Man in Space

08.09.16

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Overview

- History of aerospace medicine
- Human physiology at high altitude and in space
  - Pressure changes, acceleration, radiation, noise, vibration, temperature
  - How the body adapt to the space environment/microgravity
- Countermeasures – how to stay healthy in space
- Medical events in space
- The future
  - Space tourism
  - Going to Mars

Four Major Periods

- Pre-Aviation
- Lighter-than-air Aviation
- Heavier-than-air Aviation
  - Non-powered
  - Powered
- Space

Pre-Aviation

Thinkers

- Roger Bacon (1220 - 1292)
  - Suggested that a balloon of thin copper sheet be made and filled with "liquid fire"; he felt that it would float in the air as many light objects do in water
    13th Century
- Leonardo Da Vinci (1452- 1519)
  - Flying machines
    - 150 different sketches
    - Ornithopters & helicopters
  - Parachutes

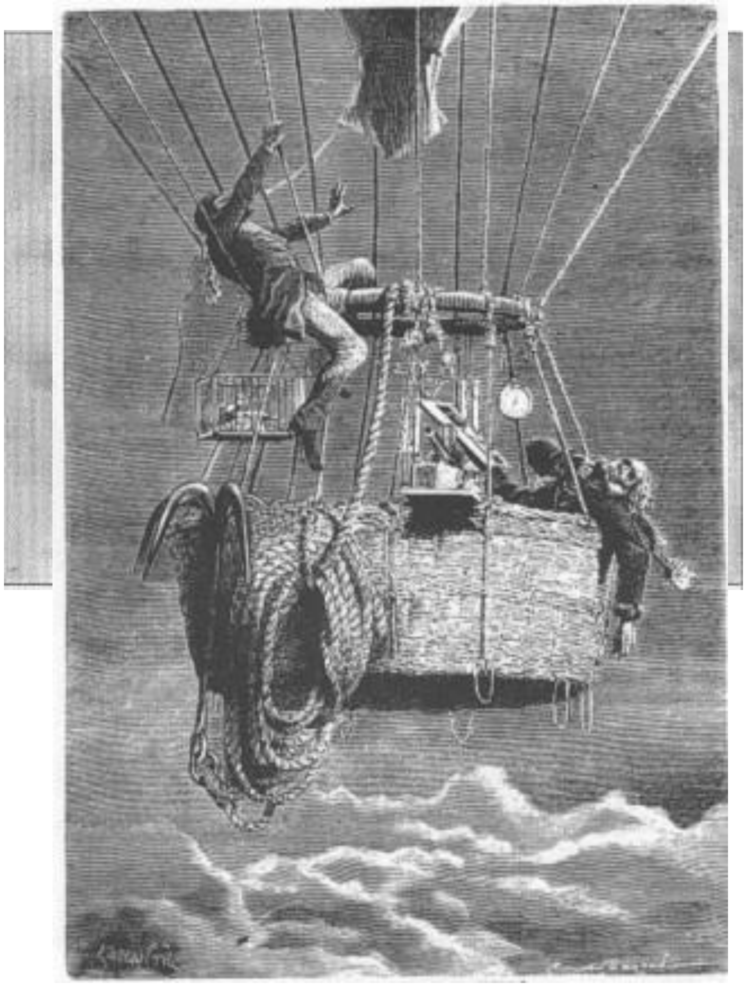
Lighter Than Air

Jean Francois Pilatre de Rozier

First man to ascend in a balloon (1783)

Lighter Than Air

- Going higher and higher
- Glashier and Coxwell
  5 Sep 1862
  - Medical records of how human body reacts to high altitude
    - 19k feet/6000 m
      - High pulse, heavy breathing, blue lips, difficulty of reading instruments
    - 24k ft/7300 m
      - Seasick, unwell
    - 29k ft/8800 m
      - Great muscular weakness
      - Temperature minus 12 degrees

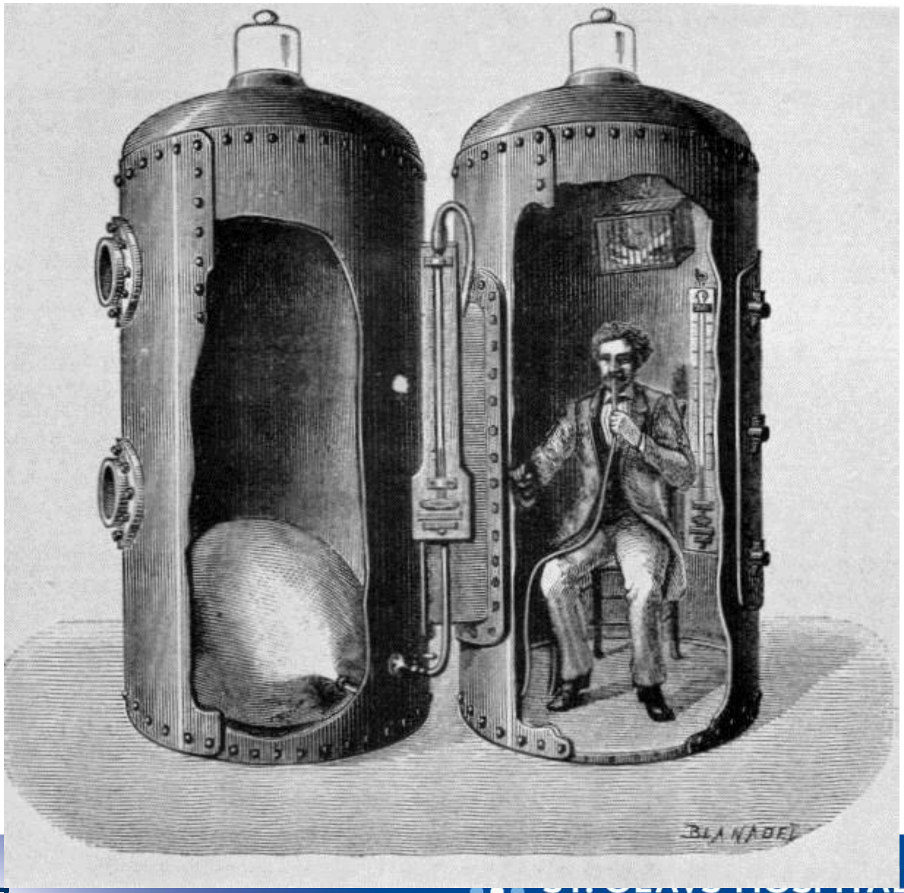


Lighter Than Air

- **Paul Bert - Father of Aviation Medicine**

Degrees in medicine, law, and engineering

Published:
***La Pression barométrique, recherches de physiologie expérimentale;* 1878**



Lighter Than Air

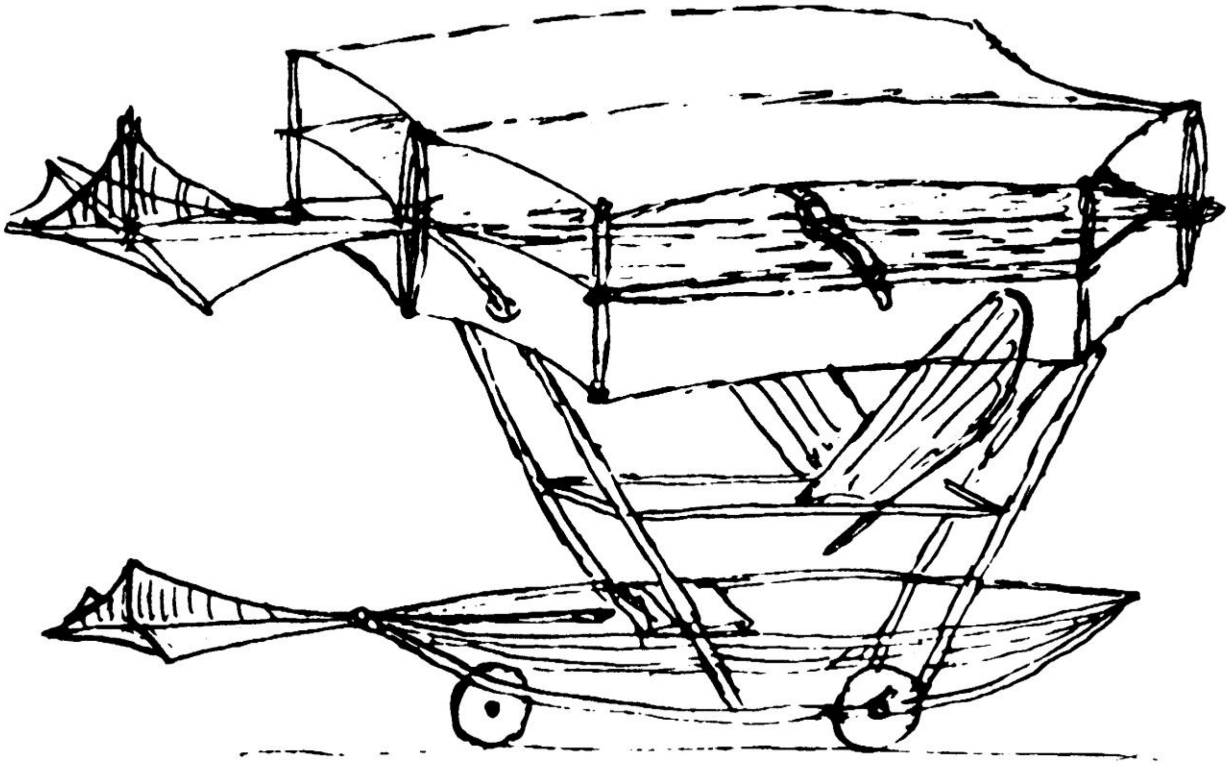
- In the lighter than air period:
  - Balloons capable of ascending to > 30k feet
  - Basic research into human physiology & altitude
  - Basic knowledge of the atmosphere
    - oxygen and temperature decrease with ascent

Heavier Than Air

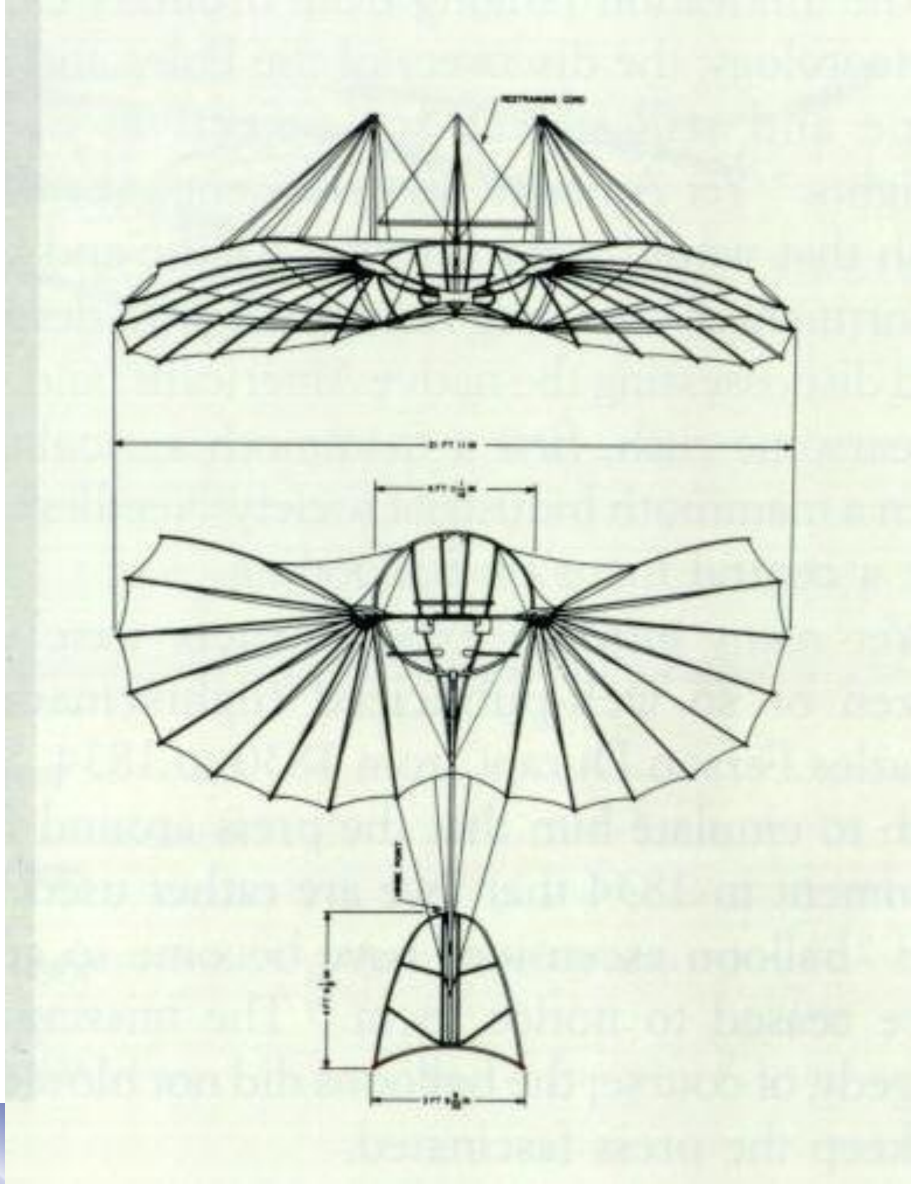
- Two Basic Divisions
  - Unpowered
  - Powered

Heavier Than Air - Unpowered

- Sir George Cayley (1773-1857)
  - First man-carrying glider flown in 1853

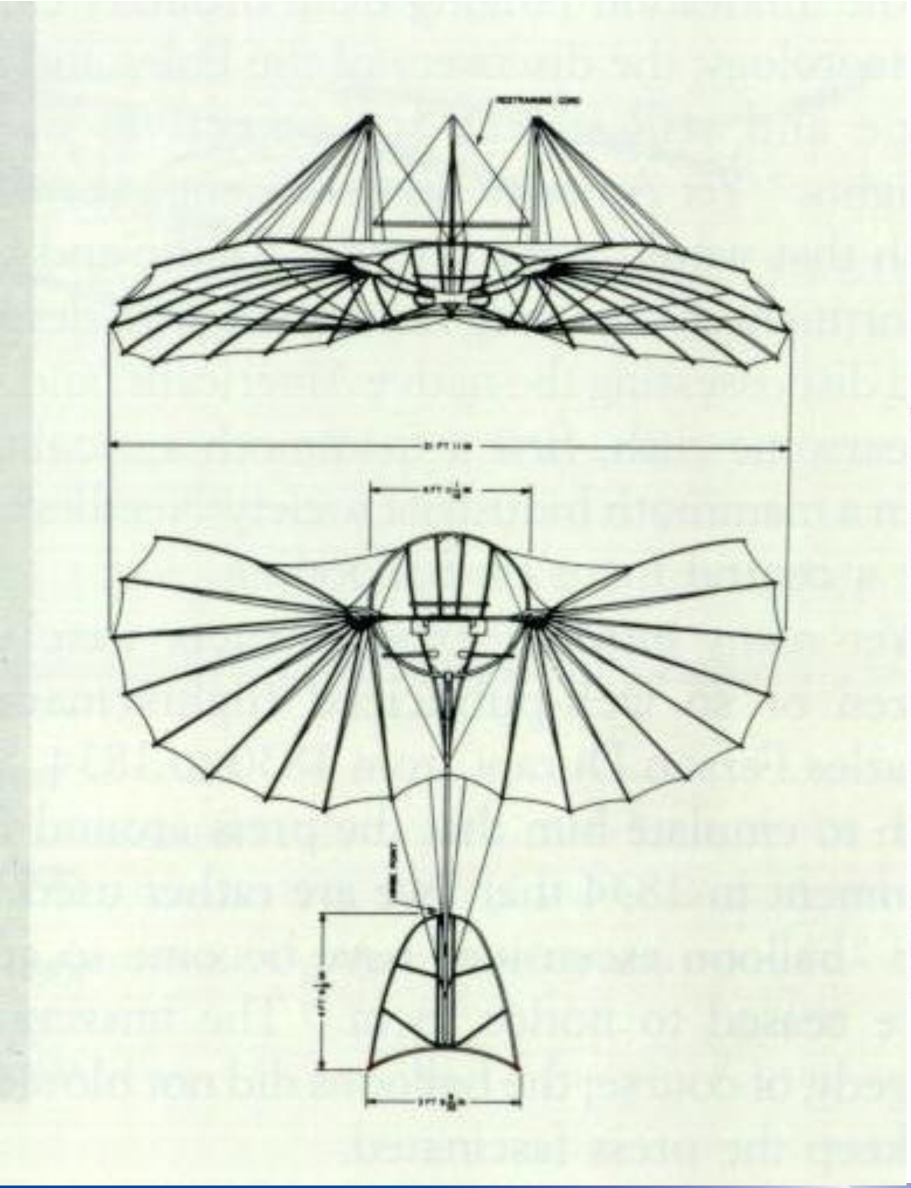


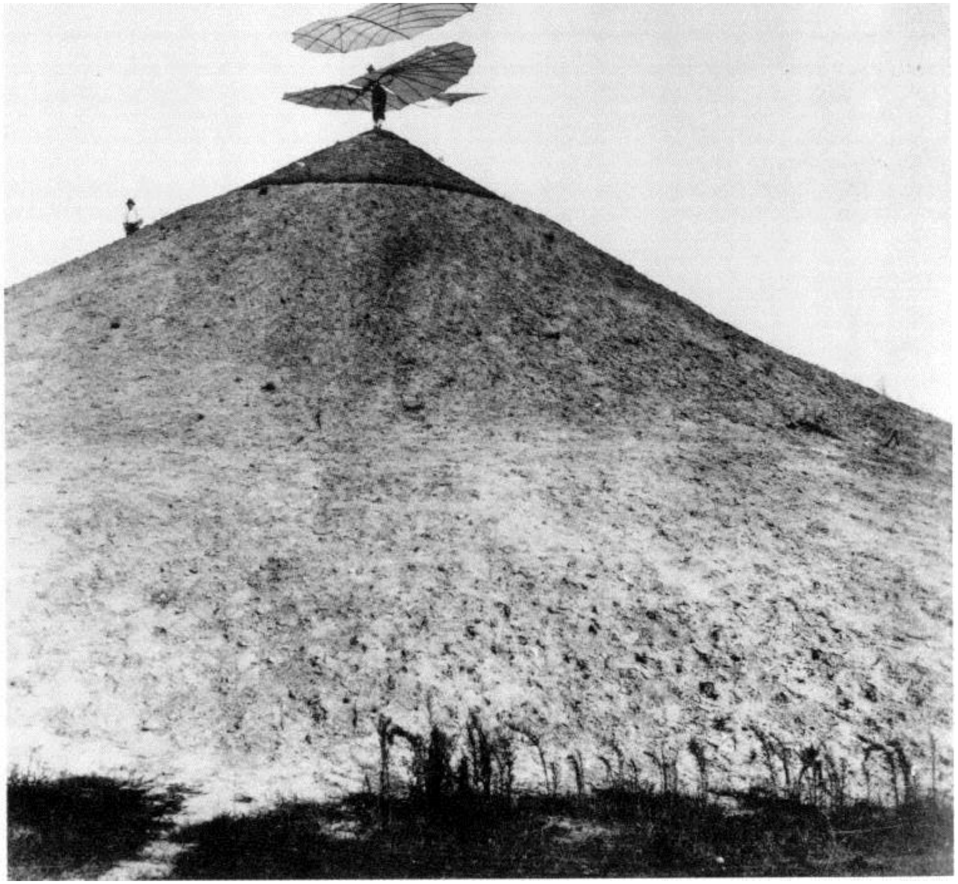
Heavier Than Air - Unpowered



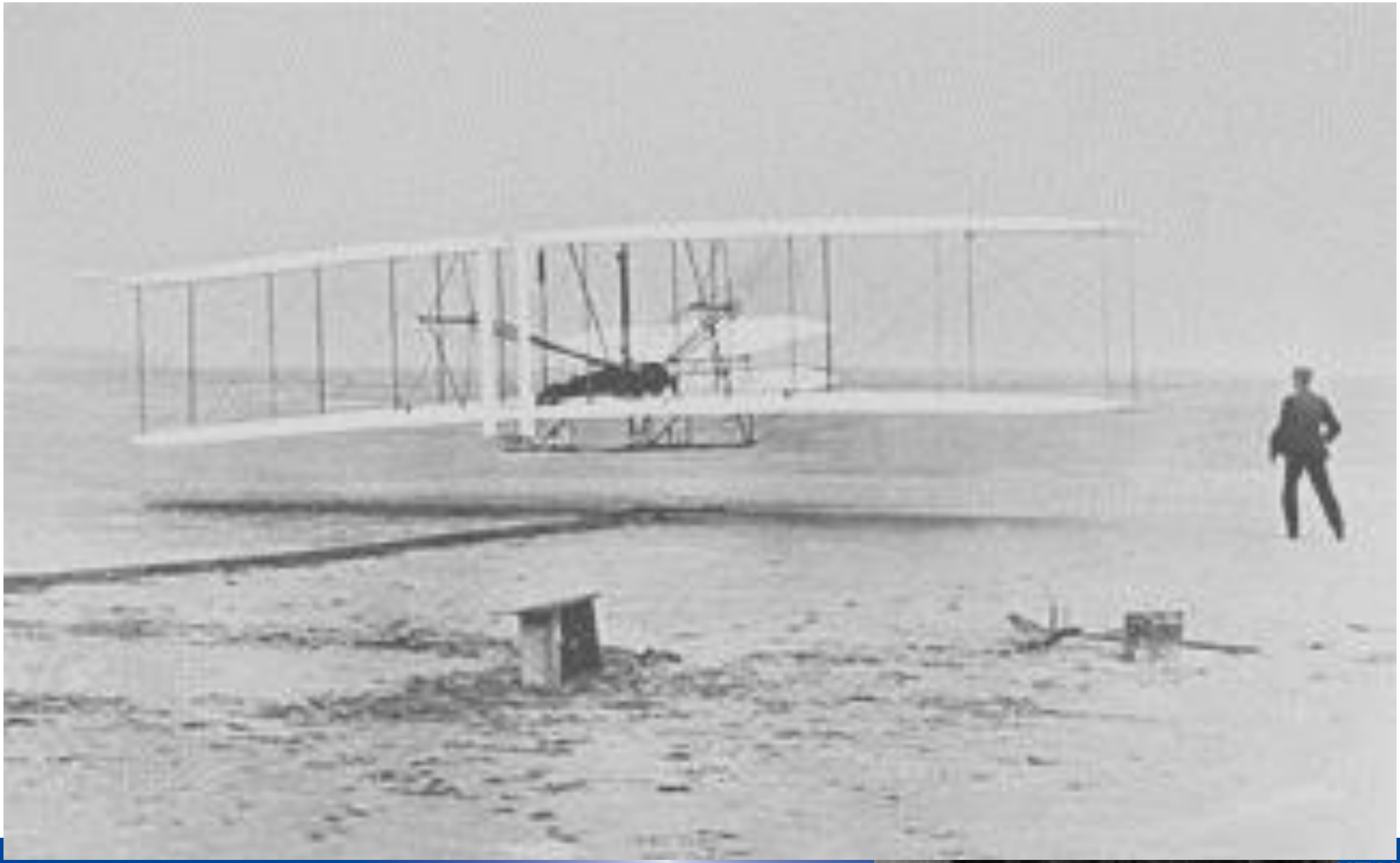
Otto Lilienthal

(1848-1896)



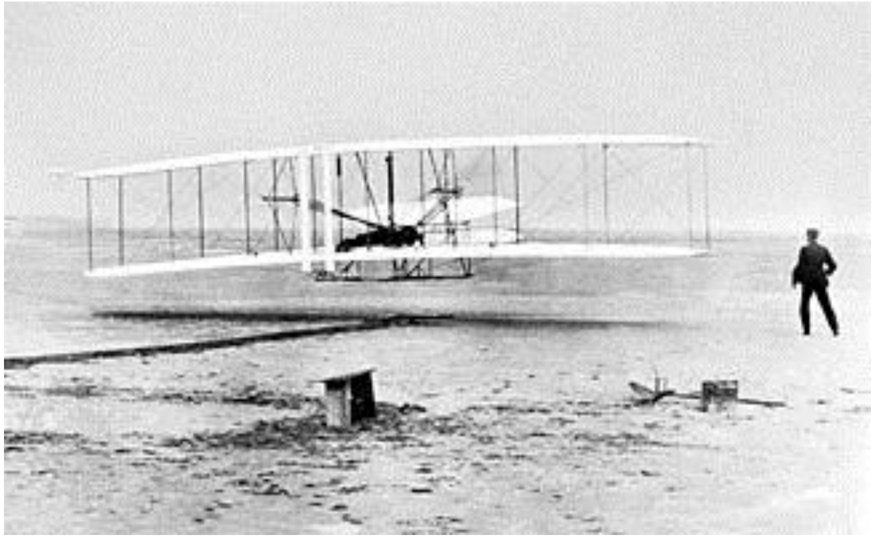


Heavier Than Air - Powered



Powered Flight
The Early Years

- 1903 to 1917
  - Speed increased from 6.8 mph (9.7 km/h) to 126 mph (203 km/h)
  - Altitude increased from a few ft to over 20,000 ft (6009 m)
  - Time aloft increased from seconds to 21 hours
  - Distance increased from feet to 600 miles (966 km)



101. 3RD A.I.C.
E-5780
C-4018

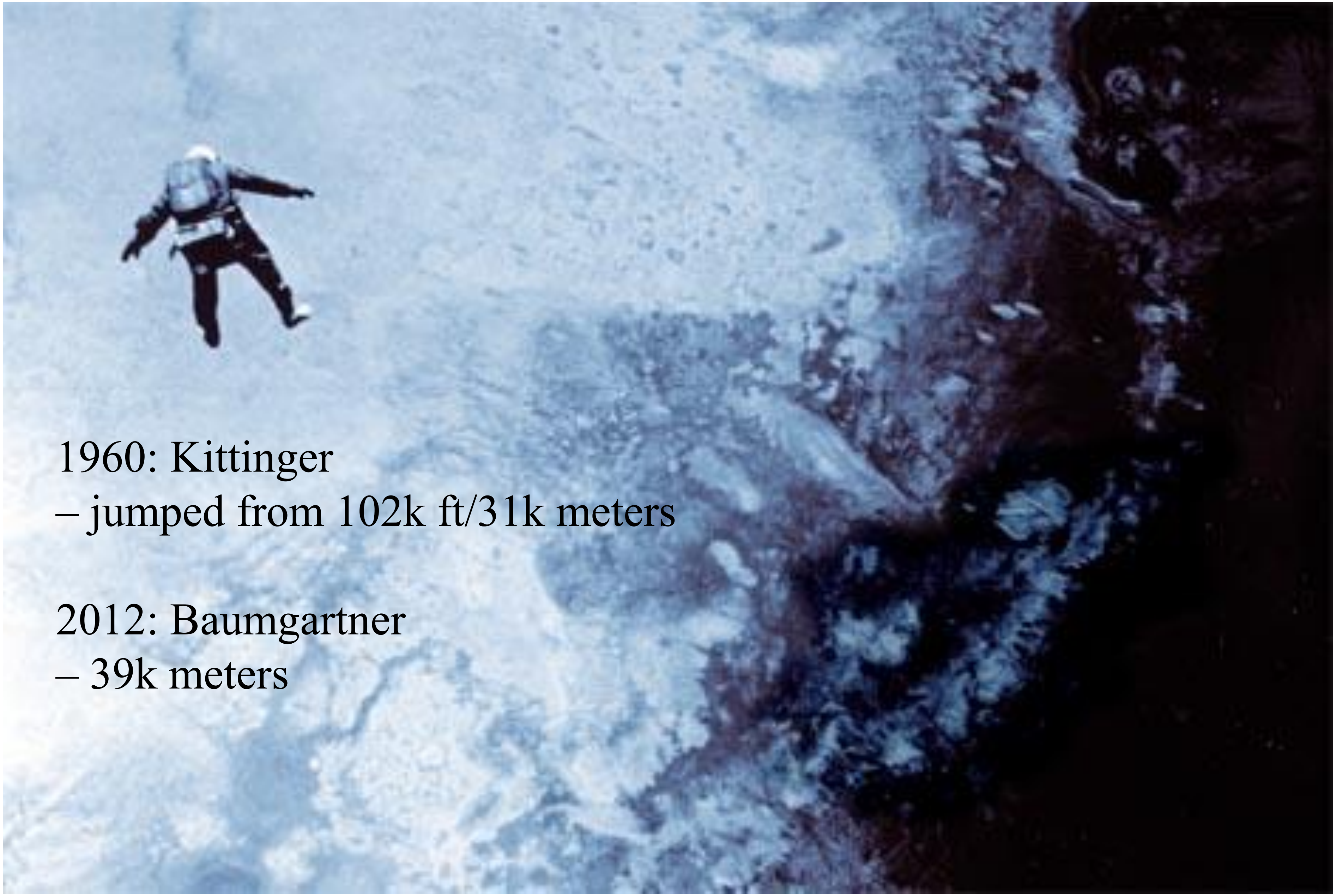
E-5777
C-4015

22. 'The first successful pressure cabin airplane to be flown anywhere in the world.' The U.S. Army Air Corps' pressurized Lockheed XC-35, delivered in 1937. (Air Force Museum)

Official Photograph, U. S. Army Air Corps

EQUIPPED FOR A HIGH-ALTITUDE FLIGHT

The pilot is clad in several suits of woolen underwear, his regulation army uniform, a knitted woolen garment, and a suit of leather heavily padded with down and feathers. Fur-lined gloves, fleece-lined moccasins over the boots, and goggles treated with an antifreeze gelatine complete the costume (see text, pages 760-761).



