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 – 7.5×10⁻⁶</td>
<td>1/100,000</td>
</tr>
<tr>
<td>High Vacuum</td>
<td>7.5×10⁻⁶ – 7.5×10⁻¹⁰</td>
<td>1/10 quadrillionth</td>
</tr>
</tbody>
</table>

STP – 1.0 atm. = 1.01×10⁵ Pa = 1.01 bar = 760 Torr

Deep Space ranges between 10⁶ to 10¹⁰ Torr. High-Altitude Research Balloons range between 760 to 0.8 Torr.

Particles in a Vacuum

- Air = 78% Nitrogen, 21% Oxygen
- Rough Vacuum = 10⁶ to 10⁸ Torr
- High Vacuum = 10⁻⁶ to 10⁻¹⁰ Torr

Note: If molecules were to stick to a surface, using kinetic theory of a gas, at 10⁶ Torr it takes 1 second to cover a surface with contaminating gas... it would take 100 seconds at 10⁻⁶ Torr.

Mean Free Path

\[ \ell = \frac{1}{\sqrt{2PN}} \]

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
- Assume particles have no volume

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 1/16th inch gap in the bottom of a 1/4 inch hole contains ≈0.6 Torr-liters of gas (equivalent to 6×10⁻³ Torr in a 100 liter chamber).

A single fingerprint can outgas 10⁻⁴ Torr-liters/sec.

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