Cardiopulmonary Physiology

• Discussion of the term project(s)
• The cardiovascular system
• Gravitational effects
• Acceleration effects
• G-induced loss of consciousness
• The pulmonary system
• Oxygen transport
• Effects of altitude
Space Physiology Assignment

• This unit covers five topics
  – Cardiopulmonary system
  – Musculoskeletal system
  – Neurovestibular system
  – Decompression
  – Radiation effects

• 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. 15
The Human Circulatory System

Arterial Network:
- Heart
- Aorta
- Pulmonary artery
- Systemic arteries
- Branches to organs
- Peripheral arteries
- Capillaries

Vein Network:
- Heart
- Atria
- Vena cava
- Systemic veins
- Portal veins
- Hepatic veins
- Inferior vena cava
- Superior vena cava

Muscle contracts
Valve closed
Muscle relaxes
Valve open
Blood propelled forward by muscle contractions and, possibly, by gravity
Back pressure due to contractions of atria, contractions of muscles, and, possibly, gravity
Blood Pressure in Circulatory System

![Diagram of blood pressure and blood flow through the circulatory system, showing the transition from large arteries to small arteries, arterioles, capillaries, venules, and veins, with corresponding changes in blood pressure and velocity.](image)
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

Cardiovascular System Diagram

- Doppler sound (cholesterol plaque)
- Carotid Artery
- Jugular Vein
- Cephalic Vein
- Axillary Artery and Vein
- Superior Vena Cava
- Ascending Aorta
- Pulmonary Trunk
- Celiac Artery
- Renal Artery and Vein
- Superior Mesenteric Artery
- Portal Vein
- Radial Artery and Vein
- Ulnar Artery and Vein
- Inferior Vena Cava
- Abdominal Aorta
- Ultrasound image (aneurysm)
- Peroneal Artery
- Tibial Vein
- Subclavian Artery and Vein
- Pulmonary Arteries and Veins
- Coronary Arteries
- Common Iliac Artery and Vein
- Internal Iliac Artery and Vein
- External Iliac Artery and Vein
- Great Saphenous Vein
- Femoral Artery and Vein
- Popliteal Artery and Vein
- Anterior Tibial Artery
- Posterior Tibial Artery
- Coronary angiogram (atherosclerotic plaque)

Pressure Levels:
- 95/55 mmHg (320 mm)
- 120/80 mmHg (1200 mm)
- 210/170 mmHg

1000 mmH$_2$O = 74.1 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

![Graph showing change in leg volume over flight time]

- Change from preflight, %
- Flight time, days

Values indicated on the graph represent specific days during the flight.
In-Flight Change in Body Mass

![Graph showing change in body mass over flight time in days](image-url)
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 mmH₂O = 296 mmHg

120/80 mmHg
25/- mmHg
475/435 mmHg
320 mm
1200 mm
475/435 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 points and lines indicating different G forces and durations.]

- T = 2666e, -1.265G
- T = 14.08e, -0.328G

Symbols and annotations:
- △ = SAM STUDY
- AL = ARBITRARY LIMITS
- • = ANTI-G SUIT
- ○ = NO ANTI-G SUIT
- Δ = ESTIMATED (WITH ANTI-G SUIT)
Variation in G Tolerance

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

Crew Loads Limits for sustained or short term plateau accelerations

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

Acceleration (g/s) vs Duration (sec)

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

Graph showing 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**

**Axes:**
- **Y-axis:** Acceleration (g/s)
- **X-axis:** Duration (sec)

**Legend:**
- **+Gz Eye Balls Down**

**Note:**
- Sustained accelerations are indicated.
Sustained Linear G Limits (-Gz)

Crew Loads Limits for sustained or short term plateau accelerations

- Gz  Eye Balls Up

Acceleration (g/s)

Duration (sec)

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

sustained
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

Notes:
1. All figures are average values. There is considerable variation between individuals.
2. STPD means “standard temperature and pressure, dry gas.” As given here it is medical STPD (i.e., 32°F, 1 ata, dry gas). For oxygen cylinder endurance or helmet ventilation calculations, the numbers should be multiplied by 1.08 to yield engineering STPD.
3. BTPS means “body temperature (98.6°F), ambient barometric pressure, saturated with water vapor at body temperature.” For open-circuit scuba endurance calculations, this value should be multiplied by 0.95 to give corresponding values for dry gas at 70°F. The 0.95 factor ignores difference in the water vapor content between dry and saturated gas, but this is very small at most diving depths.
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:** \( C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \) \( (RQ = 1.0) \)
  
  - **Protein:** \( 2C_3H_7O_2N + 6O_2 \rightarrow 5CO_2 + 5H_2O \) \( (RQ = 0.83) \)
  
  - **Fat:** \( C_{57}H_{104}O_6 + 80O_2 \rightarrow 57CO_2 + 52H_2O \) \( (RQ = 0.71) \)

- **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
### Partial Pressures of Gases in Respiration

<table>
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<th>Respiratory Gas</th>
<th>ppO2</th>
<th>ppCO2</th>
<th>ppN2</th>
<th>ppH2O</th>
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<td>0.3</td>
<td>595</td>
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<td>760</td>
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<td>755</td>
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<td>573</td>
<td>47</td>
<td>706</td>
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<tr>
<td>Tissues</td>
<td>≤40</td>
<td>≥46</td>
<td>573</td>
<td>47</td>
<td>≤706</td>
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