HARVEY MUDD COLLEGE

Engineering 80 – Spring 2016

Flight Hardware

A "ONE-PAGER"…

- **Problem Statement (or Purpose, or Goal)**
  - The final E80 project needs to be completed to pass the course
- **Success Criteria (envision successfully crossing the finish line)**
  - Submit a final report and give a presentation about your E80 rocket flights (e.g. results of the flight, comparison of data with modeling)
- **Strategies (how are you going to get to that finish line?)**
  - Work as a team to meet all weekly project deliverables
- **Timeline (detailed plan for implementing the strategies)**

Sample Timeline for **Section 2**

TASK	Start	End	Status
Meet Week 1 Deliverables (Propose & Design)	3/10/2016	3/23/2016	In Progress
Meet Week 2 Deliverables (Breadboard & Test)	3/24/2016	3/30/2016	Not Started
Meet Week 3 Deliverables (PC Board & Test)	3/31/2016	4/6/2016	Not Started
Meet Week 4 Deliverables (Build, Test, & Launch)	4/7/2016	4/16/2016	Not Started
Meet Week 5 Deliverables (Rebuild, Retest, & Relaunch)	4/14/2016	4/23/2016	Not Started
Meet Week 6 Deliverables (Prepare Report & Presentation)	4/21/2016	5/4/2016	Not Started
Submit Report and Give Final Presentation	5/4/2016	5/4/2016	Not Started

Today We Will Discuss…

- E80 Rocket Requirements
- Surviving Launch and Recovery
- Rocket Construction
- Deliverables

E80 Engineering Rocket Requirements

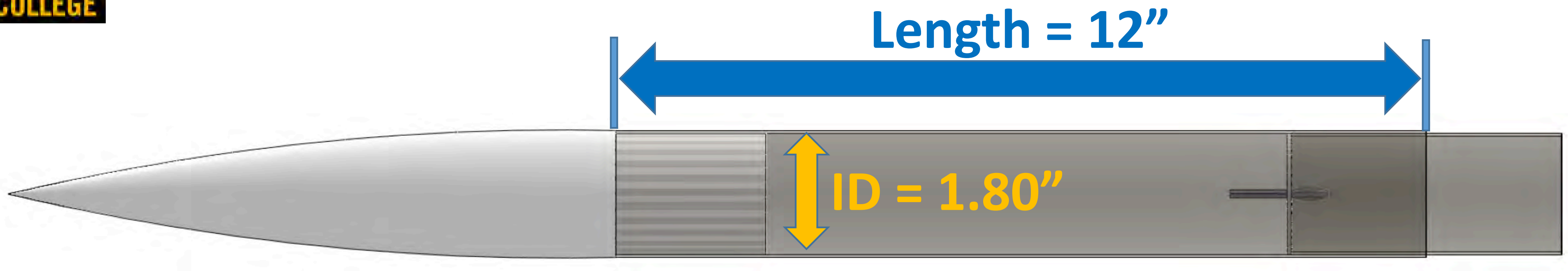
- Payload Dimensions
- Sensor Requirements
- Speed of Response
- Power Requirements
- Acceleration, Shock, and Vibration
- Temperature Profile
- Construction Standards

Your Rocket

SOURCE: http://www.jcrocket.com/images/arreaux/arreauxlogorocket.jpg

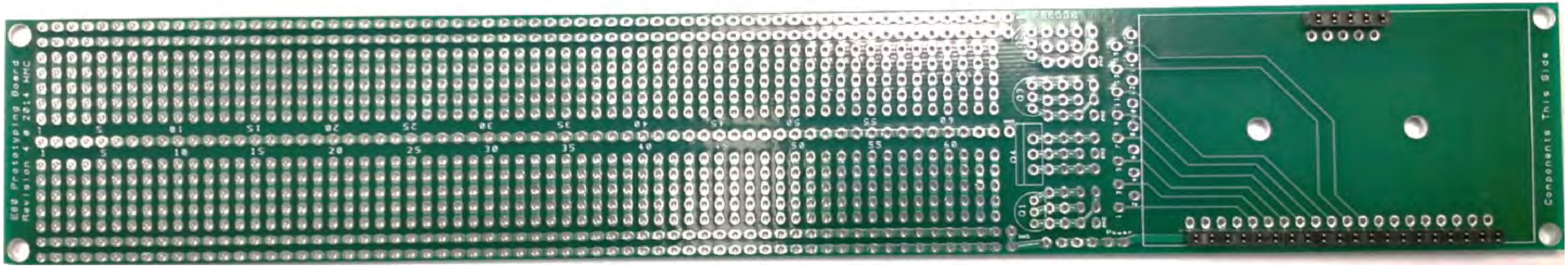
- You will be assigned an…
  - Aerotech Arreaux <.rkt> <.ork> <.zip>
    - Payload Section ID: 1.80 inches
    - Payload Section Length: **12.00 inches**

Payload Dimensions



- You will be assigned an…
  - Aerotech Arreaux <.rkt> <.ork> <.zip>
    - Payload Section ID: 1.80 inches
    - Payload Section Length: **12.00 inches**

Your Precious Payload – The PC Board

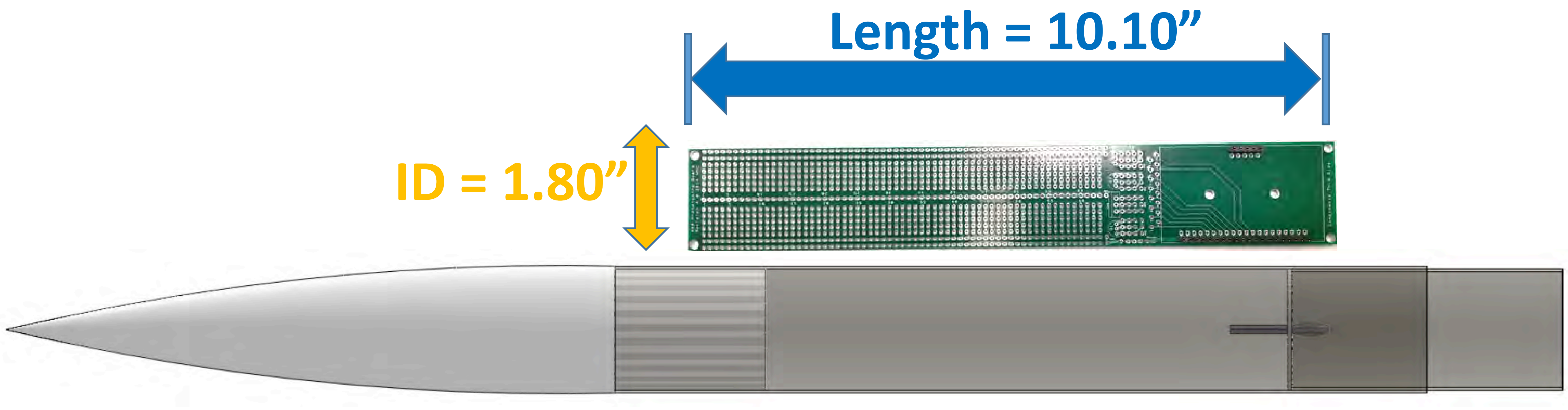


- Top laid out like your protoboard
  - 4 exterior buses slightly closer
  - 1 extra power bus
- Bottom has connectors for a data logger
- 4 Holes for mounting
- 2 holes for mounting battery holder

If it works on your protoboard, then it will work on the PC Board
Chip for Chip
Wire for Wire

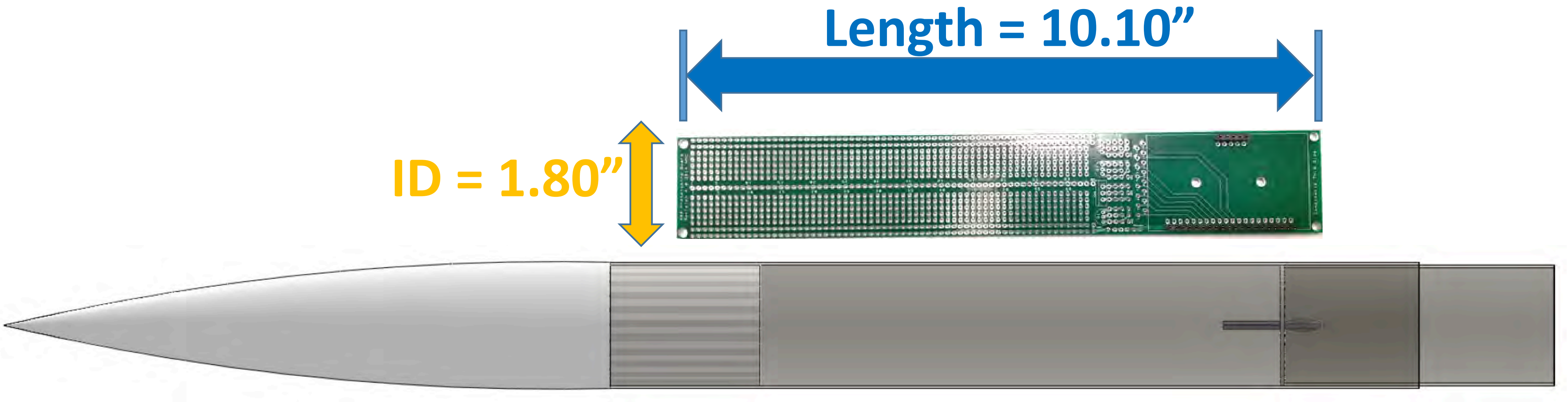
Payload Sections

- PC board matches Aerotech body tubing diameter
- Arreaux payload section too short
- An Aerotech body tube that fits the PC board will be provided

