Magnetostrictive Actuator

Project Proposal

Randall Bateman, Aaron Bolyen, Chris Cleland
Alex Lerma, Xavier Petty, Michael Roper

December 11, 2015

NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Honeywell

Overview

- Introduction
- Need Statement/Goals
- Constraints for Project/Design
- CAD Model Images of Proposed Design
- Justifications for Design
- Material Selection for Design
- Bill of Materials
- Risk Management
- Contingencies
- Design Alternatives
- Gantt Charts
- Conclusion

Introduction

- Honeywell Aerospace designs and manufactures numerous products and services for the commercial and military aircraft industry

- Honeywell contacts initiating the project are Michael McCollum, the Chief Engineer of Pneumatic Controls Technology for Honeywell and Mitchell Thune, a recent NAU graduate who is working with Michael McCollum on this project

- The clients want to replace an standard electromagnetic solenoid with a solenoid using a magnetostrictive material, Terfenol-D, in the pneumatic control systems used on commercial airliners

Need Statement

Currently, there are no feasible actuators for aircraft valve systems using the magnetostrictive material Terfenol-D.

Project Goal

The goal of this project is to develop a viable actuator that applies the magnetostrictive properties of Terfenol-D.

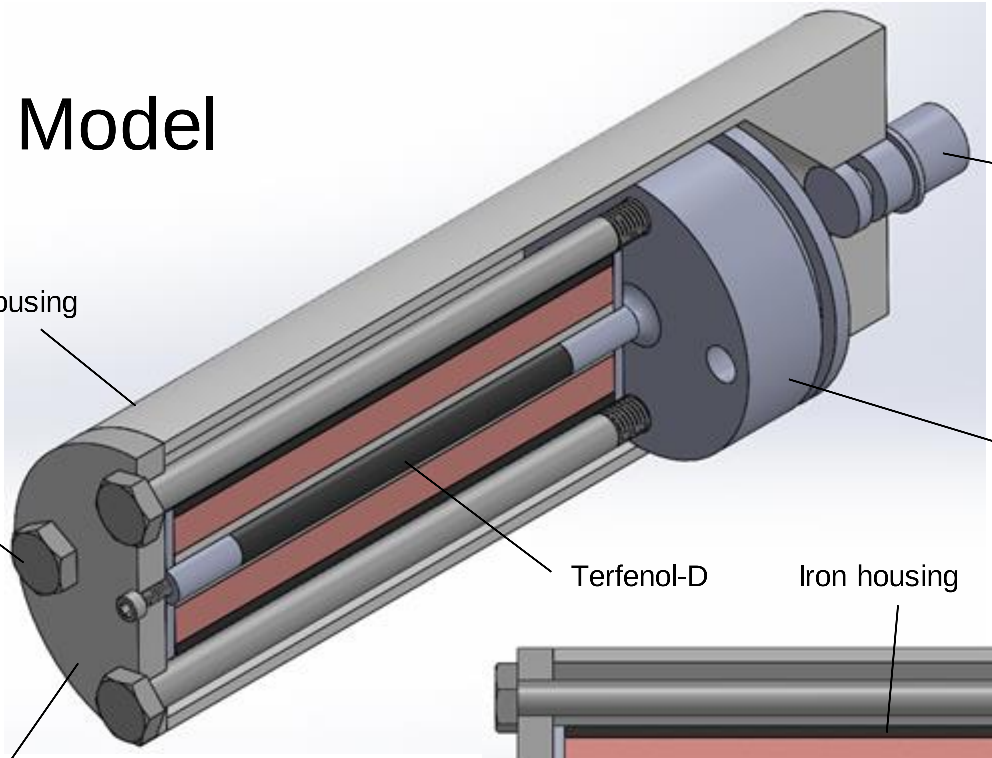
Constraints

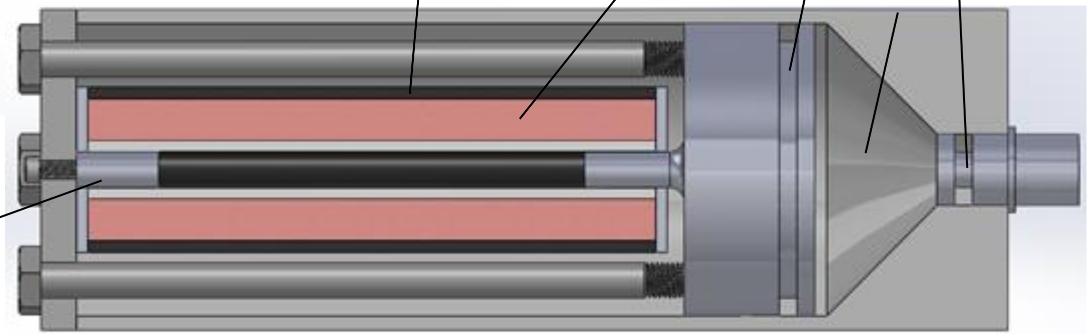
- At least 25lbf of force exerted
- Need at least 0.03in stroke (based off of 3in length rod)
- Must cost less than $5000
- Must be smaller than 3 x 5 x 12in
- Coefficients of thermal expansion must be constant throughout device
- System must be cooler than 212°F
- Greater than 1:10 ratio of input to output distances

Proof of Concept

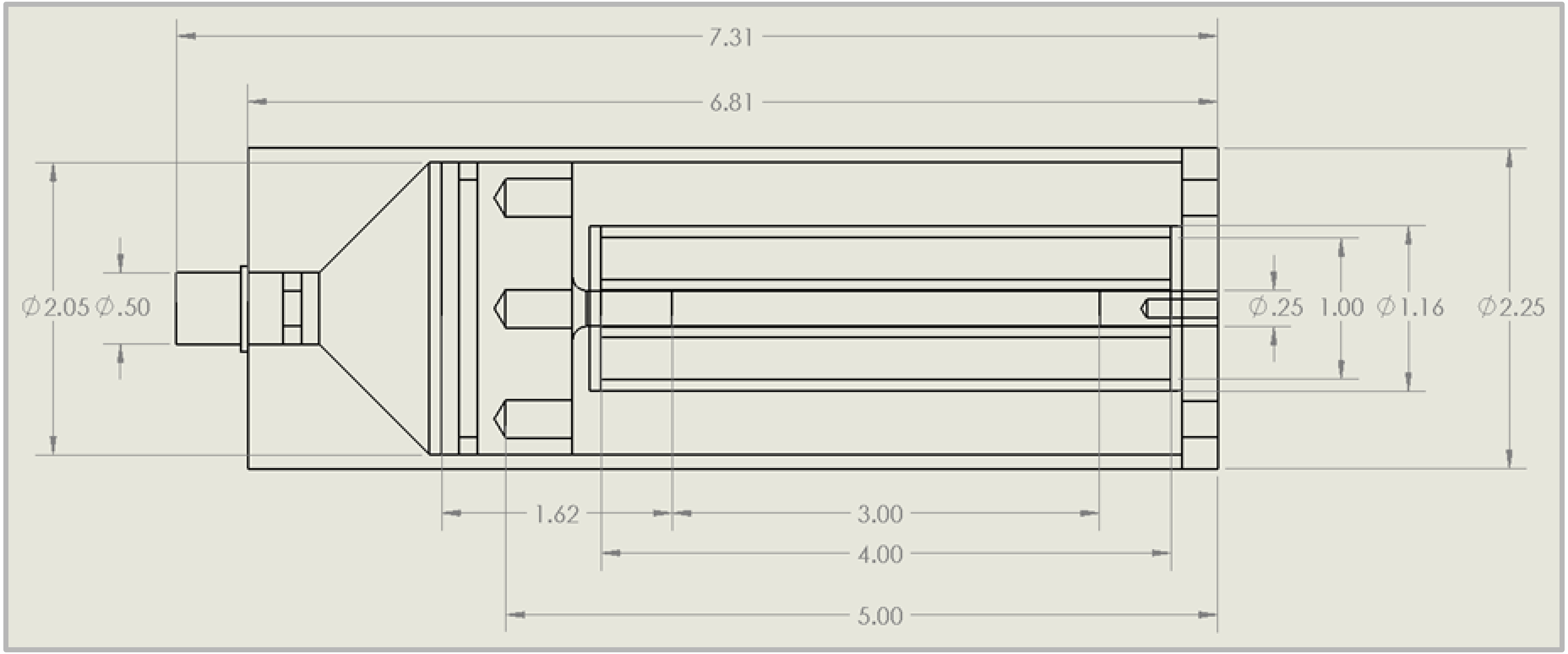
- Design coil to generate a magnetic field
  - 30mT
  - 2A
  - 12V
- Prove that the small stroke can be amplified
  - 75μm converted to ~1mm

