Individual, Environmental & Operational Risk Factors of Commercial Human Space Flights

Congreso Internacional de Medicina Aeroespacial

Melchor J. Antuñano, M.D., M.S.

President, International Academy of Aviation & Space Medicine

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“I never think of the future. It comes soon enough”

Albert Einstein

At the present time, the U.S. is the only country that has established licensing requirements for manned commercial space operations

FAA AST MISSION

- Issue licenses for commercial space operations including commercial launch sites, reentry operations, reentry sites

- Promote, encourage, and facilitate the growth of the U.S. commercial space industry

- Carry out this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States

Projected Orbital Launch Vehicles That May Be Available for Commercial Use in the US

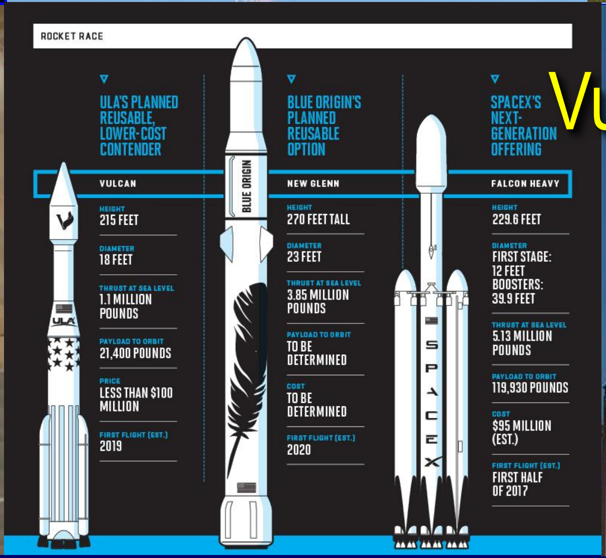
Falcon Heavy
LauncherOne
New Glenn
SpaceX
Blue Origin
NASA


StratoLaunch


VECTOR
Vector R/H


VECTOR

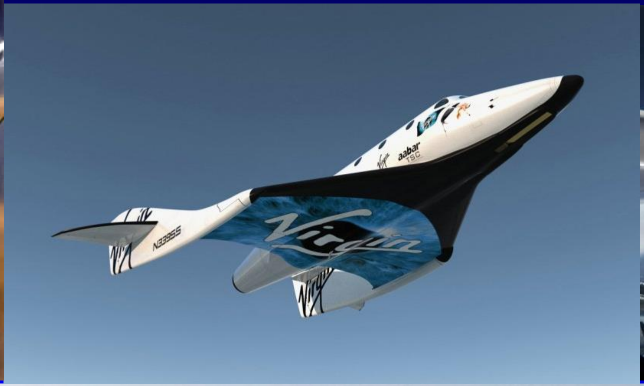

abc WORLD NEWS TONIGHT WITH DAVID MUIR


ROCKET RACE
ULA'S PLANNED REUSABLE, LOWER-COST CONTENDER
VULCAN
HEIGHT
215 FEET
DIAMETER
18 FEET
THRUST AT SEA LEVEL
1.1 MILLION POUNDS
PAYLOAD TO ORBIT
21,400 POUNDS
PRICE
LESS THAN $100 MILLION
FIRST FLIGHT (EST.)
2019
BLUE ORIGIN
BLUE ORIGIN'S PLANNED REUSABLE OPTION
NEW GLENN
HEIGHT
270 FEET TALL
DIAMETER
23 FEET
THRUST AT SEA LEVEL
3.85 MILLION POUNDS
PAYLOAD TO ORBIT
TO BE DETERMINED
COST
TO BE DETERMINED
FIRST FLIGHT (EST.)
2020
SPACEX
SPACEX'S NEXT-GENERATION OFFERING
FALCON HEAVY
HEIGHT
229.6 FEET
DIAMETER
FIRST STAGE: 12 FEET
BOOSTERS: 39.9 FEET
THRUST AT SEA LEVEL
5.13 MILLION POUNDS
PAYLOAD TO ORBIT
119,930 POUNDS
COST
$95 MILLION (EST.)
FIRST FLIGHT (EST.)
FIRST HALF OF 2017


Vulcan

Suborbital Reusable Launch Vehicles

USA
New Shepard

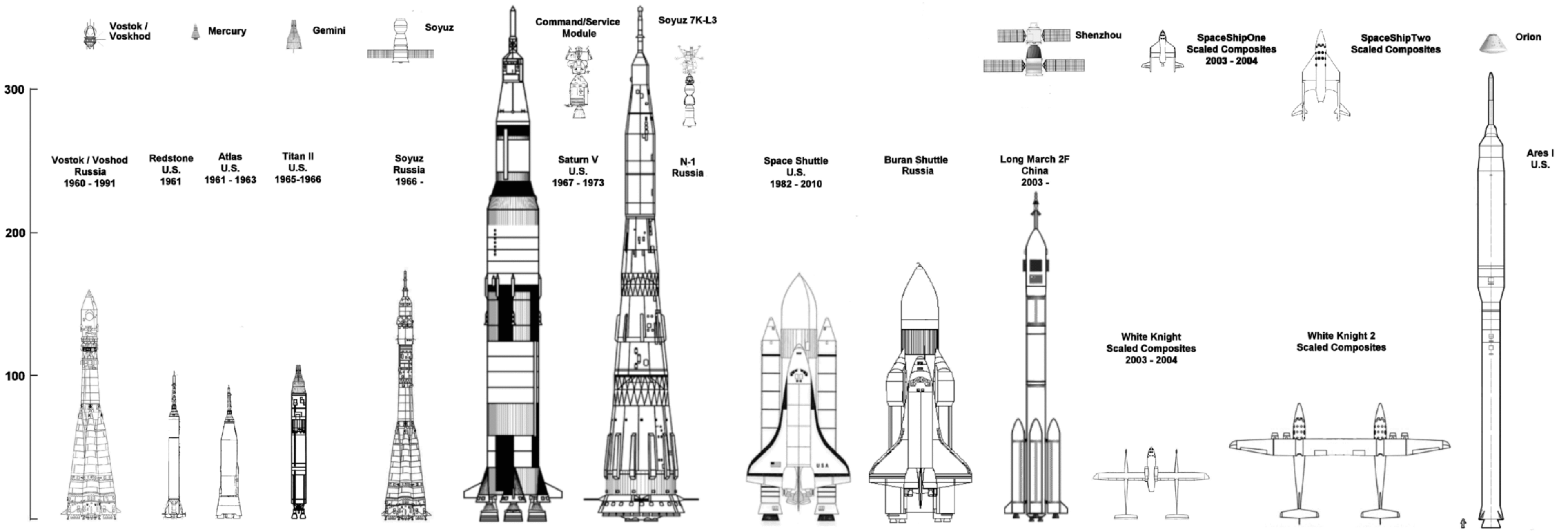


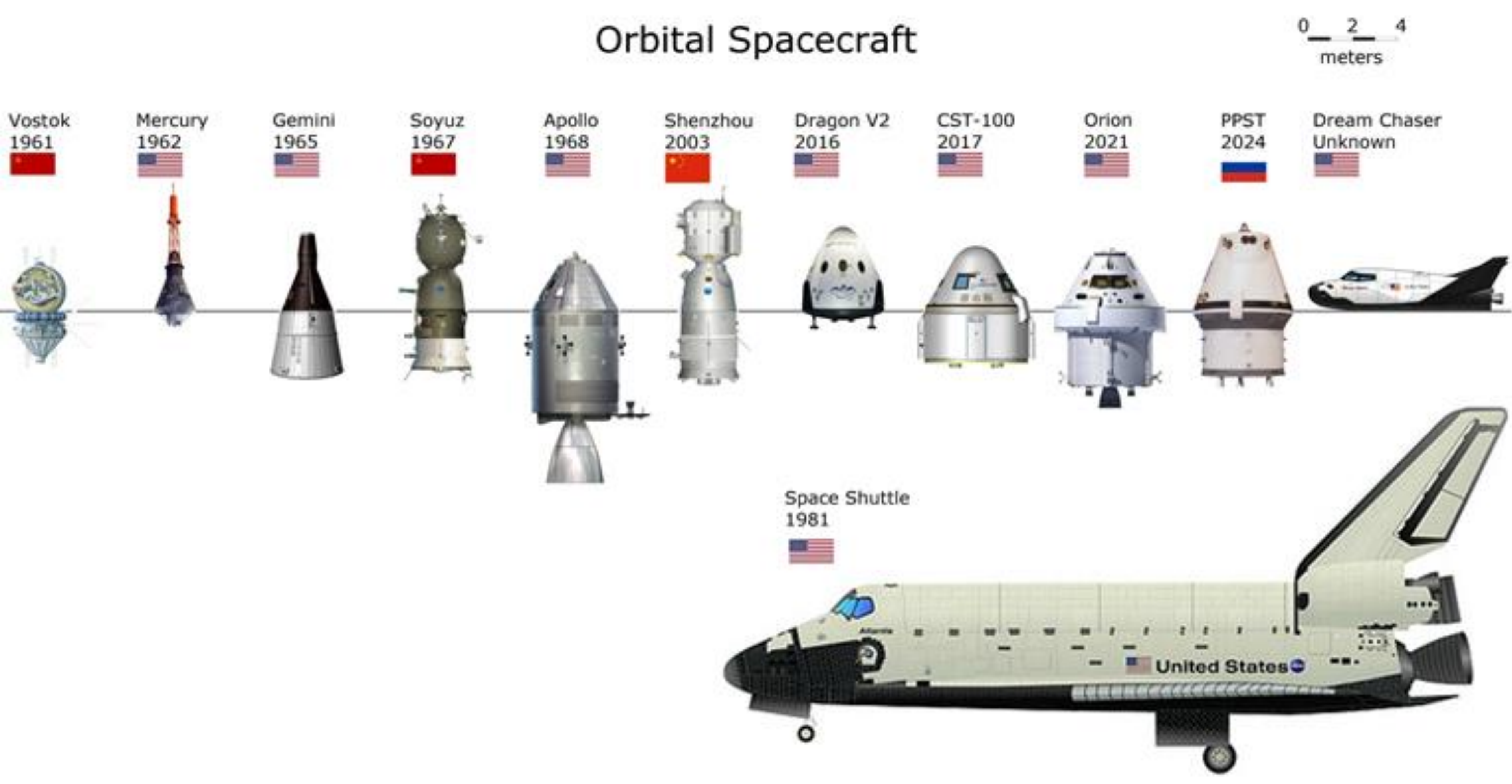
USA - SpaceShipTwo

USA - Voyager

57 Years of Human Spaceflight

Crewed Spacecraft




Orbital Spacecraft
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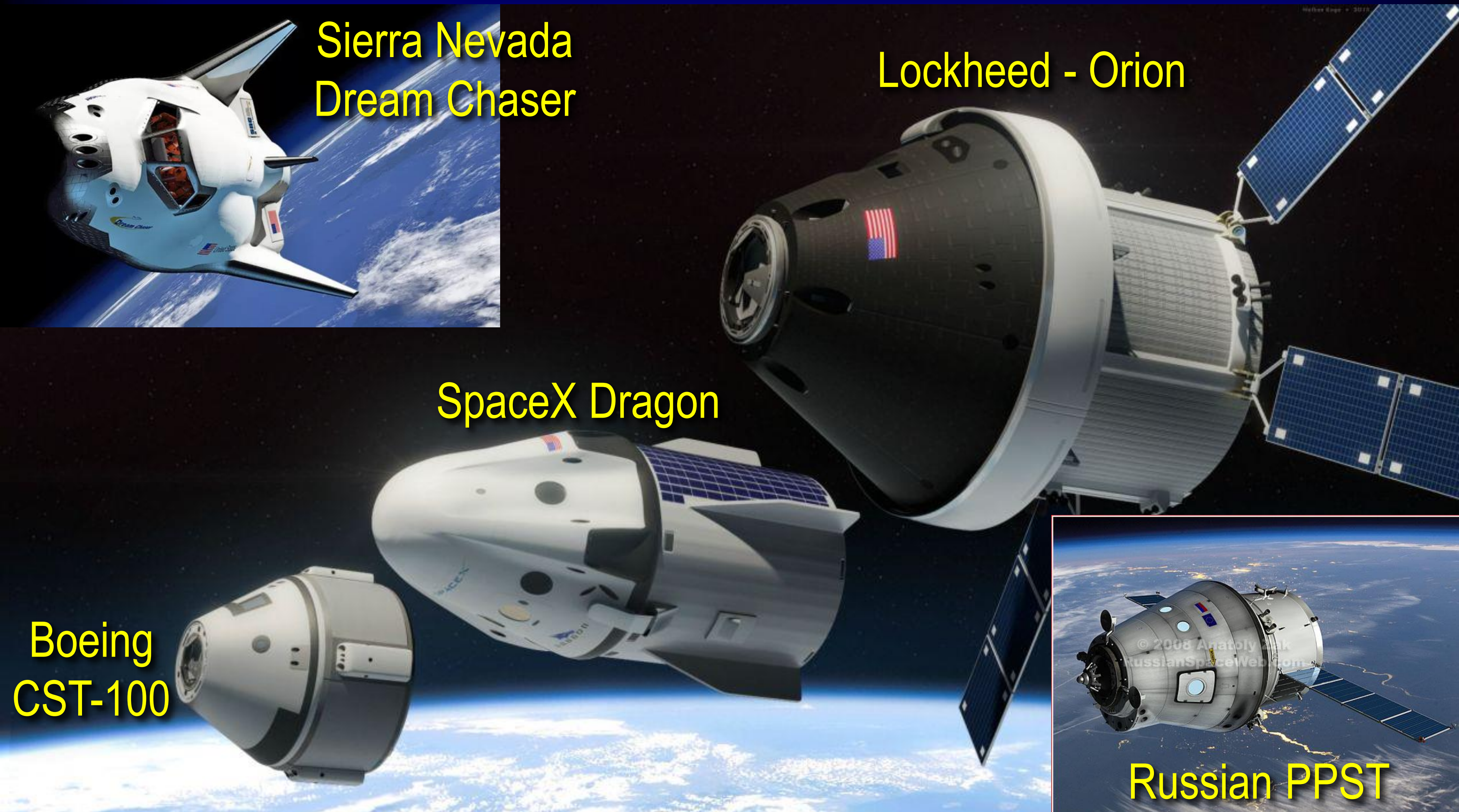
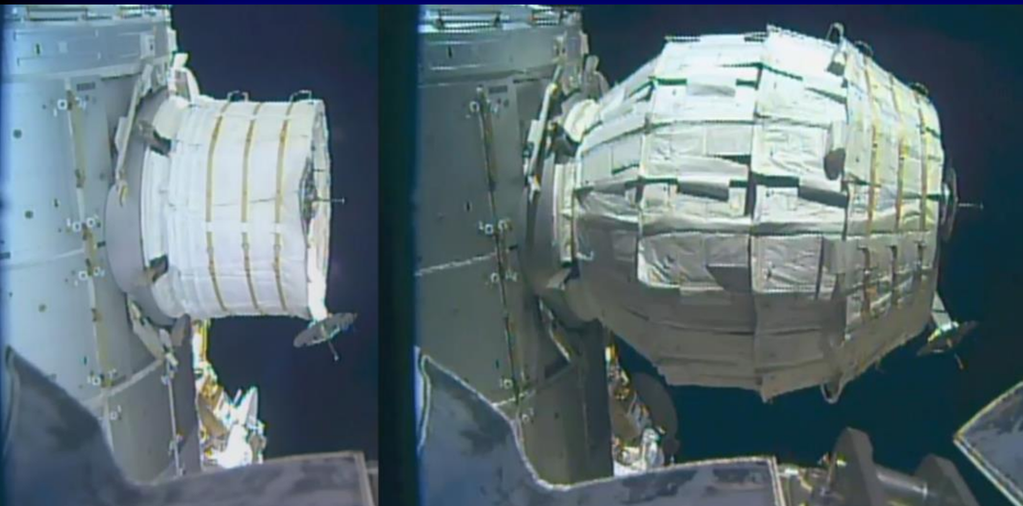
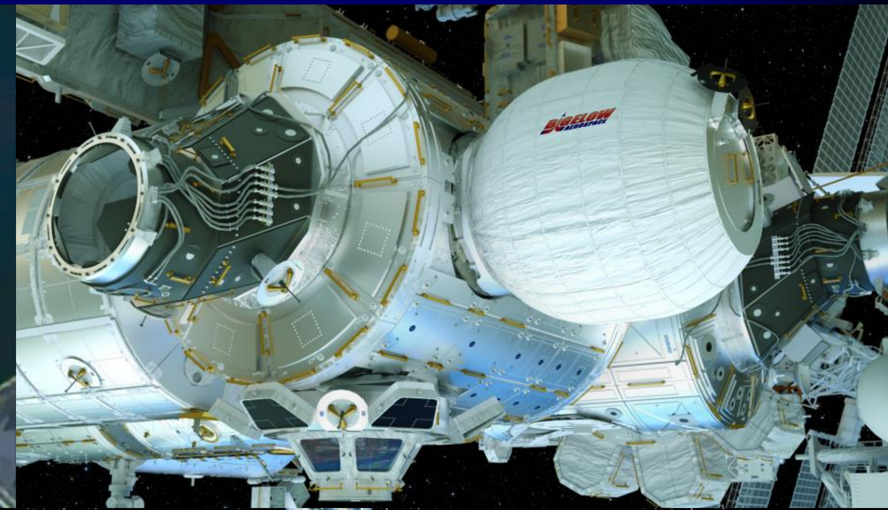
meters
Vostok
1961
Mercury
1962
Gemini
1965
Soyuz
1967
Apollo
1968
Shenzhou
2003
Dragon V2
2016
CST-100
2017
Orion
2021
PPST
2024
Dream Chaser
Unknown
Space Shuttle
1981
United States


Sierra Nevada
Dream Chaser
Lockheed - Orion
SpaceX Dragon
Boeing
CST-100
Russian PPST





Robert Bikgelow’s Inflatable Space Station

Regulatory Oversight

Commercial Space Launch Amendments Act of 2004

The CSLAA was signed into law on December 23, 2004 to promote the development of the commercial human space flight industry

- ✓ The public interest is served by creating a clear legal and regulatory regime for commercial human space flight
- ✓ Establishes "Experimental Permit"
- ✓ AST has sole authority over licensing of suborbital vehicles
- ✓ Allows "informed consent" of the customer to accept the risks of spaceflight

What potential risks should be disclosed?

What is an appropriate/sufficient full-disclosure of potential risks that would:

- **Minimize liability for the operator?**
- **Not produce excessive fear among prospective space participants?**

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:

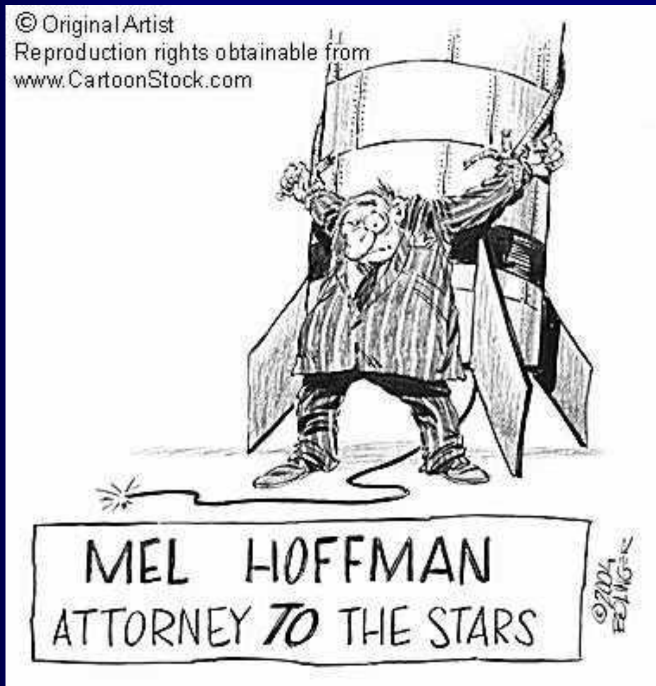
(1) For each mission, each known hazard and risk that could result in a serious injury, death, disability, or total or partial loss of physical and mental function.

(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.

Why is Risk Disclosure Important?

Passenger Safety & Liability Issues



The problem is that we live in a litigious society where the safety of space passengers is a critical issue that the manned commercial space transportation industry must address proactively and comprehensively.

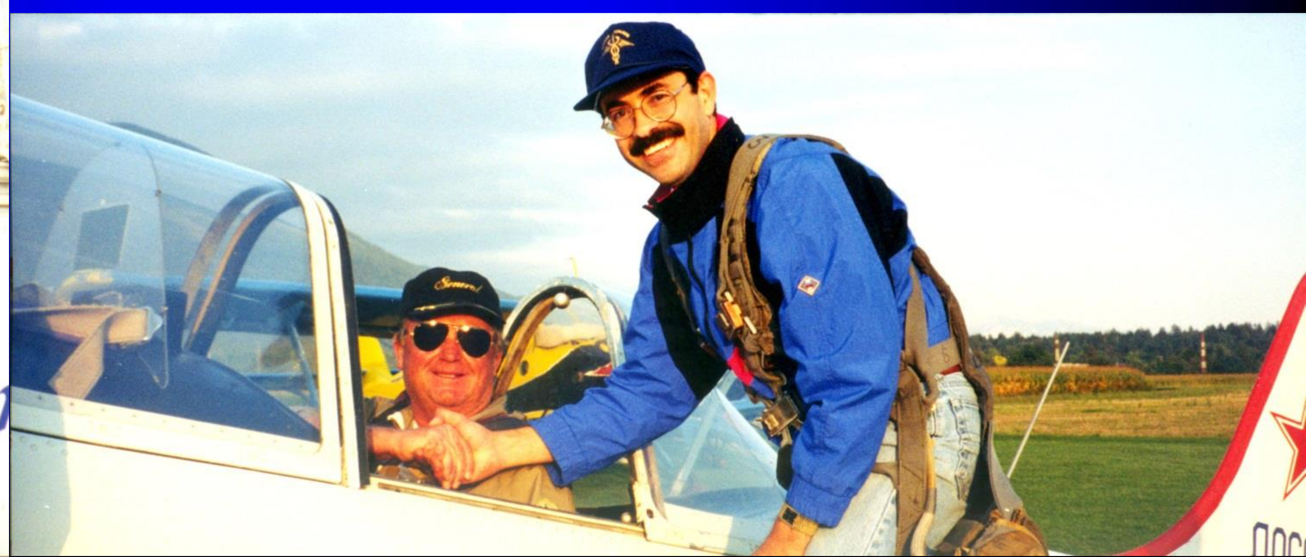
At the same time, the public has the right to take some personal risks!

"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

Always be prepared to deal with risks in disguise!

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



Risks in Space

Is it Risky to Fly in Space?