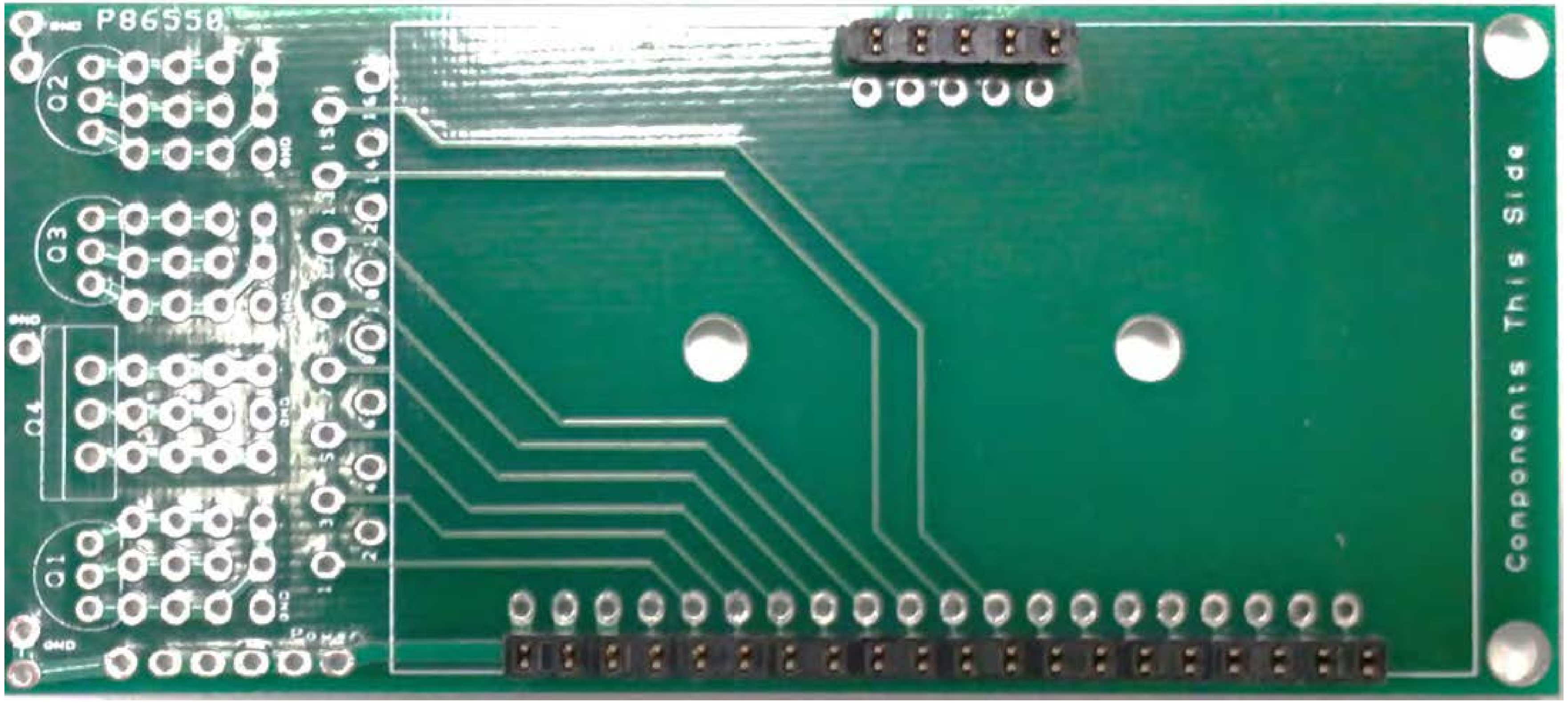


Data Logging

- How do you acquire and log data in the rocket?



Your Precious Payload – The PC Board



- Center has place for 5 V regulator + three more
- Regulators can tie common to ground or not
- Bottom has connectors for data logger

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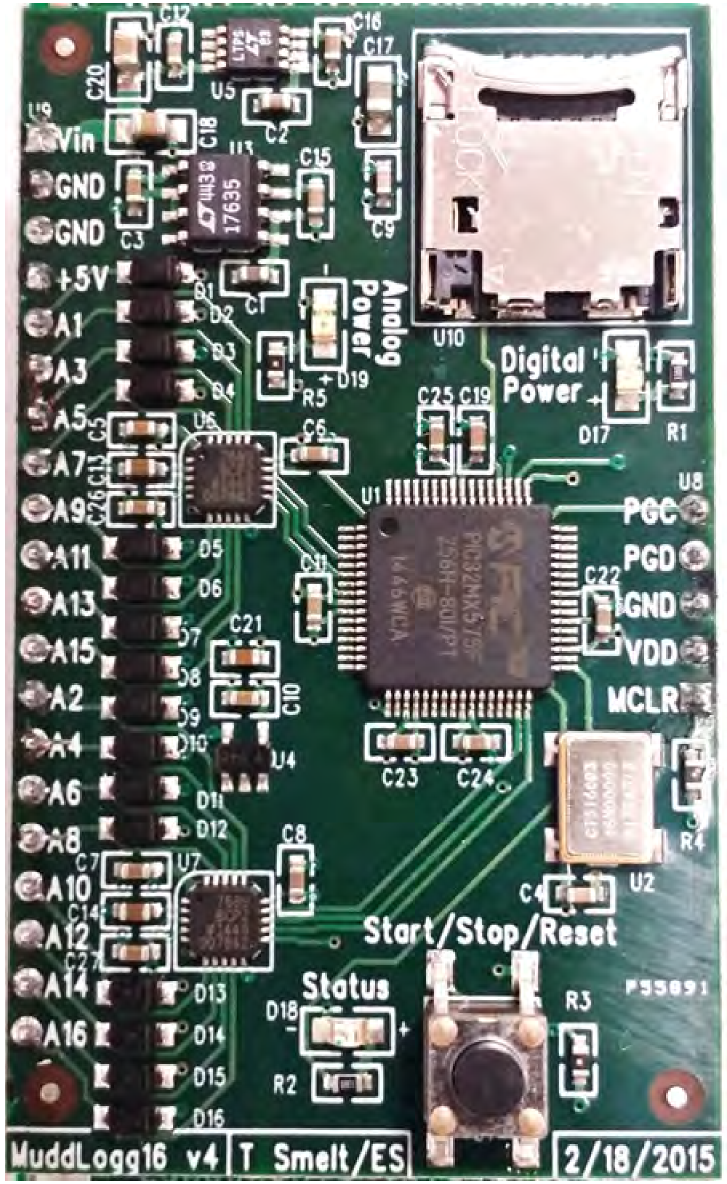
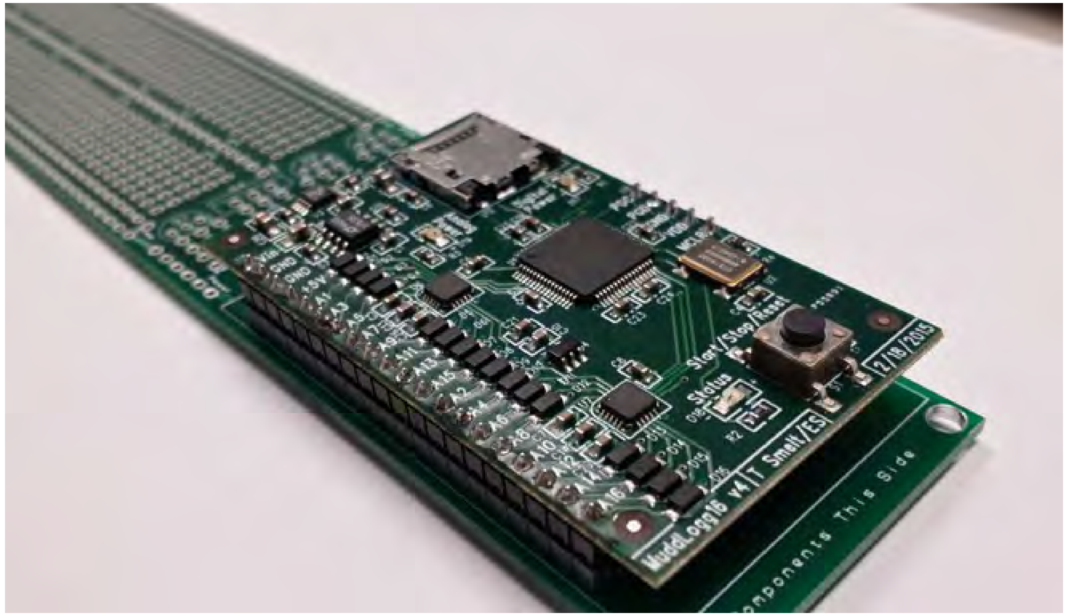
Your Precious Payload – The Data Logger

- Created and programmed by Tyler Smelt
- 16 channels (Can measure up to 16 sensors)
- 16-bit resolution
- Max 400 kSPS composite rate (25 kSPS/chan)
- Max 200 kSPS on single channel (read in pairs)
- Power with 6 V to 20 V (9 V recommended)
- Uses microSD for storage (have 16 GB cards)
    - **Need to tape/secure the SD card in the reader!**
- Input range 0 to 3.3 V
- Input Impedance ≈2.2kΩ (MyDAQ is 10 GΩ)
    - **Low impedance, may need to buffer your input signals**
- Set parameters with Config File (Initialize on PC)
- Have VI and .m file to read binary data files
- PIC-32 microcontroller; Two AD7689 A/D Chips



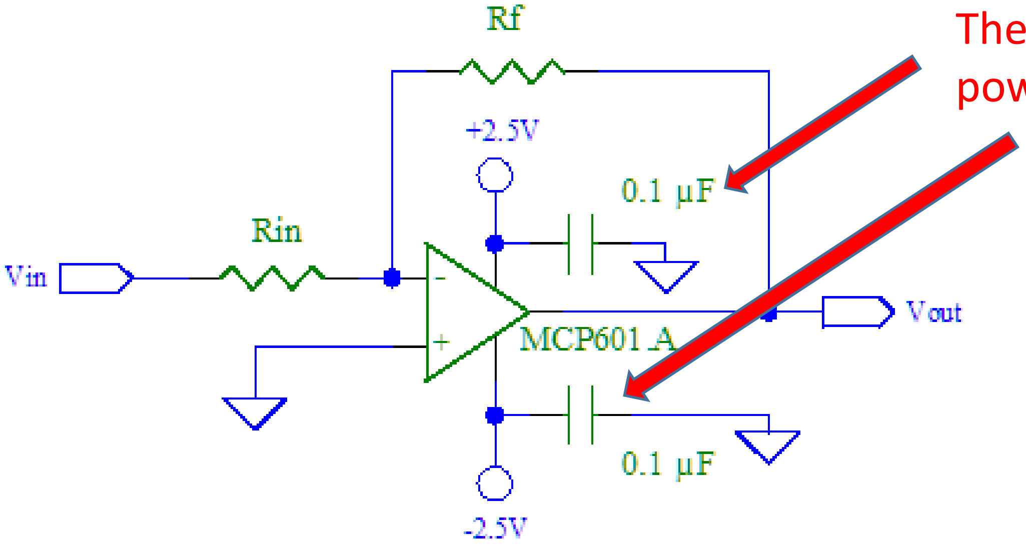
Single–Sided Circuits

- Data logger expects 0 V to 3.3 V signals
- Classical op-amp circuit power ±15 V
- Low-voltage op-amp circuit power
  - ±1.4 V to ±3 V
  - 0-to-2.8 V to 0-to-6 V
- Signal offset
  - Normal signal that goes above and below zero will need DC offset
- Reference offset
- Virtual ground
  - This is where we want all signals referenced
  - **WHAT IS A VIRTUAL GROUND?**