CAD Model


Small piston
Aluminum housing
Large piston
Pre-stress
bolts (4)
Terfenol-D
Aluminum end cap


Seal grooves
Iron housing
Coil
Fluid
chamber
Core stop

Dimensions of Design



Calculations and Justifications

- Terfenol-D Dimensions
  - Based on maximum force output of Terfenol-D at 1000lbf
  - A 0.25in diameter rod can handle the compressive stress
  - Factor of safety is 8.54
  - A 0.125in diameter rod of Terfenol-D will also handle the compressive stress, but due to the large cost of the material, the diameter is pushed up to 0.25in diameter
- Solenoid Dimensions
  - The solenoid must produce around 200mT for the correct stroke length
  - With the amperage capacity of 30 gage magnetic wire, the 200mT can be produced with 6954 turns
  - The outer diameter of the solenoid results in 0.822in

Calculations and Justifications Continued

- Stress Concentrations
  - The primary failure points are points where there is a drastic change in geometry
  - These locations are the notches in the pistons, the large piston shoulder, and the slope change within the lever
  - The material selected has high yield strength, so the majority of the components can be machined from the same material stock
- Lever Pressure
  - To ensure 25lbf output the input must be over 400lbf
  - The resulting pressure is 132.4psi
  - Thickness of 0.08in which provides a factor of safety at 13.5
  - At max input force of 1000lbf, the pressure is 318.3psi

Calculations and Justifications Continued

- Bolt Thread Depths
    - The two common bolt diameters that can fit within the casing are 0.25in and 0.125in
    - The 0.125in bolt fails under the tensile load
    - The thread engagement length for the 0.25in diameter bolt is 0.4in to get a factor of safety greater than 2
- End Plate Loading
    - The end plate is supported in 5 locations with the maximum bending stress and shear stress at the center
    - The center is supported by the 0.25in core stop
    - The required thickness of the end plate must be at least 0.162in
    - The accepted thickness is 0.25in with a factor of safety above 2

Material Selections

- Bolt Selection: Stainless Steel Grade 316
- Lever Material: Aluminium 2011-T3
- Piston Material: Aluminium 2011-T3
- Solenoid Casing: Soft Iron, ASTM A848
- Solenoid Wiring: 30 Gage Magnetic Copper Wire
- Lever Fluid: SAE J1703 Brake Fluid
- Seal: Teflon

Bill of Materials

Component	Manufacturing Cost ($)	Purchasing Cost ($)	Qty.
Terfenol-D core	Included with Purchase	447.00	1
Soft iron casing	Included with Purchase	138.00	1
Aluminum casing	1.31	48.74	1
Magnetic coil	Included with Purchase	TBD	1
0.25in bolt	N/A	5.59	4
0.125in bolt	N/A	0.51	1
Brake fluid	N/A	4.99	TBD
Teflon seal	Included with Purchase	15.00	2
250V USA Power Plug adapter	N/A	6.08	1
Total	698.99		

Risk Management

- All factors of safety are 2 or higher
- Stress concentrations at changing geometry have been taken into account
- Several components of the design are stronger than required due to other constraints. **For example:** The width of the large piston must be several times longer than needed to prevent failure, because it must also be able to handle bolt depths
- All materials are designed to never go above yield strength
- Non-solenoid components are made from materials with very low magnetic permeability
- Solenoid temperature is designed to never exceed 212°F
- Consider purchasing additional Terfenol-D at beginning of second semester