Yes, but risks vary

Suborbital

vs

Orbital

Yes, but risks vary

Short Flights

vs

Long Flights

Populations Impacted by Commercial Space Flights

Crews & Spaceflight Participants


RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

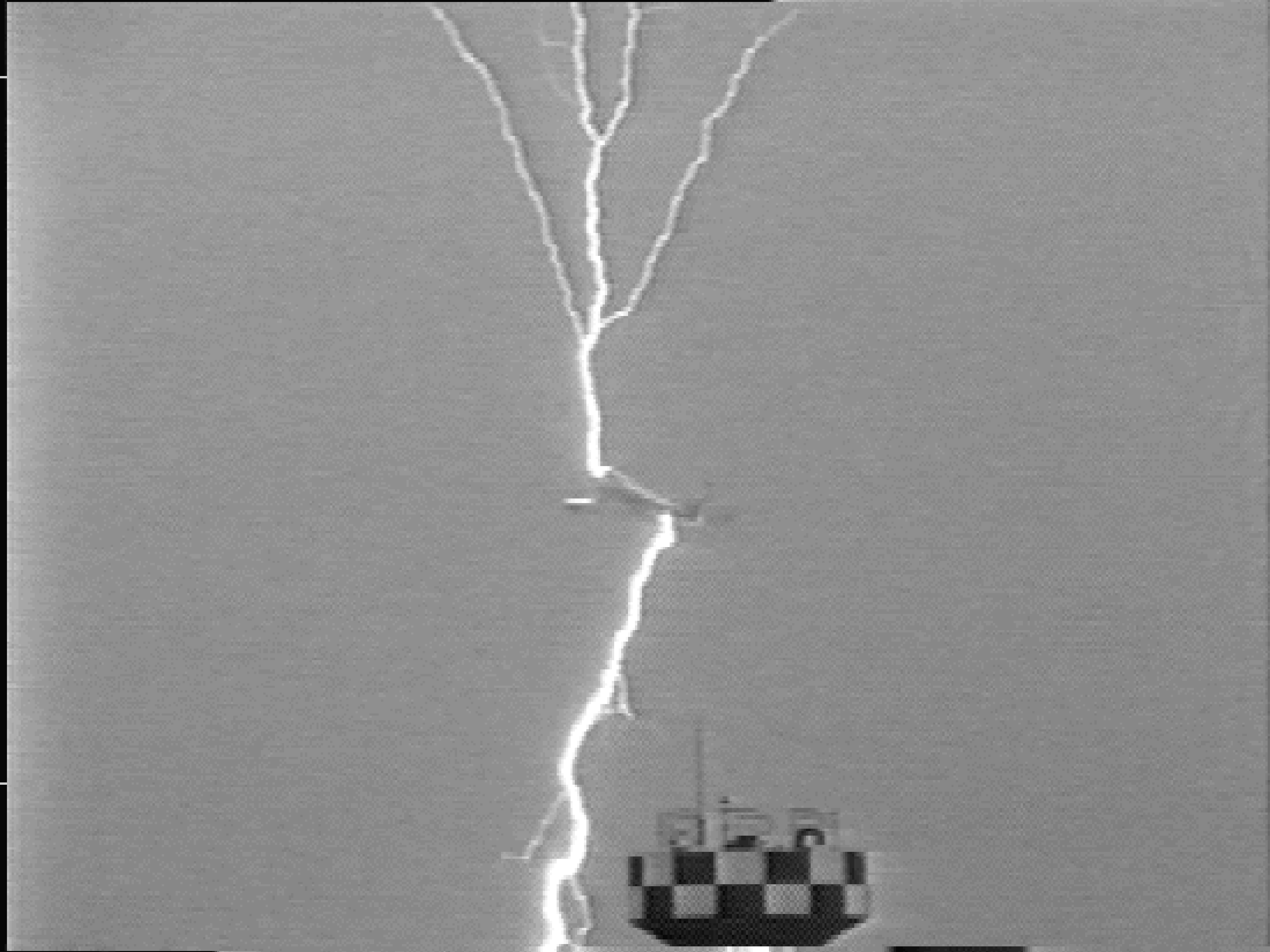
1. *INDIVIDUAL FACTORS*
2. *EXTERNAL ENVIRONMENTAL FACTORS*
3. *OPERATIONAL FACTORS (Vehicle and Flight Operations)*

RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

2) EXTERNAL ENVIRONMENTAL FACTORS:

- Weather (during the atmospheric phase of flight)
- Wildlife strikes
- Barometric pressure and decompression
- Ambient temperature extremes
- Ionizing and non-ionizing radiation
- Microgravity/weightlessness
- Space debris (natural and human-made)

Weather-Related Risks



November 14, 1969

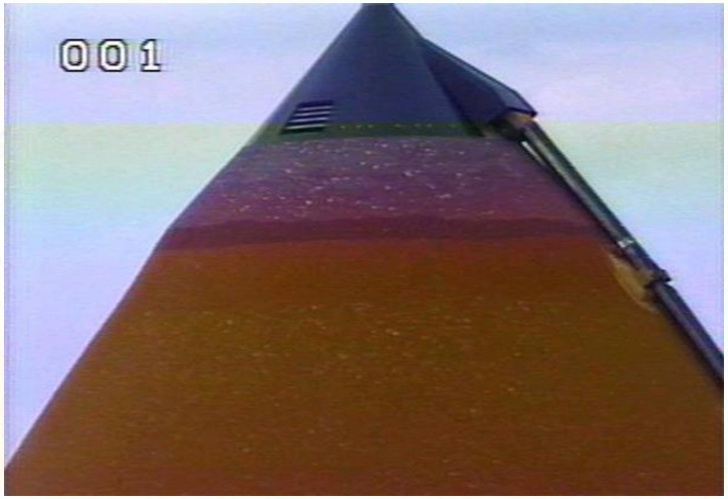
Apollo 12 experienced major electrical disturbances after been hit by lightning 36.5 and 52 seconds after lift off

March 26, 1987

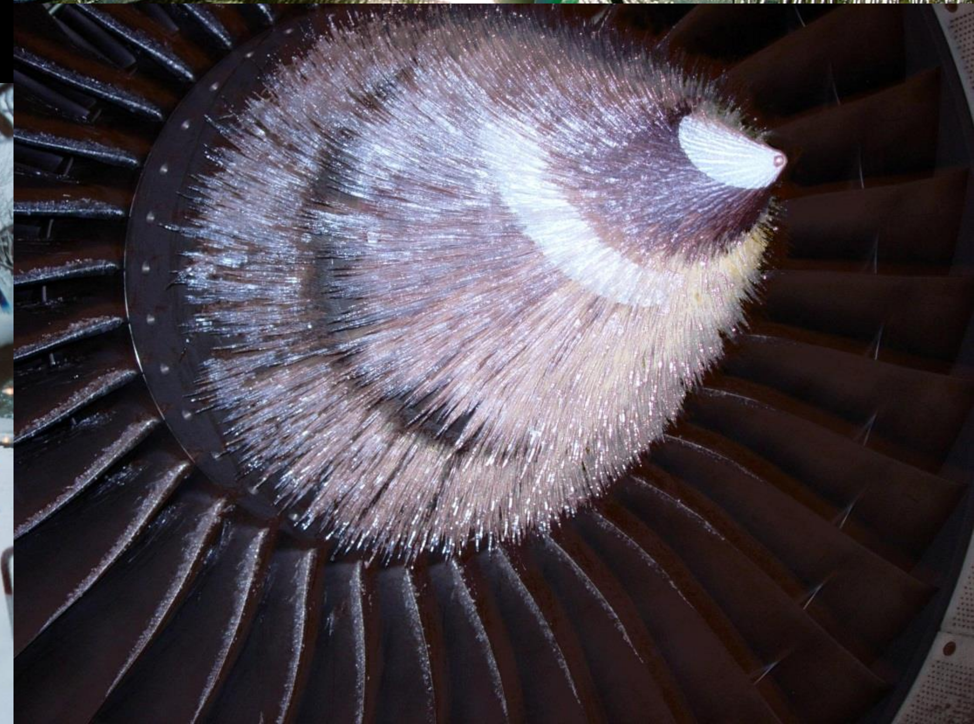
- The Atlas-Centaur 67 rocket was hit by lightning 4 times 49 seconds after launch causing a memory disfunction in the vehicle guidance system.
- The hit led to an unplanned yaw rotation that made the vehicle begin breaking apart and ground control had to destroy it.

Other Lightning Incidents

STS-117 Hail Storm Damage

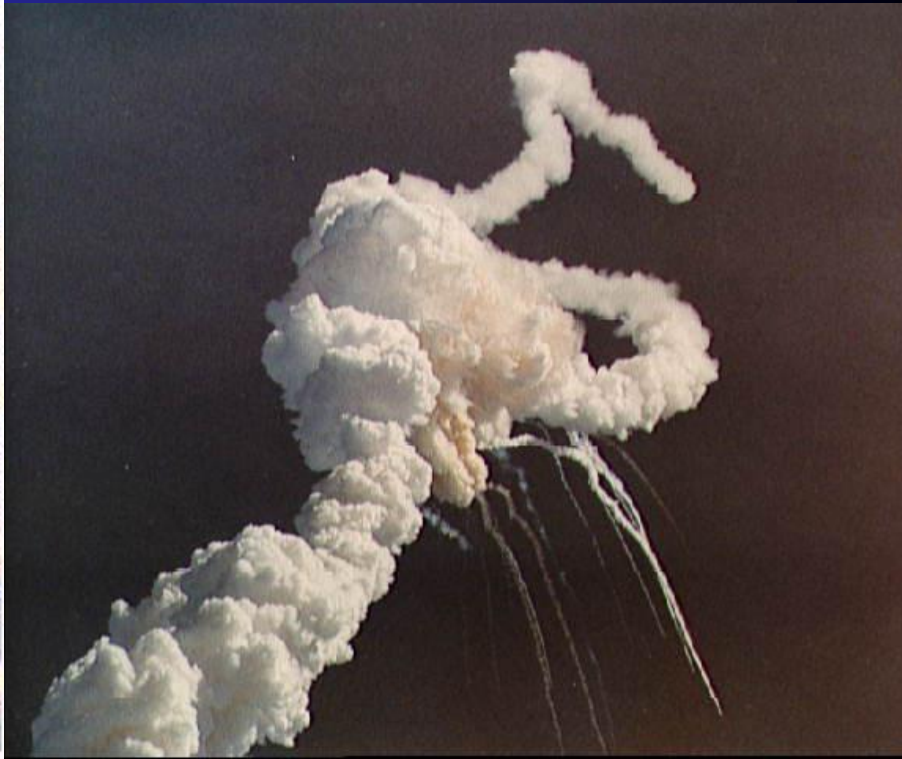




January 28, 1986

Space Shuttle Challenger explodes 73 sec after launch killing Christa McAuliffe, Dick Scobee, Michael Smith, Ellison Onizuka, Judith Resnik, Ronald McNair and Gregory Jarvis.



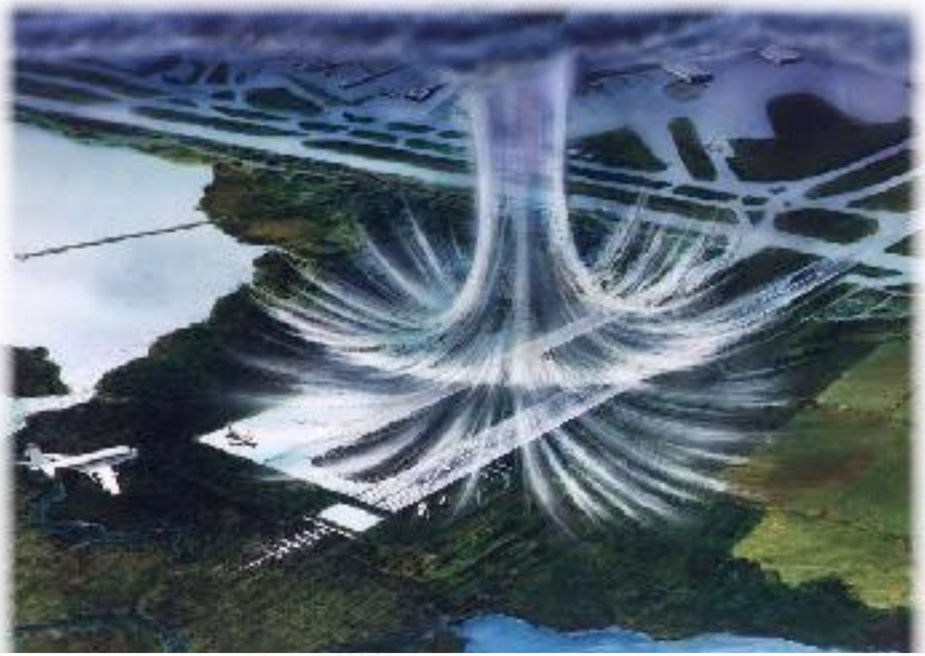
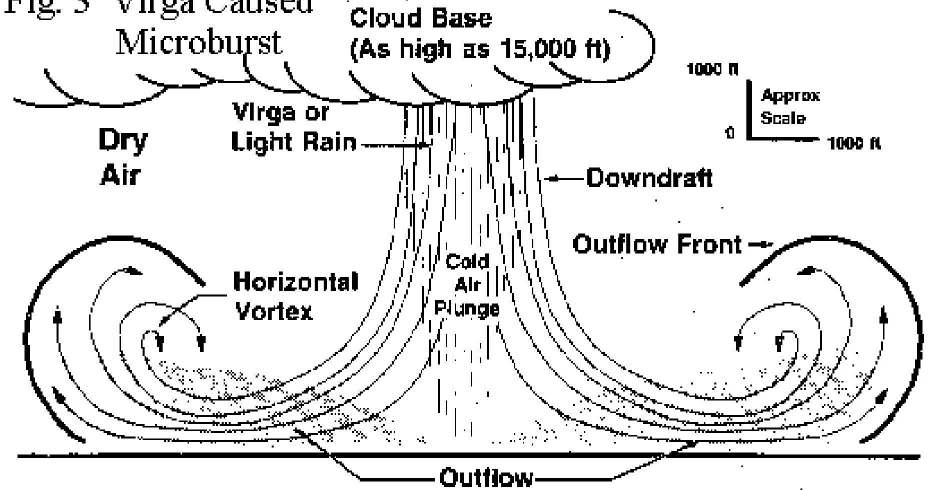


Fig. 3 Virga Caused Microburst



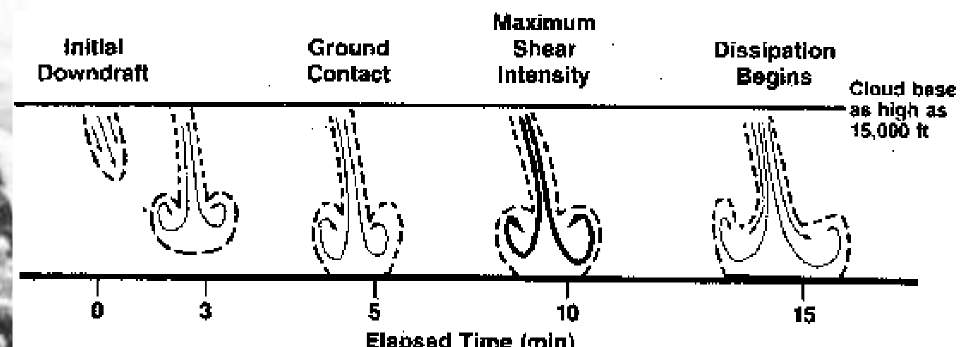


Fig. 4 Lifecycle of a typical Microburst.

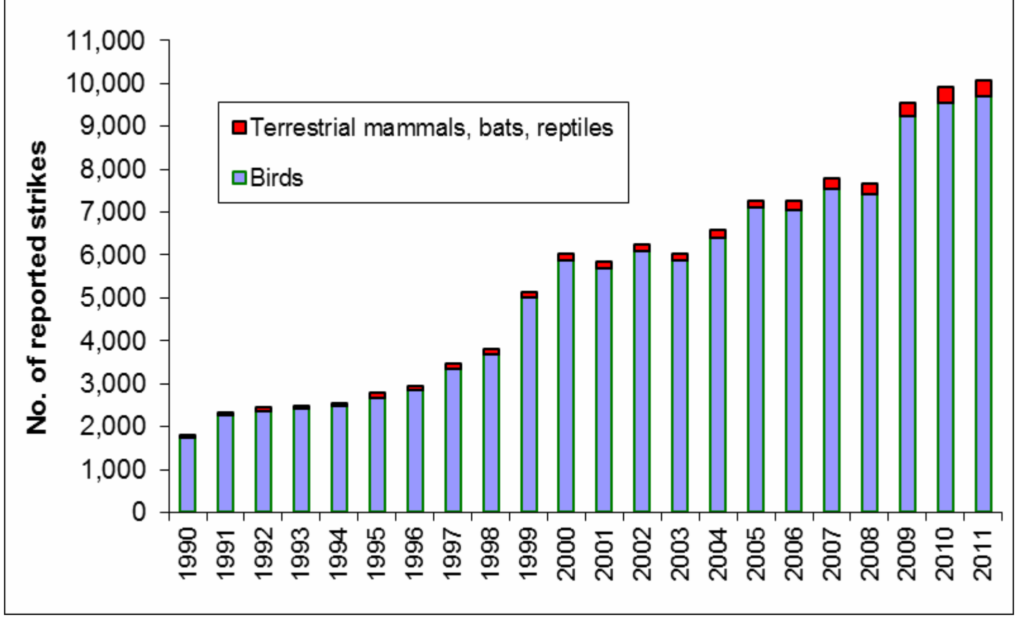


Figure 1. Number of reported wildlife strikes with civil aircraft, USA, 1990–2011. The 119,917 strikes involved birds (116,408), terrestrial mammals (2,754), bats (618), and reptiles (137, see Table 1).

Wildlife

Bird Strikes

July 2005

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


161

INFLIGHT DECOMPRESSION

Time of Useful Consciousness

Feet (thousands)	*Kilometers*	*Time*
50	15.2	9 – 12 seg
43	13.1	9 – 12 seg
40	12.2	15 – 20 seg
35	10.7	30 – 60 seg
30	9.1	1 – 2 min
28	8.5	2.5 – 3 min
25	7.6	4 – 6 min
22	6.7	8 – 10 min
18	5.5	20 – 30 min

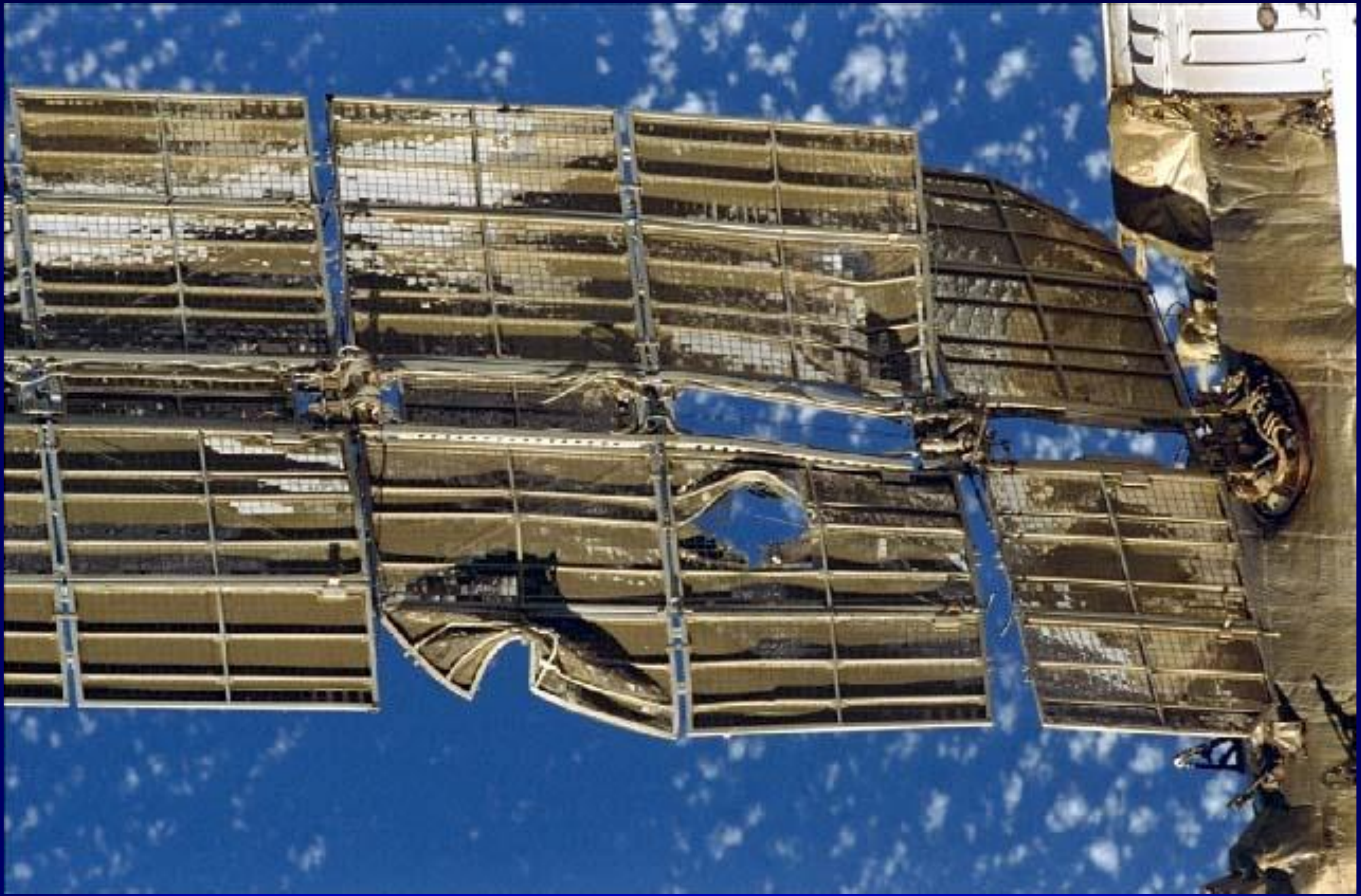
Loss of Cabin Pressure

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.


