James Connolly
Parker Eason
Jeff Magoon

University of Maine

Human Powered Submarine
Linear Actuators
Team #1

~Potential World Record Holders

Crosby Laboratory
University of Maine
Orono, ME 04469

December 13, 2007

Written by:
James P. Connolly
Jeffrey Magoon
R. Parker Eason

The human powered submarine's linear actuators are the most essential mechanical components remaining to make the submarine a competitor for the world record. The linear actuators are the components that convert the electronic signals from the joystick (steering input) or autopilot into the mechanical movement of the control surfaces. They consist of a servo motor and various linkages to the control surfaces. The design of such a system converting an electrical signal to mechanical motion would be a relatively elementary engineering problem. However, designing such a system to be entirely submersible and operate in tight space constraints proved to be a much more difficult feat, and as such was the primary downfall of teams in the past. Our initial design is shown in Figure 1, and any revisions to the original design are discussed in further detail throughout this report.

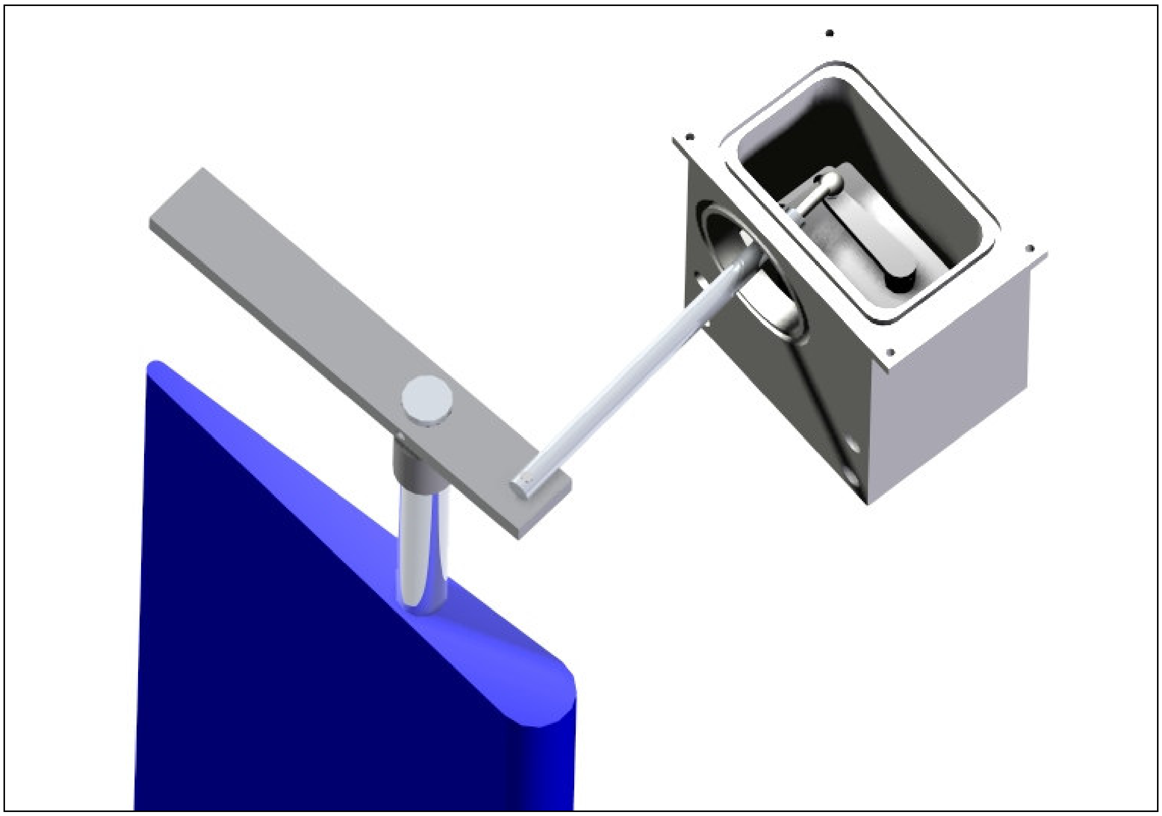

Figure 1 – Initial design of servo and linkage to the control system

Our design progress to date consists of the following:

