#20 - Direct Drive Solar Powered Arcjet Thruster

SPONSOR – NASA, MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE AL

ADVISORS – DR. GUO, DR. KWAN, DR. ANDREI

SENIOR DESIGN COORDINATORS – DR. AMIN, DR. FRANK

Team Members

Date – 4/17/14

Chris Brolin - ME
Cory Gainus - ME
Gerard Melanson - ECE
Tara Newton - ME
Griffin Valentich - ME
Shane Warner - ECE

Griffin Valentich

Abstract

- **Project Scope:**
  - Design, fabricate, and test an electric arcjet thruster within a vacuum chamber that will be designed to simulate the space environment.
    - Operate via “direct-drive” in order to power the system.
- **Accomplishments:**
  - Thruster fabricated
  - Circuit designed and tested
  - Testing apparatus designed
  - Vacuum chamber tested
- **Future Recommendations:**
  - Adequate vacuum chamber needed
  - Acquire measurement devices to quantify performance
  - Incorporate solar panels

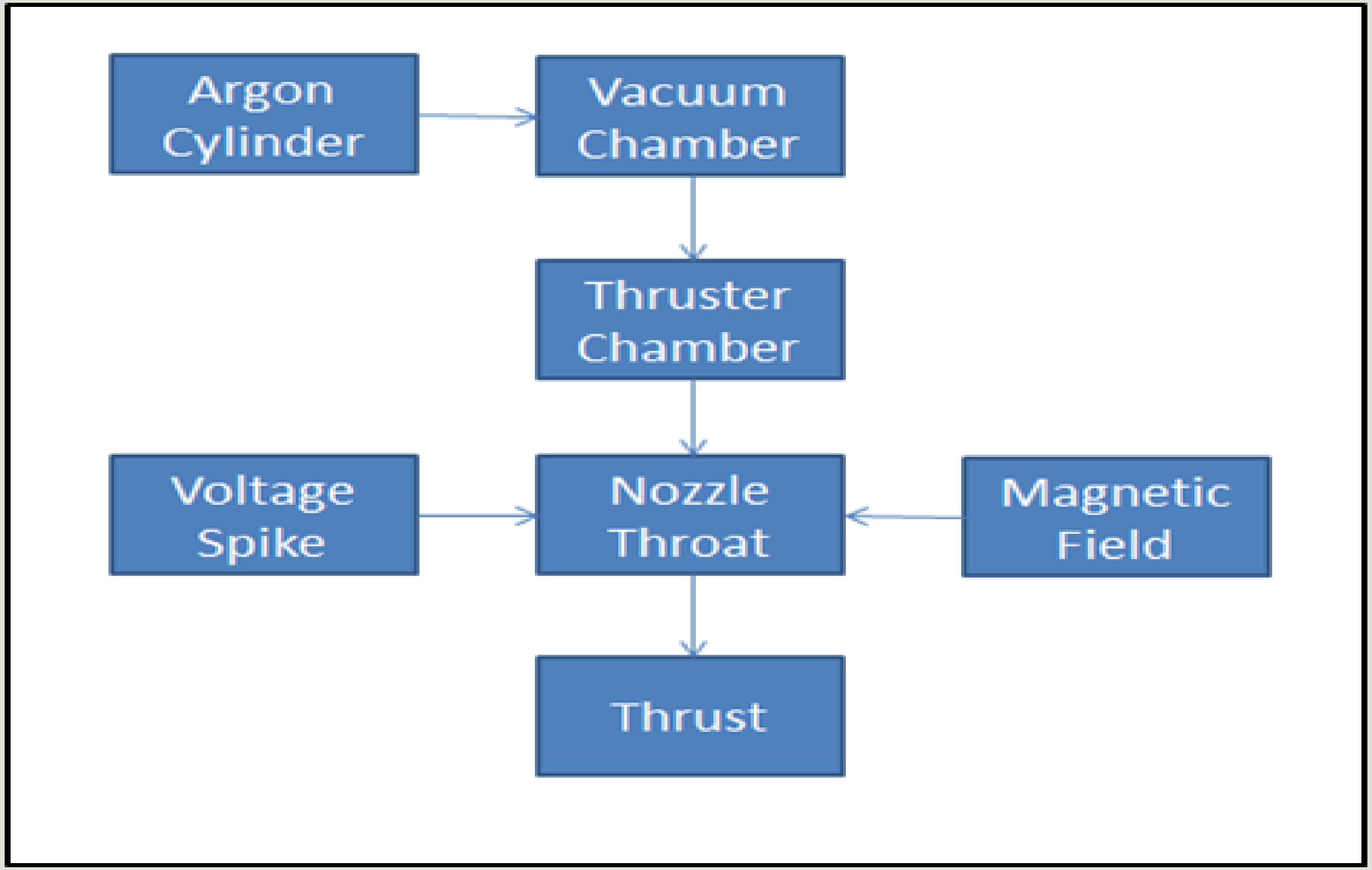
Griffin Valentich

Sponsor Requirements

- **Eliminate the PPU**
  - Generate a high-voltage pulse from a simple robust circuit
  - Obtain power directly from solar panels or power supply
- **Design, manufacture, and test an arcjet thruste**r
  - Design and build a thruster capable of processing 50-400 W of power
    - Test under vacuum conditions
  - Independently control propellant flow
  - Design and execute a test plan to quantify the range of operating conditions where breakdown can be achieved
  - Perform testing to see if a continuous discharge at these power/current levels can be sustained
    - Quantify the conditions over which this is possible

