Assessing the Viability of Nickel-Titanium 'Muscle Wire' for Aerospace Control Applications

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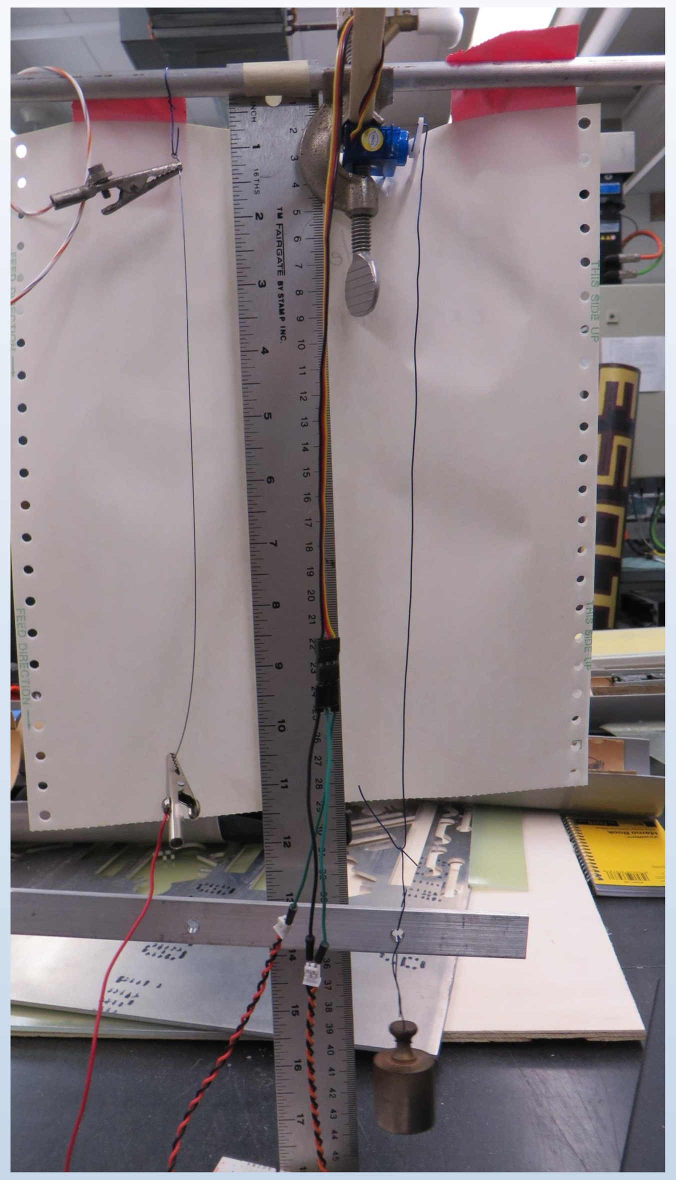
Abstract

This experiment is concerned with determining if smart materials such as nickel-titanium wire provide a working alternative to conventional servos in applications such as aircraft control surfaces. This was accomplished by comparing the power used to produce a certain deflection under a certain load, with a secondary objective of finding the relative ease of use of each actuator, such as space and mounting requirements. Power consumption comparisons showed that the Flexinol consumed an inconsistent amount of power that was generally greater than that used by the servo by a factor of more than 25. In addition, it was found that the Flexinol required 30cm of linear space not contacting any other materials to accomplish the same deflections, as well as being less consistent in maintaining said deflections and requiring much more time to change deflections. From these results it was concluded that Flexinol is ill-suited for aerospace control applications.

Introduction

Smart materials are manmade materials that have unique properties allowing them to change physical properties based upon external stimuli, such as stress or temperature. Nitinol, an alloy of nickel and titanium has the ability to change shape when heated. This experiment compares this effect with the movement of a servo for the purposes of actuating a control surface in an airfoil. By constructing a testbed composed of a wing segment and control surface in which both control setups can be mounted without differences in mass or aerodynamic properties, the two methods of actuation can be compared by holding a deflection in a wind tunnel. The main focus of research between the two materials is their relative efficiency, i.e. how much power they require to perform the same task, with a secondary focus on how they compare in usability and robustness.