Inverting Amps

LOW POWER OP-AMP



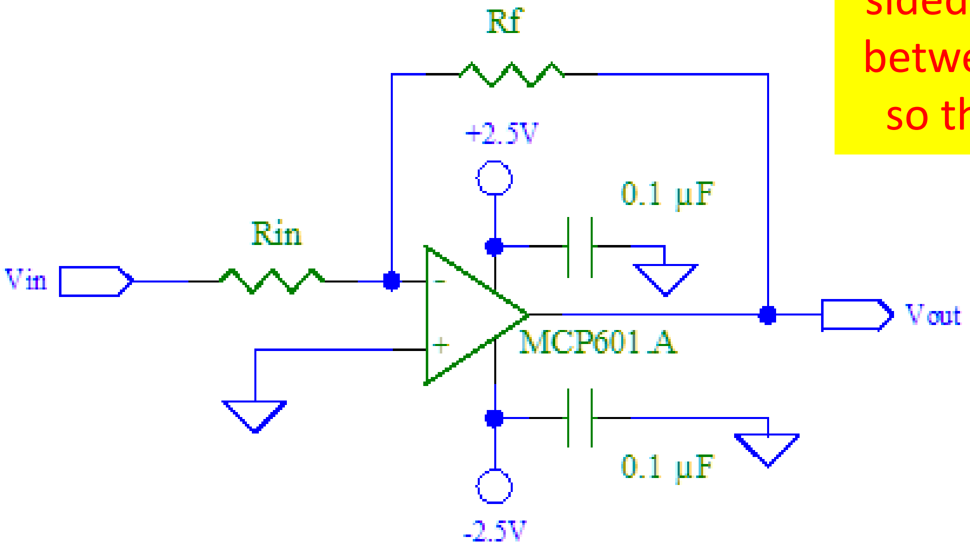
These filter out noise in the power lines; Use them!

$$V_{out} = -\left(\frac{R_f}{R_{in}}\right) V_{in}$$

Inverting Amps

LOW POWER OP-AMP

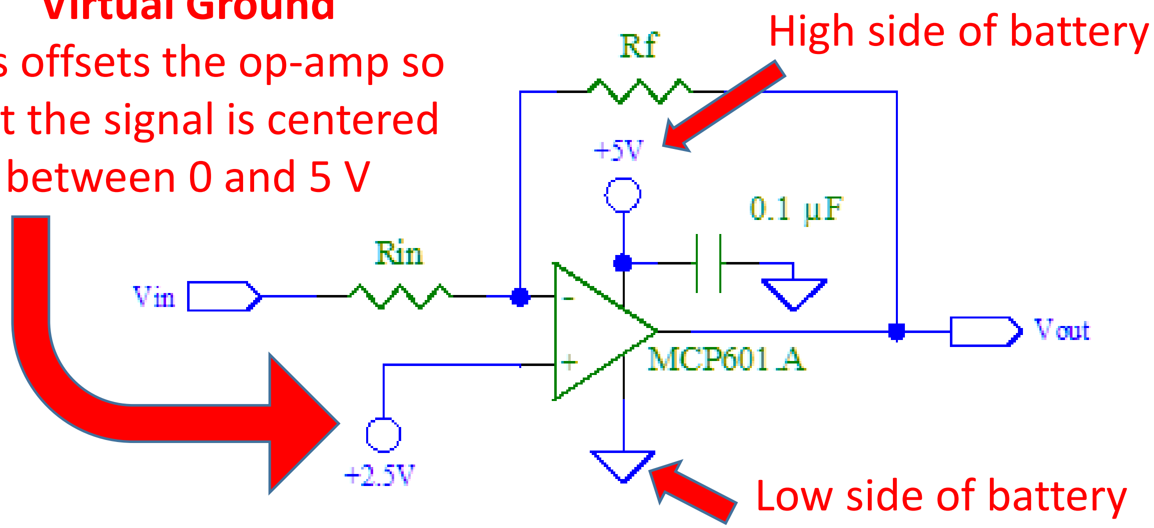
If you are powering your circuit by battery and you have a single sided supply, you need to think of creating a virtual ground halfway between your low and high on your op amp; then offset your signal so that you have your average value in the middle instead of zero



$$V_{out} = -\left(\frac{R_f}{R_{in}}\right)V_{in}$$

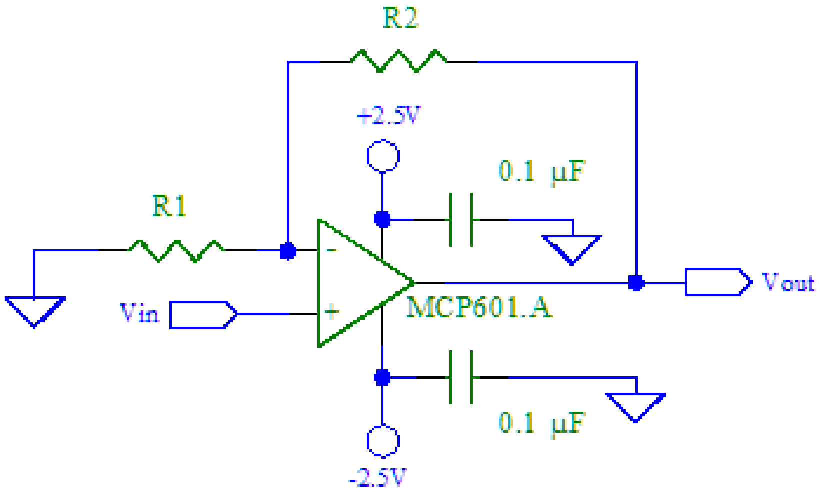
Data logger needs 0 to 3.3 V;
You could go from 0 to 3.3 V with 1.8 V as center

Virtual Ground
This offsets the op-amp so that the signal is centered between 0 and 5 V

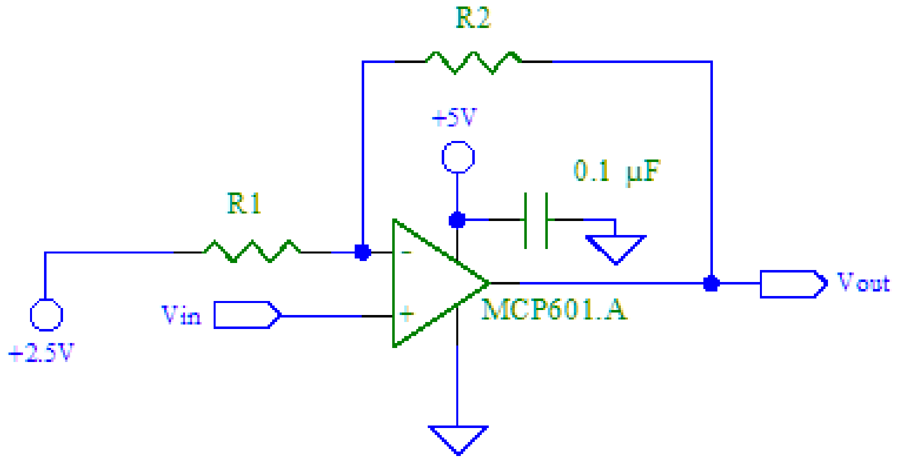


$$V_{out} = -\left(\frac{R_f}{R_{in}}\right)V_{in} + 2.5\left(1 + \frac{R_f}{R_{in}}\right)$$

Non-Inverting Amps



$$V_{out} = \left(1 + \frac{R_f}{R_{in}}\right) V_{in}$$



$$V_{out} = \left(1 + \frac{R_f}{R_{in}}\right) V_{in} - 2.5\left(\frac{R_f}{R_{in}}\right)$$

Scientific vs. Engineering Measurements

Engineering Measurements "What you measure about a rocket."

Scientific Measurements "What you measure with a rocket."

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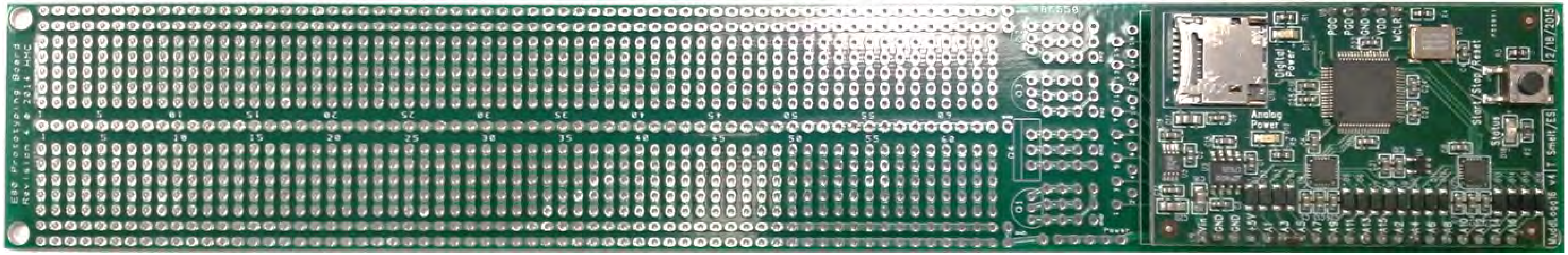
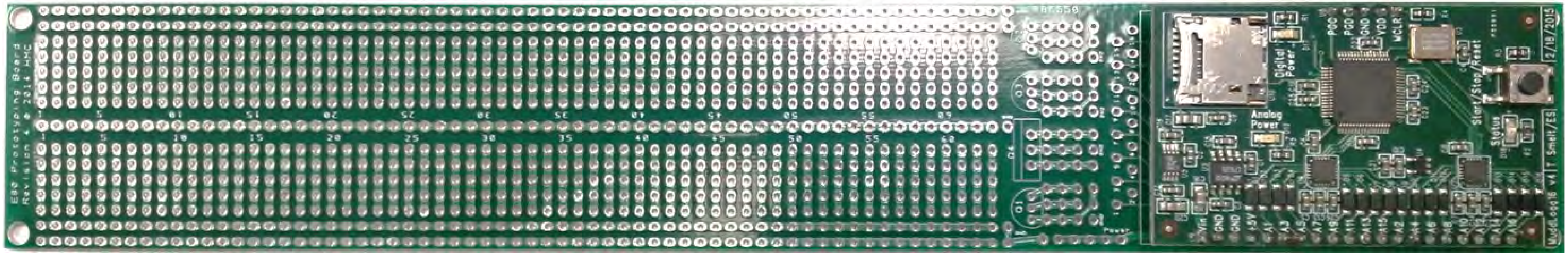
Sensor Requirement



