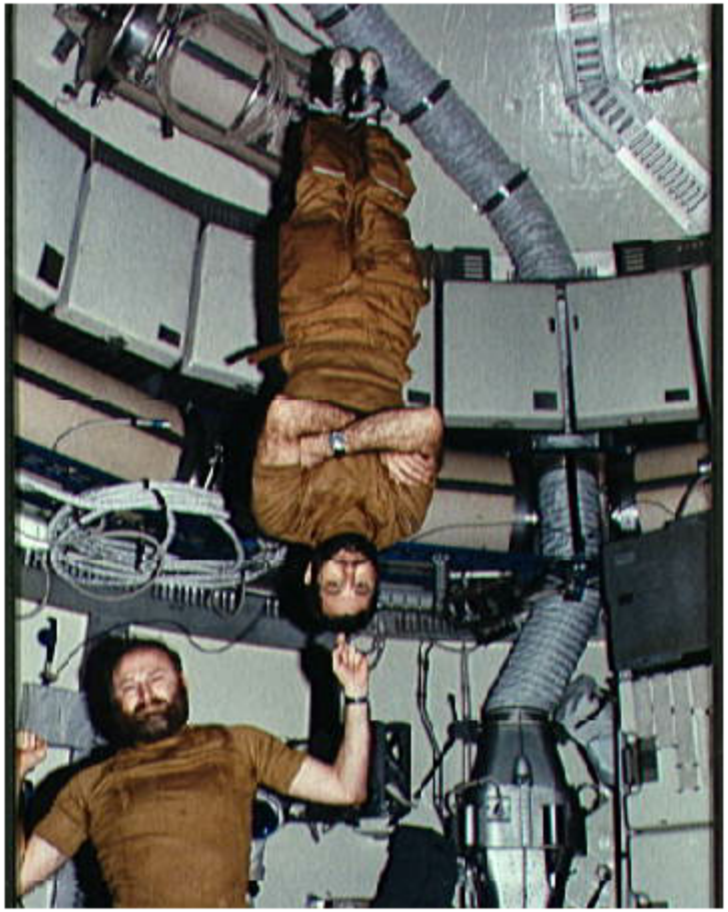
- Measurements taken on various bones of returned Gemini, Apollo, and Salyut crews show bone losses even during short spaceflights.
- Skylab measurements indicate mineral losses increase in approximate proportion to mission duration, primarily in weight-bearing bones.
- Russian and American investigations show fecal and urinary calcium losses in spaceflight to be more severe than in bed-rest.
- Autopsies of cosmonauts who died after a 21-day flight showed wide osteocytic lacunae.
- Both Russian and American studies indicate that individuals with high bone densities and low basal metabolic rates lose bone more slowly than others.
- Current research suggests that stress magnitude has a much greater influence on bone density than does the number of daily loading cycles: $T = t * (w / W)^4$

Countermeasures

Numerous countermeasures have been tried, with varying degrees of success.

- Exercise
- Body-loading devices
- Hormonal and pharmaceutical agents
- Artificial gravity

Some exercises are more effective than others...



Spaceflight Environmental Factors Affecting Psychological Health

Withdrawal from the macrosociety of earth; immersion in the microsociety of the spacecraft.

- Isolation
- Confinement
- Habitation volume
- Quality of habitation environment
- Crew composition
- Absence of fresh air
- Reduced sensory stimulation
- Boredom
- Work/rest schedules
- Strangeness of environment
- Awareness of risk

Psychosocial Problems

"There are many advantages to having two men in a space vehicle, except when one of them is psychotic."

- Hartman and Flinn, 1964.

- Relative to concern for the astronaut's physical safety, little consideration has been given to the psychological impacts and adjustments associated with spaceflight.
- As we prepare for longer, more complex, and more distant space travel, the full spectrum of human psychological and social requirements must be seriously addressed.