Griffin Valentich

Functional Analysis



Argon Cylinder

Vacuum Chamber

Thruster Chamber

Voltage Spike

Nozzle Throat

Magnetic Field

Thrust

Griffin Valentich

Background

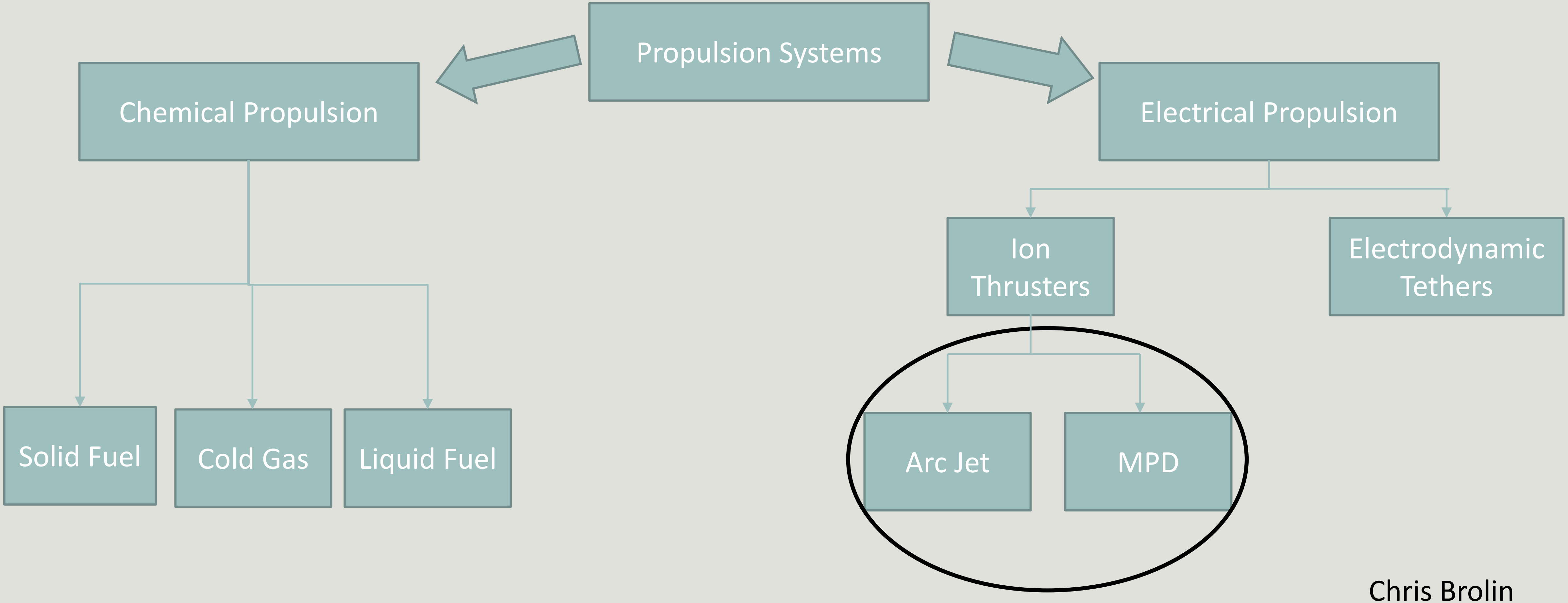
- Electrical Propulsion Systems
        - High specific impulse – low thrust
    - Electro-thermal thruster– arcjet
        - Produce thrust by heating gas propellant (Ar) and expelling through C-D Nozzle
    - Electromagnetic thruster – MPD
        - Accelerates particles with applied magnetic force

- Purpose of Electric Propulsion Systems
    - Station keeping – lower overall lifetime costs
    - Satellite altitude and attitude adjustment
    - Potential for deep space applications

- Power Processing Unit (PPU)
    - Expensive and complex
    - Largest prohibitive component to electronic propulsion systems
    - Converts input power to correct current and voltage

Chris Brolin

Background



Chris Brolin

Paschen’s Law

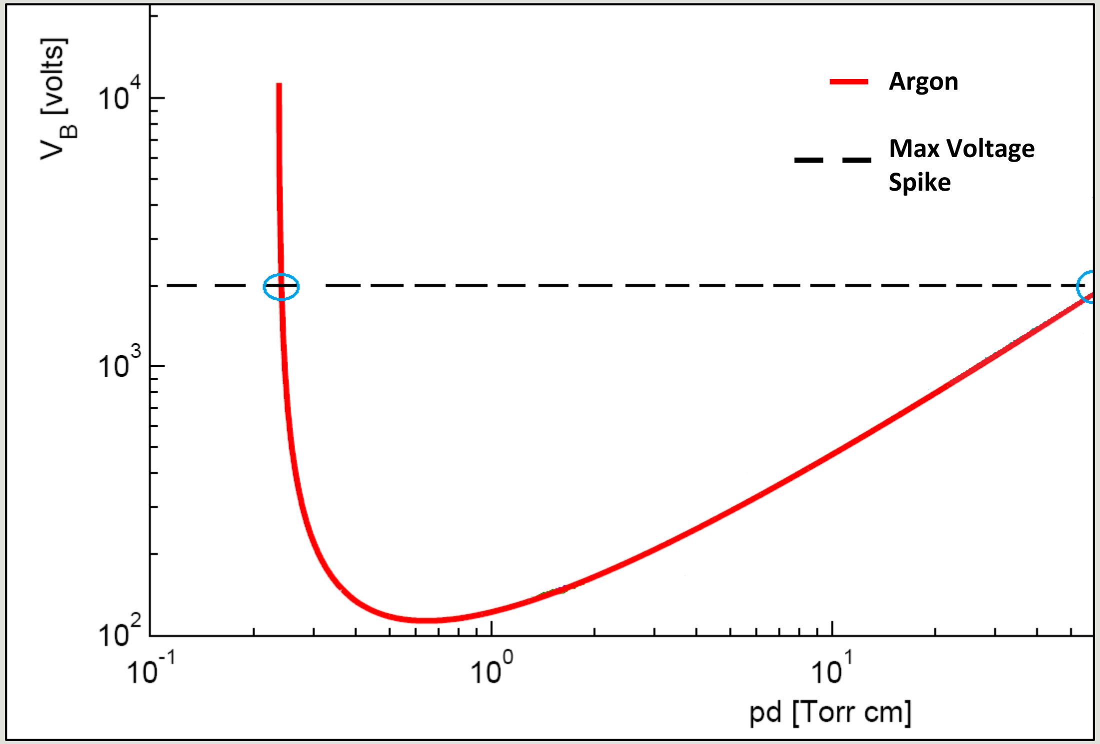
- Relates the product of pressure and distance between anode and cathode to the voltage necessary to initiate breakdown

