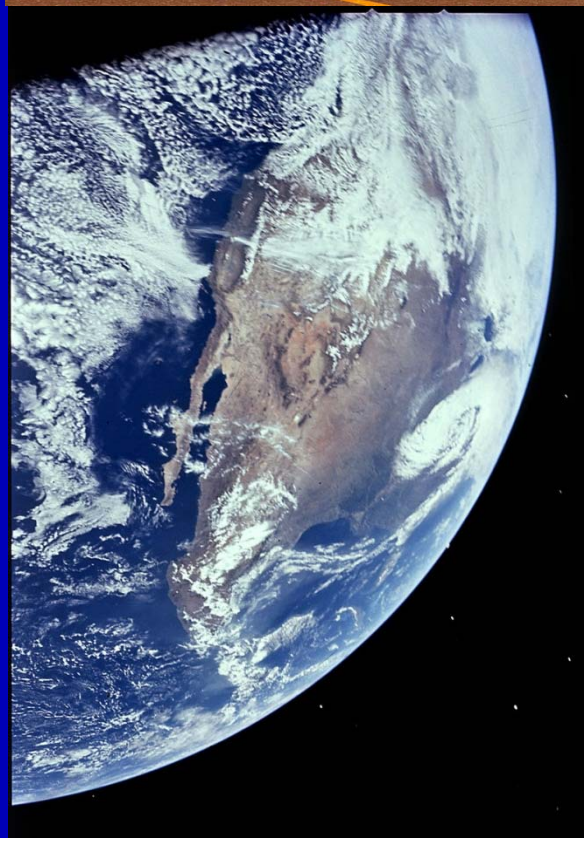
**Federal Aviation Administration**

# Commercial Human Space Flight Medical Issues



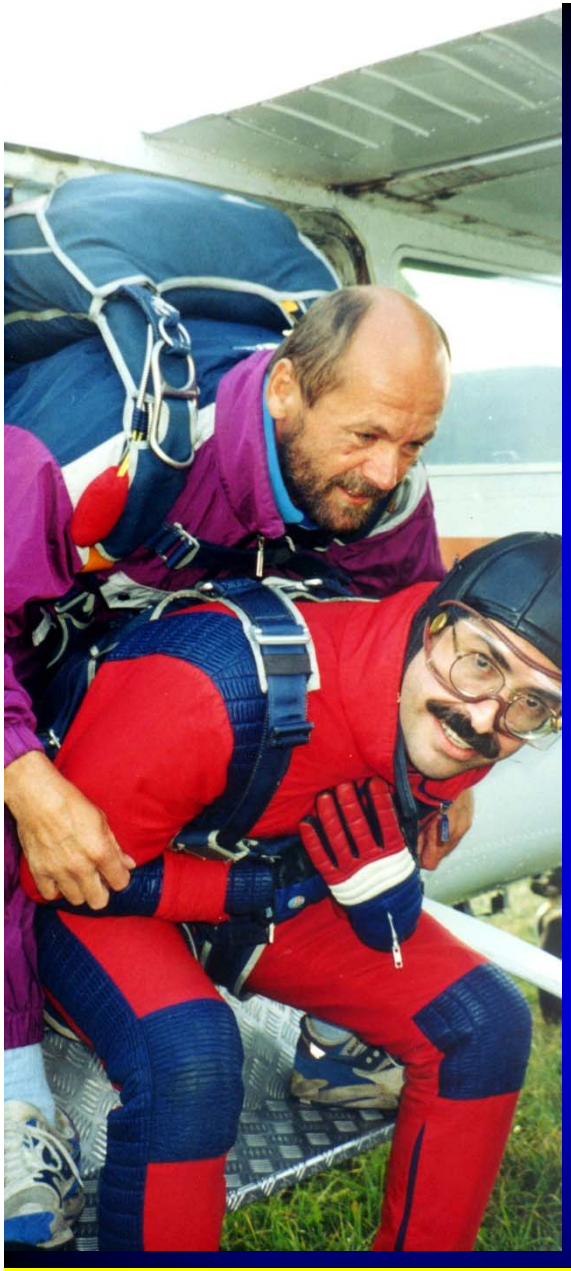
**Presented at:** *CSTC*

**By:** *Melchor J. Antuñano, M.D., M.S.*

*Director, Civil Aerospace Medical Institute*

**Date:** *February 2014*

# Open your Eyes to See New Possibilities

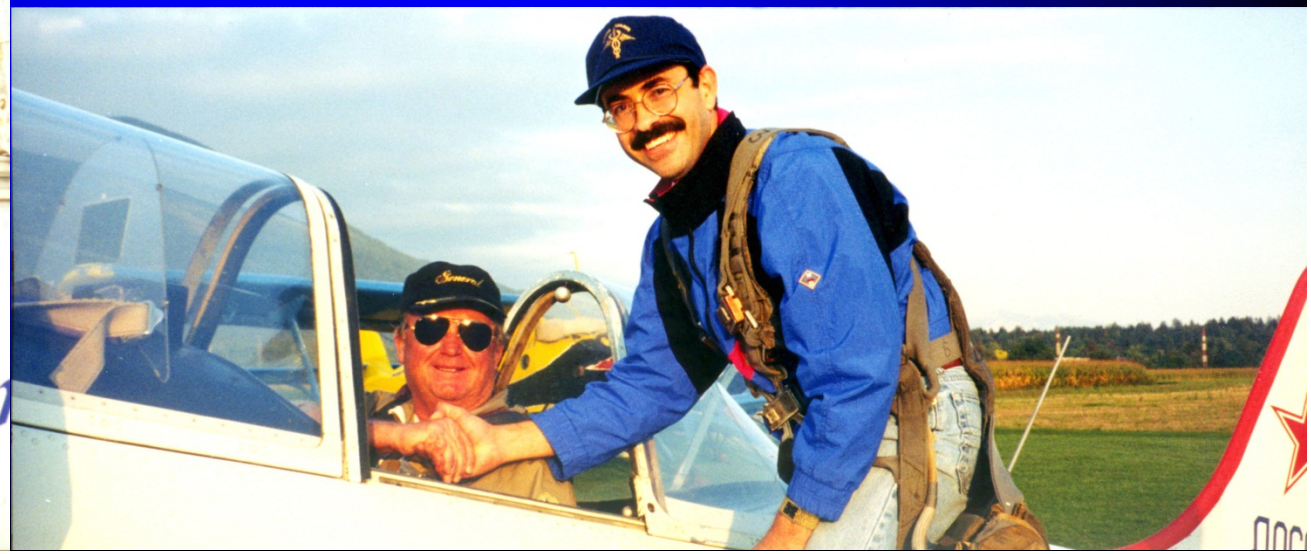


*At the same time, the public has the right to take some personal risks!*

"The greatest danger for most of us is not that our aim is too high and we miss it, but that it is too low and we reach it"

*Michelangelo*

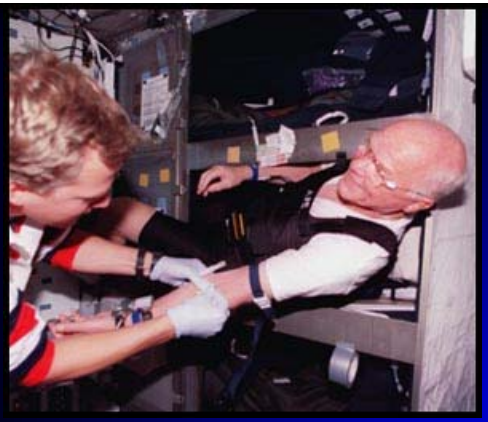
Risk assessment, prevention, and mitigation requires an effective multi-disciplinary stepwise approach



# Would you Like to Fly in Space?

# *Populations Impacted by Commercial Space Flights*

## Crews & Spaceflight Participants



# Do we know

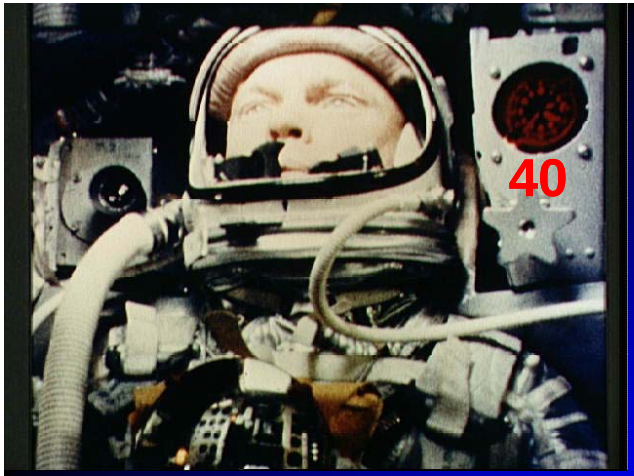
# *all the* Medical Risks

# *of Flying* in Space?

# NO!

We have very limited medical experience and knowledge on individuals with significant medical problems who have flown in space

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)

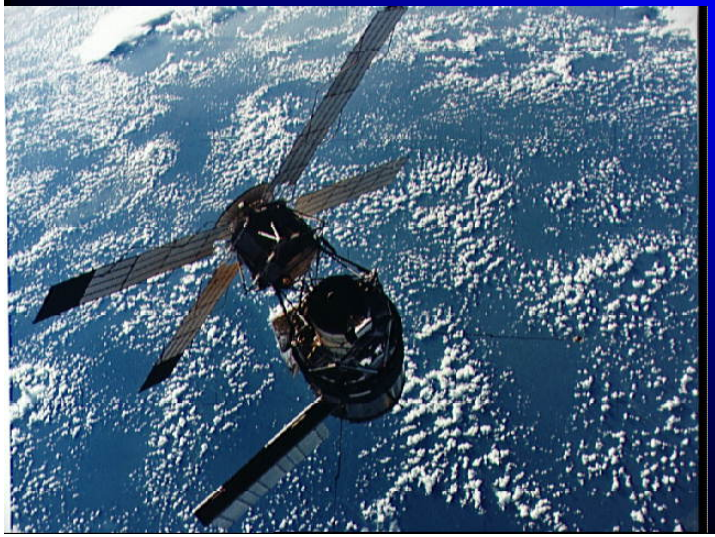


Until now most people who have flown in space are <u>healthy career astronauts aged 35 to 50 years old (only exception is John Glenn)</u>

Due to medical privacy regulations and career considerations <u>individual medical data from career astronauts is not available for study by the scientific community</u>

# What Medical Data is Available to the Public?

# *U.S. Government Space Program Experience with Medical Pathology*



NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

# Ground Medical Events Among U.S. Astronauts

| MEDICAL EVENT | FREQUENCY |
|---|---|
| Allergic reaction (severe) | 1 |
| Choledocholithiasis | 3 |
| Retinal detachment | 2 |
| Pancreatitis | 2 |
| Appendicitis | 2 |
| Diverticulitis | 1 |
| Ventricular tachycardia | 1 |
| Atrial fibrillation | 1 |
| Coronary artery disease | 1 |
| Hemorrhagic cyst | 1 |
| Abdominal pain | 1 |
| Duodenal ulcer | 1 |

SOURCE: Jon Clark, MD, Space Medicine Liaison, National Space Biomedical Research Institute, Baylor College of Medicine, Personal Communication, 2007

| | |
|---|---|
| Inguinal hernia | 4 |
| Ureteral calculus | 3 |
| Pneumonia | 2 |
| Sudden hearing loss | 2 |
| Cervical disk herniation with impingement on spinal cord | 1 |
| Corneal ulcer | 1 |
| Malignant melanoma | 1 |
| Severe epistaxis | 1 |
| Right ovarian cyst | 1 |
| Olecranon bursitis r/o septic joint | 1 |
| Clostridium difficile infection | 1 |
| Gastroenteritis/colitis | 1 |
| Dysmenorrhea | 1 |

SOURCE: Jon Clark, MD, Space Medicine Liaison, National Space Biomedical Research Institute, Baylor College of Medicine, Personal Communication, 2007

# SpaceCalc

# Astronaut Fatalities

| Name | Nation | Date | In-flight Fatalities |
|---|---|---|---|
| Komarov, Vladimir | USSR | 04/24/67 | Soyuz 1 parachute failure |
| Dobrovolsky, Georgy | USSR | 06/29/71 | Soyuz 11 depressurized during entry |
| Patsayev, Victor | USSR | 06/29/71 | Soyuz 11 depressurized during entry |
| Volkov, Vladislav | USSR | 06/29/71 | Soyuz 11 depressurized during entry |
| Scobee, Francis | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| Smith, Michael | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| Resnik, Judith | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| Onizuka, Ellison | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| McNair, Ronald | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| Jarvis, Gregory | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| McAuliffe, Christa | US | 01/28/86 | SRB failure; Challenger, STS-51L |
| Husband, Rick | US | 02/01/03 | Entry breakup; Columbia, STS-107 |
| McCool, William | US | 02/01/03 | Entry breakup; Columbia, STS-107 |
| Chawla, Kalpana | US | 02/01/03 | Entry breakup; Columbia, STS-107 |
| Anderson, Michael | US | 02/01/03 | Entry breakup; Columbia, STS-107 |
| Brown, David | US | 02/01/03 | Entry breakup; Columbia, STS-107 |
| Clark, Laurel | US | 02/01/03 | Entry breakup; Columbia, STS-107 |
| Ramon, Ilan | Israel | 02/01/03 | Entry breakup; Columbia, STS-107 |
| **TOTAL:** | **18** | | |
| | | | **Other Active-Duty Fatalities** |
| Freeman, Theodore | US | 10/31/64 | T-38 jet crash in Houston |
| Bassett, Charles | US | 02/28/66 | T-38 jet crash in St Louis |

| | | | |
|---|---|---|---|
| See, Elliott | US | 02/28/66 | T-38 jet crash in St Louis |
| Grissom, Virgil | US | 01/27/67 | Apollo 1 launch pad fire |
| White, Edward | US | 01/27/67 | Apollo 1 launch pad fire |
| Chaffee, Roger | US | 01/27/67 | Apollo 1 launch pad fire |
| Givens, Edward | US | 06/06/67 | Houston car crash |
| Williams, Clifton | US | 10/15/67 | Airplane crash near Tallahassee |
| Robert Lawrence | US | 12/08/67 | F-104 crash (MOL AF astronaut) |
| Gagariin, Yuri | USSR | 03/27/68 | MiG jet trainer crash near Star City |
| Belyayev, Pavel | USSR | 01/10/70 | Died during surgery |
| Thorne, Stephen | US | 05/24/86 | Private plane crash near Houston |
| Levchenko, Anatoly | USSR | 08/06/88 | Inoperable brain tumor |
| Shchukin, Alexander | USSR | 08/18/88 | Experimental plane crash |
| Griggs, David | US | 06/17/89 | Plane crash |
| Carter, Manley | US | 05/04/91 | Commuter plane crash in Georgia |
| Veach, Lacy | US | 10/03/95 | Cancer |
| Robertson, Patricia | US | 05/24/01 | Private plane crash near Houston |
| | | | **Compiled by William Harwood** |

# Short-Duration Orbital Flights

# Inflight Medical Events Among U.S. Astronauts

*106 Space Shuttle Missions (Apr 1981 – Dec 2001)*
*607 Astronauts (521 men and 86 women)*
*5,496 Flight Days*

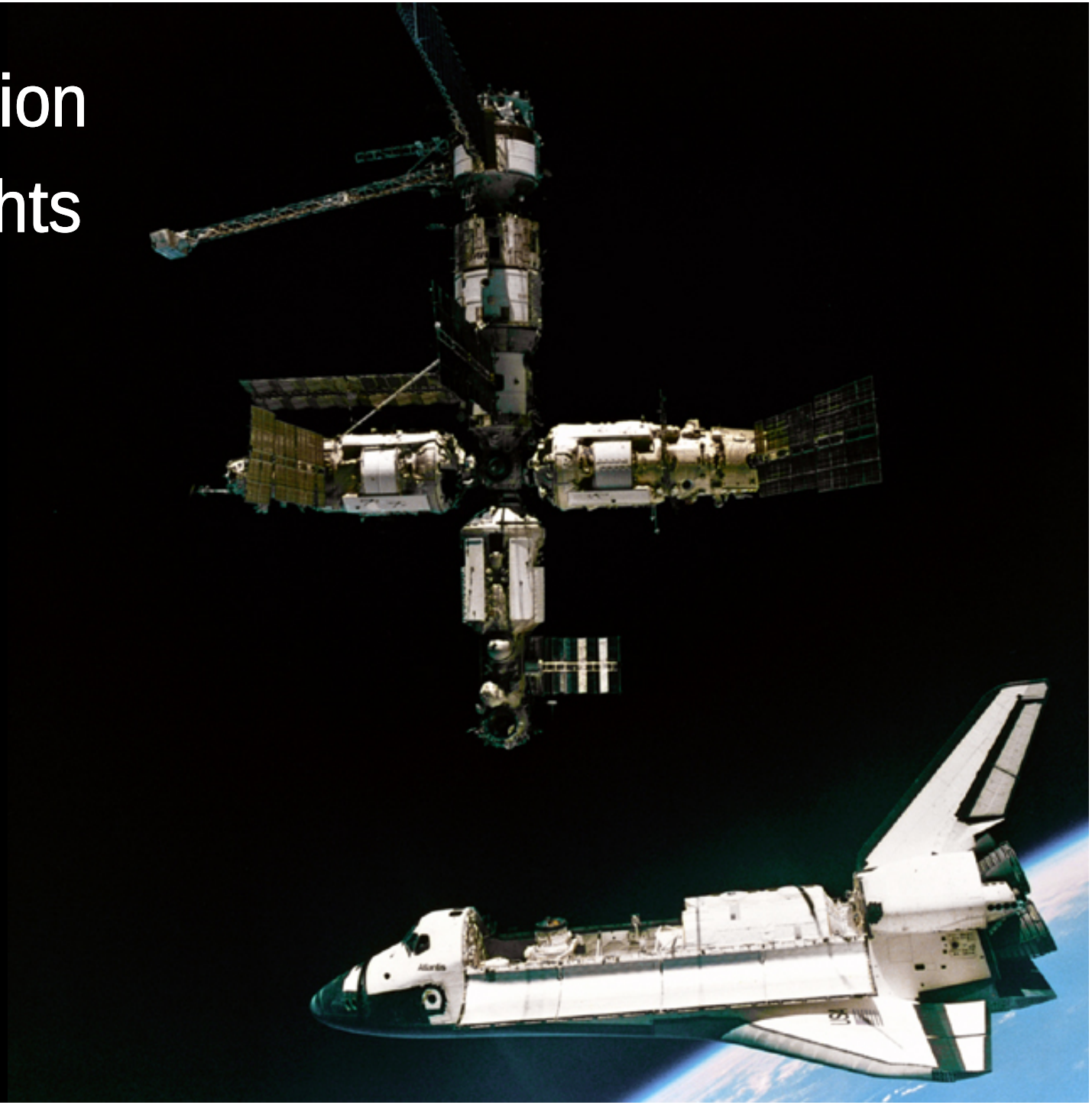
- *98.1% of men and 94.2% of women reported 2,207 medical events or symptoms during flight:*
  - Space adaptation syndrome (39.6%)
  - Nervous system and sensory organs (16.7%)
  - Digestive system (9.2%)
  - Injuries and trauma (8.8%)
  - Musculoskeletal system and connective tissues (8.2%)

- Skin and subcutaneous tissue (8%)
- Respiratory system (4.5%)
- Behavioral signs and symptoms (1.8%)
- Infectious diseases (1.3%)
- Genitorurinary system (1.5%)
- Circulatory system (0.3%)
- Endocrine, nutritional, metabolic & immunity disorders (0.1%)

194 events due to injury (including 14 fatalities)

SOURCE: Jon Clark, MD, Space Medicine Liaison, National Space Biomedical Research Institute, Baylor College of Medicine, Personal Communication

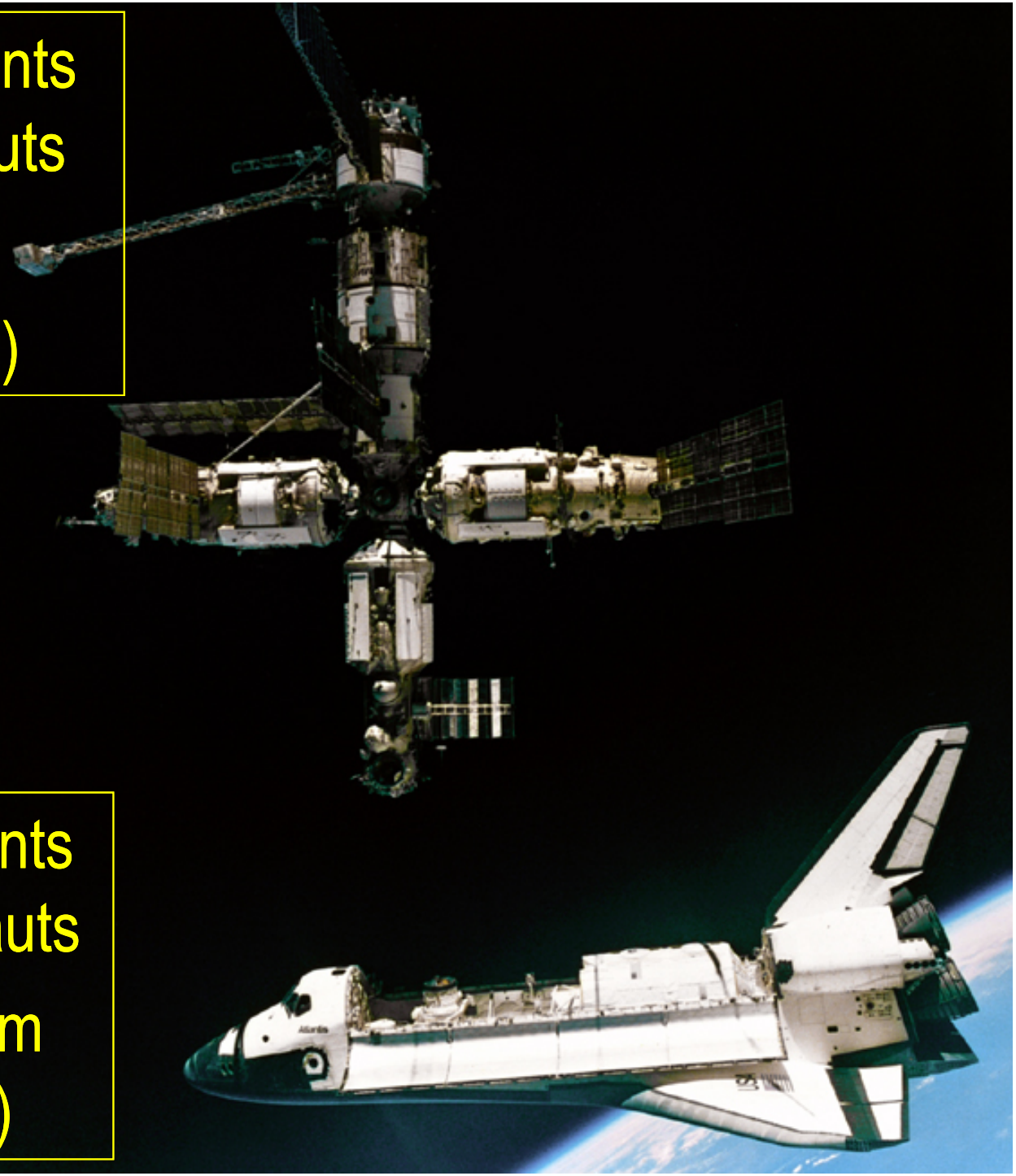
# Long-Duration Orbital Flights



Inflight Medical Events among Cosmonauts

MIR Program

(Feb 87 – Feb 96)



Inflight Medical Events among U.S. Astronauts

NASA/MIR Program

(Mar 95 – Jun 98)

# Inflight Medical Events Among U.S. Astronauts during the NASA/MIR Program (Mar 95 – Jun 98)

| MEDICAL EVENT | FREQUENCY |
|---|---|
| Musculoskeletal | 7 |
| Skin | 6 |
| Nasal congestion, irritation | 4 |
| Bruise | 2 |
| Eyes | 2 |
| Gastrointestinal | 2 |
| Hemorrhoids | 1 |
| Psychiatric | 2 |
| Headaches | 1 |
| Sleep disorders | 1 |

# Inflight Medical Events Among Cosmonauts during the MIR Program (Feb 87 – Feb 96)

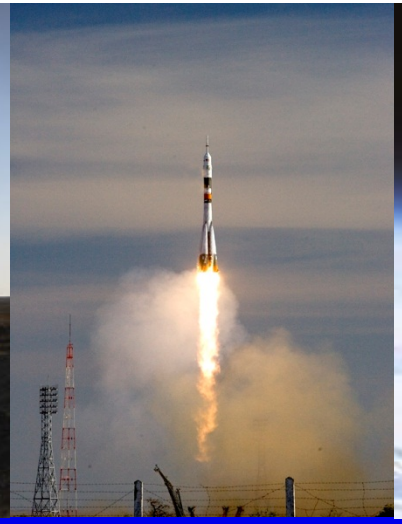
| MEDICAL EVENT | FREQUENCY |
|---|---|
| Arrhythmia/conduction disorder | 128 |
| Superficial Injury | 36 |
| Musculoskeletal | 29 |
| Headache | 24 |
| Sleeplessness | 19 |
| Tiredness | 14 |
| Contact dermatitis | 7 |

SOURCE: Jon Clark, MD, Space Medicine Liaison, National Space Biomedical Research Institute, Baylor College of Medicine, Personal Communication, 2007

| | |
|---|---|
| Conjunctivitis | 6 |
| Laryngitis | 6 |
| Asthenia | 5 |
| Erythema of face, hands | 4 |
| Acute respiratory infection | 3 |
| Surface burn, hands | 3 |
| Glossitis | 3 |
| Dry nose | 2 |
| Heartbrun /gas | 2 |
| Foreign body in eye | 2 |
| Dry skin | 2 |
| Hematoma | 1 |
| Constipation | 1 |
| Eye contusion | 1 |
| Dental caries | 1 |
| Wax in ear | 1 |

