Human Spaceflight
Space System Design, MAE 342, Princeton University
Robert Stengel

- Historical concepts and mis-concepts
- Manned spacecraft and space stations
- Extravehicular activity
- Physiological and metabolic issues
  - Health and space medicine
  - Radiation exposure
  - Life support systems
- Control capabilities and human error
A Voyage to the Moon
Cyrano de Bergerac
(1619-1655)

- Hercule-Savinien Cyrano de Bergerac
- “Comical History of the States and Empires of the Moon”, written about 1649, published 1656 or 1657
- English translation, 1687
- In Firestone Library (below & left)
Cyrano's Voyage to the Moon and Back

1952 Rocket Ship/Space Station Concept
Trouble in the Spacecraft: Ejection Capsule

Why Humans in Space?

- Exploration
- Scientific discovery
- Engineering development
- Construction, maintenance, and repair
- Pilots, tourists, and tour guides
Man vs. Machine
(Handbook of Astronautical Engineering, 1961)

Table 26.4. Superiority of Man and Machine in Various Activities

<table>
<thead>
<tr>
<th>Man</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility</td>
<td>Physical strength and power</td>
</tr>
<tr>
<td>Multipurpose adjustment</td>
<td>Speed of sensing</td>
</tr>
<tr>
<td>Multipurpose response</td>
<td>Speed of recognition</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Speed of certain performances</td>
</tr>
<tr>
<td>Multipurpose sensitivity</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>Communication</td>
<td>Speed of computation</td>
</tr>
<tr>
<td>Learning</td>
<td>Constancy of performance</td>
</tr>
<tr>
<td>Judgment</td>
<td>Repetitive performance</td>
</tr>
<tr>
<td>Inductive reasoning</td>
<td>Reliability</td>
</tr>
<tr>
<td>Understanding of essentials</td>
<td>Endurance</td>
</tr>
<tr>
<td>Establishment of hypotheses</td>
<td>Stability of memory</td>
</tr>
<tr>
<td>Taking risks</td>
<td>Short-term storage capacity</td>
</tr>
<tr>
<td>Problem solving</td>
<td>Complete erase capability</td>
</tr>
<tr>
<td>Pattern interpretation</td>
<td>Conformity</td>
</tr>
<tr>
<td>Decision making</td>
<td>Reaction time</td>
</tr>
<tr>
<td>Ingenuity and intuition</td>
<td>Sensitivity to certain environmental conditions</td>
</tr>
<tr>
<td>Invention of new things</td>
<td>Innsensitivity to certain environmental conditions</td>
</tr>
<tr>
<td>Utilization of subjective experiences</td>
<td>Simultaneous activity</td>
</tr>
<tr>
<td>Utilisation of external means</td>
<td></td>
</tr>
<tr>
<td>Design and construction of machines and equipment</td>
<td></td>
</tr>
<tr>
<td>Integration of internal and external stimuli</td>
<td></td>
</tr>
<tr>
<td>Concluding</td>
<td></td>
</tr>
</tbody>
</table>

Performance Issues for Manned Spaceflight

- Flexibility, learning, and judgment
- Information bandwidth, display, and communication
- Pre-flight training
- Performance variation
- Extra-vehicular activity
- Physical labor
- Physical labor
- Endurance
- Ergonomics
- Control systems
- Re-entry systems and recovery
- Tools and equipment
- Recycling
Cooper-Harper Pilot Opinion Rating
(NASA TN D-5153, 1969)

**Adequacy for Selected Task or Required Operation**

- Yes: Satisfactory without improvement
- No: Deficiencies, needs improvement

**Aircraft Characteristics**

- Excellent, highly desirable
- Good, negligible deficiencies
- Fair - Some mildly unpleasant deficiencies
- Minor but annoying deficiencies
- Moderately objectionable deficiencies
- Very objectionable but tolerable deficiencies
- Major deficiencies

**Demands on the Pilot in Selected Task or Required Operation**

- Pilot compensation is not a factor for desired performance
- Pilot compensation is a factor for desired performance
- Minimal pilot compensation required for desired performance
- Required moderate pilot compensation
- Adequate performance requires considerable pilot compensation
- Adequate performance requires extensive pilot compensation
- Considerable pilot compensation is required for control
- Extreme pilot compensation is required to maintain control
- Control will be lost during some portion of the required operation

**Pilot Rating**

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10

*Definition of required operation involves designation of flight phase and/or subphase with accompanying conditions.*

---

Cooper-Harper Pilot Opinion Rating
(NASA TN D-5153, 1969)

**Definitions from TN-D-5153**

**Compensation**
The measure of additional pilot effort and attention required to maintain a given level of performance in the face of deficient vehicle characteristics.