SpaceShipOne test pilots did not use pressure suits
N318SL

Space Debris Risks

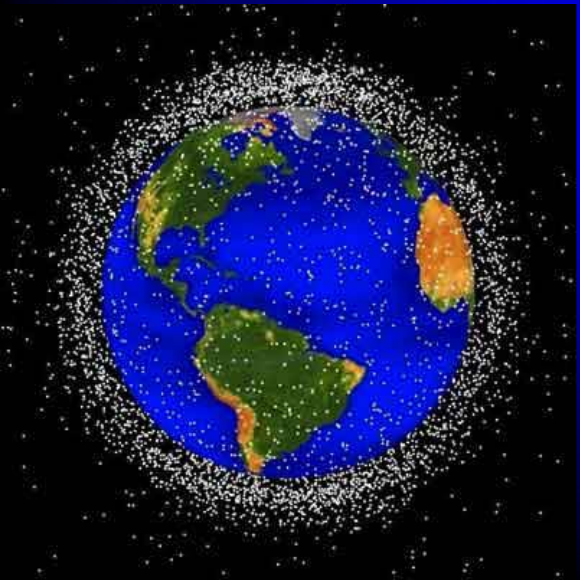
The USAF Space Command uses 30 radar and optical sensors to track about 10,000 man-made objects as small as 10 cm. (baseball) flying in LEO or low-earth orbit (below 2,000 km) at about 17,500 mph

About 84% of these objects travel below 800 km

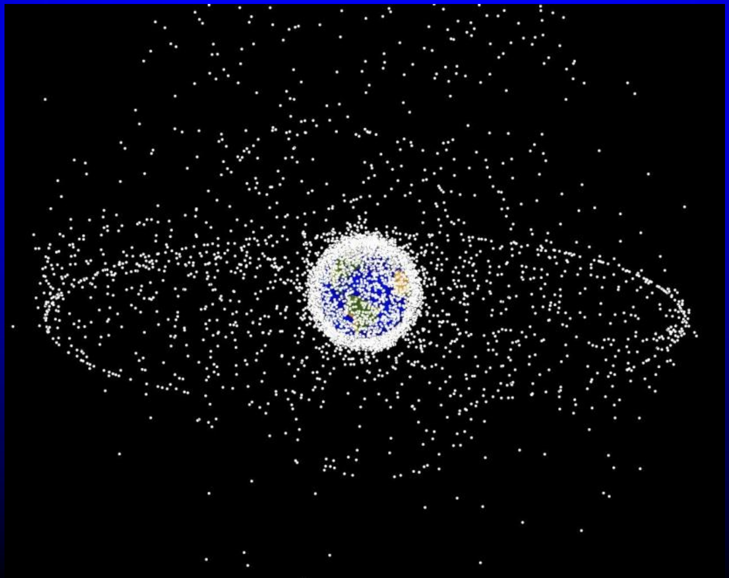
A 1999 study estimated there are ~4 mill pounds of space junk in LEO

~110,000 objects are larger than 1 cm

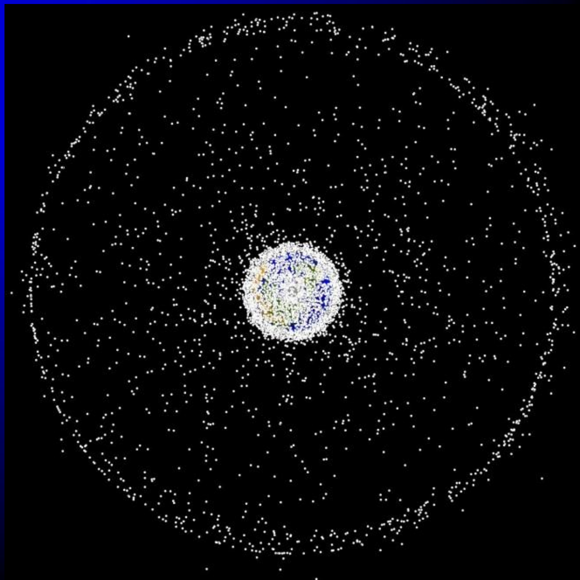
LEO



GEO



GEO Polar



Since Sputnik was launched more than 17,000 objects have re-entered the Earth’s atmosphere

The oldest object is Vanguard I launched in 1958

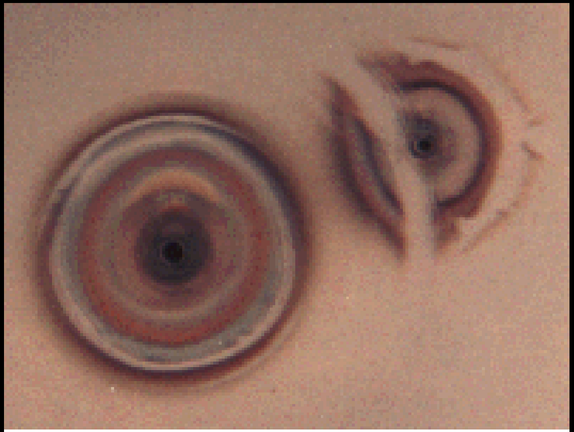
Ed White lost a globe during a Gemini 4 EVA in 1965

Mir space station released 200 objects during its first 10 years of operation

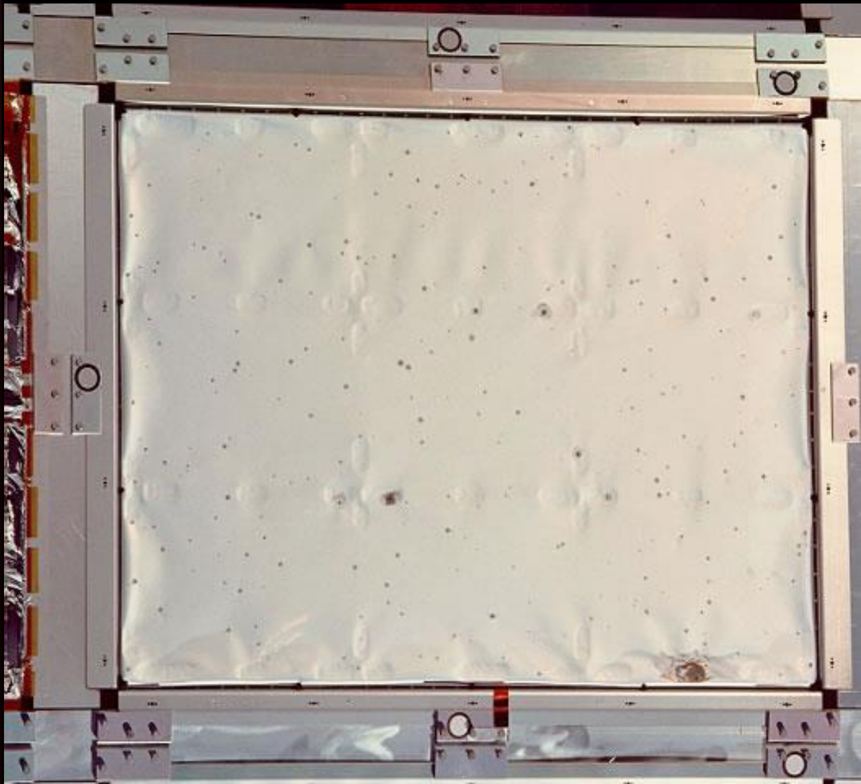
The explosion of a Pegasus upper stage rocket produced 300,000 objects bigger that 4 mm

ASAT TEST
Xichang Space Center, China
January 11, 2007

Visualization using the data tracks available on March 1, 2007



Dust grains travelling in space at high velocities made these 2 mm impact holes and surrounding rings of damage on an LDEF thermal blanket.




T180-2
T180-38
T180-5
T180-7
T180-40
T180-1
T180-3
T180-6
T180-4
T180-39
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T180-68
T180-67
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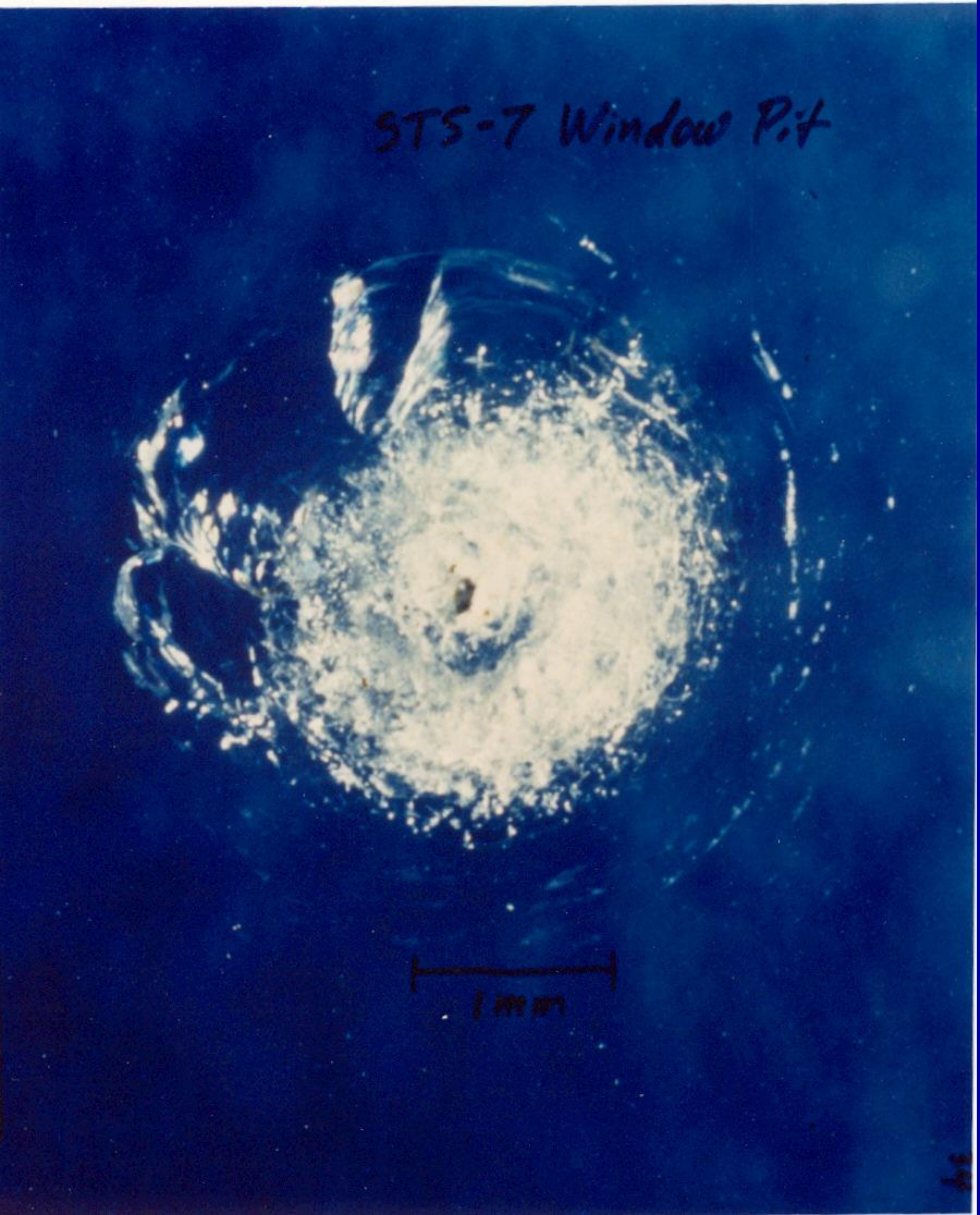
150
180



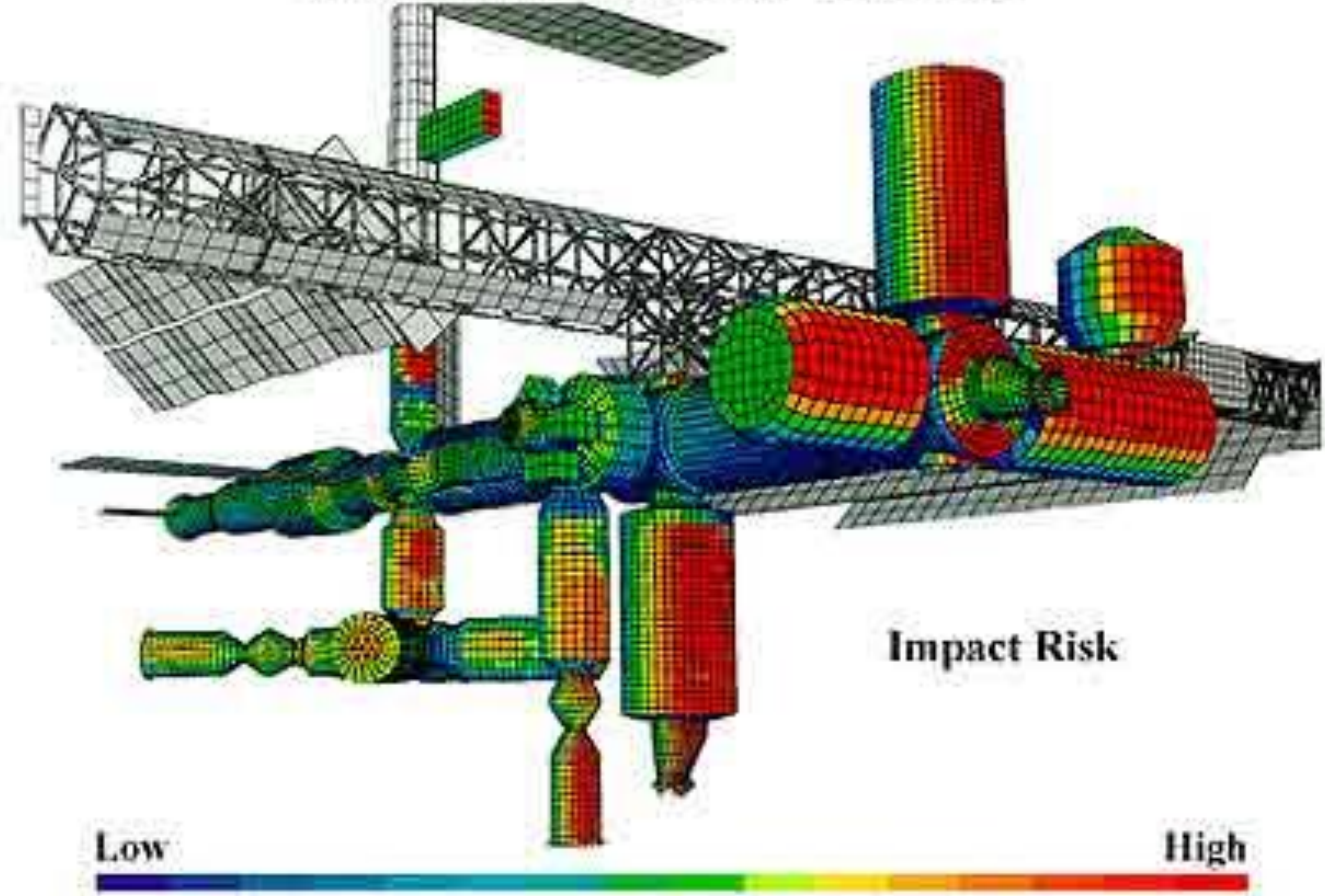
Space debris will be a risk factor for the occupants of orbital space vehicles

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

International Space Station

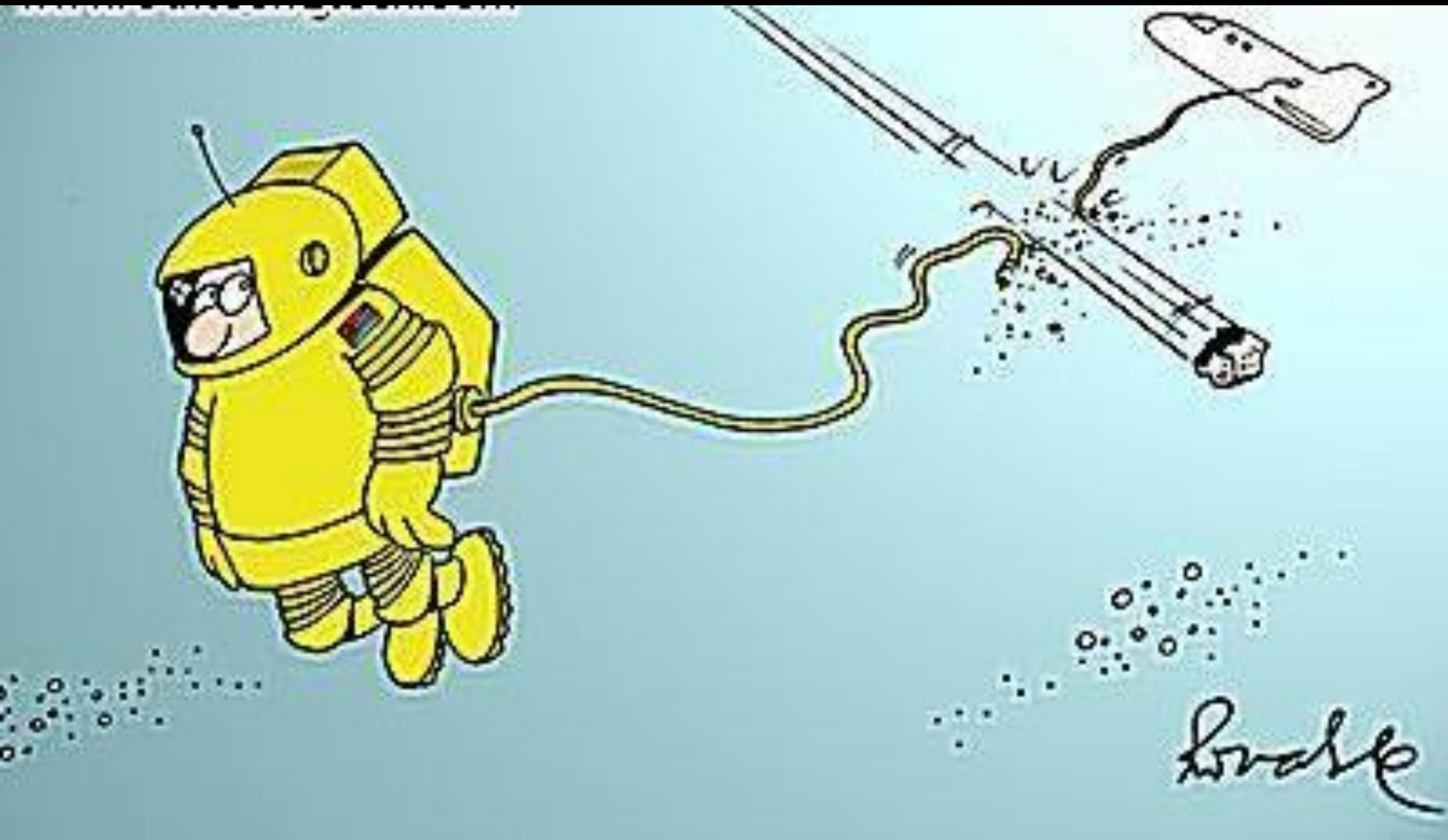
Probability of No Impacts From a > 1 cm Ø Debris



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

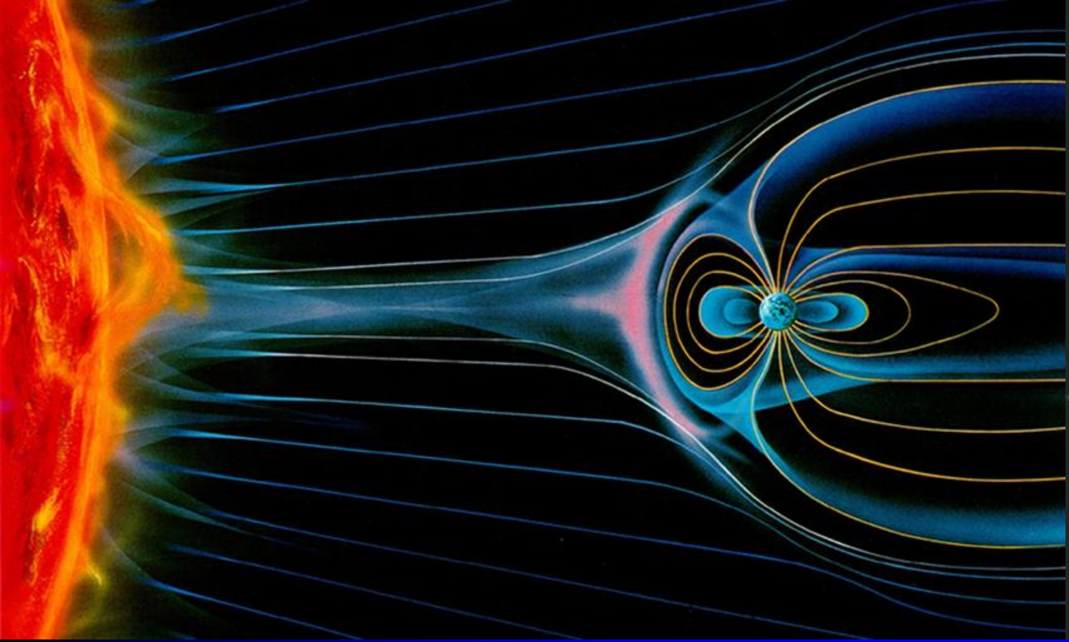


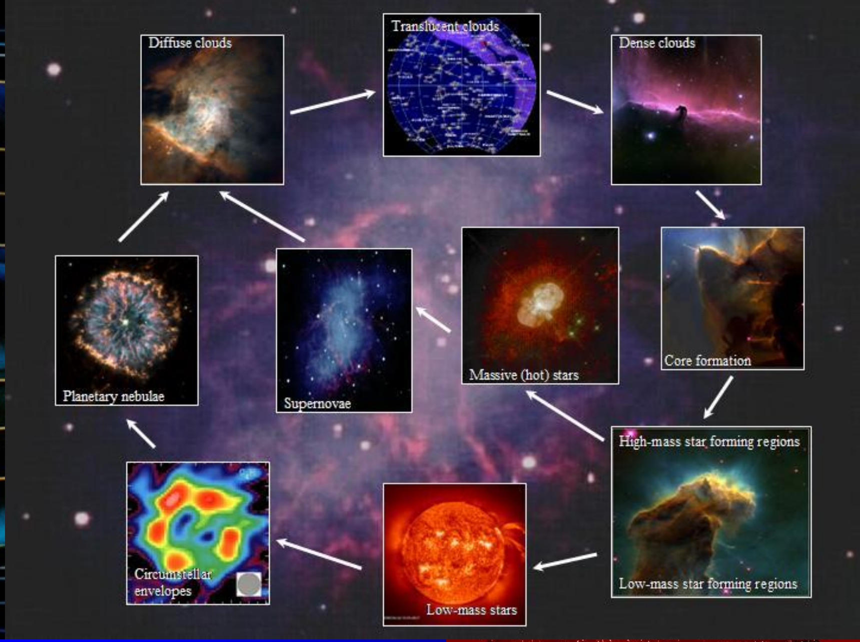
Debris Risk for Space & Aviation

Space debris could become a concern for the safety of people on the ground

January 1997 – A 580 pound tank from the 2nd stage of a Delta 2 survived reentry and crashed in Georgetown, Texas