# October 11-22, 1968

- Apollo-VII
- Walter Schirra, Jr, Donn Eisele & Walt Cunningham
- Schirra develops common cold 15 hrs into the flight. Others follow later
- 7/8 onboard Kleenex® boxes used up
- Refusal to don helmets during reentry*
- Schirra anounces retirement before reentry
- Crew takes Actifed® before reentry
- Eisele and Cunningham were making their first flight and felt they had to follow their commander but, because of their actions, neither one would ever fly in space again



# *Medical Findings Among Commercial Orbital Space Flight Participants*

# COMMERCIAL ORBITAL FLIGHTS

(Soyuz TMA Launch Vehicles)

*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 (March 2009)
- Guy LaLiberte (September 2009)

Guy LaLiberte (40)

# Dr. Gregory Olsen

# Dr. Gregory Olsen

- 57 year-old man with a history of pneumothorax, moderately severe emphysema, bilateral parenchymal bullae, pulmonary and mediastinal masses, and ventricular and atrial ectopy

- Received preventive treatment of these conditions, including surgery before being cleared to fly in space

- Completed medical evaluation in analog environments (altitude chamber, high altitude mixed-gas simulation, zero-G flight, and high-G centrifuge)

Jennings RT et al. "Medical Qualification of a Commercial Spaceflight Participant: Not Your Average Astronaut." Aviat Space & Environ Med Journal, Volume 77, No. 5, May 2006. (Dr. Olsen released his medical data)

# Dr. Gregory Olsen

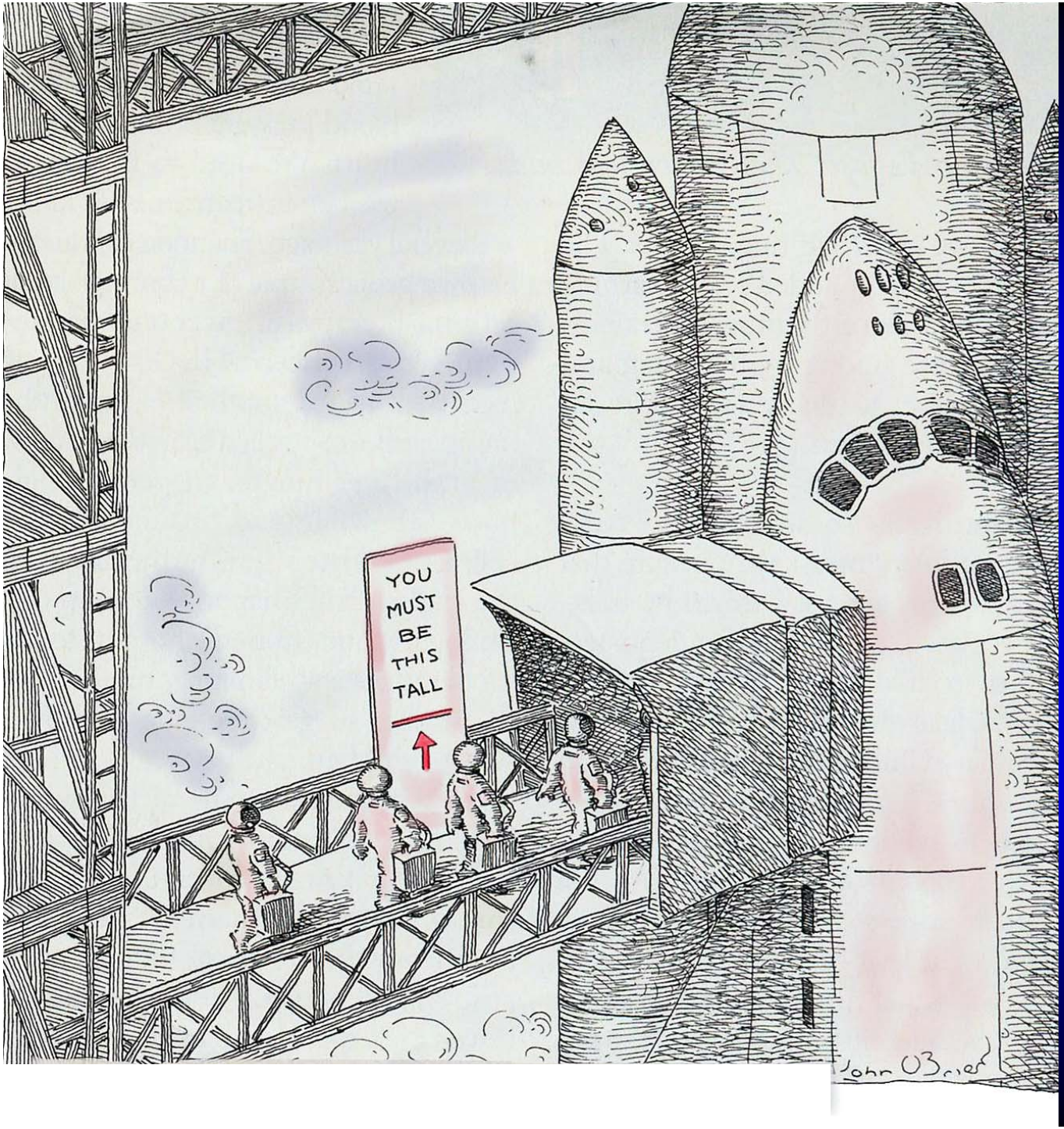
- Had no difficulties during the training and performed well during space flight
- Post-flight medical testing showed that he was in excellent condition and unchanged medically by the flight

Credit: AP Photo/Ivan Sekretarev

Jennings RT et al. "Medical Qualification of a Commercial Spaceflight Participant: Not Your Average Astronaut." Aviat Space & Environ Med Journal, Volume 77, No. 5, May 2006. (Dr. Olsen released his medical data)

Dr. Olsen made the decision to openly share his medical case

# Medical Issues may not be a Concern in the Future




However, at the present time flying in space is not like taking a role coaster ride

# Roller Coaster Fatalities in the US
## (May 15, 1994 - May 14, 2004)

- 40 people (7-77 y/o) were killed in 39 separate roller coaster incidents
- 18 died from medical conditions that might have been caused or exacerbated by riding a roller coaster
- 15 were the result of intracranial hemorrhages or cardiac problems

# Adventure Tourism Fatalities in NZ
## (June 2004 – June 2009)

- 29 deaths in 5 years
- More than 540 incidents resulted in “Serious Harm”
- Industry could provide more clarity on industry standards including operating practices and staff qualifications

# Medical Screening Guidance

# for Commercial Space Flights



Federal Aviation Administration

# What is the minimum "Right Stuff" for passengers in commercial space flights?

# *Main Risk Factors Relevant to the Development of Guidelines for Medical Screening of Space Flight Participants*

- Exposure to acceleration/deceleration
- Exposure to decreased barometric pressure
- Exposure to microgravity
- Exposure to radiation (solar and cosmic)

## *Medical screening guidance is based on the following assumptions:*

- An in-flight cabin environment with a barometric pressure not exceeding 8,000 ft (10.91 psi), where passengers will not be required to use a pressurized suit
- Passengers will be able to perform an emergency evacuation without assistance

# Orbital Space Flight Participants

Medical Guidelines for Space Passengers. Aerospace Medical Association (AsMA) Task Force on Space Travel. Aviation, Space & Environmental Medicine Journal, 72:948-950, 2001

Medical Safety and Liability Issues for Short-Duration Commercial Orbital Space Flights. Study Group 2.6, Commission 2 (Life Sciences), International Academy of Astronautics, 2009

# Sub-Orbital Space Flight Participants

Medical Guidelines for Space Passengers -II. AsMA Task Force on Space Travel. Aviation Space & Environmental Medicine Journal, 73:1132-1134, 2002.

Guidance for Medical Screening of Commercial Aerospace Passengers. Federal Aviation Administration, Office of Aerospace Medicine, Washington, D.C. 2006. Technical Report No. DOT-FAA-AM-06-1

# Sub-Orbital Crew Members

Medical Certification for Pilots of Commercial Suborbital Space Flights. AsMA Ad Hoc Committee. Aviat Space Environ Med 80: 824-826. 2009

Suborbital Commercial Space Flight Crewmember Medical Issues. Special Report. AsMA Space Flight Working Group. 2010

# International Association for the Advancement of Space Safety (IAASS)

## *Suborbital Space Safety Technical Committee*

Established three Suborbital Safety Working Groups: Regulatory, Technical and Operations

The Operations Working Group produced a report on recommended best practices on Flight Crew and Spaceflight Participant Medical and Training Requirements - 2013

# FAA CST COE

# Flight Crew Medical Standards

# &

# Spaceflight Participant Medical Acceptance Guidelines

SPACE TRANSPORTATION ASSOCIATION

SPACE MEDICINE BRANCH · AEROSPACE MEDICAL ASSOCIATION

INTERNATIONAL ASSOCIATION FOR THE ADVANCEMENT OF SPACE SAFETY

www.iaass.org

International Academy of Astronautics

AEROSPACE MEDICAL ASSOCIATION

# Phase I:

Collected and reviewed existing documents addressing orbital and suborbital crew member medical certification, SFP medical evaluation and acceptance guidelines, and developed recommendations for medically–related testing and training for both crew members and SFPs

# Phase II:

Prepared a preliminary document incorporating the various guidelines and recommendations as outlined in Phase I and obtained input and comment from those involved in the commercial space flight industry, NASA, and the FAA

Convened a working group of experts in aerospace medicine and physiology, operations, training, safety, government, and the public to consider the comments from phase II

# Phase III:

Prepared a consolidated set of recommendations for the medical certification of crew members, medical acceptance guidelines for SFPs

The report was provided to the FAA as part of the COE CST task

# Final Report

www.coe-cst.org/publications.html

FEDERAL AVIATION ADMINISTRATION

# FAA Office of Aerospace Medicine

*February 11, 2005*

The "Guidance for Medical Screening of Commercial Aerospace Passengers " was released to the public during the 8th FAA Commercial Space Transportation Forecast Conference

This was the culmination of a team effort that started in July 1998

# Medicine is a Science

# and an Art

# The Key for CST HSF is the

# Medical Waiver Process

# *Other Considerations*

Some medical conditions may be cleared for space flight following special medical assessments in simulated spaceflight environments including the use of a zero-G aircraft, a high performance aircraft, a hypobaric (altitude) chamber, or a human centrifuge

Using a flexible approach that applies aerospace medicine knowledge and experience-based medical risk analysis, it may be possible to permit special medical accommodations for prospective participants who have certain pathologies (including disabilities)

FIRST AID
EQUIPMENT

NASA

AFRL CENTRIFUGE

# Example

Professor Stephen Hawking suffers advanced amyotrophic lateral sclerosis with significant mobility impairment and he was able to safely participate in a zero-G flight

He was accompanied by a medical team (including an aerospace medicine specialist) who were involved in providing inflight medical support as needed

# The aeromedical preparation for this very unique flight included:

1) A training flight carrying a healthy volunteer on the day before Professor Hawking's flight

2) The use of non-invasive biomedical monitoring equipment for blood pressure, heart rate, electrocardiography, respiratory rate, oxygen saturation and carbon dioxide saturation

3) A practical simulation of possible inflight medical emergencies

ZERO-G

www.goZeroG.com

the weightless experience

This zero-G flight demonstrated that it is feasible to allow selected individuals with severe disabilities (or other pathologies) to participate in short-duration space flights, but this may require:

1) A comprehensive preflight aeromedical preparation

2) Appropriate in-flight biomedical monitoring (including medical equipment and supplies)

3) It may even require a special flight dedicated to carry such an individual with real-time support provided by a medical team to ensure his/her health and safety

Operator-owned medical databases will be of critical importance (medical & legal) to the success of the manned commercial space transportation industry, and, more importantly, to the health and safety of subsequent space flight participants

# *Other Guidance*

No conclusive data exist concerning the potential adverse physiologic and pathologic effects of space flight on <u>infants or young children</u>

Operators may wish to establish a <u>minimum age</u> for passengers participating in space flights

Because of the potential hazards of space flight (including exposure to solar and cosmic galactic radiation, acceleration, and microgravity), it is highly recommended that a female of child-bearing age be offered a pregnancy test

Operators may wish to consider excluding pregnant women from participating in space flights, until more medical information becomes available to assess the actual risks of space flight for pregnant women and their unborn children

# *Controversial Consideration*

There may be some individuals suffering terminal medical conditions who may wish to participate in a space flight before they pass away

Operators will have to decide whether or not such individuals will be allowed to participate in a space flight

This will be a very difficult decision to make due to a number of significant ethical and legal implications

# LIMITED MEDICAL INTERVENTION CAPABILITIES DURING FLIGHT

# Other FAA CST COE Medical R&D Tasks

- Wearable Biomedical Monitoring Equipment for Space Flight Participants
- Medical & Physiological Database System for Commercial Space Flight
- Human System Risk Management Approach to Commercial Suborbital and Short Duration Orbital Flights
- Development of a Minor Injury Severity Scale (MISS) for Orbital Human Spaceflight
- Radiation and EMI Effects on Implantable Medical Devices

# New Potential COE R&D Issues

Evaluate effects of exposure to repeated complex acceleration profiles (including +Gz and +Gx exposures) and their impact on performance and fatigue during repetitive simulated flights

Evaluate the methods, procedures, and technologies available for the protection of crew-occupied space in commercial spaceflight vehicles including a review of methods for the de-lethalization of the cabin environment, space vehicle crashworthiness, individual restraint systems, emergency evacuation systems, survival equipment, and related objectives

Evaluate the need for safety-related technical training standards for space vehicle crews and spaceflight participants

# New Potential COE R&D Issues

Should a preflight quarantine/social isolation period be recommended to prevent the occurrence of acute infectious diseases during orbital flight?

Should there be medical criteria for early termination of an orbital flight due to unexpected illnesses or medical emergencies?

What types of medical conditions could result in an early termination of an orbital flight?

What type of emergency medical kits should be recommended to be carried on-board orbital commercial space vehicles (first aid, basic life support, advanced life support)?

What should be the minimum medical equipment and supplies included in an emergency medical kit for orbital inflight use?

Evaluate effects of exposure to repeated complex acceleration profiles (including +Gz and +Gx exposures) and their impact on performance and fatigue during repetitive simulated flights

# New Issues

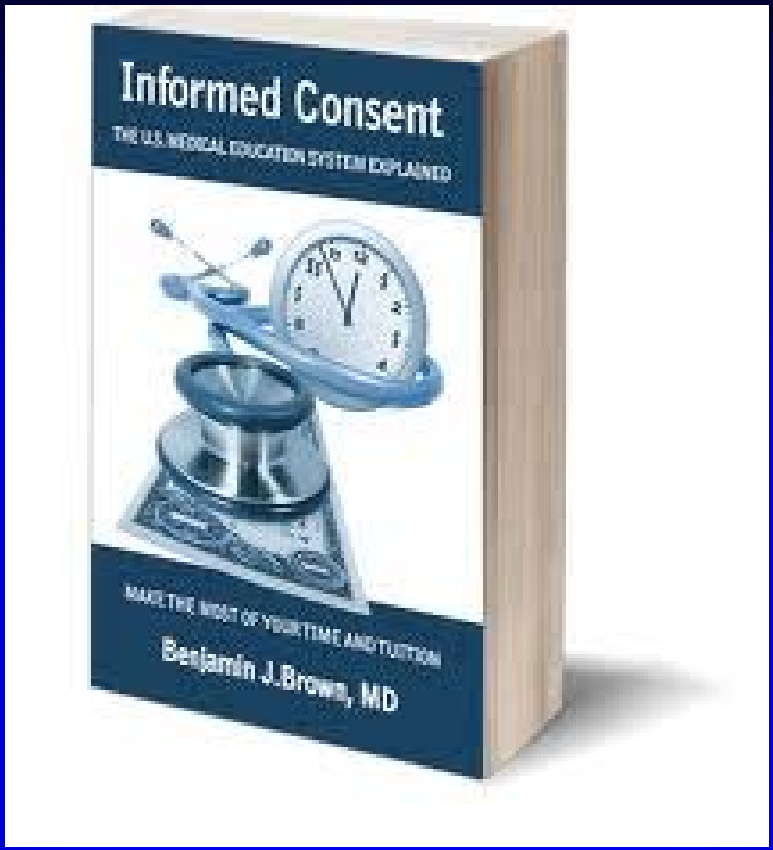
Should somebody (crew or passengers) be trained to use inflight medical kits and provide inflight medical care if needed? What should be the minimum knowledge and skills included in an inflight medical care training program?

How to formulate a practical definition of a medical hazard or operational risk that could result in a serious injury, death, disability, or total or partial loss of physical or mental function?

# Operational Safety & Liability Issues

"Take me to your lawyer."

The reality is that we live in a litigious society




# Medical Informed Consent

## *The Good, the Bad and the Ugly*

# 14 CFR Part 460, Subpart B
# Launch and Reentry
# with a Space Flight Participant

§ 460.45 Operator informing space flight participant of risk.

(a) Before receiving compensation or making an agreement to fly a space flight participant, an operator must satisfy the requirements of this section. An operator must inform each space flight participant in writing about the risks of the launch and reentry, including the safety record of the launch or reentry vehicle type.

An operator must present this information in a manner that can be readily understood by a space flight participant with no specialized education or training, and must disclose in writing: *(Language Issues)*

(1) For each mission, each known hazard and risk that could result in a serious injury, death, disability, or total or partial loss of physical and mental function.

(2) That there are hazards that are not known.

(3) That participation in space flight may result in death, serious injury, or total or partial loss of physical or mental function.

# Medical Malpractice Insurance Issues for Commercial Space Company Physicians and/or Aviation Medical Examiners

**The first obsessive-compulsive on the moon.**

# Other Practical Considerations

# Emergency Medical Readiness at Spaceports



Federal Aviation Administration

# ICAO Standards & Recommended Practices for Medical Facilities at International Airports

While provisions on medical facilities, ambulances and hospitals are mentioned in the ICAO Annexes and other pertinent materials, the decision on what to provide is left to the local authorities

# Airport Disaster Drills

# 14 CFR PART 420
# LICENSE TO OPERATE A LAUNCH SITE

420.53 Control of public access

(b) A licensee shall notify anyone entering the launch site of safety rules and emergency and evacuation procedures prior to that person's entry unless that person has received a briefing on those rules and procedures within the previous year

(c) A licensee shall employ warning signals or alarms to notify any persons at the launch site of any emergency

# *Impact of Exponential Technological Innovations in Medicine*

Digital Medicine

Bio-Engineering

Virtual Medical Imaging

Cloning

Induced Pluripotent Stem Cells

Regenerative Medicine

Human-Machine Interfaces

Personal Biomedical Devices

Micro-Electro-Mechanical Systems
MEMS

Genomics, Gene Therapy,
Synthetic Biology

Nanomedicine

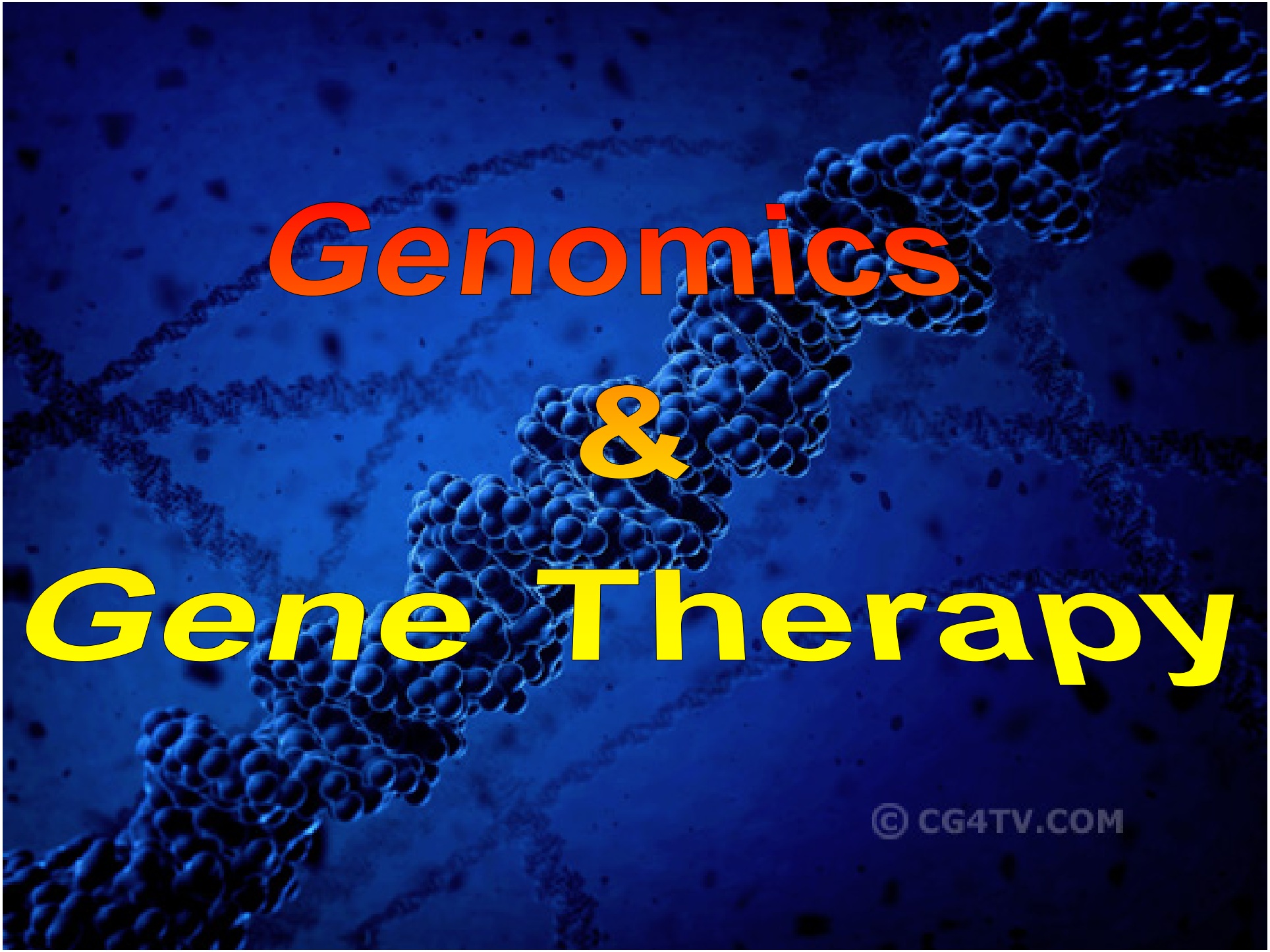
Neurotechnology

Networked Health Care

Medical Robotics

Engineered Replacement Organs

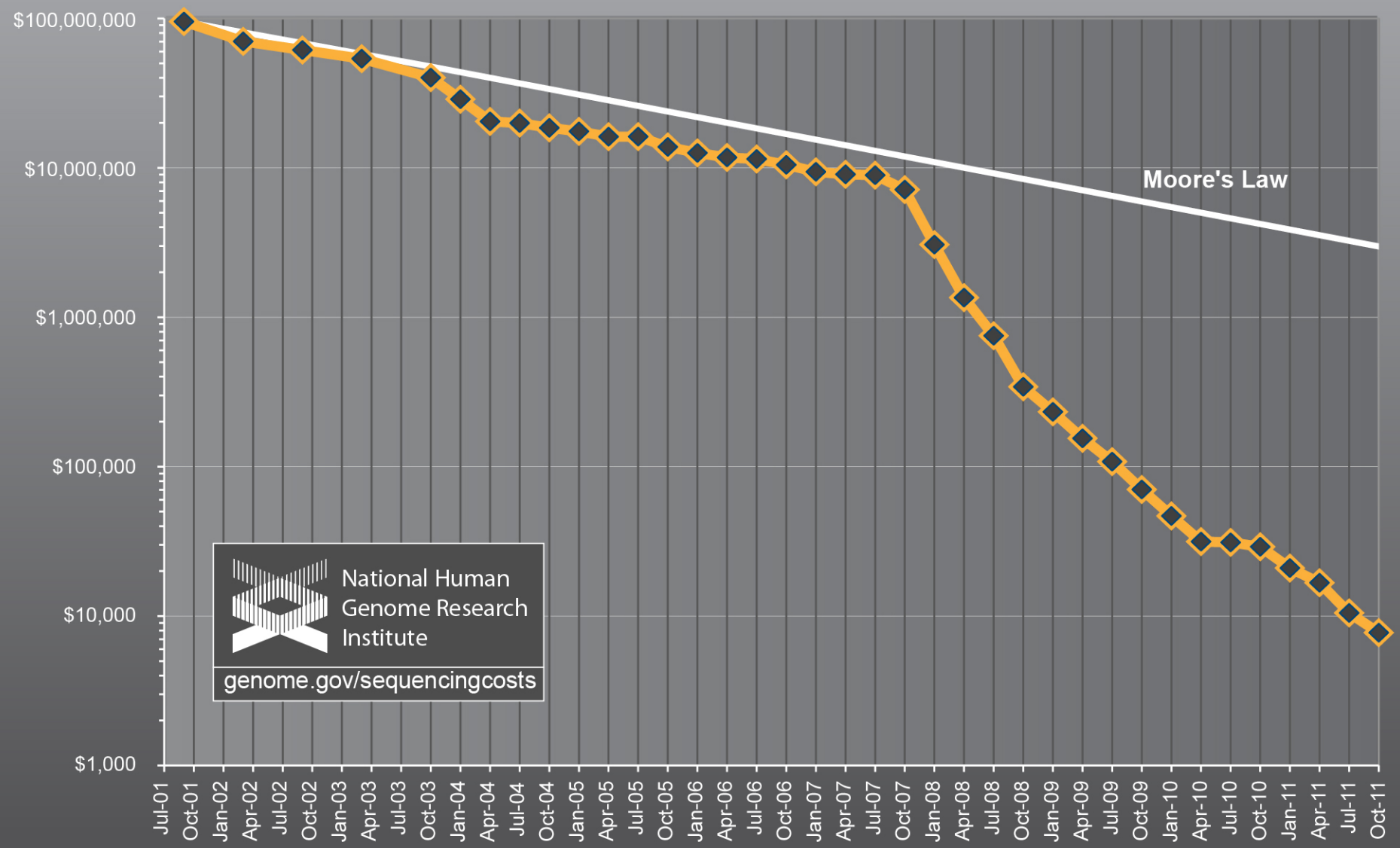
# Genomics & Gene Therapy



**ClinicalTrials.gov**
**US National Institutes of Health**
**583 Studies on Genomics**

**ClinicalTrials.gov**
**US National Institutes of Health**
**2,958 Studies on Gene Therapy**

# Cost per Genome



A $100 genome sequence test by 2014?