1960: Kittinger
– jumped from 102k ft/31k meters

2012: Baumgartner
– 39k meters

History – Manned and Unmanned Missions to Space

- October 4, 1957, Sputnik 1 satellite, the first man made object launched into space
- One month later, Sputnik 2, the dog Laika survived 200 days in space
- January 31 1958, launch of the first American satellite, Explorer-1

- Now the “Space Race” started……….

- 1961, April 12, Yuri Gagarin, 1hour and 48 min in space

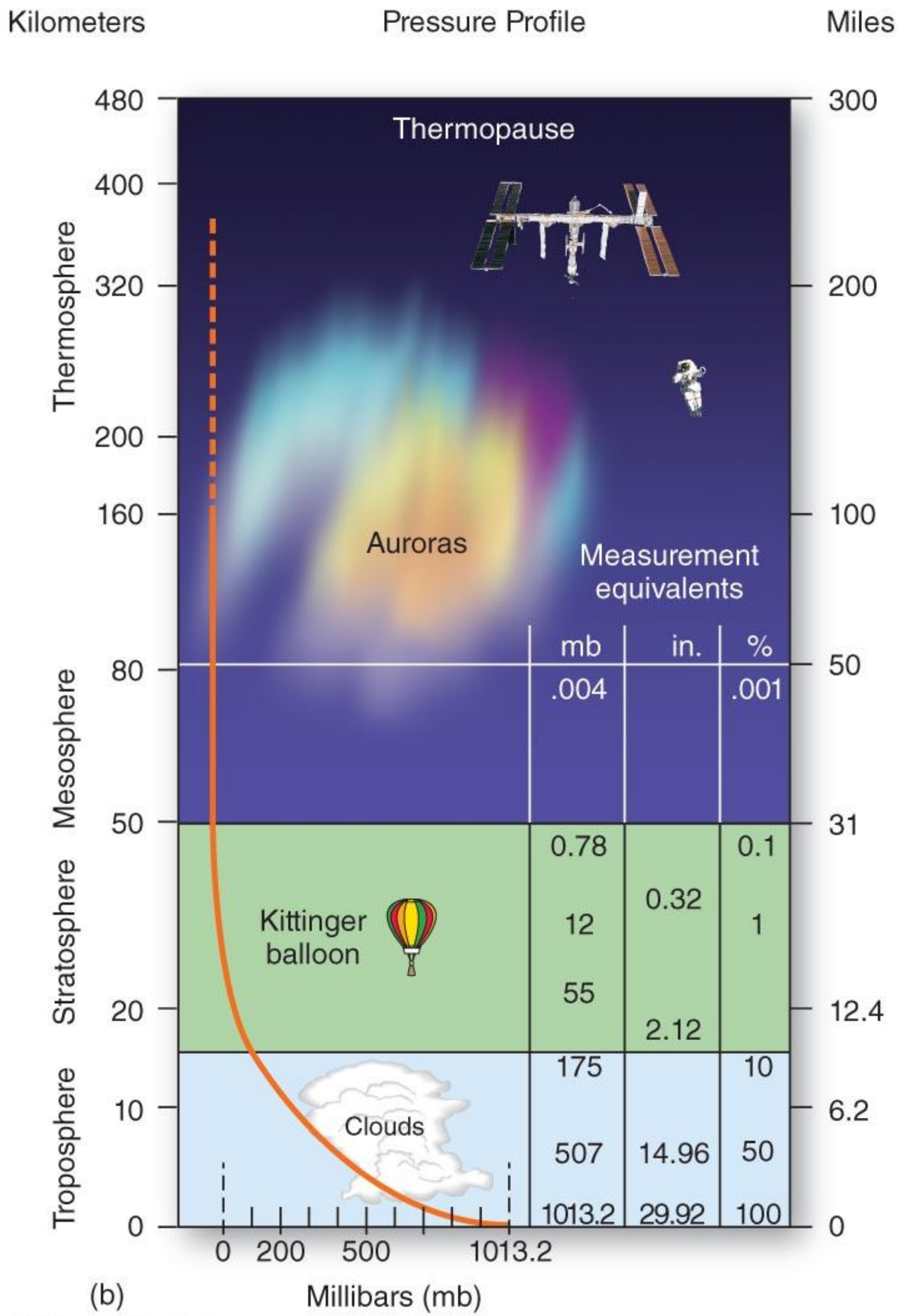
- 1969, July 21, Neil Armstrong first man to walk on the moon

- Discussions of outcome, expences etc..

Challenges going to space

- Where is the boundary to space?
- No clear boundary between the atmosphere and space - 100 km
- Astronaut - > 80 km
- ISS – 330 – 435 km
- Jet plane record 37 km (official, 1977)
- Turbojet 107 km (unofficial record, 1963)

The Atmosphere

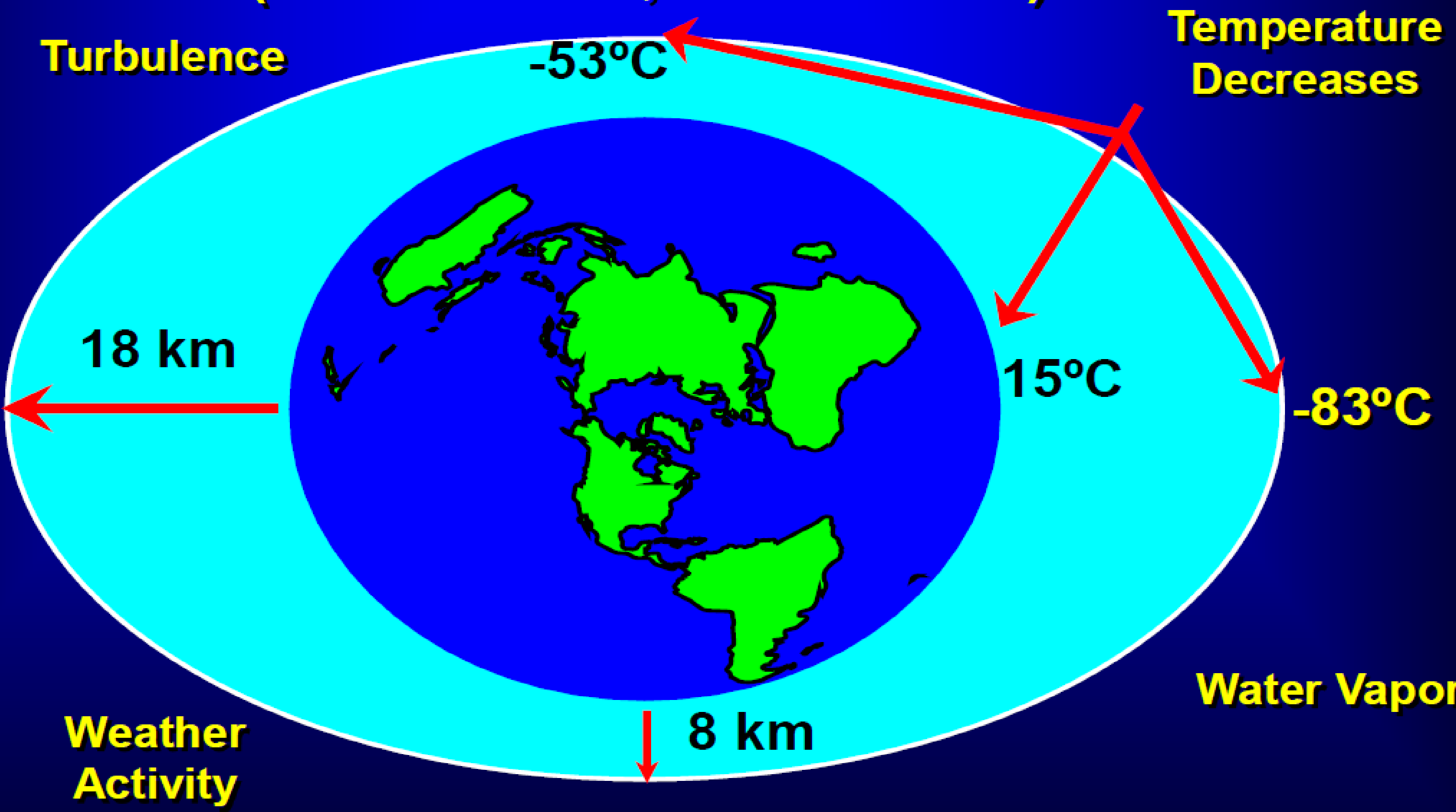


Kilometers
Pressure Profile
Miles
480
400
320
200
160
80
50
20
10
0
300
200
100
50
31
12.4
6.2
0
Thermosphere
Mesosphere
Stratosphere
Troposphere
Thermopause
Auroras
Measurement equivalents
mb
in.
%
.004
.001
0.78
0.1
0.32
12
1
55
2.12
175
10
507
14.96
50
1013.2
29.92
100
Kittinger balloon
Clouds
0
200
500
1013.2
Millibars (mb)

(b)

TROPOSPHERE

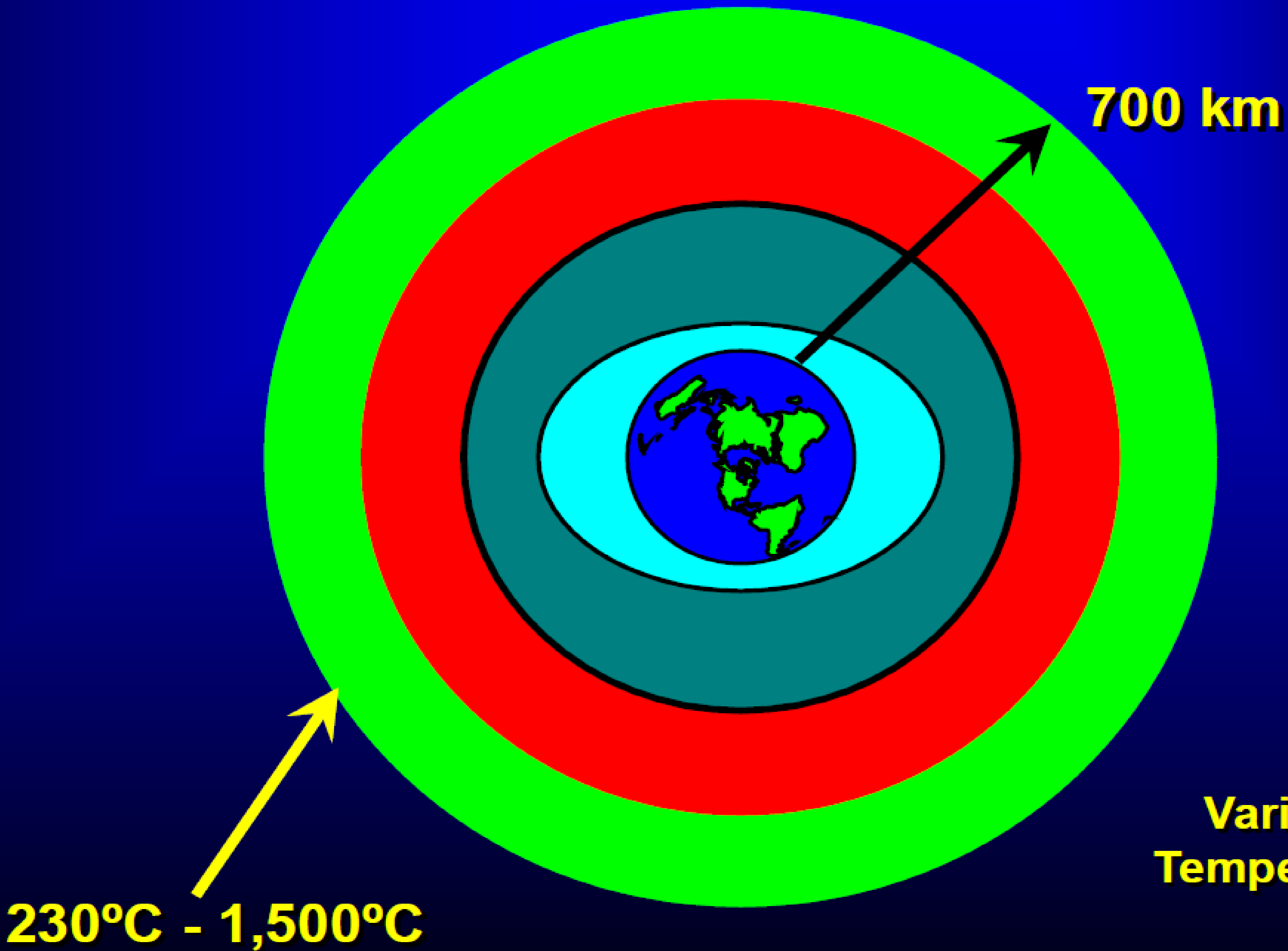
(Sea Level - 58,000 ft/18000m)



Proportion of gases is constant

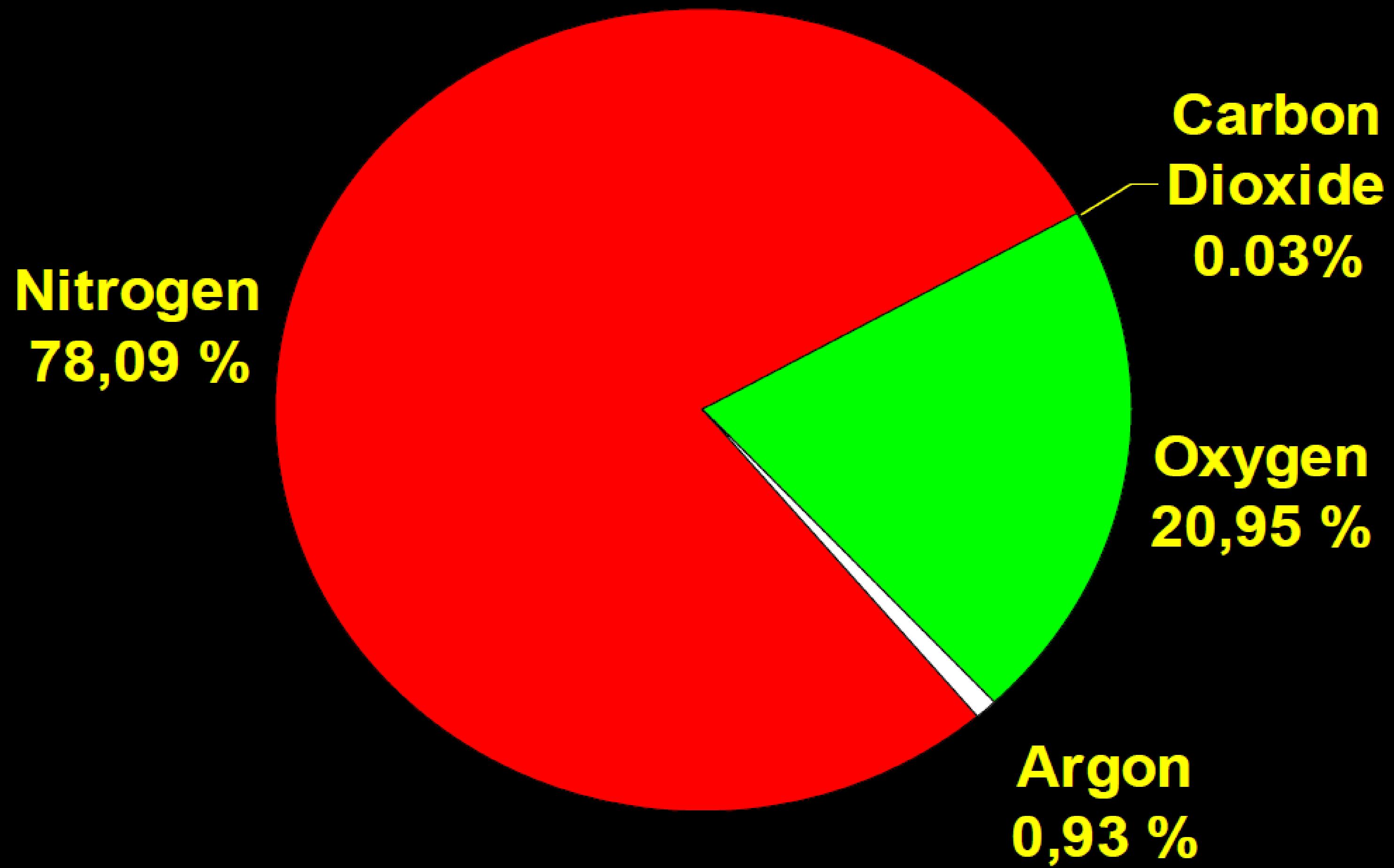
THERMOSPHERE IONOSPHERE

(290,000 ft - 2,300,000 ft)



Variable Temperature

CHEMICAL COMPOSITION



Dalton's Law
(Aeromedical Implications)

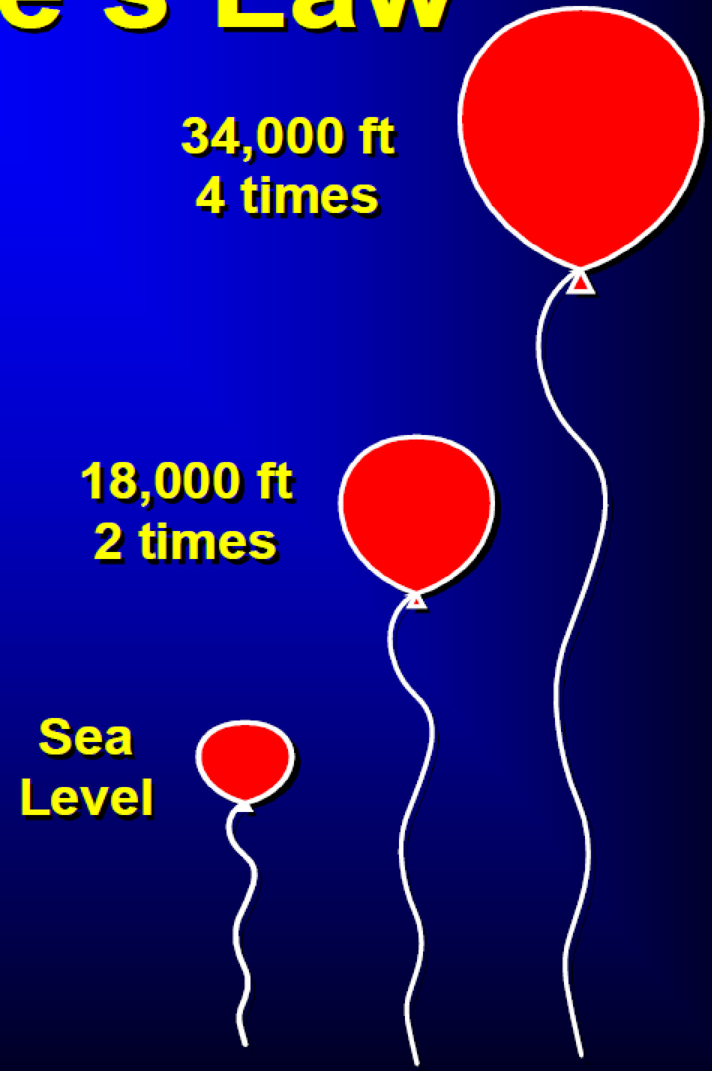
A decrease in barometric pressure (altitude exposure) results in a decrease in the partial pressure of oxygen, even though it's concentration in the gas mixture remains constant at 21%

Consequently the availability of breathing oxygen in ambient air decreases (risk of hypoxia)

Boyle-Mariotte's Law

"At constant temperature, the volume of any gas is inversely proportional to the barometric pressure"

This law explains the expansion of gases during exposure to altitude



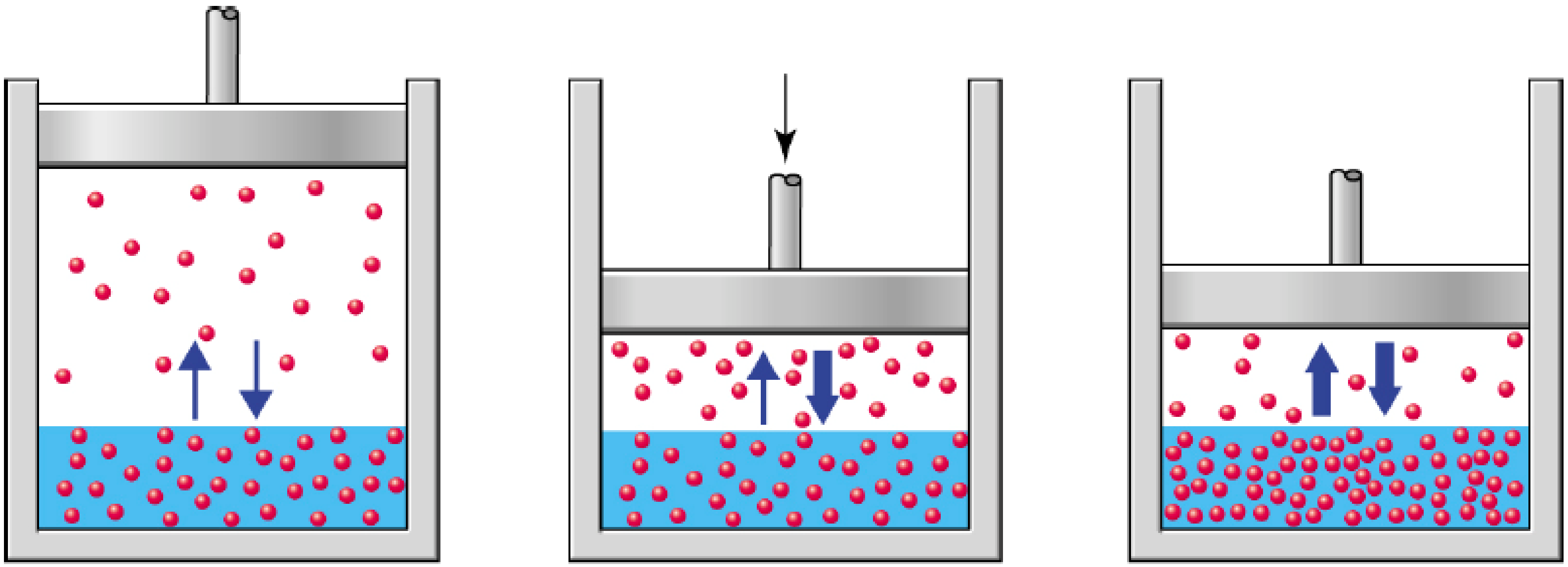
Boyle-Mariotte's Law
(Aeromedical Implications)

During decreased barometric pressure the volume of gas normally present in body cavities (middle ear, sinuses, and gastrointestinal tract) increases and can cause symptoms

Henry's Law

"The amount of gas contained in a liquid is directly proportional to the partial pressure that such a gas exerts over the liquid"

Gas Solubility – Effect of Pressure



(a)

Initial equilibrium

(b)

Increased pressure

(c)

New equilibrium

Henry's Law
(Aeromedical Implications)

More than 60% of the human body is water

Gases (mainly nitrogen) are present in physical solution in all body fluids and tissues