$$V_{Breakdown} = f(P * d)$$

- Argon had lowest breakdown voltage

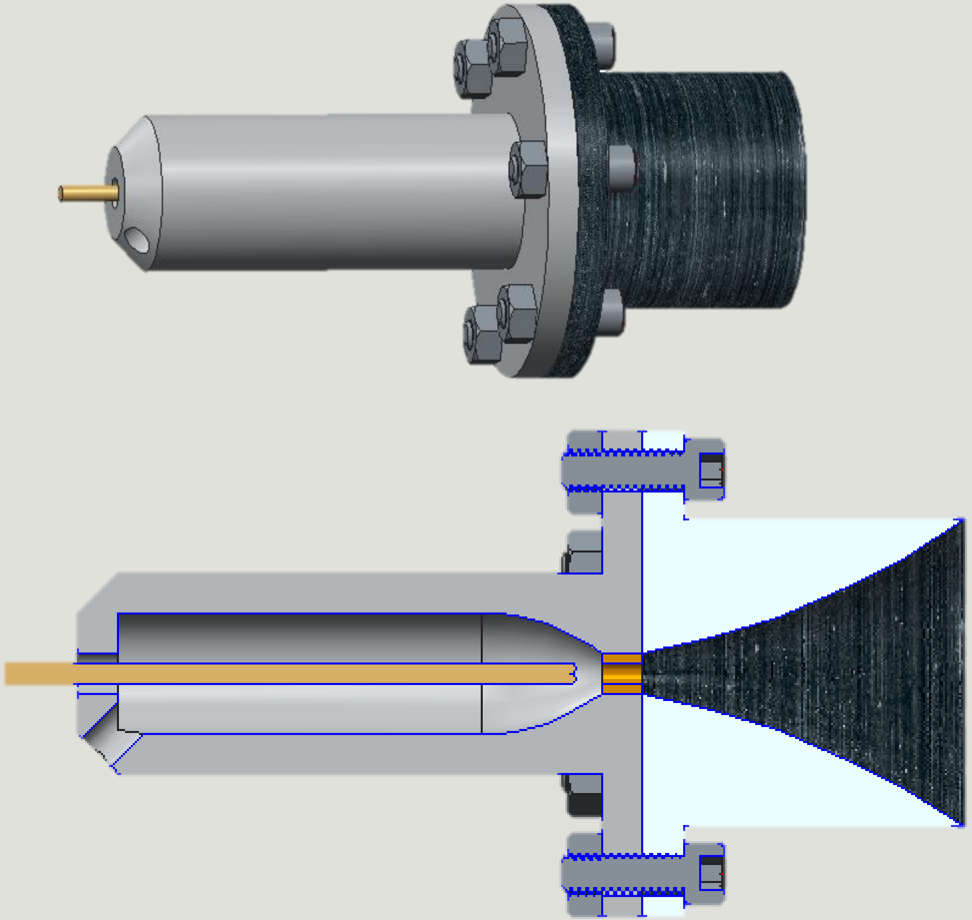
$$\sim 137\ V$$

- Good starting point, but values will be different due to complex geometry



Chris Brolin

Initial Thruster Design



Characteristics

- Gas injected at angle
- Magnets more evenly spaced over nozzle

Pros

- Swirling gas helps to keep nozzle walls cool
- Metal nozzle is not part of circuit
- Magnets on diverging nozzle protect nozzle walls
- Conventional nozzle construction