Oxford Nanopore has built the “MinION” a disposable DNA sequencer that's the size of a thumb drive, and powered by a USB port

Capable of sequencing 150 million base pairs in six hours, and uses the computer's own CPU to perform the analysis

Dtect Aviator

## Genetic Screening Services for Aerospace Medicine

Be involved with pushing the aerospace medicine envelope. Fill out a short survey online using the QR code or web address below and **be in to win** one of four other Dtect genetic screening assays. Personalise your prize and choose between Dtect Cardio, Dtect Immuno, Dtect Metabolic, or Dtect Onco.

http://landing.performancegenomics.com.au/dtect-aviator/

## The Dtect Aviator Panel

The genome variants analysed by Dtect Aviator are categorised into three domains: risk factors for sudden incapacitation, genetic markers for lifestyle diseases, and genetic markers for adverse drug reactions and other medically relevant diseases in aviation medicine.

| Risk factors for sudden incapacitation | 43 SNPS |
|---|---|

AF, Stroke, Heart Attack, Aneurysm, Narcolepsy, DVTs/Pulmonary Embolism, Analphylaxis, QT Syndrome, Hypertropic Cardiomyopathy

| Genetic markers for lifestyle diseases | 84 SNPS |
|---|---|

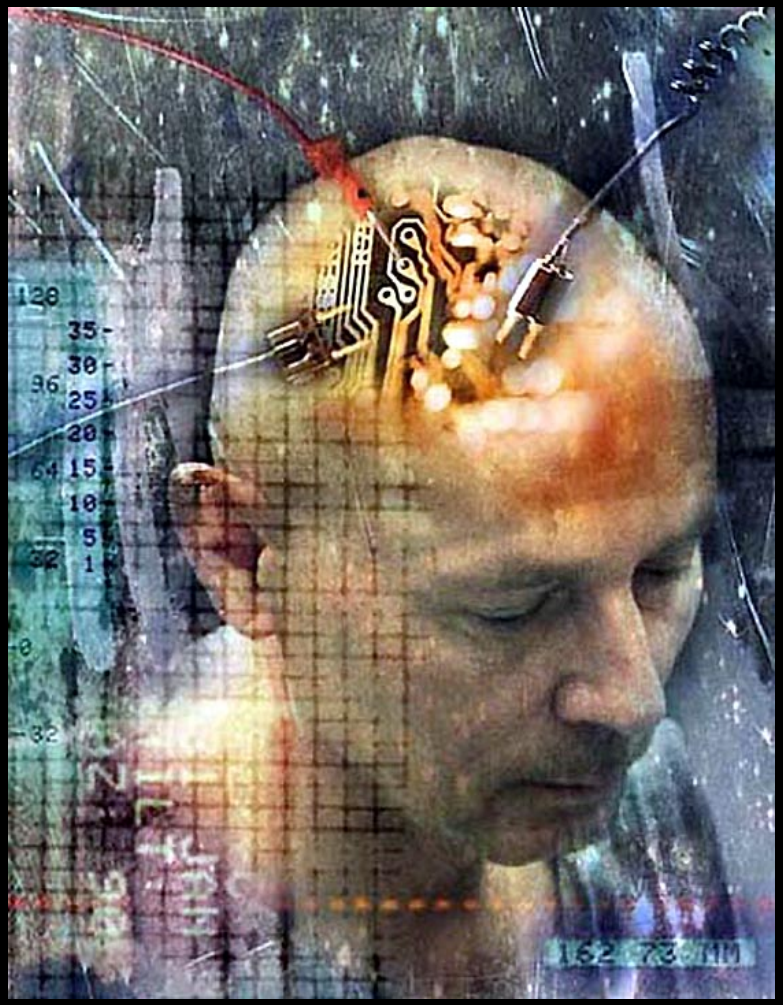
Peripheral Vascular Disease, Alpha-1 Antitrypsin Deficiency, COPD, Lung Cancer, Throat Cancer, Colorectal Cancer, Coronary Heart Disease, Hypertension, Hypertriglycerimedia, Hypercholesterolemia, Obesity, Type 2 Diabetes, Alcohol Dependence.

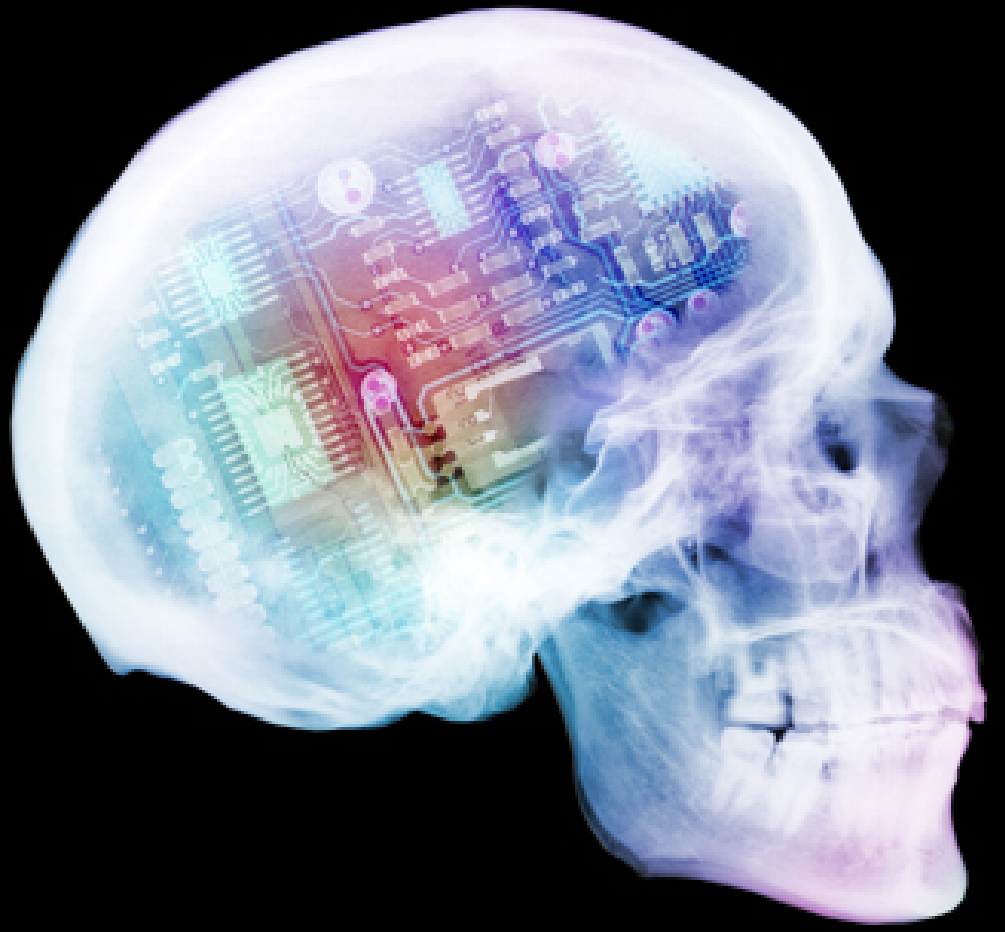
| Genetic markers for other diseases relevant to aviation medicine | 118 SNPS |
|---|---|

Pharmacogenomics (Clopidogrel, Caffiene, Statins, Aspirin, Wafarin, Beta-blockers, NSAIDS), Testicular Cancer, Prostate Cancer, BCC, SCC, Malignant Melanoma, Gallstones, Graves Disease, and Macular Degeneration.

Contact andrew@performancegenomics.co.nz if you interested in incorporating Dtect Aviator into your practice. Buccal swabs are sent to your practice and results are provided in 7-10 days.

# Neurotechnology





**ClinicalTrials.gov**
**US National Institutes of Health**
**259 Studies on**
**Neurotechnology**

Mindwave Mobile is a research-grade brain-computer interface EEG headset

It interfaces with mobile devices (iOS and Android) and a desktop computer and can be used to play a variety of games, brain trainers, and educational apps

Johns Hopkins University Applied Physics Lab and the University of Pittsburg - Modular Prosthetic Limb funded by DARPA is controlled by a microchip in the brain and has the ability to bend, rotate, and twist in 27 different ways. The microchip records neuron activity and decodes the signals to activate motor neurons that control the prosthetic

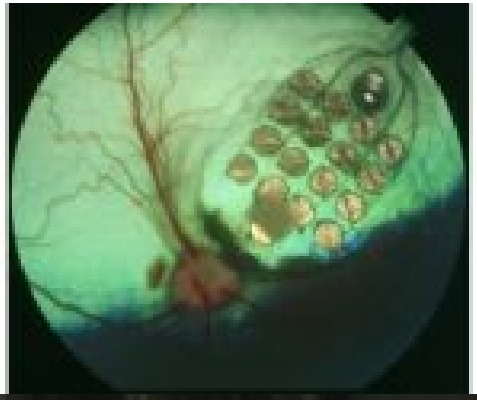
It is designed to restore almost complete hand and finger function to patients dealing with spinal cord injury, stroke, or amputation

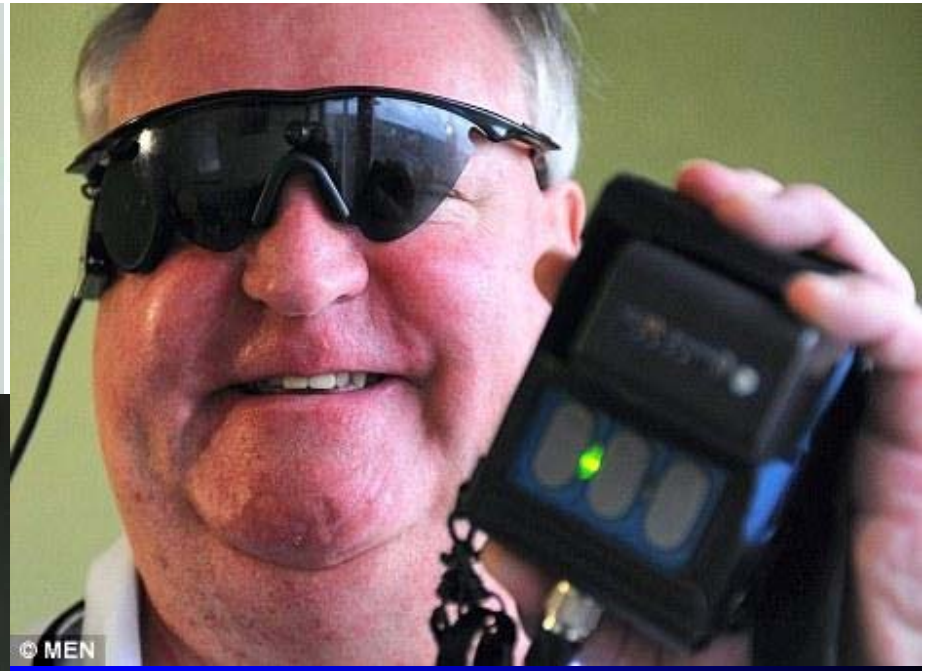
Researchers at the University of Minnesota are developing a mind-controlled quadcopter using a Brain Computer Interface

# Engineered Replacement

# Tissues & Organs

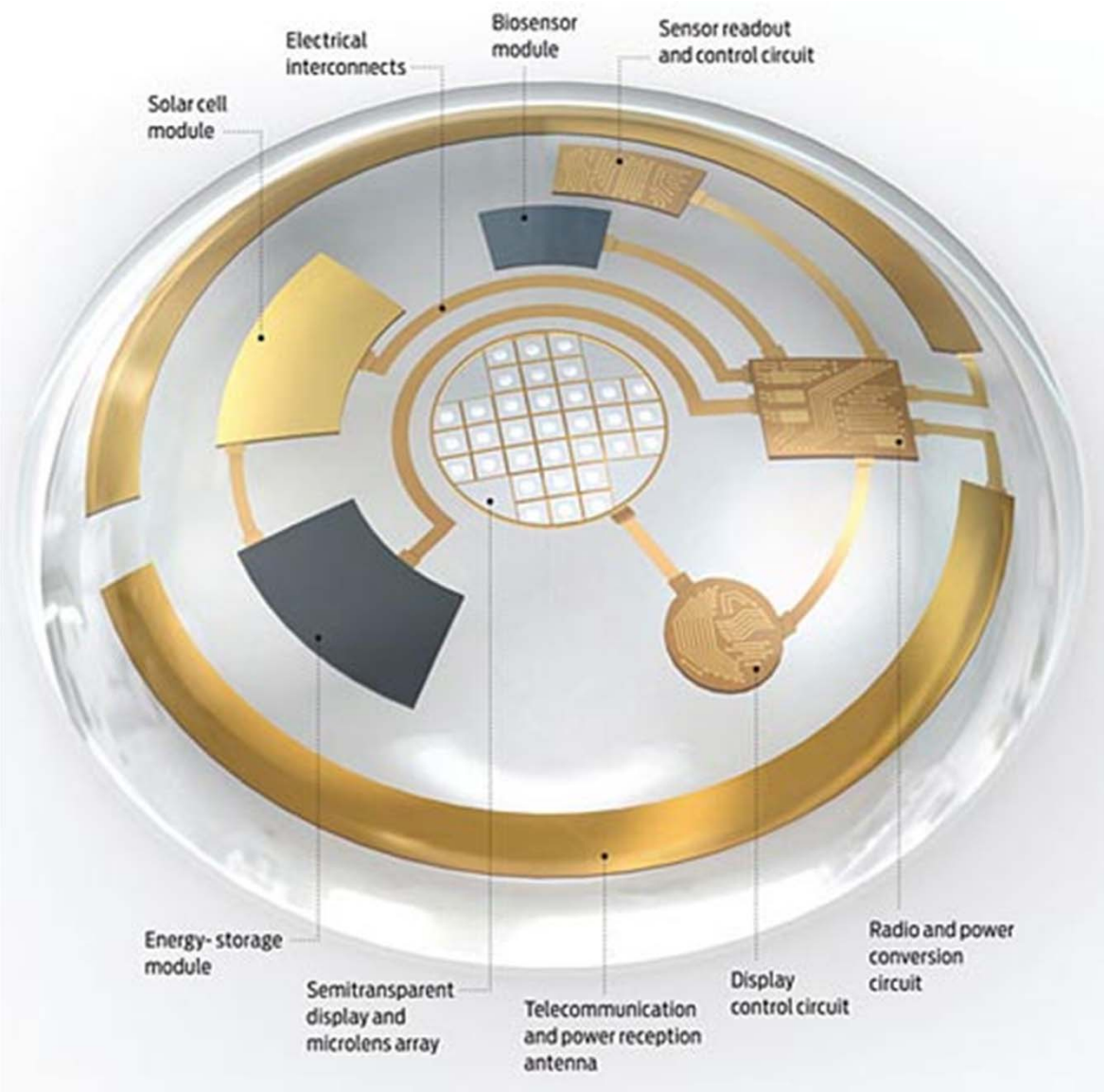
**ClinicalTrials.gov**
**US National Institutes of Health**
**628 Studies on Biomedical Engineering**



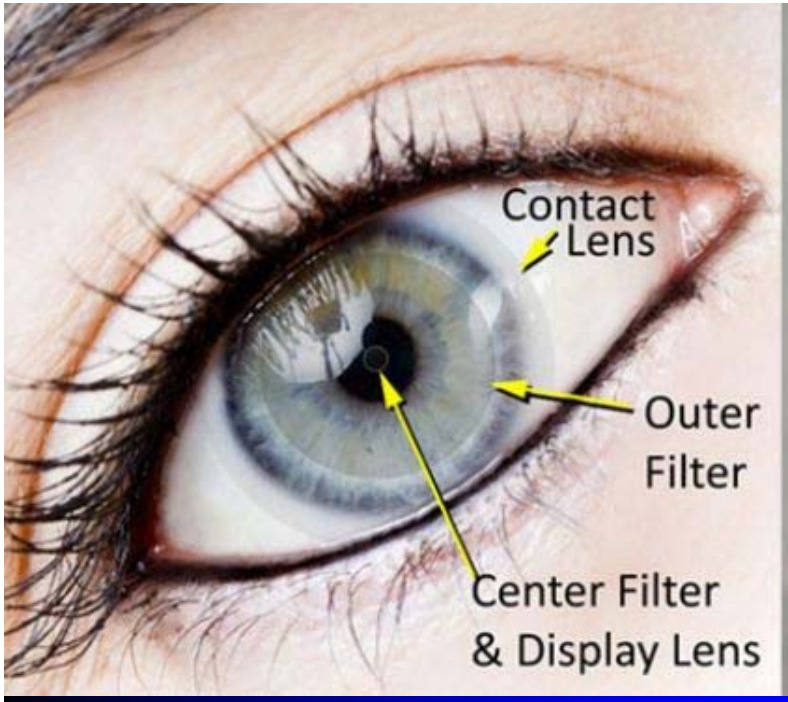


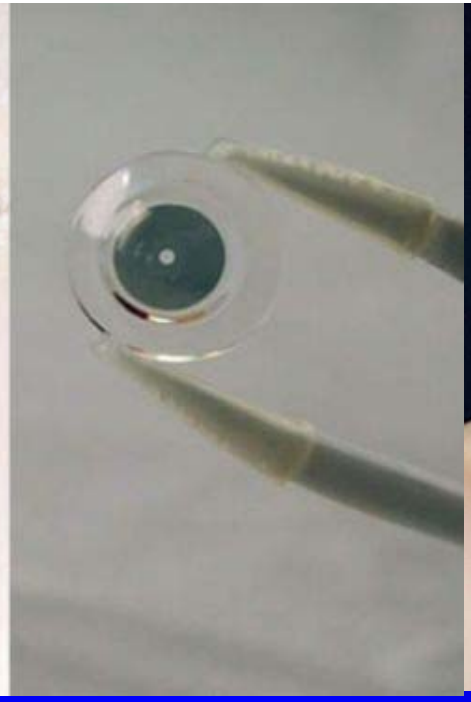

Funded by the US Department of Energy and lead by Lawrence Livermore National Labs the Argus I and II Epiretinal Prosthesis have had extraordinary success with implants in more than 30 blind patients with degenerative eye diseases like macular degeneration and retinitis pigmentosa

Approved by the FDA in February 2013 it has a 200+ pixels resolution to see areas of high contrast, such as curbs and crosswalks




University of Washington researchers have developed the "Assisted Living Contact Lenses"

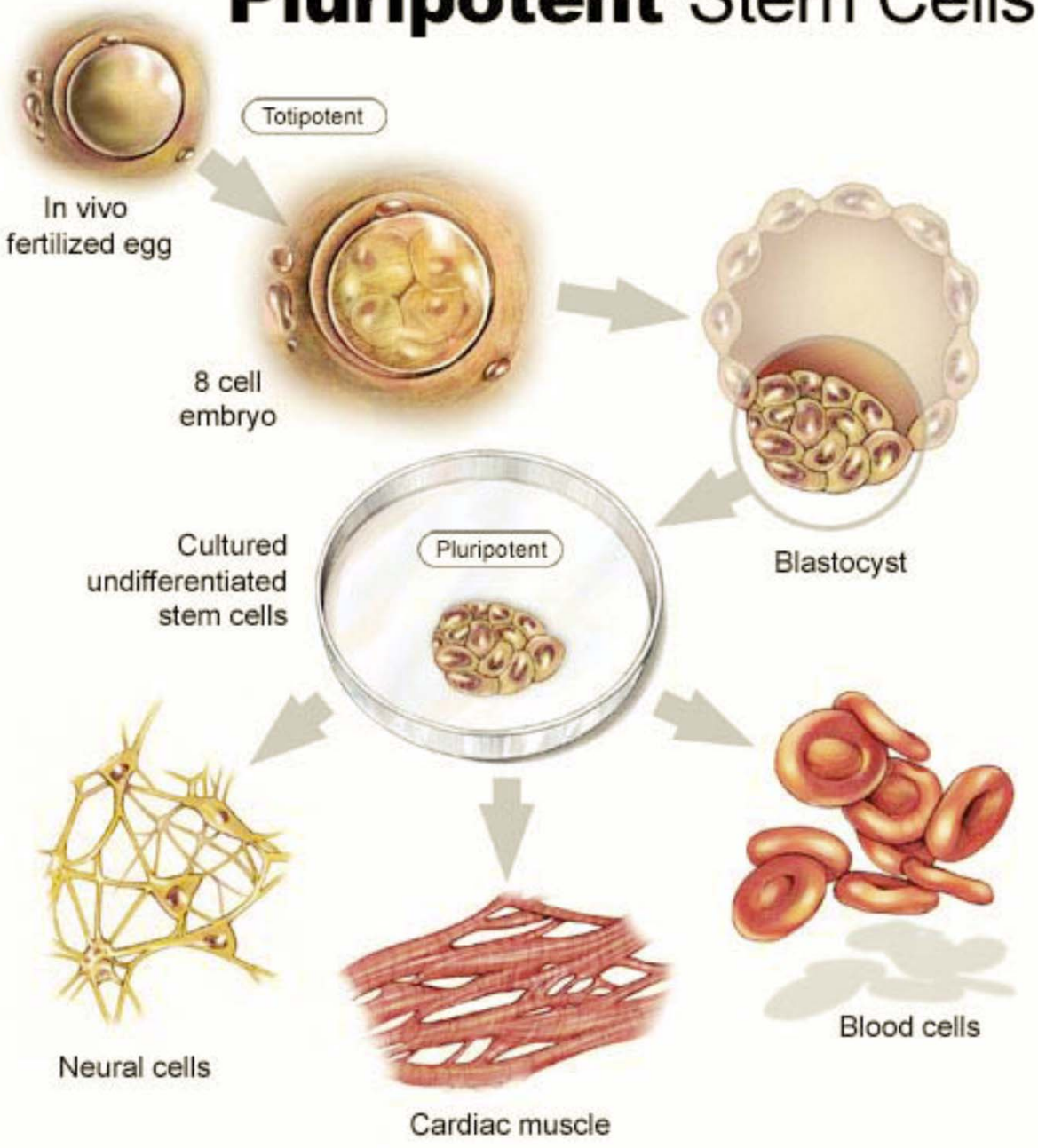


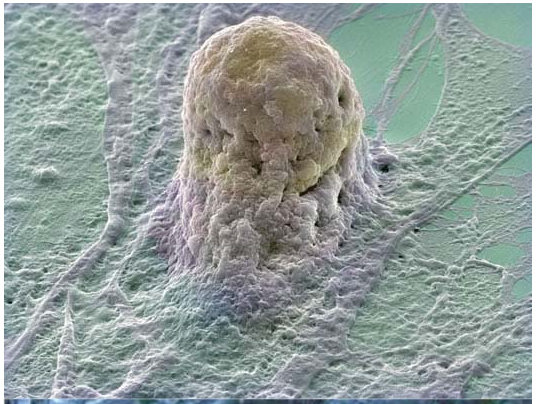



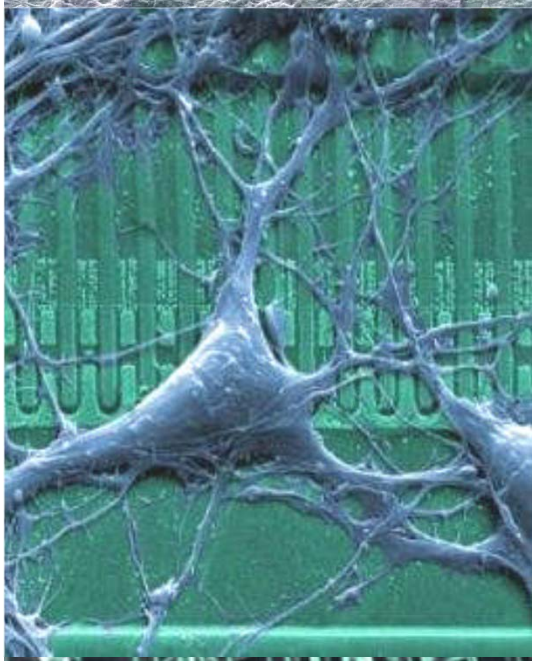
DARPA funded Innovega's iOptik contact lenses are intended to enhance normal vision by allowing to view virtual and augmented reality images without the use of any bulky device