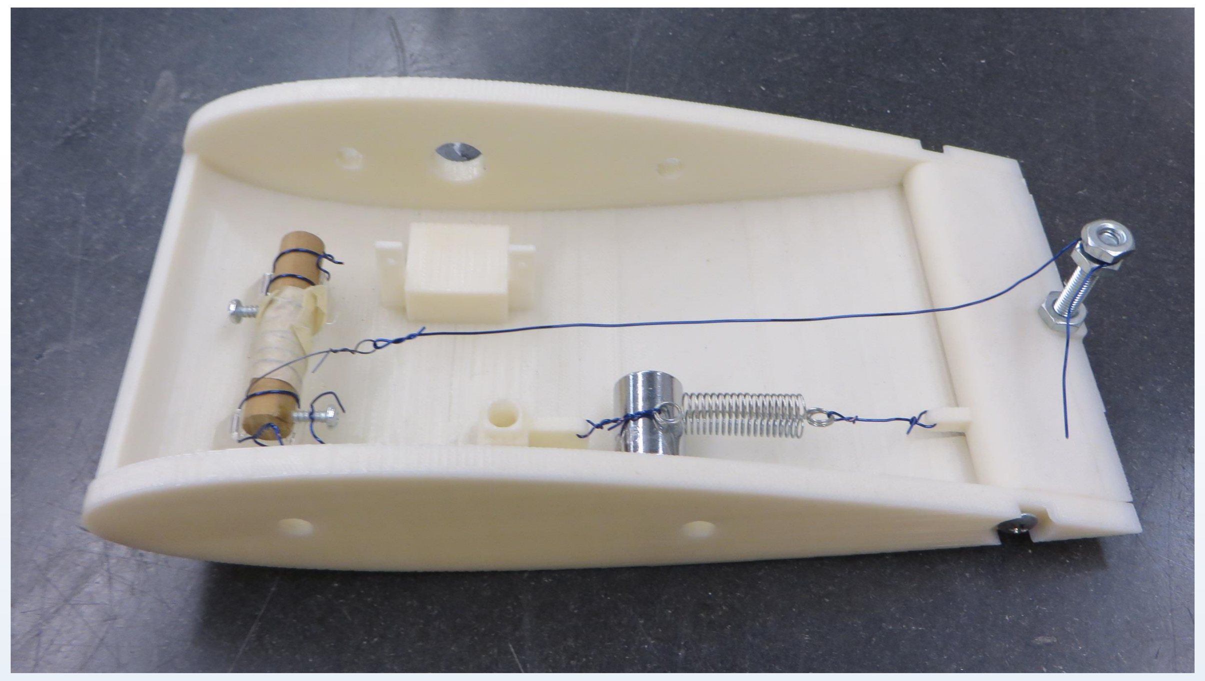


The testing rig used to compare the methods of actuation. The weights are attached to the same mounting point as the actuator wire so that the geometry of the rig does not affect the outcome. In this image, the servo is being tested.

[1] The control program used was adapted from http://robotics.hobbizine.com/flexinolresist.html

Materials & Methods

At the beginning of the design of the experiment, the design of the testbed was that of a hollow airfoil containing the mountings for both a Hitec HS-55 servo and a coil of Dynalloy Flexinol brand nickel-titanium smart alloy (hereafter referred to as "Flexinol") wire, with ports for linkage wires and electrical supply. When construction of this design was completed, it was found that, in order for the Flexinol to properly expand and contract, if must be kept straight and not contacting anything. Because the Flexinol used contracts by 4.5% at maximum when heated, the required 20+ cm would not fit inside the wing segment. The experiment was then changed to compare the two actuator styles in a test of their ability to hold up a given mass at a given deflection. It was also discovered that the Nitinol was also incapable of being controlled finely. As the wire would change resistance based on its length, the control program used would find the range of resistances for a range of length values, then increase or decrease the current through the wire as required to maintain the set resistance.[1] This turned out to be somewhat inaccurate, since the Flexinol takes a few moments to expand or contract so the control circuit would often overreact and it would take a while to stabilize. Because of this, rather than a large range of deflections the experiment was modified to use only 4mm and 8mm deflections, the latter chosen because 8mm is approximately the wire contraction required to deflect the airfoil in the testbed to its maximum angle.