Contingencies

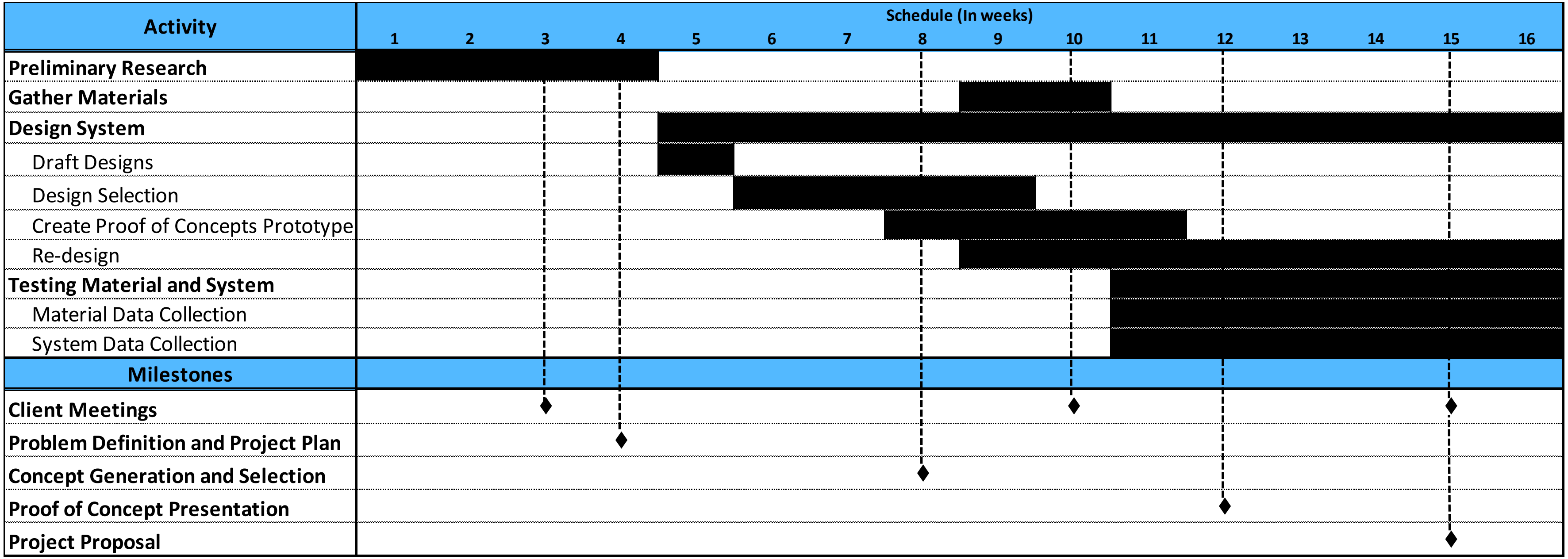
- Class 1 lever can be used if hydraulic lever does not function correctly
- Custom manufacturing if closer tolerances are needed
- Increase solenoid diameter if Terfenol-D’s stroke is too small
- Have a third party pressurize the lever
- Increase piston lengths to help maintain airtight seal
- Bolts can be tightened or loosened to change prestress value*
- If failure occurs, then reiterate with higher factors of safety

* The pre-stress value must be obtained during testing due to opposing stroke vs. pre-stress relationships