- You are required to have a **MINIMUM of 2** types of sensors
  - One thermocouple and one thermistor would count
  - Two thermocouples would **NOT** count

Sensor Requirement



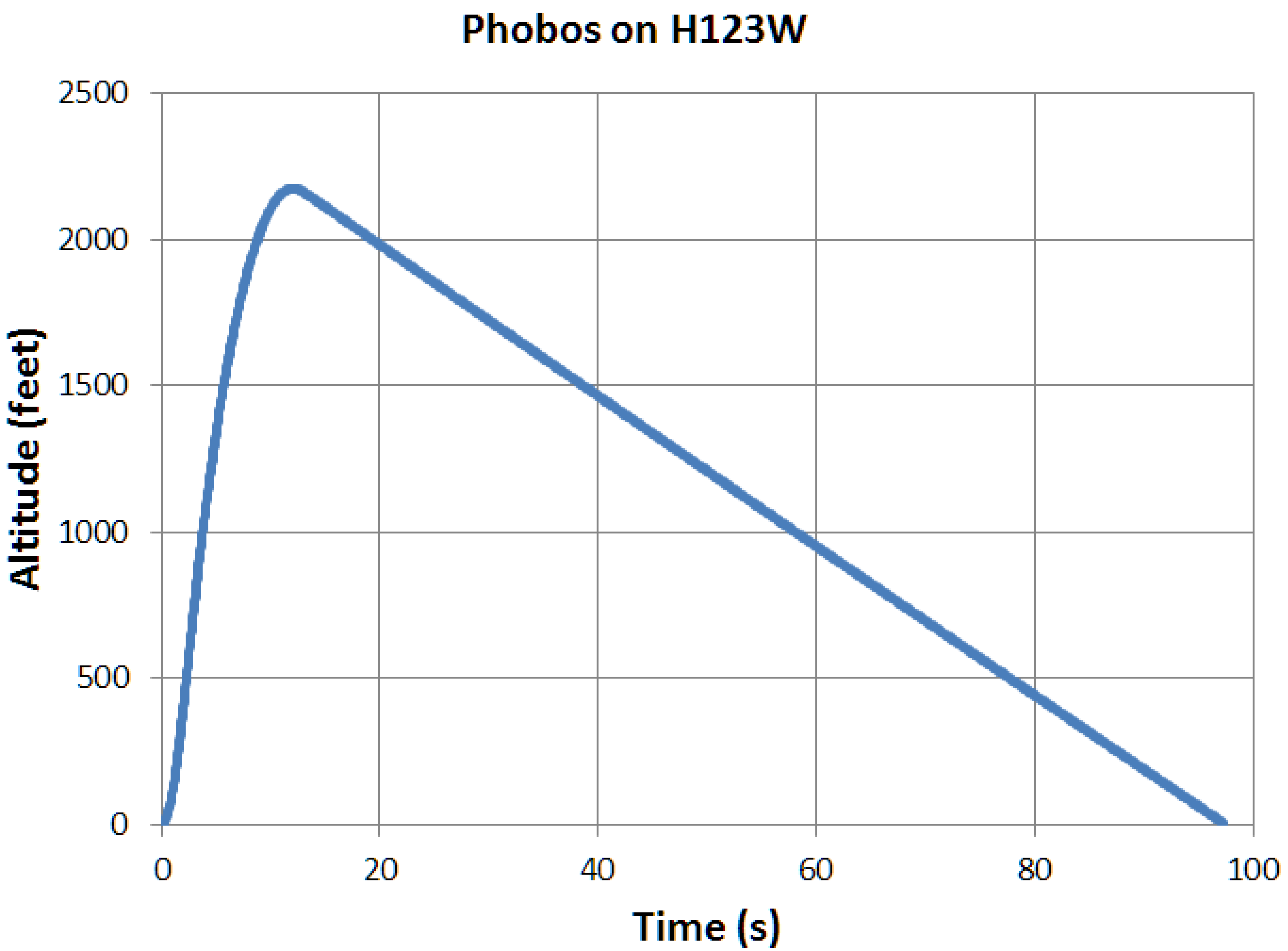
- You are required to have a **<u>MINIMUM of 2</u>** types of sensors
  - One thermocouple and one thermistor would count ✔
  - Two thermocouples would **<u>NOT</u>** count ✘

SOURCE: http://www.eng.hmc.edu/NewE80/LargePhotos/KC20120421_IMG_1658.jpg

Speed of Sensor Response

- We recommend using…
  - At least one sensor with a time constant faster than 1 ms
    - Bandwidth ≥ 1 kHz
  - Sensor adequate: $\tau_S < 0.1\tau_P$
    - The bandwidth of the sensor is 10 times higher than the phenomenon that you want to measure
  - Sensor needs deconvolution: $0.1\tau_P < \tau_S < 10\tau_P$
  - Sensor is "Hopeless": $\tau_S > 10\tau_P$

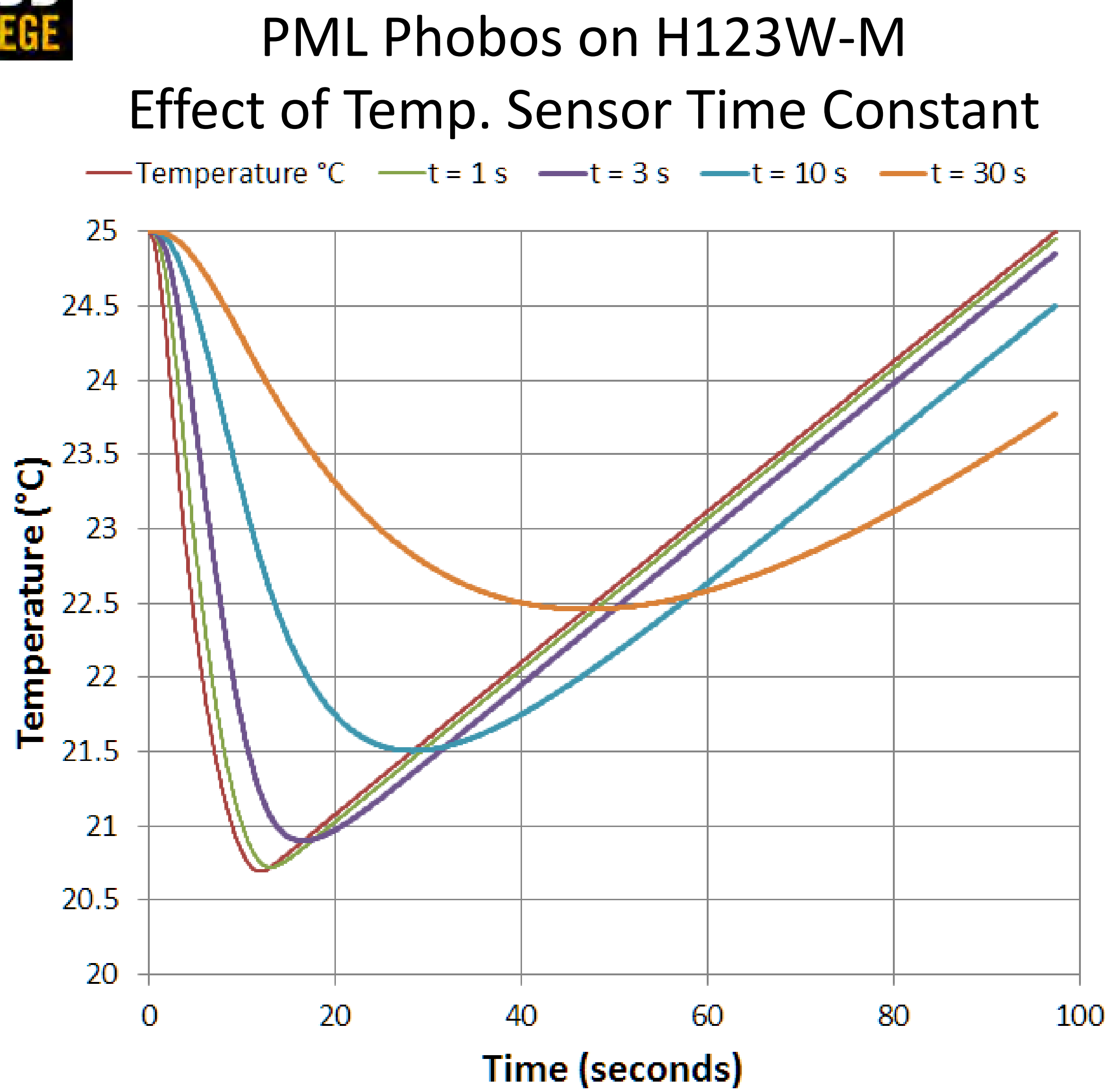
Effect of Temperature Sensor Time Constant



Temperature Measurement Devices in Lab

	Thermocouple	Thermistor	Integrated Silicon
Temperature Range	–270 to 1800°C	–100 to 450°C	-55 to 150°C
Sensitivity	10s of µV / ˚C	several Ω / Ω / ˚C	Based on technology that is -2mV/°C sensitive
Accuracy	±0.5°C	±0.1°C	±1°C
Linearity	Requires at least a 4th order polynomial or equivalent look up table.	Requires at least 3rd order polynomial or equivalent look up table.	At best within ±1°C. No linearization required.
Ruggedness	The larger gage wires of the thermocouple make this sensor more rugged. Additionally, the insulation materials that are used enhance the thermocouple's sturdiness.	The thermistor element is housed in a variety of ways, however, the most stable, hermetic Thermistors are enclosed in glass. Generally thermistors are more difficult to handle, but not affected by shock or vibration.	As rugged as any IC housed in a plastic package such as dual-in-line or surface outline ICs.
Responsiveness in stirred oil	less than 1 Sec	1 to 5 Secs	4 to 60 Secs
Excitation	None Required	Voltage Source	Typically Supply Voltage
Form of Output	Voltage	Resistance	Voltage, Current, or Digital
Typical Size	Bead diameter = 5 x wire diameter	0.1 x 0.1 in.	From TO-18 Transistors to Plastic DIP
Price	\$1 to \$50	> \$10	\$1 to \$10