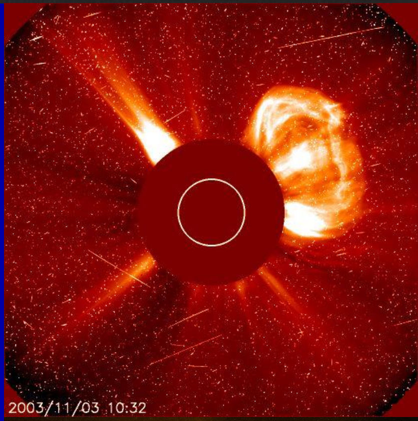
January 2001 – A 140 pound payload assist module of a Delta 2 crashed in Saudi Arabia

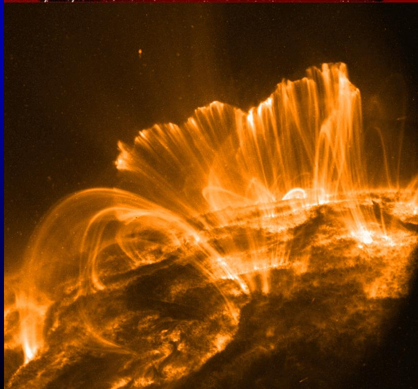




IONIZING SOLAR AND GALACTIC COSMIC RADIATION

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



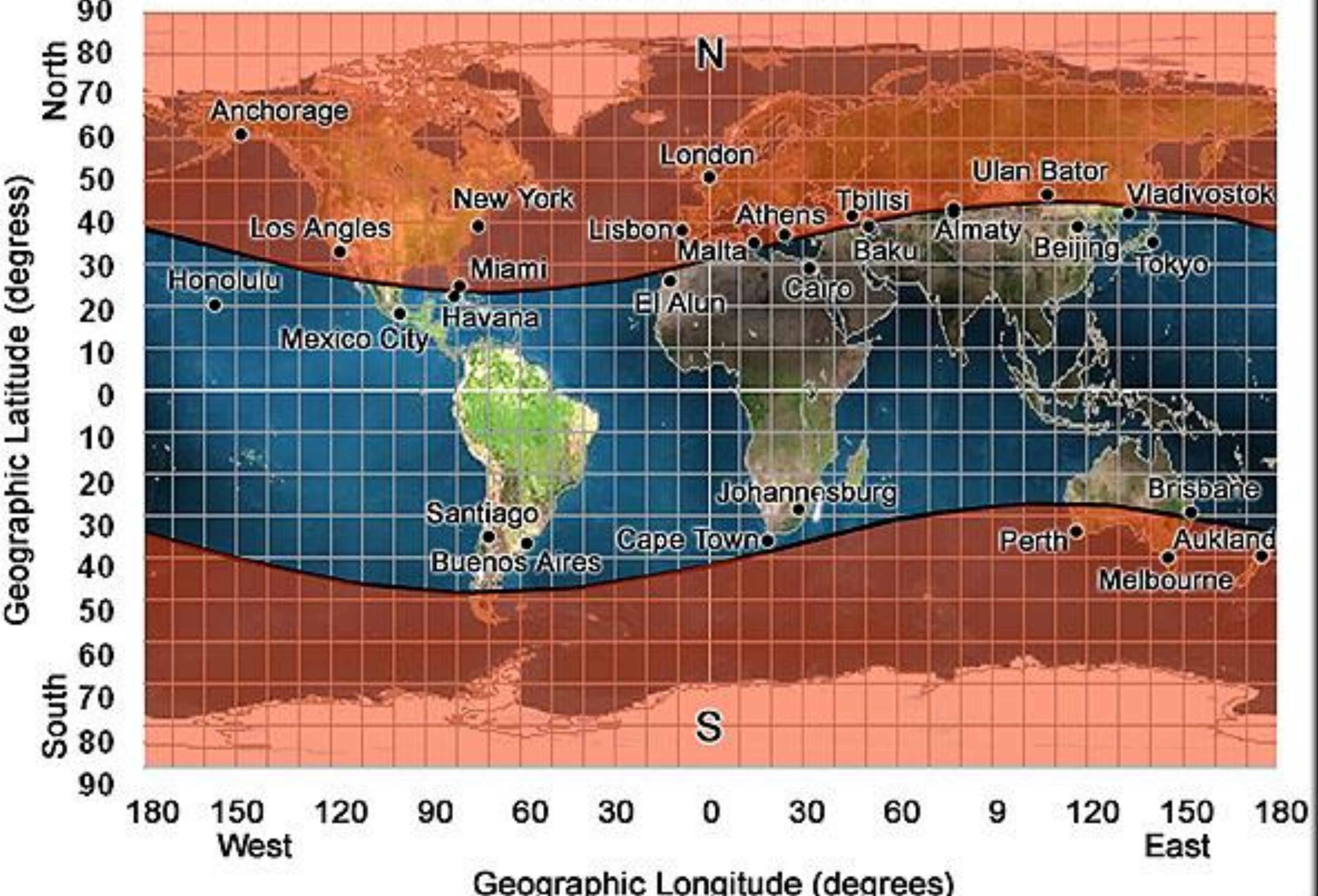


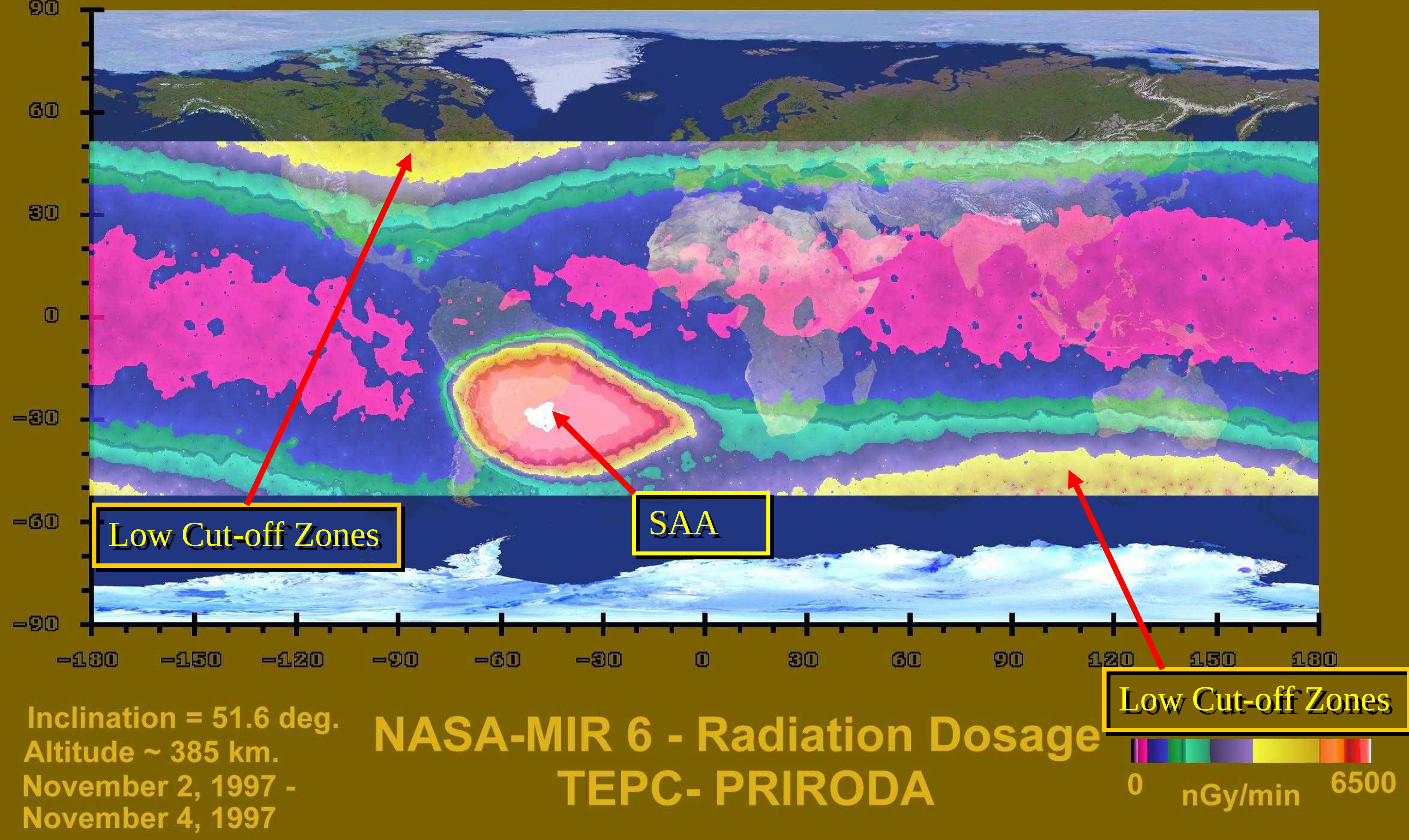
Galactic Cosmic Radiation (GCR)

- Originates outside the solar system
- Solar Cycle Dependent
  - Highest during Solar Minimum
- Extremely High Energy
  - Very Penetrating
  - Hard to Shield
- Fully Charged Atomic Nuclei
  - Protons
  - Biologically Most Damaging
- Highest Levels in open magnetic field areas (aka low cutoff zones)

SOLAR RADIATION ALERT REGIONS

(Alert regions in orange)





The yellow zones over North America and Australia correspond to areas of open geomagnetic field lines or low magnetic cutoffs. In these regions, the free space environment is seen at low earth orbit (ISS). Normally, the yellow region is the location of maximum Galactic Cosmic Radiation.

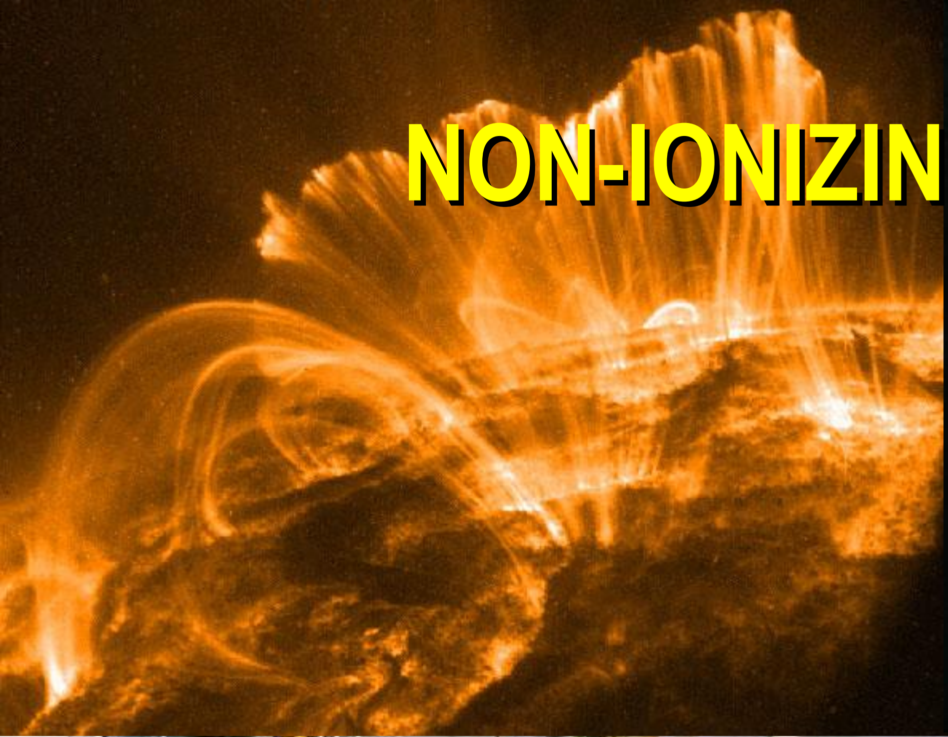
Space radiation is more damaging than radiation typically encountered by ground-based workers

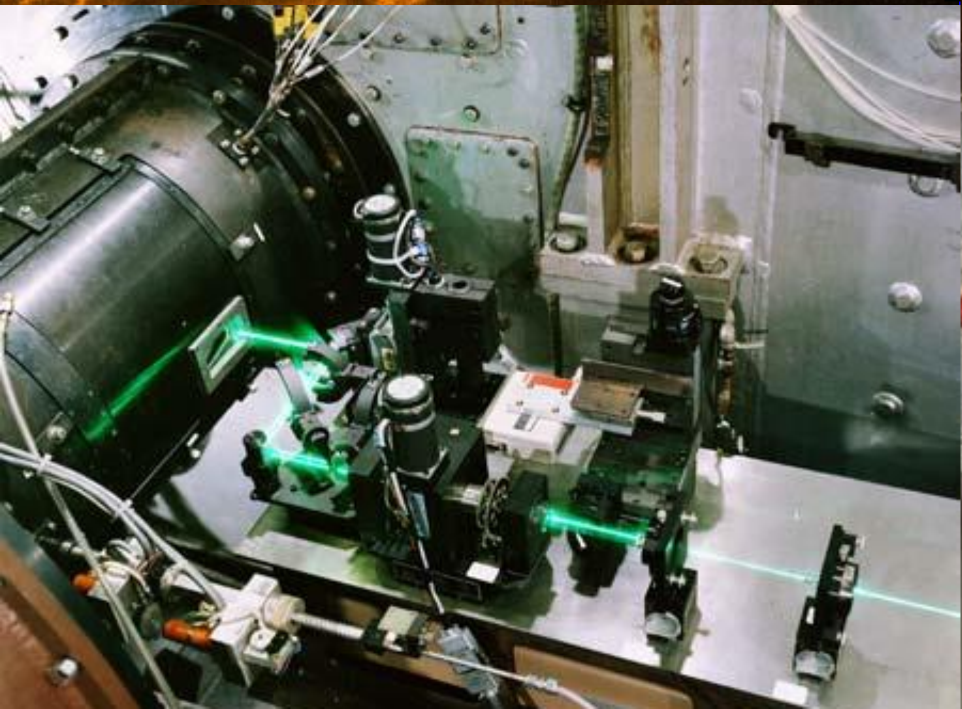
Experimental evidence indicates that space radiation is more effective at causing the type of biological damage that ultimately leads to cancer than the gamma or x-rays commonly encountered on Earth.

Animal experiments show evidence of biological damage unique to high-energy heavy ions encountered in space.

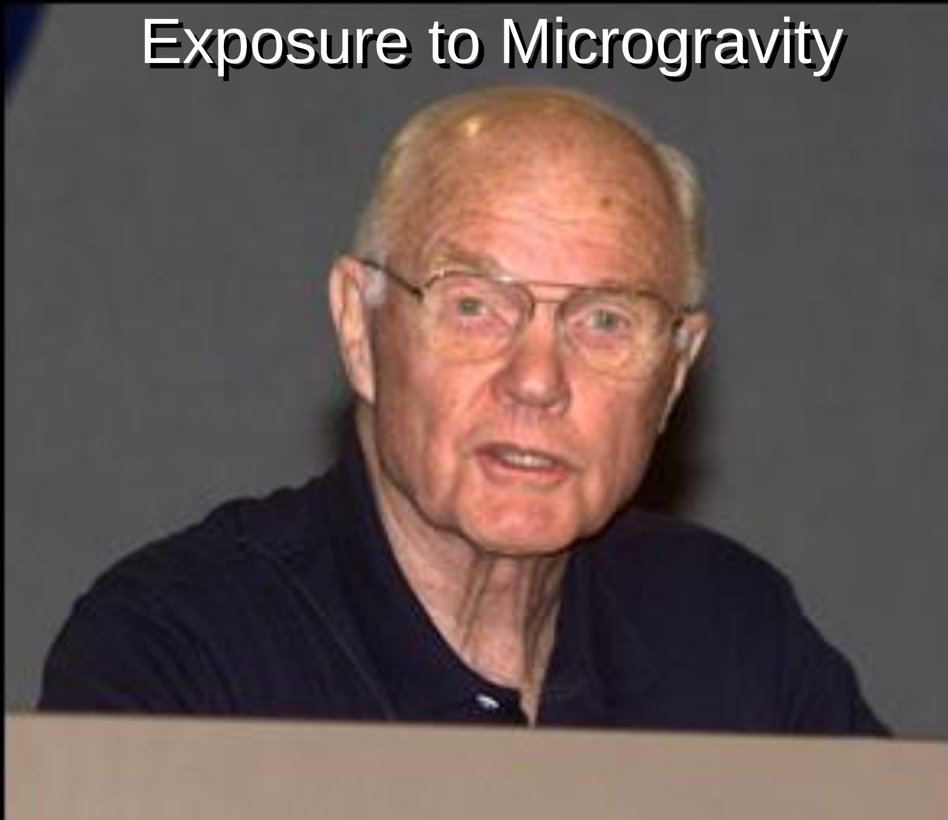
Damage to the central nervous system similar to that associated with aging.