Psychosocial Adaptation Phases

- Long duration polar, subsea, and space studies show:
  - “**Acute Phase**” lasts about 2 months
    - Adjustment to new, busy environment
  - “**Intermediate Phase**” after 2 months until about midpoint
    - Increasing fatigue, decreasing motivation
    - Loss of vitality, decline in mental functions
    - Emotional hypersensitivity, irritability, anger
    - Psychosomatic and psychological problems
  - “**Long-Duration Phase**” from midpoint through third quarter
    - Asthenia worsens
    - Interpersonal tension, conflicts
    - Disinterest, apathy, withdrawal
    - Perceptual hypersensitivity
    - Instances of depression, declining productivity

Prevention, Treatment & Management

In a pressurized can deep in space where a psychological crisis could mean certain disaster, an ounce of prevention is worth much more than a pound of cure.

- Vehicle/habitat design
- Mission/work design
- In-flight ground support
- Crew selection and composition
- Crew training

- Psychotherapy
- Designated on-board counselor
- Awareness training
- Meditation, relaxation, autogenic, and biofeedback techniques
- Exercise
- Drugs
- Crisis Intervention

Habitat Design

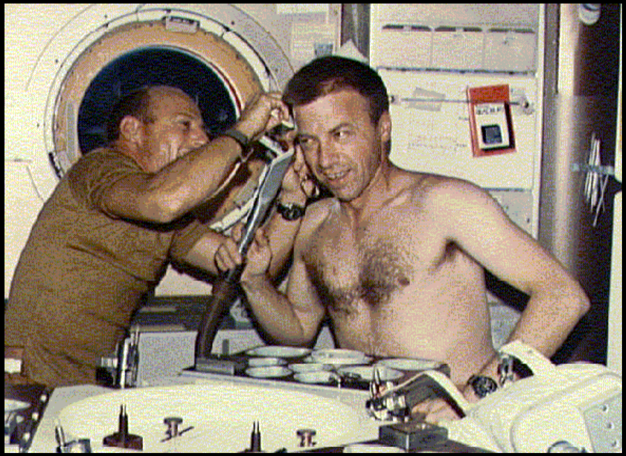
Earthlike
Local vertical
Privacy
Personal touches
Reminders of home

- Sleeping space
  - padded board (72”x30”)
  - ventilated fireproof sleeping bag
  - reading light
  - privacy panels
  - eye shades
  - earmuffs

Sleeping aboard Skylab

A favorite pastime: taking in the view!