- Box hand milled with care out of ABS plastic

  A watertight box was chosen as the means of waterproofing the servo because the servo would work best unimpeded by stuffing it with grease or anything else (as other teams had done in the past). ABS plastic was chosen for the material due to its ease of machinability and cost. The main objectives for the box design were as follows:

1. Make as much of the box out of one piece as possible, minimizing interfaces between box parts and therefore minimizing the opportunities for leakage.
2. Make the box as small as possible while still allowing movement.

The inside of the servo box was designed to follow the contours of the servo motor while allowing for a spot to solidly mount the servo within the box. The hole in the box was then enlarged from the minimum required size to fit the servo in order to allow for proper movement of the cantilever arm. An additional hole was drilled in the bottom of the box for the servo wire, and two holes were drilled through the box for bolts to pass through to allow mounting to the tail section of the submarine (see Figure 2), although these holes do not pass through the pocket where the servo is housed, so no waterproofing measures need to be taken here.

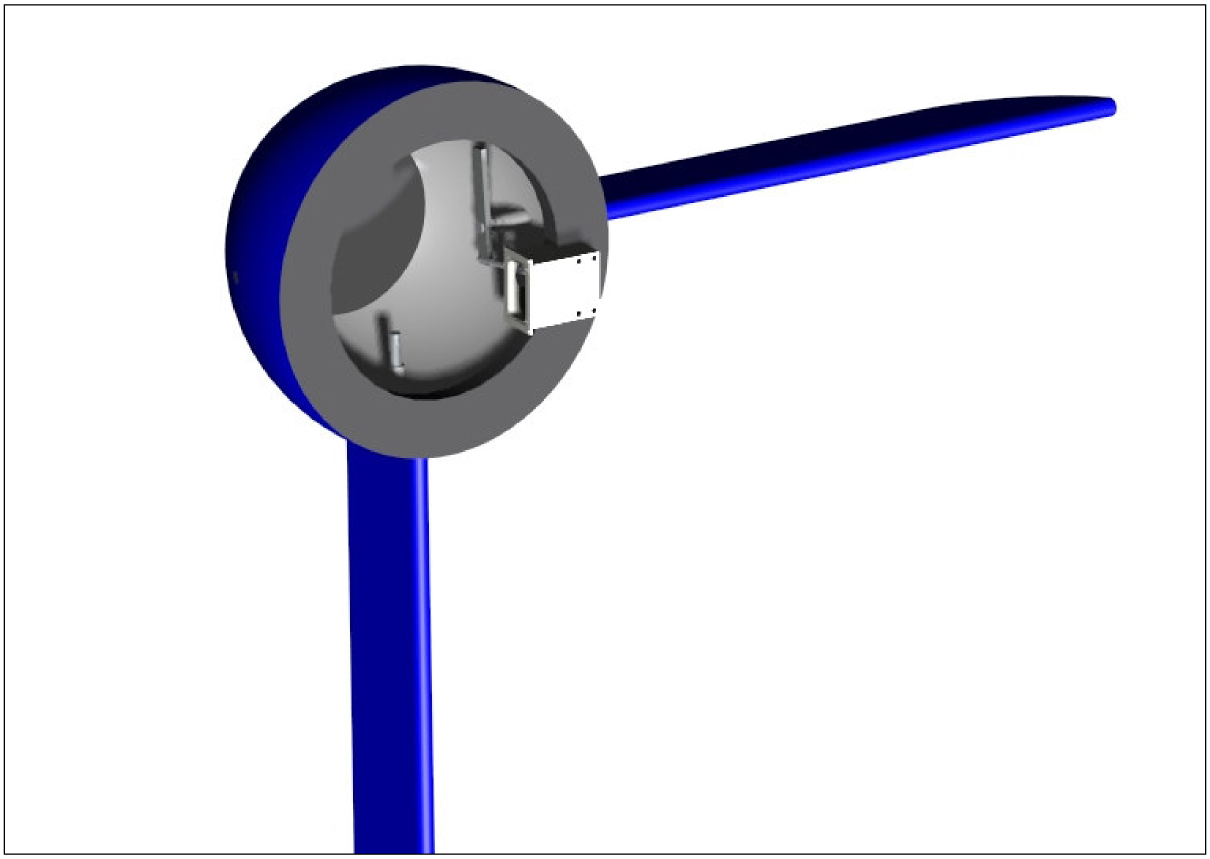

Figure 2 – Linear actuator integration with submarine rear (one control box shown out of four)