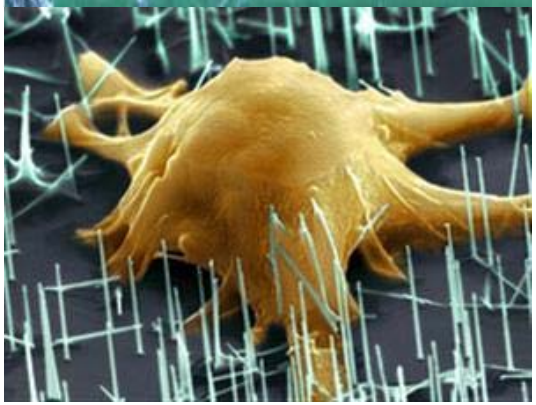
# Regenerative Medicine

# **Pluripotent** Stem Cells







**ClinicalTrials.gov**
**US National Institutes of Health**
**4,857 Studies on Stem Cells**

## Stem Cell Therapy Clinical Trials

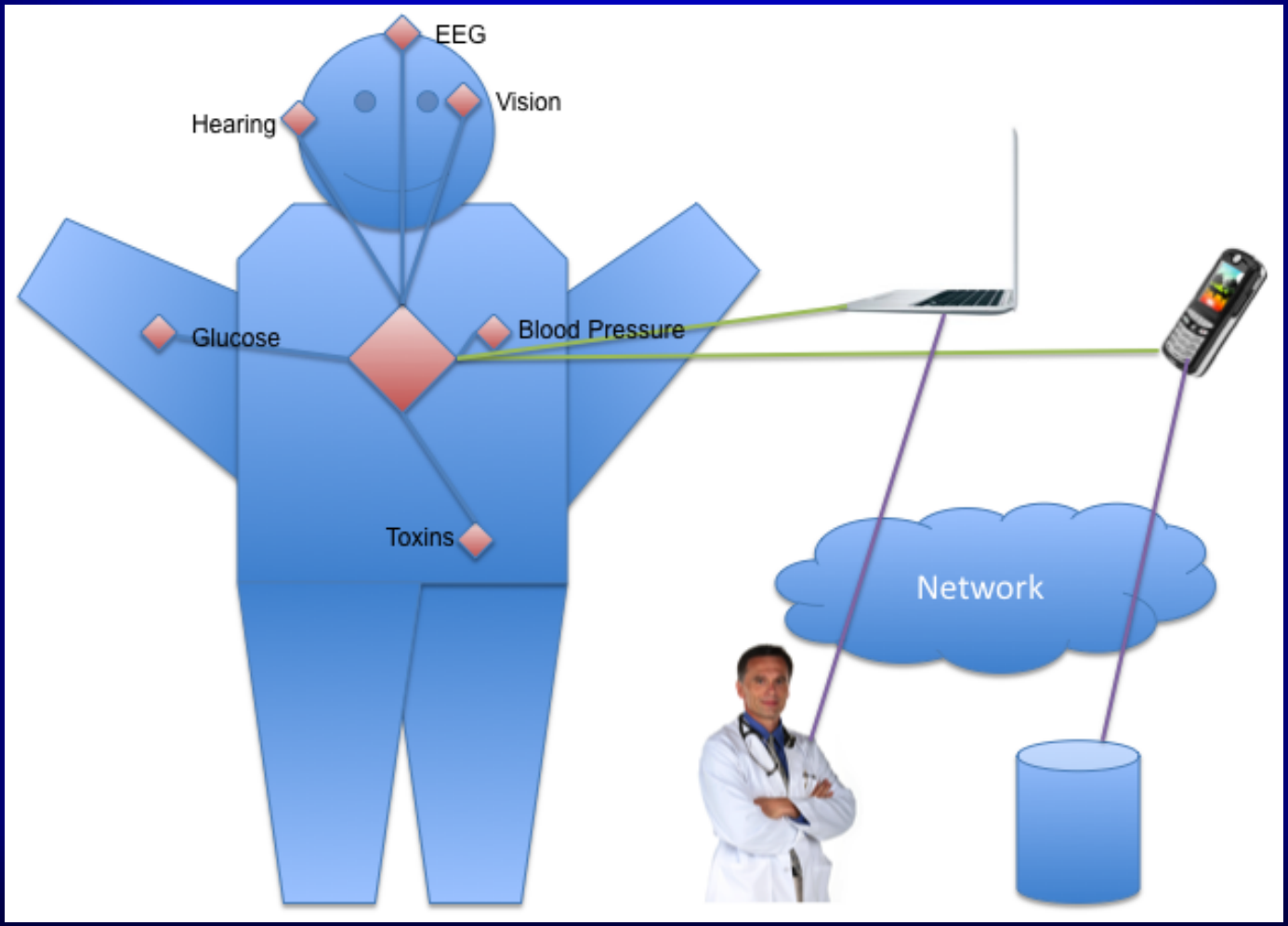
- Brain damage
- Cancer
- Spinal cord injury
- Heart damage
- Haematopoiesis (blood cell formation)
- Baldness
- Missing teeth
- Deafness
- Blindness and vision impairment
- Amyotrophic lateral sclerosis
- Graft vs. host disease and Crohn's disease
- Neural and behavioral birth defects
- Diabetes
- Orthopaedics
- Wound healing
- Infertility, etc

Cornell and Weill Cornell Medical College have created an artificial ear that looks and acts like a natural ear

They used 3-D printing and injectable gels made of living cells to fashion ears that are practically identical to a human ear

Over a three-month period, these flexible ears grew cartilage to replace the collagen used to mold them

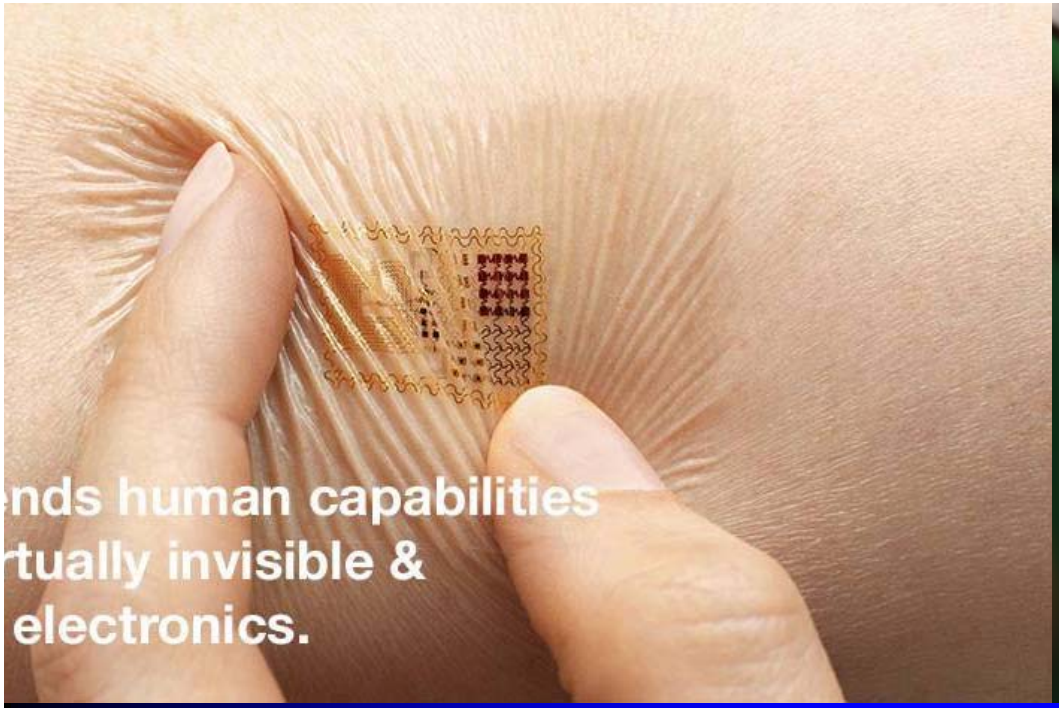
# Body-Worn Medical Sensors



The wearables market is perhaps $3 billion to $5 billion today, rising to perhaps $30 billion to $50 billion over the next three to five years

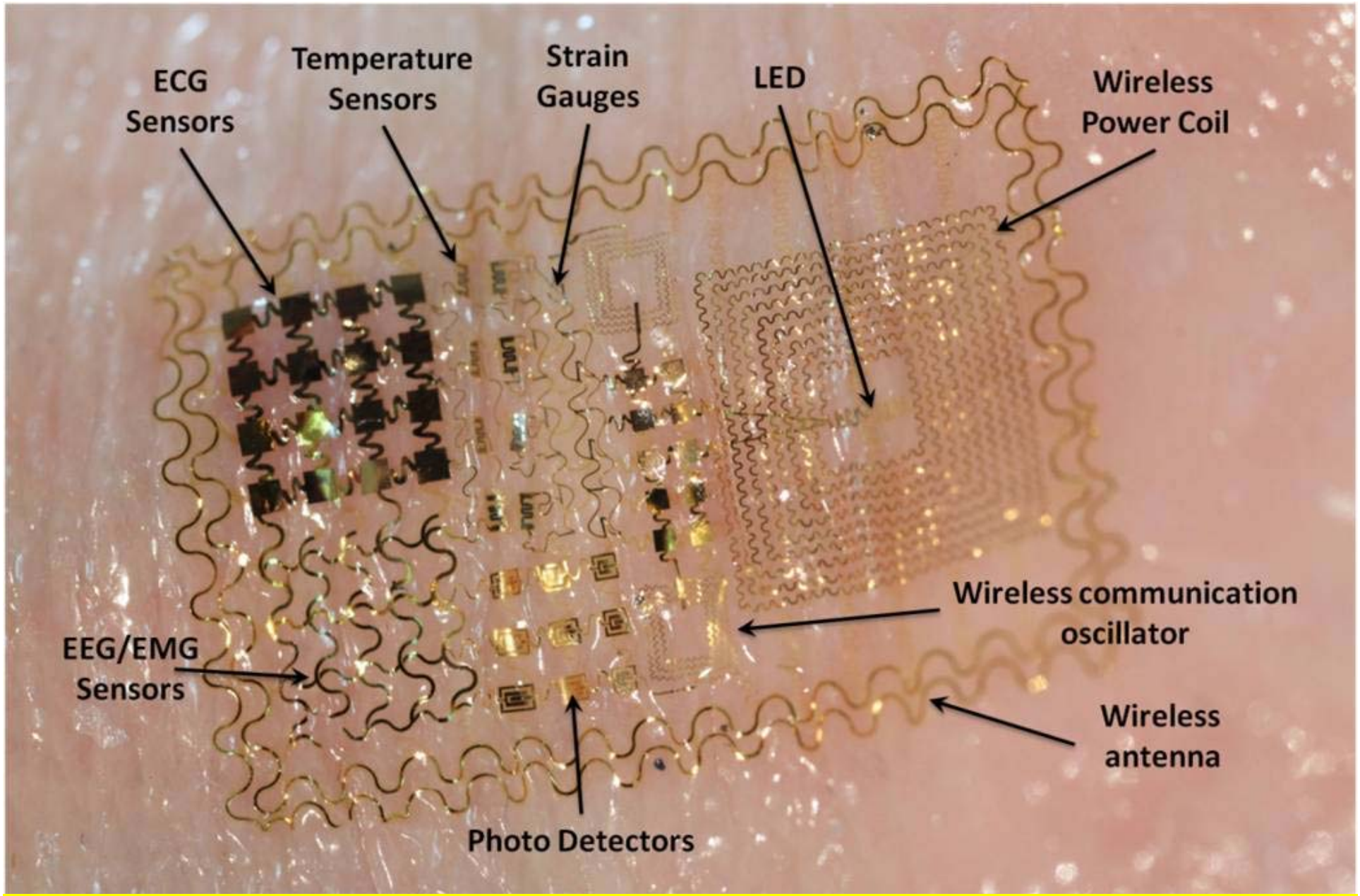
Research firm ABI is predicting that Medical Body Area Network (MBAN) sensor shipments will hit 5 million by 2018

ABI also reported that 160 million wearable health devices will ship in 2017



A new electronic skin patch developed by MC10, no more invasive than a temporary tattoo, marks a major breakthrough in human-machine interfaces

Tiny semiconductor circuits that stretch with the skin could be rubbed onto a person's skin to monitor muscle activity, heart activity or even brain waves in real time without using bulky medical equipment

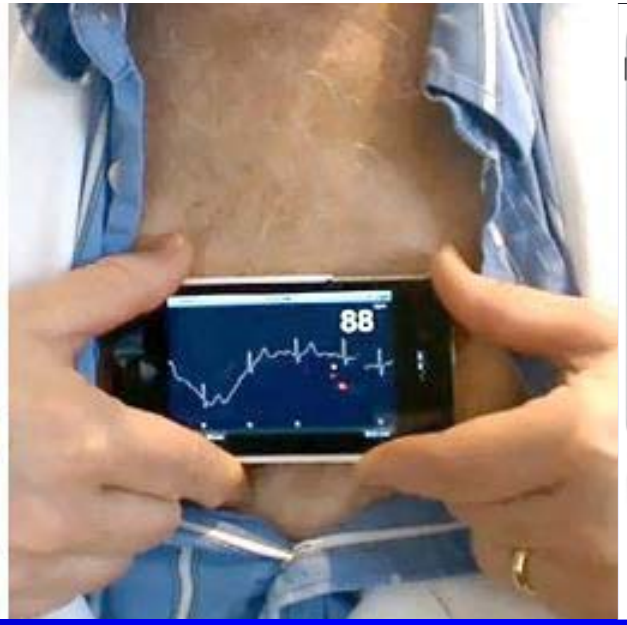

ECG Sensors
Temperature Sensors
Strain Gauges
LED
Wireless Power Coil
Wireless communication oscillator
EEG/EMG Sensors
Wireless antenna
Photo Detectors

# Personal Biomedical Devices

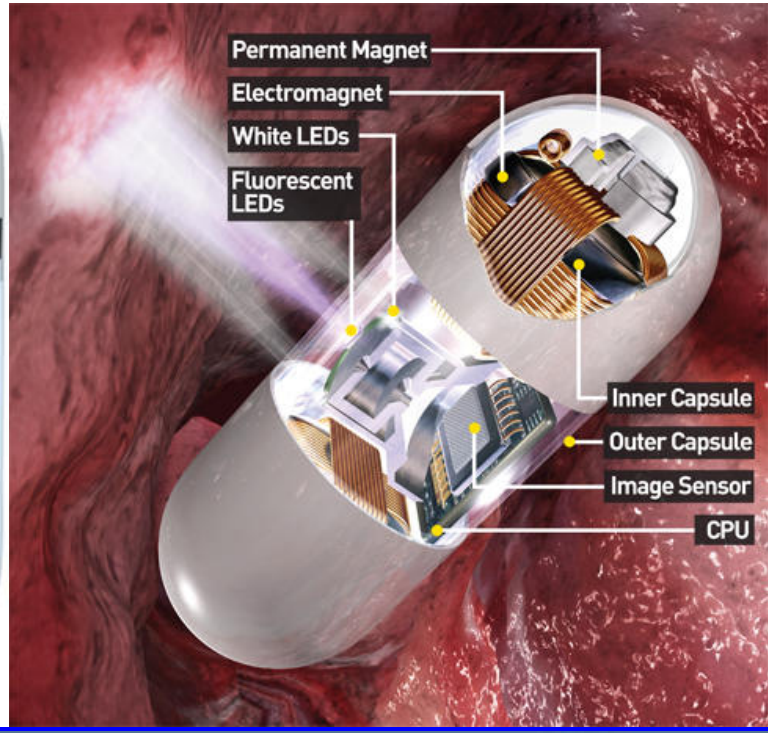
# X-Prize and Qualcomm Announce $10 Million Tricorder Prize

Will be a tool capable of capturing key health metrics and diagnosing a set of 15 diseases

It will collect large volumes of data from ongoing measurement of health states through a combination of wireless sensors, imaging technologies, and portable, non-invasive laboratory tests



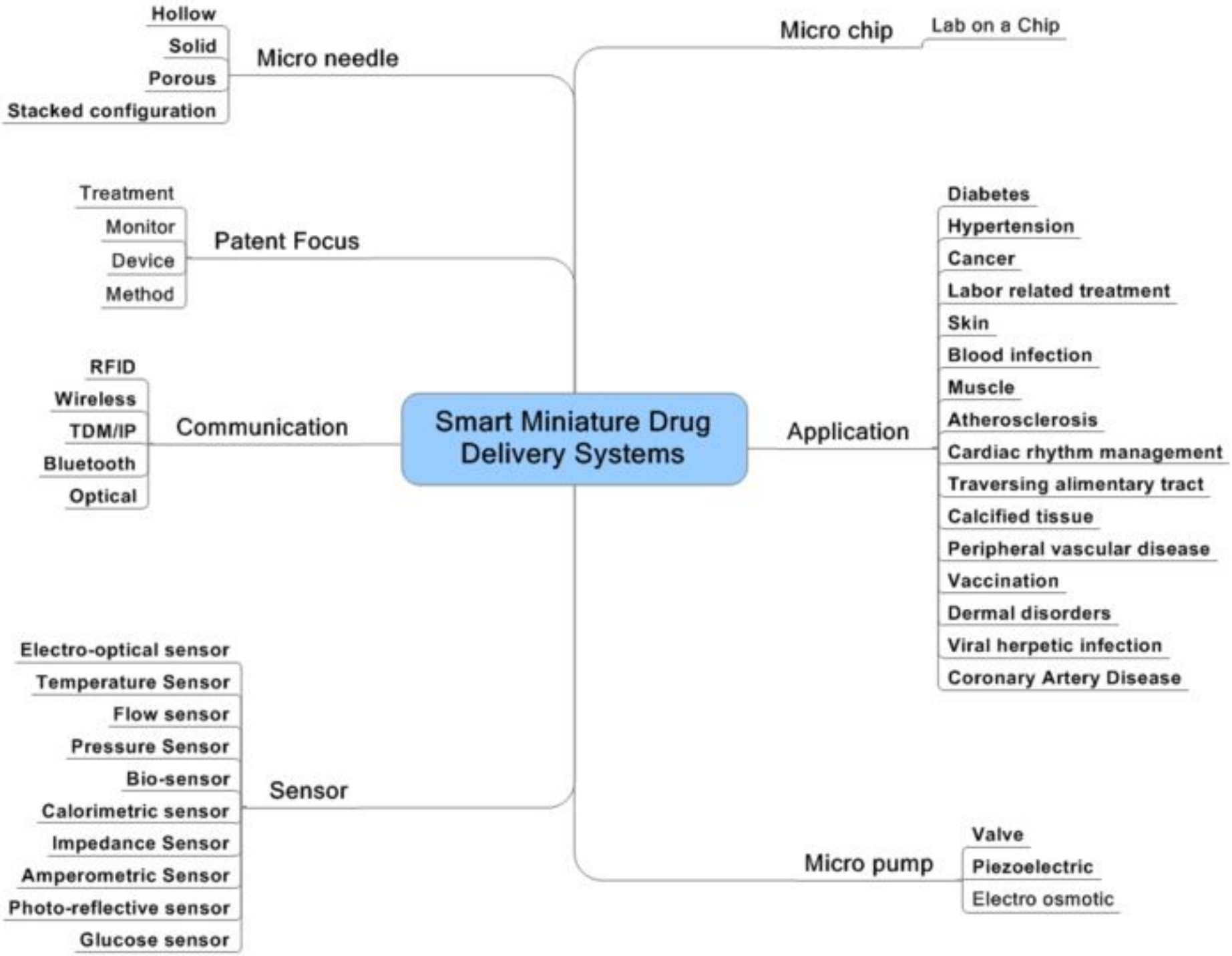
*AliveCor* iPhone ECG case and iCard device, works with iPhone 4 and 4S and transforms a smartphone into a clinical-quality single lead electrocardiogram (ECG) recorder that can be purchased by prescription only

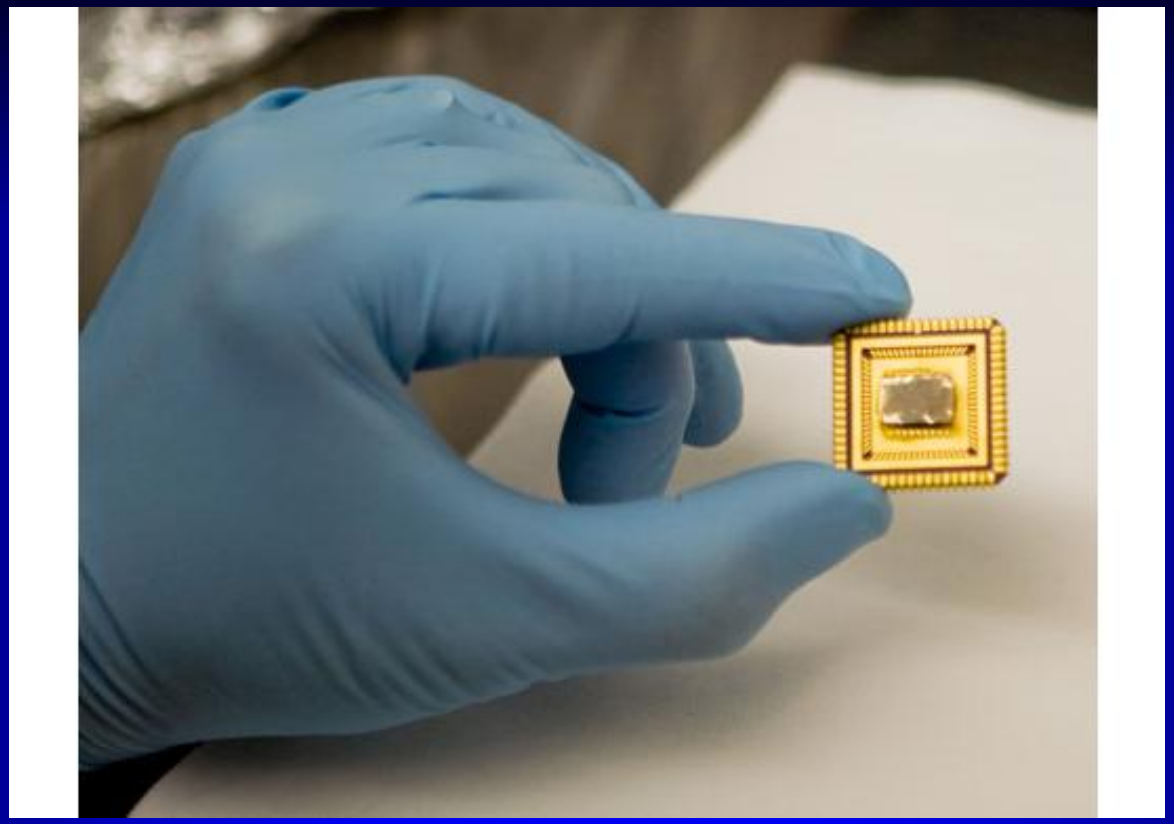



Given Imaging's Pill Cam SB 3 (FDA approved) contains an imaging device and light source and records images at a variable rate of 2-6 frames per second based on intestinal transit speed. It is being used to detect and monitor small bowel abnormalities associated with Crohn's disease, obscure gastrointestinal (GI) bleeding and iron deficiency anemia

# Micro-Electro-Mechanical

# Systems


Smart Miniature Drug Delivery Systems
Micro needle
Hollow
Solid
Porous
Stacked configuration
Micro chip
Lab on a Chip
Patent Focus
Treatment
Monitor
Device
Method
Communication
RFID
Wireless
TDM/IP
Bluetooth
Optical
Application
Diabetes
Hypertension
Cancer
Labor related treatment
Skin
Blood infection
Muscle
Atherosclerosis
Cardiac rhythm management
Traversing alimentary tract
Calcified tissue
Peripheral vascular disease
Vaccination
Dermal disorders
Viral herpetic infection
Coronary Artery Disease
Sensor
Electro-optical sensor
Temperature Sensor
Flow sensor
Pressure Sensor
Bio-sensor
Calorimetric sensor
Impedance Sensor
Amperometric Sensor
Photo-reflective sensor
Glucose sensor
Micro pump
Valve
Piezoelectric
Electro osmotic



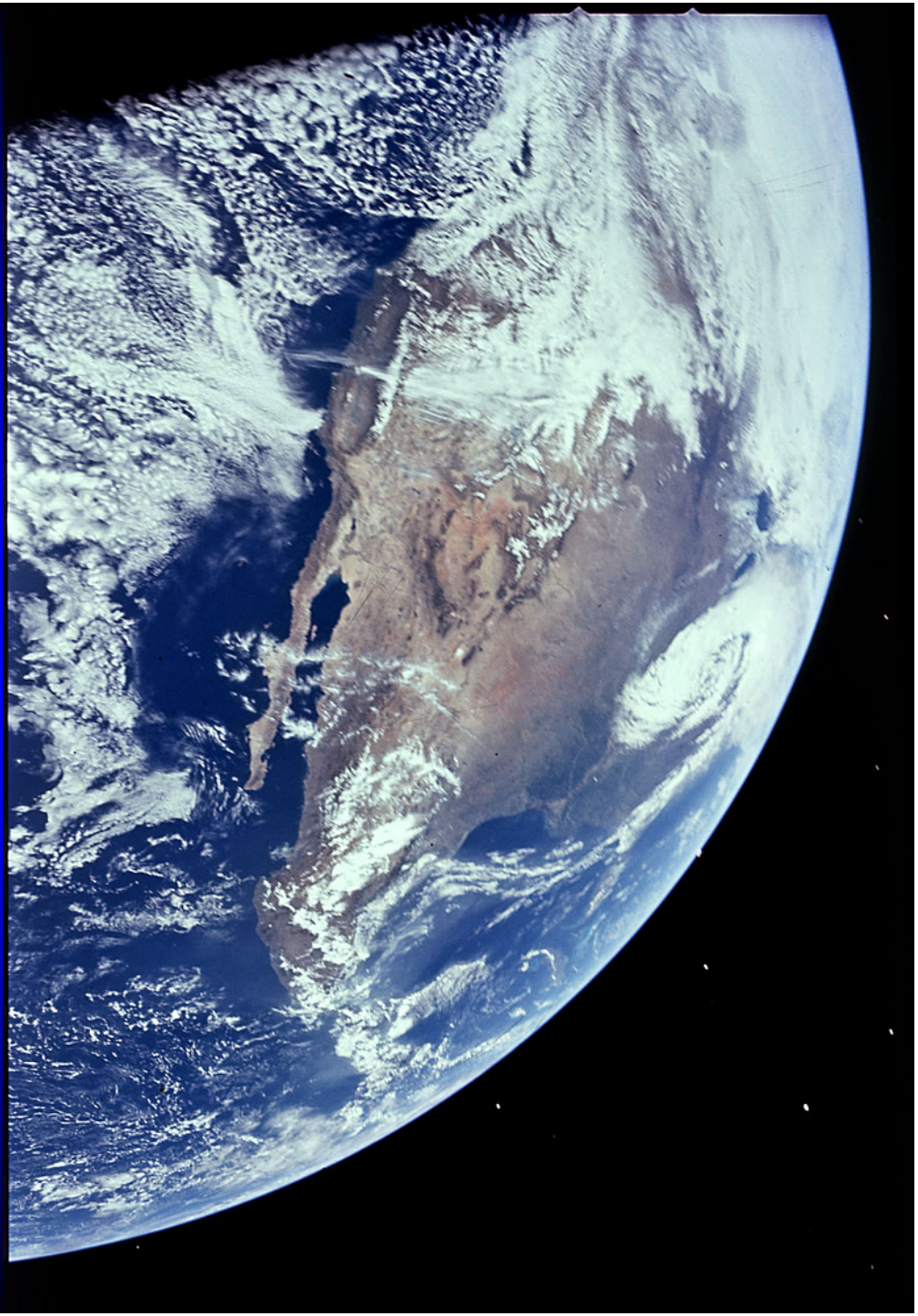
HP Labs adapted inkjet-printer technology to create a skin patch that automatically delivers precise drug dosages painlessly and on schedule