Sudden exposure to low barometric pressure can cause Decompression Sickness

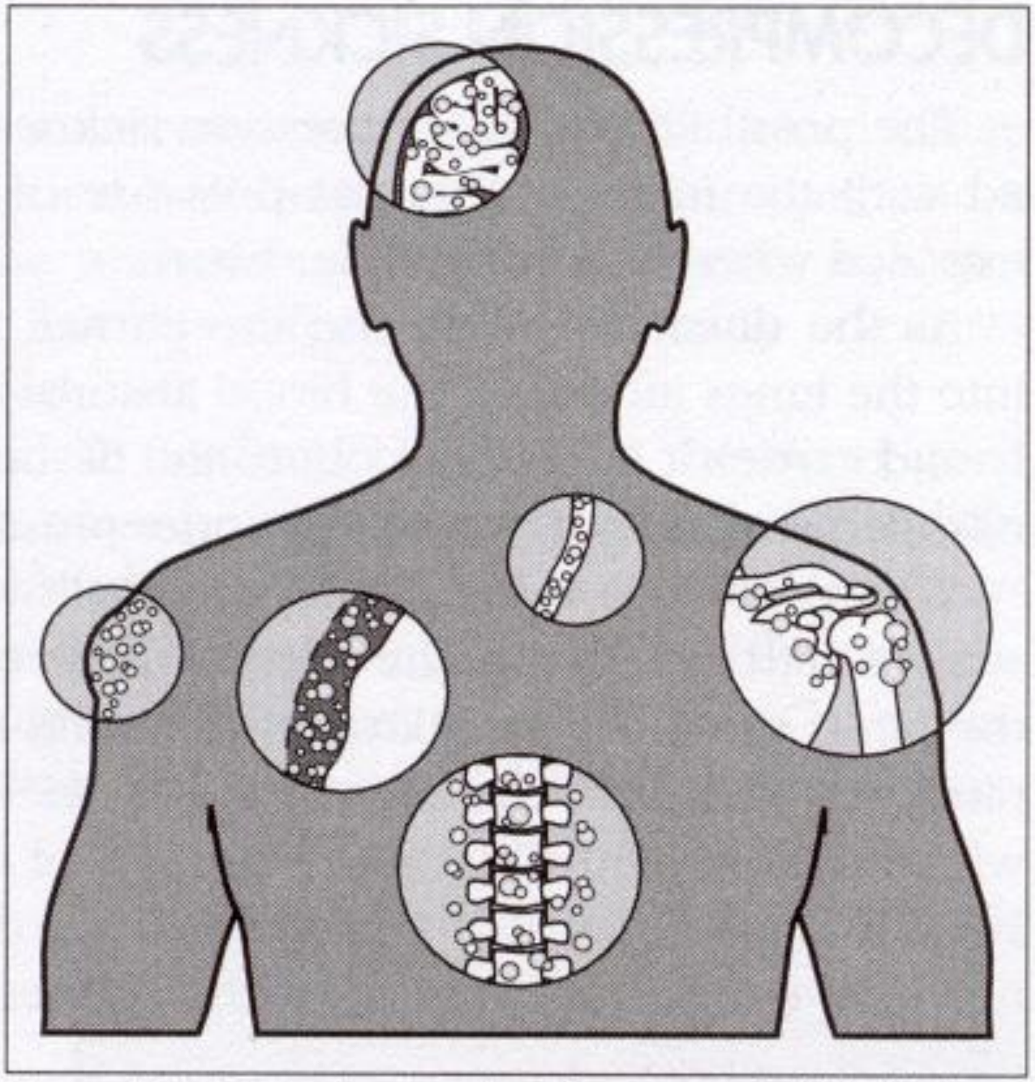
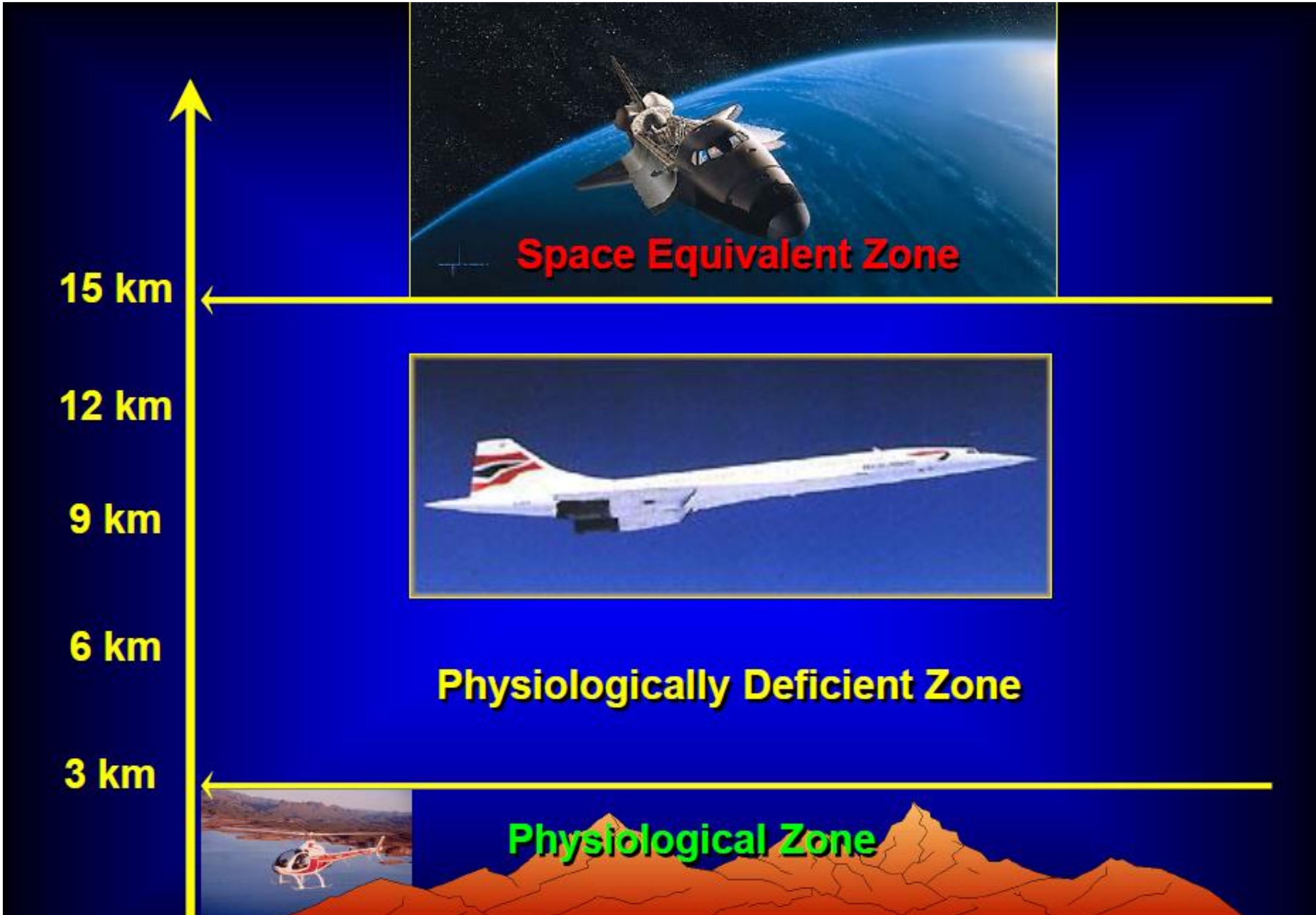


Figure 4-4 Depending on where the nitrogen bubble blockages form, a variety of problems can result.


Space Equivalent Zone
15 km
12 km
9 km
6 km
Physiologically Deficient Zone
3 km
Physiological Zone

Physiological Zone

SL - 10k ft (3 km)

- Humans can adapt under these conditions
- Supplementary oxygen is not required during flight
- Gas expansion in the middle ear and sinuses can cause problems

Physiologically Deficient Zone

10k ft (3 km) - 50k ft (15 km)

- Humans cannot adapt to live at altitude/elevations above 18k ft (5.5 km)
- >10k ft (3 km) supplementary oxygen is required during flight and >40k ft (12 km) 100% oxygen must be delivered with positive pressure
- Gas expansion in the gastrointestinal tract can cause problems

Space Equivalent Zone

> 50k ft (15 km)

- At 63k ft (19km) body fluids boil (ebullism) due to the low barometric pressure (47 mm Hg) - Armstrong Line
- Between 200-265k ft (60-80 km) aerodynamic flight becomes impossible - Von Karman Line
- Air density is very low and it becomes necessary to use sealed cabins or pressurized suits (pressurized cabins are ineffective)

Is it Risky to Fly in Space?

Yes, but risks vary

Suborbital
vs
Orbital

Dryden Flight Research Center EC65-885 Photographed 1965
X-15 on wing pylon of B-52 inflight (NASA photo)

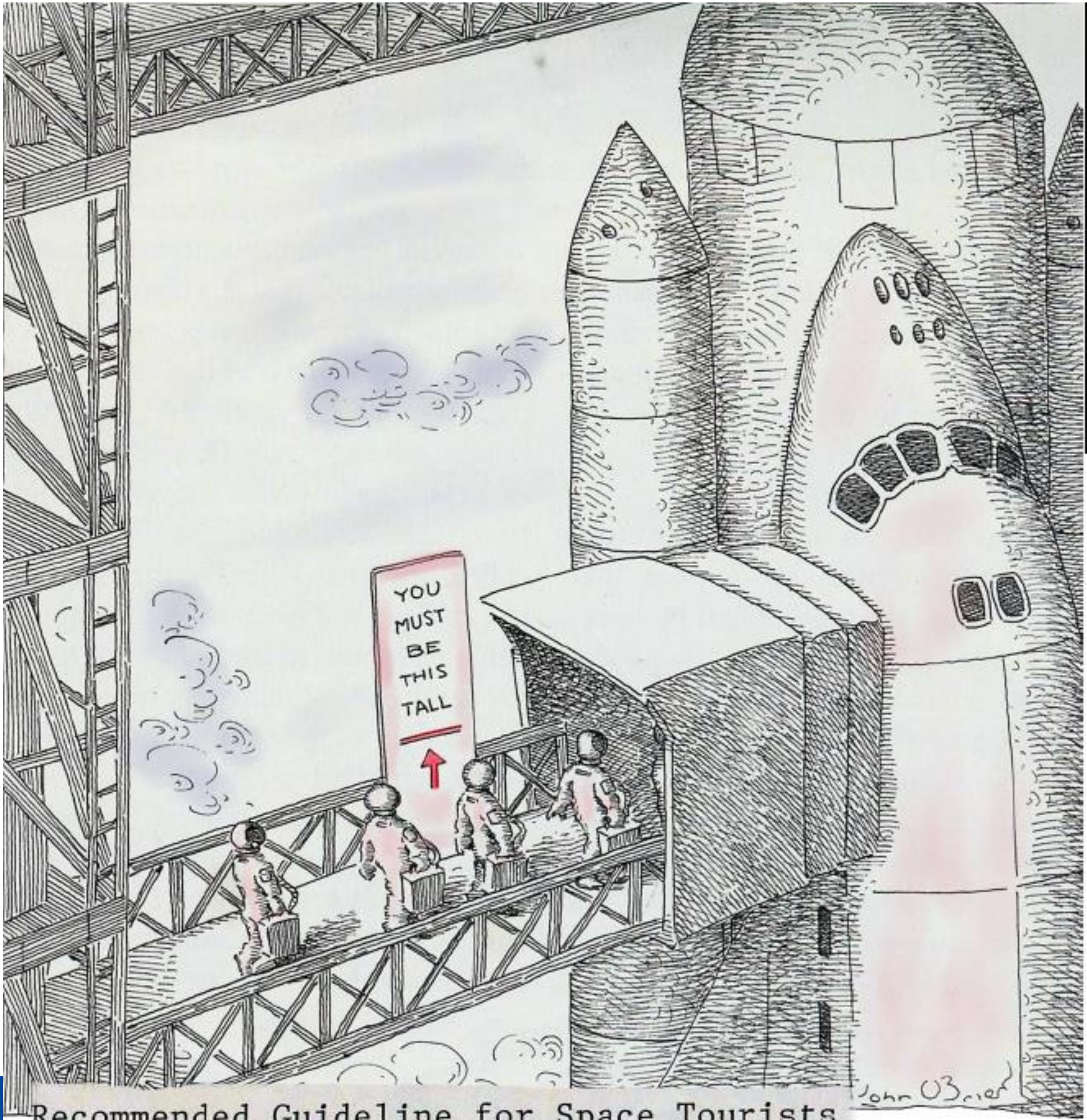
Short Flights
vs
Long Flights

Getting to the Worksite

Challenging Transportation and logistics – everything has to go well

~80% of training spent on ascent and entry

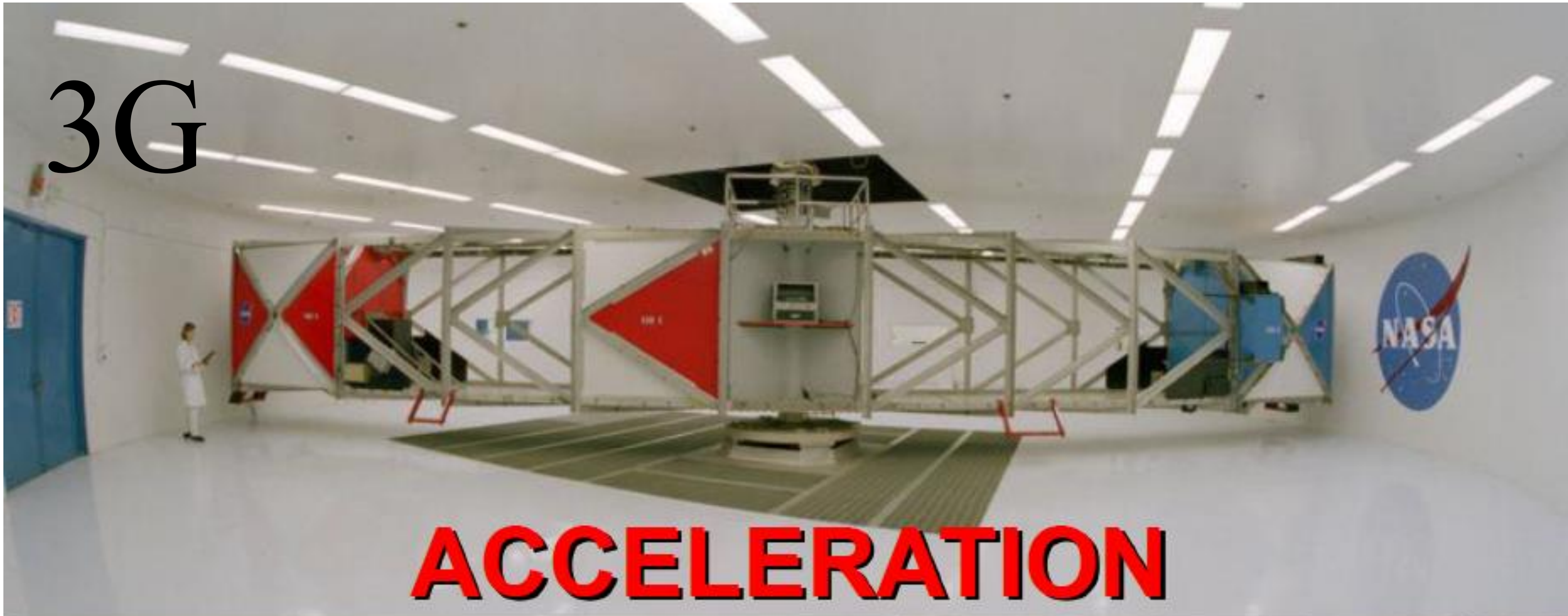
Video



Recommended Guideline for Space Tourists

Flying in space is not like taking a roller coaster ride


LIMITED MEDICAL INTERVENTION CAPABILITIES IN SPACE
….. Thus astronauts needs to be thoroughly examined before a flight and in good physical and psychological shape


3G
NASA
ACCELERATION


AFRL CENTRIFUGE

ACCELERATION

Medical Conditions that could be Adversely Impacted by Exposure to Acceleration

- *Cardiovascular pathologies such as congenital* ***heart diseases****, valvular heart diseases, cardiomyopathies, pericarditis, myocarditis, endocarditis, ischemic heart diseases, dysrhythmias, aortic aneurysm, peripheral vascular diseases,* ***uncontrolled hypertension****, or autonomic neuropathy associated with hypotension*

- *Cerebrovascular diseases such as* ***stroke****, transient ischemic attack (TIA),* ***intracranial bleed****, intracranial aneurysm, AV malformations, cavernous angiomas*

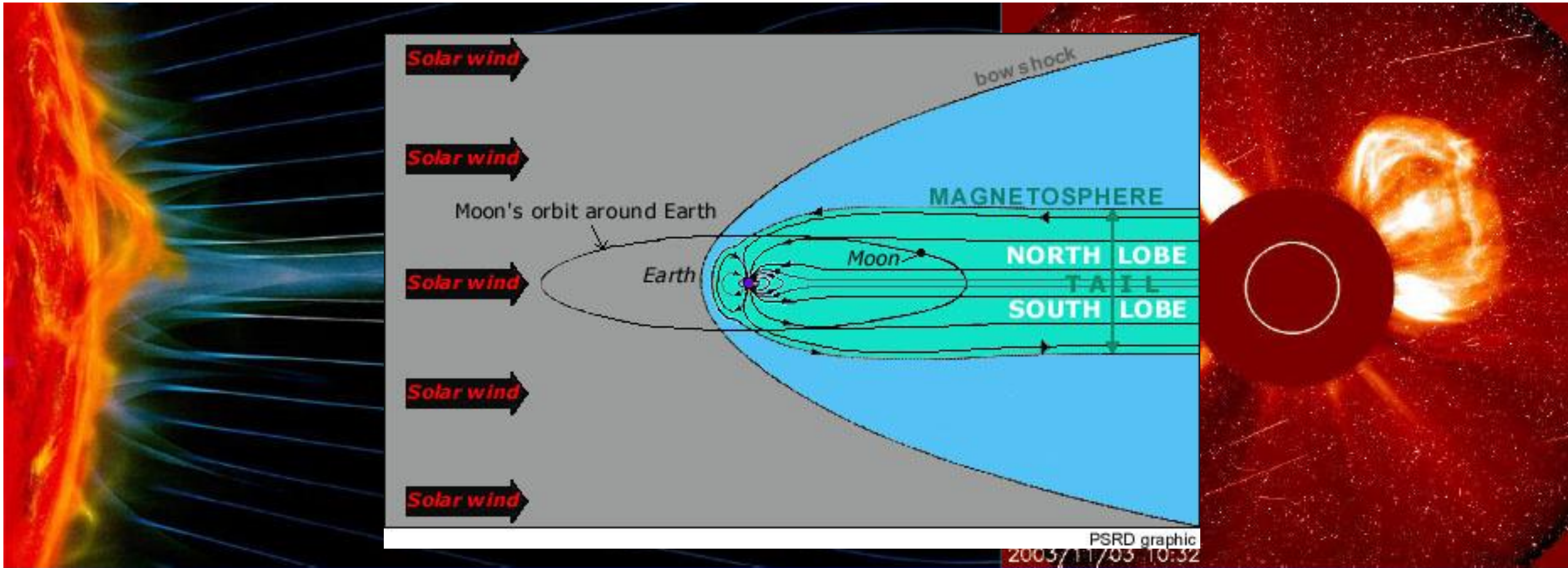
- ***Loss of consciousness*** *of unknown origin or recurrent syncope*

- ***Severe chronic dizziness****, positional vertigo, motion sickness, or other vestibular/orientation problems of any cause*

- ***Musculoskeletal disorders*** *such as symptomatic cervical arthritis, recent spinal injury, severe osteoporosis, spondylolysis, spondylolisthesis, herniated nucleous pulposus, non-healed* ***displaced fractures****, non-reduced dislocations of large joints*

- *Ophthalmologic disorders such as* ***retinal detachment****, hemorrhages or other retinal vascular problems*

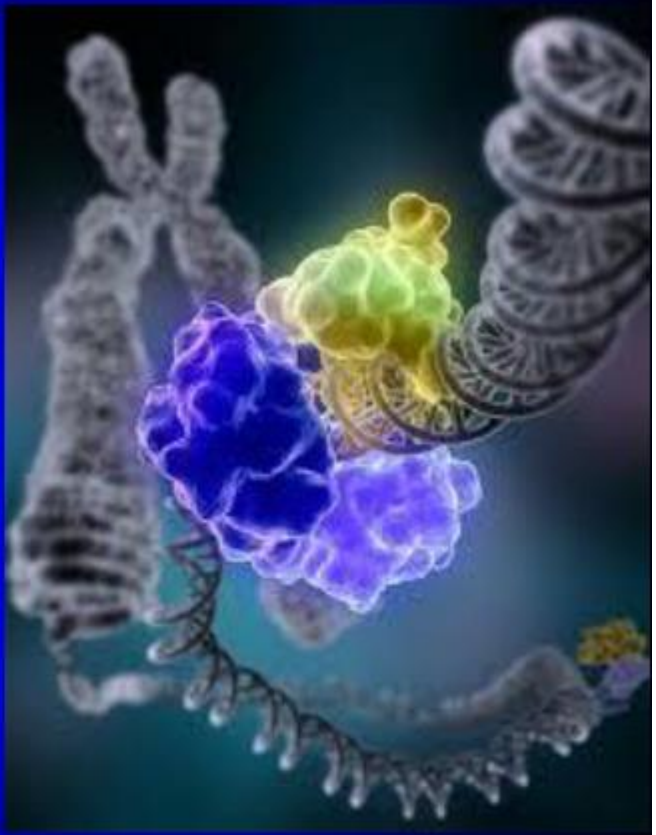
BAROMETRIC PRESSURE



IONIZING SOLAR AND GALACTIC COSMIC RADIATION

The main sources of ionizing radiation in space are geomagnetically trapped radiation, solar particle, and galactic cosmic radiation

Galactic cosmic radiation contains high-energy subatomic particles that can cause damage to human cells



HIGH-INTENSITY NOISE

Noise is produced by:

- *Rocket propulsion systems, thrusters, hydraulic and electrical actuators,*
- *Cabin air conditioning and pressurization systems, cockpit advisory and alert systems, communications equipment, motors, fans, pumps, transformers, oscillators, etc*

VIBRATION

Vibration is transmitted throughout the entire body

Vibration exposure usually occurs during the launch and atmospheric entry phases of a space flight, or while using the thrusters

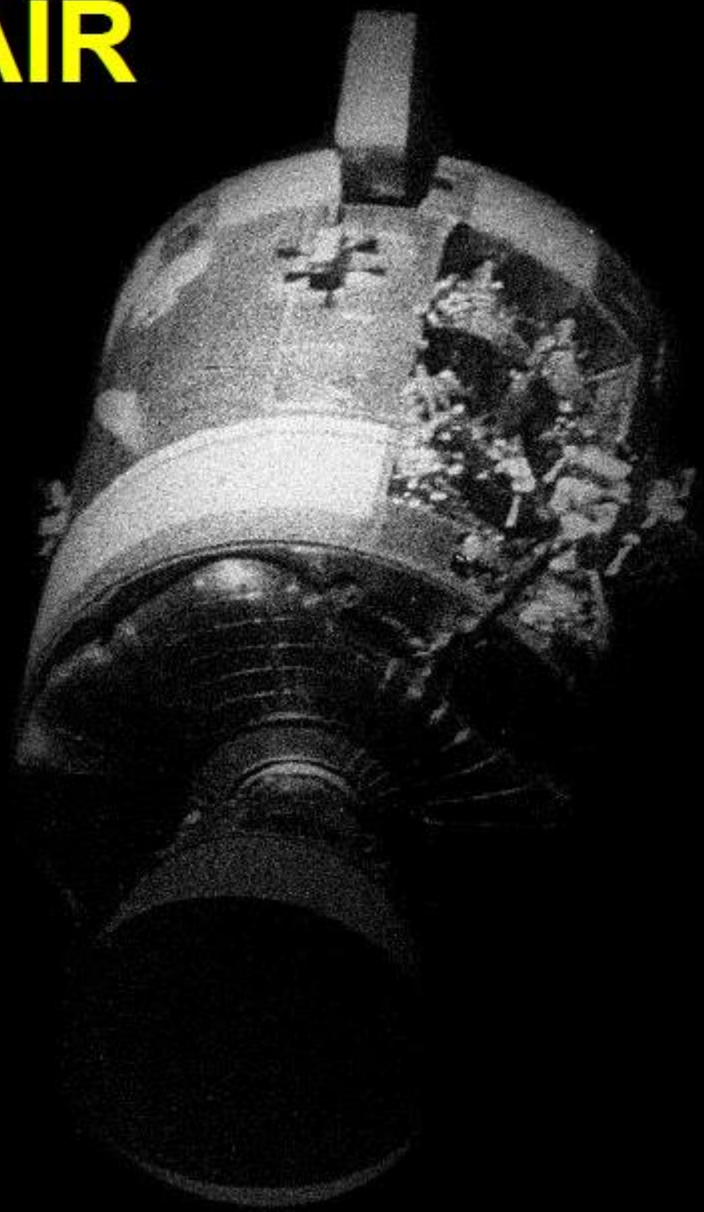
Other sources of inflight vibration include motors, pumps, and other mechanical equipment

TEMPERATURE EXTREMES

The lack of an atmosphere in space exposes space vehicles to extremely cold and hot ambient temperatures

