You’ll Fly Sensors on Your Rockets

• Also, you need them in your work

http://thehauntedrocket.tumblr.com/post/135268424227/marsvikings-the-viking-lander-is-a-superbly
Motivating Question

• What kind of altimeters are suitable for our big flight?
• How are we going to answer that question?
Isn’t Sensors a Super Broad Topic?
A Disciplined Way to Consider Sensors

• Static Performance

• Dynamic Performance

• Interface and Readout

• Physics Sanity Checks
Static Performance Summarized in a Graph

- Reported Quantity (e.g., voltage)
- Sensed Quantity (e.g., temperature)
- Offset
- Max Output
- Linearity
- Full Scale Range
- Max Input
- Sensed Quantity (e.g., temperature)
Digitized Sensor Output has Same Properties

![Diagram showing the concept of linearity in digitized sensor output. The y-axis represents code values from $2^N$ to 1, and the x-axis represents input quantity (usually voltage). The diagram illustrates how the output changes in steps, indicating linearity.]
Calibration Can Fix Offset and Non-Linearity

• Fixes non-linearity and offset.

• Doesn’t fix noise. Can only fix noise with more power / less loss.

• Difficult to calibrate in production settings: time is money

• Be careful of time-variance. Fancy sensors have online calibration.
Resolution Varies w/ Input if Very Non-linear

Big input swing $\rightarrow$ small output
Susceptible to output noise

Higher gain here
Dynamic Performance is Described by E59

**NTC Thermistors, Radial**

**QUICK REFERENCE DATA**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance value at 25 °C</td>
<td>3.3 Ω to 470 kΩ</td>
</tr>
<tr>
<td>Tolerance on $R_{25}$ value</td>
<td>± 2 %, ± 3 %, ± 5 %</td>
</tr>
<tr>
<td>$B_{25/85}$ value</td>
<td>2880K to 4570K</td>
</tr>
<tr>
<td>Tolerance on $B_{25/85}$ value</td>
<td>± 0.5 % to ± 3 %</td>
</tr>
<tr>
<td>Maximum dissipation</td>
<td>500 mW</td>
</tr>
<tr>
<td>Dissipation factor $\delta$</td>
<td>7 mW/K, 8.5 mW/K (for $R_{25}$ value ≤ 680 Ω)</td>
</tr>
<tr>
<td>Response time (in oil)</td>
<td>≈ 1.2 s</td>
</tr>
<tr>
<td>Thermal time constant $\tau$</td>
<td>15 s</td>
</tr>
</tbody>
</table>

**FREQUENCY RESPONSE CURVE**

http://www.vishay.com/sensors/sensors-temperature/ntc/  
https://www.adafruit.com/datasheets/CMA-4544PF-W.pdf
Sensor Interfaces – Analog

- Use a buffer if Req is big
- Apply gain or offset if Voc is small or centered at an odd voltage
- Probably need to digitize the analog output to record it
Sensor Interfaces – Digital

• Voltage Levels
• Serial vs. Parallel
• If Serial, what is the protocol?

Physics Sanity Check

- Make sure you’re measuring what you think you’re measuring
- Check magnitude and phenomenology
Apply Sensors Checklist to the Theodolite
Apply Sensors Checklist to the Theodolite

• Physics: pendulum points down and user points at rocket.

• Second order system calculation $\omega_0 = \sqrt{\frac{g}{l}} = \sqrt{\frac{9.8}{0.1}} \approx 10 \text{ rad/s}$. Flights take 2-3 seconds before apogee.

• ~90 notches: 1/degree. I can’t aim to 1 degree.

• Readout is manual / mechanical. Slow, but launches slower
Apply the Sensors Checklist to an Altimeter

