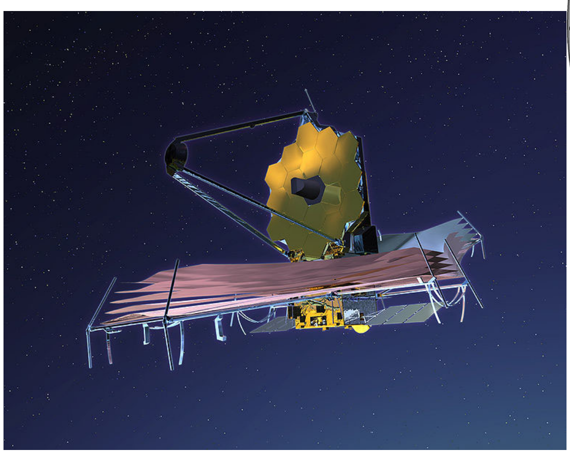
Amog Ram 9/21/2009
Summer 2009 Electric Propulsion Lab Report

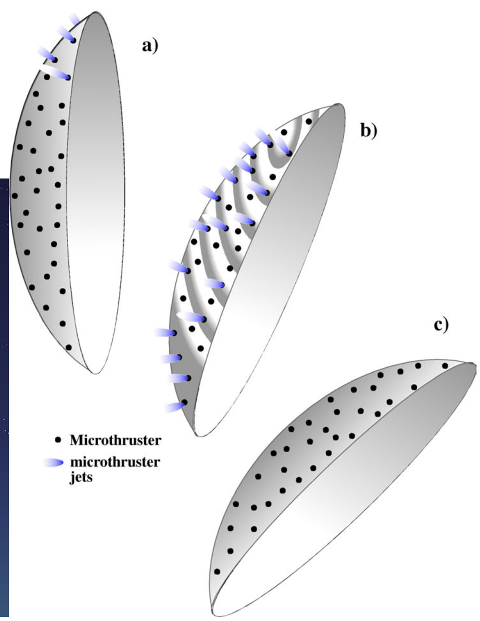
This past summer at the Electric Propulsion Lab at Princeton University I had the opportunity to work on two very interesting projects. The first consisted of restoring an old argon thruster found in the lab that had not been used in quite some time. We hoped to replace the current Lithium Lorentz Force thruster whose operation required meticulous handling and care due to the dangers associated with lithium.

The argon thruster had been previously damaged during a firing when argon had leaked outside of the anode chamber and created an "arc" of electrons through the leaked, and now ionized, argon. This arc burns nearly everything in its path as the electrons search for a grounded piece of metal. The stand of the thruster needed to be reinforced and all burnt or deformed pieces of the structure had to be replaced. The thruster stand also had to be modified to accommodate a solenoid for future tests, whose addition should increase specific impulse.

A video of the restored argon thruster during its successful first firing can be seen at the link below
http://alfven.princeton.edu/graphics/Argon%20Thruster%20Firing.3GP

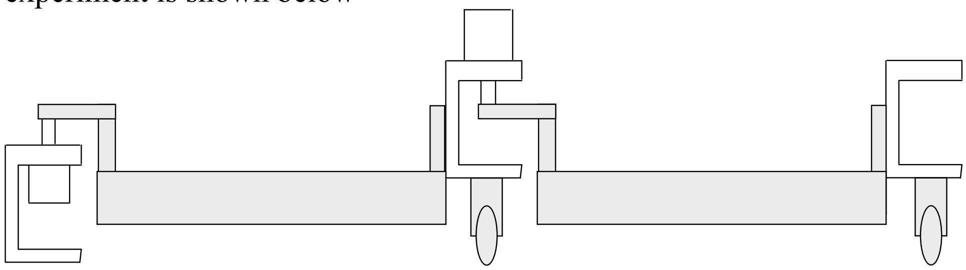
The second project was a proof of concept idea for the use of plasma micro-thrusters in space structures for the purpose of vibrational damping and orientation.