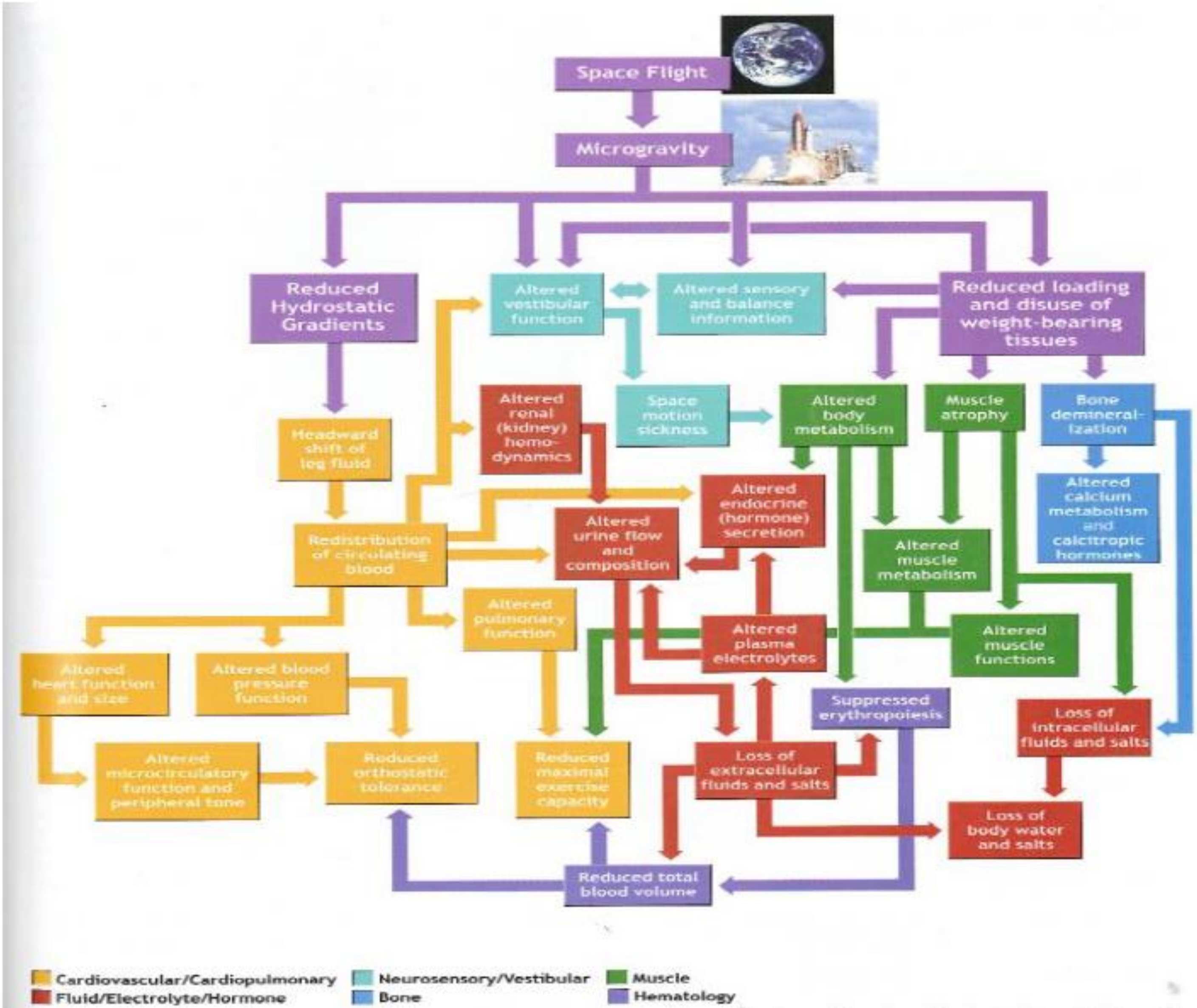
A space vehicle is exposed to high levels of aerodynamic heat produced during the atmospheric entry

CABIN AIR



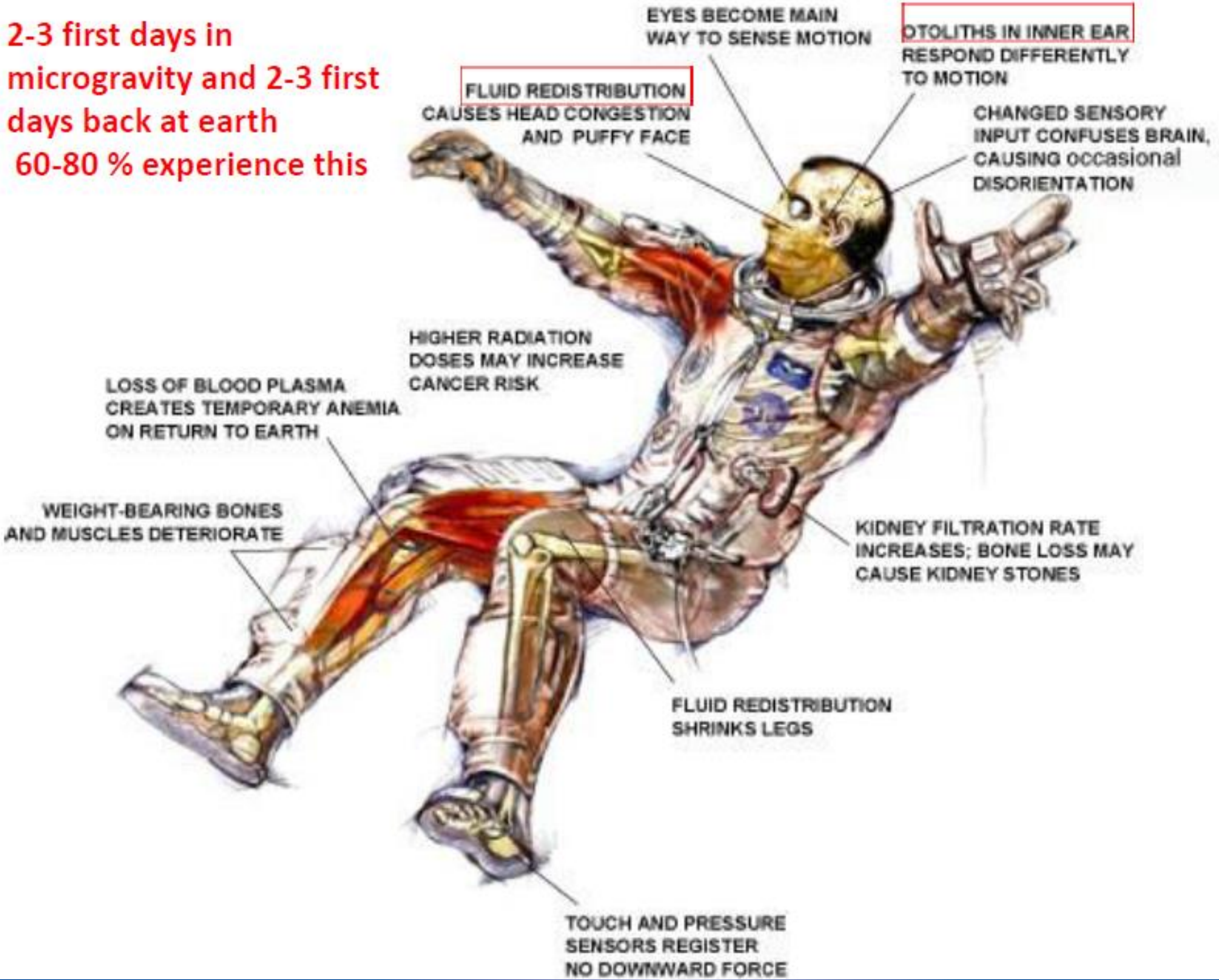
- Several potential risks from biological, chemical and contaminants
- Carbon dioxide released by all occupants during exhalation could accumulate and become a breathing hazard
- Breathing 100% oxygen (instead of a gas mixture) for prolonged periods of time is not healthy
  - Could cause reduced vital capacity, respiratory disturbances, heart problems, blindness, and loss of consciousness
- Odors may be a problem

Overall Physiological Responses to Space Flight



Space motion sickness

- 2-3 first days in microgravity and 2-3 first days back at earth
- 60-80 % experience this

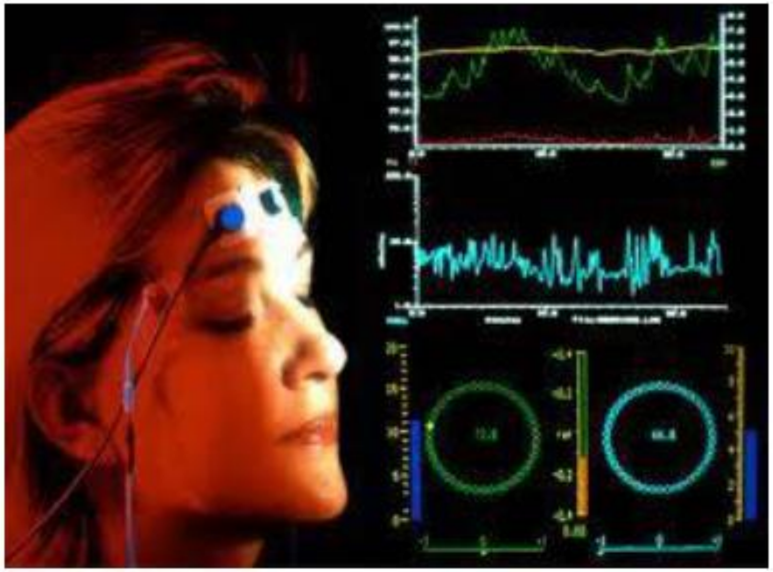


INCIDENCE AND SEVERITY OF SPACE MOTION SICKNESS DURING 36 SPACE SHUTTLE FLIGHTS

	Number of Crewmembers		
Motion-Sickness Rating	First Shuttle Flight	Later Shuttle Flight	Totals
None	32 (29%)	28 (45%)	60 (35%)
Mild	36 (33%)	24 (39%)	60 (35%)
Moderate	29 (27%)	10 (16%)	39 (23%)
Severe	12 (11%)	0 (0%)	12 (7%)
Totals	109 (64%)	62 (36%)	171 (100%)

(Adapted from Davis et al [1988] and Beck [personal communication, 1991].)

Counter measurements for SMS

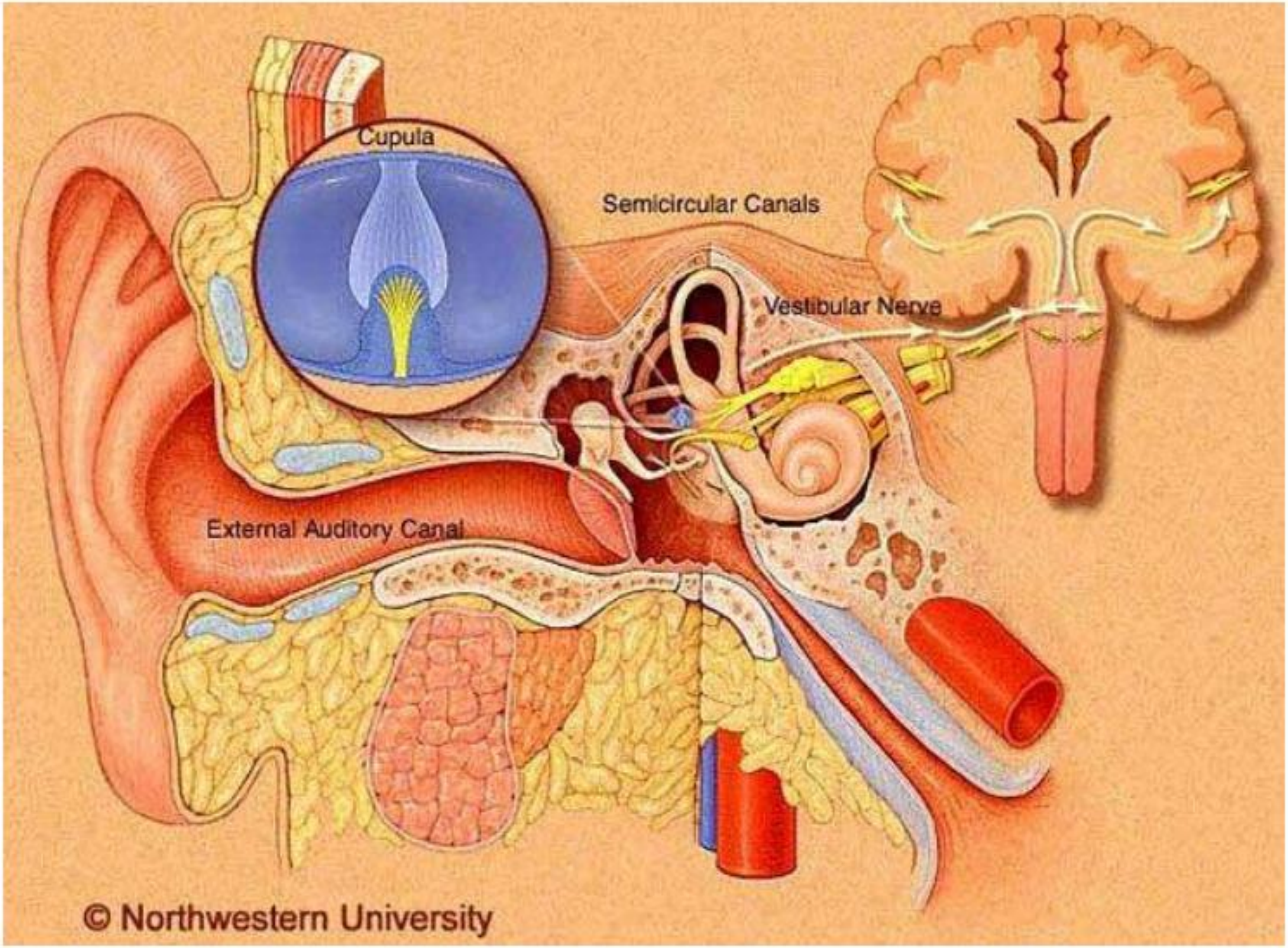


- Motion sickness drugs
- Acupuncture
- Biofeedback training (Therapy to control physiological processes)
- Adaption (patience)

Balance/Neurovestitubular

Components

- Vestibular - Inner ear
- Visual – Eyes
- Proprioceptive – Joints, muscles, tendons
- Neuro – Brain and nervous system


Cupula
Semicircular Canals
Vestibular Nerve
External Auditory Canal
© Northwestern University

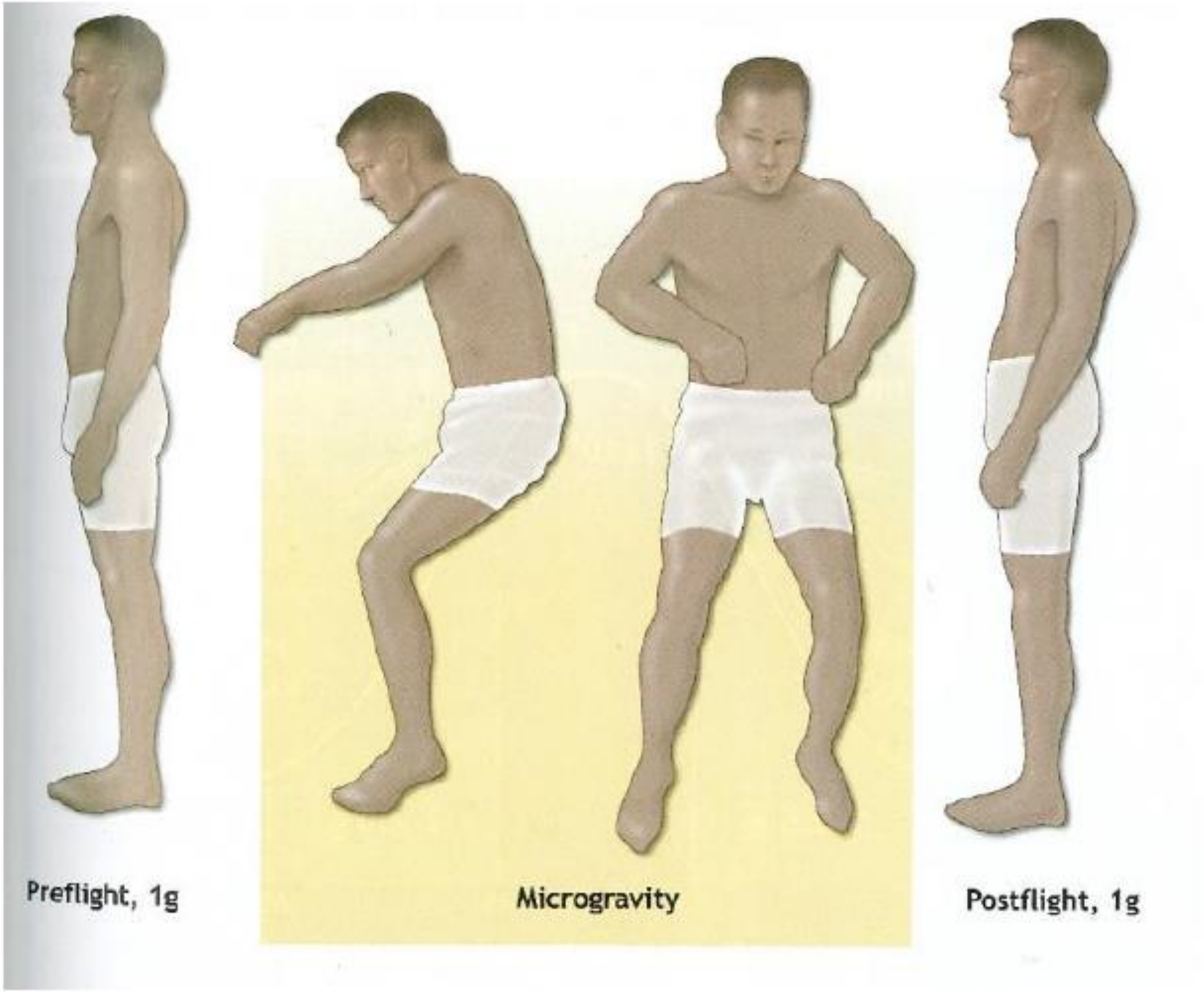
Sensory and Balance System

- Signal conflict – eyes main way to sense motion
- Gravity sensor under the feet

- Space motion sickness
  - Adapt pretty quickly - 2-3 first days in microgravity and 2-3 first days back at earth
  - 60- 80 % experience this

- Postural changes
  - Inflight
  - Postflight

Change in body position



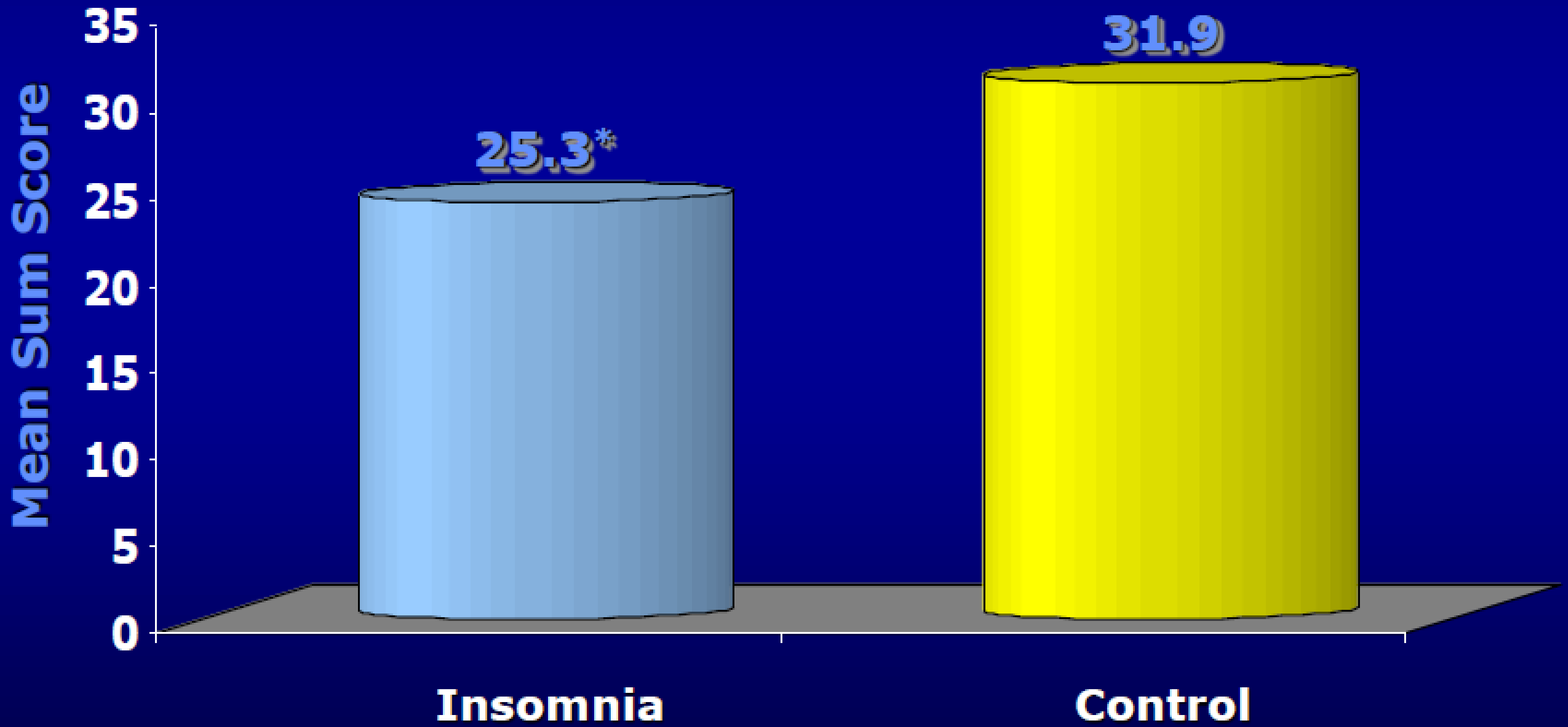
FATIGUE !!!

Environmetal factors

Sleep loss

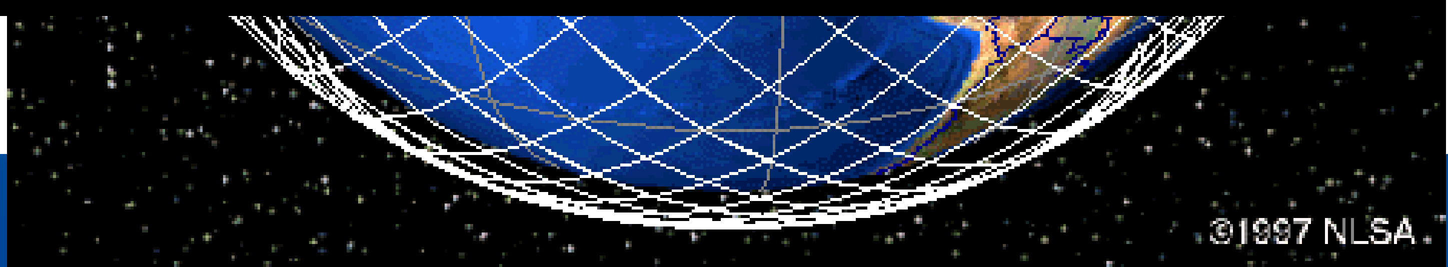
Circadian Rhythms

Cognitive Functioning Scale



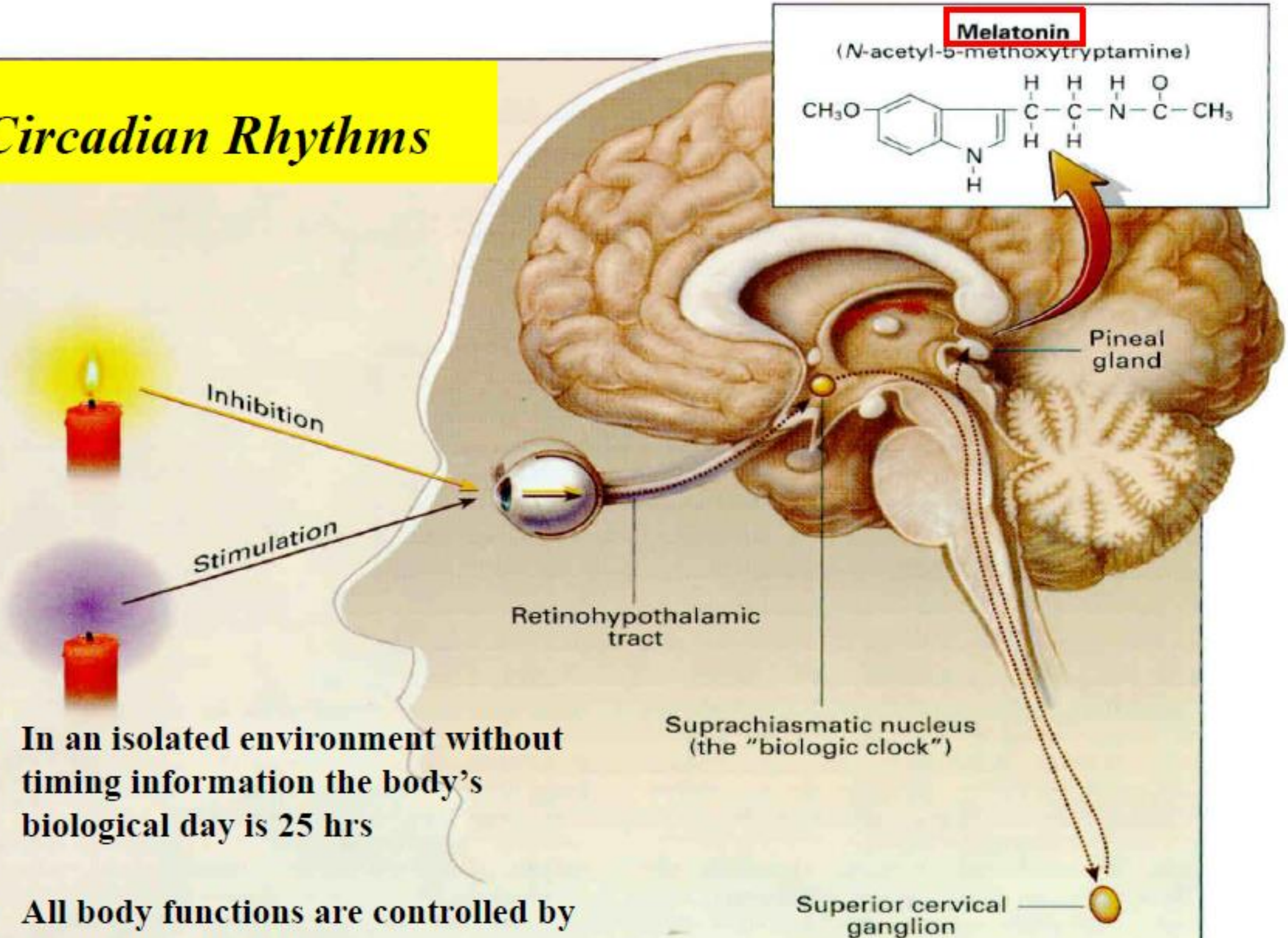
*$P<0.0001$ vs control.

Zammit GK et al. *Sleep.* 1999;22(suppl 2):S379-S385.



NTNU

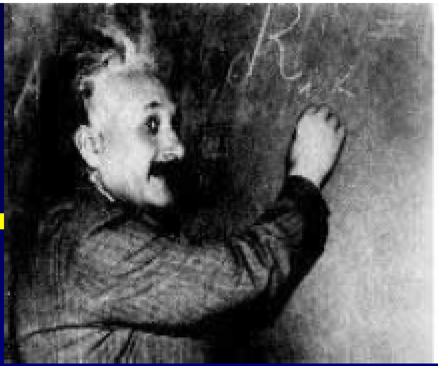
Circadian Rhythms



- **In an isolated environment without timing information the body's biological day is 25 hrs**
- **All body functions are controlled by the circadian clock**

Non-visual brain centers use information from *bright, blue-weighted light exposures* to control circadian physiological & psychological processes essential for optimal well-being

Turner PL, Mainster MA. Circadian photoreception: ageing and the eye's important role in systemic health. *Br J Ophthalmol* 2008;92:1439-44.