MPXA6115AC7U

### Table 1. Operating Characteristics (V$_D$ = 5.0 Vdc, T$_A$ = 25°C unless otherwise noted, P$_1$ > P$_2$)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Range</td>
<td>P$_{OP}$</td>
<td>15</td>
<td>—</td>
<td>115</td>
<td>kPa</td>
</tr>
<tr>
<td>Supply Voltage$^{(1)}$</td>
<td>V$_S$</td>
<td>4.75</td>
<td>5.0</td>
<td>5.25</td>
<td>Vdc</td>
</tr>
<tr>
<td>Supply Current</td>
<td>I$_S$</td>
<td>—</td>
<td>6.0</td>
<td>10</td>
<td>mA</td>
</tr>
<tr>
<td>Minimum Pressure Offset$^{(2)}$</td>
<td>V$_{ref}$</td>
<td>0.133</td>
<td>0.200</td>
<td>0.268</td>
<td>Vdc</td>
</tr>
<tr>
<td>@ V$_S$ = 5.0 Volts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Scale Output$^{(2)}$</td>
<td>V$_{FSS}$</td>
<td>4.633</td>
<td>4.700</td>
<td>4.768</td>
<td>Vdc</td>
</tr>
<tr>
<td>@ V$_S$ = 5.0 Volts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Scale Span$^{(4)}$</td>
<td>V$_{FSS}$</td>
<td>4.433</td>
<td>4.500</td>
<td>4.568</td>
<td>Vdc</td>
</tr>
<tr>
<td>@ V$_S$ = 5.0 Volts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy$^{(5)}$ (0 to 85°C)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>±1.5</td>
<td>%V$_{FSS}$</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>V/IP</td>
<td>—</td>
<td>45.0</td>
<td>—</td>
<td>mV/kPa</td>
</tr>
<tr>
<td>Response Time$^{(6)}$</td>
<td>t$_R$</td>
<td>—</td>
<td>1.0</td>
<td>—</td>
<td>ms</td>
</tr>
<tr>
<td>Warm-Up Time$^{(7)}$</td>
<td>—</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>ms</td>
</tr>
<tr>
<td>Offset Stability$^{(8)}$</td>
<td>—</td>
<td>—</td>
<td>±0.25</td>
<td>—</td>
<td>%V$_{FSS}$</td>
</tr>
</tbody>
</table>

- Information pulled from datasheet
- Asking: “Would this work for the final flight?”
Physics Check: Get Altitude from Air Pressure

- Need a model of air pressure and a model of our flight
Find Model of Troposphere in 2015 Lecture

\[ h = \frac{T_0}{-(dT/dh)} \left[ 1 - \left( \frac{P}{P_0} \right)^{-\frac{(dT/dh)}{gM}} \right] \]

where
- \( h \) = geopotential altitude (above sea level) (in meters)
- \( P_0 \) = standard atmosphere pressure = 101325Pa
- \( T_0 \) = 288.15K (+15°C)
- \( dT/dh = -0.0065 \) K/m: thermal gradient or standard temperature lapse rate
- \( R = 8.31432 \) Nm/mol K (Current NIST value 8.3144621)
- \( g = 9.80665 \) m/s²
- \( M = 0.0289644 \) kg/mol

(Originally from 1976 Standard Atmosphere Model)

• Be sure to use all resources at your disposal so we can help you!
• Be sure to attribute everything you use. (Thanks, Prof. Spjut!)
Find Arreaux Flight Models

• Apogee is
  • 1 mile AGL
  • At 15s

• Velocity
  • Is ~330 ft/s
  • (~100 m/s)

• Launch at 3000 ft. MSL
Static Properties

• $P_{\text{launch}} = 90\text{kPa}$, $P_{\text{apogee}} = 74\text{kPa}$

• Add -13% to +7% for Barometric pressure $\rightarrow$ range is 64kPa – 104kPa

• Accuracy +/- 1.5% Vfs and range is 4.5V representing 100kPa
  • +/- 0.157 kPa, +/- 157m. Resolution OK? Depends on needs.

• Result is non-linear b/c of exponential pressure model. Calibrate.
Dynamics

• Response time (10%-90% rise time) is 1.2ms → $\tau = 0.46\text{ms}$
• Velocity is $330\text{ ft/s} = 0.33\text{ ft/ms} = 10\text{cm/ms}$

$\tau=1$ and DC gain = 1 in this example
Interface – Analog output

• Need to measure Zout, datasheet says little. (How?)

• Expect to get 675 mV of swing on top of 200 mV offset. (Fixable?)
Interface – Digitizing With the Data Logger

- 16 analog channels: 16 bit, 2.2 kOhm Zin, sampled at 12.5 kHz
- 3.3 V supply and full scale input range.
- Saves to on board SD card.
Interface – Data Loggers and Digital Sensors


CLOCK 1

Connect
Synchronizing
Signal

CLOCK 2

Figure 1. MuddLogg16 v3 PCB layout.
Interface – Be Careful of Your Power System

Voltages cannot be negative!

Battery has ~250 mA-hrs energy

Separate batteries for high power subsystems
Final Project Ideas

• Science Measurements (measure stuff around the rocket)
  • Atmosphere: Particles, chemicals, flow rate, humidity, material phases, charge
  • Radiation: UV, IR, any optical frequencies, gamma rays, etc.
  • Multimedia: sounds, images, video

• Engineering Measurements (measure stuff about the rocket)
  • Flight: rotation, acceleration, vibration, displacement, orientation, flow rate
  • Electrical: power consumption, voltages, capacitances, inductances

• Don’t forget that you often need a way to get airflow over sensors
Where do I find More Sensors?

• Digikey demonstration

• Last year’s lecture has a deeper dive into a few datasheets.
  • MQ-2 Methane gas sensor (requires heater)
  • GP2Y1010AF Particle sensor (requires pulse signal, could roll your own)
  • A few humidity sensors (capacitive sensors require cool readout circuits!)