Cardiopulmonary Physiology

• Discussion of the project for the Physiology section
• The cardiovascular system
• Gravitational effects
• Acceleration effects
• G-induced loss of consciousness
• The pulmonary system
• Oxygen transport
• Effects of altitude
• Cabin depressurization
Space Physiology Assignment

• This unit covers six topics
  – Cardiopulmonary system
  – Musculoskeletal system
  – Neurovestibular system
  – Decompression
  – Radiation effects
  – Thermal regulation

• Find papers relevant to human space flight in two of these areas

• Post the papers and a one-page synopsis of each to the Canvas site for this course

• No duplications! (It’s good to do this early.)

• Due Feb. 13
Blood Pressure in Circulatory System
Gas Exchange in the Lungs

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Gas Exchange in the Tissues

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Gravity Effects on Arterial Pressure

120/80 mmHg

95/55 mmHg

320 mm

120/80 mmHg

1200 mm

1000 mmH₂O = 74.1 mmHg

210/170 mmHg
The Human Circulatory System, Revisited

Muscle contracts
Valve closed

Muscle relaxes
Valve open

Valve open

Valve closed

Blood propelled forward by muscle contractions and, possibly, by gravity

Back pressure due to contractions of atria, contractions of muscles, and, possibly, gravity
Cardiovascular Regulatory System
In-Flight Change in Leg Volume
In-Flight Change in Body Mass
Change in Leg Volume (Skylab)
Lower Body Negative Pressure (LBNP)
Cardiovascular Effects of Microgravity

- Cardiovascular deconditioning
- Upper body blood pooling
- Changes in blood volume
- Increased calcium content
Acceleration Effects on Arterial Pressure

At 4 g’s longitudinal:

1000 mmH\textsubscript{2}O = 296 mmHg
Inertial Acceleration Nomenclature

\(+g_x\) (forward) “transverse anterior-posterior G”, “supine G”, “eyeballs in”

\(-g_x\) (rearward) “transverse P-A G”, “prone G”, “eyeballs out”

\(+g_z\) (headward) “positive G”, “eyeballs down”

\(-g_z\) (footward) “negative G”, “eyeballs up”

\(+g_y\) (to left) “right lateral G”, “eyeballs right”:

\(-g_y\) (to right) “left lateral G”, “eyeballs left”
Tolerance to Sustained Acceleration

![Graph showing data on tolerance to sustained acceleration](image)
Variation in G Tolerance

F-16 seat orientation, gradual onset, no G-suit
G Tolerance to ACM (PLL Criteria)
Sustained Linear G Limits (+Gx)
Sustained Linear G Limits (-Gx)

Crew Loads Limits
for sustained or short term plateau accelerations

-\( G_x \) Eye Balls Out

Limit for Abort or Emergency Entry
Limit for Launch to Mission Destination
Limit for Return to Earth

Acceleration (g/s)

Duration (sec)

sustained
Sustained Linear G Limits (+Gz)
Sustained Linear G Limits (-Gz)

Crew Loads Limits
for sustained or short term plateau accelerations

Limit for Abort or Emergency Entry
- Limit for Launch to Mission Destination
- Limit for Return to Earth

- Acceleration (g/s)
- Duration (sec)
Symptomatology of GLOC

A. G/ sec rate of onset
B. Asymptomatic (eye/brain tissue reserves)
C. GLOC
D. Blackout
E. Light loss
F. Asymptomatic (vasoconstriction)
The Human Respiratory System
Lung Measurements

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Respiratory Volume vs. Exertion

- All values are average values. There is considerable variation between individuals.
- STPD means standard temperature and pressure, dry gas.
- For oxygen cylinder endurance and helmet ventilation calculations, the numbers should be multiplied by 1.08 to yield engineering STPD.
- STPS means steady-state temperature and pressure, saturated with water vapor at body temperature. For non-steady-state endurance calculations, the value should be multiplied by 0.90 to give corresponding values for dry gas at 70°F. The 0.90 factor ignores differences in the water vapor content between dry and saturated gas, but this is very small at most working depths.

* Swimming, 1.2 knots (2.5, 80) (Note 2)
* Running, 6 mph (2.0, 50)
* Max Walking Speed, Mud Bottom (1.8, 40)
* Max Walking Speed, Hard Bottom (1.5, 34)
* Swimming, 0.05 knot (avg. speed) (1.4, 30)
* Walking, 4 mph (1.2, 27)
* Slow Walking on Mud Bottom (1.1, 23)
* Swimming, 0.5 knot (avg. speed) (1.0, 18)
* Walking, 2 mph (0.7, 16)
* Slow Walking on Hard Bottom (0.6, 13)
* Standing Still (0.4, 10)
* Sitting (0.3, 7)
* Bed Rest (Baran) (0.25, 6)
VO2 Metabolic Workload Measurement
VO2 Measurement in (Simulated) Suit
Metabolic Processes

• Respiratory Quotient ("RQ")

\[
RQ = \frac{\text{Exhaled volume of } CO_2}{\text{Inhaled volume of } O_2}
\]

• Function of activity and dietary balance
  – Sugar: \[C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad (RQ = 1.0)\]
  – Protein: \[2C_3H_7O_2N + 6O_2 \rightarrow 5CO_2 + 5H_2O \quad (RQ = 0.83)\]
  – Fat: \[C_{57}H_{104}O_6 + 80O_2 \rightarrow 57CO_2 + 52H_2O \quad (RQ = 0.71)\]