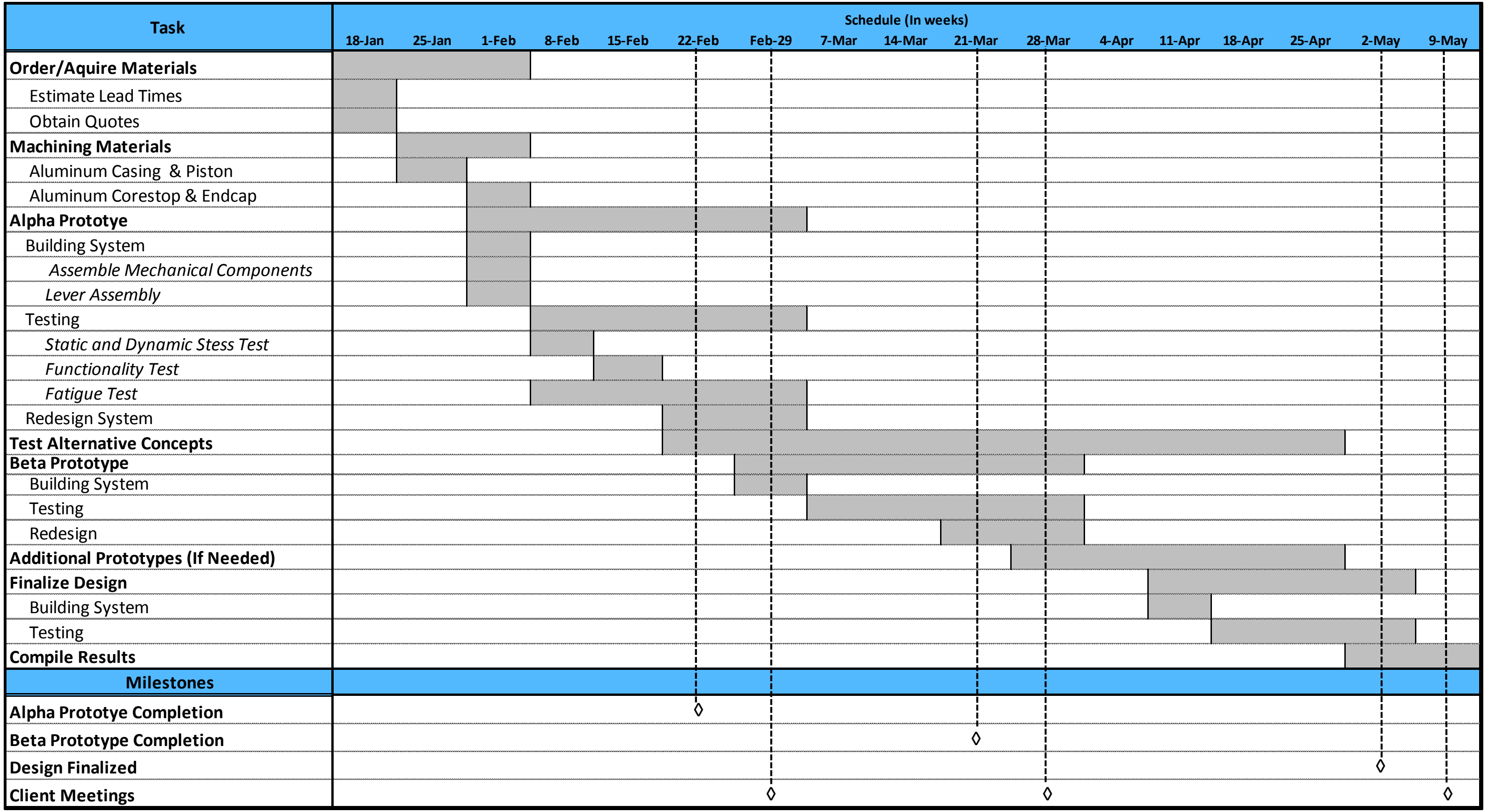
Possible Design Alternatives

- Ferrofluid Hydraulic Lever
- Vibrating Wire Hysteresis Control
- Iron Filings Hysteresis Control
- Randomized Magnetic Field for Hysteresis Control
- Adding a Valve to the Output Stroke
- Hollow Terfenol-D Core
- Permanent Magnets to Create Magnetic Exchange Bias

Updated Fall 2015 Gantt Chart



Spring 2016 Gantt Chart



Conclusions

- Our goal is to design a feasible actuator using the magnetostrictive material Terfenol-D
- The proof of concept demonstrated that our design can amplify the stroke through a lever system and produce a sufficient magnetic field
- The overall dimensions of the current design are 7.31 x 2.25in diameter
- The most costly component of the design is the Terfenol-D itself, the overall cost for materials is $698.99
- Stress values and concentration factors were calculated to determine the most efficient material to use
- Several contingency plans are outlined and alternative designs options are described
- January, 2016 will begin with the construction of first prototype

References

- ETREMA Products, Inc., 'Terfenol-D - ETREMA Products, Inc.', 2015. [Online]. Available: http://www.etrema.com/terfenol-d. [Accessed: 1- Dec - 2015].
- Mcmaster.com, 'McMaster-Carr', 2015. [Online]. Available: http://www.mcmaster.com/. [Accessed: 08- Dec- 2015].
- Autozone.com, 'Prestone/12 oz. DOT 4 brake fluid', 2015. [Online]. Available: http://www.autozone.com/brake-and-power-steering-fluid-additives/brake-fluid/prestone-12-oz-dot-4-brake-fluid/433371_0_0/. [Accessed: 05- Dec- 2015].
- Fastenal.com, 'Products', 2015. [Online]. Available: https://www.fastenal.com/products/. [Accessed: 08- Dec- 2015].
- Ahpseals.com, 'Spec-A-Seal-American High Performance Seals', 2015. [Online]. Available: http://www.ahpseals.com/services/calc_piston_V2b.php5?sid=43S. [Accessed: 03- Dec- 2015].
- H. Roters, Electromagnetic Devices. New York: John Wiley & Sons, Inc, 1941.
- M. McCollum, 'Solenoid Design: Pneumatic Controls Engineering - Lecture 9', Online.