Effect of Temperature Sensor Time Constant

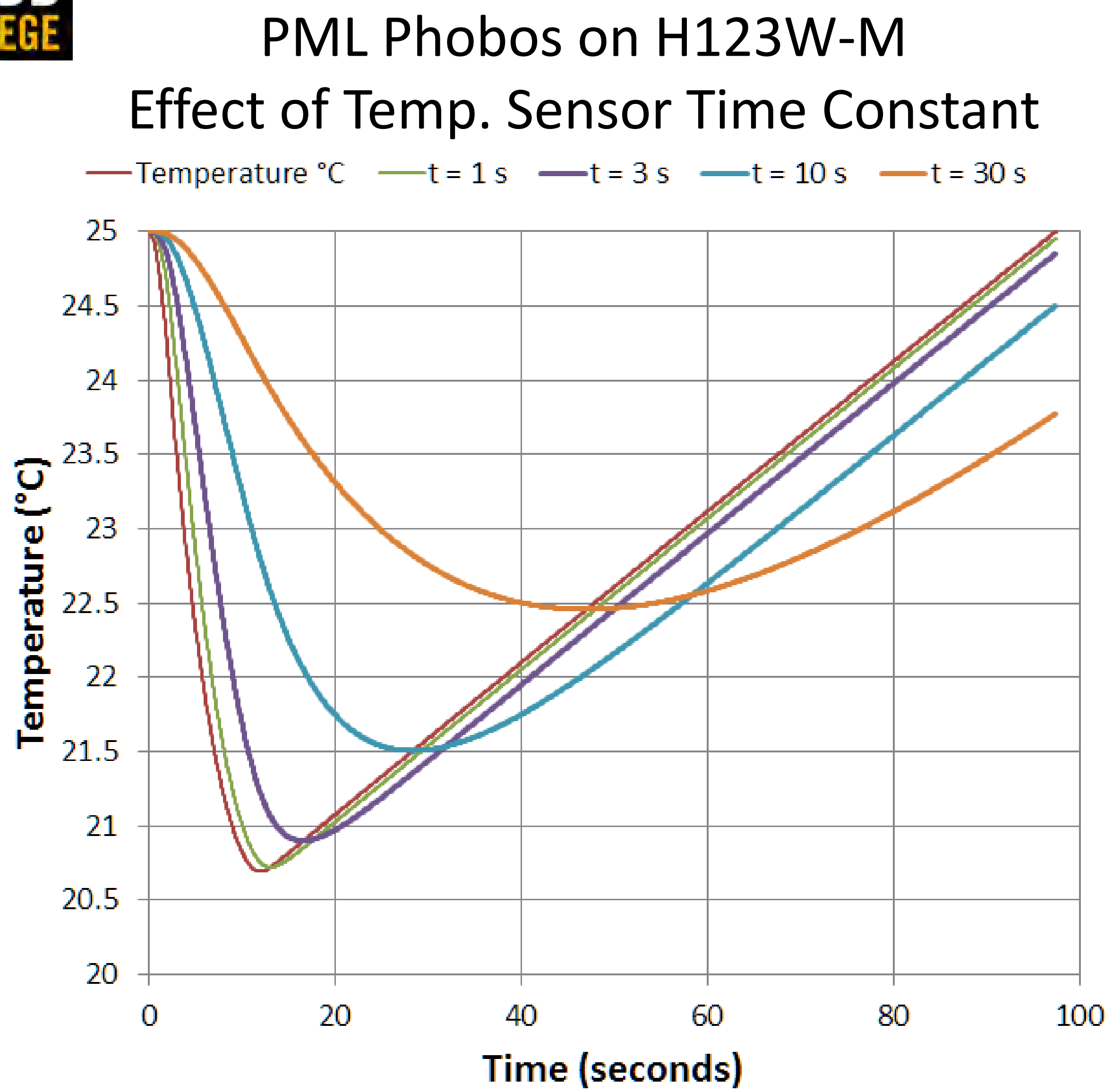


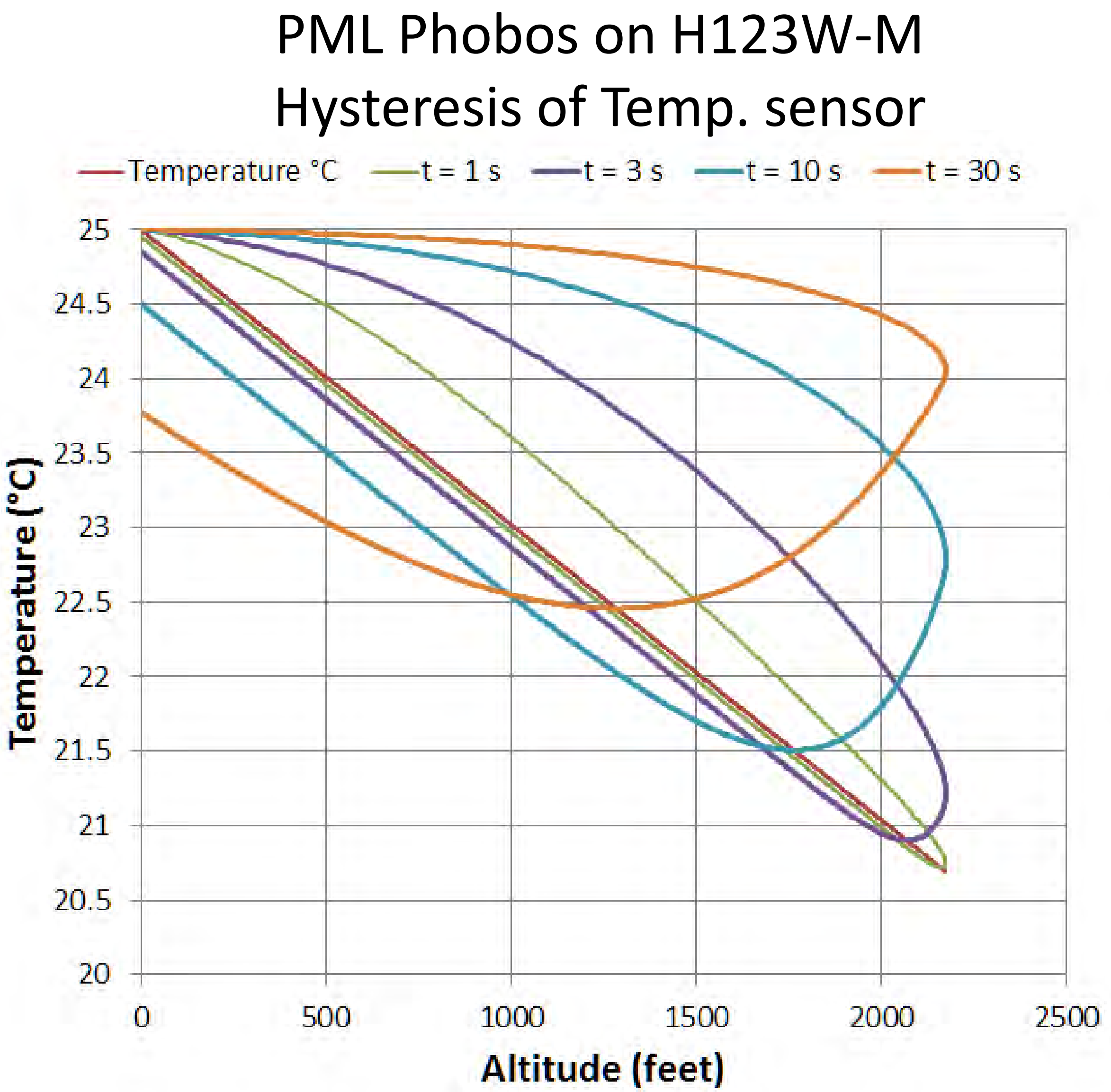
At standard lapse rate

ΔT = –7.8°C @ 1200 m AGL

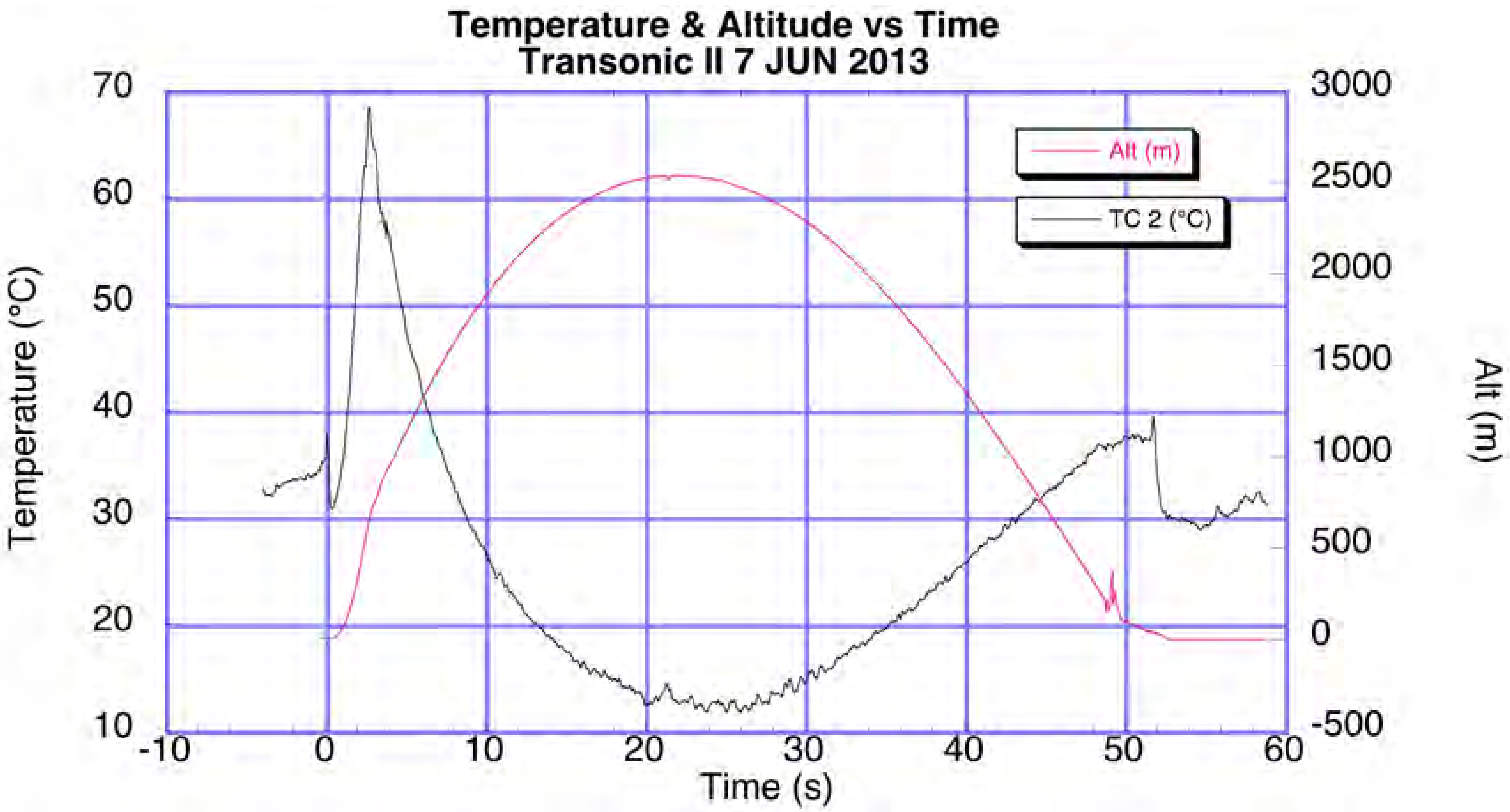
- Temperature drops by 0.0065°C for every meter going up