NON-IONIZING RADIATION



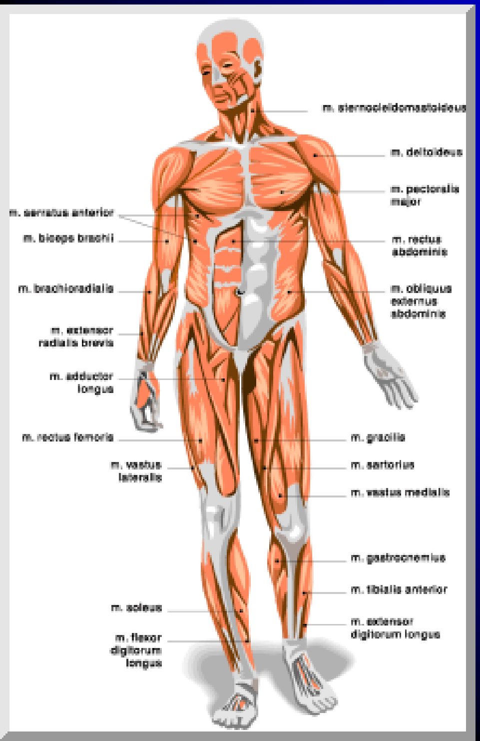


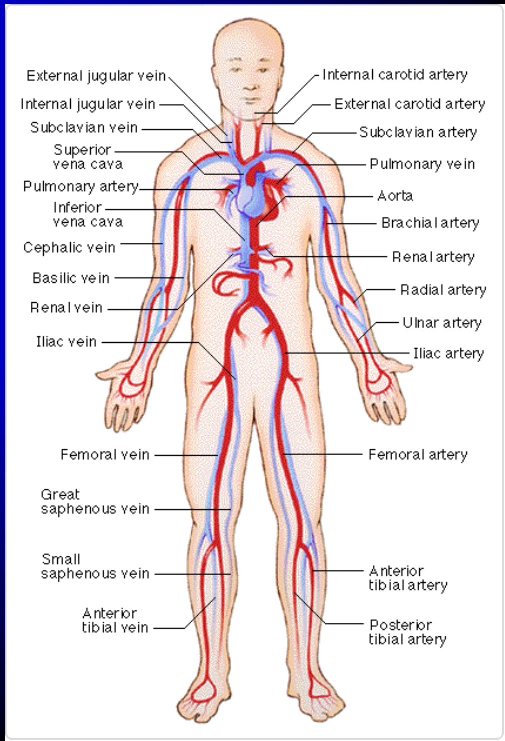
Exposure to Microgravity

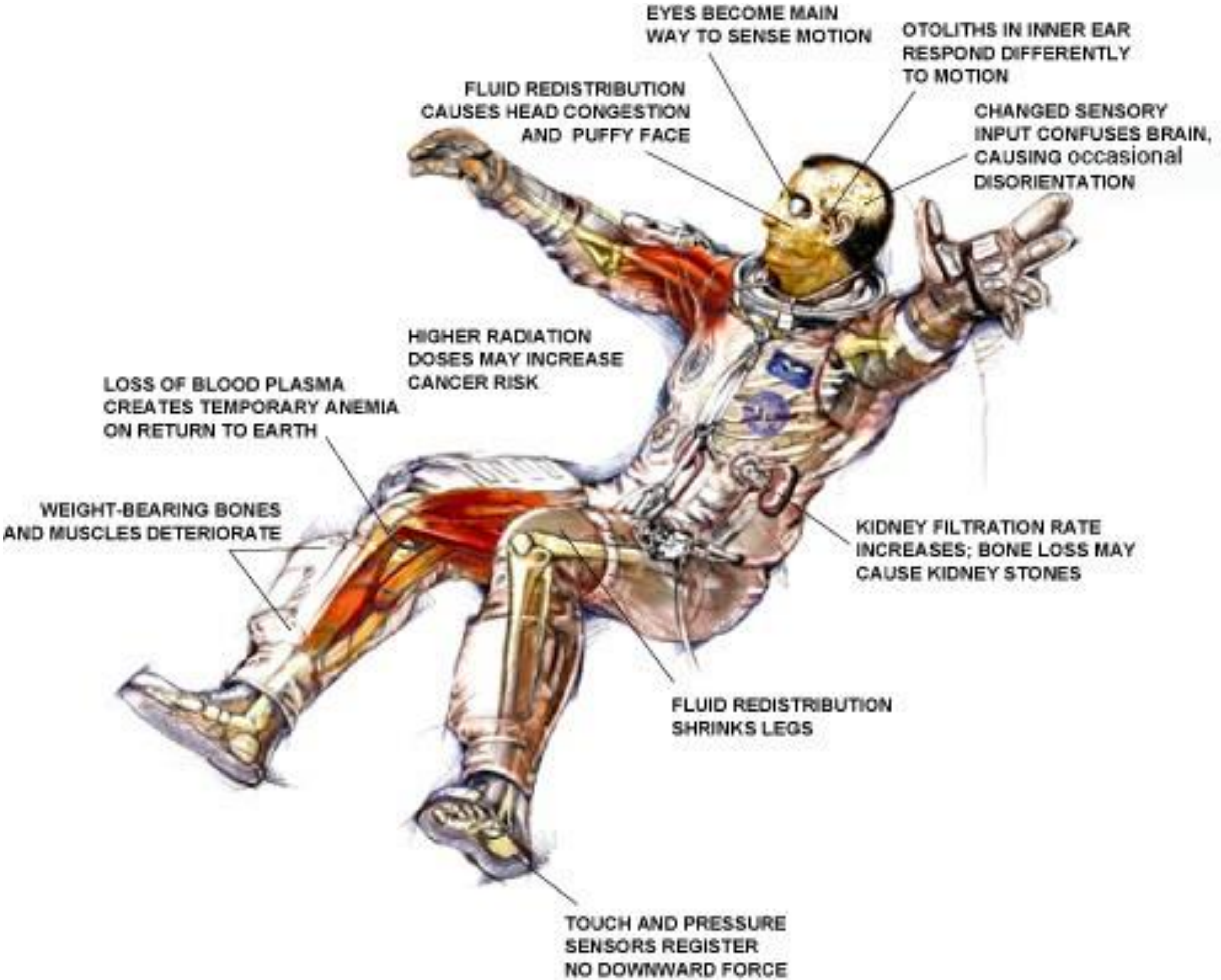


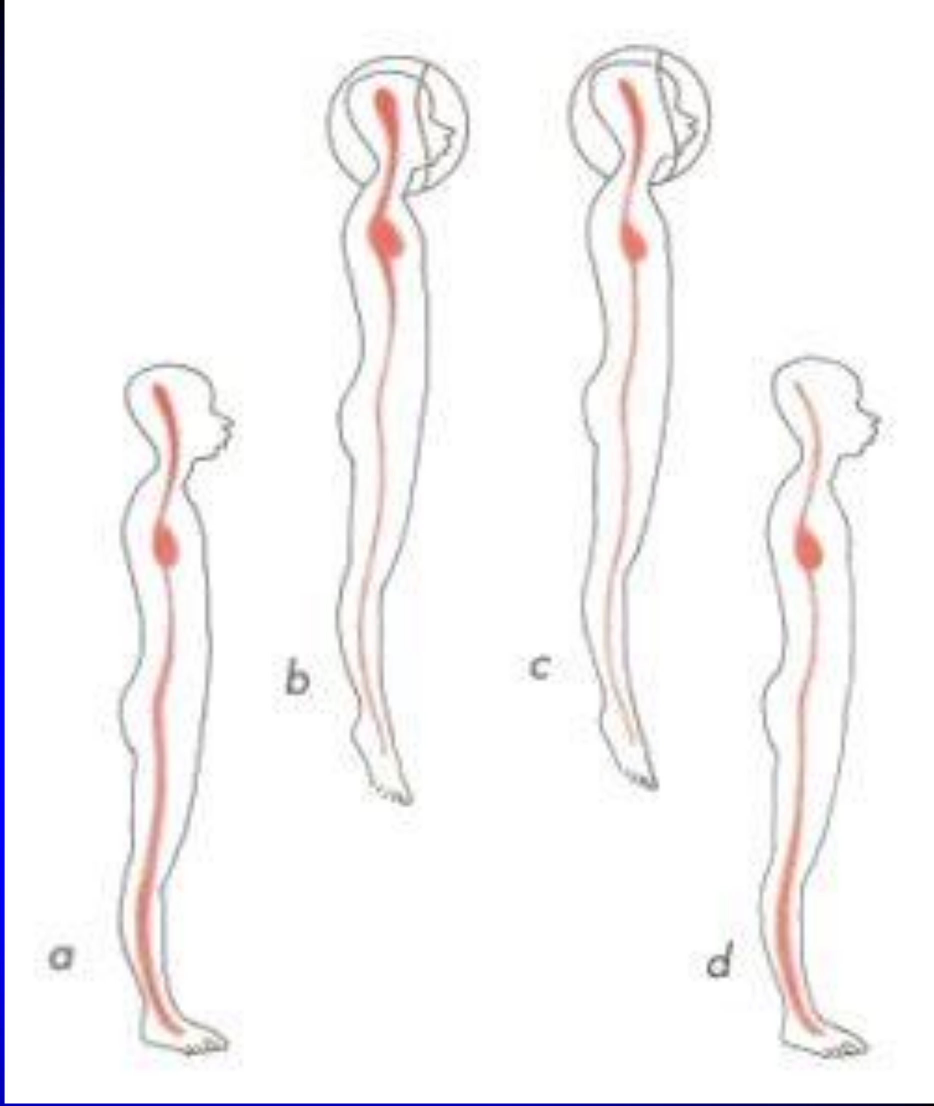
Physiological Effects of Exposure to Microgravity

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



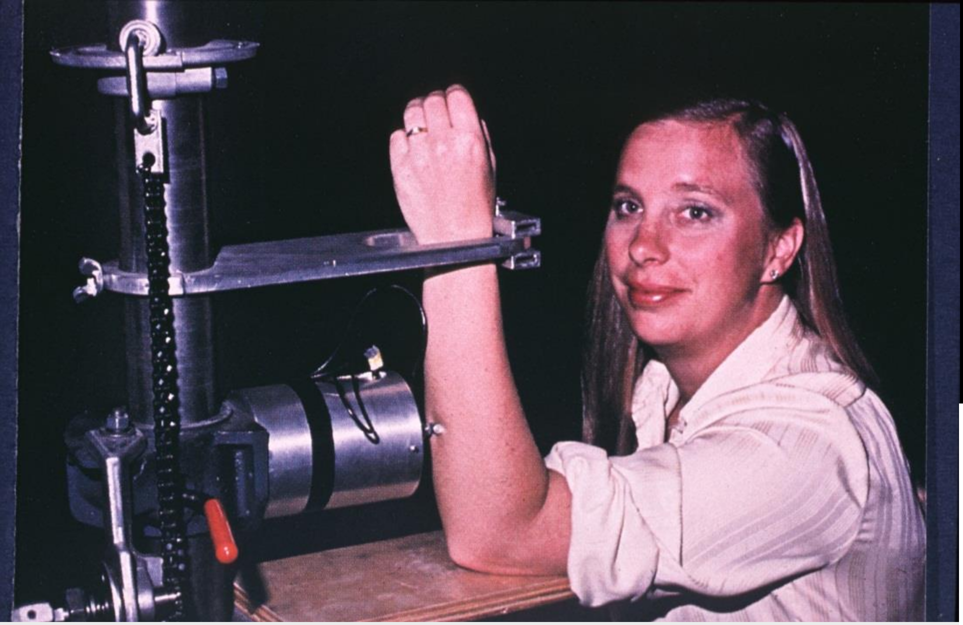


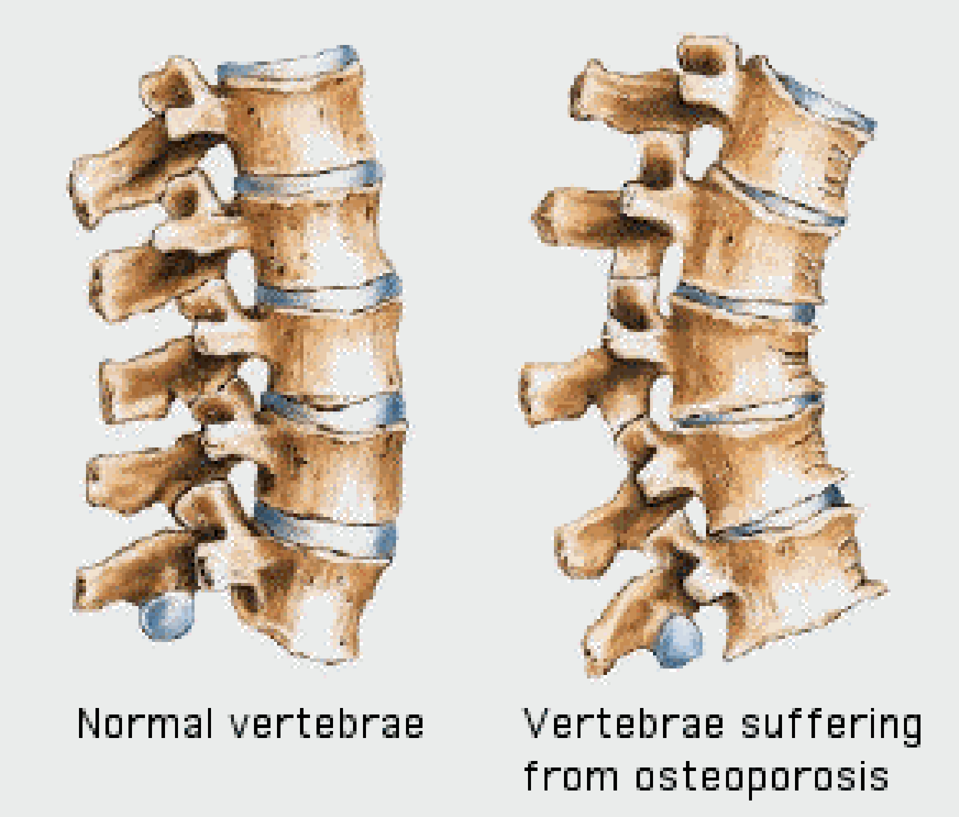

EYES BECOME MAIN WAY TO SENSE MOTION
OTOLITHS IN INNER EAR RESPOND DIFFERENTLY TO MOTION
FLUID REDISTRIBUTION CAUSES HEAD CONGESTION AND PUFFY FACE
CHANGED SENSORY INPUT CONFUSES BRAIN, CAUSING occasional DISORIENTATION
HIGHER RADIATION DOSES MAY INCREASE CANCER RISK
LOSS OF BLOOD PLASMA CREATES TEMPORARY 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

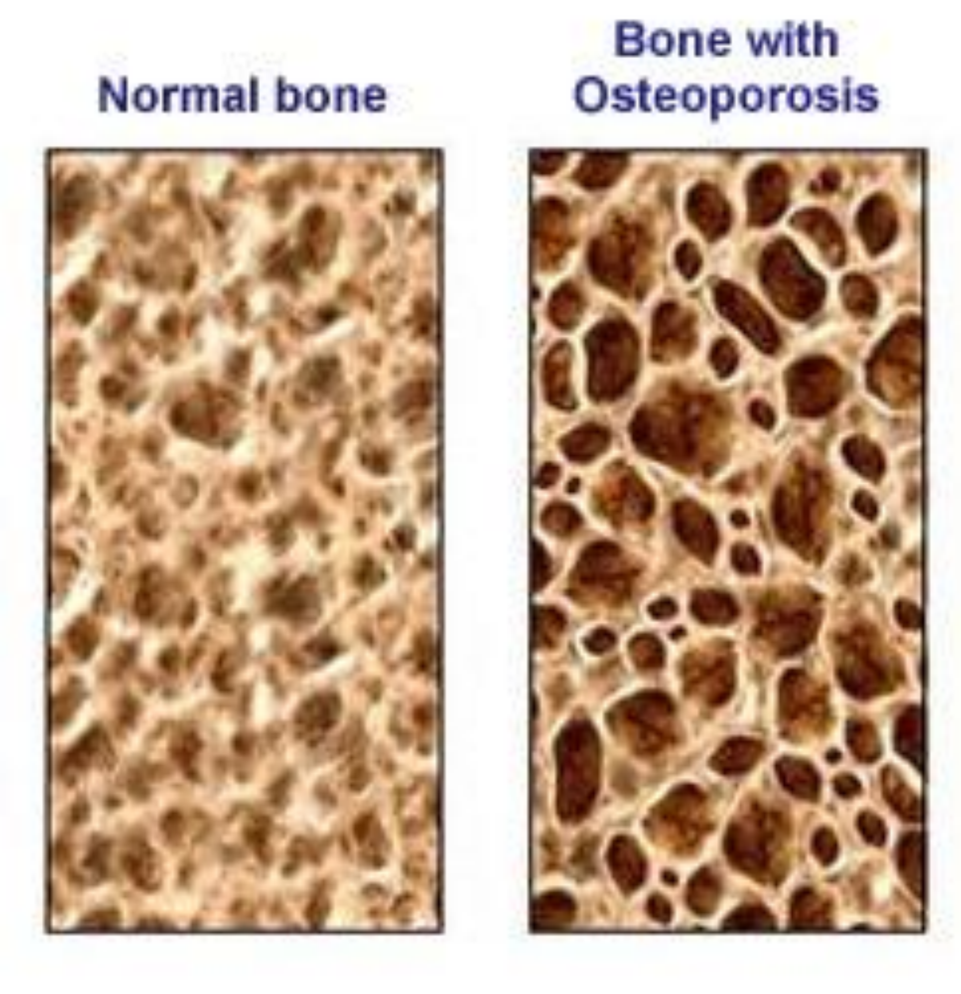


a. Fluid distribution on Earth
b. In microgravity fluids redistribute
c. Kidneys eliminate fluids
d. Returning to Earth

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







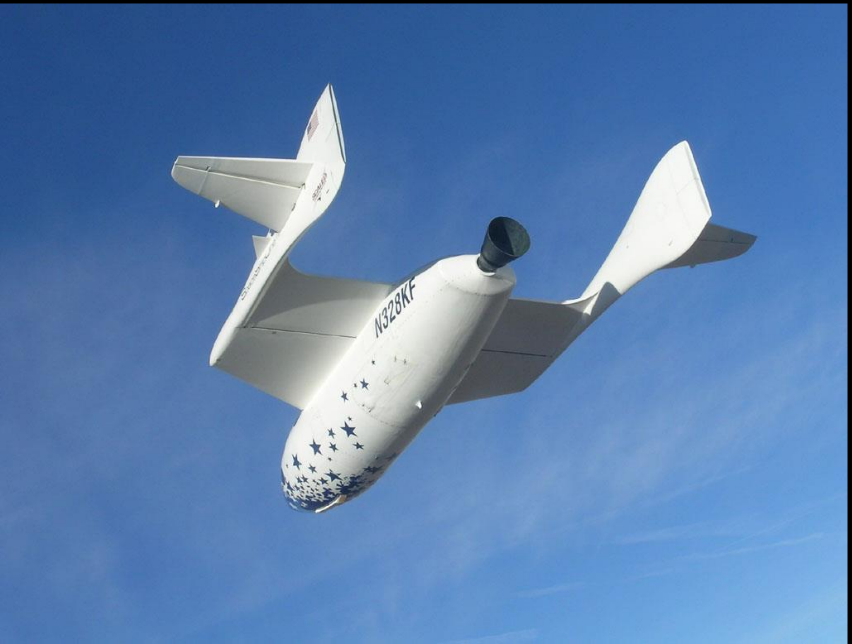
The physiological changes resulting from exposure to microgravity depend upon the total duration of the exposure, and can vary in magnitude from individual to individual

RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

3) OPERATIONAL FACTORS (Vehicle and Flight Operations):

- Type of acceleration profile (take off/launch, cruise, landing) and relative position of the occupants during acceleration exposure
- Type of flight profile (ascent rate, maximum altitude, descent rate, duration of the flight)
- Cabin/suit pressurization profile
- Noise/vibration exposure during flight

ACCELERATION




N318SL

November 15, 1967

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

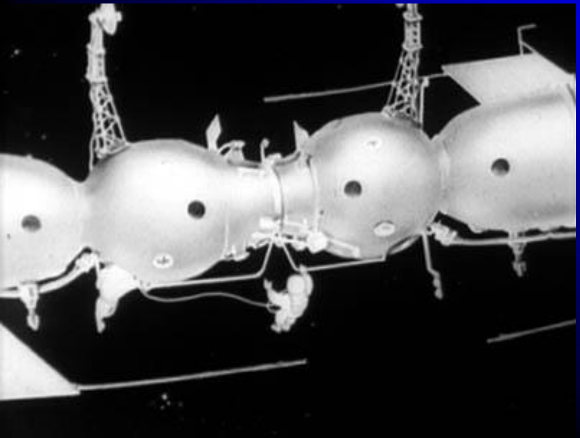
March 16, 1966

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

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

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

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 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

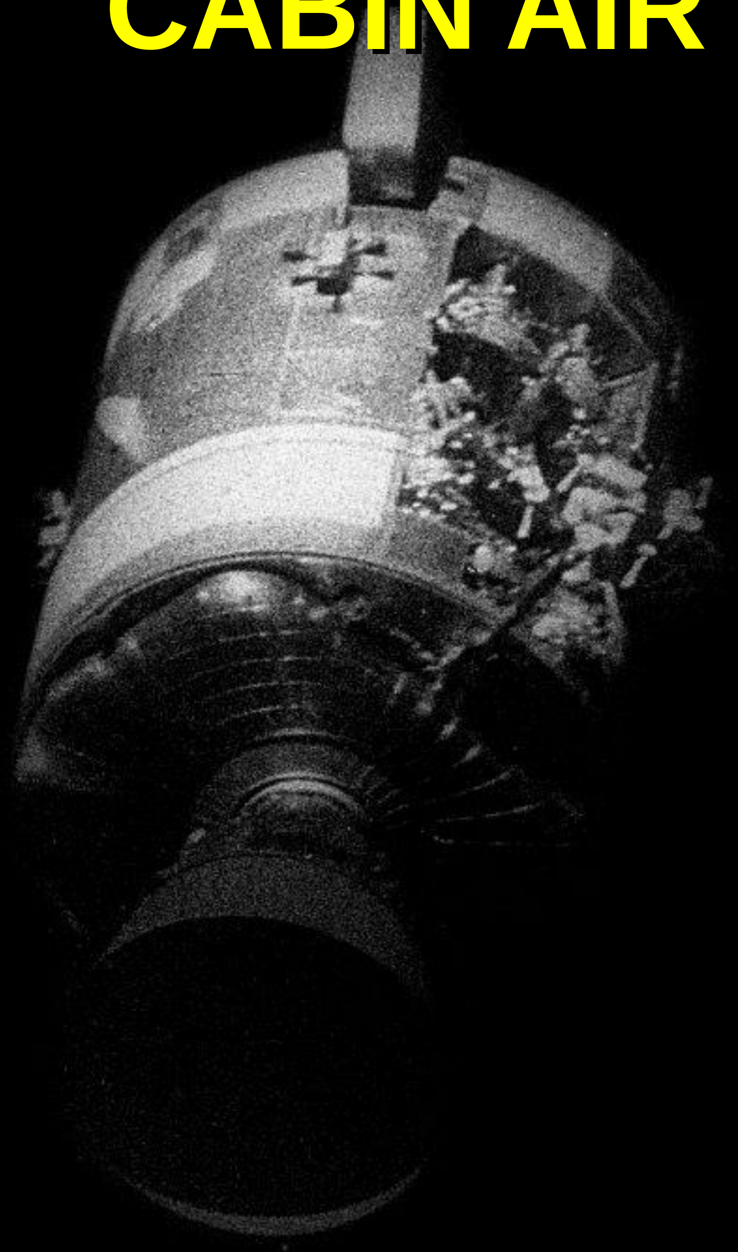
Other sources of inflight vibration include motors, pumps, and other mechanical equipment

RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

2) OPERATIONAL FACTORS (Vehicle and Flight Operations):

- Breathing air (composition, contaminants, CO_2 removal, volume per occupant)
- Cabin/suit temperature and humidity
- Impact/crash exposure (structural integrity or crashworthiness, occupant restraint systems, personal protective equipment, emergency evacuation systems, etc.) and survival

CABIN AIR



April 1970

- Apollo-XIII
- Lovell/Haise/Sweigert
- Explosion in service module
- Limited O_2/Mission aborted
- Dehydration – UTI – Fatigue - $\uparrow CO_2$

- 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

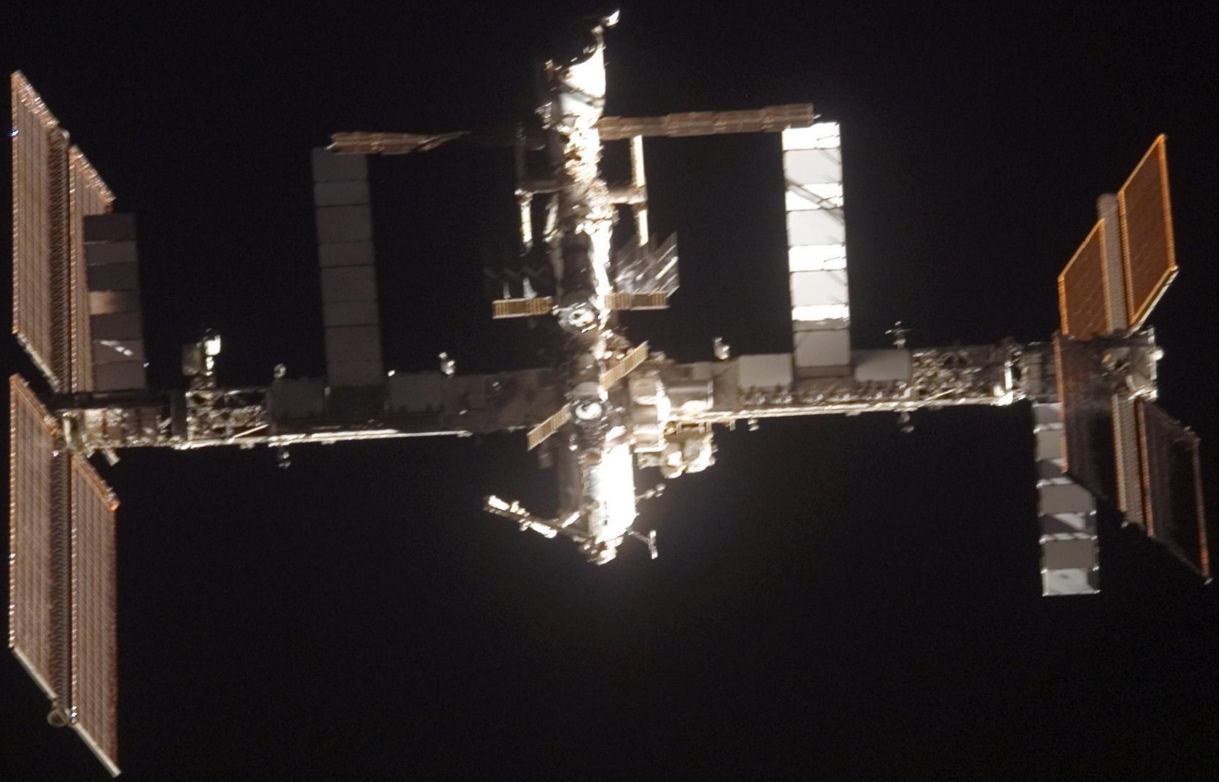

N318SL


N328KF
PHOTO COURTESY OF SCALED COMPOSITES, LLC

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

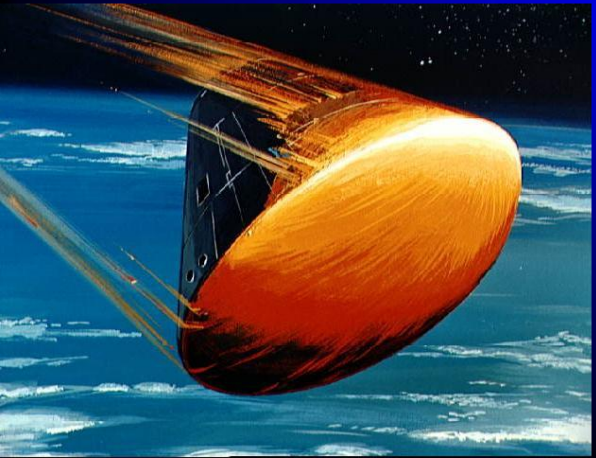
- *The most common sources of odor onboard a space vehicle are sweat, food, and organic waste*

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

RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

2) OPERATIONAL FACTORS (Vehicle and Flight Operations):

- Physical hazards (electrical, chemical, thermal) of the cabin
- Injuries due to accidental contact with internal structures or objects especially during microgravity
- Inflight fire (fire retardant materials, toxic materials, fire suppression systems)

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.

