Abstract:

Behavior of equipment when flown to the edge of space can vary dramatically from what is observed on the ground, so we set out to build a facility we could use to simulate the pressure extremes experienced in such a flight.

Our goals were to design and build a portable system with a large and easy-to-access chamber that could reach high vacuum pressure, using both a mechanical and diffusion pump. We wanted to use primarily surplus and hand-made parts, using as few purchased parts as possible. We also wanted to build a system that could obtain significantly higher vacuum levels than needed for flight testing so that it could also be used for semiconductor and other material science research.

There are a wide variety of issues that can cause problems in a system this highly sensitive. There are several strategies used to avoid, detect, and solve these problems. We successfully constructed a system that has been, and will continue to be, used in a wide variety of other student research projects.

Defining Vacuum

<table>
<thead>
<tr>
<th>Class</th>
<th>Pressure (Torr)</th>
<th>Fraction of STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rough Vacuum</td>
<td>750 – .75</td>
<td>1/1000</td>
</tr>
<tr>
<td>Medium Vacuum</td>
<td>.75 – 7.5x10^-5</td>
<td></td>
</tr>
<tr>
<td>High Vacuum</td>
<td>7.5x10^-7 – 7.5x10^-10</td>
<td>1/10 quadrillionth</td>
</tr>
<tr>
<td>Ultra High Vacuum</td>
<td></td>
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</tbody>
</table>

STP – 1.0 atm. = 1.01x10^5 Pa = 1.01 bar = 760 Torr

Deep Space ranges between 10^-8 to 10^-10 Torr.

High-Altitude Research Balloons range between 760 to 0.8 Torr.

Particles in a Vacuum

- Air = 78% Nitrogen, 21% Oxygen
- Rough Vacuum = 10^-8 to 10^-2 Torr molecules per cubic cm
- High Vacuum = 10^-2 to 10^-4 Torr molecules per cubic cm

Note: If molecules were to stick to a surface, using kinetic theory of a gas, at10^-4 Torr it takes 1 second to cover a surface with contaminating gas... it would take 100 seconds at 10^-6 Torr.

Mean Free Path

\[ \ell = \frac{1}{\sqrt{2PNa^2}} \]

When the mean free path is large, normal fluid dynamics breaks down. This changes the Pumping behavior of a gas.

Ideal Gas Law

\[ P = \frac{nRT}{V} \]

- Assume particles have no volume
- Assume no intermolecular forces

Virtual Leaks

A virtual leak behaves like a normal leak to the system, but there are no leaks to outside air. Virtual leaks can be very difficult to detect. Sources include:

- Bolt holes
- Finger prints
- Equipment outgassing
- Water vapor

A 1/16" inch gap in the bottom of a 1/4 inch hole contains approximately 0.6 Torr-liter of gas (equivalent to 6x10^-3 Torr in a 100 liter chamber).

A single fingerprint can outgas 10^-5 Torr-liters/sec.

Particles in a Vacuum

- Chemical Makeup of Air
  - N2: 78.08% 
  - O2: 20.95% 
  - Ar: 0.93% 
  - CH4: 1.8x10^-4% 
  - CO2: 5.0x10^-8% 
  - char: 5.24x10^-6% 
  - H2O: 1.1x10^-10% 
  - Xe: 3.5x10^-13% 

- Note: If molecules were to stick to a surface, using kinetic theory of a gas, at10^-4 Torr it takes 1 second to cover a surface with contaminating gas... it would take 100 seconds at 10^-6 Torr.

Oil Comparisons

Motor oil - Vapor Pressure = 0.88 Torr

- D6 for 1 liter

Mechanical pump oil – VP = 10^-6 Torr

$65$ for 1 gallon

Our Diffusion pump oil – VP = 6.65x10^-10 Torr (max vacuum = 3.99x10^-7) $125$ for 500cc

Diffusion pump oil – VP = 6.65x10^-10 Torr $890$ for 500cc $8,365$ for 1 gallon

Acknowledgements:
This project was funded by the Val A. Browning Foundation and the Weber State University Department of Physics.