Effect of Temperature Sensor Time Constant



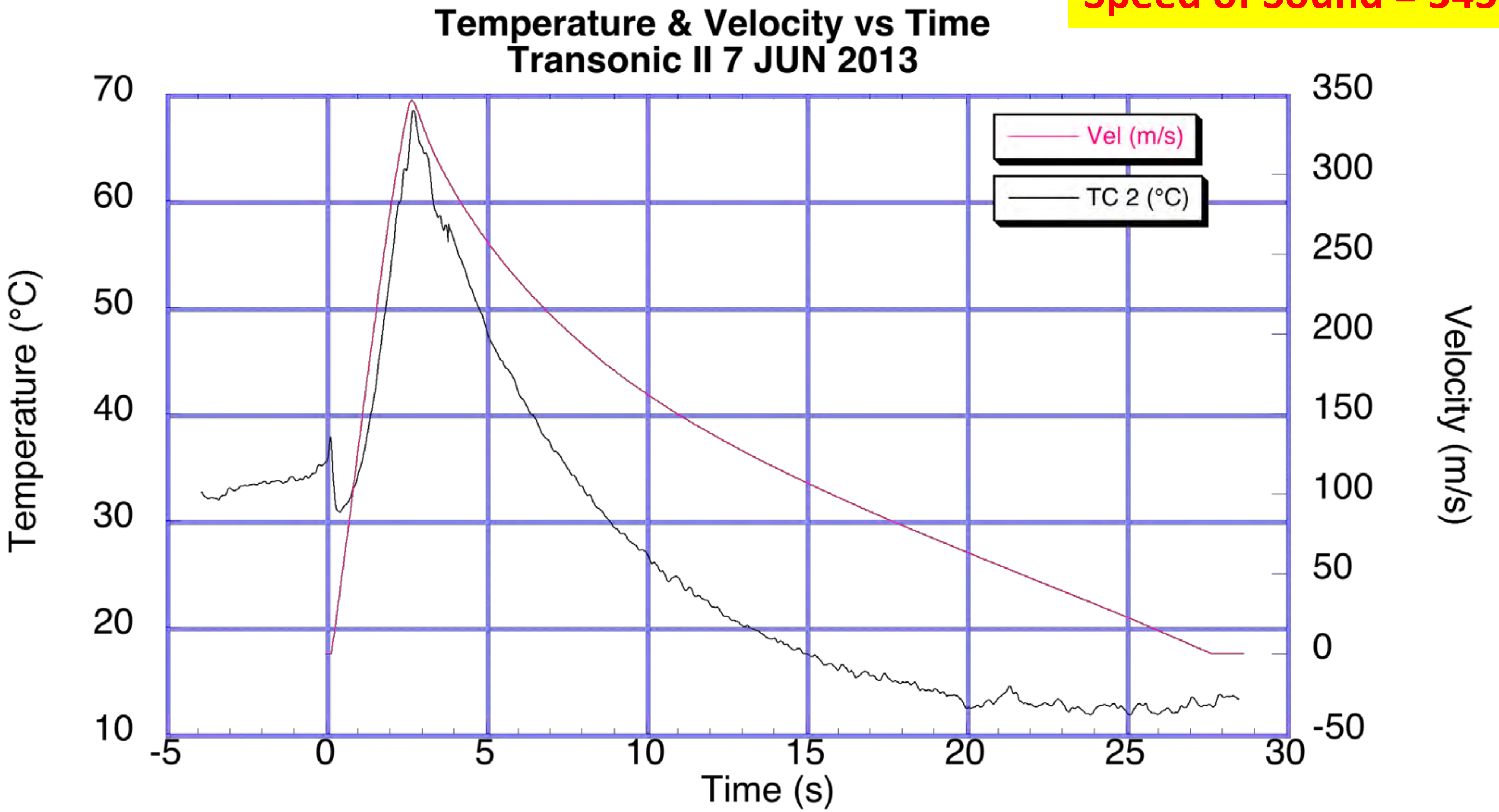


Actual Data from Sensors



Actual Data from Sensors

Speed of Sound = 343 m/s



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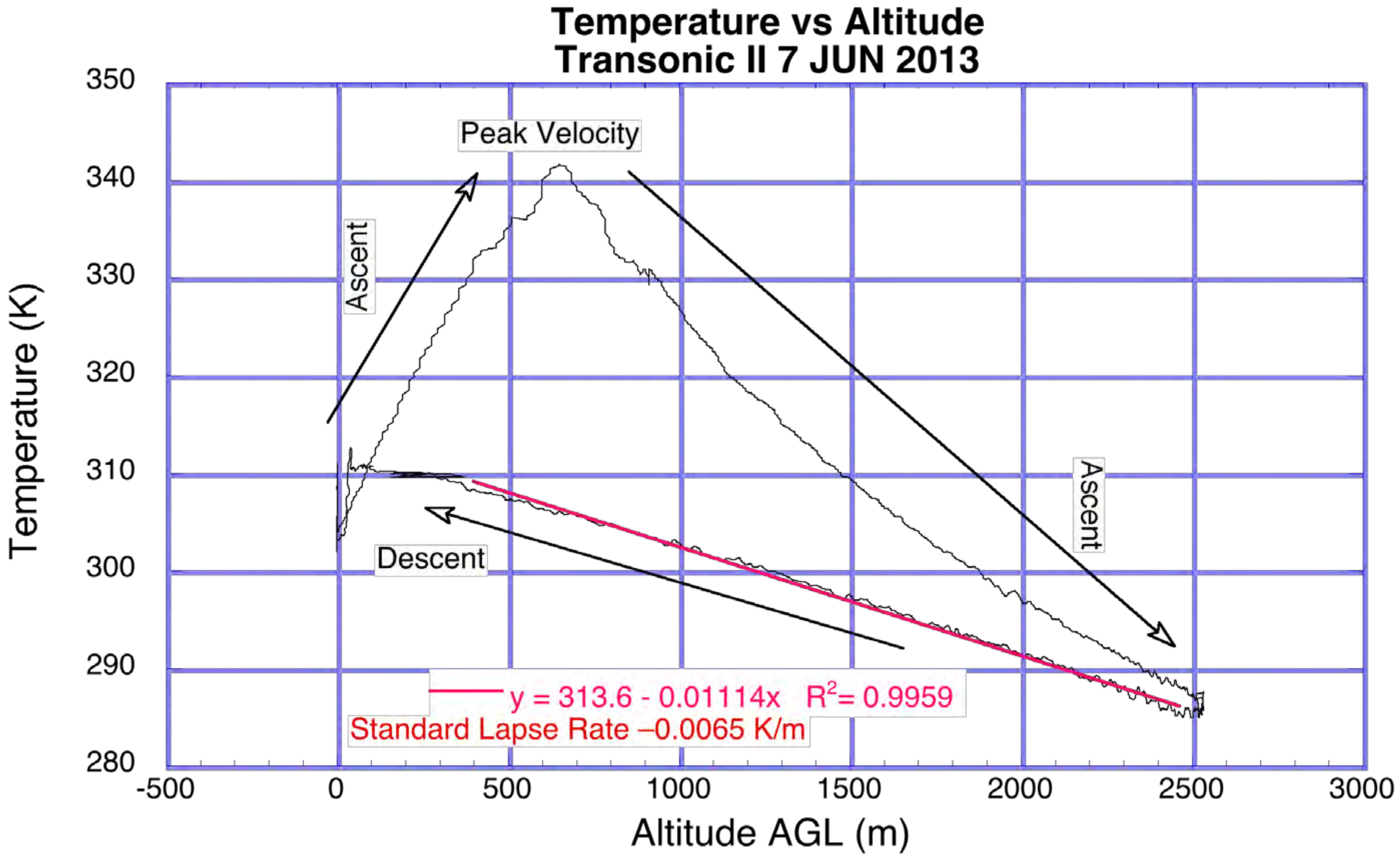