Sleep:

- Humans average 7-9 hours of sleep each night
- Total sleep duration decreases throughout life
- Sleep divided into two distinct types
    - **Rapid eye movement (REM)**
        - Dreaming occurs, Wakeful-like EEG
        - Reduced voluntary muscle activity
    - **Non Rapid Eye Movement (NREM)**
        - Considered restorative sleep
        - Arousability, BP, and heart rate decreased
        - Stage 1-drowsy sleep
        - Stage 2-intermediate sleep
        - Stages 3-4, slow wave (delta) sleep

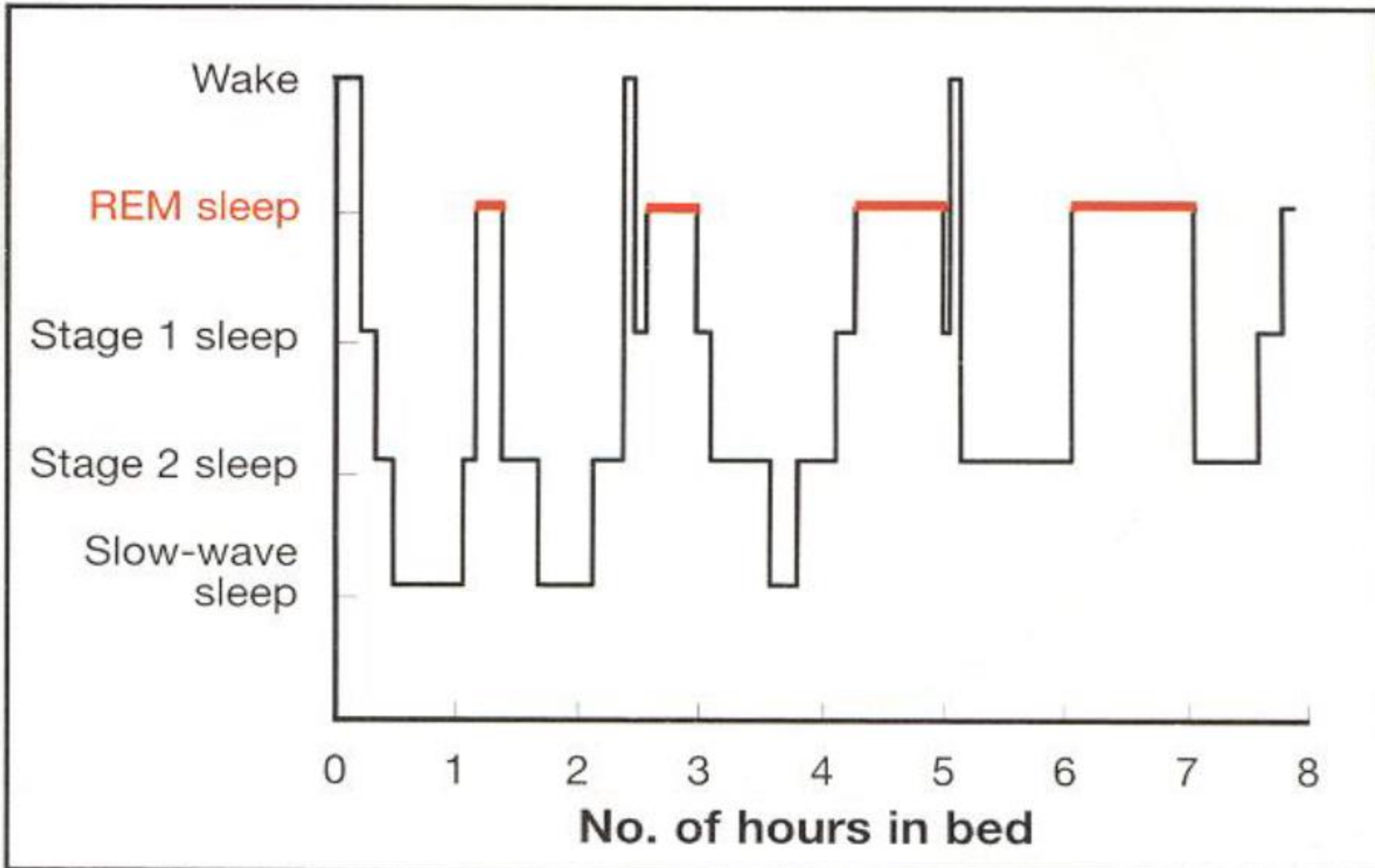


Figure 1. Eight-hour EEG recording in healthy person without insomnia. REM, rapid eye movement.

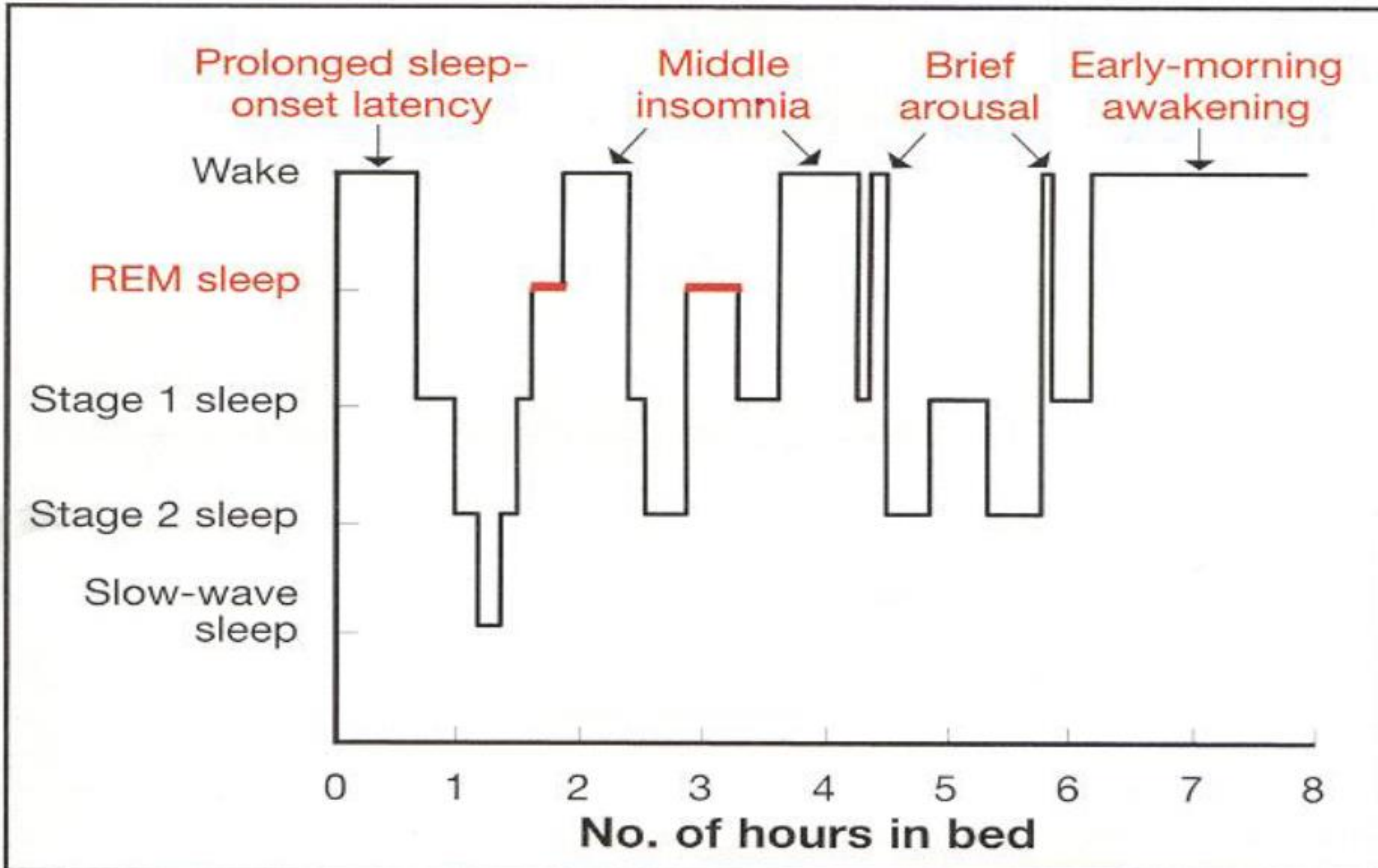


Figure 2. Eight-hour EEG recording in person with insomnia. REM, rapid eye movement.

Average Sleep Time During Spaceflight

- Space Shuttle (n=39)
  - 5.9 $\pm$ 0.5 hours
- International Space Station (n=9)
  - 6.3 $\pm$ 0.5 hours

HMS

BWH

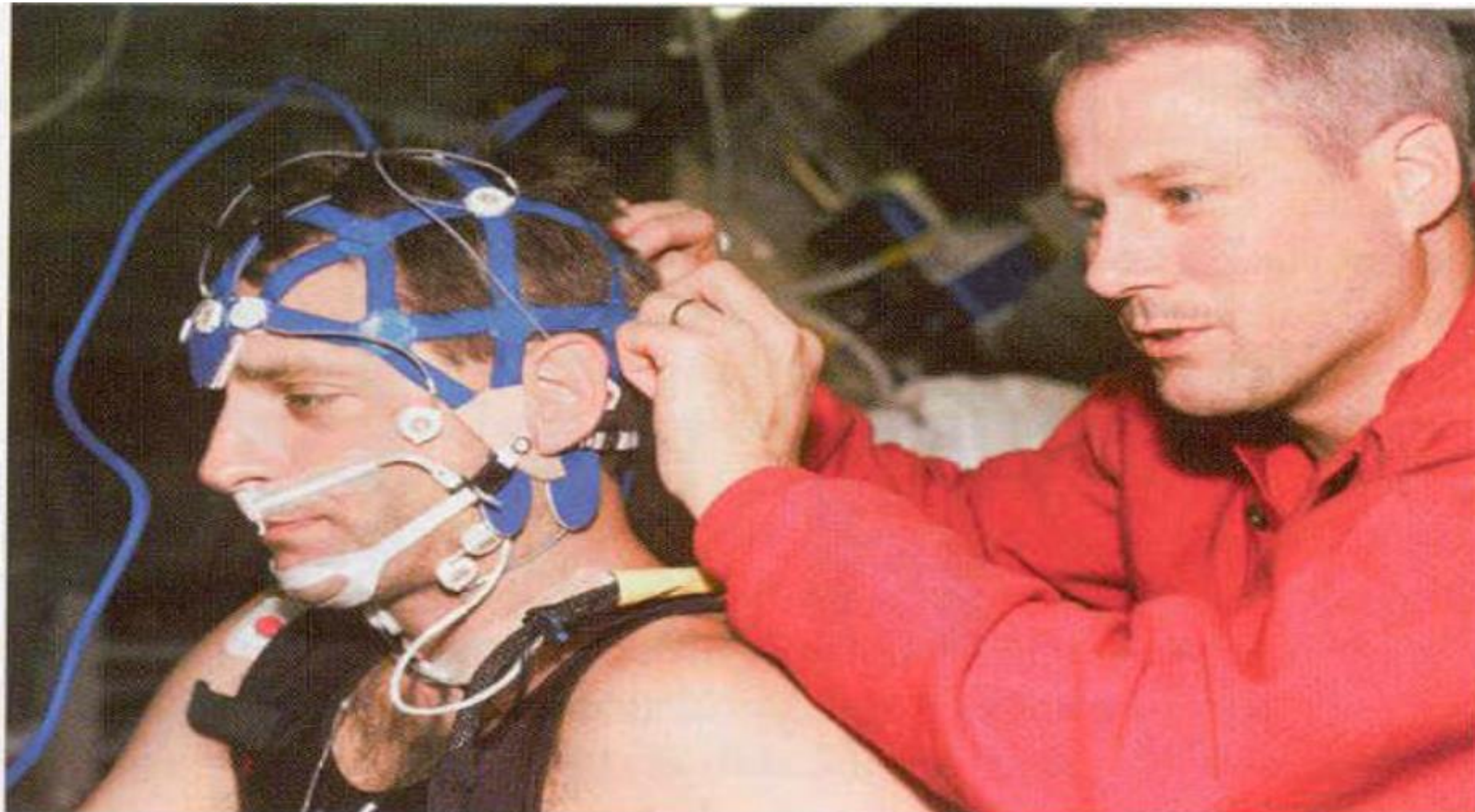
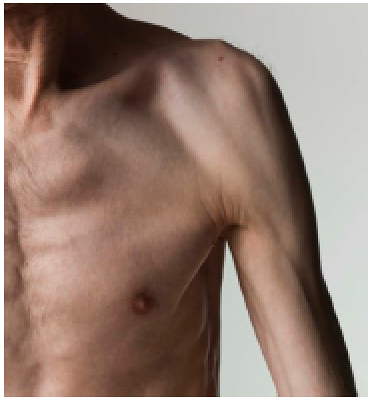


Figure 4. Brainwaves, eye movements, and airflow were recorded by means of a sleep net and additional sensors. This photograph shows payload commander Rick Linnehan being instrumented by payload specialist Jay Buckey during the STS-90 mission.

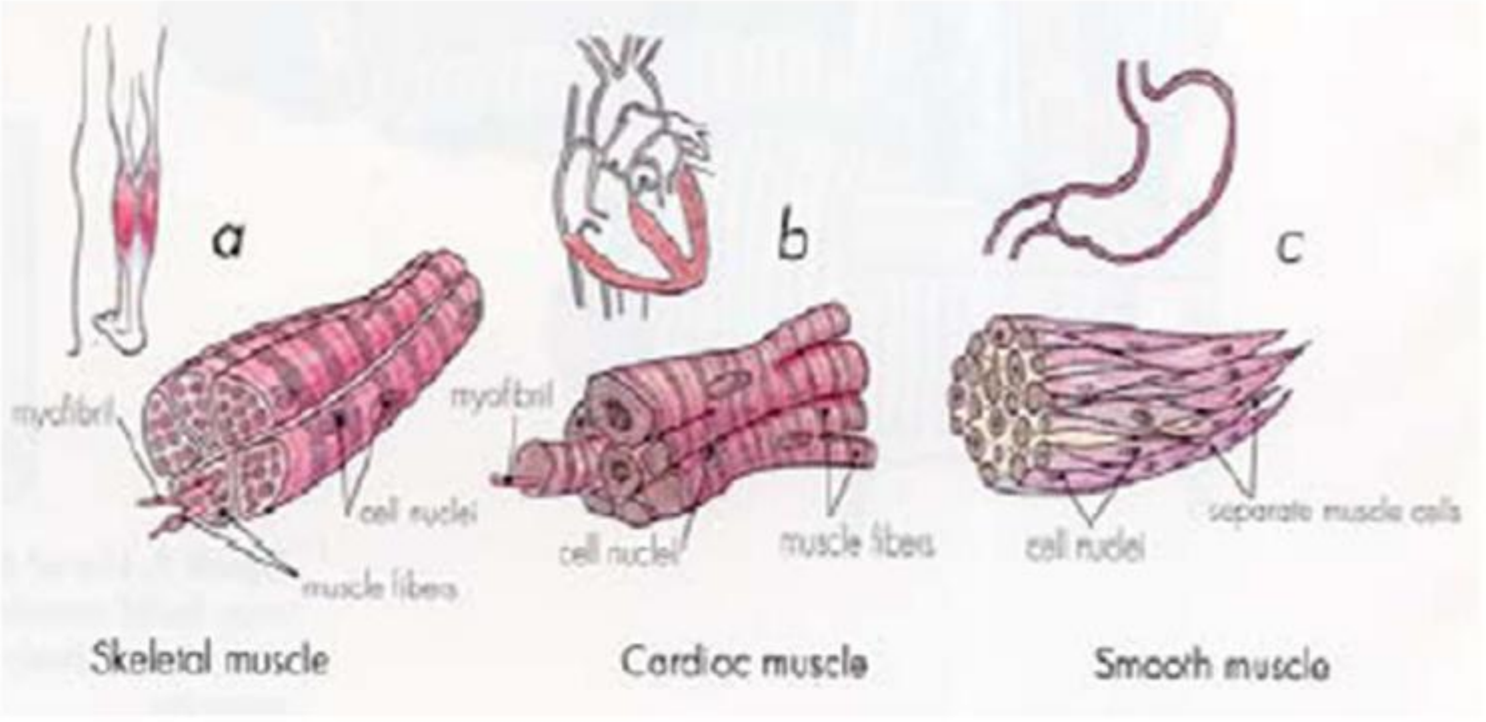
Muscular Systems in Space



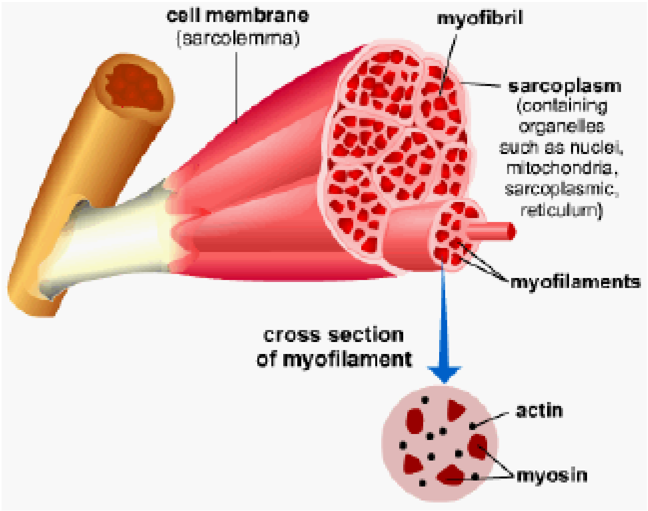
- Muscle functions
  - Motion and locomotion
  - Movements of substrate in the body
  - Postural maintenance
  - Heat production

Types of Muscle

- Skeletal, - slow and fast twitch (Type 1, Type II)
- Cardiac muscle
- Smooth muscle



Muscle Atrophy



- Wasting away of muscle. Individual fibers decrease in size due progressive loss of myofibrils (actin and myosin)

- Caused by:
  - Disuse
  - Denervation
  - Disease

Muscle function in space

Force

- Skylab astronauts who exercised maintained muscle force
- Leg volume reduced, exercise or not
- Proximal antigravity muscles (torso, posture) deconditioned after 5 days

Change in muscle fiber type

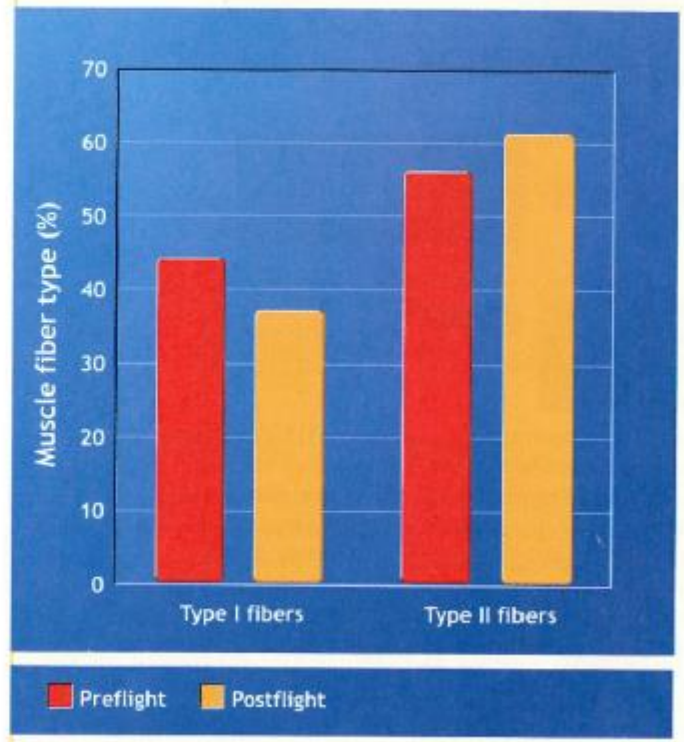
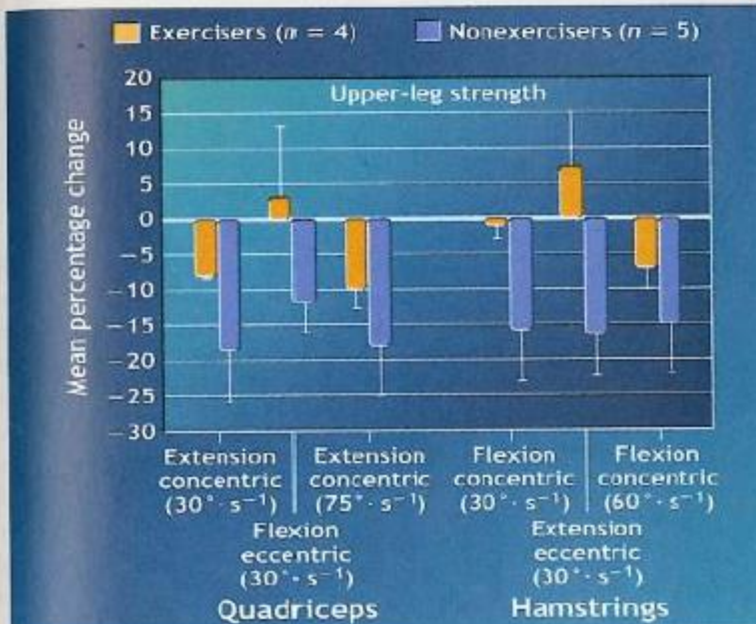


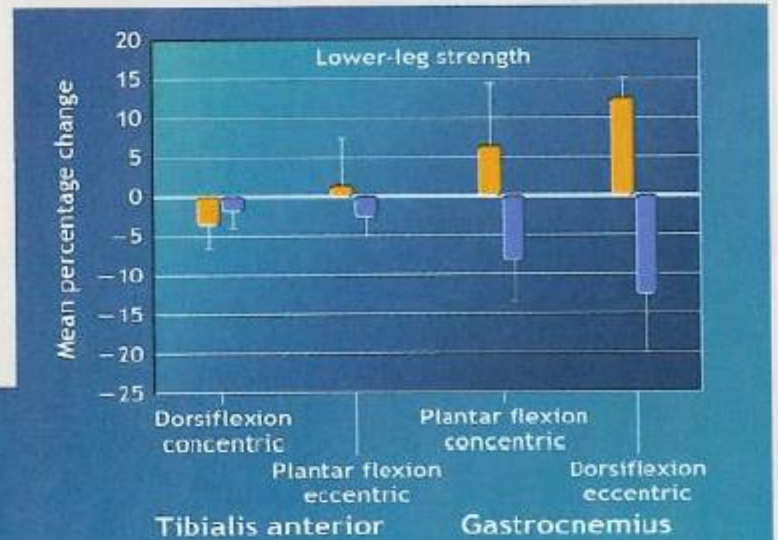
Figure 1 • Muscle fiber-type percentage before and immediately after 11 days of spaceflight.

TABLE 27.9 • *Top Left.* Changes in Skeletal Muscle Strength Performance on Landing Versus Preflight. *Bottom Left.* Percentage Changes in Upper-Leg, Lower-Leg (*Top Right*), and Trunk Strength (*Bottom Right*) Following Spaceflight in "Space Exercisers" vs. Nonexercisers

Muscle Group	Test Mode: Concentric	Test Mode: Eccentric
Back	−23 (±4)*	−14 (±4)*
Abdomen	−10 (±2)*	−8 (±2)*
Quadriceps	−12 (±2)*	−7 (±3)
Hamstrings	−6 (±3)	−1 (±0)
Tibialis anterior	−8 (±4)	−1 (±2)
Gastroc/soleus	1 (±3)	2 (±4)
Deltoids	1 (±5)	−2 (±2)
Pecs/lats	0 (±5)	−6 (±2)
Biceps	6 (±6)	1 (±2)
Triceps	0 (±2)	8 (±6)

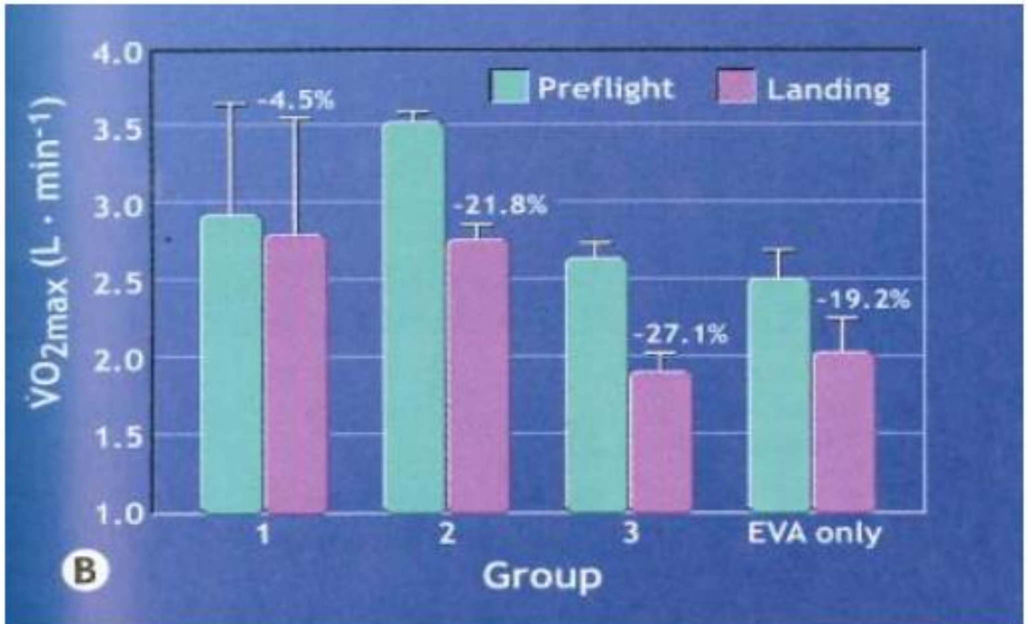
*Significantly lower than preflight value.