Hundreds of microneedles draw medicine from individual wells and inject it beneath the skin, where it enters the bloodstream quickly

# Post-Accident Human Survival Factors

LIFE THREATENING EMERGENCIES

Can happen to anybody, anywhere, and anytime



# Factors Affecting Crash Survivability

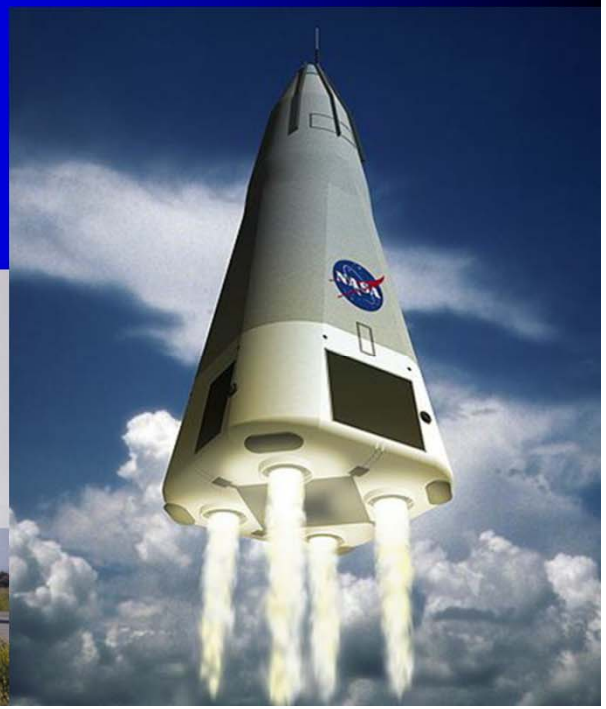
C - Container
R - Restraints
E - Environment
E - Energy Absorption
P - Post-Crash Factors

# Commercial Space

# Vehicle Crash Worthiness

# Types of Aircraft Structural Damage that Cause Occupant Injuries/Death

- Longitudinal structural overload
- Vertical structural overload
- Transversal structural overload
- Deformation and rupture of the floor structure
- Penetration of the landing gear into the fuselage



# VARIABLES AFFECTING HUMAN TOLERANCE TO DECELERATION

*Body part(s) directly exposed to the impact force:*
Back and buttocks have greater tolerance than the head, chest and limbs

*Secondary impact of body parts against the aircraft structure*

*Distribution of the impact force over the various body structures*

*Type of seat and restraint system*

# TYPES OF INJURIES

| | |
|---|---|
| Pulmonary contusion | 25 G |
| Nose fracture | 30 G |
| Vertebral fracture | 20-30 G |
| Cervical (C1) fracture | 20-40 G |
| Lower jaw fracture | 40 G |
| Upper jaw fracture | 50 G |
| Aortic tear (intimal layer) | 50 G |
| Aortic transection | 80-100 G |
| Pelvic fracture | 100-200 G |
| Spinal transection | 200-300 G |
| Body fragmentation | 350 G |
| Cerebral contusion | 60 G for .02 seg |
| | 100 G for .005 seg |
| | 180 G for .002 seg |

# AIRCRAFT OCCUPANT RESTRAINT SYSTEMS

- Must be comfortable and adjustable
- Must provide protection against multi-directional deceleration forces
- Must be easy to use (intuitive)
- Must have a locking mechanism (preferably one) that can be released with one hand and must prevent unintentional release
- Must allow limited mobility of the user

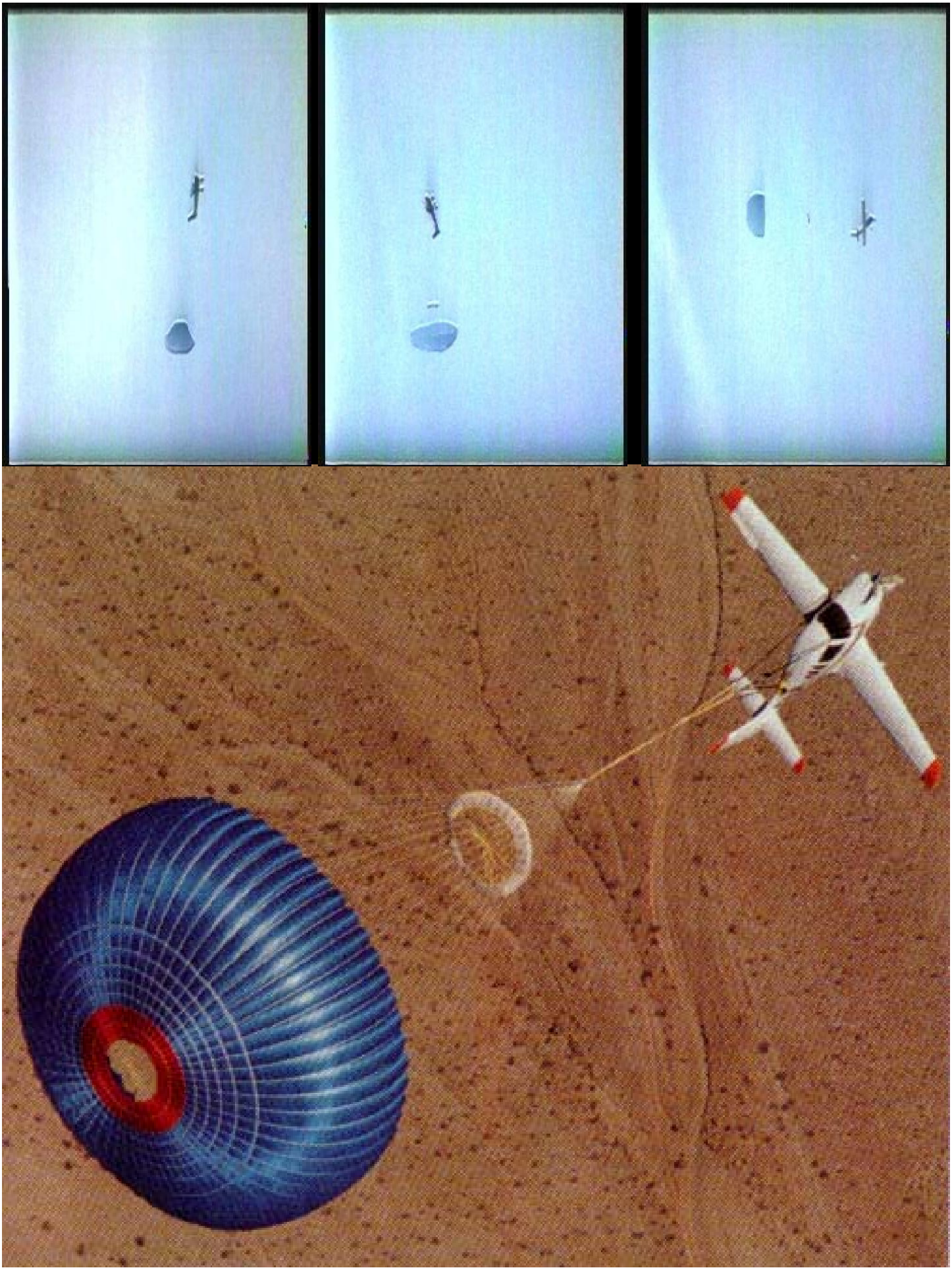
# HUMAN TOLERANCE TO DECELERATION (250 G/sec)

+ Gz: 25 Gs for 0.1 sec
- Gz: 15 Gs for 0.1 sec

+ Gx: 83 Gs for 0.04 sec
45 Gs for 0.1 sec
25 Gs for 0.2 sec
- Gx: 45 Gs for 0.1 sec (full harness)
25 Gs for 0.2 sec (full harness)

± Gy: 11-20 Gs for 0.1 sec (full harness)

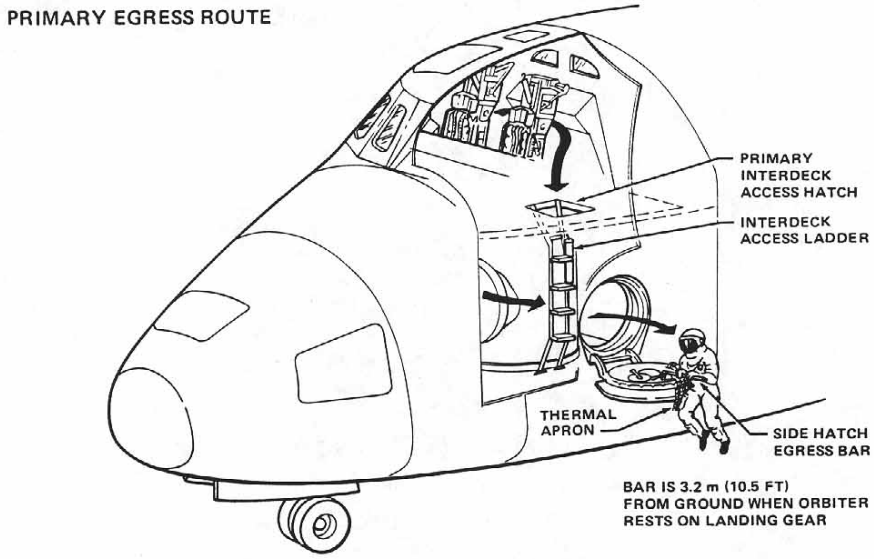
Dryden Flight Research Center E-9543 Photographed 1959
X-15 after a hard landing by pilot Scott Crossfield.
NASA photo

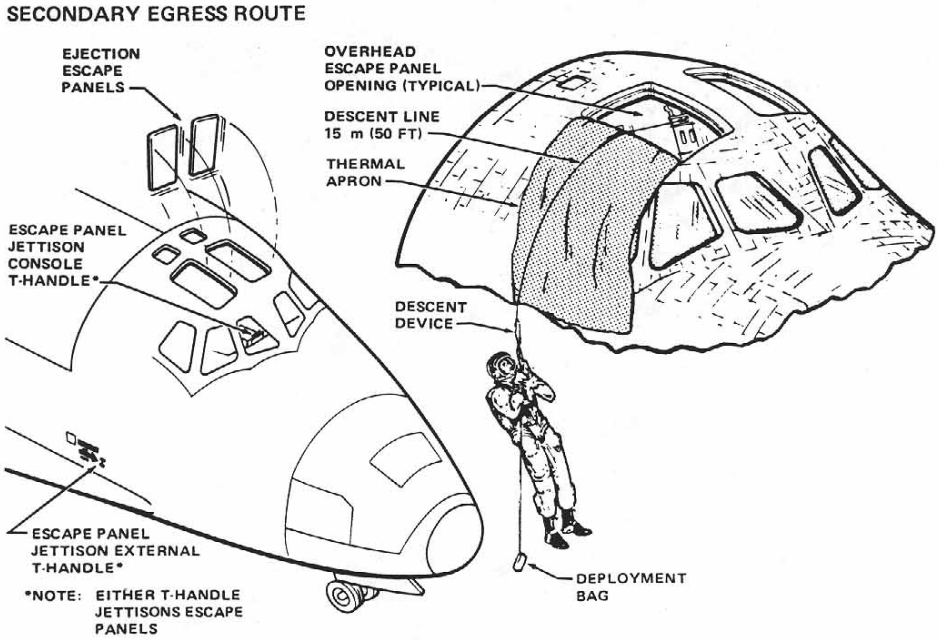


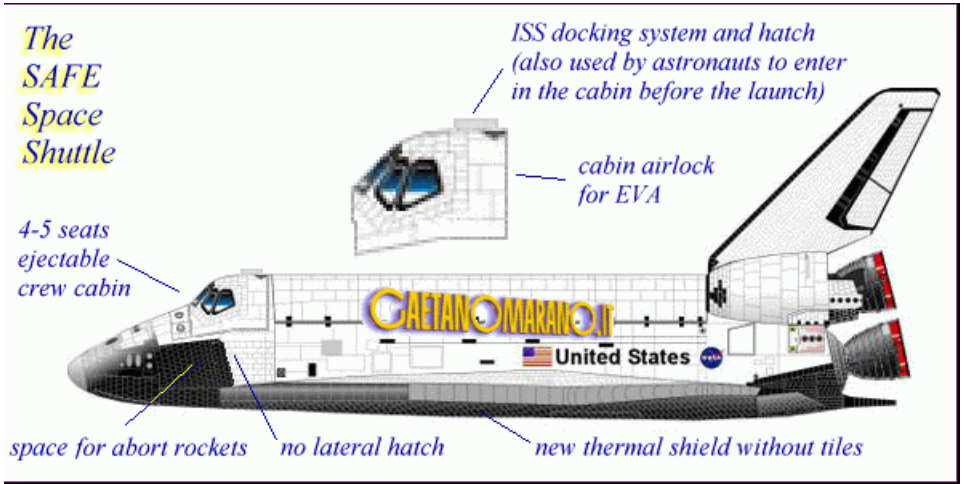
NASA
BOEING
ILC
DOVER

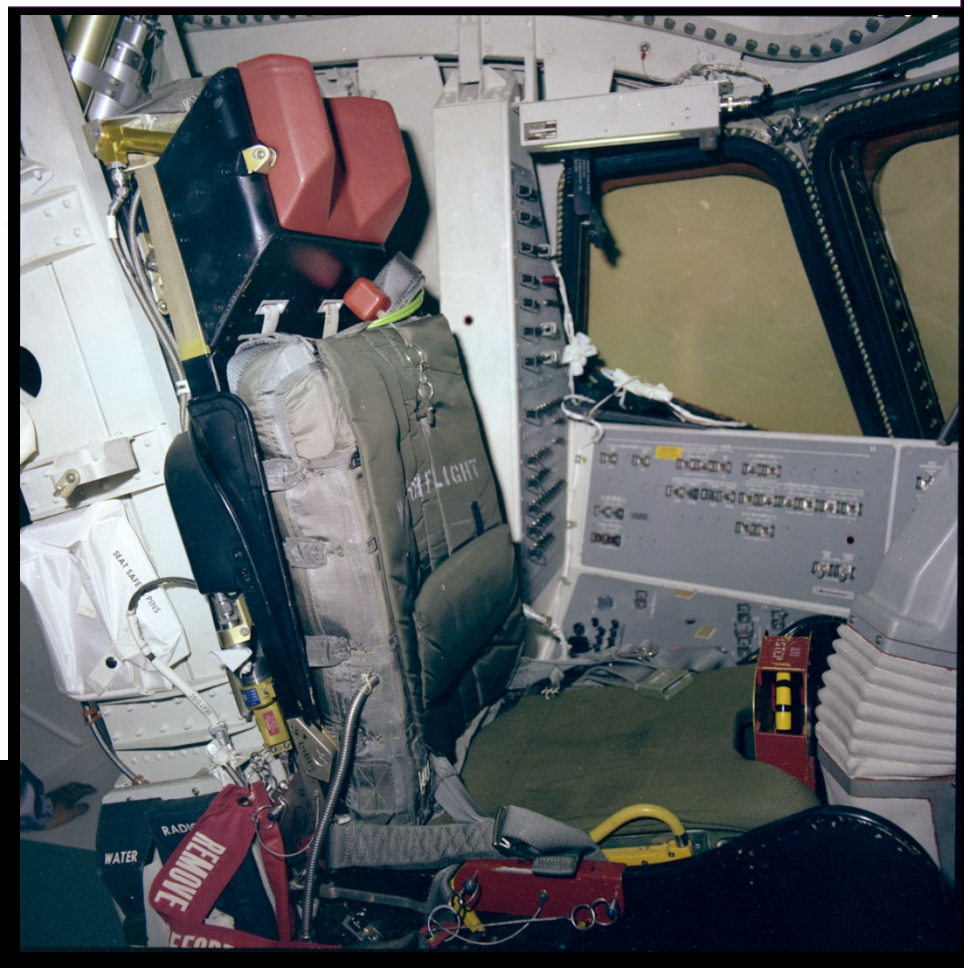
After orbital insertion of Soyuz 1 one of the solar panels failed to deploy. Although only receiving half of the planned solar power, an attempt was made to maneuver the spacecraft but it failed. The decision was made to bring Komarov back. Re-entry was successful and the drag chute deployed. However due to a failure of a pressure sensor, the main parachute would not deploy. Komarov released the reserve chute, but it became tangled with the drag chute. The descent module crashed.

# Stratos


PRIMARY EGRESS ROUTE
PRIMARY INTERDECK ACCESS HATCH
INTERDECK ACCESS LADDER
THERMAL APRON
SIDE HATCH EGRESS BAR
BAR IS 3.2 m (10.5 FT) FROM GROUND WHEN ORBITER RESTS ON LANDING GEAR


SECONDARY EGRESS ROUTE
EJECTION ESCAPE PANELS
OVERHEAD ESCAPE PANEL OPENING (TYPICAL)
DESCENT LINE 15 m (50 FT)
THERMAL APRON
ESCAPE PANEL JETTISON CONSOLE T-HANDLE*
DESCENT DEVICE
ESCAPE PANEL JETTISON EXTERNAL T-HANDLE*
DEPLOYMENT BAG
*NOTE: EITHER T-HANDLE JETTISONS ESCAPE PANELS

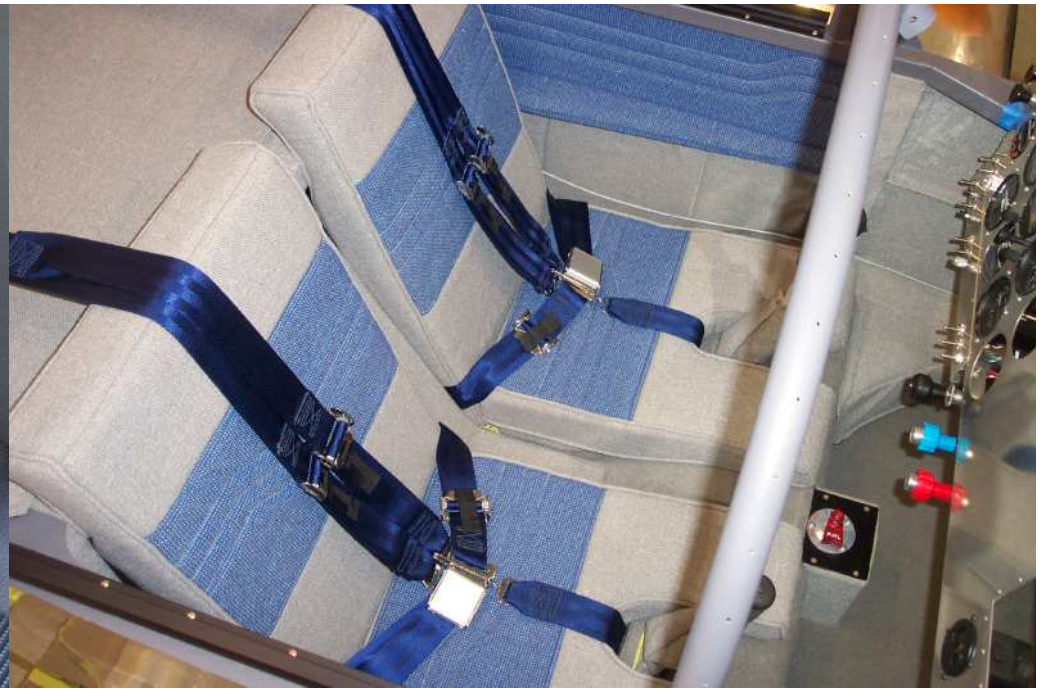

The SAFE Space Shuttle
ISS docking system and hatch (also used by astronauts to enter in the cabin before the launch)
cabin airlock for EVA
4-5 seats ejectable crew cabin
CAETANOMARANO.IT
United States
space for abort rockets
no lateral hatch
new thermal shield without tiles