Cons

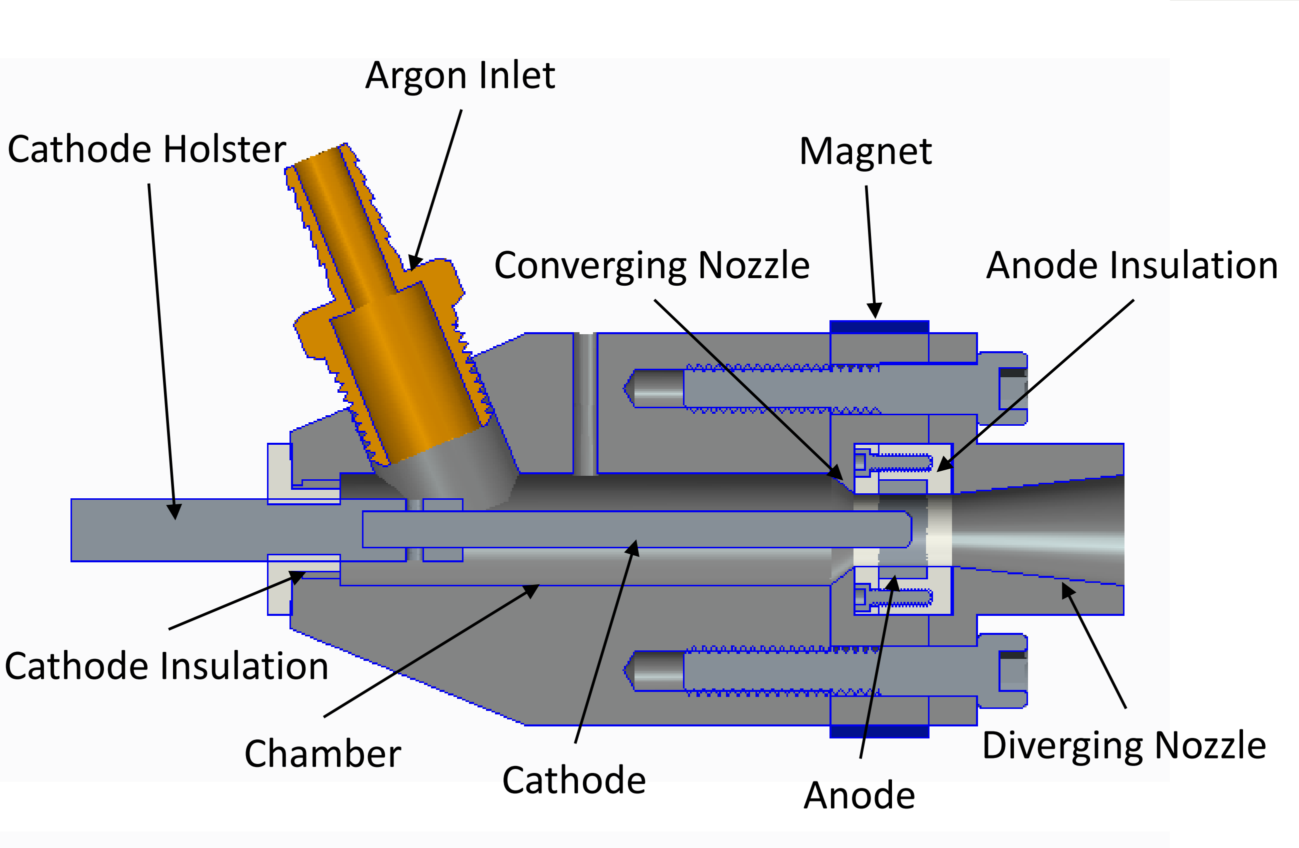
- More difficult to place magnet at diverging nozzle with flange location
- Difficult to complete circuit due to anode placement

Tara Newton

Final Thruster Design

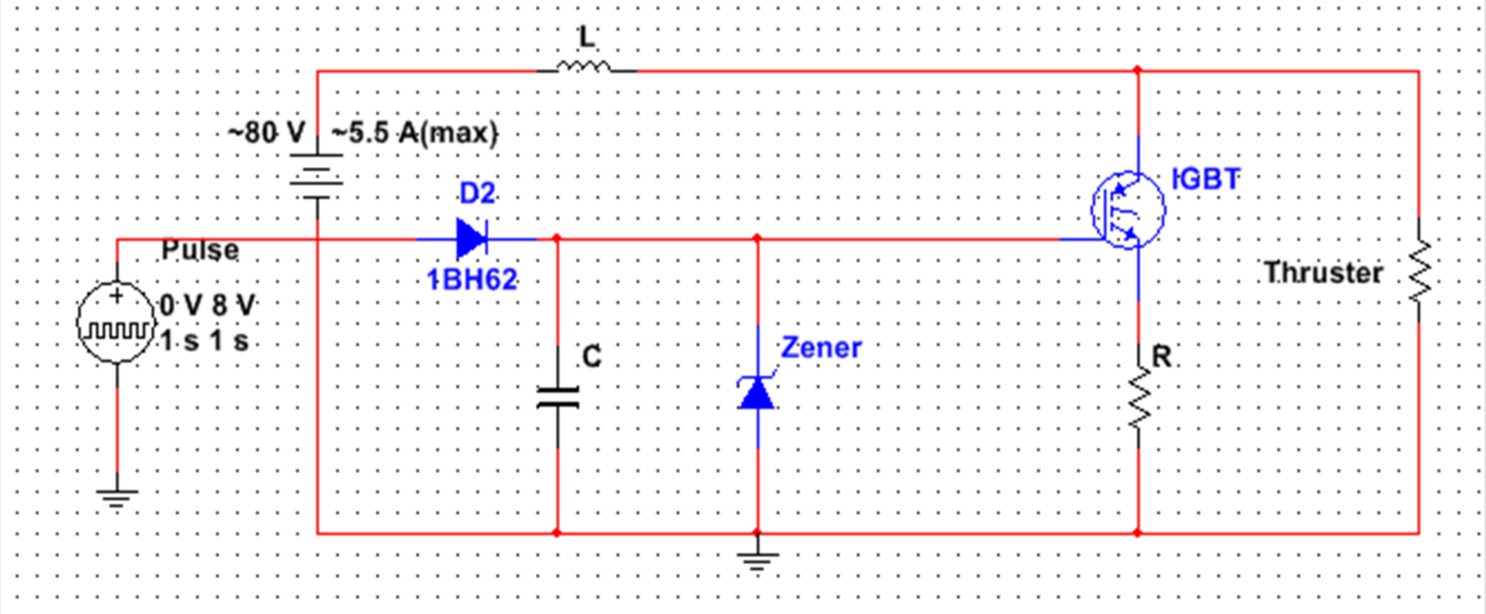
Characteristics

- 3 part nozzle construction
  - Easier machinability
  - Designed for Mach 2.65 - A/A* = 3.15
- Magnet placed at diverging nozzle to protect nozzle walls
- Stagnation Pressure – 550 Pa
- Static Pressure at throat – 267 Pa
  - Pressures from Bernoulli's Eq with const. mass flow rate
  - $P/P_0 = 0.4867$, at throat M = 1
- Anode/Cathode Spacing – 0.15"
- Product of pressure and distance gives breakdown voltage of 137 V
  - Well within circuit's capabilities