- Linkage arm between control surface and push rod

When shaping this piece of the puzzle, consideration was taken into account that the manual controls would be much more touchy than the servo driven controls, and would require a much simpler steering mechanism. Instead of making two separate linkage arms to attach to the control surface shaft, one arm used with two attachment points (See Figure 3). The manual control connection point was further from the shaft than the automatic control connection point. This lowered the sensitivity of the manual controls in order to make the manual operation of the submarine less prone to accidental oversteering by the operator.

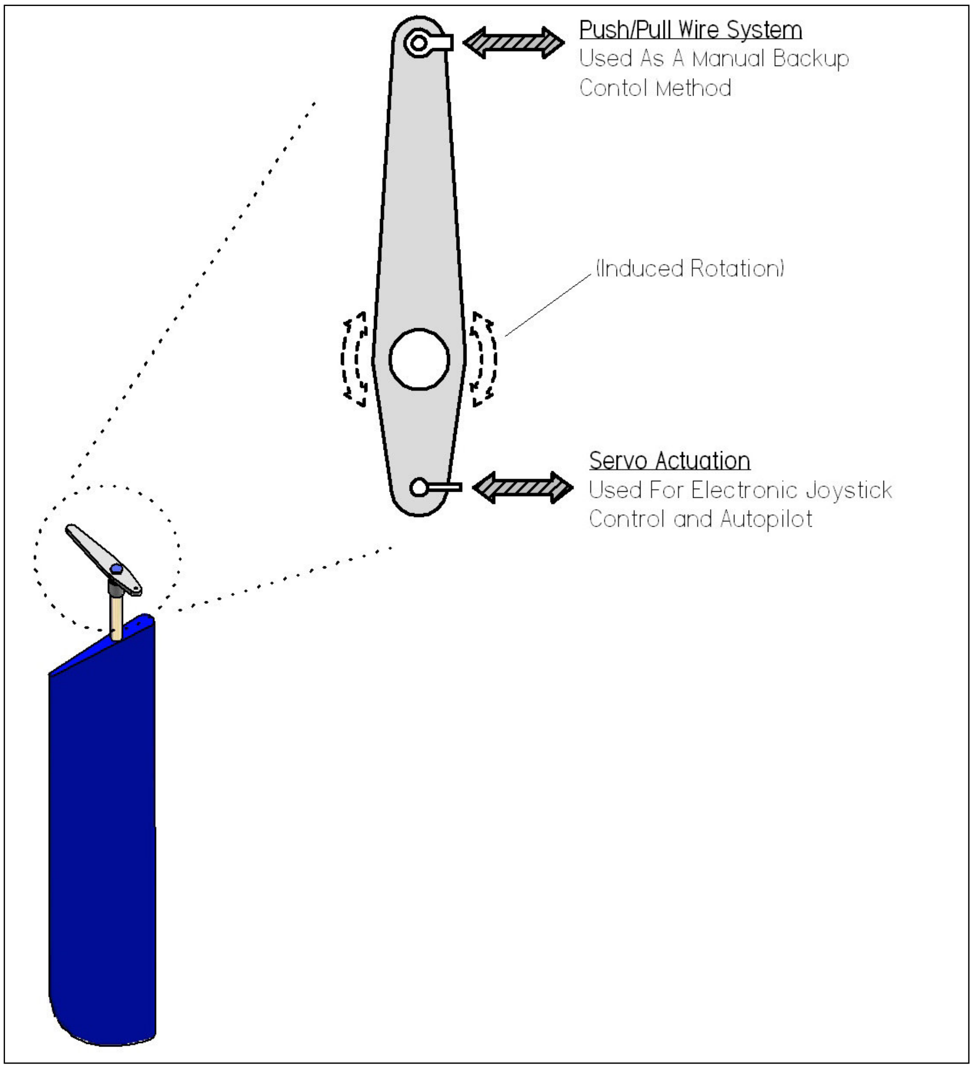

Figure 3 – Illustration of manual and automatic control attachments

- Servo

The servos used were left over from a previous submarine group's attempt at a control system, and were surprisingly still in perfect working condition. The high torque and precision of that specific model fit perfectly to our specific application. Furthermore, the servos were also closed loop, essential to our design. That allows for the microprocessor to know where the arm is in relation to neutral—which is extremely important for our friends doing the autopilot programming.

- Futaba® 1" Aluminum Single Arm for servo (silver)

This arm would hold up better than a plastic arm and also look a lot better. It was chosen to be an inch long to provide more torque than a .5" arm while maintaining a small enough size that it did not require much additional room beyond the size the box had been designed for to accommodate the servo motor.

- Push Rod and Ball and Socket Connections

Doing some catalog engineering we found that there were tiny ball and socket connections available for use with servo arms. They accepted a 2-56 threaded rod and would allow for the proper pivoting of the pushrod in relation to the linkage arms attaching it to the servo and the control surface. The ball/socket approach would also compensate for any misalignment that would inevitably occur during low precision machining operations. Seeing that it the sockets accepted a 2-56 threaded rod, we selected one from the company and opted to use it as our pushrod. In tests it was adequately stiff to transfer force from the servo to the control surface link.

- Acrylic Cover