**Handling Qualities**
Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role.

**Mission**
The composite of pilot-vehicle functions that must be performed to fulfill operational requirements. May be specified for a role, complete flight, flight phase, or flight subphase.

**Performance**
The precision of control with respect to aircraft movement that a pilot is able to achieve in performing a task. (Pilot vehicle performance is a measure of handling performance. Pilot performance is a measure of the manner or efficiency with which a pilot moves the principal controls in performing a task.)

**Role**
The function or purpose that defines the primary use of an aircraft.

**Task**
The actual work assigned a pilot to be performed in completion of or as representative of a designated flight segment.

**Workload**
The integrated physical and mental effort required to perform a specified piloting task.
Human Space Experience to April 2016

- Continuous human space presence since Oct. 31, 2000
- Total people in space: 544
- Total person-days: 47,930
- Most space flights: Jerry Ross and Franklin Chang-Diaz (7)
- Cumulative spaceflight record: 878 days (Gennady Padalka)
- Single mission record: 438 days (Valeri Polyakov)
- Total ISS EVAs (2/16): 193
- Total ISS EVA time (2/16): 1205 hr
- EVA record: 16 (Anatoliy Solovyov)
- Longest EVA: 8hr 56 min (Susan Helms and James Voss)

Physical Issues for Manned Spaceflight

- Physiology
  - Loss of bone and muscle mass
    - Intensive exercise regimen
  - Fluid redistribution to upper body
  - Disruption of vision due to intracranial pressure
- Life support
  - Breathing and pressurization
    - Exposure to vacuum
  - Nutrition and hydration
  - Rest and work cycles
  - Thermal environment
    - Temperature extremes
  - Acoustic noise level
  - Waste disposal

Physical Issues for Manned Spaceflight

- Acceleration level during launch and re-entry
- Effects of weightlessness
- Angular rate and orientation
  - Motion sickness
- Radiation hazards
  - Cosmic radiation
  - Van Allen belts

Human Acceleration Tolerance
(NASA TN D-337, 1960)

Figure 10. - Time tolerance to acceleration boundaries.
Effect of Drag/Mass on Direct Reentry Deceleration

(Handbook of Astronautical Engineering)

Flight path angle = constant
Lift = 0

Fig. 10.13 Velocity variation during direct reentry through the Earth’s atmosphere.
Fig. 10.14 Variation of deceleration with altitude for direct entry into the Earth’s atmosphere.

Effect of Flight Path Angle on Direct Reentry Deceleration

(C_D S/m = 0.1)

(Handbook of Astronautical Engineering)
Mercury

- One crew member
- Command module
- 1,935 kg
- Conical reentry capsule
- Large-radius heat shield
- Negligible reentry crossrange capability
- Parachute recovery of capsule and astronaut
- 9-g reentry
- Low earth orbit

Vostok

- One crew member
- 2,460 kg
- Command + service modules
- Spherical reentry capsule
- Small-radius heat shield
- Negligible reentry crossrange capability
- Parachute recovery of capsule
- Cosmonaut lands on personal parachute
- 8-g reentry
- Low earth orbit
Effect of Lift/Drag on Reentry Deceleration

*(Handbook of Astronautical Engineering)*

![Graphs showing velocity variation and deceleration with altitude for bodies with gasdynamic lift.]