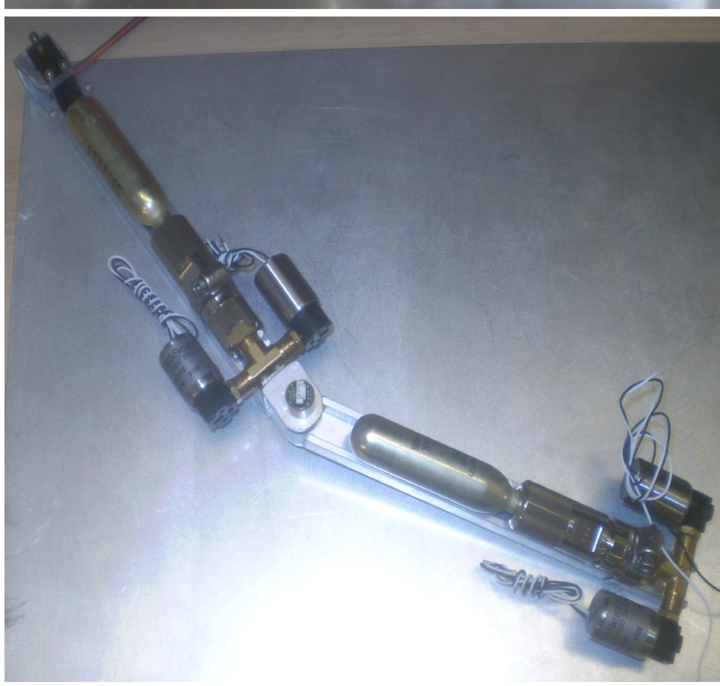
Structures such as the one shown above would use hundreds of tiny micro-thrusters to damp out vibrations that develop after maneuvering. Such a high specific impulse micropropulsion system will allow fuel-efficient operation and precision control.

A feasible analogous experiment was subsequently designed. The basic design of the experiment is shown below



The structure consists of two linked aluminum bars which hold the tabletop equivalent of microthrusters: compressed CO_2 and solenoid valves. The angle of each arm is sensed by rotary encoders which are housed in C brackets and also serve as the joints for the arms. The end of only the first arm is held; the rest are free to rotate Teflon wheels. The entire experiment is mounted on polished aluminum to allow for a low friction environment. If the arms can be controlled to rotate to the desired angle and maintain it even in the presence of external disturbances, further advances can be made in the design to resemble the final goal.

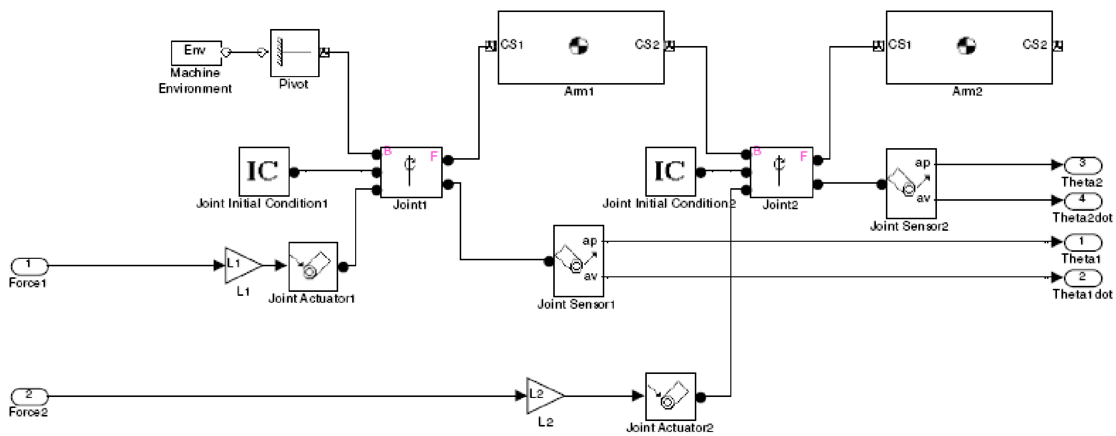
(Side view)