WATER
REMOVE

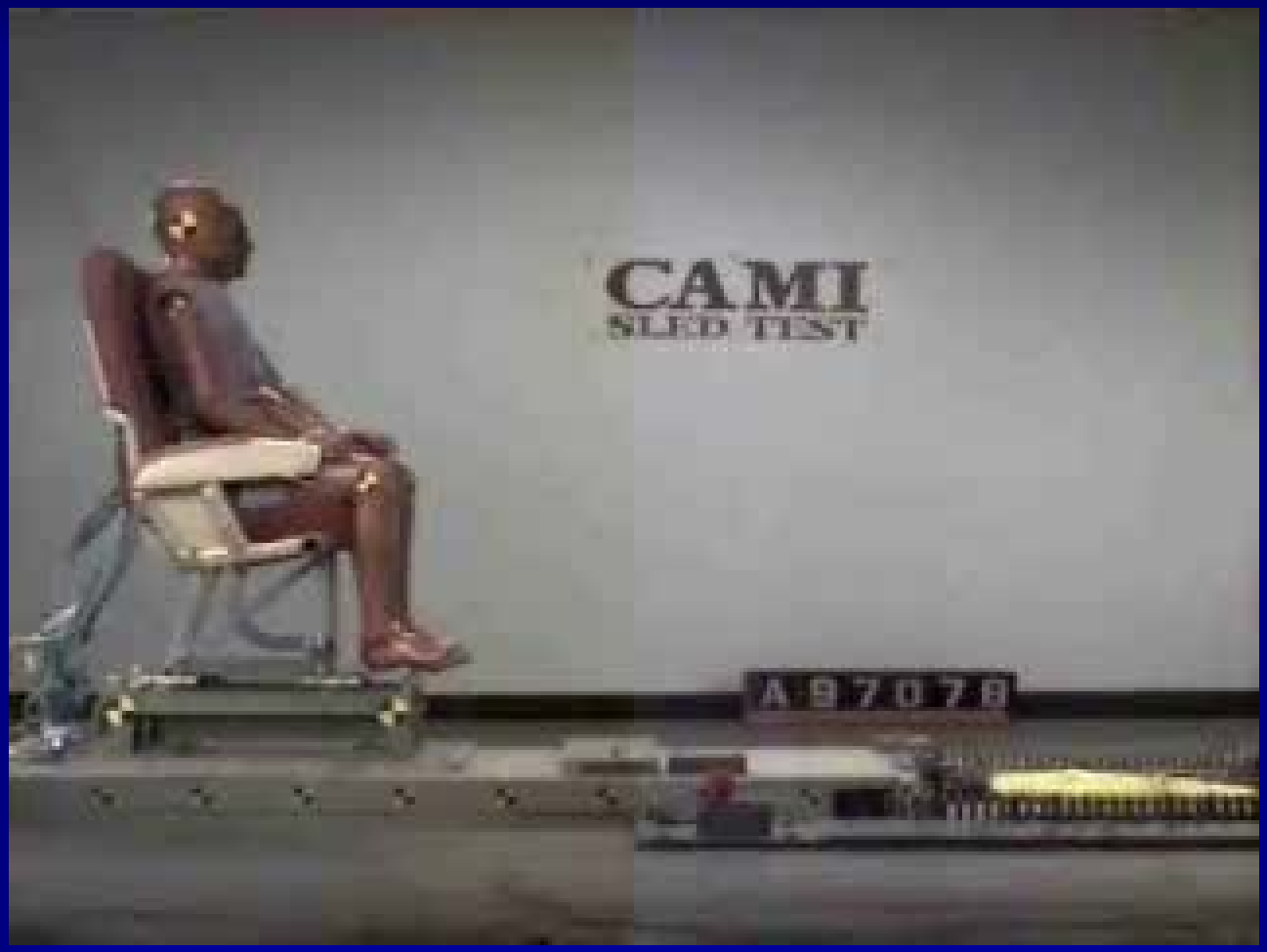
# Restraint Systems

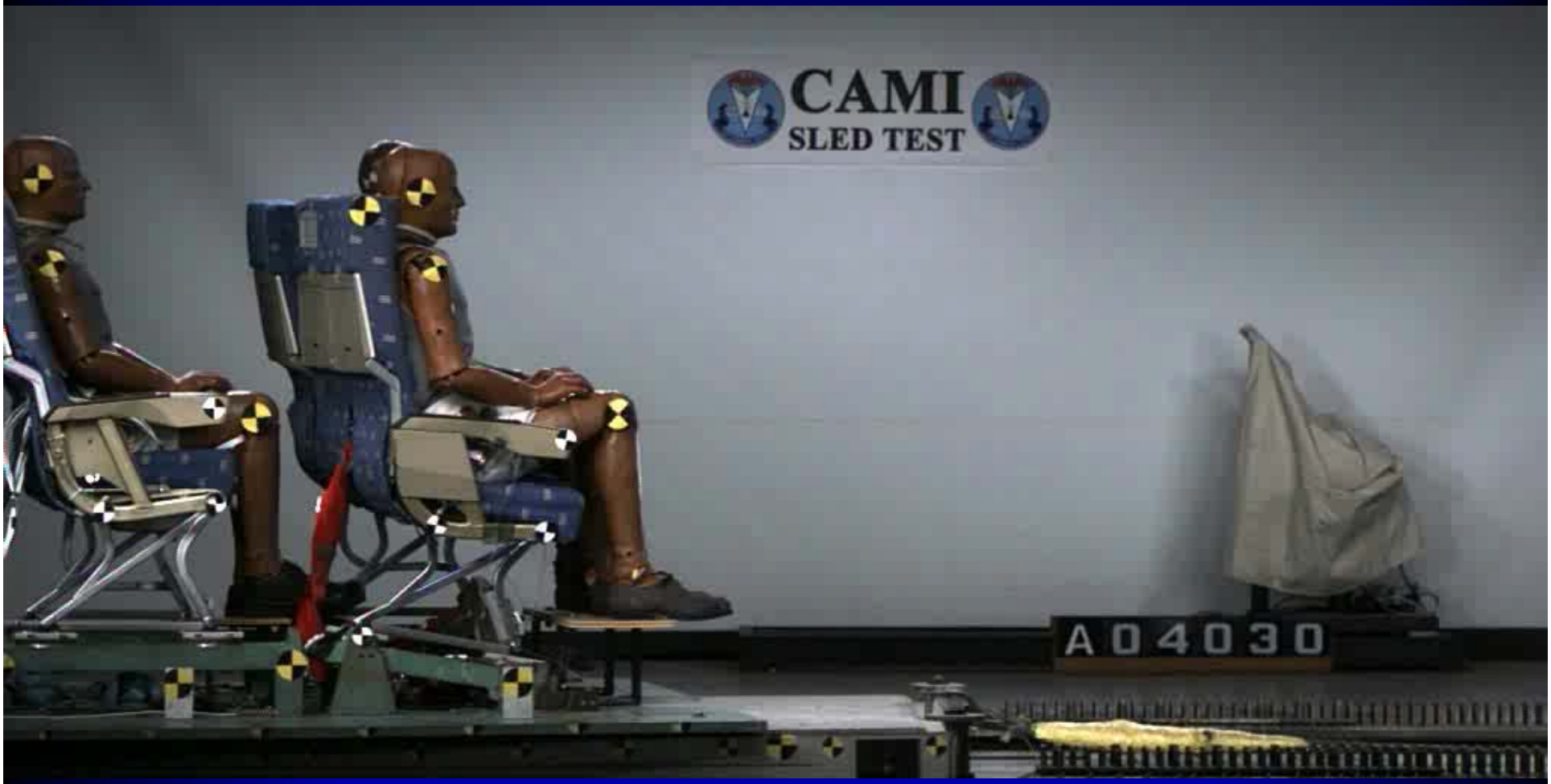
60”
SeatBeltsPlus
.com

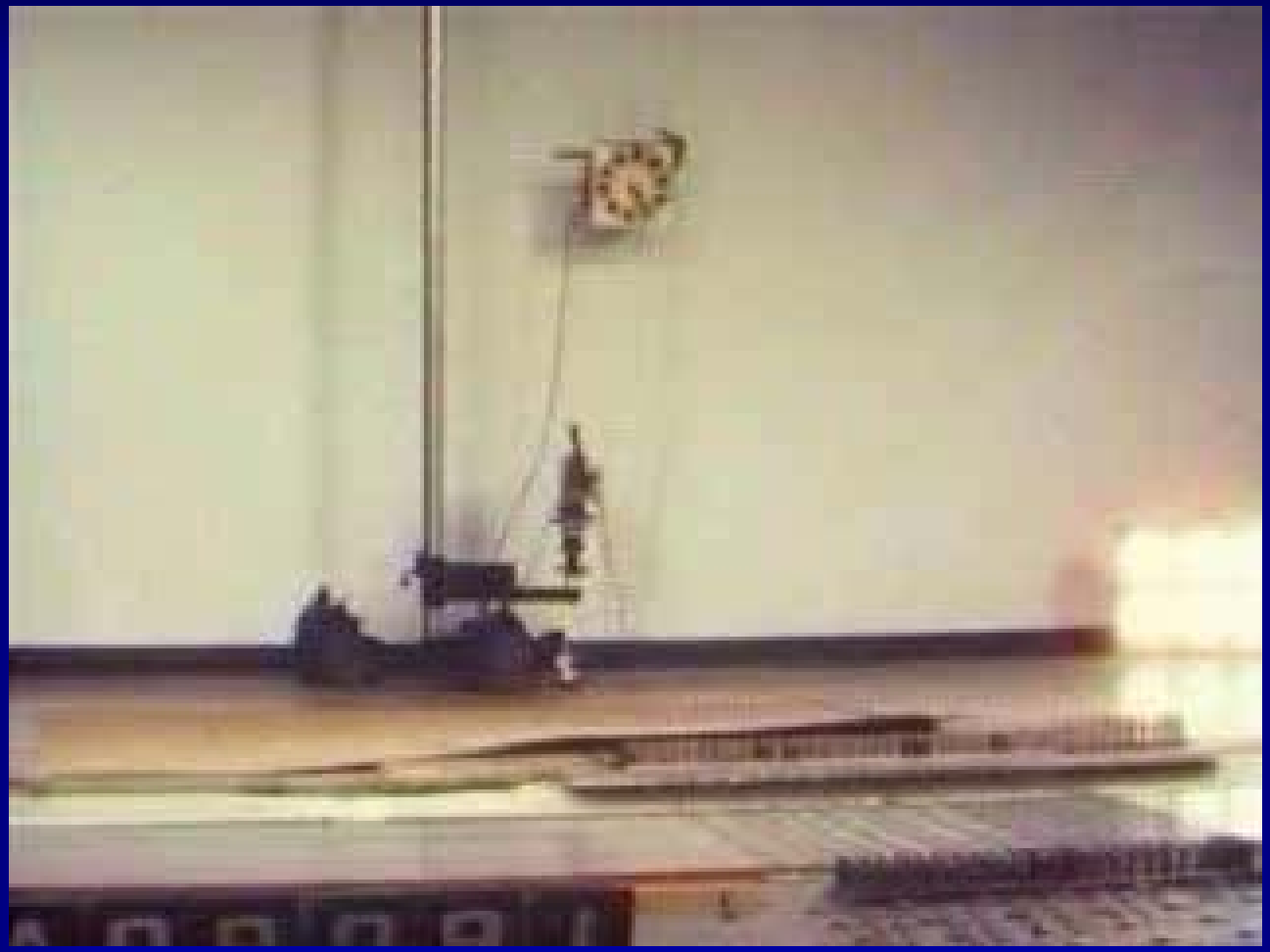
AUG 27 2007



NASA


CAMI
SLED TEST
A 9 7 0 7 8


CAMI
SLED TEST
A04030



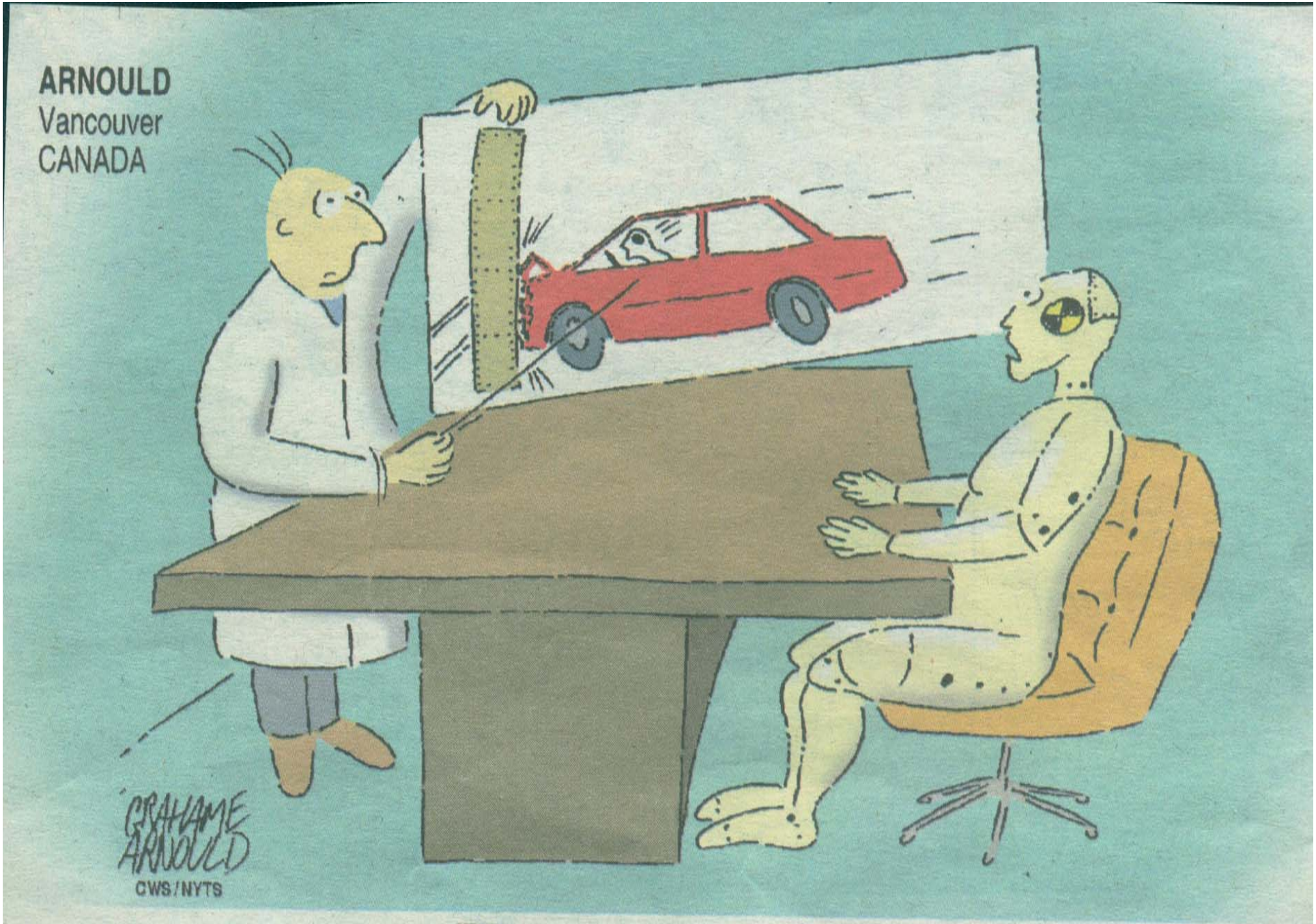
CAMI
SLED TEST
CAMI

AMI
TEST
A04026

# OTHER PROTECTIVE SYSTEMS

- Air bags
- Rear-facing seats
- Crashworthy seats
- Crashworthy aircraft structures

CAMI
SLED TEST
A07009




"You want me to do what?"

All 157 passengers and eight crewmembers safely evacuated the China Airlines Boeing 737-800 that caught fire after landing at Okinawa Naha Airport.

60 seconds

120 seconds

60 seconds

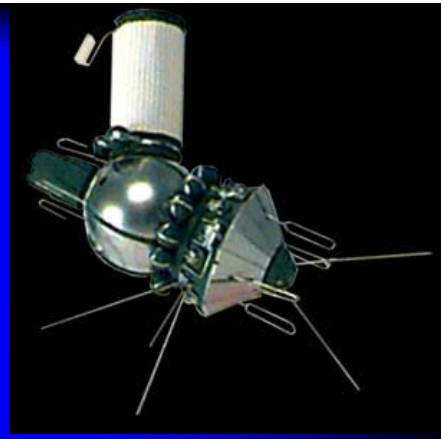
120 seconds

01 286

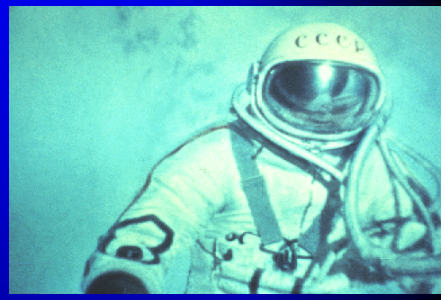
# January 27, 1967

Apollo 1 Astronauts Gus Grissom, Edward White and Roger Chaffee died when a fire blazed their command module during a ground test at KSC.

# March 18, 1965



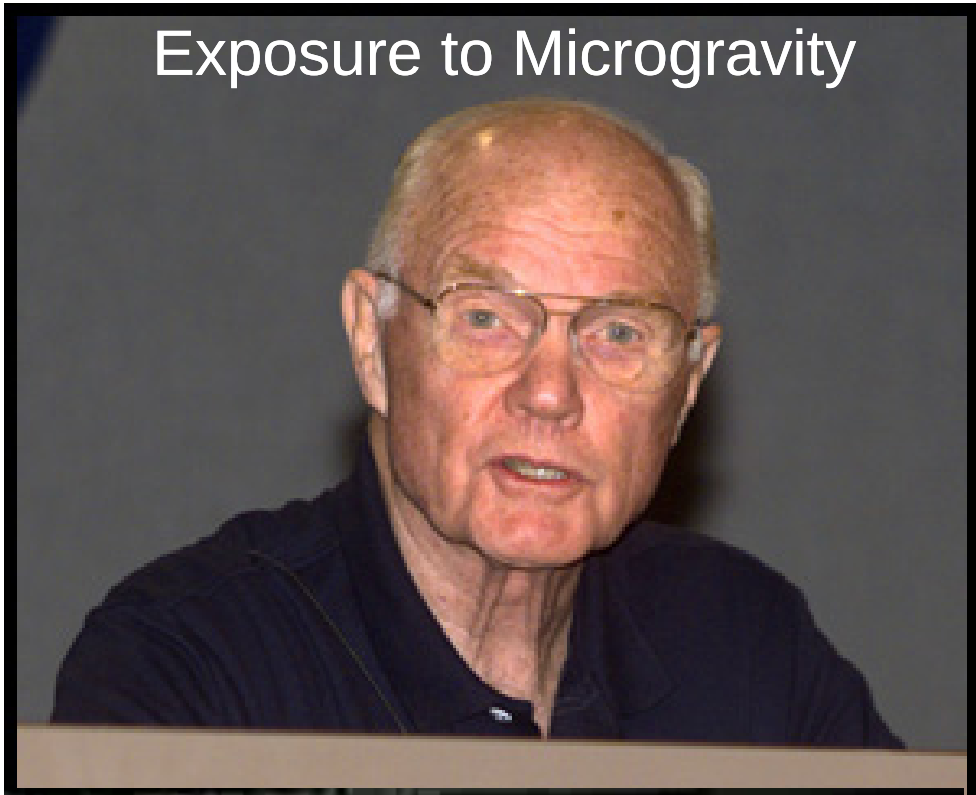
- Voskhod-2 “Sunrise”
- Pavel Belyayev and Aleksei Leonov (1st EVA)
- EVA suit failure with suit ballooning
- Unable to squeeze through narrow hatch without bleeding air from suit
- Primary hatch reseal failure
- Environmental control systems compensated by flooding cabin with 100% O2
- Service module failed to separate completely
- Wild gyrations on re-entry
- Crash landed in deep woods, 1,200 miles off target & spent the night surrounded by wolves

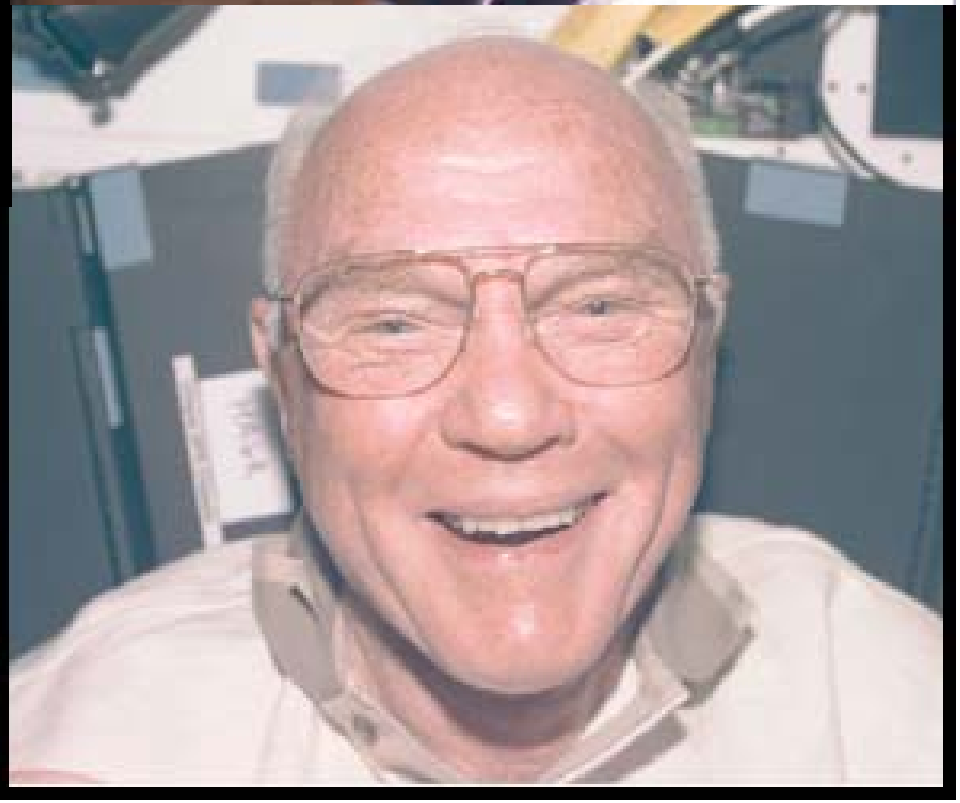


Leonov A and Scott D. *Two Sides of the Moon*. Thomas Dunne Books. St. Martin’s Press LLC. 2004

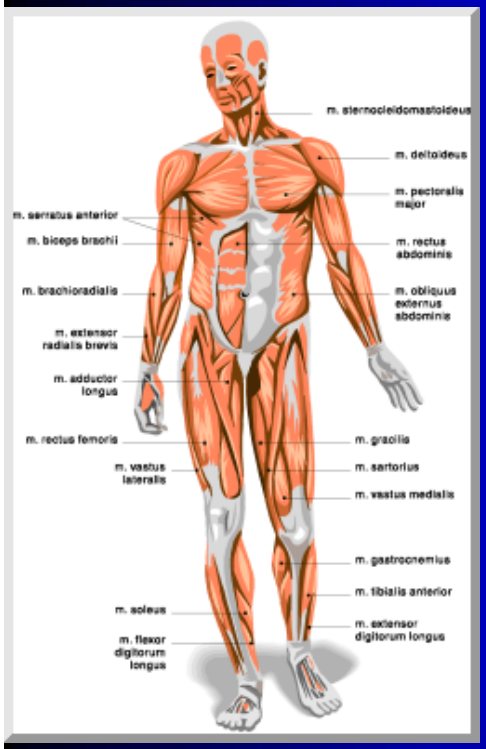
# Physiological Effects Of Space Flight

# Exposure to Microgravity

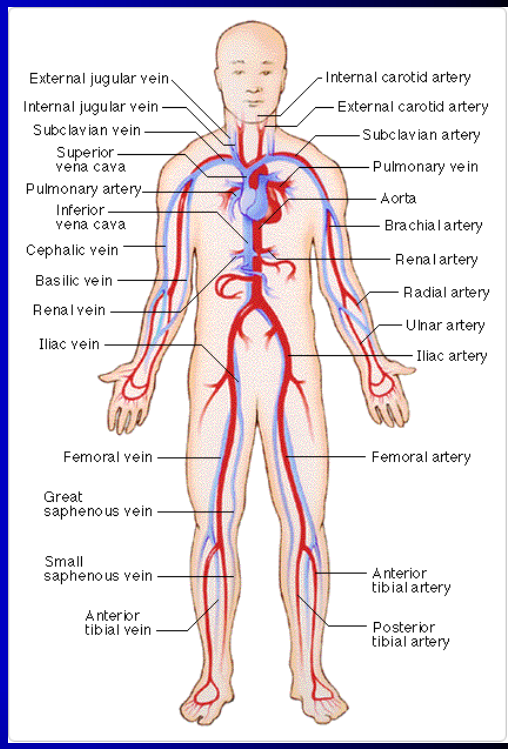


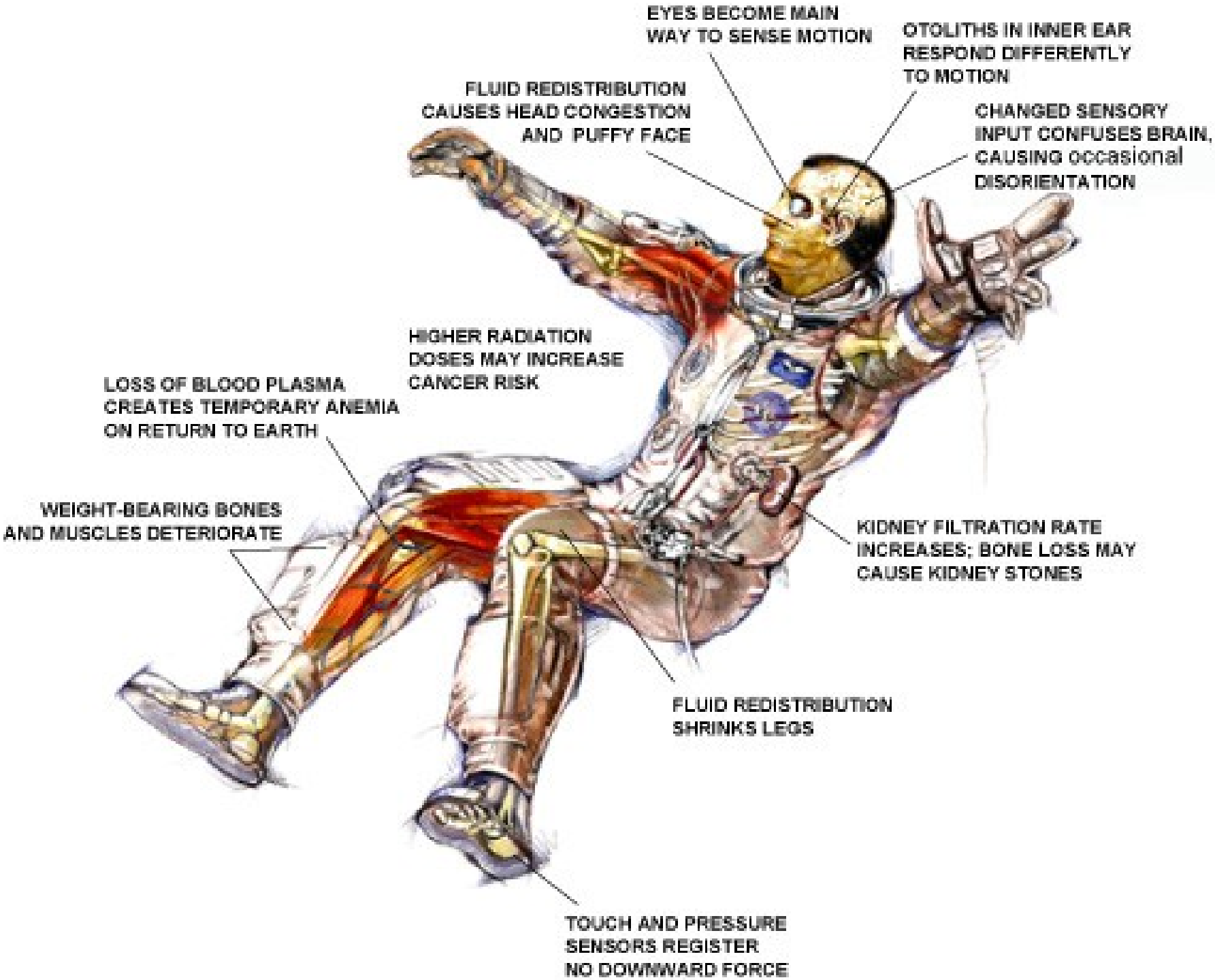


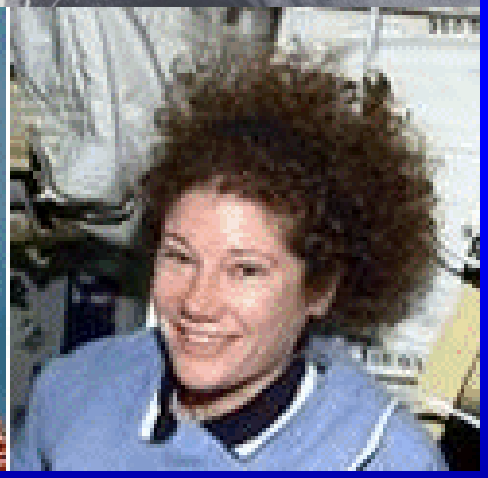
# Physiological Effects of Exposure to Microgravity