We needed a cover, so why not have a sweet looking one? The acrylic cover not only looked amazing, but it also was a very practical choice as it provided a port to view possible leaks or mechanical failures without completely disassembling the box, or just to watch the arm move when we got bored. The cover is removable for ease of maintenance and seals with a gasket made from Permatex® RTV Ultra Blue Gasket Maker. The cover bolts into the box with 4 bolts—because if it wasn't held on it wouldn't be waterproof.

- Permatex® RTV Ultra Blue Gasket Maker

  This essential product costs under $4 a tube at VIP and is amazingly engineered—just the stuff to use when attempting a world speed record. This was used to form the gasket with the box cover, waterproof the battery cord hole, and pretty much everywhere else we needed to waterproof.

- Push Rod Waterproofing System

  This consisted of latex surgical tubing attached to the box by custom machined attachment pieces and hose clamps (see Figure 4). One end of the tubing is clamped to a threaded cylinder which is wound on to the pushrod, whereas the other end is clamped to a flanged sleeve. The flange is recessed into a pocket in the box both to improve waterproofing ability and so it is flush with the exterior and is and securely bolted on. Gasket maker is again used here as the waterproofing agent, as it outperformed Epoxy in our preliminary waterproofing tests. The metal cylinder's threading seals around the rod by means of Loctite® and as a backup measure, gasket maker is applied generously to one face around the rod/hole interaction point. The other face of the cylinder is milled down such that an adjustable wrench can be used to take it off the rod, if necessary (as the Loctite would make this difficult otherwise).

  The original design used a fork boot off of a bicycle suspension to act as a waterproof bellows. However, any movement would cause a change in inner volume of the container and as a result would cause the air inside to be compressed or expand. As a result, the servo motor had to do much more work than was otherwise necessary. To solve this problem, the original approach was to install a thin latex membrane on one side of the box. This way, when the pushrod moves and the air inside the box starts to compress, the membrane can deform and allow the volume inside the box to remain constant. When the fork boot was replaced in the design with a latex tube (which is cheaper, more spatially efficient and should provide a better seal) the membrane could be eliminated, as the latex tubing should deform itself and serve the same purpose.