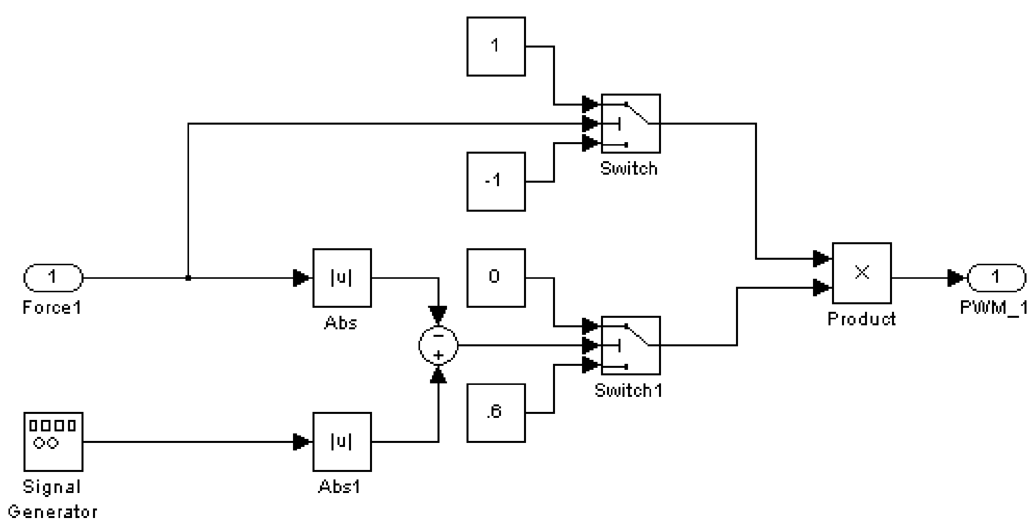
(Top view of both arms)

The next step would be to model the control system for such a physical system. In attempting to replicate the dynamics of the physical system two things quickly became apparent. First, the system was nonlinear and more advanced control methods then what we had learned were necessary. Second, the valves could not mediate the flow through them; they were either open or closed, but nothing in between. The first problem was solved through a Matlab program called SimMechanics, in which physical systems could be modeled graphically instead of through code. A good simulation of the physical system is essential to control design in order to assess the performance of a controller without risking damage to the experiment. The second problem required the use of pulse width modulated signals as opposed to varying voltages. By controlling the time that the valves were either open or closed, an approximation of a variable flow valve could be obtained.

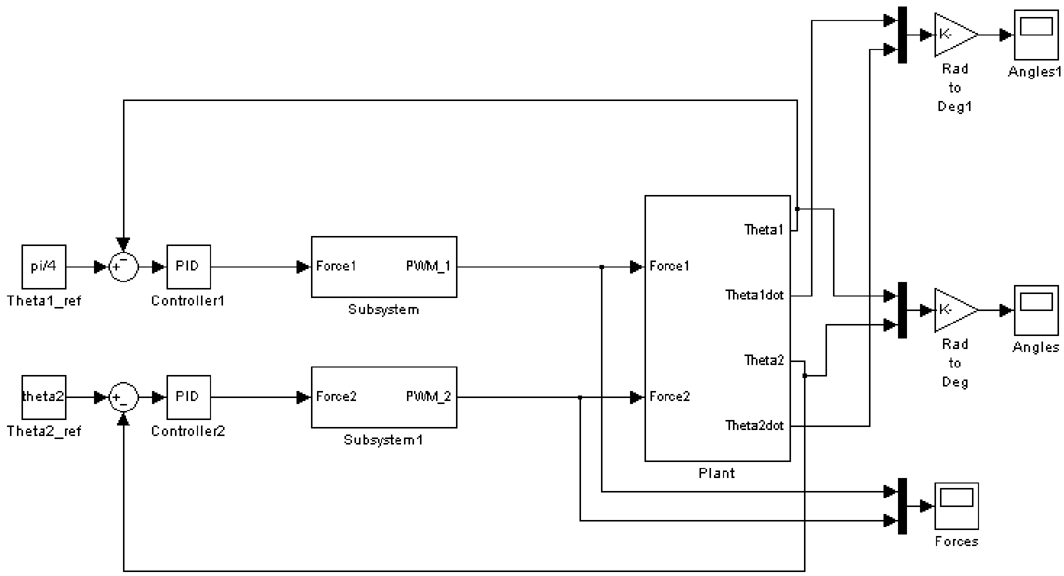
(SimMechanics model of experimental two arm linkage)