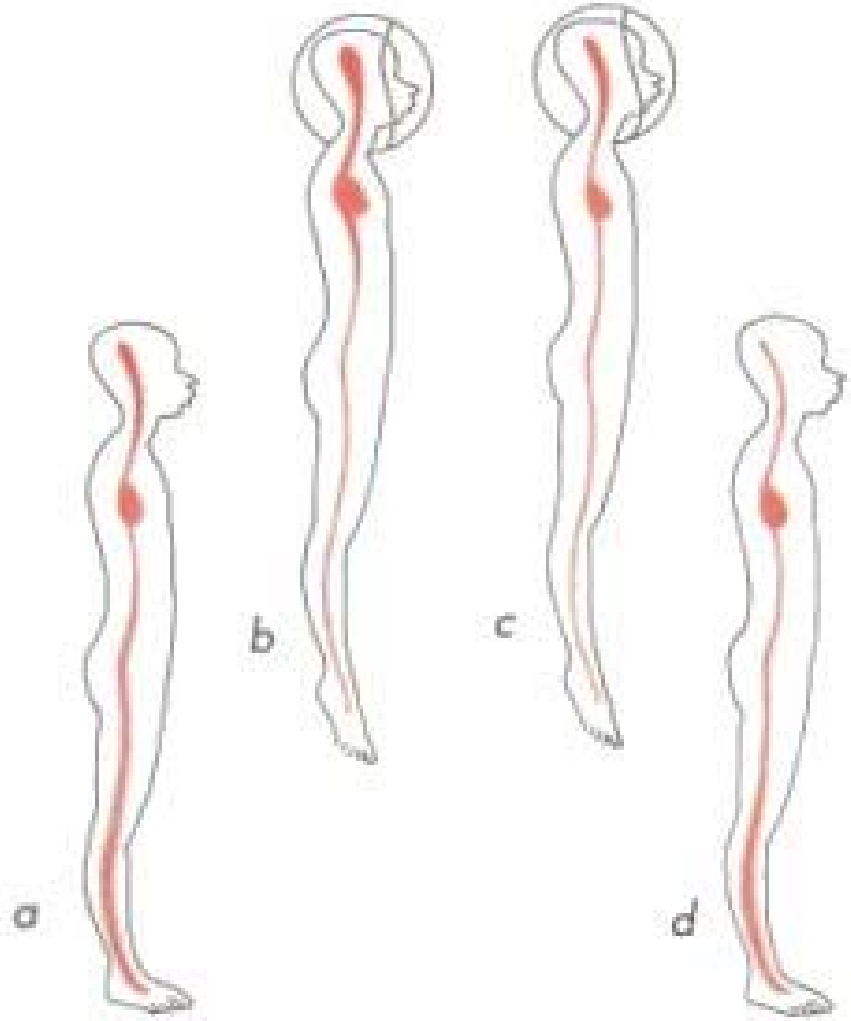



- Cardiovascular
- Musculo-skeletal
- Neurovestibular
- Hematologic & immunologic




EYES BECOME MAIN WAY TO SENSE MOTION
OTOLITHS IN INNER EAR RESPOND DIFFERENTLY TO MOTION
FLUID REDISTRIBUTION CAUSES HEAD CONGESTION AND PUFFY FACE
CHANGED SENSORY INPUT CONFUSES BRAIN, CAUSING occasional DISORIENTATION
HIGHER RADIATION DOSES MAY INCREASE CANCER RISK
LOSS OF BLOOD PLASMA CREATES TEMPORARY ANEMIA ON RETURN TO EARTH
WEIGHT-BEARING BONES AND MUSCLES DETERIORATE
KIDNEY FILTRATION RATE INCREASES; BONE LOSS MAY CAUSE KIDNEY STONES
FLUID REDISTRIBUTION SHRINKS LEGS
TOUCH AND PRESSURE SENSORS REGISTER NO DOWNWARD FORCE

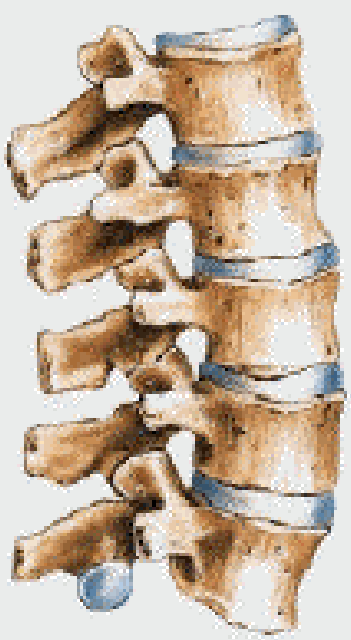





a. Fluid distribution on Earth
b. In microgravity fluids redistribute
c. Kidneys eliminate fluids
d. Returning to Earth

- The muscles used to fight gravity and maintain posture can vanish at the rate of 5% a week
- After only 11 days in space microgravity can shrink muscle fibers as much as 30%

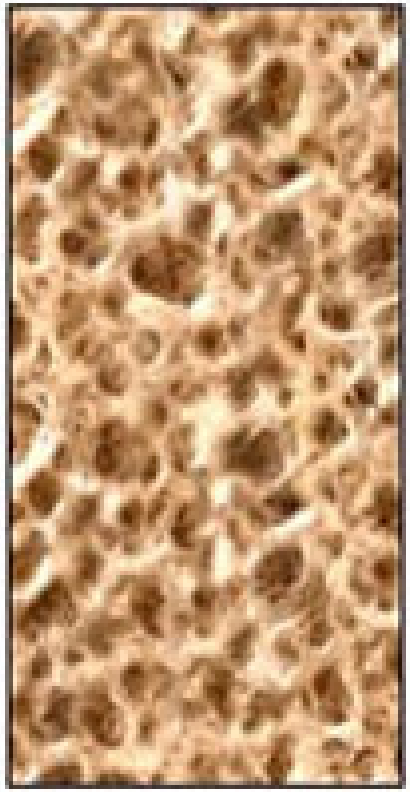
It is reported that 3.2% of bone loss occurs after 10 days of microgravity



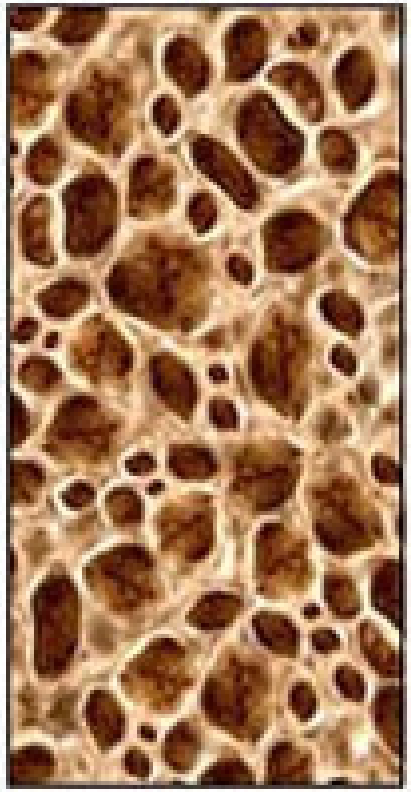
Normal vertebrae

Vertebrae suffering from osteoporosis

Normal bone

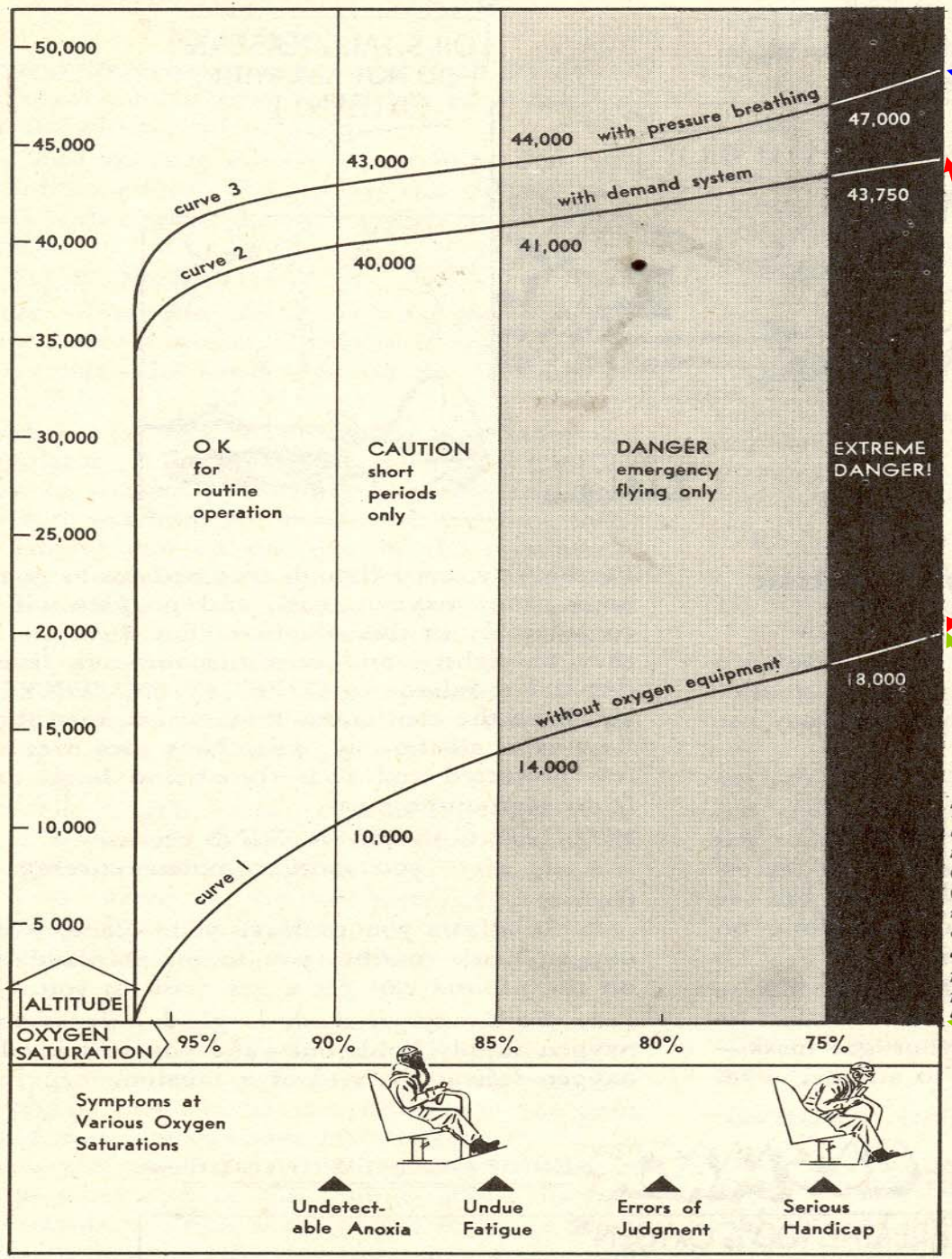


Bone with Osteoporosis



The physiological changes resulting from exposure to microgravity depend upon the total duration of the exposure, and can vary in magnitude from individual to individual

# INFLIGHT DECOMPRESSION



*The relation between altitude and blood oxygen saturation is shown for the flyer without oxygen equipment (curve 1); with the demand system (curve 2); and with pressure-breathing (curve 3). Curves 2 and 3 are based on the assumption that no mask leakage occurs. A special advantage of pressure-breathing is that it completely eliminates the chance of inboard mask leaks.*

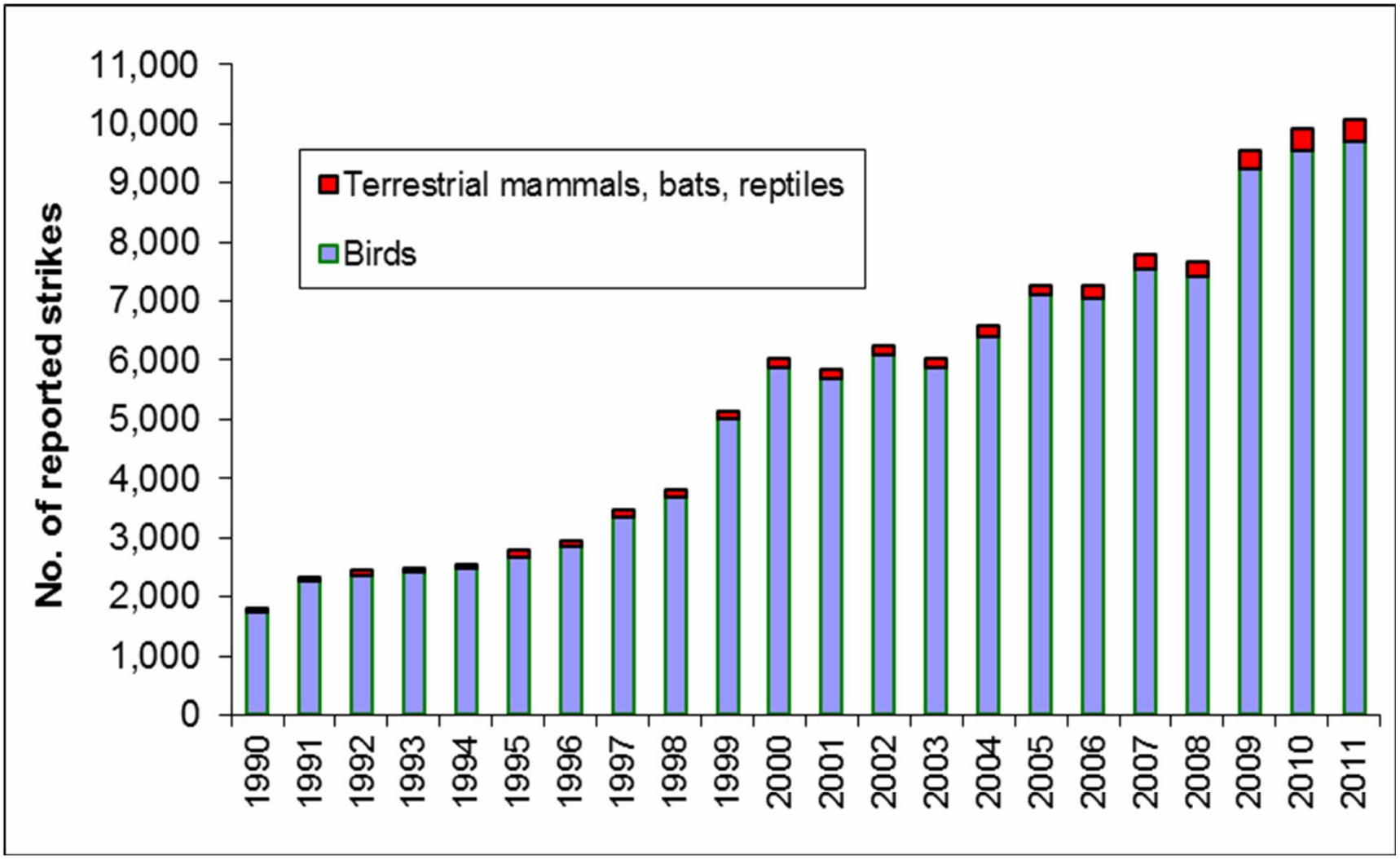


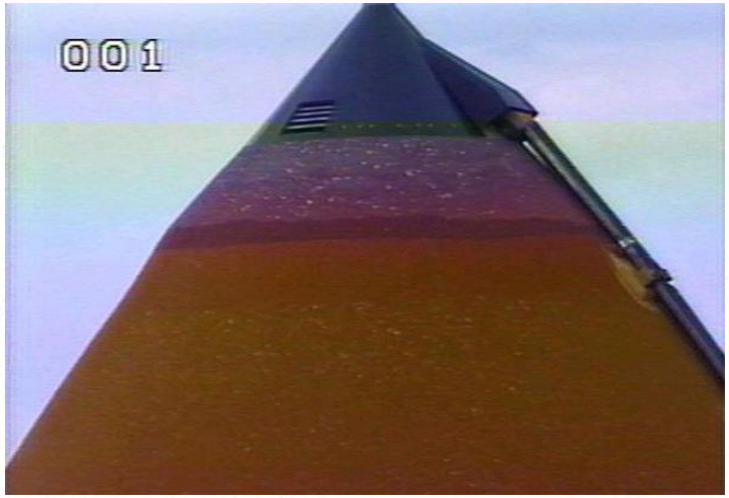

Figure 1. Number of reported wildlife strikes with civil aircraft, USA, 1990–2011. The 119,917 strikes involved birds (116,408), terrestrial mammals (2,754), bats (618), and reptiles (137, see Table 1).

845

July 2005

Space Shuttle external tank was hit by a turkey vulture during launch

# STS-117 Hail Storm Damage



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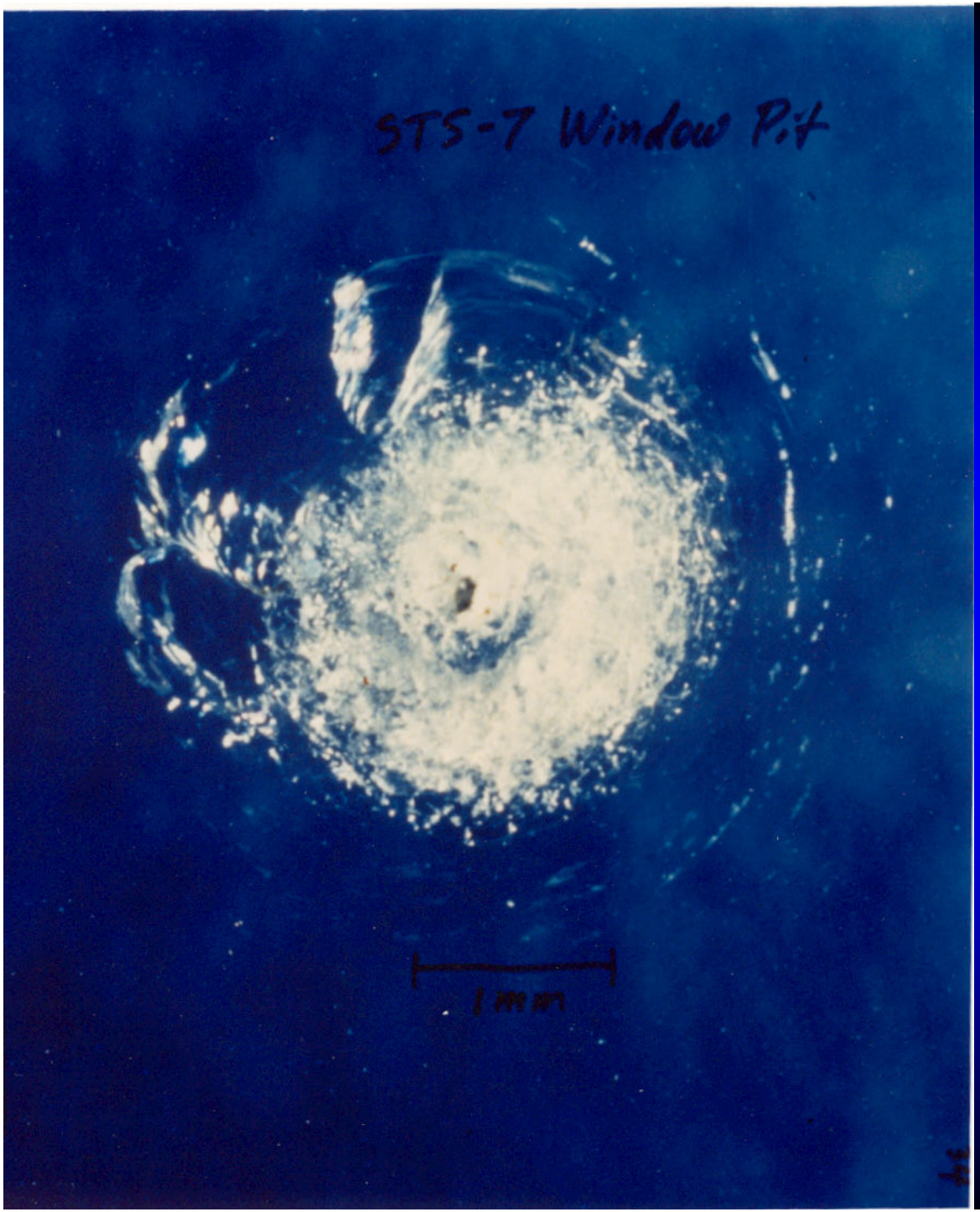



# Space debris will be a risk factor for the occupants of <u>orbital</u> space vehicles

A speck of paint from a satellite dug a pit in a space shuttle window nearly ¼ inch wide

NASA has replaced more than 80 shuttle windows due to debris impacts

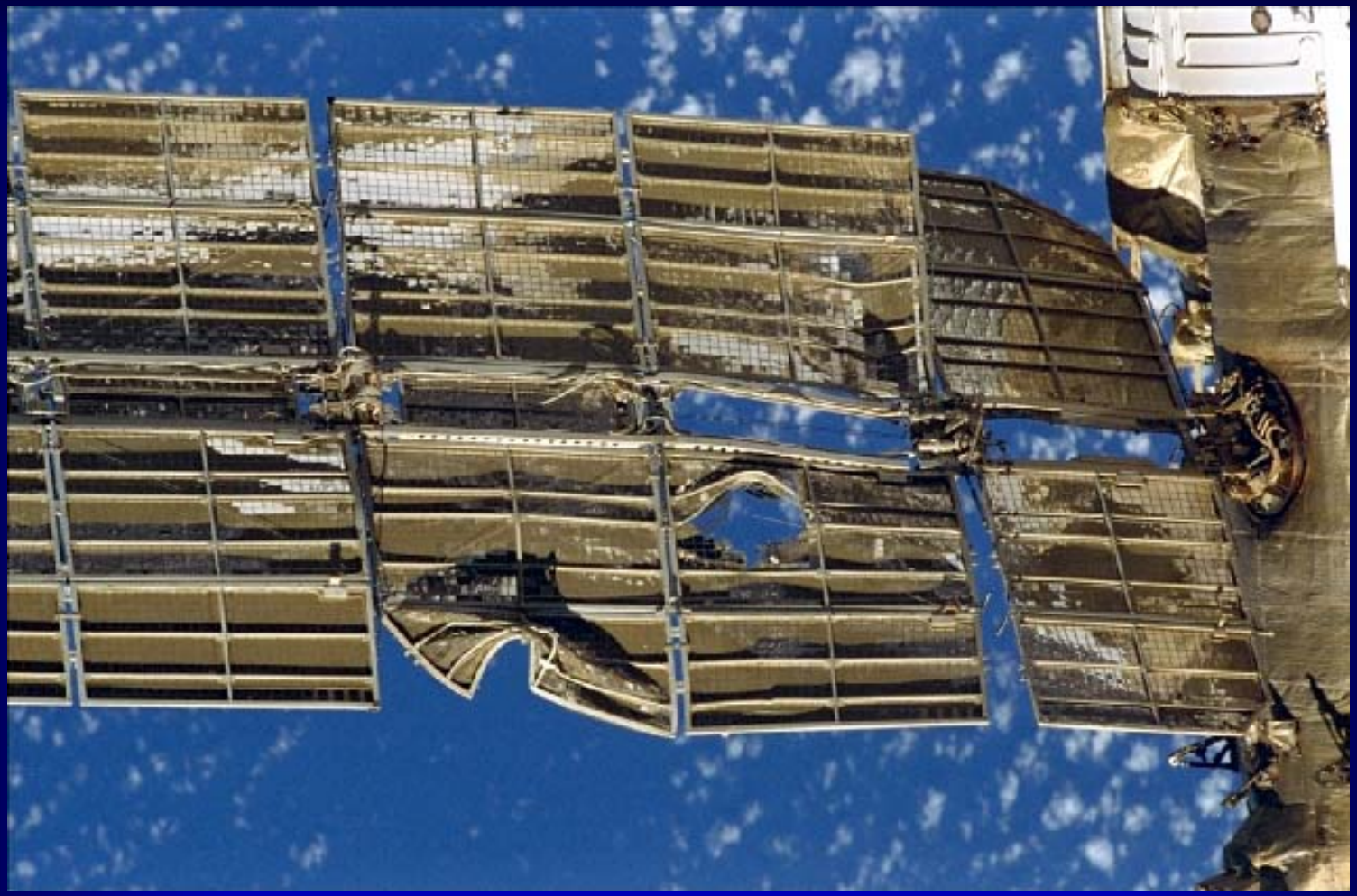
# Loss of Cabin Pressure

June 29, 1971

Cosmonauts Georgy Dobrovolsky, Vladislav Volkov and Viktor Patsayev died during re-entry of their Soyuz 11.

An investigation discovered that they died 30 minutes before landing because a faulty valve depressurized the spacecraft.