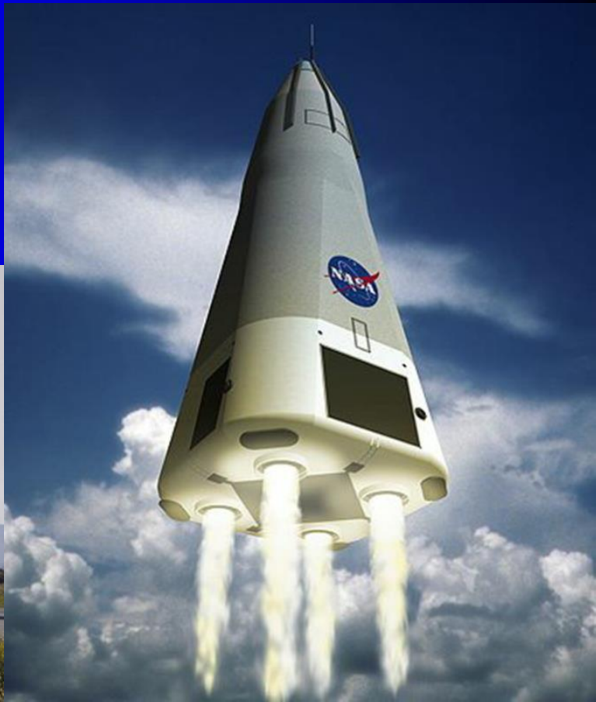
Commercial Space
Vehicle Crash Worthiness

<u>Factors Affecting Crash Survivability</u>

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

Types of Aircraft Structural Damage that Cause Occupant Injuries/Death

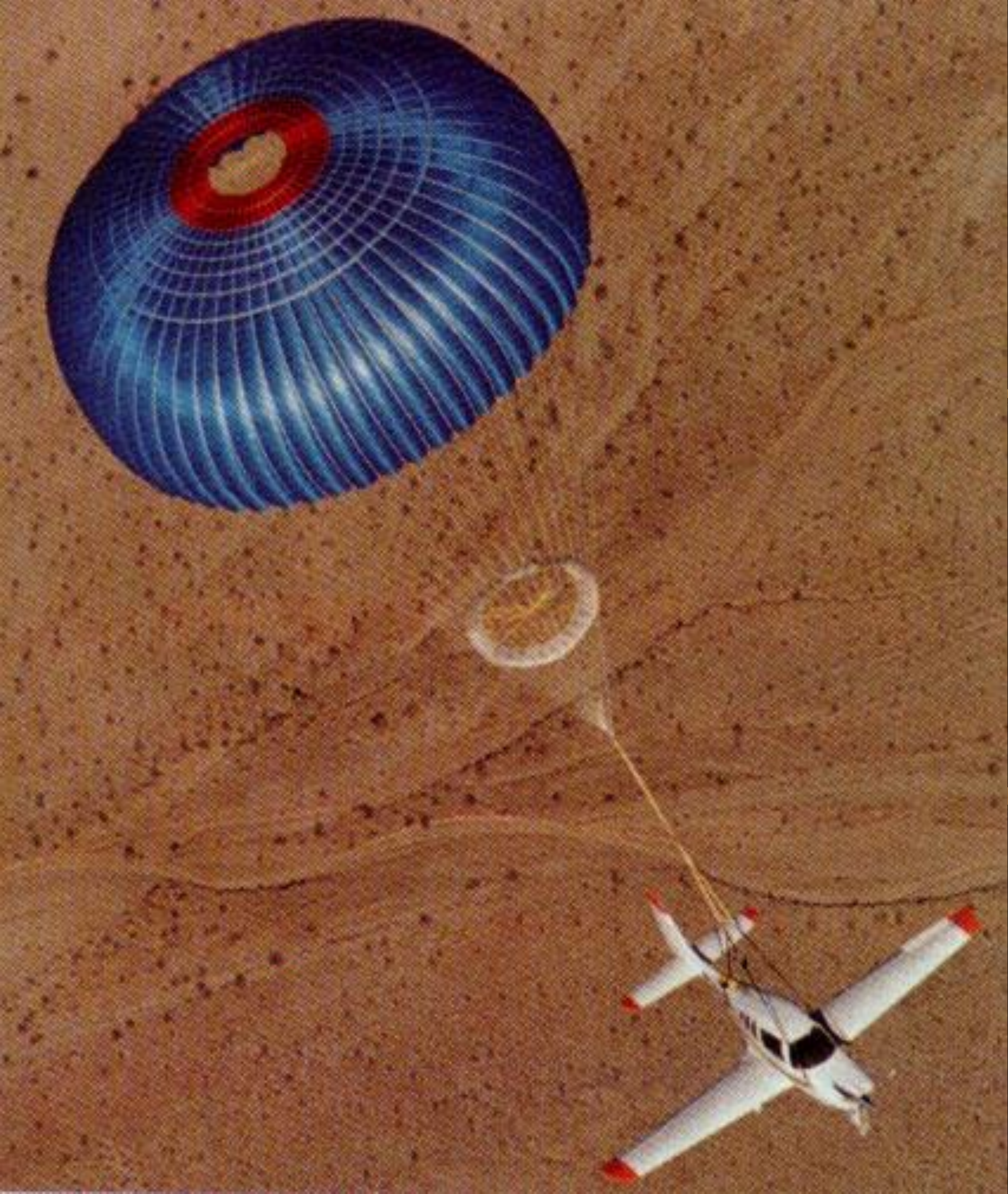
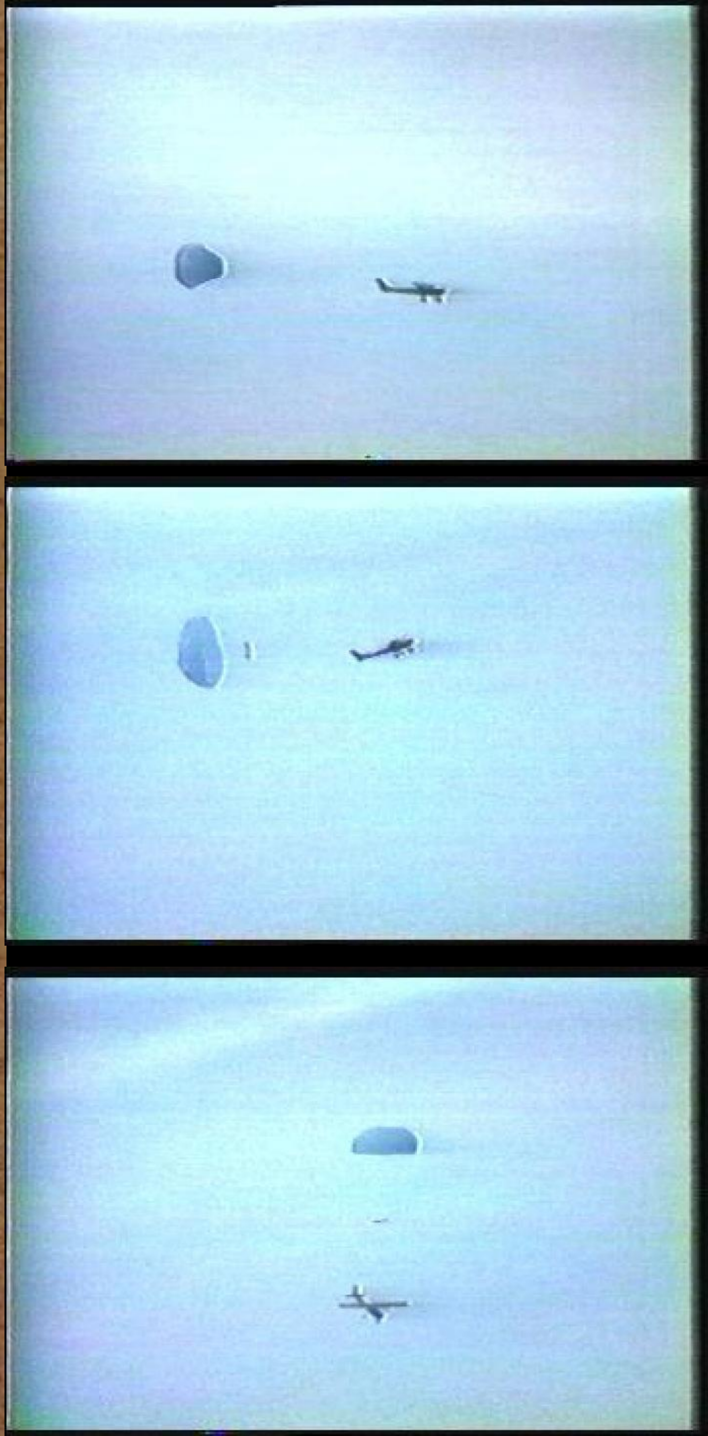
- Longitudinal structural overload
- Vertical structural overload
- Transversal structural overload
- Deformation and rupture of the floor structure
- Penetration of the landing gear into the fuselage



April 24, 1967

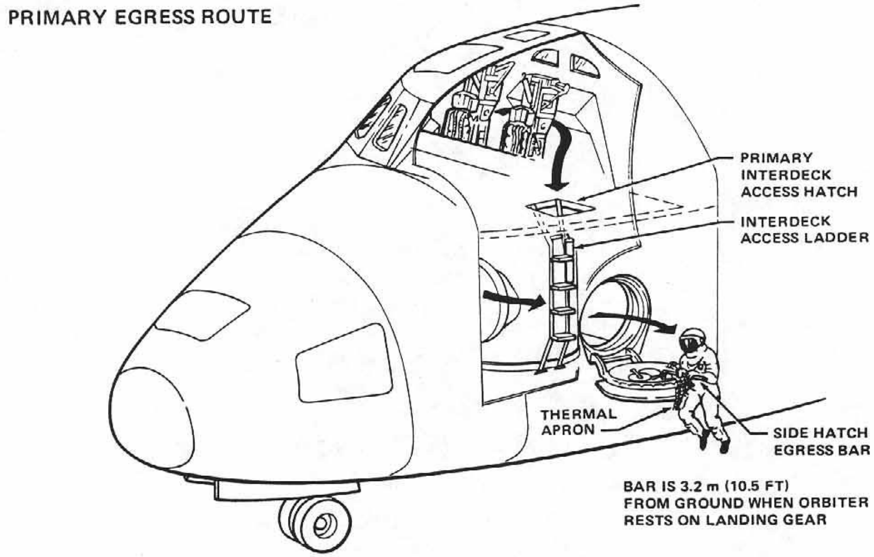
After orbital insertion of Soyuz 1 one of the solar panels failed to deploy. Although only receiving half of the planned solar power, an attempt was made to maneuver the spacecraft but it failed. The decision was made to bring Komarov back. Re-entry was successful and the drag chute deployed. However 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.

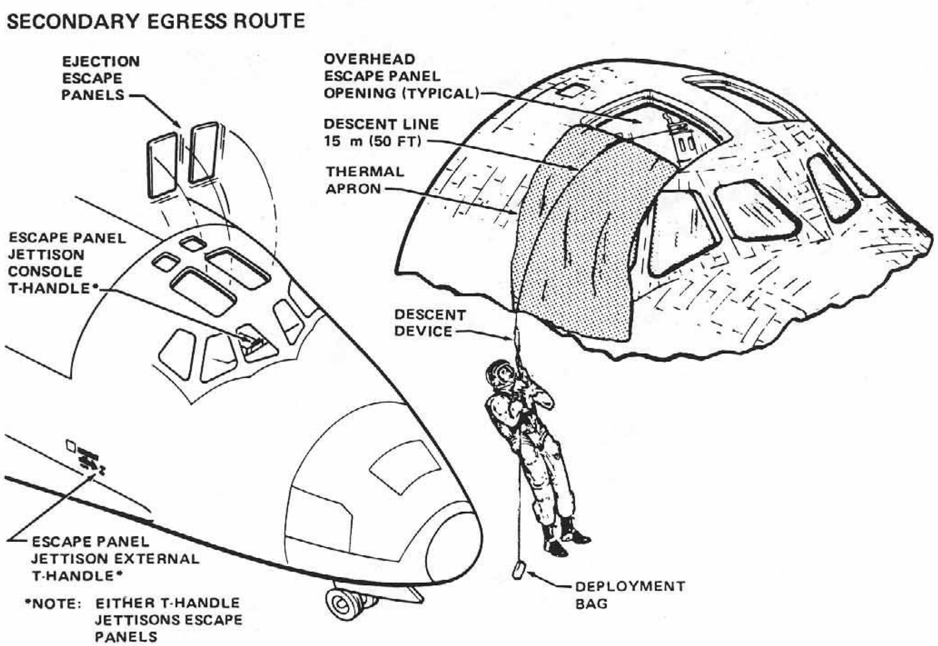
SpaceShipTwo broke apart in a test flight on October 31, 2014

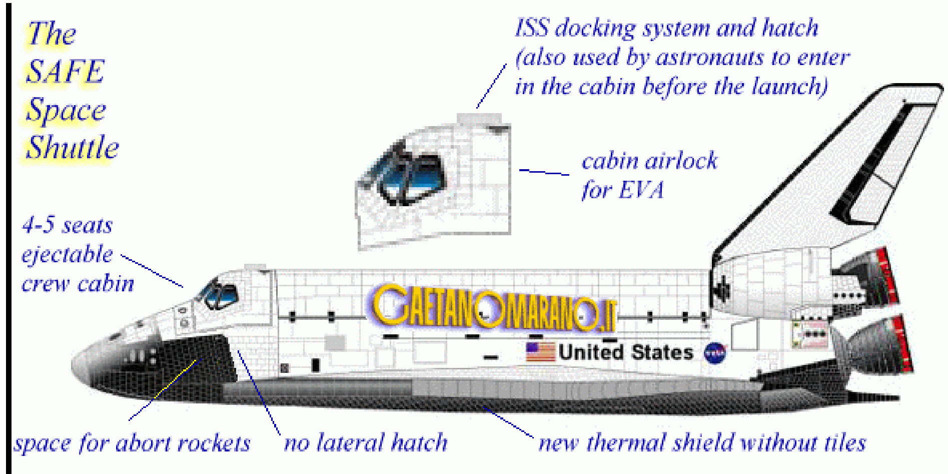



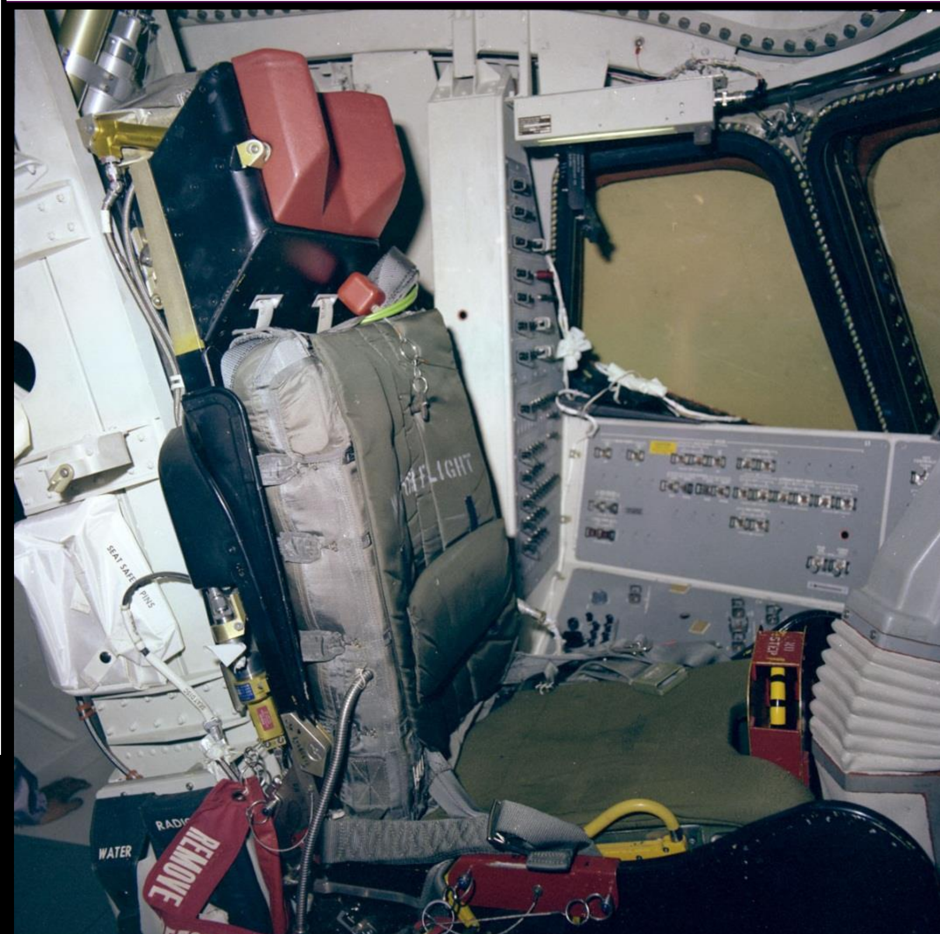

NASA
BOEING
ILC
DOVER

Stratos

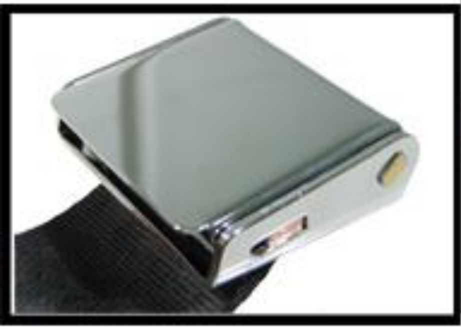

PRIMARY EGRESS ROUTE
PRIMARY INTERDECK ACCESS HATCH
INTERDECK ACCESS LADDER
THERMAL APRON
SIDE HATCH EGRESS BAR
BAR IS 3.2 m (10.5 FT) FROM GROUND WHEN ORBITER RESTS ON LANDING GEAR


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
GAETANOMARANO.IT
United States
space for abort rockets
no lateral hatch
new thermal shield without tiles

