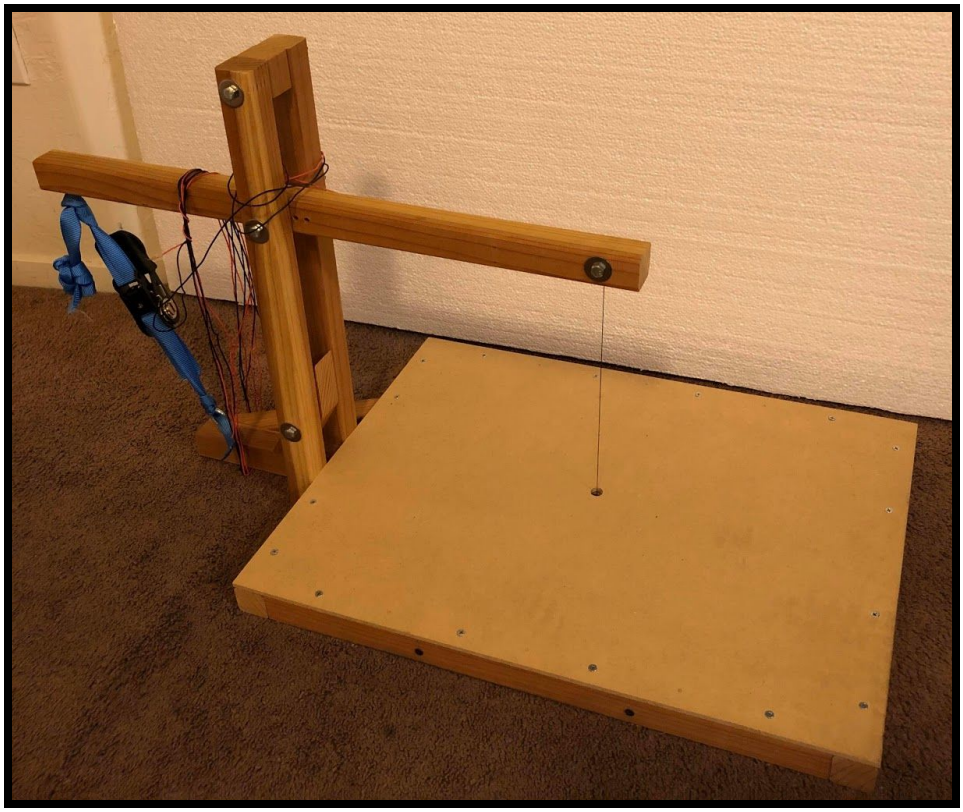
SAE Aero Competition Capstone Team - Honors Project

Hot-Wire Foam Cutter Operation Manual



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Introduction

In designing an aircraft, one of the primary areas to first consider is material selection. Traditionally, RC aircraft have been constructed from lightweight balsa wood. A frame of ribs and spars is constructed, glued together, and wrapped in monokote plastic. During my tenure on NAU's 2020 SAE Aero (Regular) Competition Team, I discovered the benefits of working with a *foam* construction rather than a wood one. Foam is lower density, cheaper, and above all else, faster to manufacture. To shape foam into aerodynamic surfaces, specific tools and processes must be used. This document will detail our team's construction of a "hot-wire foam cutter" and the process by which it can be used and serviced.

Disclaimer

Due to the circumstances surrounding the COVID19 pandemic, the author was forced to relocate. I did not have access to the foam cutter and could not take accurate measurements of the device. For this reason, this report will omit fully-dimensioned drawings, instead including detailed photographs taken before I lost access to the device. Because the concept of the device isn't restricted in size, it is my belief that the omission of these dimensions will not take away from the purpose of this document: to explain generally how the tool was built, and how to operate and repair it.

Construction

This section will detail how our hot-wire foam cutter was constructed. It is our team's intent to donate our hot-wire foam cutter to NAU's Machine Shop for future use by Aero and other Capstone teams, but in the event that our device is lost or broken beyond repair, this document should serve as a guide for building one anew.

1. The Frame: The first part of construction involved the creation of a frame. For our frame, we used 1x1 redwood beams. It was found that redwood had excellent strength-to-weight characteristics, and could be easily sourced from Home Depot. All connections were made with common 2-inch cabinet screws. The geometry of this frame can be seen in the figure below, and features a planar base, with a 30-inch "lever arm" bolted between two, 24-inch "towers" with a quarter-inch bolt.