Data from Extended Duration Orbiter Medical Project. 1989–1995. Final report NASA/SP-1999-534. NASA. Lyndon B. Johnson Space Center. Houston, TX, 19

Exercise regiments and VO2 max



Group 1 (n=3): Ex.>3x/week, HR >130, >20 min/session (regular exercise group)
Group 2 (n=5): Ex.>3x/week, HR <130, >20 min/session (reduced intensity exercise group)
Group 3 (n=8): Ex.<2x/week; HR and min/session variable (minimal exercise group)
EVA Only (n=4): EVA subjects. Minimal other exercise peformed during flight (Hubble Mission)

Counter measurements

- Exercise
  - Astronauts exercise at least 2,5 hours per day at the space station
  - Hypertrophic training (many reps)increase muscle mass
  - Maximal strength training (neural adaption & strength)

- Passive stretch
- Electrical stimulation
- Proper nutrition
- Anabolic drugs

Treadmill running

Resistance training (weight training)

Ergometer bike

Energy consumption

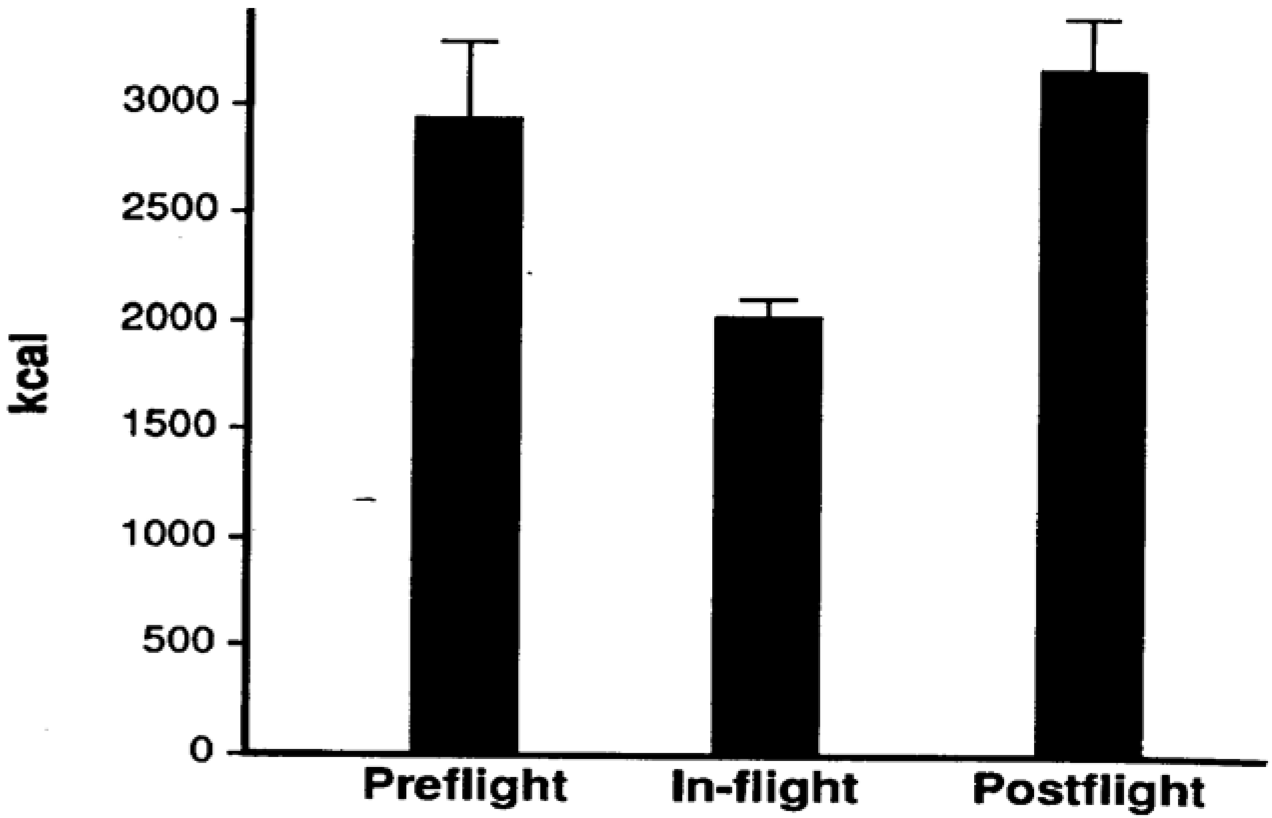


Figure 15–3. Energy consumed by the STS-4 payload crew before, during, and after flight.

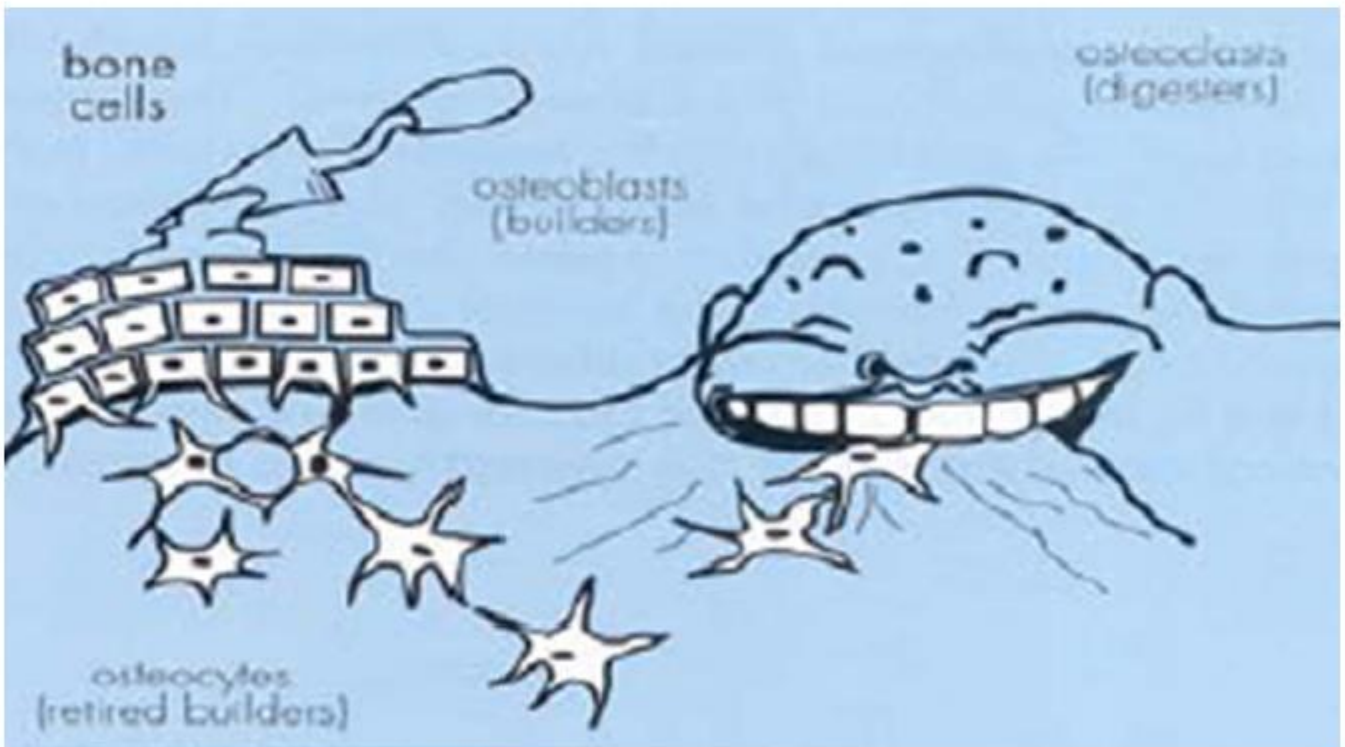
Skeletal System

Functions

- Support
- Protection
- Movement
- Mineral storage and homeostasis
- Site of blood production (red bone marrow)
- Energy storage (yellow bone marrow)

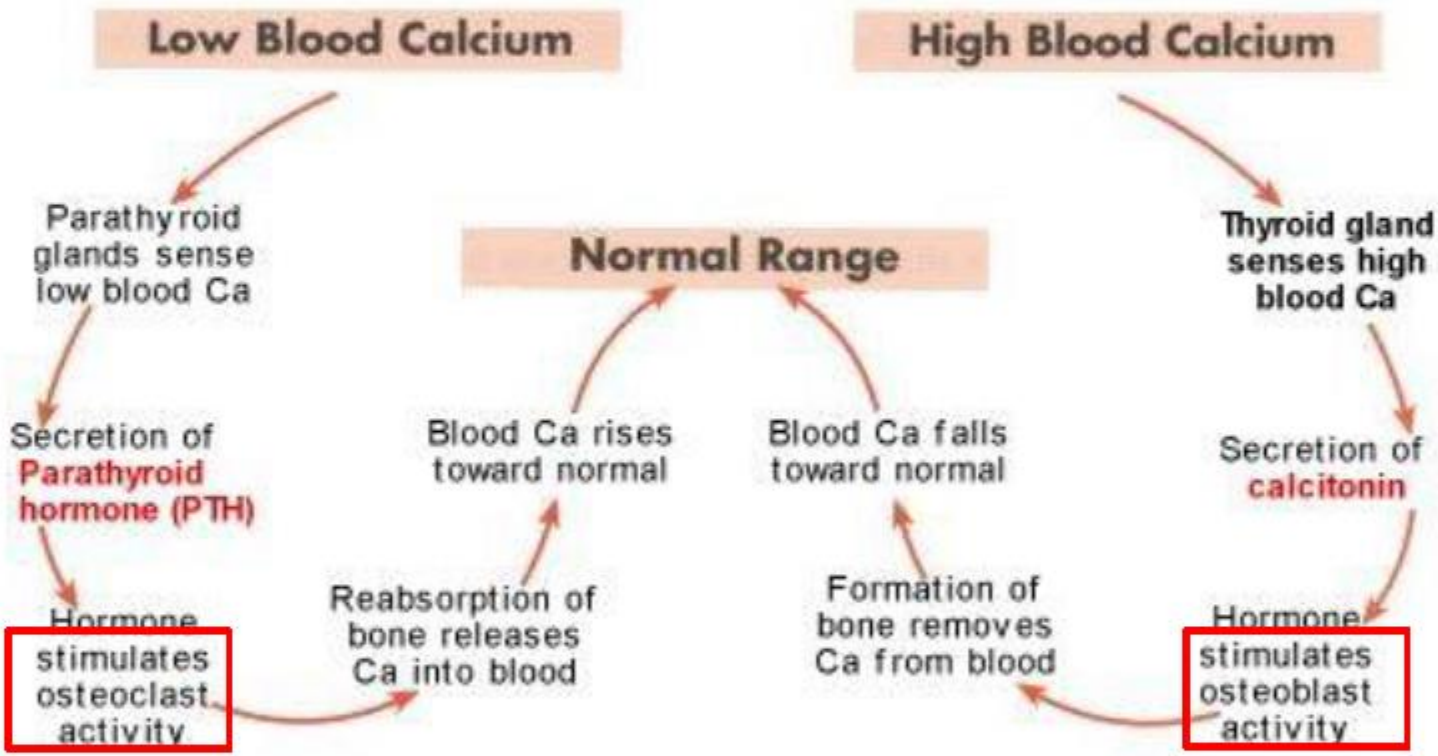
Bone in constant turnover

- Osteoblasts make and Osteoclasts reabsorb
- Bone strengthen with mechanical stress



Calcium loss in the human body

- Women begin at 30 yrs (30% loss by 70yrs)
- Men begin at 60 yrs

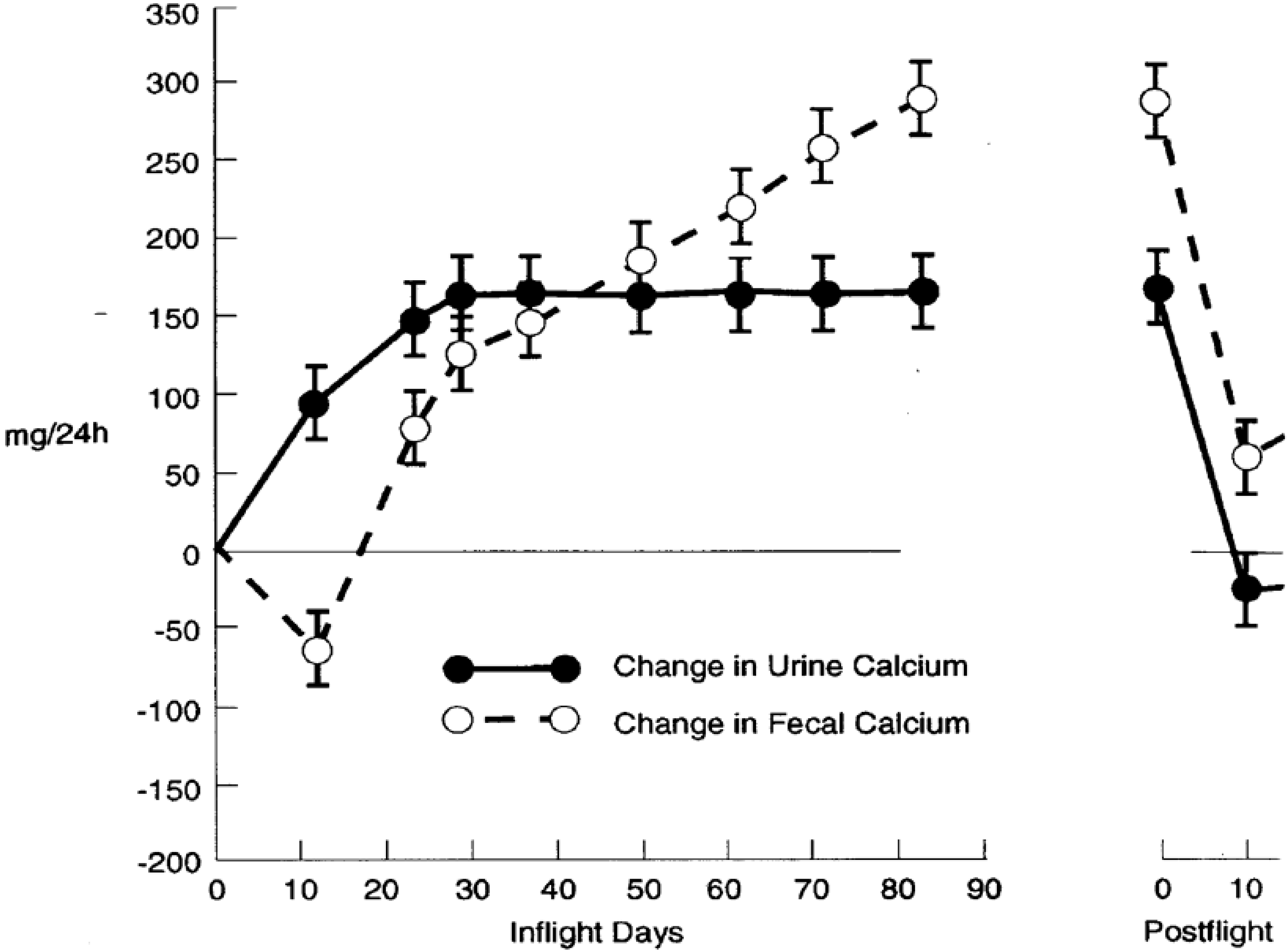


Calcium balance in space

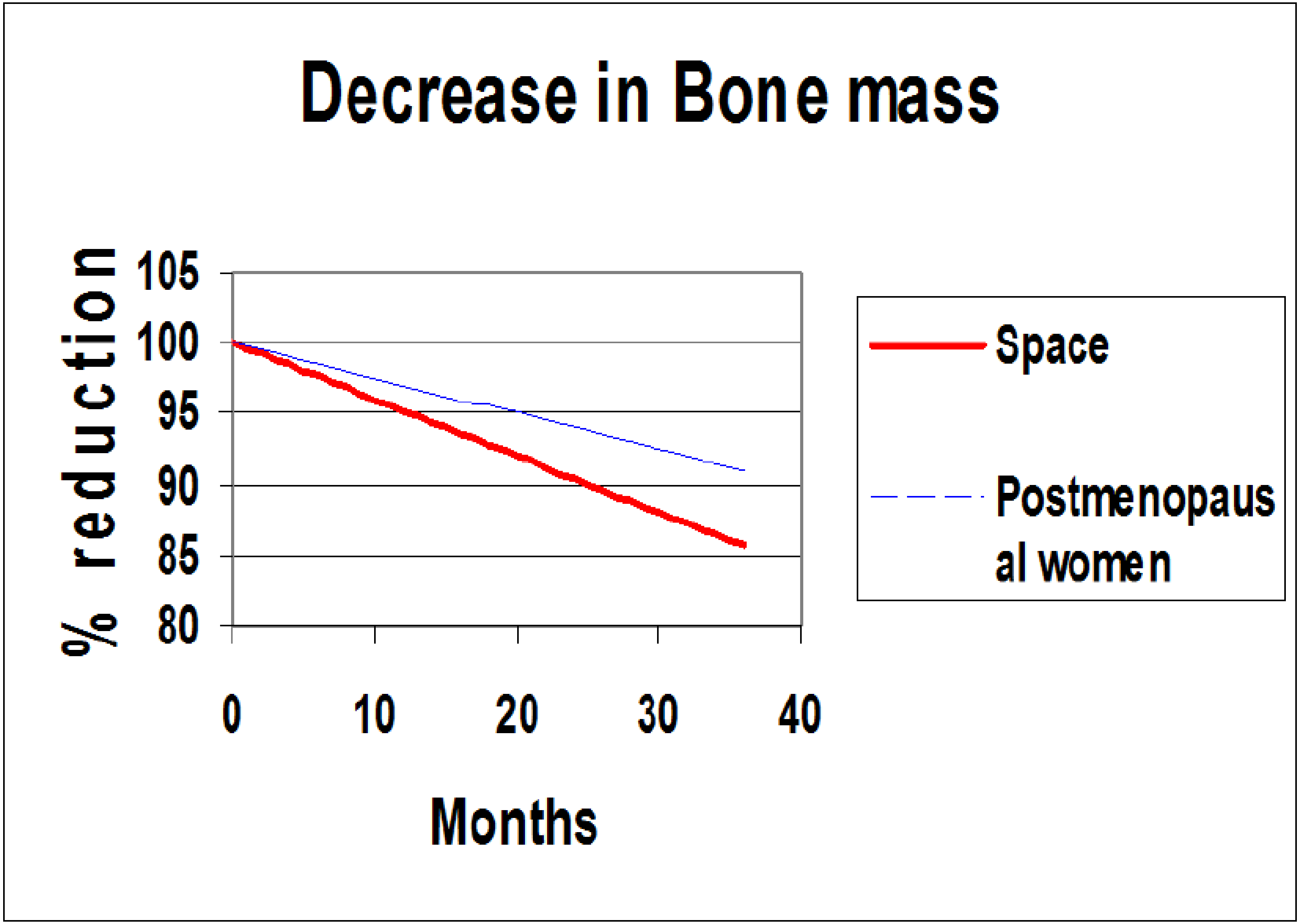
- Skylab (84d) – Showed Ca output in urine and feces
- Calculated that after 1 yr in space that 25% of Ca would be lost
- Recovery of Ca balance (urine/fecal) begins soon after return

- This could be a problem – Why?

Because bone is in a constant state of turnover.
If the Ca balance returns to normal quickly, the bone density (strength) may never recover or recover very slowly



mg/24h
350
300
250
200
150
100
50
0
-50
-100
-150
-200
0
10
20
30
40
50
60
70
80
90
Inflight Days
0
10
Postflight
Change in Urine Calcium
Change in Fecal Calcium

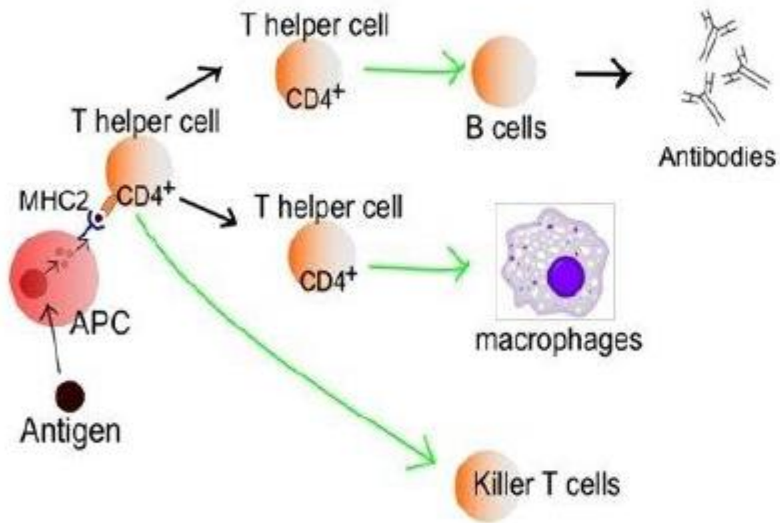

Decrease in Bone mass
% reduction
105
100
95
90
85
80
0
10
20
30
40
Months
Space
Postmenopausal women

Counter measurements

- Weight loading exercises (still will be bone loss)
- Centrifugation (reduces Ca loss from rat long bone)
- Nutrition (supplement diet with Ca – problem with kidney stone)
- Drugs (been effective in bed rest studies)

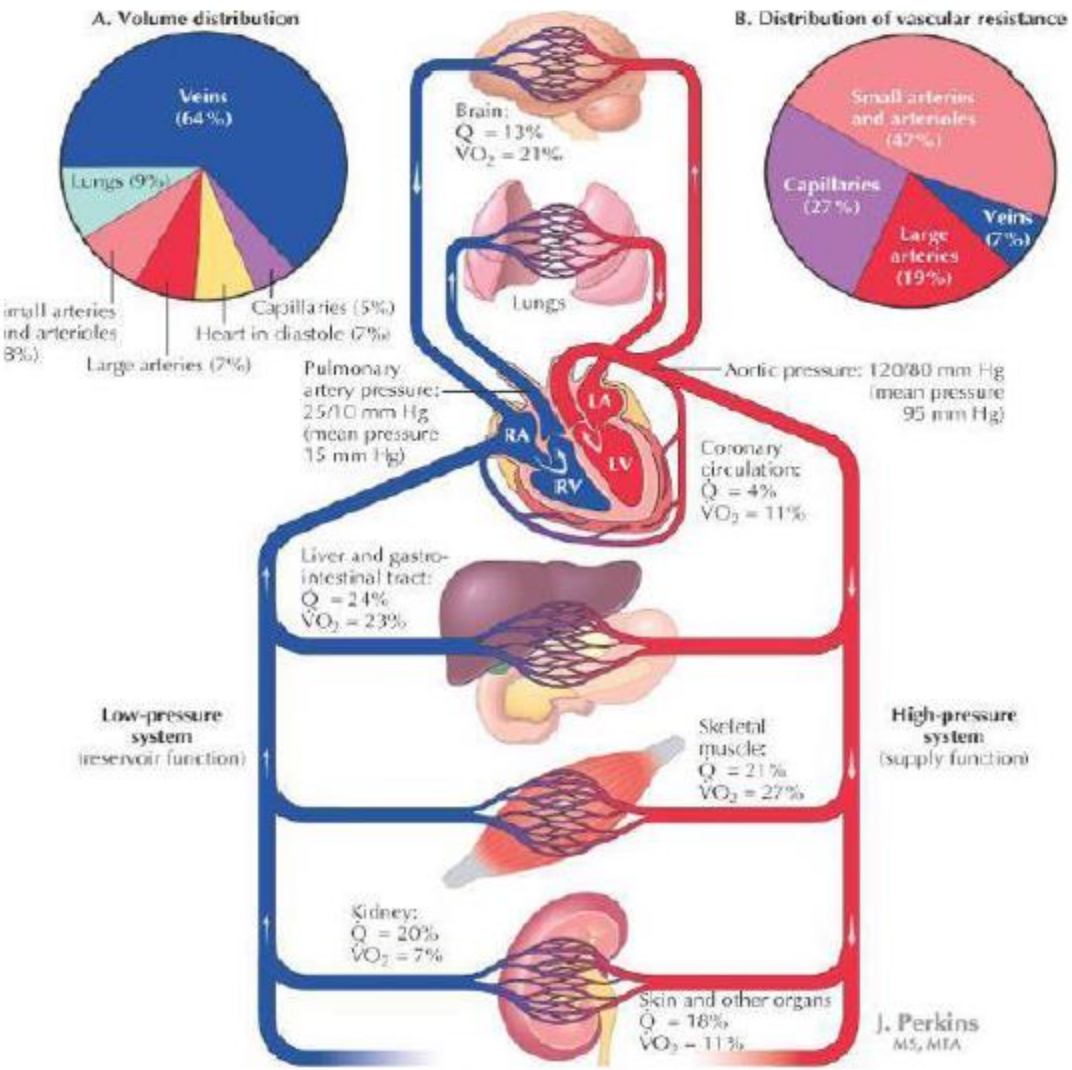
Immune system

- Human immune response may be attenuated during space flights
- Results point to a decrease in the cell mediated immune response