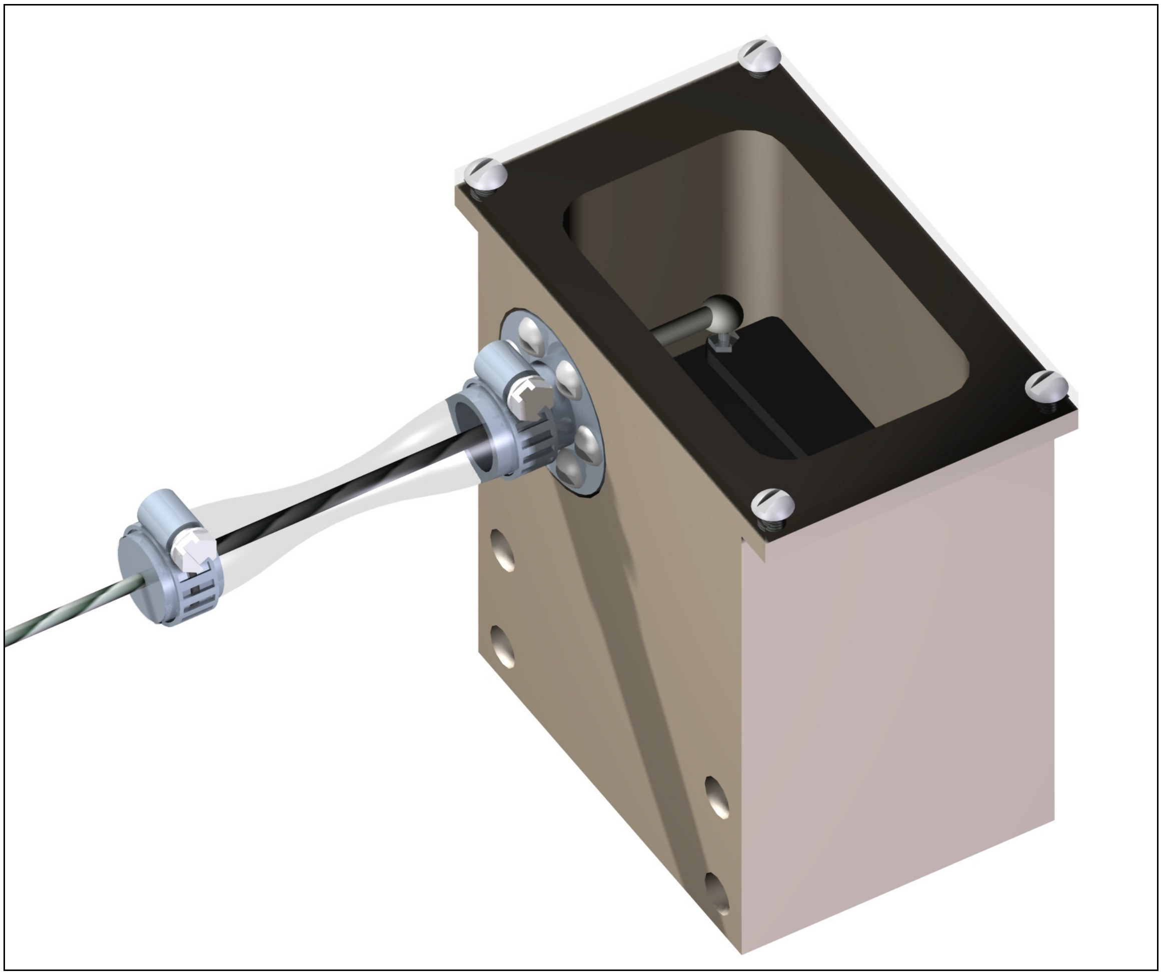

Figure 4 – Illustration of waterproofing techniques used.

Overall, the design process went pretty smoothly, and our team did not encounter any major setbacks this semester. As a result, our milestones were met and we have a complete working prototype that has undergone successful mechanical testing and is ready to be placed underwater for waterproof testing. If the prototype performs well underwater, our team's first focus next semester will be to manufacture three other similar models and test all of the linear actuators in conjunction with the joystick and autopilot control systems. Other goals to be achieved before the competition can be found on the team website under the Linear Actuator team milestones.