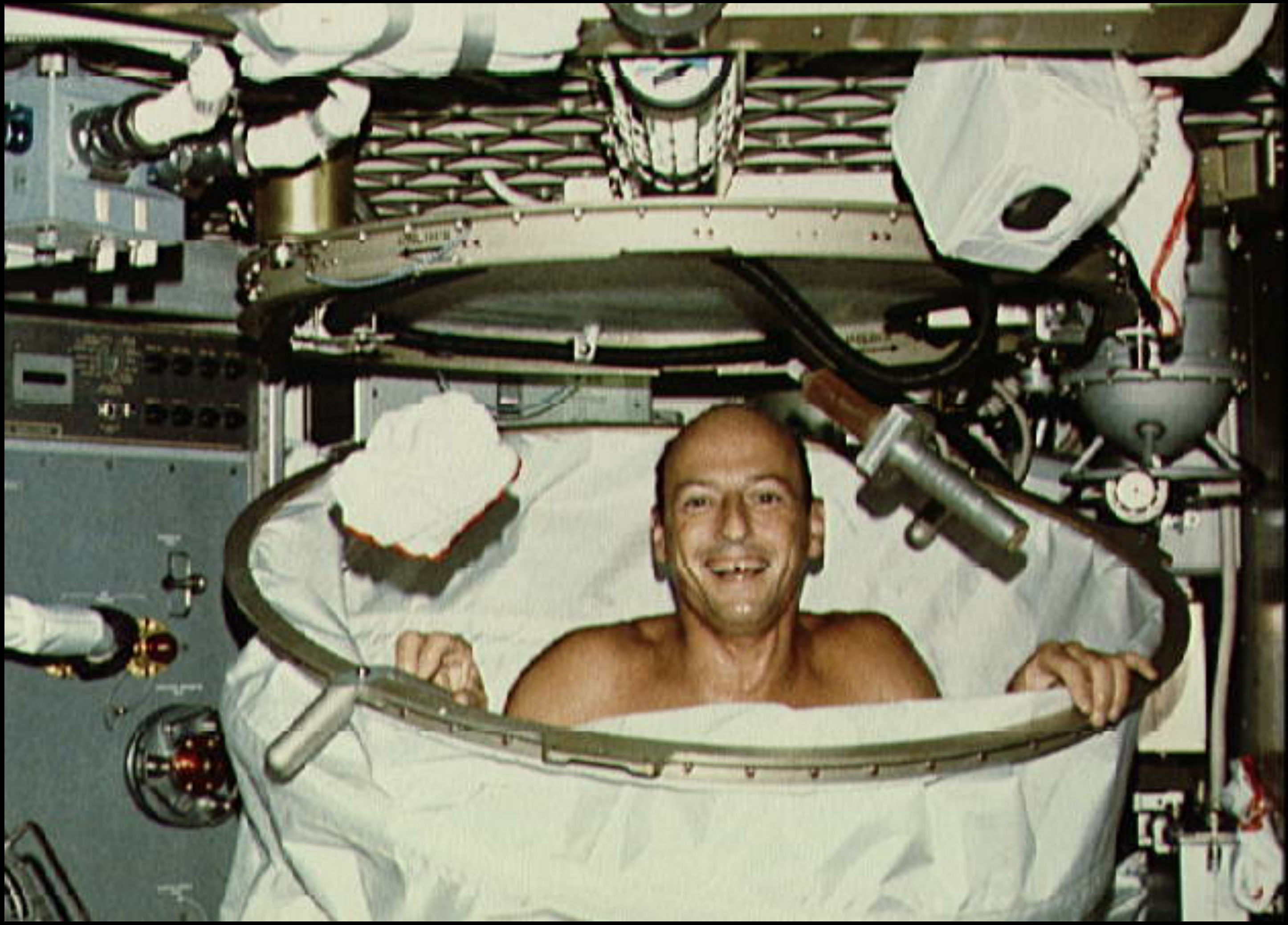
Personal Hygiene and Health



- Full body showers
  - (Skylab, ISS)
- Sponge baths
  - (Shuttle)
- Private lockers for personal items and clothing
- Toiletry/cosmetic care
- Waste management

- Medical Care
  - diagnostics
  - first aid kit
  - respirator
  - defibrillator
- Regular Exercise
  - treadmill, exercycles, resistance training

Cleanliness is next to godliness...



“News” from Home!

Recreation...

Design for Human Interaction

- IVA: Intra-vehicular Activity - working inside the spacecraft in a "shirtsleeve," or pressurized environment
- EVA: Extra-vehicular Activity - any in-situ activity performed by humans outside a pressurized parent spacecraft, including earth-orbital, lunar surface, or planetary activities. Excludes robotics, teleoperations, etc.)
- Performing EVAs or "space walks" is still one of the most exciting yet utilitarian aspects of spaceflight. Gemini missions proved the feasibility of EVA; many subsequent missions have proved its indispensable practicality.

Working in Space

- Weightlessness, or "microgravity"
  - centrifugal effect offsets gravity

Without gravity:

everything floats!

- altered body posture - "neutral body position"