Tara Newton

Initial Circuit Design



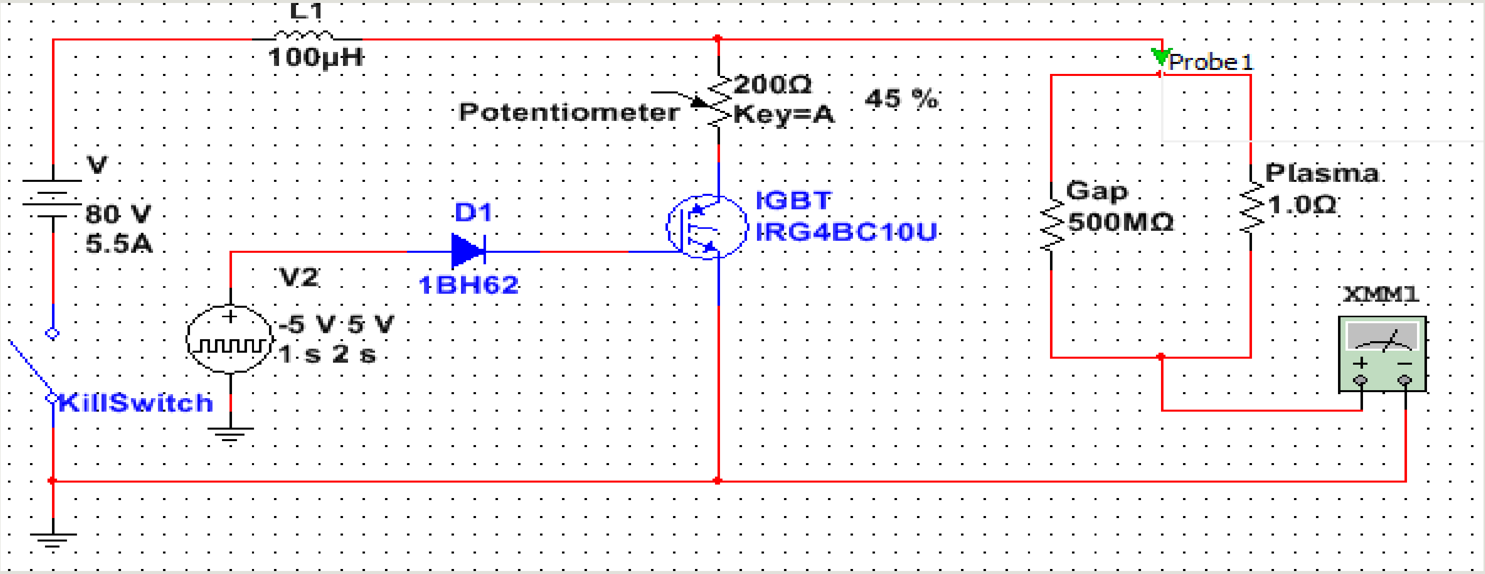
- Once in steady state: I = $\frac{V_S}{R}$ When the switch opens:

$$V_L = L\frac{di}{dt} = L\frac{I-0}{dt} = L\frac{V_S}{R*dt}$$ dt = 130 ns, L = 100 uH

- Theoretically capable of achieving 4.2 kV spike

Shane Warner

Final Circuit Design



- The concepts of the circuit are the same but slightly modified
- No need for capacitor and Zener diode in parallel

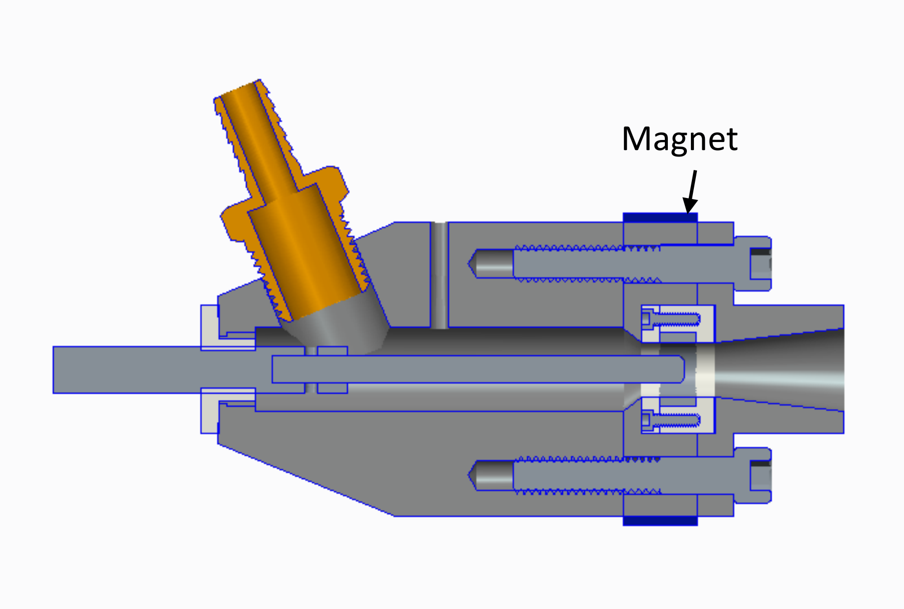
Shane Warner

Maximum Magnetic Field

- The desired magnetic field is given by B = $\frac{mv}{qr}$, $v = \sqrt{\frac{20eV}{3m}}$, where m is mass, v is velocity, q is charge, r is radius, eV is an electron-voltage, and B is the magnetic field. These equations simplify to give us:

$$B = 0.316\ T\ \text{(calculated)}$$

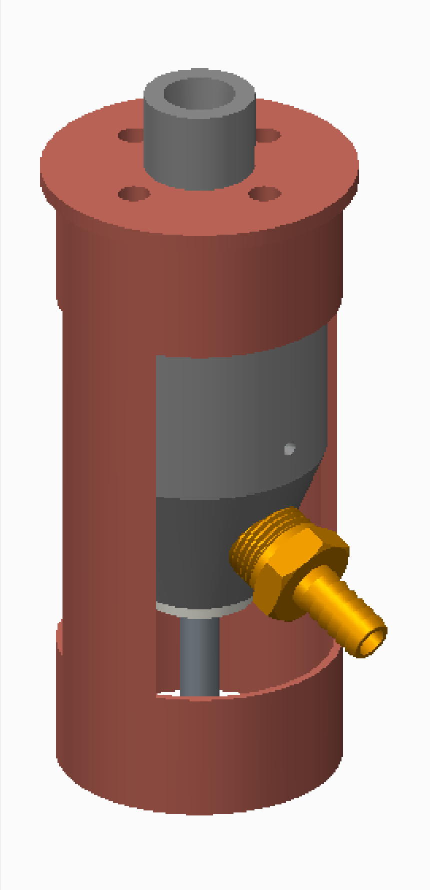
- However, our sponsor advised us that any magnetic field would help
  - A flexible permanent magnet is used and rated at: **B = 0.1 T at the center**



Shane Warner

Test Stand

- Standard Pipe with cap
  - Separate Pieces
- Easy to machine
- Easily attached to thruster and detached for any required adjustments
- Lightweight
- Easy to access argon and pressure ports
- Adaptable for whatever force measurement equipment is used



Cory Gainus

Vacuum Chamber Components

Vacuum Pump
- Welch 1400
- Vacuum rated to 1×10^{-4} Torr

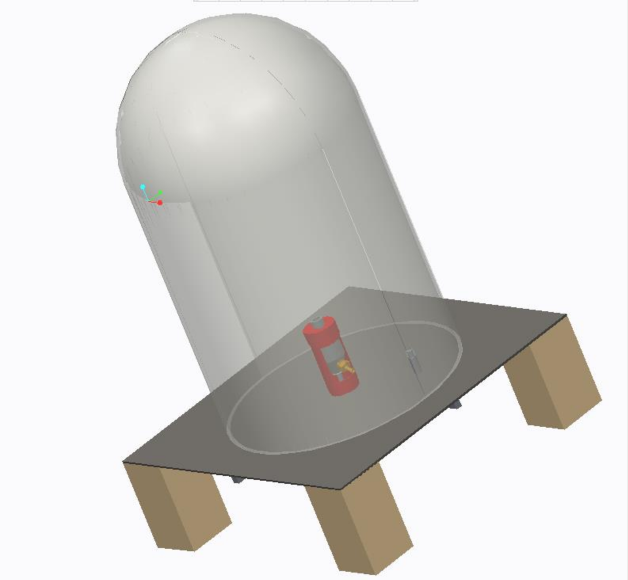
Vacuum Chamber
- Owen's Corning Bell-Jar
  - 18" x 30" x 0.5"
- Donated by Dr. Weatherspoon

Baseplate
- Donated by Dr. Weatherspoon
- Argon and electrical connection input through baseplate
- Reinforced to withstand absolute vacuum