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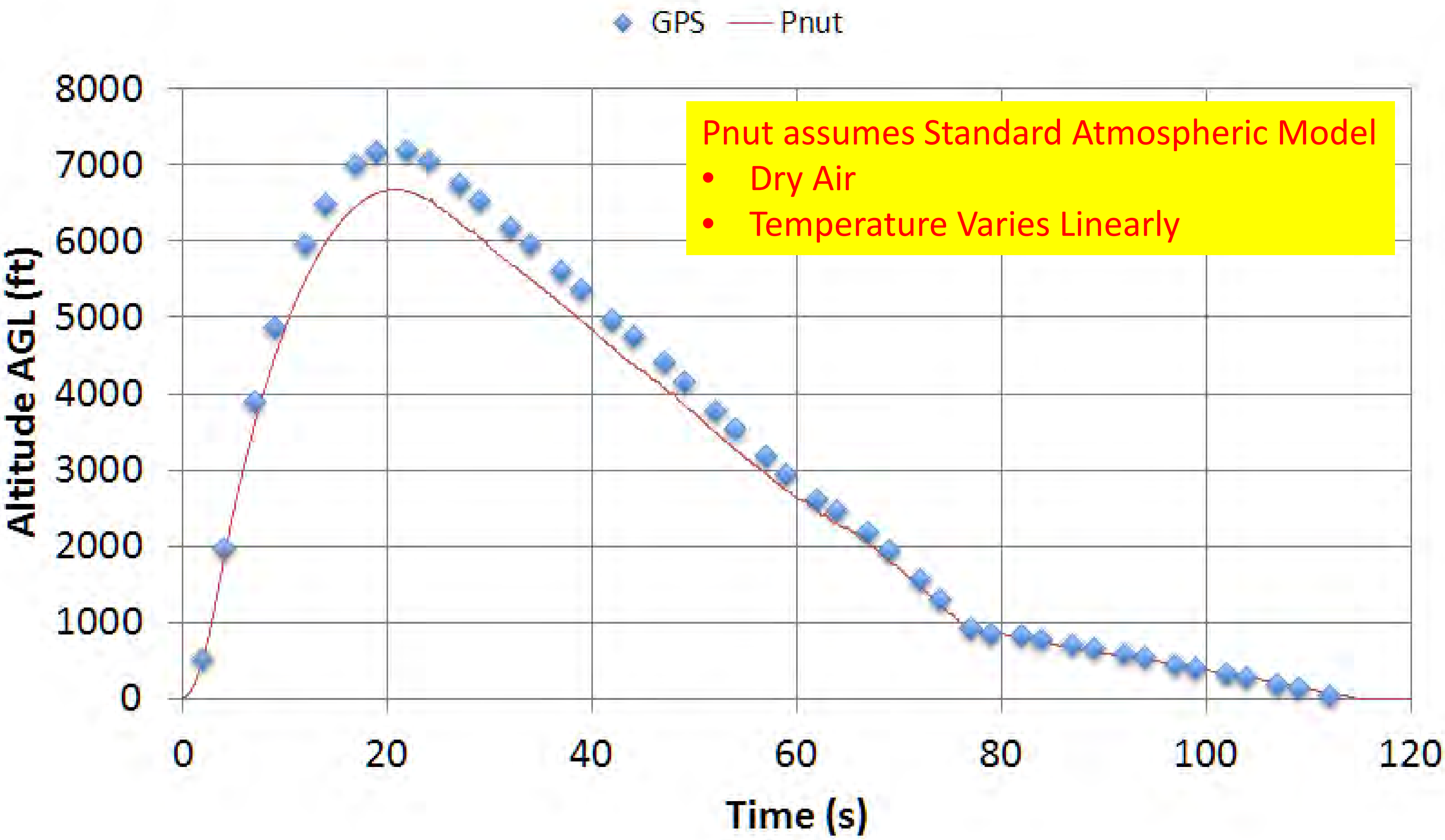
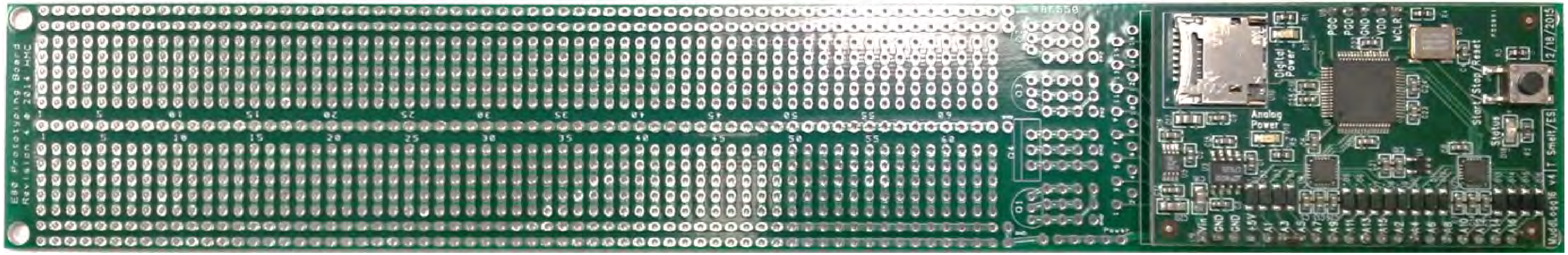


Sensor Requirement



- You are required to have a **<u>MINIMUM</u>** of 2 types of sensors
  - One thermocouple and one thermistor would count
  - Two thermocouples would **<u>NOT</u>** count
- **WHAT OTHER TYPES OF SENSORS COULD WE USE?**
  - Pressure Altimeter
  - Pitot-Static Tube
  - Accelerometer/Rate Gyroscope
  - Gas/Humidity Sensor; Vibration Sensor; Light Sensor

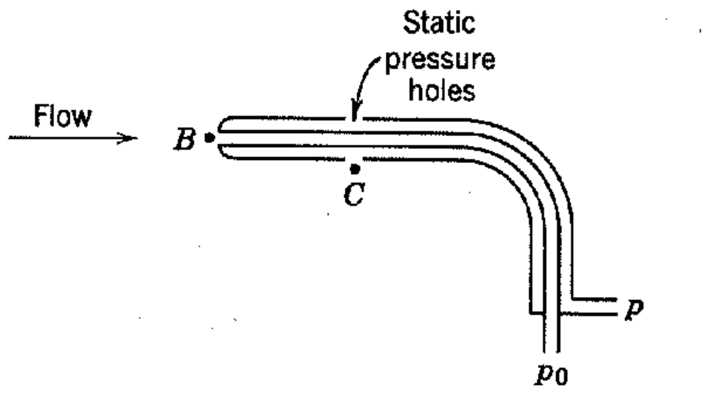
Sensor Requirements

Your Team has a Budget of $50

- Air Temperature Sensor
  - Sensor in the free stream
- Pressure Altimeter
  - No flow; 3 or 4 symmetric pressure taps
- Accelerometer/Rate Gyroscope
  - Known fixed orientation
  - Means to deal with baseline and drift
- Pitot-Static Tube
  - Pitot tube in free stream and direction of motion
  - Static Tap should be normal to the flow
    - Preferable 4+ “calibers” (rocket tube diameters) from the nose cone
    - Multiple in symmetric pattern is best

SOURCE: http://www.ipscustom.com/ProdImages/Wire_E_tt_pp_m.gif

SOURCE: http://cdn2.bigcommerce.com/server2900/730e2/products/56/images/248/PnutTop__64333.1405342120.1280.640.png?c=2



SOURCE: http://web.stanford.edu/class/me220/data/lectures/lect05/static_probe.gif

Sensor Requirements

- Light Sensor
  - Proper orientation and view field
- Vibration Sensor
  - Best on anti-node; avoid node
  - Nor for DC strain
- Gas Humidity Sensor
  - Gas flow to sensor is desired
- Particle/Dust Sensor
  - Gas flow through sensor
  - If optical, reduce or eliminate background light
  - Often needs pulse train

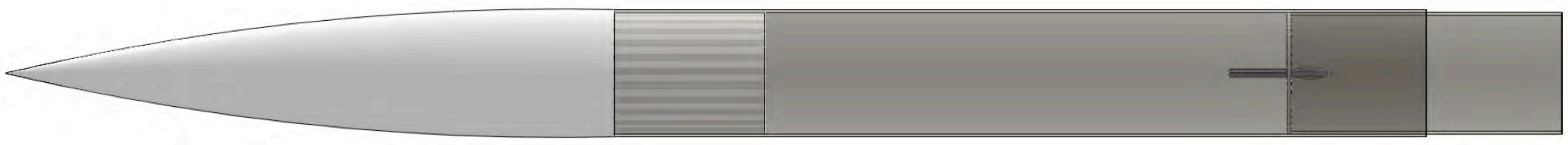
SOURCE: http://www.digikey.com/product-search/en?vendor=0&keywords=605-00004-ND

SOURCE: http://www.digikey.com/product-detail/en/HIH-5030-001/480-3294-1-ND/2061078

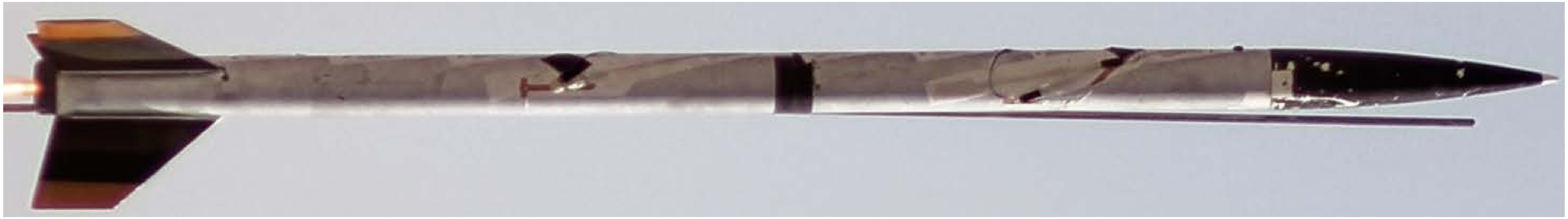
SOURCE: http://www.digikey.com/product-detail/en/GP2Y1010AU0F/425-2068-ND/720164

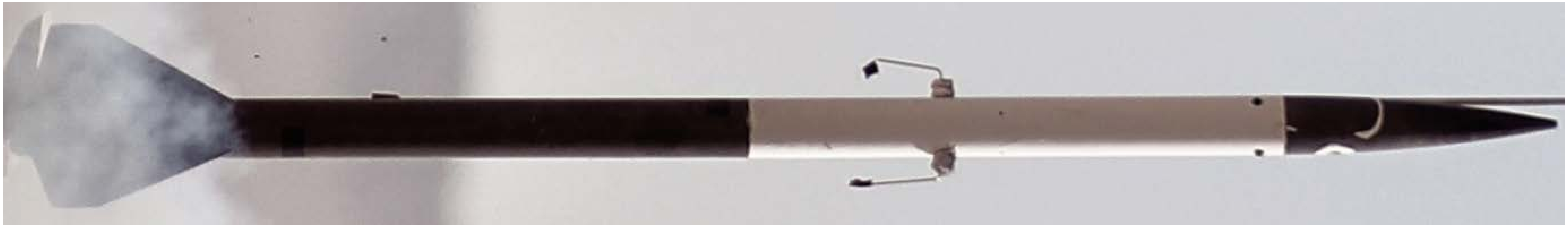
Sensor Placement

- Sensors need to be placed in locations where a measurement is desired
- Easiest in Payload Section
- Next easiest in Nosecone
- Ports/Channels to rout to exterior
- Don’t forget separation for recovery
  - Can run (very long) wires through shock cord
  - Can make connector that separates at recovery
  - Can have separate sections



What Does a Rocket with Sensors Look Like?