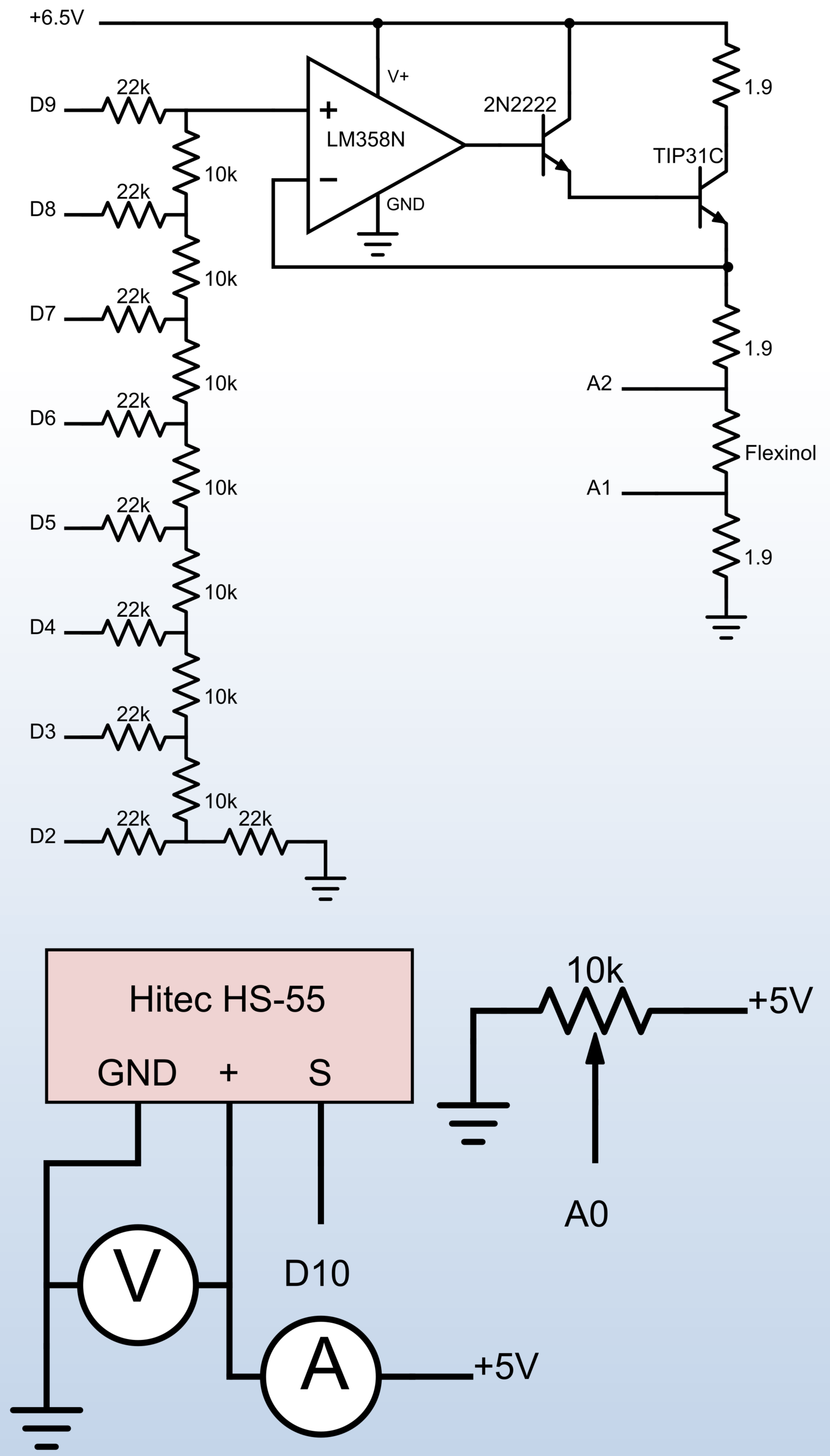
The intended testing rig for use in the wind tunnel. All of the materials excluding the wires used to actuate the control surface are contained within the plastic shell.

Discussion

During the experiment, the design and construction of the testing rig unearthed many problems with the Flexinol wire that hurt its performance in comparison with the servo, primarily the large gap in power consumption between the two. Other issues include the relative size of the assembly required to create a given deflection, the environment in which the actuator must be housed, and the speed and accuracy of the actuator itself. Outside of the significantly higher power consumption, the Flexinol required a space of about 30mm in length to produce the tested 8mm deflection, in which it cannot be contacting anything, otherwise it would conduct heat. The Flexinol also takes several seconds to change deflections and is significantly less accurate and stable over that range. In comparison, the servo is significantly smaller and easier to control, as well as being more robust in how it may be mounted, with no problems contacting other components in the assembly. In addition, the servo responds without delay and is accurate to within significantly smaller fractions of a degree. In terms of usability, the servo is more robust than the Flexinol by a large margin