Cory Gainus

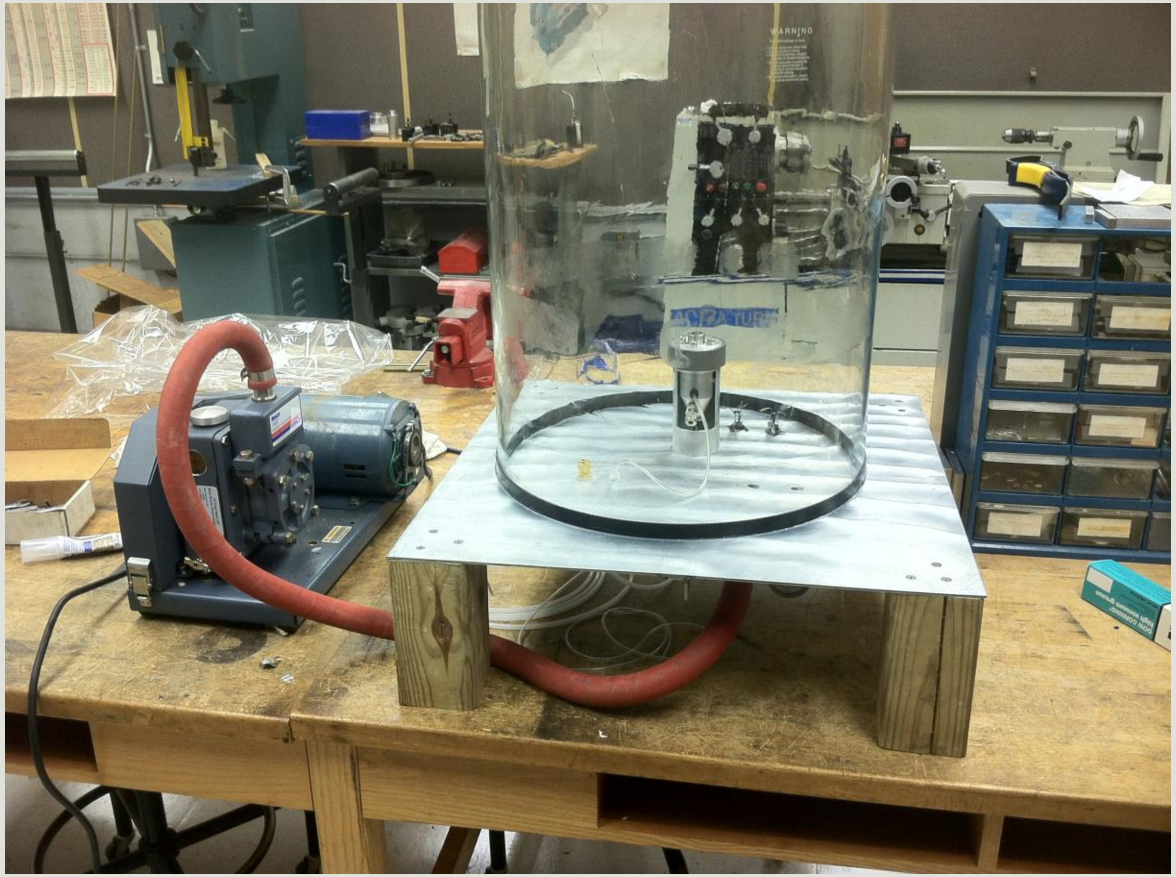
Final Testing Set Up

- Angled steel reinforced baseplate
- Pipes welded for
  - Vacuum hose
  - Vacuum gauge
  - Argon inlet
- Wires throughput with stycast epoxy
  - Supplied by Dr. Guo
- Edges of chamber sealed with vacuum grease



Cory Gainus

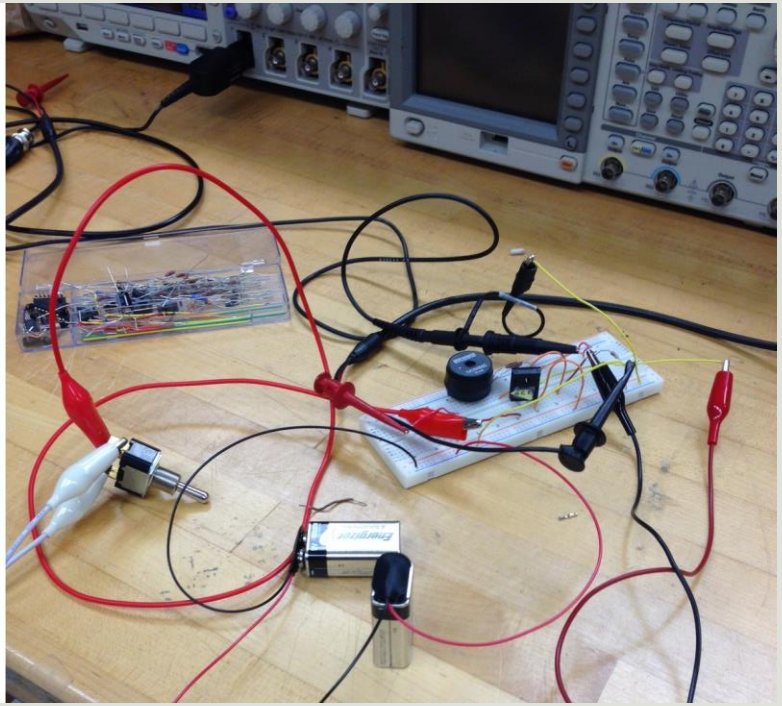
Vacuum Testing

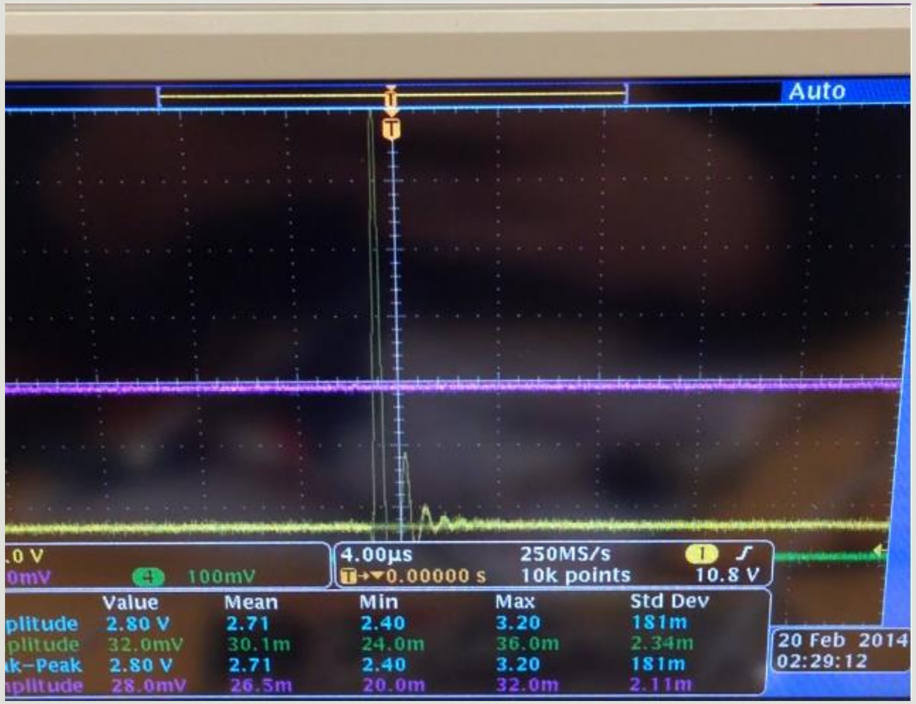


Cory Gainus

Circuit Test and Results

- Full Circuit Testing
- Approximately 150 V spike at Vsource = 20 V and Rtop = 50 ohm
- Theoretical max spike
  2 kV