$L/D = 1$ to $3$

**Gemini**

- 2-person crew
- 10 manned missions
- Up to 7 days in orbit
- Low reentry crossrange capability
- Extravehicular activity
- Rendezvous and docking
- Formation flying

*"Pete" Conrad, '53, two Gemini missions, 1965 and 1966*
Apollo’s Return to Earth

Reentry of Apollo 13 Service and Lunar Modules

Radiation Exposure

- Annual Limit
- Lifetime Limit

Indicated limits are controversial
Psychological Issues for Manned Spaceflight

• Psychology
  – Egocentricity (“autonomization”)
  – Isolation and monotony
  – Increased holistic respect for Earth

• Psychiatry
  – Transient anxiety or depression
  – Fatigue, irritability, sleep disorder
  – Readjustment on return to Earth

• Sociology
  – Bonding of vehicle crew
  – Importance of supportive mission commander
  – Lack of confidence in ground personnel
  – Misunderstandings among crew from different cultures

Space Medicine

• Cardiac rhythm disturbance
• Decompression sickness
  – Transition from air to oxygen for EVA
    (“nitrogen purge”)
  – Barotrauma
• Decreased immune response
• Medications
• Health and medical emergency
  – Procedures and protection
  – Use of ultrasound diagnostics in space
  – Intervention, e.g., robot-assisted surgery
X-15: The First US Spaceplane

1st powered flight: 1959
Maximum altitude: 108 km, 1963
Maximum speed: 7,273 km/hr, 1967
USN Commander Forrest Petersen, Princeton AE, 4th X-15 pilot, 1960

Project Mercury Flights (manned)

- Redstone
  - 5/61, Shepard
  - 7/61, Grissom
  - Atlas
  - 2/62, Glenn
  - 5/62, Carpenter
  - 10/62, Schirra
  - 5/63, Cooper
Project Gemini Flights

Unmanned Manned

Apollo

Columbiad Projectile (Jules Verne)
Similarities Between Verne’s *Columbiad* and *Apollo*

- Launch from Florida at Cape Canaveral’s latitude
- Size of capsule
- Number of astronauts
- Required launch velocity
- Time of flight
- Weightlessness
- Capsule recovery at sea

**Apollo Command and Service Modules**

- 3-person crew
- Upper and lower decks
- Autonomous guidance and control capability
Saturn IB, 1966-1975

- 9 launches
  - Uprated S-I and S-IV stages
- AS-201, -202: sub-orbital
- AS-203: orbital
- AS-204: Apollo 1: Block 1, Jan 1967, no launch, loss of crew (Grissom, White, Chaffee)
- No Apollo 2 or 3
- Apollo 5: Jan 1968, LM test (unmanned)
- Apollo 7: Block 2, Oct 1968, 1st manned flight, (Schirra, Eisele, Cunningham)
- 3 flights to SkyLab, 1973
- Docking with Soyuz, 1975

Saturn V, 1968-1975

- New 1st and 2nd stages
- S-IVB became 3rd stage
- Apollo 4, 6: Unmanned
- Apollo 8: 1st to the Moon
- Apollo 9: orbital
- Apollo 10: 2nd to the Moon
- Apollo 11: 1st lunar landing
- Apollo 12: 2nd lunar landing
- Apollo 13: aborted lunar mission
- Apollo 14-17: successful lunar missions
- Skylab launch (2 stages)
Space Shuttle

- 5 operational vehicles, 1 experimental vehicle
- 135 missions
- Retired in 2011
- *Challenger* and *Columbia* losses

Pilot-Induced Oscillations

Uncommanded aircraft is stable but piloting actions couple with aircraft dynamics to produce instability
Space Shuttle Crew Compartment

- Flight deck
- Middeck
- Lower level equipment bay
- Airlock

Space Shuttle: Spacelab Module

- Modular space station supplied by ESA
  - Spacelab module provides main laboratory
  - Spacelab pallet provides mounting base for experiments
  - Instrument pointing system
  - Tunnel to lower deck
  - Pressurized “igloo” for pallet-only missions
- Components flown on 25 Space Shuttle missions
Space Stations: Skylab

- On orbit from 1973 to 1979
- 77,088 kg
- Station based on refined S-IVB stage
- Launched on modified Saturn V
- Damaged during launch
- Two of 3 crews commanded by Princeton alums
  - 1973: “Pete” Conrad, ’53
  - 1973: Gerald Carr, ’62