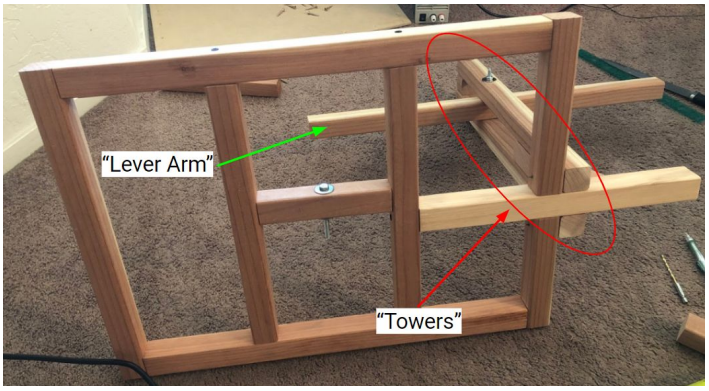

Figure 1: The Frame

2. Wire Connection Points: The points where the nichrome wire connects are just simple quarter-inch bolts. These bolts penetrate through the planar base and the lever arm with enough protrusion to fasten two nuts and two washers. The nichrome wire will be wrapped around the bolt protrusion and squeezed between the washers with a nut to form a tight "grip." The second nut will serve as a clamping device for the wire coming from the power source. Note: be sure to align the connection points so that the wire will form a line perpendicular to the plane of the tabletop.

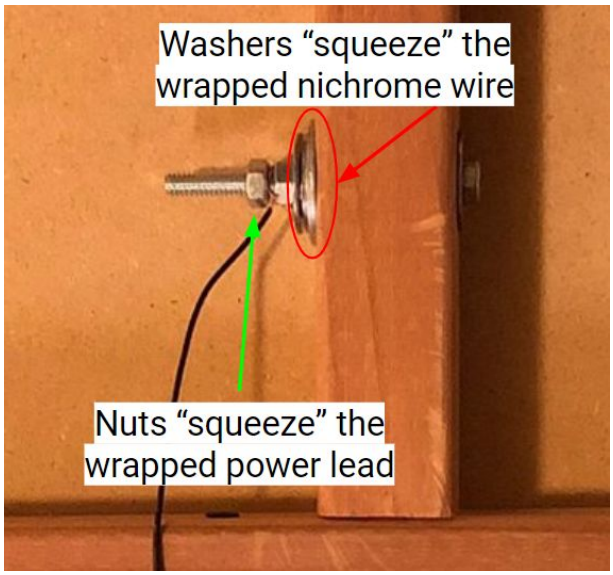

Figure 2: Wire Connection Point

3. The Tabletop: The tabletop is just a sheet of quarter-inch particle board. A small hole is drilled into the location where the wire crosses the tabletop plane. This hole does not need to be large, but big enough to accommodate the inevitable flex in the wire. If the device has the proper tension, a half-inch hole will be large enough. The edges are screwed into the planar frame with #6 wood screws. Note: countersink these screw holes before inserting screws for a smooth, level surface.

4. The Wire: The nichrome wire is cut with enough excess to be wrapped around the Wire Connection Points a few times. The angle that the wire makes with the Tabletop should be perpendicular, and this depends on the length of the wire. After attaching the wire and adding tension to the system, check for orthogonality. If this is not satisfied, release the tension and adjust the wire for a new length. It may take a few tries. Understand that the wire will stretch some small amount under tension, so always use a smaller length than you measure.

5. Tensioning System: The tension of the wire is crucial to the functionality of the device. Attach eyelet hooks to the back of the lever arm and the back of the towers. The best way to provide tension to the wire is to use a ratcheting, cloth tie-down. Our team experimented with different bungee cords and elastics, but none provided the tension that the tie-down did.

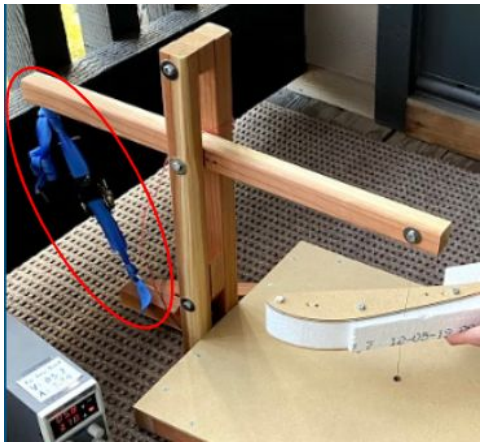

Figure 3: Tensioning System

6. Power: Power can be provided by an off-the-shelf power supply. Our team used the Eventek KPS305D. Voltage and Current will be adjusted using this device. Connect its positive and negative leads to the Wire Connection Points as described in Step 2.

Operation

The primary function of this device is to cut cross-sectional "slices" of a wing. To do this, one attaches airfoil templates to both sides of a foam block, and "traces" the templates with the hot wire. The wire will melt through the foam without harming the template, effectively imprinting the 2D shape of the template into the 3D section of foam. The following section will detail the operation of this device to complete such a task.