(Subsystem to convert analog voltages to a PWM signal)

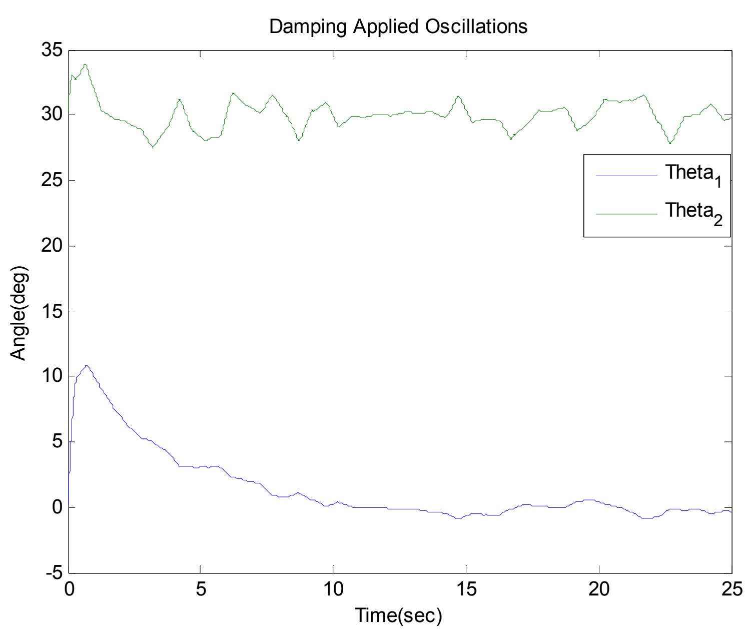


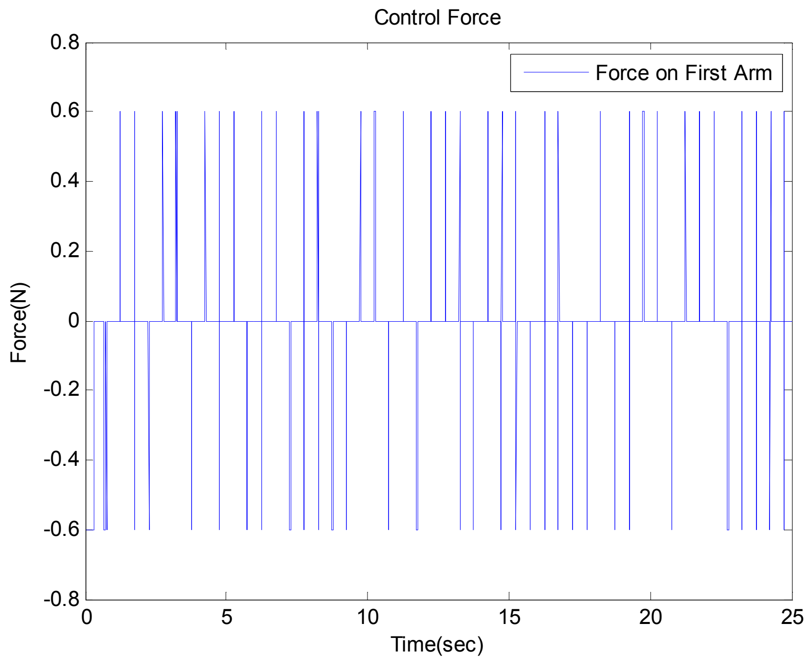
After measuring the physical parameters of our system and calculating moments of inertia, thrust generated by the valves, and kinetic coefficients of friction, a PID controller could be effectively implemented as shown in the diagram below