Charles “Pete” Conrad, ’51
(1930-1999)
Space Stations: Skylab

Russian Space Stations

- 6 stations successfully orbited
- 31 crews launched to stations
International Space Station

http://iss.astroviewer.net/

• 4 laboratory modules orbited, 3 to follow
• ESA viewing cupola scheduled for 2009
• Docking cargo module scheduled for 2010
Today’s ISS Sighting Time

Sighting Location

Location: Princeton, New Jersey, United States

The following ISS sightings are possible from Friday Apr 15, 2016 through Sunday May 1, 2016

<table>
<thead>
<tr>
<th>Date</th>
<th>Visible Max Height</th>
<th>Appears</th>
<th>Disappears</th>
<th>Share Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fri Apr 15, 9:29 PM</td>
<td>2 min 45°</td>
<td>21° above WNW</td>
<td>45° above SW</td>
<td>[ ]</td>
</tr>
<tr>
<td>Sat Apr 16, 8:37 PM</td>
<td>3 min 86°</td>
<td>35° above NW</td>
<td>20° above SE</td>
<td>[ ]</td>
</tr>
<tr>
<td>Sun Apr 17, 9:21 PM</td>
<td>2 min 18°</td>
<td>13° above W</td>
<td>17° above SSW</td>
<td>[ ]</td>
</tr>
<tr>
<td>Mon Apr 18, 8:29 PM</td>
<td>4 min 36°</td>
<td>27° above W</td>
<td>10° above SSW</td>
<td>[ ]</td>
</tr>
<tr>
<td>Wed Apr 20, 8:21 PM</td>
<td>3 min 15°</td>
<td>13° above WSW</td>
<td>10° above SSW</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

Space Station Regenerative ECLSS Flow Diagram (Current Baseline)
ExtraVehicular Activity

- Manned Maneuvering Unit included
  - Cold-gas attitude and translational control system (24 thrusters)
  - Astronaut hand controls
  - Used until 1986 Challenger accident
- Extravehicular Mobility Unit provides life support
- SAFER: simplified MMU for rescue

Soyuz Spacecraft and Launch Vehicle

- Orbital, reentry, and service modules
- Spinoff from Soviet manned lunar program
- 3-person crew
- Apollo-Soyuz at NASM
Orion Crew Vehicle

- Command Module (reusable)
- Service Module (expendable)
- 4-6 crew members

Orion/Ares vs. Space Shuttle

<table>
<thead>
<tr>
<th></th>
<th>Orion</th>
<th>Space Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload to LEO, kg</td>
<td>1,000 (est)</td>
<td>24,400</td>
</tr>
<tr>
<td>Payload from Orbit, kg</td>
<td>Neg.</td>
<td>12,700</td>
</tr>
<tr>
<td>Crew + Passengers</td>
<td>6</td>
<td>8 (11)</td>
</tr>
<tr>
<td>Reentry Cross-Range Capability, km</td>
<td>30</td>
<td>2,010</td>
</tr>
<tr>
<td>EVA Capability</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
US and Foreign Manned Spacecraft

- NASA Orion
- SpaceX Dragon
- Blue Origin CST-100
- Russian Soyuz
- Chinese Shenzhou
- Indian Concept

Space Tourism

- SpaceShipTwo
- New Shepard
- British Ascender
- EADS Spaceplane
SpaceShipOne

Flown above 100 km twice in 2 weeks in 2004 to win the Ansari X-Prize.

Princeton SpaceShipOne Test Pilot and Astronaut

- Brian Binnie, MAE, MSE ’78, exceeded M1.2 in 60-deg climb on December 17, 2003, 100th anniversary of the Wright Brothers first flight

- Brian won Ansari X-Prize and astronaut wings by flying to 367,442-ft altitude and broke X-15 record on October 4, 2004.
Colonization of the Moon and Planets

https://en.wikipedia.org/wiki/Space_colonization

... or L4 or L5

Bernal Sphere, 1929

O’Neill Cylinders, 1975
Next Time:
System Engineering and Integration