- no friction with ground or floor to react applied forces

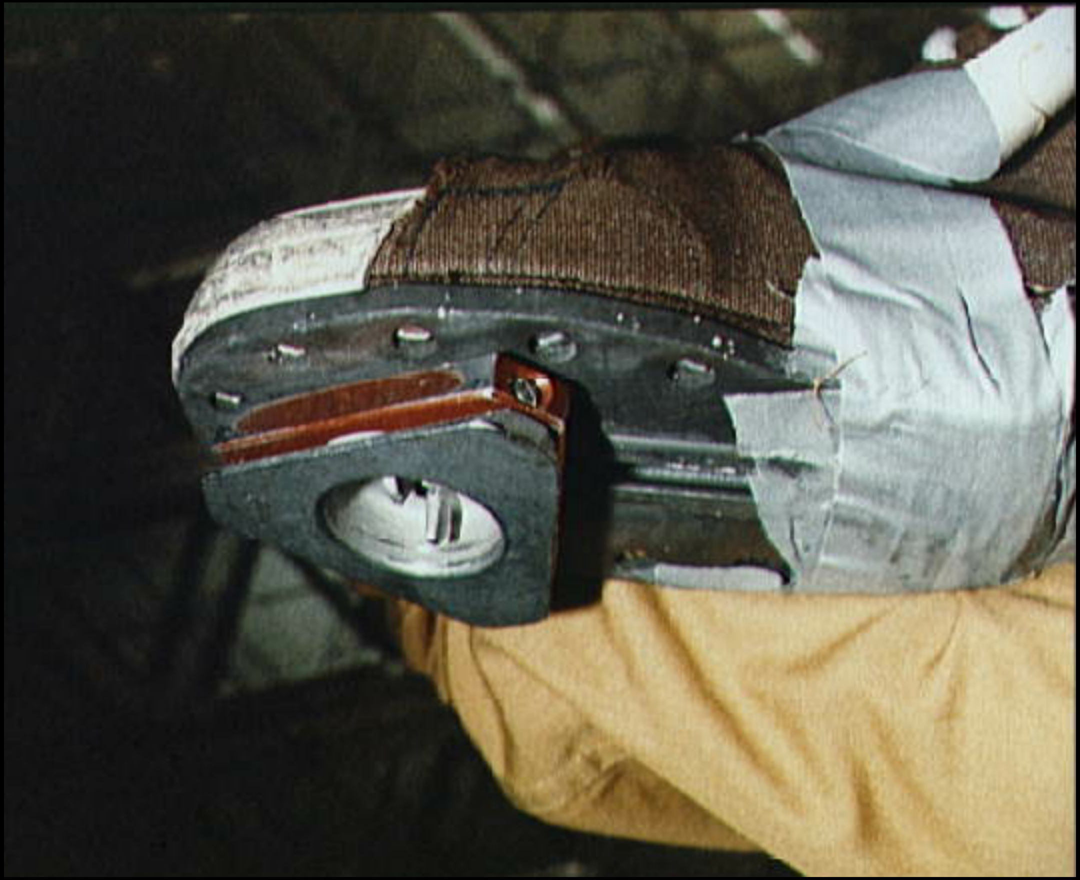
- must devise other means of reacting forces, restraining tools, equipment, and people!

Things (and people) float!

Clothing…

- safe
- comfortable
- functional
- aesthetically pleasing
- fire-proof
- storage pockets/velcro
- layered for thermal comfort
- standard size ranges

Designer footwear with a function...



EVA Design Considerations

- Crew & equipment safety
- Accessibility to worksite and interfaces; physically, visually, and with tools
- “EVA-friendly” design
- Zero-g neutral body position
- Anthropometric ranges
- Suit mobility ranges
- Optimum work volume
- Reach envelopes
- Crew force application
- Timelines
- Potential hazards
- Structural crew aids
- Stability/mobility aids
- Support equipment and tool requirements and logistics
- Alignment/capture aids
- Standard, captive fasteners
- Wing-tabbed connectors
- Lighting requirements
- Labels, color-coding
- EVA work constraints
- Backup plans/procedures!

Summary and Conclusions

- Covered **Space Biomedical Issues** of Body Mass Loss, Zero-Gravity Induced Osteoporosis, and Psychosocial Problems.

- Addressed **nutrition and physical exercise** as primary countermeasures for mass loss and osteoporosis; a variety of prevention, treatment and management options for psychoses, including **selection, training, environmental design, mind-body techniques and therapies**.

Summary and Conclusions, continued

- Covered **design of space hardware for crew interaction**.
- Designers must consider pressure-suited **capabilities and limitations**, and **simplify tasks** from the astronaut's perspective relative to how the job will be accomplished. Make space hardware "**EVA-friendly**".
- Provide **adequate accessibility** to the worksite and to the specific interfaces (connectors, fasteners, panels, etc.).
- **Minimize support equipment** needed, and provide it efficiently.
- **Crew safety must be top priority.**

SOURCES:

Dr. David Klaus, University of Colorado
Dr. David Robertson, Vanderbilt University
Dr. Oleg Atkov, Russian Institute for Space Biology
Dr. C. R. Canizares, Space Studies Board, NRC
NASA-Johnson Space Center
NASA-Ames Research Center
National Space Biomedical Research Institute