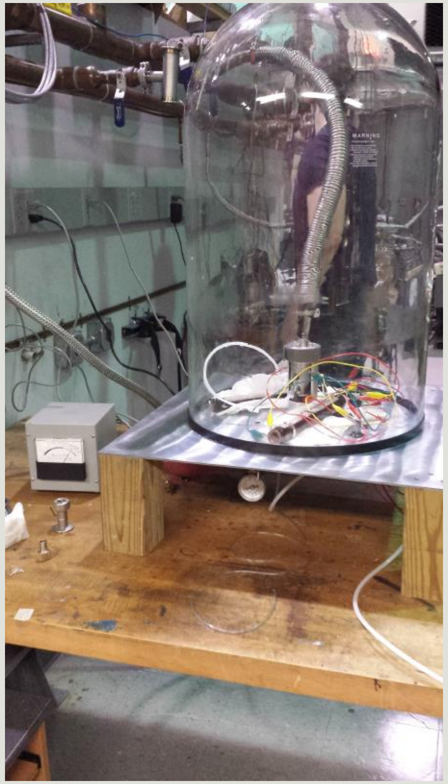


	Value	Mean	Min	Max	Std Dev
plitude	2.80 V	2.71	2.40	3.20	181m
plitude	32.0mV	30.1m	24.0m	36.0m	2.34m
k–Peak	2.80 V	2.71	2.40	3.20	181m
nplitude	28.0mV	26.5m	20.0m	32.0m	2.11m

Gerard Melanson

Final Testing

- Vacuum pump supplied by Dr. Guo from Magnet Lab
- Attempted the ionization of Helium
  - Argon not readily available in Magnet Lab
- More accurate vacuum gauge
  - Vacuum of 300 miliTorr (approx. 40 Pa) was achieved
- No pressure transducer available
  - Difficult to know what pressure of Helium was inside thruster
- Limited power supply options
  - Limited voltage spike capabilities
- Voltage spike of approx. 400V was achieved
  - Unfortunately no ionization event occurred



Gerard Melanson

Summary

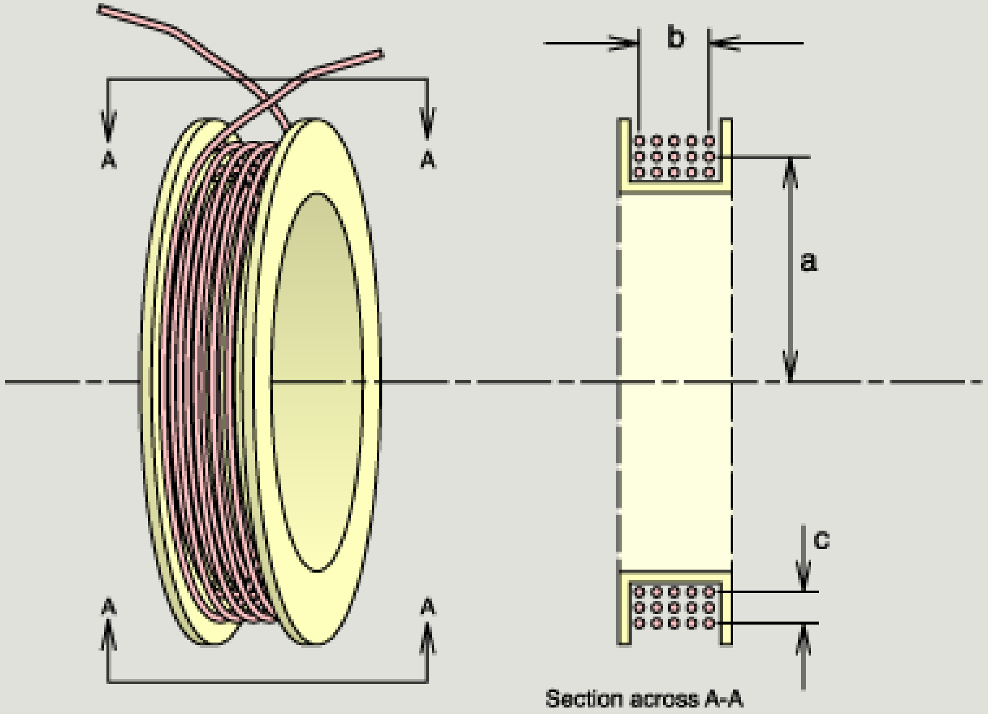
- **Electrical Design:**
  - Circuit:
    - Circuit designed, implemented and tested
      - Maximum voltage spike of 2 kV
  - Magnet:
    - Magnetic field was calculated and implemented with flexible permanent magnet around test stand
      - Still needs testing to verify effectiveness
- **Mechanical Design:**
  - Thruster:
    - Thruster designed, fabricated
      - Unable to test due to lack of proper measurement equipment
  - Vacuum Chamber:
    - Baseplate outfitted and reinforced to be able to withstand the vacuum
    - Tested using Welch 1400 vacuum pump
      - Vacuum gauge was cheap and inaccurate
      - Vacuum pump and gauge provided by Dr. Guo achieved vacuum of 0.3 Torr (approx. 40 Pa)
  - Breakdown:
    - No ionization event was achieved

Gerard Melanson

Future Recommendations - Magnet

- Max Current = 5 A
- Length = 0.01905 m
- Diameter of 22 gauge wire =0.0017 m
- Number of loops per layer = 11
- Absolute max field = 0.316 T = 4790 A-turns
- Typical ideal field = 0.050 T = 758 A- turns
- At least 14 layers needed
  - Coat with layer of insulation between wire layers

Fig. 1 Dimensions of a multi-layer coil of rectangular cross section



Gerard Melanson

Future Recommendations – Vacuum/Test

- **Adequate Vacuum Chamber Needed**
  - Current vacuum chamber and pump were donated
  - A more precise vacuum gauge is required to accurately measure vacuum.

- **Make Use of High-Voltage Plasma Laboratory**
  - Argon supply
  - High-voltage power supplies readily available
    - Higher rated electrical probes
  - Experience dealing with plasma generation

Tara Newton

Future Recommendations - Measurement

- **Acquire measurement devices for testing**
  - Measuring thrust
    - Load Cell
  - Measuring Housing Temperature
    - Thermocouple
  - Measuring Voltage Spikes
    - Differential voltage probes
  - Chamber Pressure Measurement
    - Differential Pressure Transducer

Tara Newton

Questions?

Thank You for Your Time!