Cardiovascular system

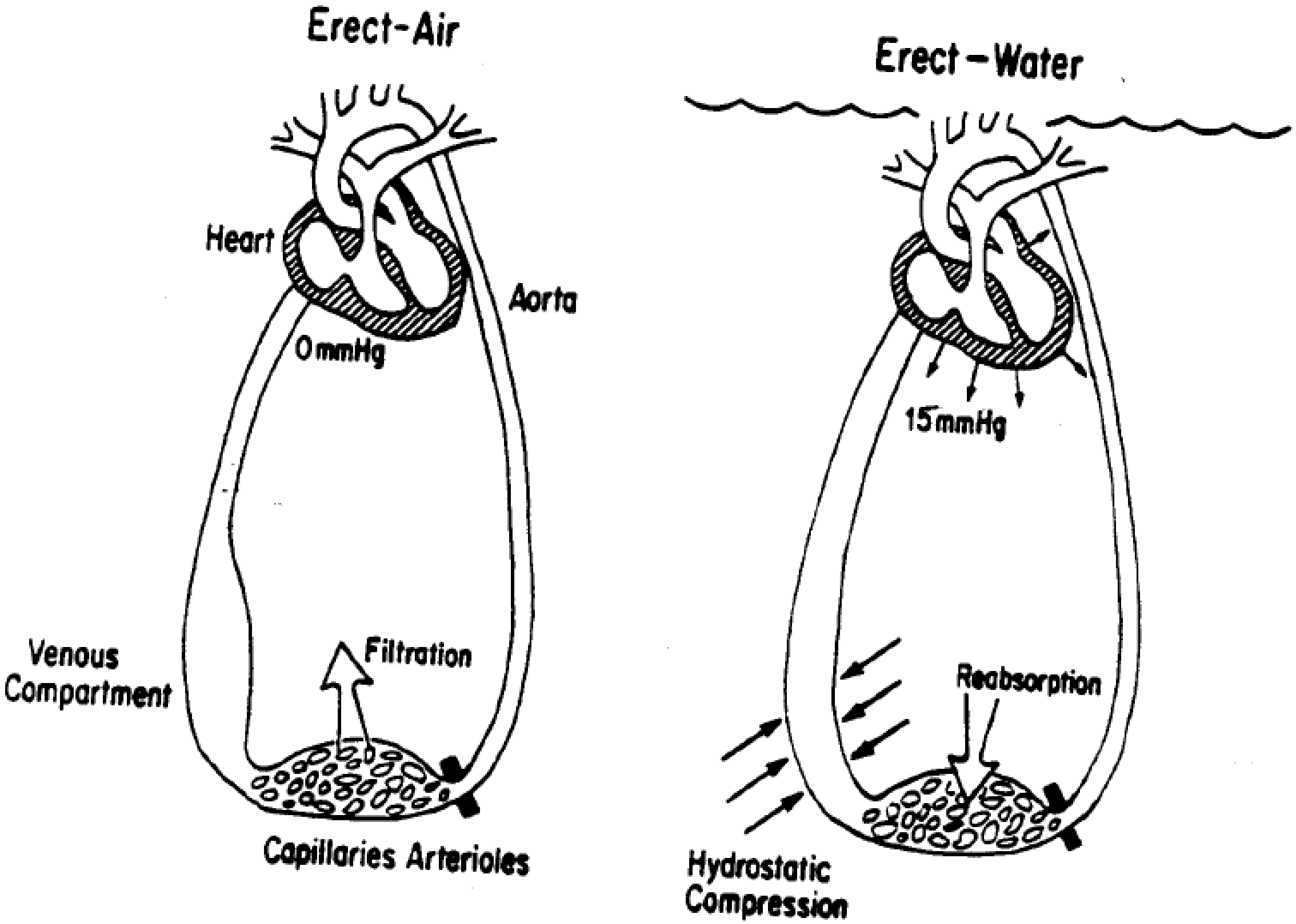
- Heart
- Lungs
- Blood vessels
- Blood



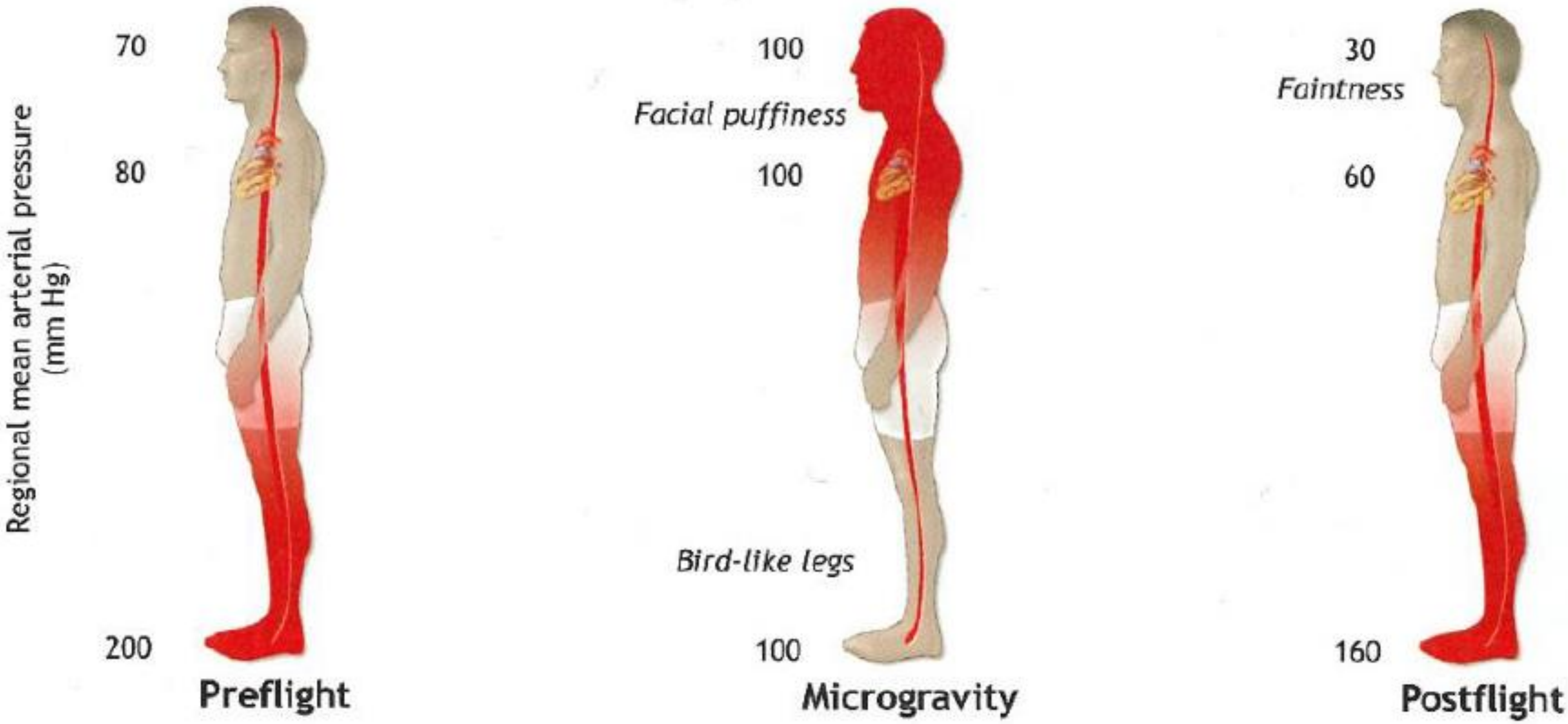
Cardiovascular problems

- Puffy face
- Fluid loss
- Anemia (RBC)
- Increased stress on the heart
- Post flight orthostatic intolerance (fainting)

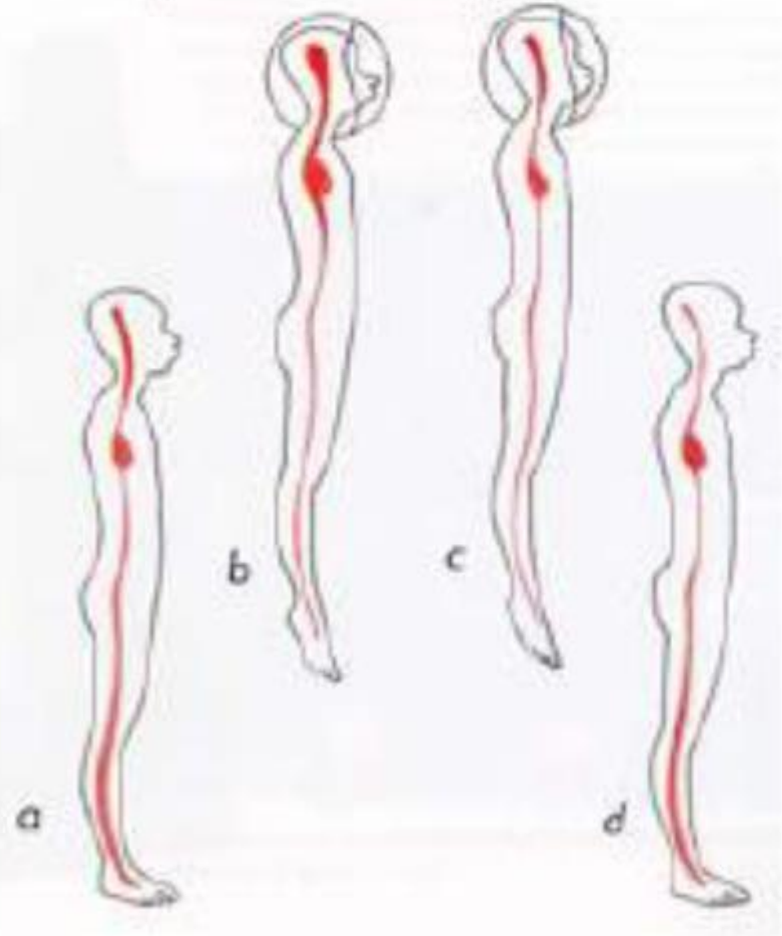
Increased stress on the heart



Microgravity
(Loss of Hydrostatic Gradient)

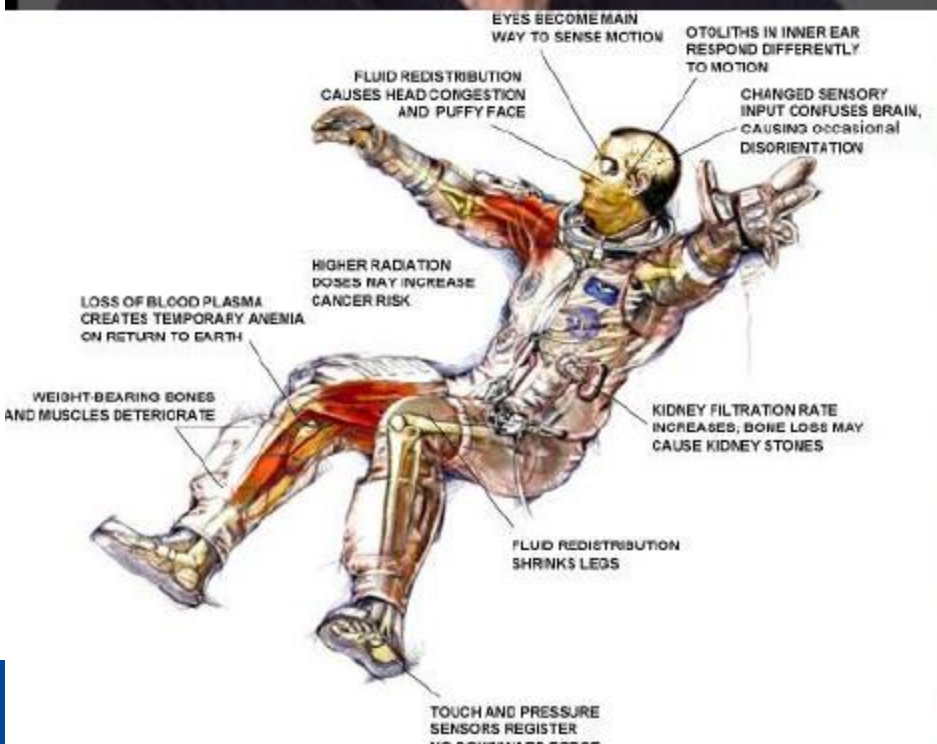


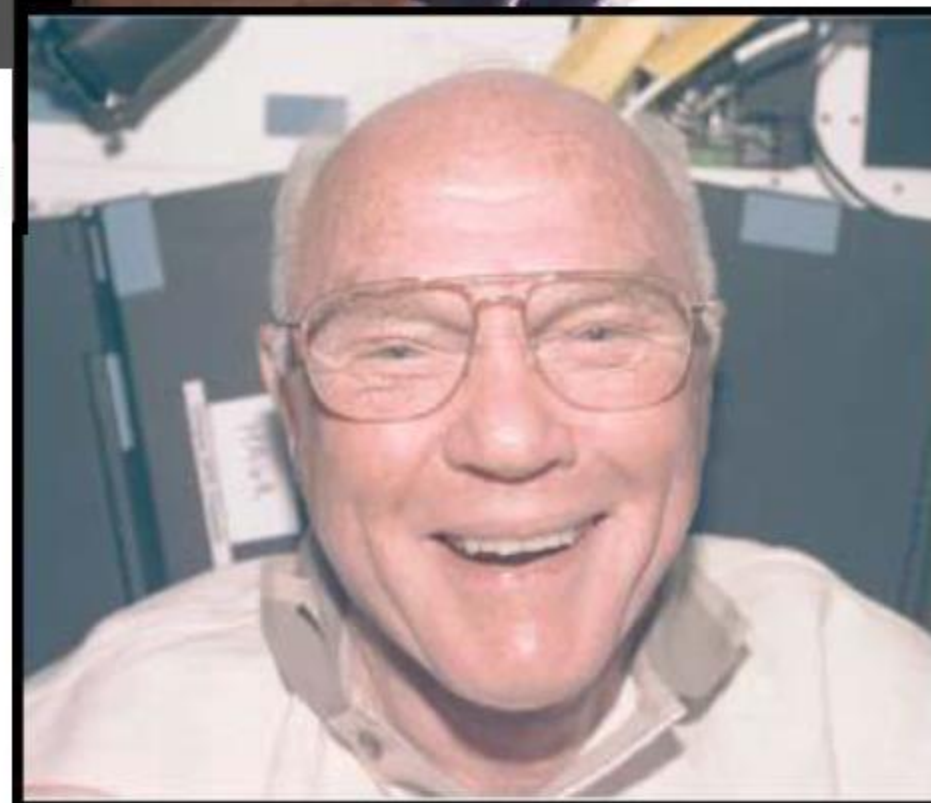
Cephalid (Headward) Fluid Shift



Assignment

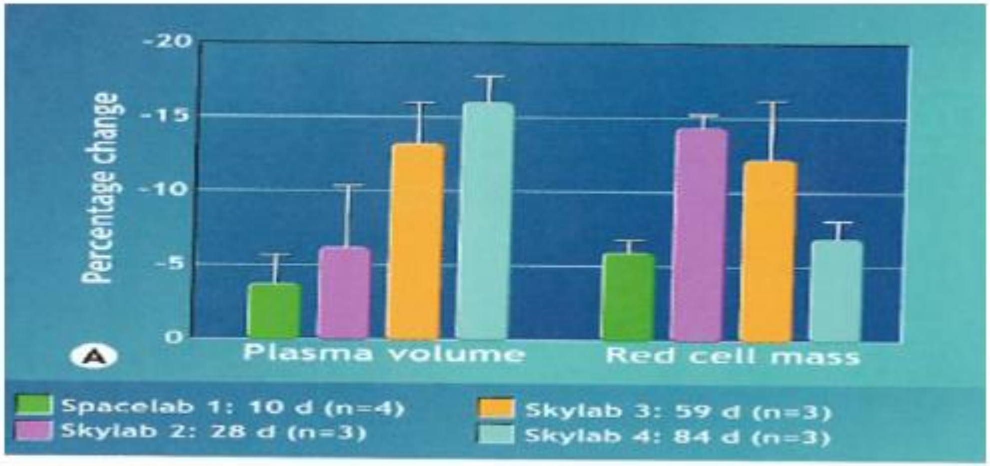
Exposure to Microgravity



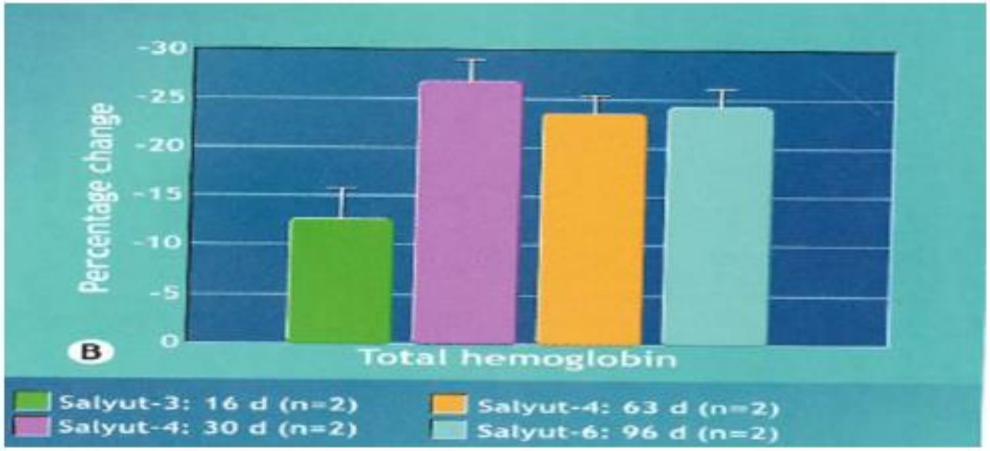


Pre- to post flight changes

A) Change in Plasma volume and Red cell mass



B) Change in Total hemoglobin

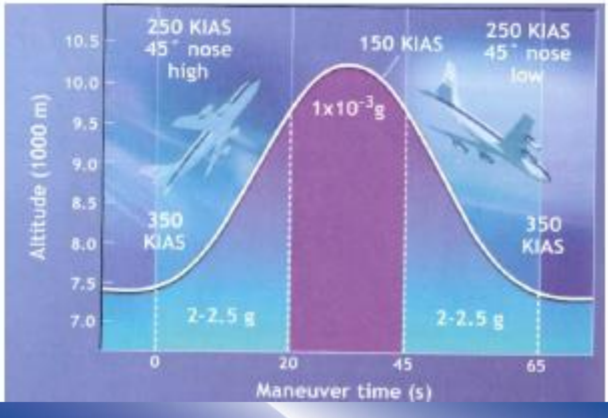


Countermeasures

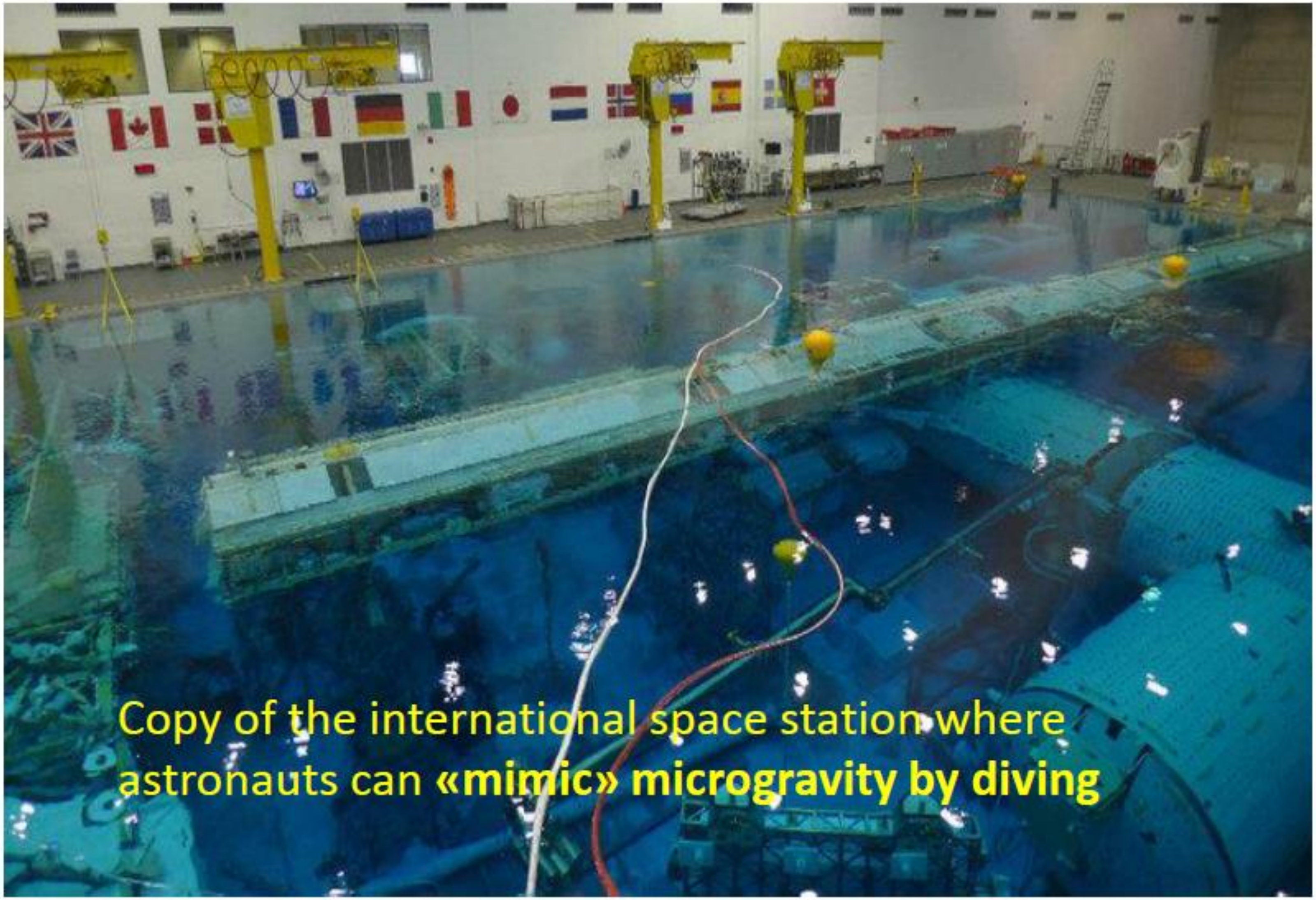
- Body fluid loading
- Electrolytes
- Lower body negative pressure (LBNP) suits

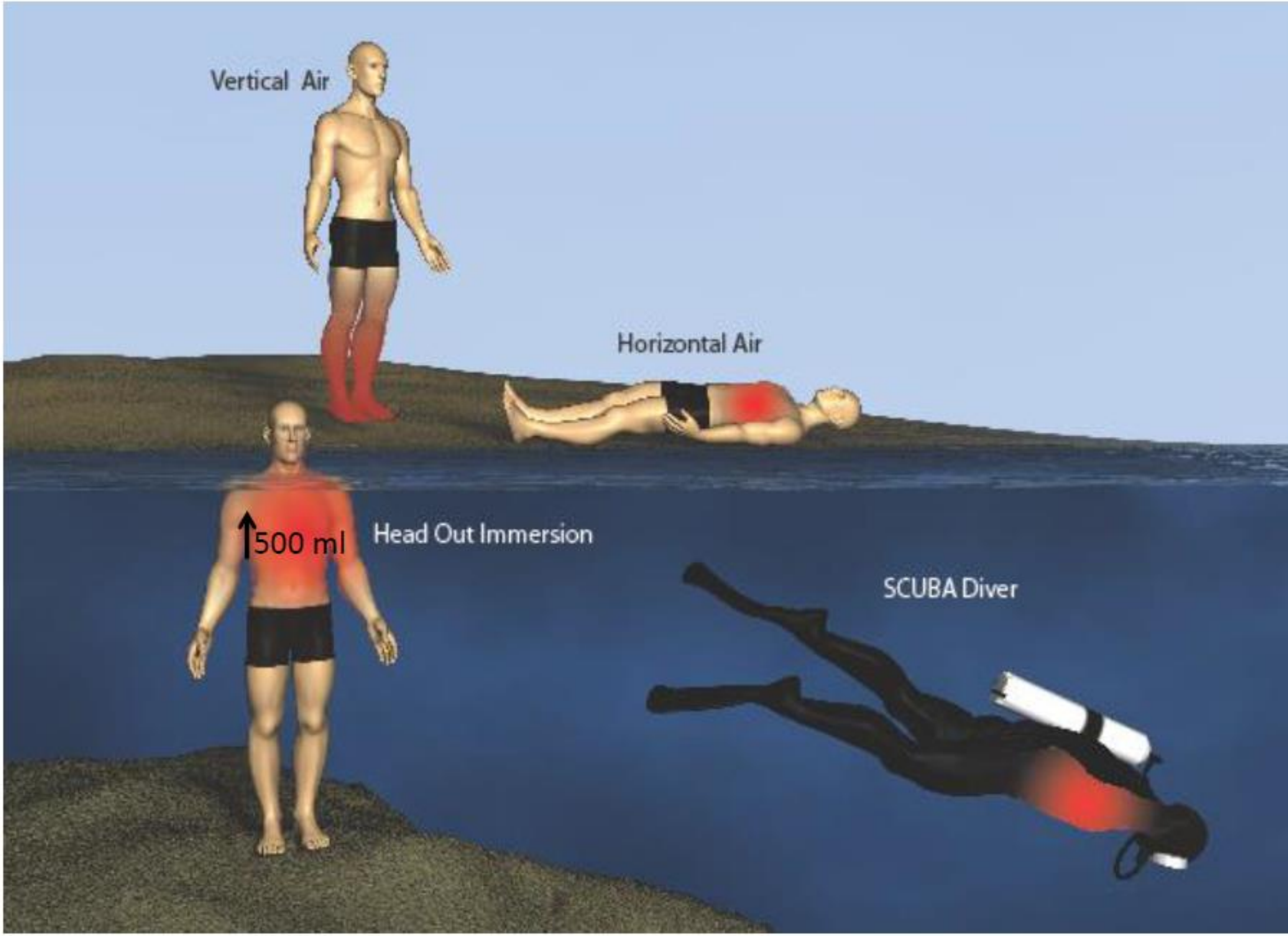
5 strategies to simulate microgravity environment

1. **Head-Down Bed Rest**
   - Confined to bed up to many months. Yielded most information
2. **Wheelchair Confinement of Paraplegics**
   - Effects from upper body exercise is useful
3. **Water immersion**
   - Mimic EVA and study cardiovascular changes
4. **Immobilization and confinement**
   - Study muscle function in "immobilized" arm. Hand limb suspension in animals
5. **Parabolic flights**
   - Aircraft achieves brief periods of weightlessness



National Buoyancy Laboratory, NASA




Vertical Air
Horizontal Air
500 ml
Head Out Immersion
SCUBA Diver

Things (and people) float!

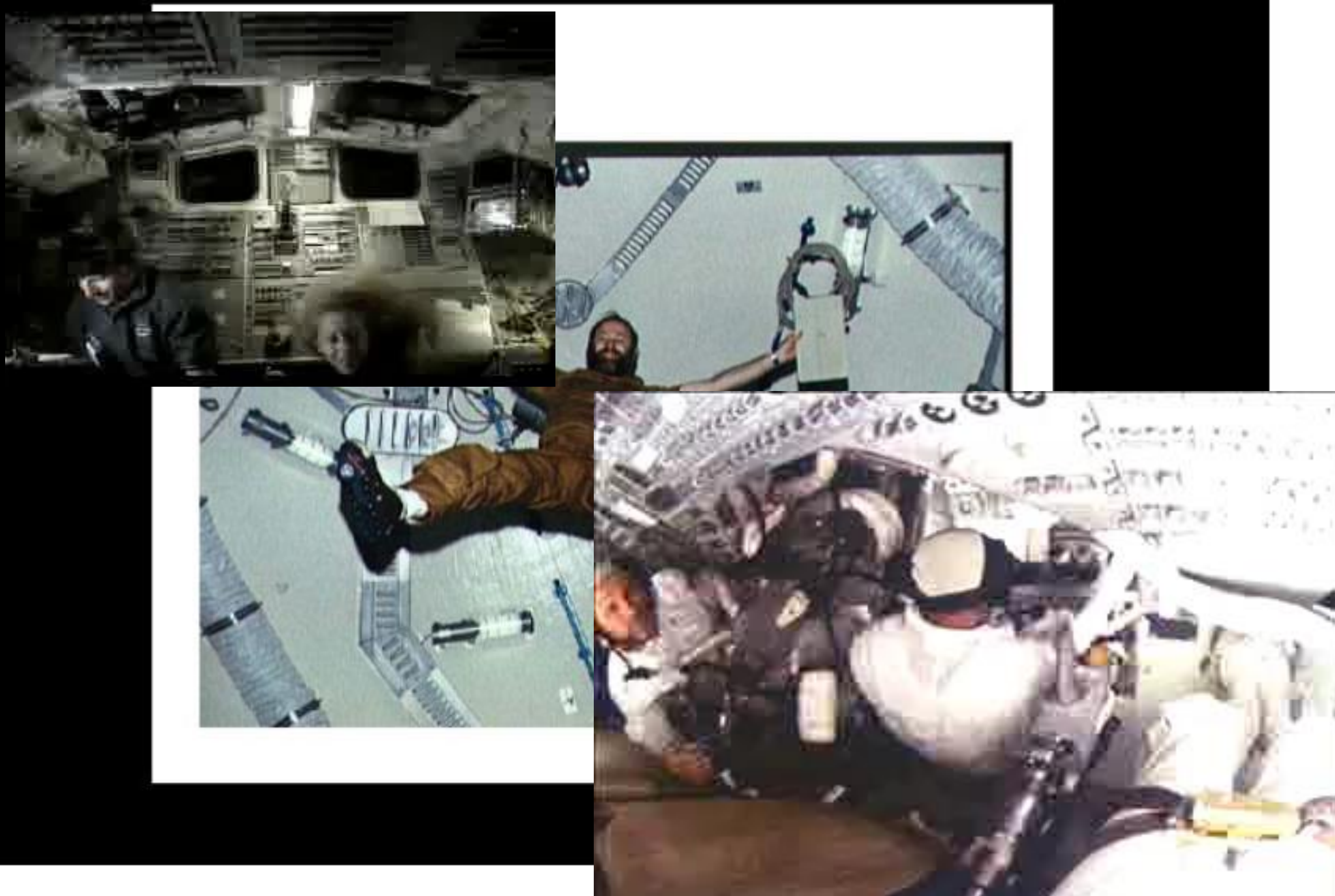


Figure 2–4. Skylab-4 astronauts demonstrate the effect of microgravity on weight.