• For well-balanced diet, RQ~0.85
Gas Exchange in the Lungs

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Gas Exchange in the Tissues

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
<table>
<thead>
<tr>
<th>Respiratory Gas</th>
<th>ppO2</th>
<th>ppCO2</th>
<th>ppN2</th>
<th>ppH2O</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Inspired Air</td>
<td>159</td>
<td>0.3</td>
<td>595</td>
<td>5.7</td>
<td>760</td>
</tr>
<tr>
<td>Tracheal Air</td>
<td>149</td>
<td>0.3</td>
<td>563.7</td>
<td>47</td>
<td>760</td>
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<tr>
<td>Expired Air</td>
<td>116</td>
<td>32</td>
<td>565</td>
<td>47</td>
<td>760</td>
</tr>
<tr>
<td>Alvolar Air</td>
<td>100</td>
<td>40</td>
<td>573</td>
<td>47</td>
<td>760</td>
</tr>
<tr>
<td>Arterial Blood</td>
<td>95</td>
<td>40</td>
<td>573</td>
<td>47</td>
<td>755</td>
</tr>
<tr>
<td>Venous Blood</td>
<td>40</td>
<td>46</td>
<td>573</td>
<td>47</td>
<td>706</td>
</tr>
<tr>
<td>Tissues</td>
<td>≤40</td>
<td>≥46</td>
<td>573</td>
<td>47</td>
<td>≤706</td>
</tr>
</tbody>
</table>
Respiratory Problems

• Hypoxia
  – Hypoxic
  – Hypemic
  – Stagnant
  – Histotoxic

• Hyperoxia

• Hypocapnia

• Hypercapnia
Types of Hypoxia

- Hypoxic (insufficient O₂ present)
  - Decompression
  - Pneumonia
- Hypemic (insufficient blood capacity)
  - Hemorrhage
  - Anemia
- Stagnant (insufficient blood transport)
  - Excessive acceleration
  - Heart failure
- Histotoxic (insufficient tissue absorption)
  - Poisoning
# Effects of Altitude on Respiration

<table>
<thead>
<tr>
<th></th>
<th>Altitude (m)</th>
<th>SL</th>
<th>3700</th>
<th>5500</th>
<th>6700</th>
<th>7600</th>
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</thead>
<tbody>
<tr>
<td>Volumetric Rate (L/min)</td>
<td>8.5</td>
<td>9.7</td>
<td>11.1</td>
<td>15.3</td>
<td>–</td>
<td></td>
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<tr>
<td>Respiratory Rate (per minute)</td>
<td>12</td>
<td>14</td>
<td>12</td>
<td>15</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Tidal Volume (L)</td>
<td>0.71</td>
<td>0.69</td>
<td>0.92</td>
<td>1.02</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Alveolar ppO2</td>
<td>103</td>
<td>54.3</td>
<td>37.8</td>
<td>32.8</td>
<td>30.4</td>
<td></td>
</tr>
<tr>
<td>Alveolar ppCO2</td>
<td>40</td>
<td>33.8</td>
<td>30.4</td>
<td>28.4</td>
<td>27</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Altitude (ft)</th>
<th>SL</th>
<th>12,000</th>
<th>18,000</th>
<th>22,000</th>
<th>25,000</th>
</tr>
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<td>27</td>
<td></td>
</tr>
</tbody>
</table>
Pressure Effects on Blood Oxygenation

Example 1

Sea Level

Alveolus $P_{O_2} = 100$ mm Hg
Pressure Gradient = 60 mm Hg
Arterial Percent Saturation = 98%

Example 2

3048 Meters (10,000 Feet)

Alveolus $P_{O_2} = 60$ mm Hg
Pressure Gradient = 29 mm Hg
Arterial Percent Saturation = 87%

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Pressure Effects on Blood Oxygenation

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Blood Oxygen Saturation with Altitude
Hypoxia Effective Performance Time

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Effects of Supplemental Oxygen

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
## Effective Performance Time at Altitude

<table>
<thead>
<tr>
<th>Altitude, m</th>
<th>Altitude, ft</th>
<th>Effective Performance Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>5500</td>
<td>18,000</td>
<td>20-30 minutes</td>
</tr>
<tr>
<td>6700</td>
<td>22,000</td>
<td>10 minutes</td>
</tr>
<tr>
<td>7600</td>
<td>25,000</td>
<td>3-5 minutes</td>
</tr>
<tr>
<td>8500</td>
<td>28,000</td>
<td>2.5-3 minutes</td>
</tr>
<tr>
<td>9100</td>
<td>30,000</td>
<td>1-2 minutes</td>
</tr>
<tr>
<td>10,700</td>
<td>35,000</td>
<td>0.5-1 minute</td>
</tr>
<tr>
<td>12,200</td>
<td>40,000</td>
<td>15-20 seconds</td>
</tr>
<tr>
<td>13,100</td>
<td>43,000</td>
<td>9-12 seconds</td>
</tr>
<tr>
<td>15,200</td>
<td>50,000</td>
<td>9-12 seconds</td>
</tr>
</tbody>
</table>
Vacuum Chamber Suit Failure (1968)

https://www.youtube.com/watch?v=KO8L9tKR4CY
Oxygen Toxicity

From Roy DeHart, Fundamentals of Aerospace Medicine, Lea & Febiger, 1985
Effects of ppCO₂ (Hypercapnia)

Acute Effects of Hyperventilation