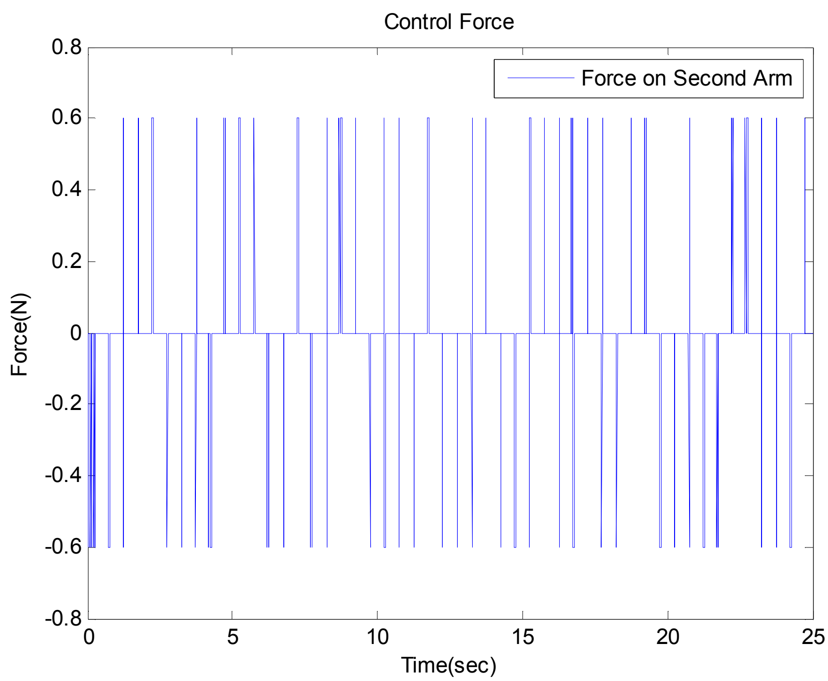


The two subsystem blocks contain the blockset that converts an analog signal to a PWM signal, while the Plant contains the blockset of the system dynamics.

The following simulation results were obtained after much tweaking to the proportional, derivative, and integral coefficients in each controller. The first three graphs represent the system damping out an initial angular velocity of 45 deg/s applied to both joints. The first joint attempts to return to 0 deg while the second joint returns to its initial condition of 30 deg