SOURCE: http://www.eng.hmc.edu/NewE80/LargePhotos/20140419_E80-FirstLaunch_SMM_341.jpg

Video Camera

- Battery charged by USB
- 40 minute battery time on full charge
- Creates 720P .mov file on microSD
- 10 minutes per 1 GB
  - On 16 GB card will run out of battery before storage
- Physical Mounting
  - Method
    - Duct tape? Electrical tape?
  - Location
    - Center of pressure?
  - Field of View

Power Requirements

- Power Inputs
  - Data Logger: 6 V to 20 V
  - IMU: 5 V (regulated) & 3 V to 3.3 V (regulated)
  - AD623AN: 3 V to 12 V or ±1.5 V to ±6 V
  - MPC 60XX: 2.7 V to 6 V
  - Other sensors – TBD
- Must measure current draw of final circuit
- Batteries must power for 1 hour minimum

Battery capacity (in mAh) / Average current consumption (in mA) = Hours of expected runtime

- Turn on before launch, stay on during flight, turn off after recovery.

Power Sources

Your Team has a Budget of $50

- Power sources
  - 9 V lithium, 750 mAh
  - 1.5 V
    - AAA Alkaline, 1000 mAh; Lithium, 1200 mAh
    - AA Alkaline, 2700 mAh; Lithium, 3000 mAh
  - 12 V (NEDEA- 1811A), 55 mAh
  - LiPo (Rechargable, High Power Density, Special Charger, HazMat)
    - 3.7 V, up to 5000 mAh
    - 7.4 V, up to 5000 mAh
    - 11.1 V, up to 5000 mAh
  - NiMH (Rechargable)
  - NiCd (Rechargable)
- **Your team will decide on which power source to use**

Surviving

- What does your rocket have to survive during launch?

BE THE ROCKET

Temperature

1) Temperature at Launch

- Often –2°C at 6 AM
- Solar heating of payload section to 50°C+
- At standard lapse rate ΔT = –7.8°C @ 1200 m AGL
  - Temperature drops by 0.0065°C for every meter going up

Standards for Parts
Commercial Grade: 0°C to 70°C
Industrial Grade: –40°C to 85°C
Military Grade: –55°C to 125°C

Acceleration

2) Acceleration

- From motor, 6g to (50+)g
- Use RockSim or OpenRocket to estimate

Vibration

3) Vibration (What causes vibration?)

- From motor
- From aerodynamics
- From shock impulse

Amplified at resonant frequencies

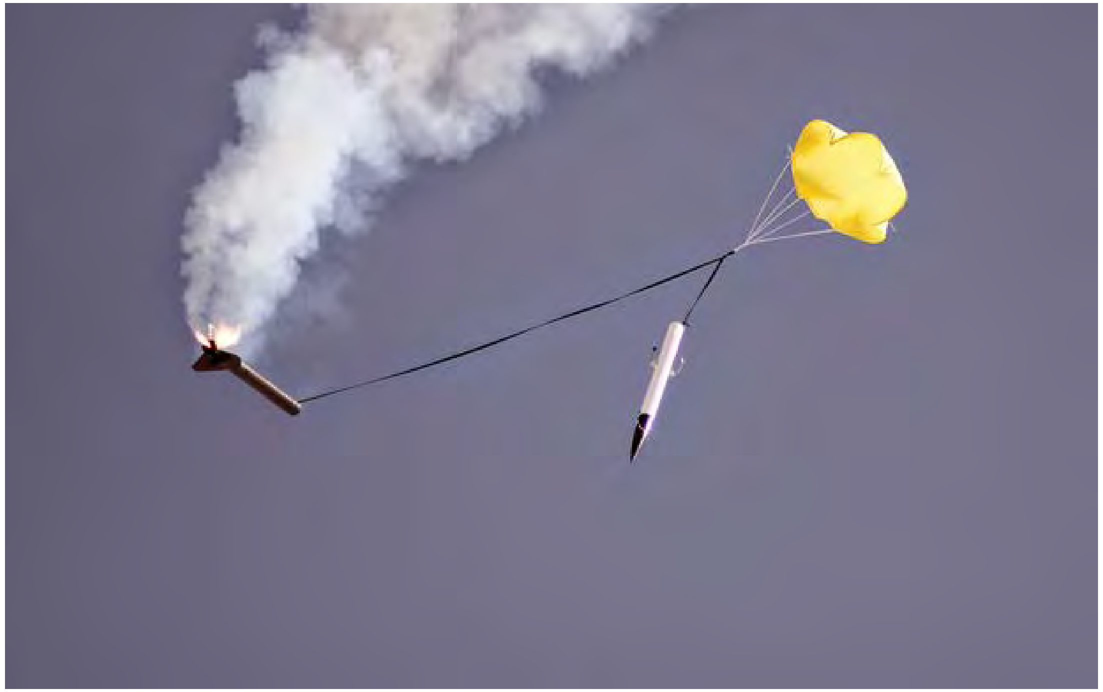
Use viscoelastic damping materials

SOURCE: http://www.sorbothane.com/blog/wp-content/uploads/2010/07/engine-vibrations.jpg

Shock

4) Shock (What causes shock?)

- Deployment charge, 2 g to 20+ g
- From parachute, 1 g to 50+ g
- From ballistic landing, 200+ g



Surviving

- What does your rocket have to survive during launch?
  1. Temperature
  2. Acceleration
  3. Vibration
  4. Shock

Constructing Your Rocket

- NAR or TRA safety Code is mandatory.
- **<u>Materials:</u>** I will use only lightweight materials such as paper, wood, rubber, plastic, fiberglass, or when necessary ductile metal, for the construction of my rocket.
- **<u>Motors:</u>** I will use only certified, commercially made rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer. I will not allow smoking, open flames, nor heat sources within 25 feet of these motors.

Constructing Your Rocket

- Adhesives must be used under fume hood, in spray-paint booth, or outdoors.
- Neoprene gloves required. Eye protection required
- G10 Fiberglass (PML fins) must be wet sanded or with full respiratory protection. Neoprene gloves strongly recommended.
- No sharp implements permitted when removing plastic rivets.
- Spray painting only permitted in paint booth or outdoors (not by Libra Complex). Skin & eye protection required.
- If you follow the **unmodified** instructions for the rockets, you will **NOT** be able to fly them.
  - Aerotech requires motor retainer, longer motor mount, modified placement, and removal of motor hook, thrust ring, and thrust ring flange

Rocket Construction

- Motor retainers attached with JB Weld ONLY!
- Cyanoacrylic/Super-Glue (Aerotech)
  - Make SURE you have adequate ventilation
  - ALWAYS use skin protection (neoprene gloves)
  - Usually sets in 30 s to 20 min
  - Can use accelerator (we have limited supplies)
  - Accelerator on one surface + Super-Glue on other surface = instant bond when joined.
  - Will have to dribble on some internal joints
- Epoxy clay
  - Not quite as strong as epoxy
  - Very useful for fillets and custom mounts
  - You always need less than you think

Rocket Hints

- For Aerotech kits…
  - There is no need for the 24 mm motor adaptor.
  - Make sure the fins snap easily into the Fink Locks BEFORE putting the Motor Tube Assembly into the Body Tube.
  - It’s very difficult to reconnect the shock cord to the nose cone. An extension from the screw eye to the end of the coupler makes the process much easier.

Deliverables

- Week 1
  - Scientific and/or Engineering objectives
  - Select sensors (min: 2, MAX: 16)
  - Parts list (especially to order)
  - Complete schematic
    - Show all calculations; bypass capacitors; power
  - Check off by Section Prof & Prof Spjut
- Week 2
  - Complete protoboard
  - Measured current draw
  - Demonstrate functionality
  - Check off by Section Prof & Prof Spjut

NO RESTRICTIONS ON WHEN YOU DO YOUR WORK.

- However, priority for resources goes to groups that were assigned to that lab section.
- Need to show up to your lab section for the check-off.

Deliverables

- Week 3
  - Fully populated PC board
  - Demonstrate functionality
    - Data acquisition works and is demonstrated
  - Check off by Section Prof & Prof Spjut
- Week 4
  - Completed Rocket
  - Complete ground and analysis procedures
  - Completed launch checklist (you have to DO steps)
  - Loaded launch motors

<u>NO RESTRICTIONS ON WHEN YOU DO YOUR WORK.</u>

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Deliverables

- Week 5
  - List lessons learned
  - Fix & correct things
  - Load launch motors
- Week 6
  - Analyze data
  - Write Final Report
  - Prepare Final Presentation

NO RESTRICTIONS ON WHEN YOU DO YOUR WORK.

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The Final Project on One Page…

- **Problem Statement (or Purpose, or Goal)**
  - The final E80 project needs to be completed to pass the course
- **Success Criteria (envision successfully crossing the finish line)**
  - Submit a final report and give a presentation about your E80 rocket flights (e.g. results of the flight, comparison of data with modeling)
- **Strategies (how are you going to get to that finish line?)**
  - Work as a team to meet all weekly project deliverables
- **Timeline (detailed plan for implementing the strategies)**

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Meet Week 4 Deliverables (Build, Test, & Launch)	4/7/2016	4/16/2016	Not Started
Meet Week 5 Deliverables (Rebuild, Retest, & Relaunch)	4/14/2016	4/23/2016	Not Started
Meet Week 6 Deliverables (Prepare Report & Presentation)	4/21/2016	5/4/2016	Not Started
Submit Report and Give Final Presentation	5/4/2016	5/4/2016	Not Started

Visualize…

https://vimeo.com/126016928

Good Luck Over the Next 7 Weeks!

MAKE IT HAPPEN!