Results

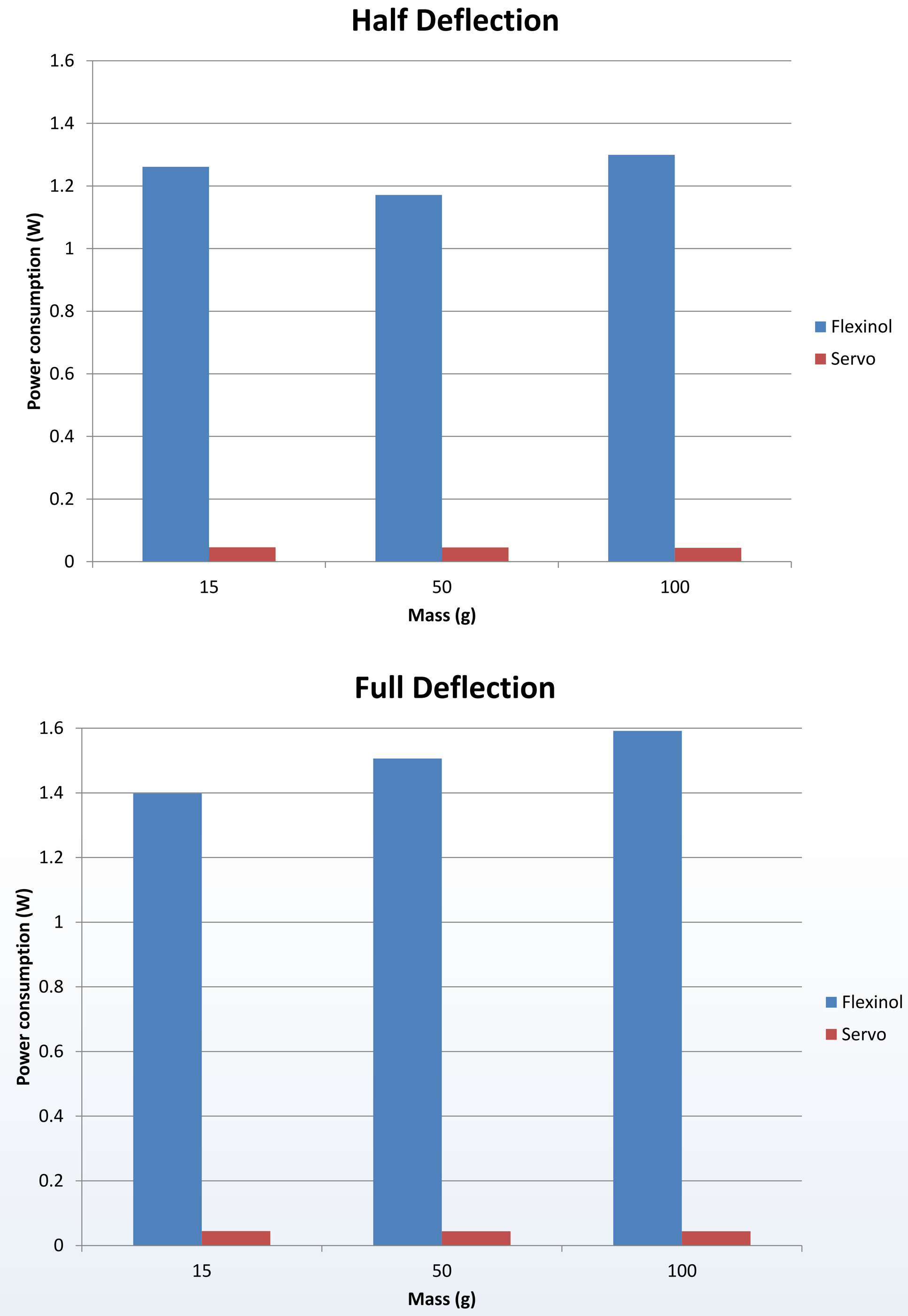
Each actuator held up masses of 15, 50, and 100g to provide a rough simulation of varying amounts of load on the wing. To represent the need for multiple control surface positions, there were two heights to which the weights were raised, 4mm and 8mm. These values were based on the original wing segment design, where they are the required linear deflections to produce half and full angular deflections of the control surface, respectively. For each set of actuator type, loading, and deflection, the deflection was set for one minute to allow the system to stabilize, then five power measurements were taken at one minute intervals. For the Nitinol, the resistance and current in the wire was known and used for the control program, so power dissipation was calculated from those values. For the servo, average current and voltage measurements were taken on the servo's power supply to calculate total power consumption. These measurements were then used to compare the relative efficiency of the two actuators via their individual power consumptions.



The circuitry used to power each method of actuation, Flexinol top and servo bottom. Power dissipation is measured in the Flexinol or servo only, not including the control assemblies so that the performance can be compared directly.

Conclusion

While the data from the Flexinol was inconsistent, the results show that the Flexinol requires much more power than the servo, by approximately a factor of more than 25, the larger the difference for the larger the deflection. It also appears that the Flexinol also requires more power for a larger deflection, while the servo only requires a small amount of power to hold a deflection and a smaller spike in power to change deflections. Because of this, it appears that the servo is significantly better-suited for applications in aerospace control surfaces.



The results of testing comparing the power consumption of the two methods of actuation when suspending a given weight at a given deflection

Limitations

This experiment is only a preliminary comparison between the Flexinol and a servo in similar roles, thus, the results do not necessarily reflect the actual performance of each actuator in a control surface application. Therefore, the results of this experiment should not be used to base design choices, rather for areas of further study.

Acknowledgements

Many thanks to Kale Hedstrom, lab coordinator for the Department of Aerospace Engineering and Mechanics, for all of his guidance in the experimentation process.

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