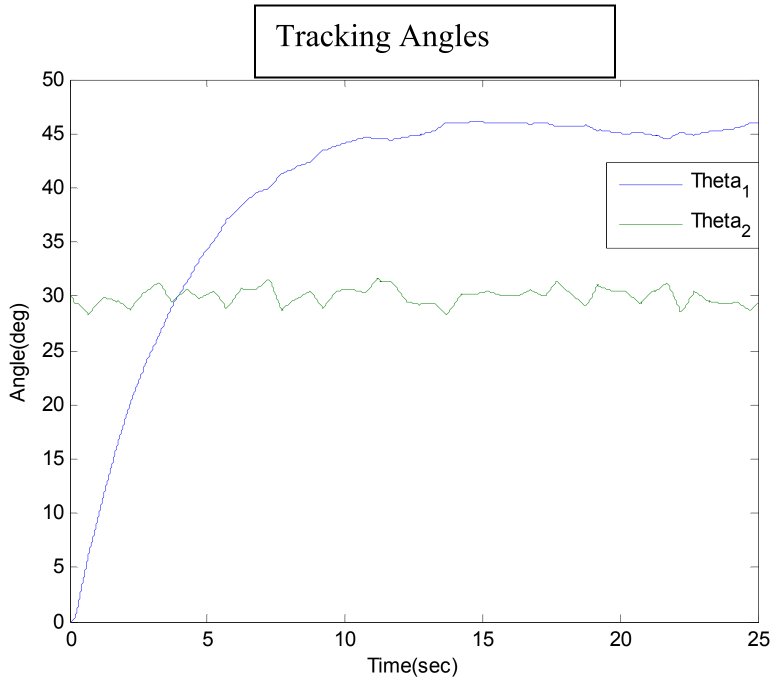


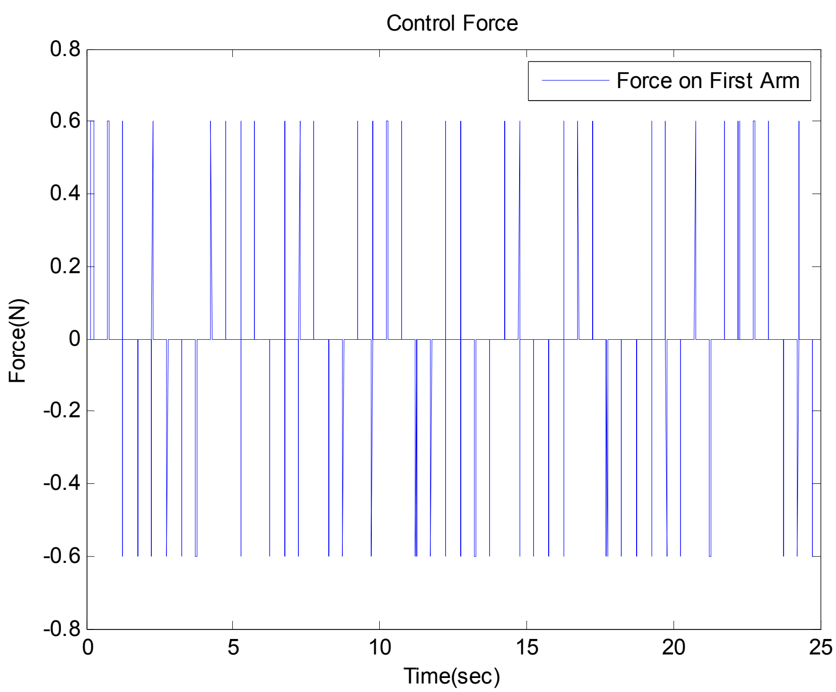


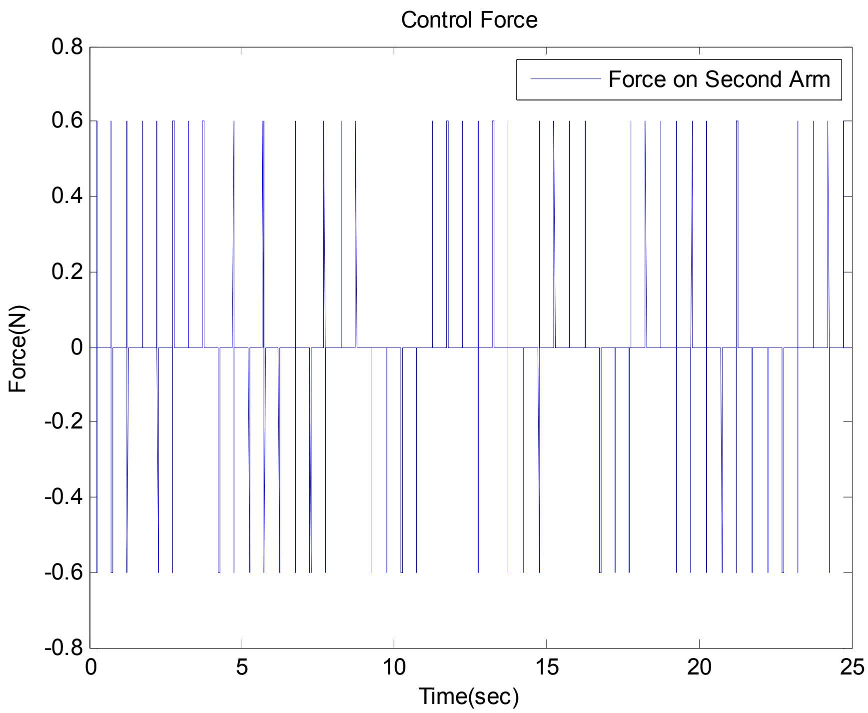


The above two graphs depict when the valves are open or closed, and for how long. The first graph corresponds to the pair of valves attached to the first arm (positive values for one valve and negative values for the other) and the second graph for the pair of valves on the second arm.

The next three graphs show the system tracking an angle of 45 deg for the first arm and maintaining an angle of 30 deg for the second arms


Tracking Angles
Theta1
Theta2
Angle(deg)
Time(sec)
0
5
10
15
20
25
30
35
40
45
50


Control Force
Force on First Arm
Force(N)
Time(sec)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
5
10
15
20
25



These simulations indicate very promising results when these valves are paired with dedicated circuits to carry out their control. Lab software such as Matlab however, became incredibly hard to configure with the valves and simultaneously achieve response times on the order of 15 milliseconds (as such are the time scales of the solenoid valves). However, with the proper software and interfaces, I am sure that the experiment's success is within reach and would like to look into continuing it as a senior project.