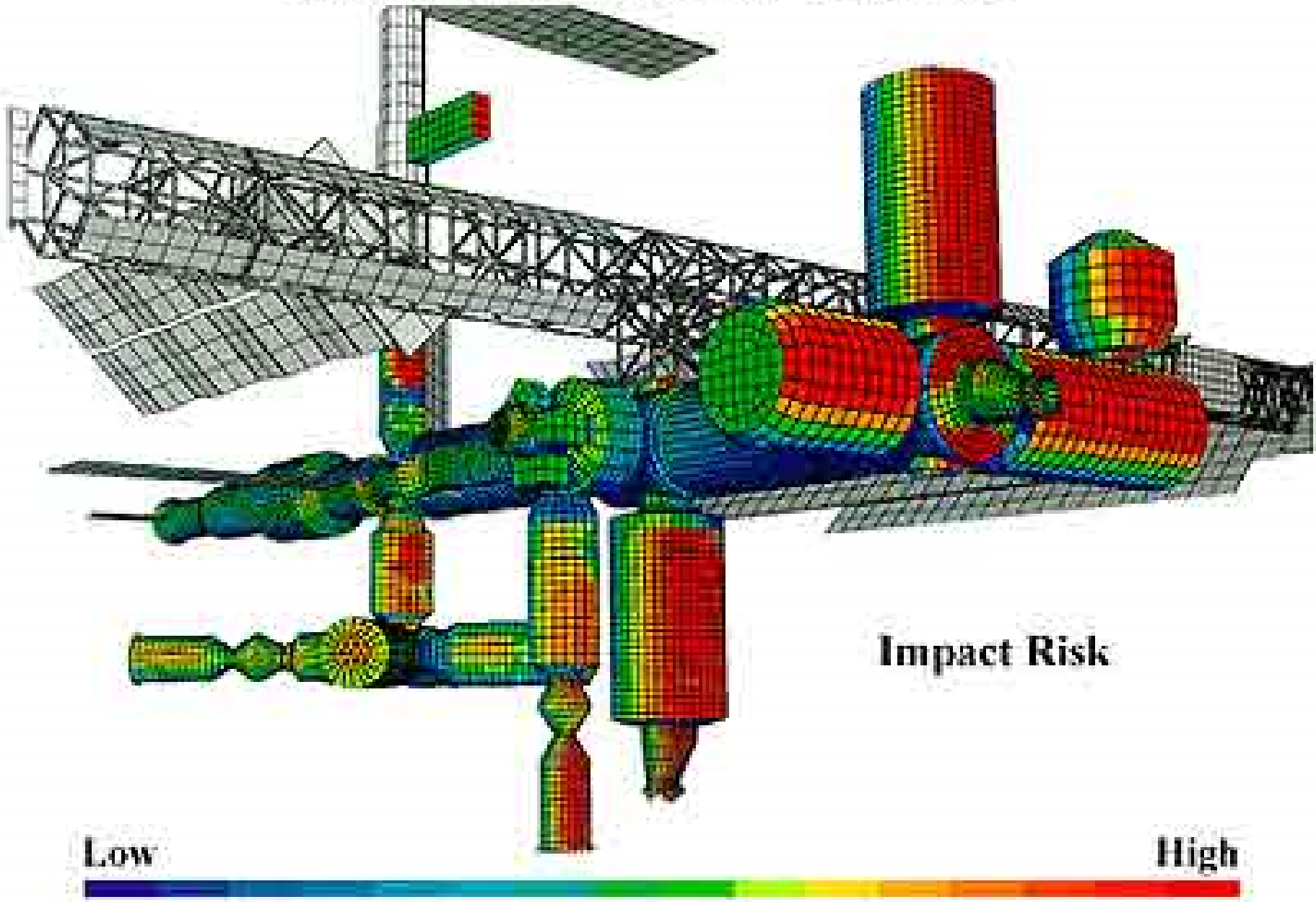
# June 25, 1997



A Progress M-34 spacecraft crashed into the Spektr module while maneuvering for a docking. The collision damaged one of Spektr's solar arrays and punctured the hull, depressurizing the module. The module was sealed off from the rest of the station to prevent depressurization of the entire Mir space station.

# International Space Station

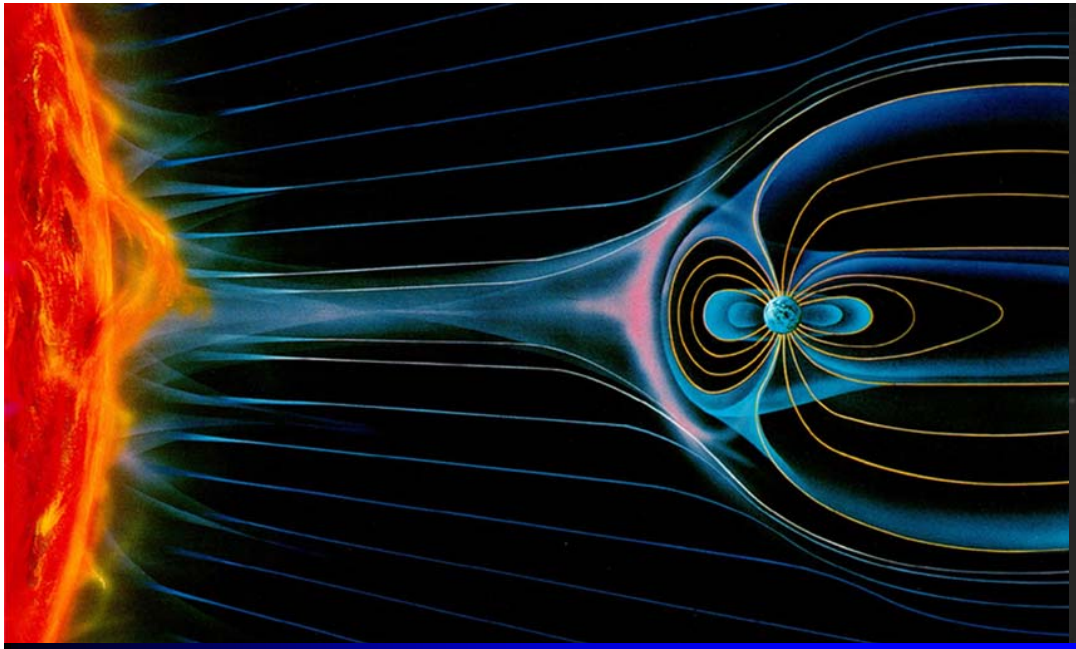
**Probability of No Impacts From a > 1 cm O Debris**

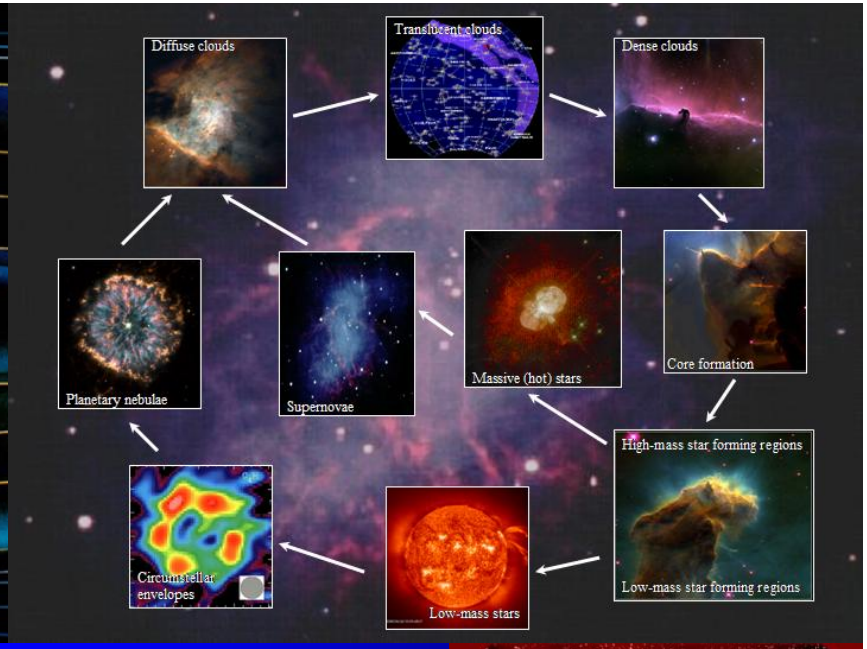


# Impact Risks in LEO

- 18% chance that a debris impact would force abandoning of ISS (when 100% completed)
- 9% chance of penetration that would lead to loss of station and/or its crew
  - Installation of 23 ISS debris shields will ↓ these odds to 14% and 8% respectively
  - Installation of 22 Kg of shields on Progress and Soyuz spacecraft will ↓ these odds to 8% and 5% respectively

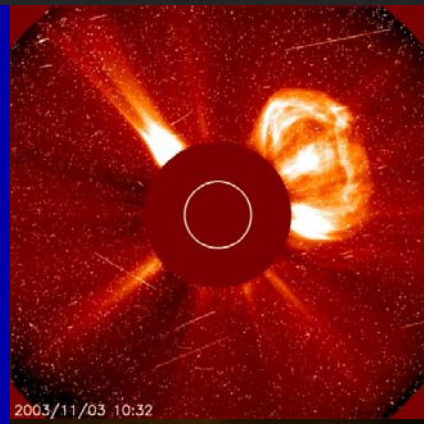
Final Report: of the International Space Station Independent Safety Task Force
February 2007

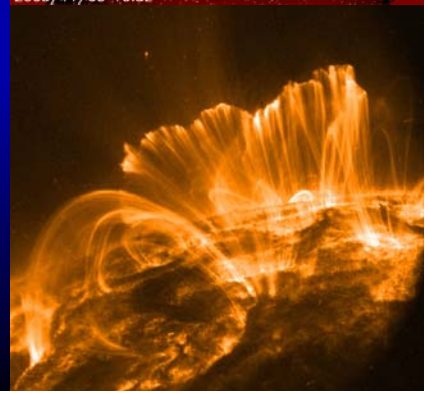




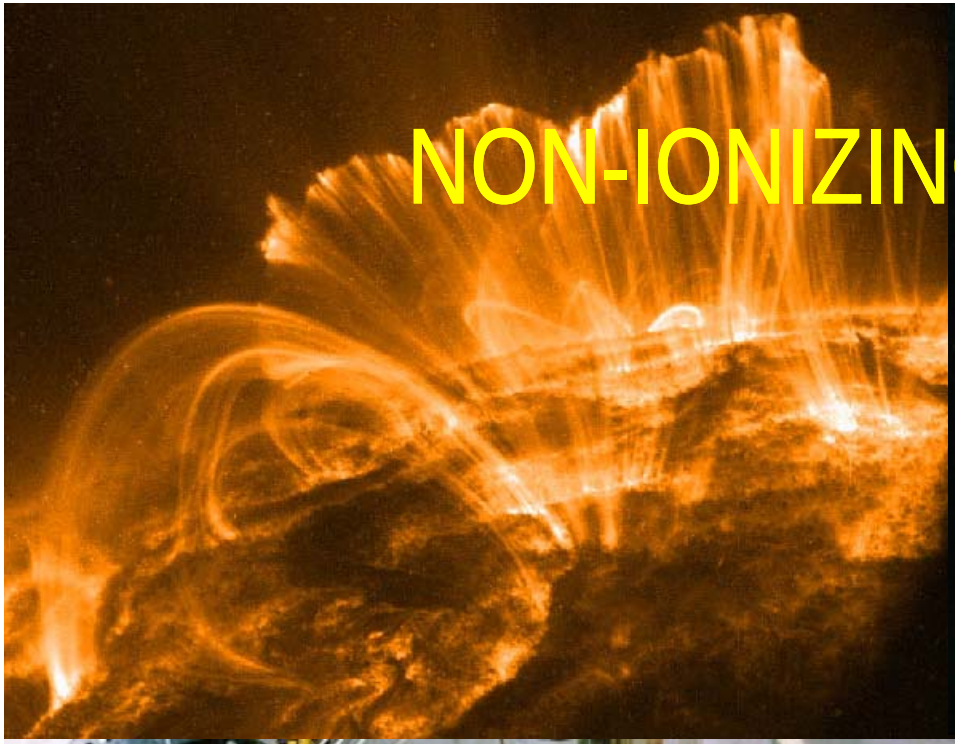

# IONIZING SOLAR AND GALACTIC COSMIC RADIATION

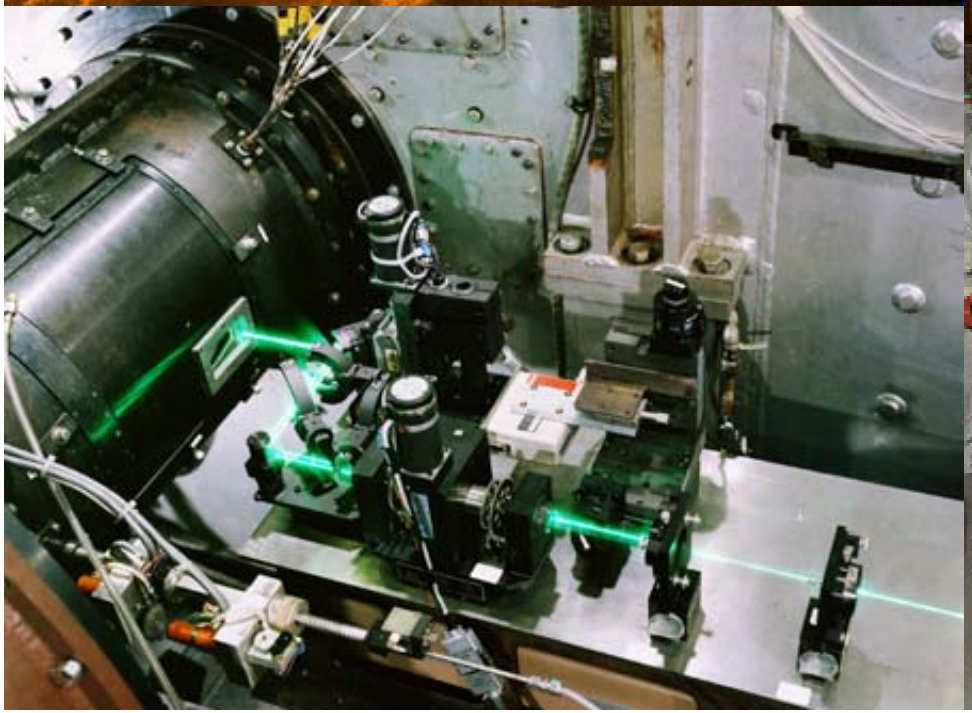
*The main sources are <u>geomagnetically trapped radiation</u>, <u>solar particle event radiation</u>, and <u>galactic cosmic radiation</u>*



# NON-IONIZING RADIATION





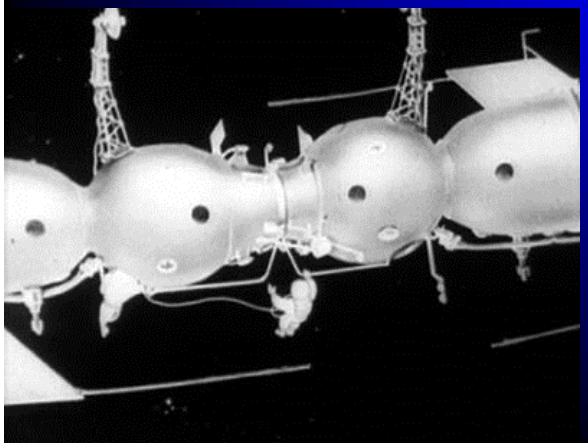
# ACCELERATION

# November 15, 1967

- X-15, Flight 191
- Michael J. Adams
- <u>Electrical problems</u>
- Enters a Mach 5 spin @ 260,000ft
- <u>15Gz and 8Gy forces</u>
- History of ‘vertigo’ on previous flight
- End of X-15 program

# 17 Jan 1969

- Soyuz 4 and 5 rendezvous and transfer of 2 cosmonauts
- Boris Volynov (5), Alexei Yeliseyev and Yevgeny Khrunov (5 to 4), Vladimir Shatalov (4)
- Incomplete separation of Soyuz-5 equipment module on reentry
- Soyuz-5 Descent module descends nose-first with inadequate heat shielding
- Tumbling with a 9G trajectory
- Partial deployment of primary parachute
- Near-fatal landing several miles off-course
- Volynov staggers to a nearby peasant hut in -40$^{O}$C, without a space suit
- Survives with loss of few teeth



The Soyuz-4 and -5 crew. Left to right: Yeliseyev, Khrunov, Shatalov, Volynov

# March 16, 1966

- Gemini VIII
- Neil Armstrong and David Scott
- Flight attitude thruster malfunction
- Roll rate reached 300°/s (50rpm)
- -0.9Gy / +0.9Gy for 46s
- -0.89Gz and +0.05Gz simultaneously

Mohler SR *et al*. ASEM, Jan 1990.

# 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*

*Noise can also be caused by the aerodynamic interaction between ambient air (boundary layer) and the surface of the space vehicle during the atmospheric portion of the flight*

# VIBRATION

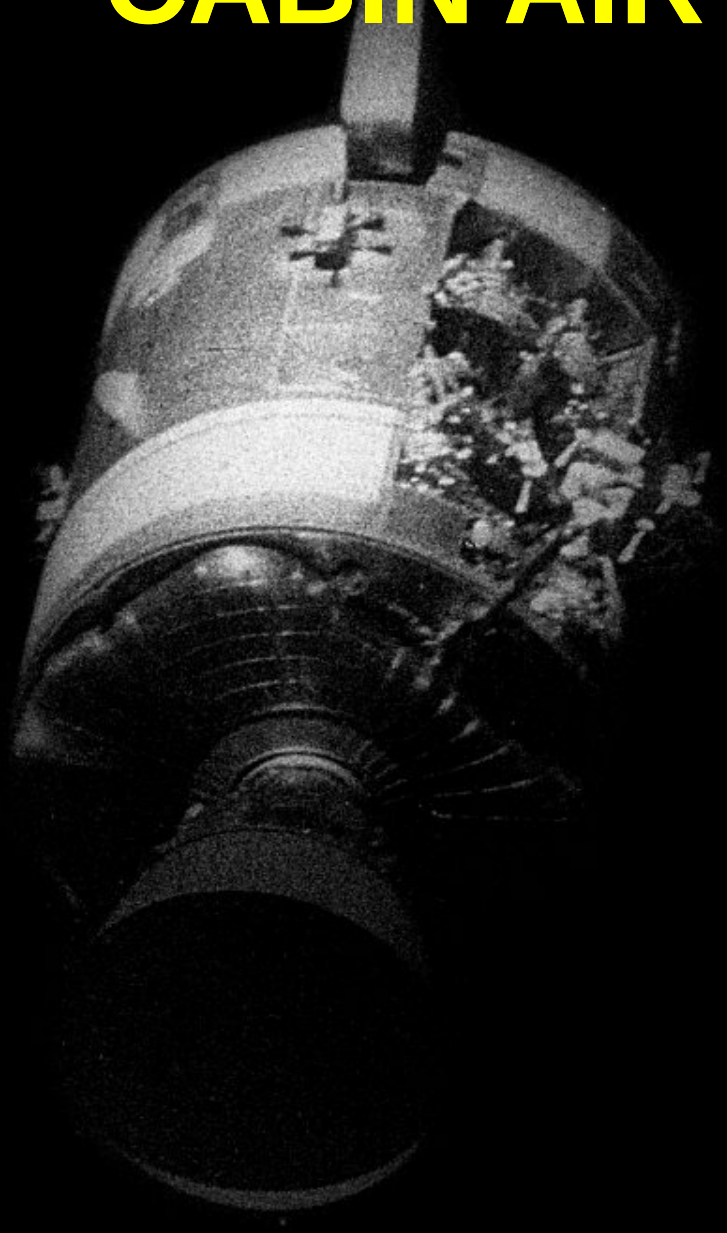
*Vibration is transmitted throughout the entire body*

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

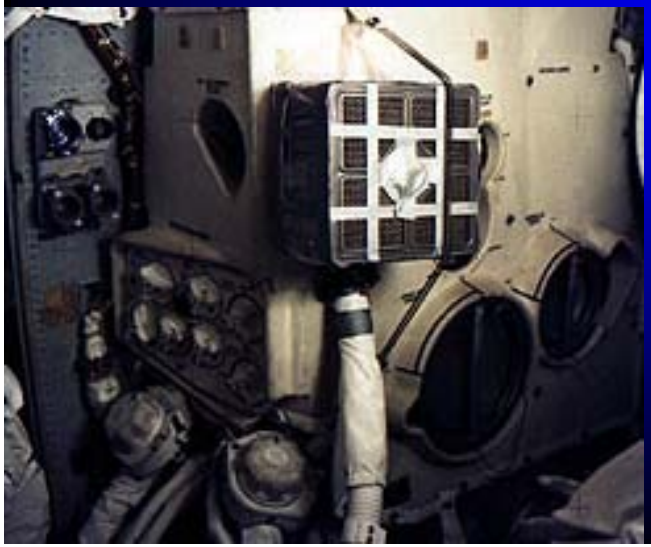
Other sources of inflight vibration include motors, pumps, and other mechanical equipment

# CABIN AIR



# April 1970

- Apollo-XIII
- Lovell/Haise/Sweigert
- Explosion in service module
- Limited O2/Mission aborted
- Dehydration – UTI – Fatigue - ↑ CO2



- In the sealed cabin environment of a space vehicle there are several potential risks including the presence of biological, chemical and particulate contaminants

- Carbon dioxide released by all occupants during exhalation could accumulate and become a breathing hazard especially during sleep due to lack of convective air circulation

- Breathing 100% oxygen (instead of a gas mixture) at sea level pressure for prolonged periods of time could cause reduced vital capacity, respiratory disturbances, heart problems, blindness, and loss of consciousness

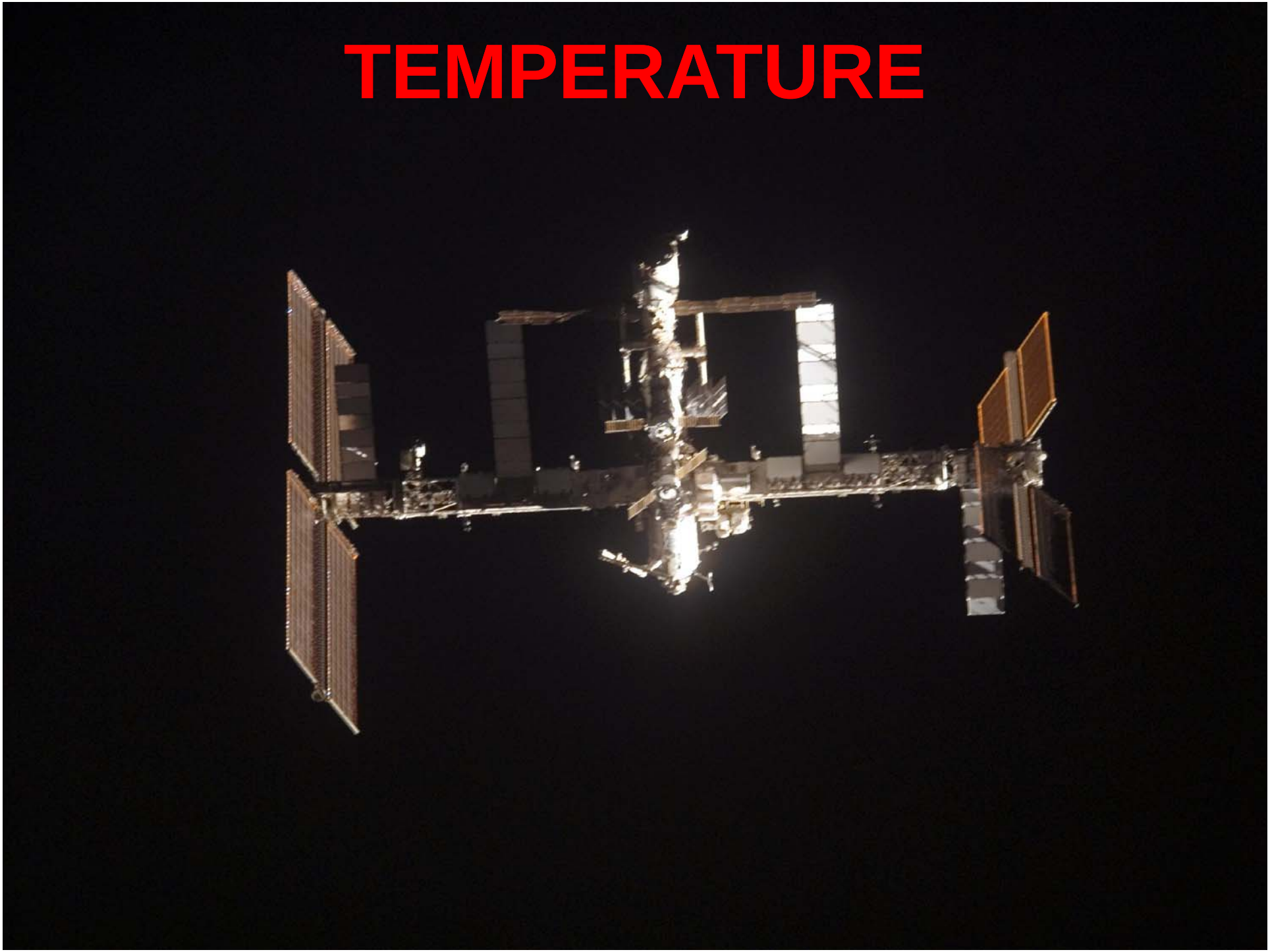
N318SL

N328KF
PHOTO COURTESY OF SCALED COMPOSITES, LLC

- *Odors are known to cause symptoms such as nausea, nasal congestion, coughing, headaches and irritability*

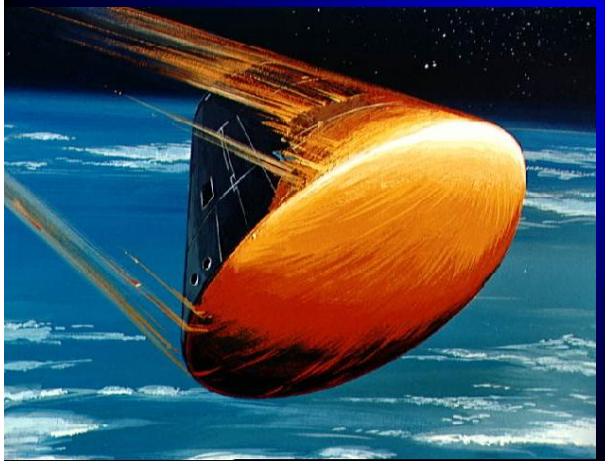
- *The most common sources of odor onboard a space vehicle are sweat, food, and organic waste*

# TEMPERATURE



*The lack of an atmosphere in space exposes space vehicles to extremely cold and hot ambient temperatures that vary depending upon the effective surface area of the vehicle that is directly exposed to radiant heat coming from the sun*

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



*These temperature extremes represent a potential hazard for all vehicle occupants, who must rely on the proper operation of the cabin heating, air circulation, and cooling systems*

*These systems must maintain the right balance between air temperature, air velocity, barometric pressure, and humidity*