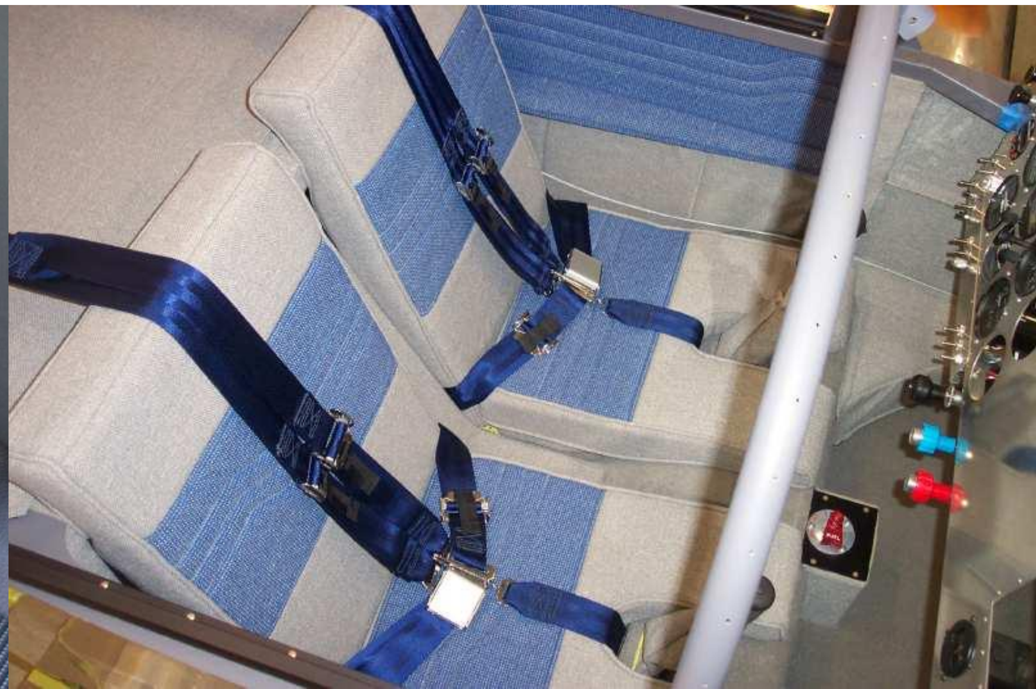

WATER
REMOVE

Restraint Systems

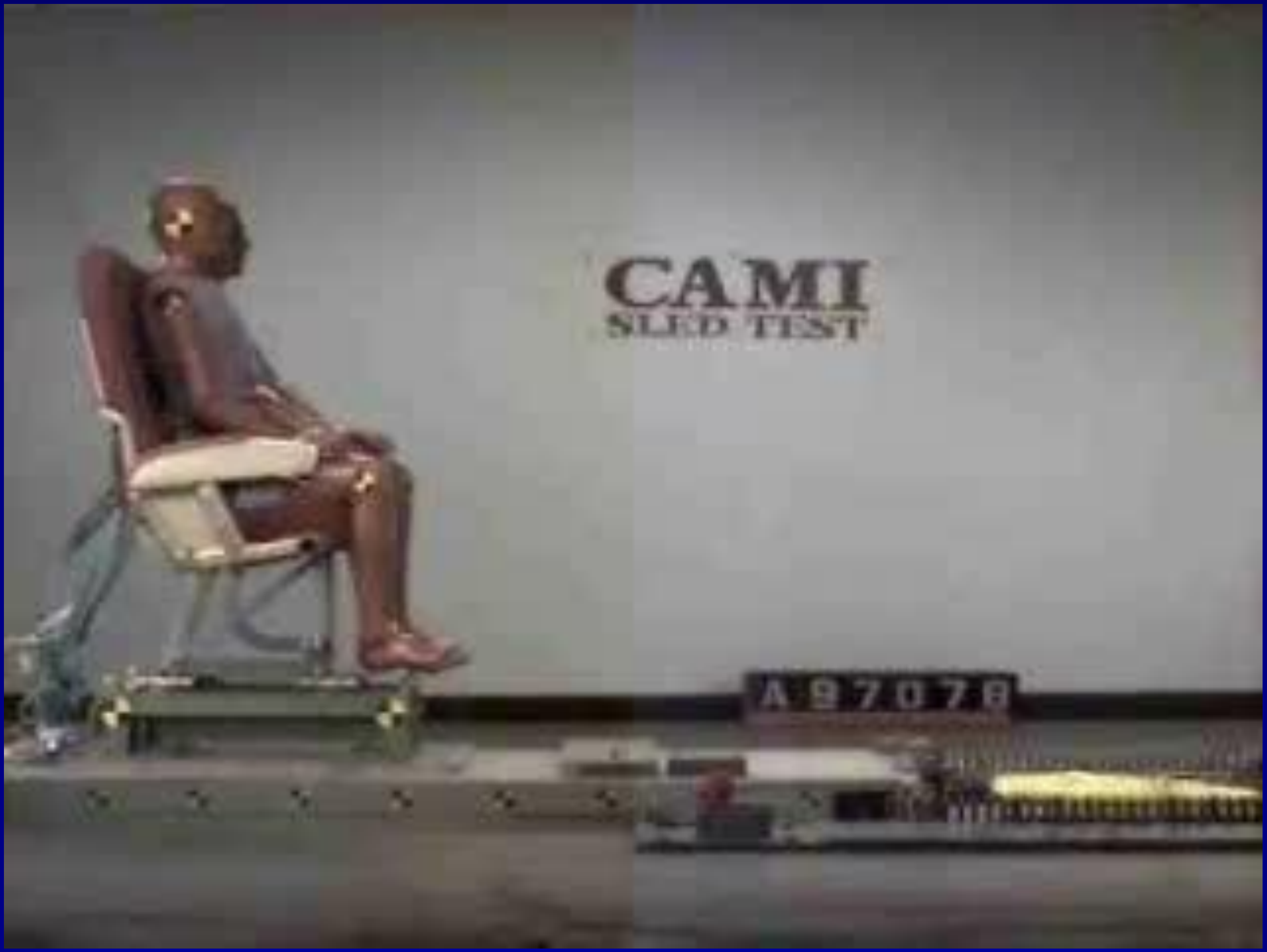


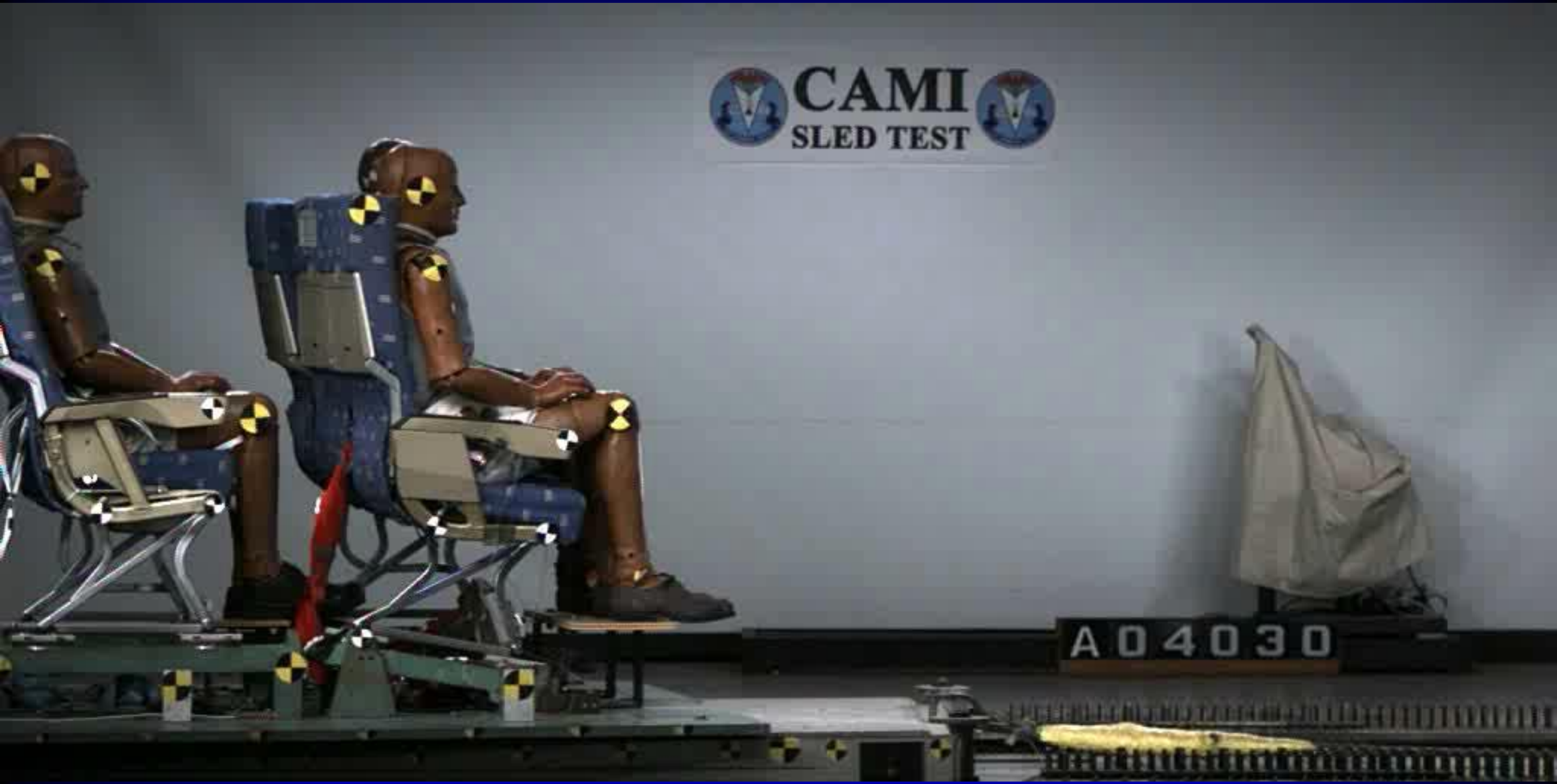

60”

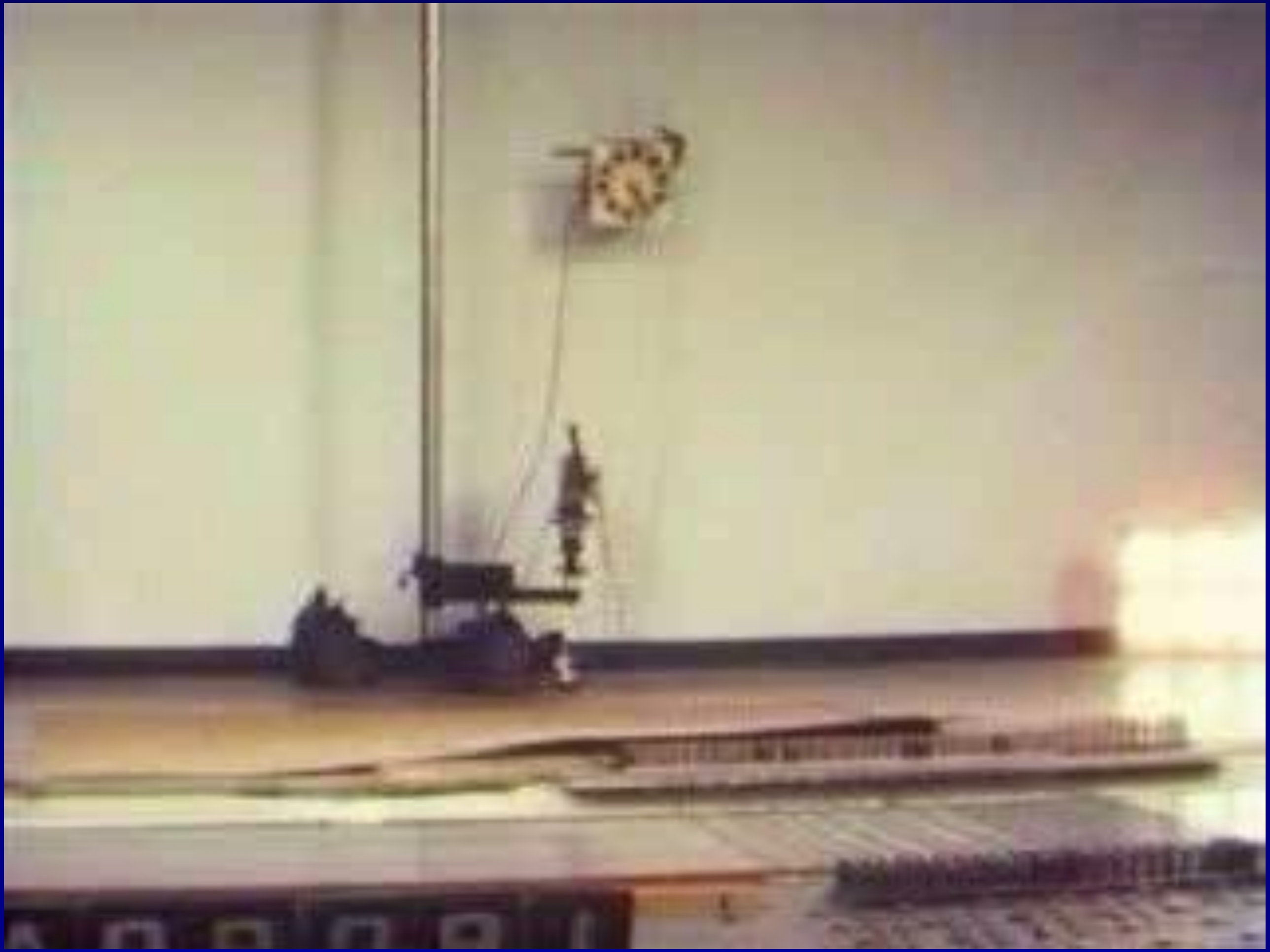

AUG 27 2007

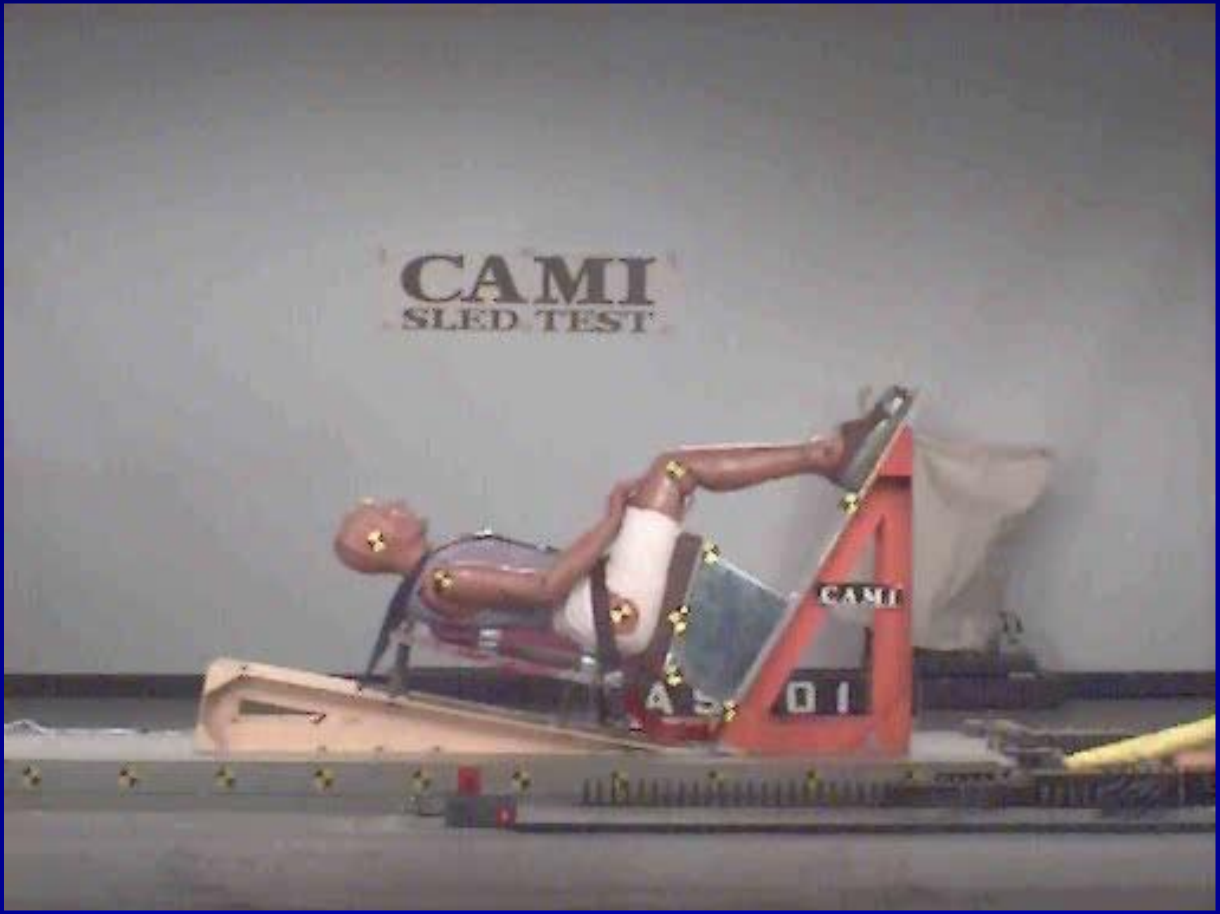



NASA


CAMI
SLED TEST
A97078


CAMI
SLED TEST
A04030



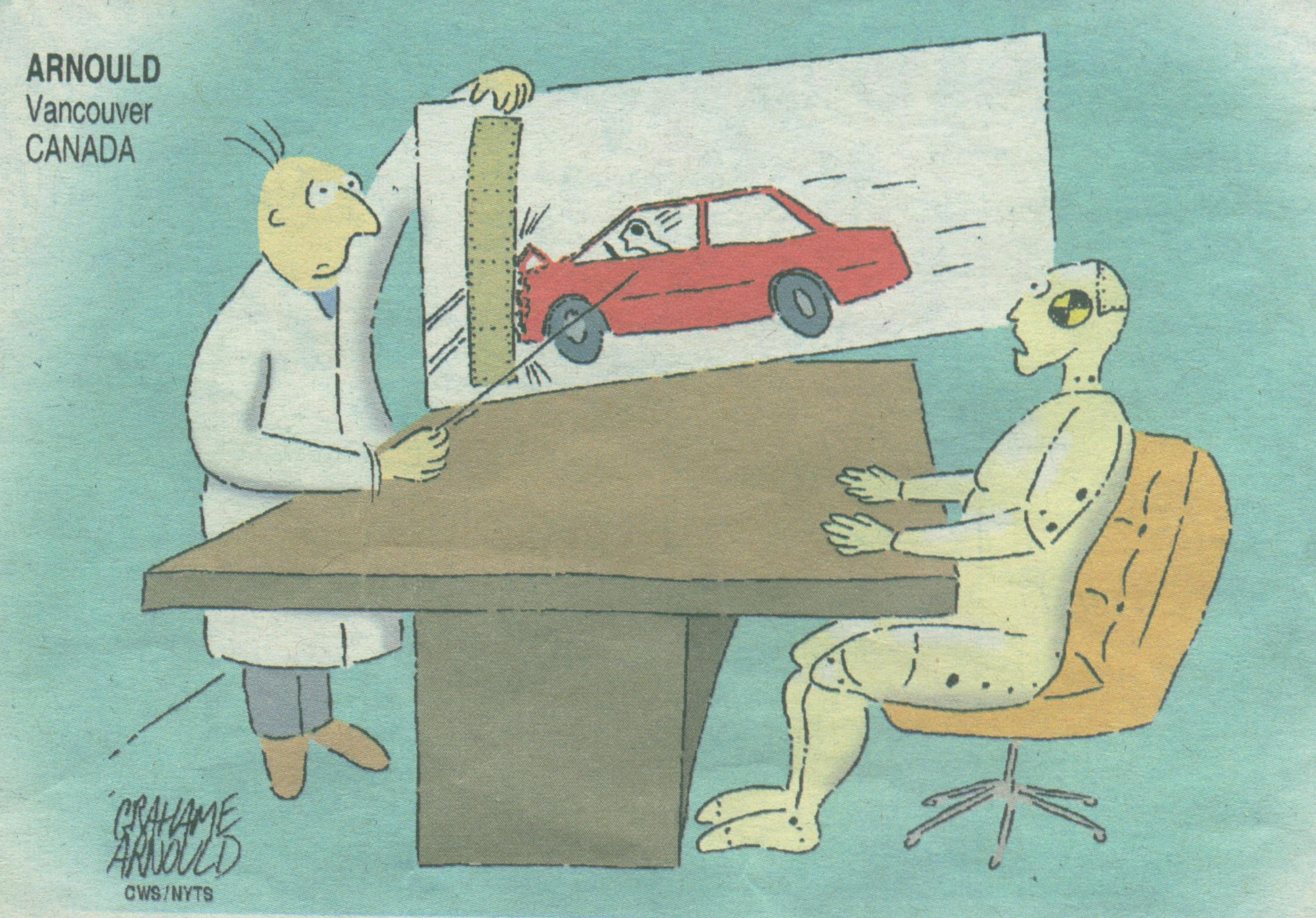

CAMI
SLED TEST
CAMI


A04026

OTHER PROTECTIVE SYSTEMS

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


CAMI
SLED TEST
A07009



"You want me to do what?"


E01 286

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

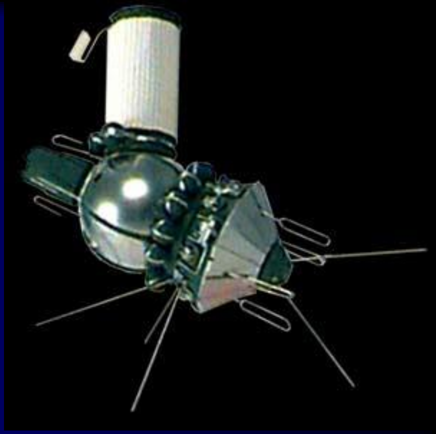
120 seconds

Post-Accident Human Survival Factors

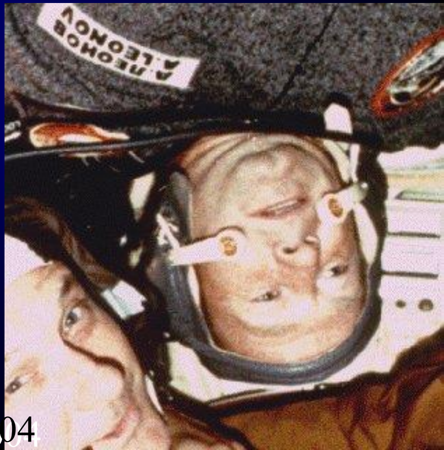
LIFE THREATENING EMERGENCIES

Can happen to anybody, anywhere, and anytime


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% O_2
- 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


SABRELINER
EVACUATION
TRAINER

RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

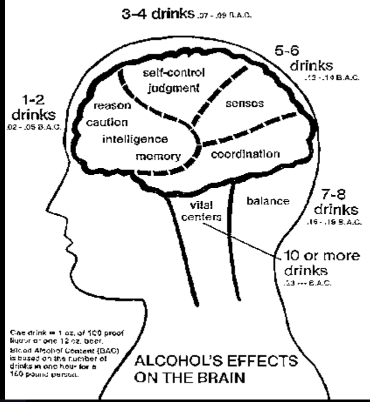
1) INDIVIDUAL FACTORS:

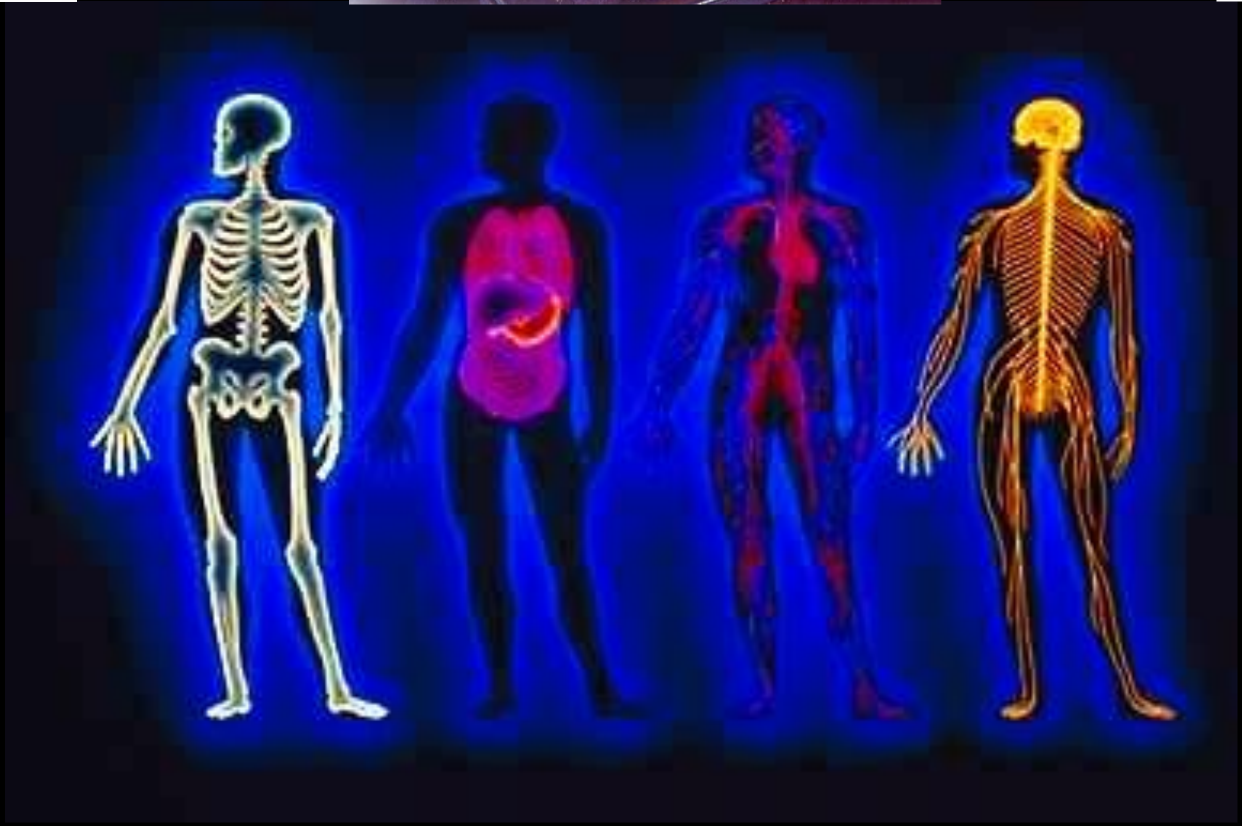
- Unidentified or undisclosed pre-existing medical conditions
- Unexpected inflight medical emergencies (acute illnesses or trauma)
- Self-imposed stress (alcohol and drug use/abuse, nicotine addiction, self-medication, fatigue, dehydration, poor fitness, extreme overweight)

RISK FACTORS FOR THE OCCUPANTS OF SPACE VEHICLES

1) INDIVIDUAL FACTORS:

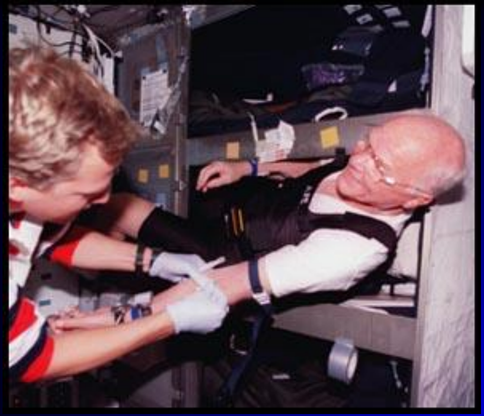
- Space motion sickness
- Unknown or undisclosed pregnancy
- Undisclosed use of medications
- Disruptive passengers

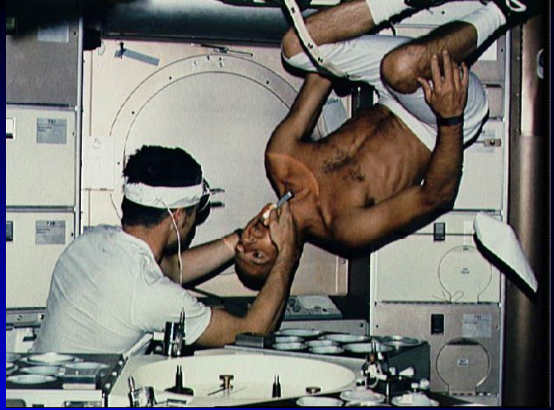




PROZAC®
fluoxetine hydrochloride

allegra®
fexofenadine HCl





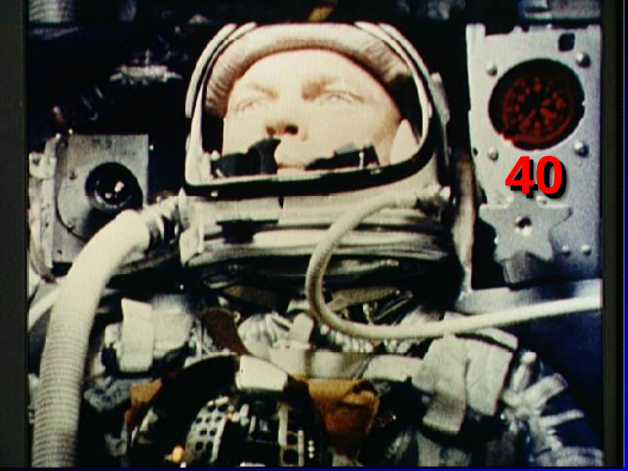
Do we know all the Medical Risks of Flying in Space?