EVA - Extravehicular Activity

Current state of EVA's

Existing NASA EVA architecture is over 36 years old (1977) and has evolved from Apollo, Skylab and Shuttle technology and operations

A United States Airlock: Doorway to Space

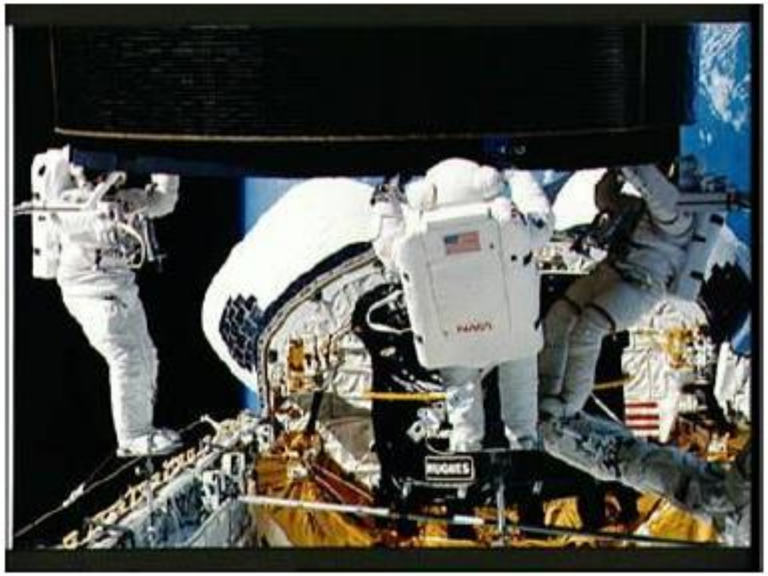
U.S. “Quest” Airlock

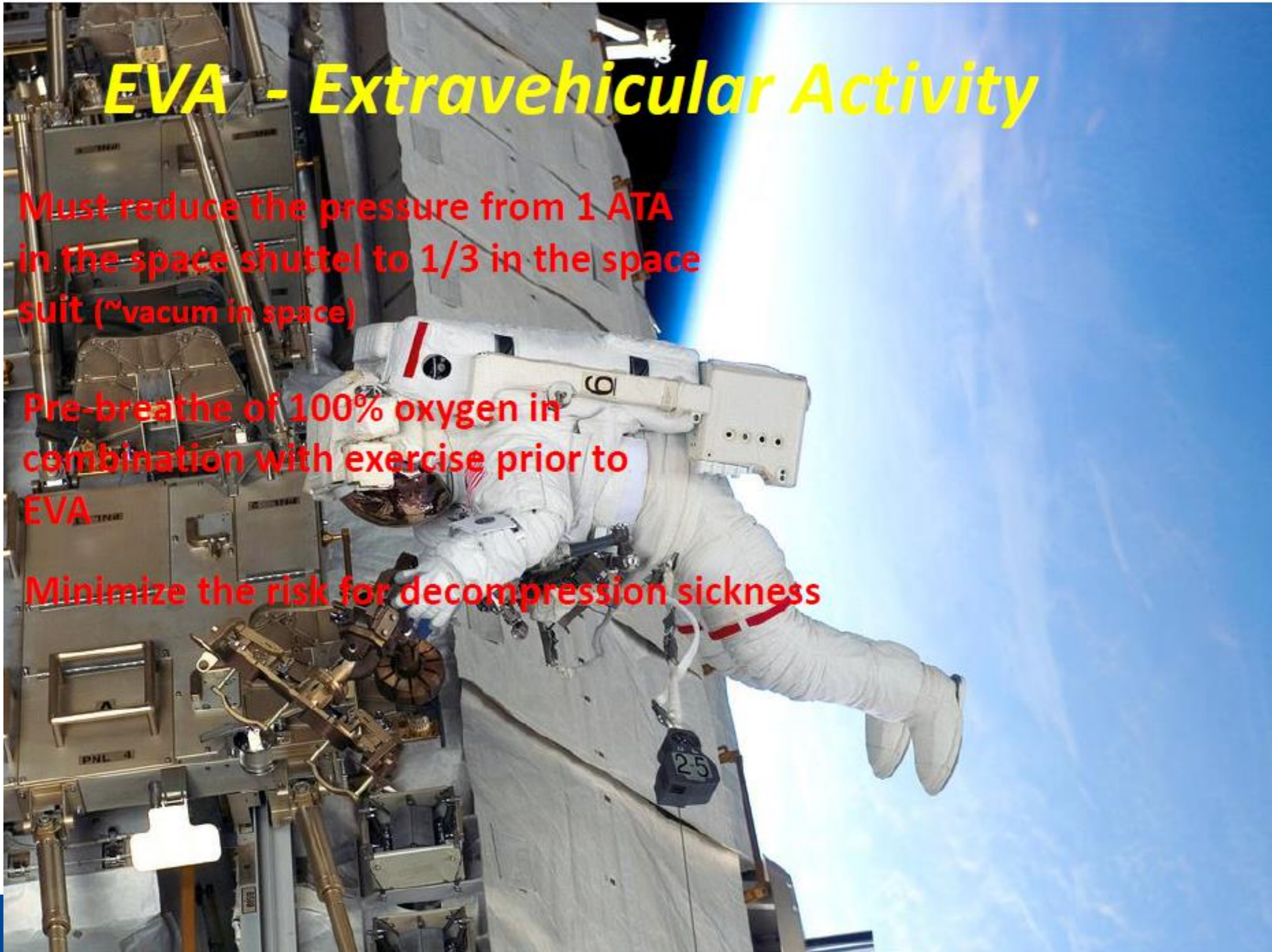
Historical overview of EVA

- The first EVA: Alexi Leonov, March 18, 1965.

U.S. EVA Experience

- Gemini (60-tallet): 9 EVA, 12 hours and 22 min
- Apollo (69-72): 7 EVA,170 hours
- Skylab (70's): 10 EVA, 82.5 hours
- Space shuttle (80's-→2011): >200 EVA, >1000 hours
- ISS: >100 EVA, > 1000 hours





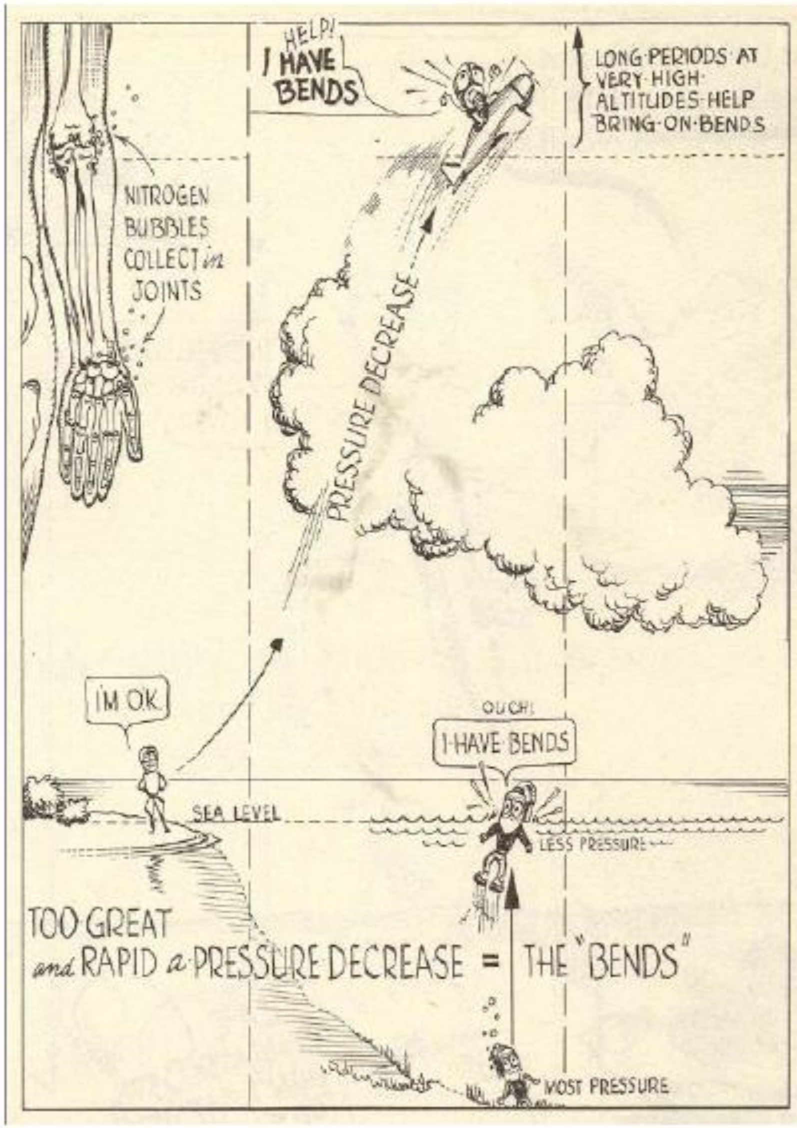
EVA - Extravehicular Activity

Must reduce the pressure from 1 ATA in the space shuttel to 1/3 in the space suit (~vacum in space)

Pre-breathe of 100% oxygen in combination with exercise prior to EVA

Minimize the risk for decompression sickness

Decompression sickness (DCS)



"DCS is various symptoms and signs caused by bubbles in blood and tissue due to reduction of ambient pressure"

May be a problem for divers, aviators and astronauts

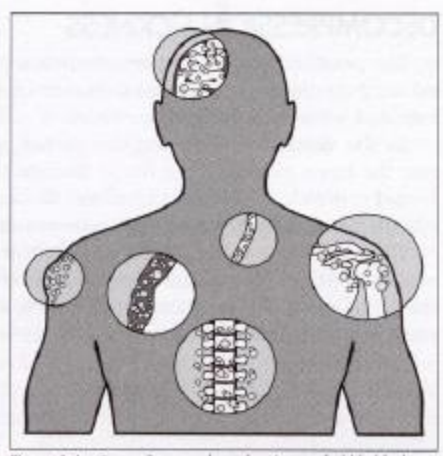
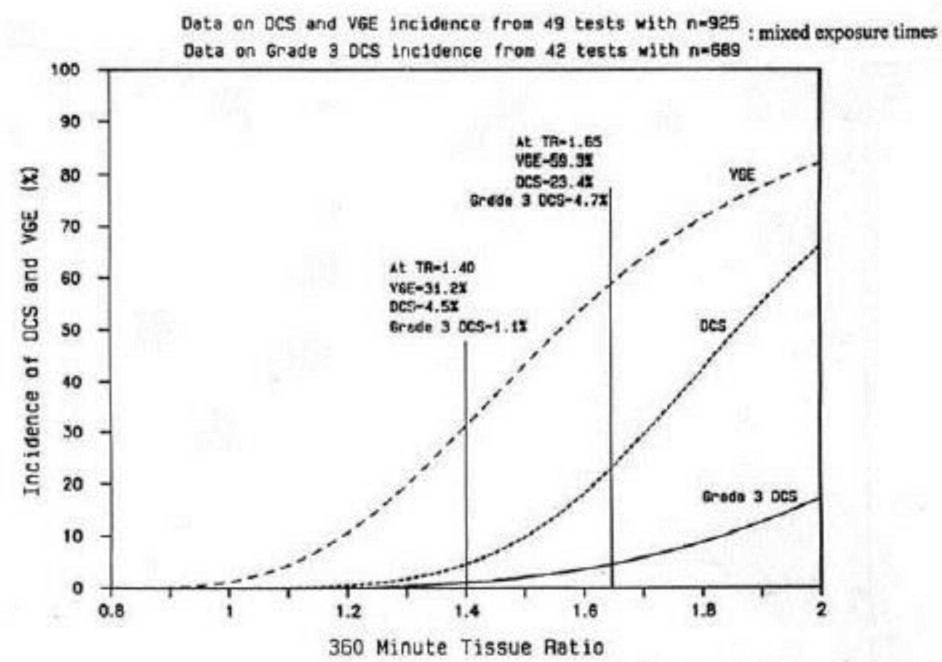
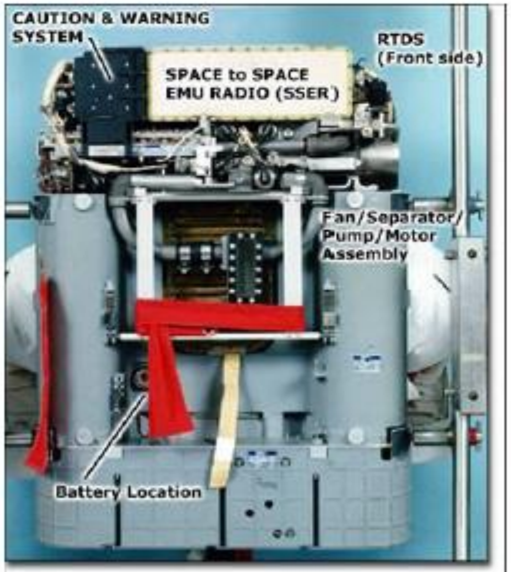


Figure 4-4 Depending on where the nitrogen bubble blockages form, a variety of problems can result.

The risk for DCS in Space

- EVA: Pressure reduction from 1 ATM (14.7 psi) → 1/3 ATM (4.3 psi), 4-8 hours exposure
- Simulation in chamber: VGE ~60%, DCS ~23%





Enabling Research

Air Force Research Laboratory

Brooks AFB, Texas

Dual-Cycle Ergometer used for Exercise-Enhanced Prebreathe

10 minutes 75% V02peak, 88% lower body, 12% upper body

ORIGINAL RESEARCH

Exercise-Enhanced Preoxygenation Increases Protection From Decompression Sickness

JAMES T. WEBB, M.S., Ph.D., MICHELE D. FISCHER, B.S., CRISTINE L. HEAPS, B.S., M.A., and ANDREW A. PILMANIS, M.S., Ph.D.

WEBB JT, FISCHER MD, HEAPS CL, PILMANIS AA. *Exercise-enhanced preoxygenation increases protection from decompression sickness.* Aviat Space Environ Med 1996; 67:618–24.

Introduction: Prevention of decompression sickness (DCS) during exposure to altitude equivalents of 30,000 ft (9144 m) requires extensive denitrogenation. In preparation for extravehicular activity (EVA), present NASA policy is to denitrogenate using a 10.2 psia staged decompression of the entire shuttle for at least 12 h, including 100 min of preoxygenation (breathing 100% oxygen at 14.7 psia prior to decompression), before decompression to the 4.3 psia (30,000 ft; 9144 m) suit pressure. This staged decompression provides the same or better protection from DCS as a 3.5 or 4-h preoxygenation used on earlier Shuttle EVA's. For high altitude reconnaissance flights at similar cockpit altitudes, a 1-h preoxygenation is currently required. **Methods:** We have investigated the use of a 1-h and a 15-min preoxygenation period, each beginning with 10 min of dual-cycle ergometry performed at 75% of each subject's peak oxygen consumption ($\dot{V}O_{2peak}$) to enhance preoxygenation efficiency by increasing perfusion and ventilation. Male subjects accomplished a 1-h preoxygenation with exercise, a 15-min preoxygenation with exercise, or a 1-h resting preoxygenation before exposure to 4.3 psia for 4 h while performing light to moderate exercise. **Results:** Incidence of DCS following the 1-h preoxygenation with exercise (42%; n = 26) was significantly less than that following the 1-h resting preoxygenation (77%; n = 26). Incidence and onset of DCS following the 15-min preoxygenation with exercise (64%; n = 22) was not significantly different from the incidence following the 1-h resting control. **Conclusions:** Preoxygenation with exercise has been shown to provide significantly improved DCS protection when compared with resting preoxygenation.

EXPOSURE TO THE ALTITUDE equivalent of 30,000 ft (4.3 psia; 9144 m) during extravehicular activity (EVA) or high altitude reconnaissance flight involves a risk of decompression sickness (DCS) (18,21). Formation and growth of gas emboli are believed to have a central role in the clinical manifestations of DCS. Venous gas emboli (VGE) and tissue gas emboli are formed due to tissue supersaturation with nitrogen following decompression from ground level.

Denitrogenation is the process of removing nitrogen from the tissues by inspiring gas with a lower partial pressure of nitrogen than contained in the body fluids and tissues. Denitrogenation reduces the potential for nitrogen supersaturation and subsequent gas emboli formation during the decompression. Breathing 100% oxygen prior to decompression (preoxygenation or prebreathing) is a common method of denitrogenating to reduce the risk of DCS (26). Improvement in denitrogenation efficiency would have application in both the space program and high altitude aviation.

Denitrogenation before extravehicular activity (EVA): Prior to EVA from the Space Shuttle's 14.7 psia environment (160 mm Hg PO_2), a staged decompression is the primary method of denitrogenation (21) because it has been shown to provide protection comparable to a 4-h preoxygenation at 14.7 psia. The staged decompression procedure begins with 1 h of preoxygenation at 14.7 psia, followed by decompression of the entire Shuttle to 10.2 psia for at least 12 h while the crew breathes 26% oxygen (137 mm Hg PO_2; equivalent to breathing atmospheric air at about 4200 ft; 1280 m), and then an additional 40-min period of breathing 100% oxygen at 10.2 psia before decompression to 4.3 psia. The staged decompression results in a 360-min theoretical tissue ratio (TR) of nitrogen (Final Tissue pN_2/Absolute Ambient Pressure) that is close to the TR resulting from a 4-h preoxygenation (1.70 vs 1.60; 8). However, the staged method also results in engineering problems such as reduced instrument cooling capacity due to lower air density. Time-efficient preoxygenation techniques allowing decompression directly from 14.7–4.3 psia while providing protection comparable to staged decompression would be preferable.

Preoxygenation before high altitude flight: A 1-h preoxygenation is presently required prior to most high-altitude flights. Surveys of the high altitude reconnaissance community (both active and retired) have revealed that over 60% had experienced DCS and that 4.2% of the flights involved symptoms; many with neurologic involvement (5). An improvement in the preoxygenation procedure could increase pilot safety and enhance operational efficiency and responsiveness.

From KRUG Life Sciences Inc. (J. T. Webb, M. D. Fischer, and C. L. Heaps), and High Altitude Protection Research, Armstrong Laboratory (A. A. Pilmanis), AL/CFTS, 2504 Gillingham Drive, Suite 25, Brooks AFB, TX.

This manuscript was received for review in April 1995. It was revised in September and December 1995, and was accepted for publication in December 1995.

Address reprint requests to: James T. Webb, Ph.D., 13818 Chittim Oak, San Antonio, TX 78232.

Exercise Prebreathe Protocol:

- Overview- The exercise prebreathe protocol has been used successfully on 34 EVAs from the International Space Station (ISS)- no DCS
  - Five Shuttle assembly flights and two increment EVAs
    - Starting in July 2001
  - These assembly missions would have been difficult or impossible to execute as base-lined, without the protocol

Space Fatalities

- Soviet Space Program
  - 1 Fatality – Soyuz 1 (1967) parachute entanglement during reentry
  - 3 Fatalities – Soyuz 11 (1971) cabin decompression during reentry
- U.S. Space Program
  - 3 Fatalities – Apollo 1 pad fire
  - 7 Fatalities – Challenger STS 51L (1986) launch breakup
  - 7 Fatalities- Columbia (2003) breakup 15 min before landing

Medical Evacuation from Space

- Salyut 5 (1976) station abandoned 49 days into 54 day mission for intractable headaches
- Salyut 7 (1985) evacuation at 56 days into 216 day mission for sepsis/ prostatitis
- Mir (1987) evacuation at 6 months into 11 month mission for cardiac dysrhythmia

Medical events in Russian Space Program

- Events not resulting in mission termination or early return
  - Spacecraft fires - 1971, 1977, 1988, 1997
  - Kidney Stone - 1982
  - Hypothermia during EVA - 1985
  - Psychological stress reaction - 1988
  - Spacecraft depressurization -1997
  - Toxic atmosphere - 1997

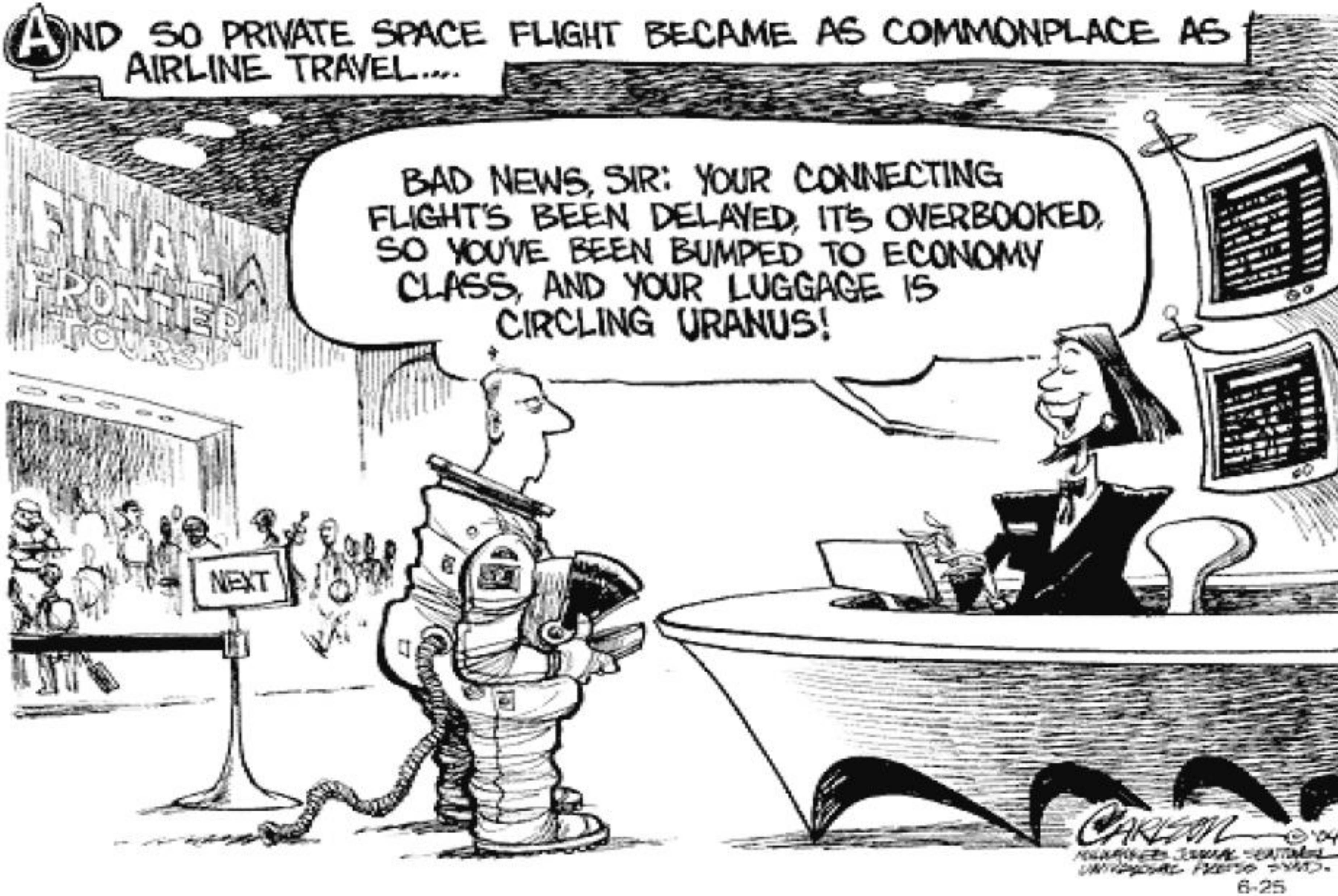
Medical symptoms in U.S. Space Program

- Shuttle program (89 shuttle missions) 1981-1998
- 508 crew (439 men, 69 women)/ 4443 flight days
  - 79% reported Space Motion Sickness
  - 98% reported some medical symptom
    - 67% reported headache
    - 64% reported respiratory complaints
    - 59% reported facial fullness
    - 32% reported gastrointestinal complaints
    - 26% reported musculoskeletal complaints

The Future

Space Tourism


Virgin
GALACTIC
XCOR
LYNX
DCX
NASA
ROCKETPLANE
40
Lotus's 155mph all-electric SUV
42
A cellphone that saves your skin
SPACE TOURISM
AND AWAY
bid to rocket tourists into orbit,
Blue Origin unveils a flying pod.
voyage sooner than you think?


AND SO PRIVATE SPACE FLIGHT BECAME AS COMMONPLACE AS AIRLINE TRAVEL....
FINAL FRONTIER TOURS
BAD NEWS, SIR: YOUR CONNECTING FLIGHT'S BEEN DELAYED, IT'S OVERBOOKED, SO YOU'VE BEEN BUMPED TO ECONOMY CLASS, AND YOUR LUGGAGE IS CIRCLING URANUS!
NEXT
CARLSON ©'04
6-25

Do you want to go into space??

COMMERCIAL ORBITAL FLIGHTS

Space Adventures
Russian Aviation Space Agency (Rosaviakosmos)
Rocket Space Corporation Energia (RSC Energia)

Dennis Tito (April 2001)
Mark Shuttleworth (April 2002)
Greg Olsen (October 2005)
Anousheh Ansari (September 2006)
Charles Simony (April 2007)
Richard Garriott (October 2008)
Charles Simony (April 2009)

Most of the medical and physiological data collected to date are based on the effects of space flight on generally normal and healthy individuals (career astronauts and cosmonauts)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Professor Stephen Hawking
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