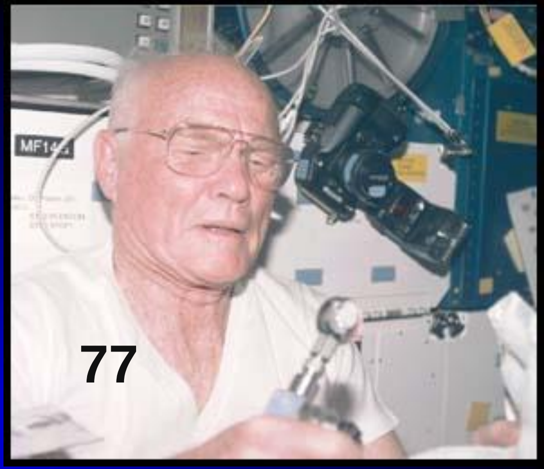
Do we know all the Medical Risks of Flying in Space?

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 healthy career astronauts aged 35 to 50 years old (only exception is John Glenn)

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

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

Short-Duration Orbital Flights

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

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

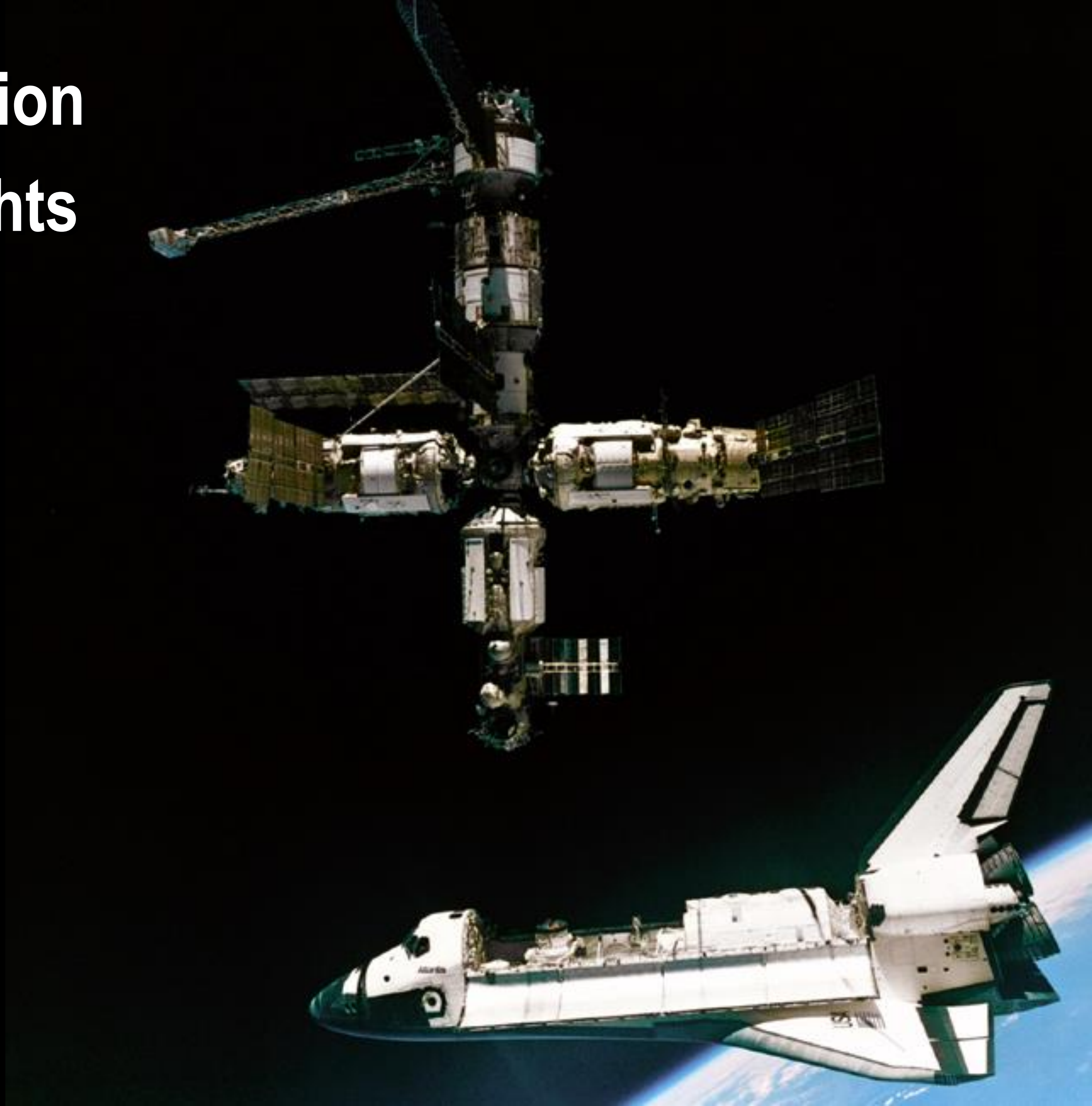
- *98.1% of men and 94.2% of women reported 2,207 medical events or symptoms during flight:*
  - Space adaptation syndrome (39.6%)
  - Nervous system and sensory organs (16.7%)
  - Digestive system (9.2%)
  - Injuries and trauma (8.8%)
  - Musculoskeletal system and connective tissues (8.2%)

- 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, 2007

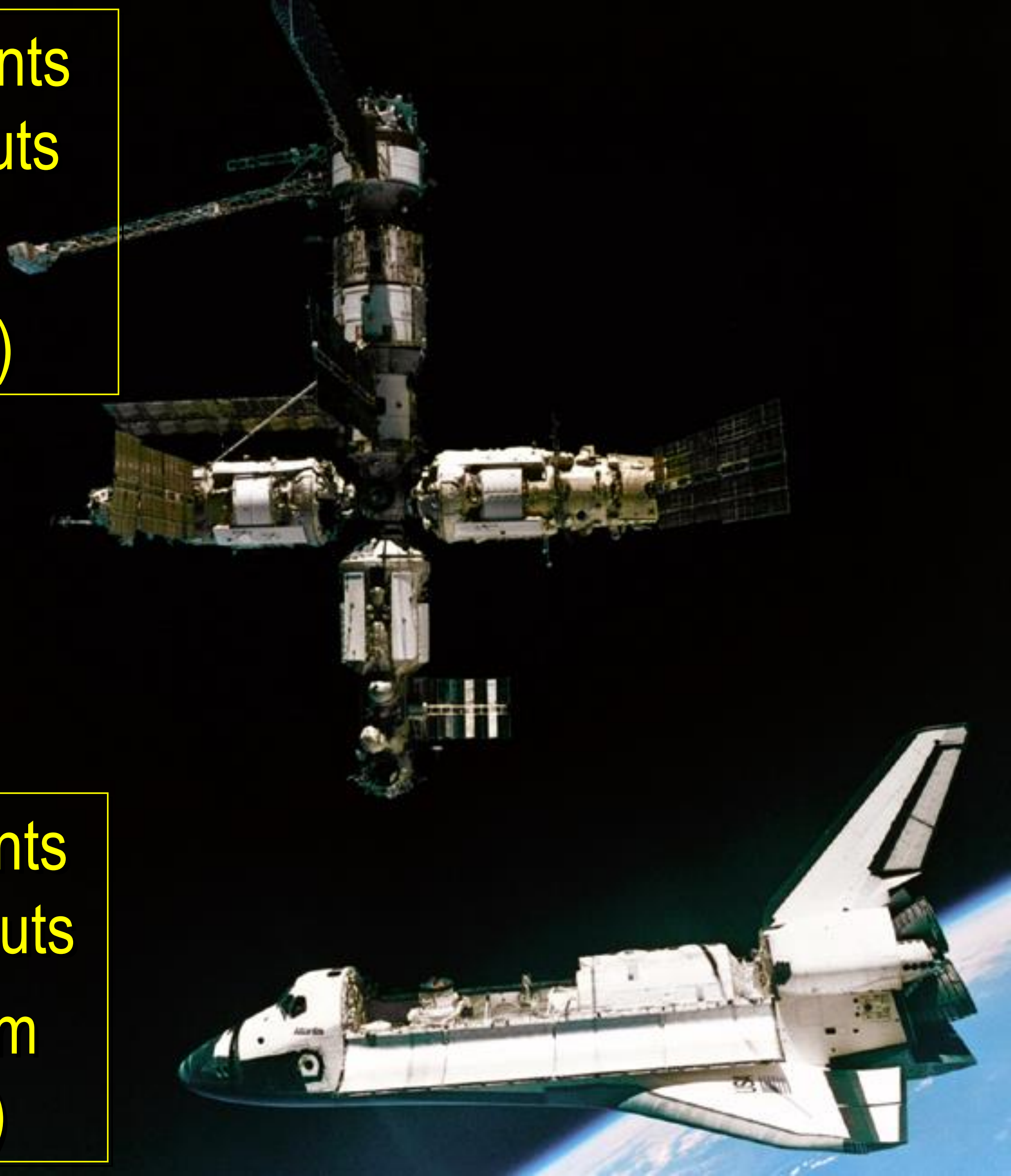
Long-Duration Orbital Flights



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



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

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)

What is the impact of Dr. Olsen's decision to openly share his medical case?

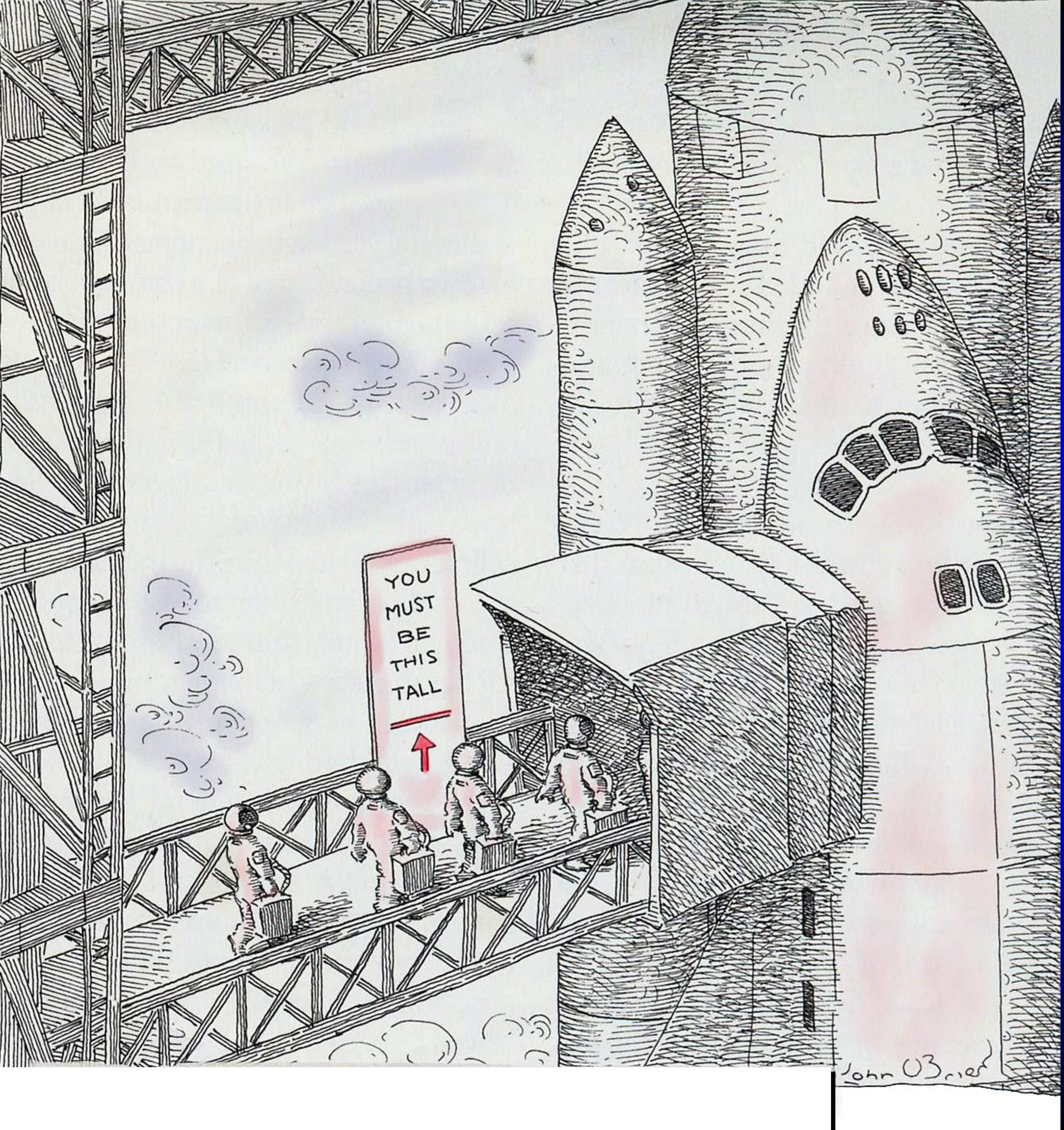
- Provides the space medicine community with an opportunity to gain critical experience with non-career astronauts who have certain abnormalities to demonstrate that they could fly safely

- Enables the revision of medical screening criteria used by operators to accommodate individuals with certain abnormalities, optimize their pre-flight treatment and observe their performance during space flight

- Provides an opportunity for controlled study of adverse medical conditions in analog and space flight environments

- Provides medical knowledge that will prove extremely valuable for future human space exploration
- Benefits other individuals who may have similar medical conditions and wish to fly in space
- Demonstrates that space flight participants and their physicians can evaluate and accept some medical risks for performance testing in hazardous environments, pre-flight training, and space flight

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

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

IAA Study Group 2.6

"Medical Safety Considerations for Passengers on Short-Duration Commercial Orbital Space Flights"

The final report contains a list of medical conditions that could be adversely impacted by exposure to the operational and environmental risk factors in orbital space flights

FAA CST COE

Flight Crew Medical Standards
&
Spaceflight Participant Medical Acceptance Guidelines

NASA

SPACE TRANSPORTATION ASSOCIATION

SPACE MEDICINE BRANCH · AEROSPACE MEDICAL ASSOCIATION

FEDERAL AVIATION ADMINISTRATION

INTERNATIONAL ASSOCIATION FOR THE ADVANCEMENT OF SPACE SAFETY

www.iaass.org

International Academy of Astronautics

IAA · ACADEMIE INTERNATIONALE D'ASTRONAUTIQUE

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

Commercial space companies will have the opportunity to incorporate these guidelines into their operations and adjust them as appropriate to meet their individual flight parameters, safety standards and risk profiles

U.S. companies are required to inform spaceflight participants about the mission-related risk, but the specific risk of certain medical conditions has yet to be determined

The pilot medical standards and SFP guidelines included in this report are considered the minimum recommended and governmental agencies and operators have the option for additional medical and operational constraints

1. Spaceflight Participant Medical Acceptance Guidelines - Suborbital

2. Spaceflight Participant Medical Acceptance Guidelines - Orbital

3. Standards for Medical Certification of Pilots -Suborbital

4. Standards for Medical Certification of Pilots -Orbital

Multiple organizations and interest groups have published medical recommendations for commercial spaceflight

There had not been a consolidation of these recommendations, guidelines, or standards into a cohesive document that could be operationally employed by commercial spaceflight operators, passengers and the FAA

Final Report

www.coe-cst.org/publications.html

FEDERAL AVIATION ADMINISTRATION

FAA's philosophy is different than NASA's on the determination of medical fitness for flight

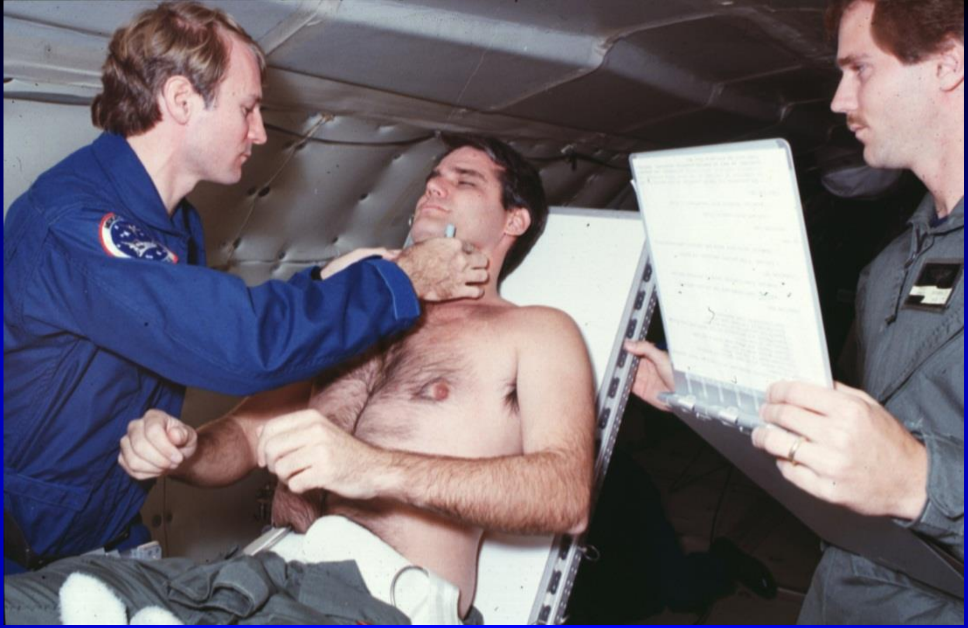
We authorized a routine Class 2 Airman Medical Certificate issued by an Aviation Medical Examiner (AME) and reviewed by the Aerospace Medical Certification Division at CAMI

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

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.



“FAA Recommended Guidelines for Medical Screening of Commercial Space Passengers”

How conservative should medical screening guidelines be for space passengers in order to:

Promote the preservation of life and the safety of the flight?

and at the same time

Avoid imposing an obstacle to the successful establishment and growth of the manned commercial space transportation industry?

Main Risk Factors Relevant to the Development of Guidelines for Medical Screening of Commercial Space Passengers

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

Guidance for Medical Screening of Passengers on Suborbital Flights or Exposed to a G-Load of up to +3Gz During any Phase of the Flight.

1. Passengers complete a <u>medical history questionnaire</u> prior to every flight (single or multiple)
2. A <u>company physician</u> who is experienced or trained in the concepts of aerospace medicine <u>reviews the completed questionnaire</u>
3. Passengers <u>may need to undergo a physical examination and complete medical laboratory testing</u> if deemed necessary by the company physician upon review of the completed questionnaire

Guidance for Medical Screening of Passengers on Orbital Flights or Exposed to a G-Load exceeding +3Gz During any Phase of the Flight.

1. Passengers complete a comprehensive medical history questionnaire prior to the flight

2. Passengers undergo a physical examination with laboratory testing

3. The medical history, physical examination, and medical tests should be valid for a period of one (1) year.

Medical Conditions that may Contraindicate Passenger Participation in Suborbital or Orbital Space Flights

Any deformities (congenital or acquired), diseases, illnesses, injuries, infections, tumors, treatments (pharmacological, surgical, prosthetic, or other), or other physiological or pathological conditions that may:

1) Result in an in-flight death
2) Result in an in-flight medical emergency
3) Interfere with the proper use (don and doff) and operation of personal protective equipment
4) Interfere with in-flight emergency procedures or emergency evacuation
5) Compromise the health and safety of the passenger or other space vehicle occupants, and/or the safety of the flight

Other Considerations

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

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


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
nogravity.com


www.goZeroG.com


zero

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

Medicine is a Science

and an Art

The Key for CST HSF is the Medical Waiver Process

Other Considerations

- It is recommended to implement <u>non-invasive biomedical monitoring of spaceflight participants</u> prior to launch, during the entire flight, and in the immediate post-landing period

- The basic physiological parameters to be monitored include body temperature, heart rate, ambulatory electrocardiography, blood pressure, respiratory rate, transcutaneous arterial oxygen saturation (PSaO2) and carbon dioxide partial pressure (PaCO2)

- Such a monitoring system should be fully portable, light and compact, self-powered, built-in automated data collection and storage capability, non-invasive and minimally intrusive on the wearer

- Commercial space flights will create the opportunity for non-career astronauts with certain medical conditions to fly in space

- Medical information collected from space flight participants (specially those with medical waivers) will be extremely important to establish prospective medical databases by the operators

- Medical databases may include the results of the initial and pre-flight medical evaluations, the results of any inflight biomedical monitoring, as well as any post-flight medical findings

- All medical information collected and archived in databases should be protected to ensure the individual medical-legal privacy rights of space flight participants
- Post-flight medical debriefs are highly recommended to collect critical medical data and to resolve and/or follow up any health issues resulting from space flight
- A practical tool to facilitate and standardize these post-flight medical debriefs would be a questionnaire

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

Pregnancy Issues

- 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