1. Prepare the Foam Member: The hot-wire should be *just* hot enough to melt through the foam and nothing else, so any tape, glue, or other attachments should be removed from the foam. Our team used inexpensive wall insulation for our foam members. This material had a thin film of plastic wrap that we had to peel off before using the foam cutter.
2. Attach Templates: The next step is to attach templates to both sides of your foam member. It is vital that these templates are in near-perfect alignment, otherwise you will introduce unwanted *twist* into your wing. One method we used for aligning templates was to establish x and y datums on our foam members by working with rectangular members. Once straight-line datums were established, we could line up templates on both sides using the x-y coordinate system. Templates must be securely fastened to the foam member. The best way to do this is with bolts that compress templates into either side of the foam member. If your member is too thick for bolts to

go all the way through, long screws may be used. Short screws or nails will just wiggle around in the foam while you're cutting it, and accurate cuts cannot be made.

Figure 4: Template Attachment

3. Check Device Calibration: There are a few things to check before the device is used. Most importantly, ensure that the wire is tensioned adequately. There should be no slack in the wire. If you pluck it, it should ring out a tone like a guitar string. If you are going to hold your foam member against the Tabletop and trust the wire to cut perpendicularly, you will want to take out a protractor and make sure the wire is still orthogonal to the Tabletop (see Construction for details on adjusting the wire angle). Finally make sure all the wire connections are secure.
4. Provide Power: Connect the power supply to a wall outlet and dial in your desired settings. Our team found that a voltage setting of 5.7 and a current setting of 3.7 work best for slow, smooth cuts. It will take about 15 seconds for the nichrome wire to get up to temperature, so have patience.
5. Cut: Cut your foam member slowly and smoothly, keeping the wire parallel to span lines. What I mean by this is that you should keep the wire perpendicular to the wing edge. If you are cutting a tapered or twisted section, be sure to adjust the angle at which you cut so that the leading and trailing edges line up. Do not move too quickly as you may rip gashes into the foam. Move smoothly, and don't pause. If you hold the wire in one place too long, the heat radiating from the wire will burn a cavity in the foam. Try to cut the foam section in as few passes as possible. I usually did one cut for the upper surface and one cut for the lower surface.
6. Turn Off Power: Careful with the wire; it will take a few minutes to fully cool down after you shut off power.
7. Sand Any Imperfections: If the cut was slow and smooth, the foam surface will be pretty free of imperfections. If not, don't worry- most imperfections can be sanded out by hand with 100 grit sandpaper.

Maintenance/Repair

The hot-wire foam cutter is a very low-maintenance device. The only maintenance one will have to do is to keep the wire clean and taut. Cleaning foam off the wire is as simple as cranking up the power until everything melts off of it, although one could also just wipe the wire with a cloth when it's not in use. Keeping the wire taut is a matter of checking the tension before use and ratcheting the tensioning system up. If the wire begins to age and plastically deform (this has not happened in our experience), the Construction Section will show you how to replace the wire.

Repair of the device should be just as simple. All parts except the power supply and nichrome wire were sourced from Home Depot. A crack in the wood or a bent bolt can easily be replaced at a local lumber/hardware store. The only thing worth mentioning is that the tension should be released before any repairs are made.

Future Work

Before I lost access to the device amidst the COVID19 pandemic, there were several design updates I intended on implementing. This section will discuss suggested future work that engineering students (or perhaps Honors Capstone students) could conduct.

Electronics Integration

I planned to "clean up" the look of the device by hiding the power leads and integrating the power supply into the device itself. This could be as simple as building up the device a few inches to store the power supply in a rack underneath the Frame and cutting a channel in the lever arm to hide the power lead.

Adjustable Throat

The first prototype of this device had a two-foot cutting throat, which allowed for the cutting of full-length wings. Our team found that it was hard to maintain tension and perform clean cuts on this device, so we instead modified the wire cutter to have a smaller, 12-inch throat that could maintain proper tension and yield smooth cuts. Despite our decision, it would be neat to have an adjustable design that could accommodate deeper cuts when necessary.

Handheld Cutter

At one point during the semester, I had a design and a prototype for a handheld version of the wire cutter. This could be used for smaller, less important cuts, like cavities for servo motors, or general surface trimming. My design never saw full implementation, but I still think it would be a valuable tool in addition to the full-size wire cutter.

Tabletop vs. Freestanding

One of the complaints that my team had about the wire cutter was that it had to be positioned on the floor for use. We got tired of crouching down or working on our knees when we needed to cut foam. One feature I had hoped to implement before my relocation was to add adjustable/retractable legs to the device so that it could be used at waist- or eye-level.

Further Research into EPS Fume Safety

Before embarking on our journey through foam-cutting techniques, our team did some preliminary research into the harmfulness of EPS fumes. When you melt through foam, it does release an odiferous smoke, but our research showed that it was no more harmful than microwaving a foam Cup-o-Noodles. Still we took precautions to cut in ventilated areas, outside, or under the protection of face masks just in case. The next team to use this device may want to finish the research we started and form a safety procedure for using this device.

Appendix A: Video Link

I made a short presentation to accompany this Operation Manual. I would recommend future users of the hot-wire foam cutter device to view this video, as it includes further instruction as well as some helpful operation tips. The video can be found here: https://youtu.be/vZYh41DZMpw

Appendix B: Gallery


W:L
P:R2
W:L
P:L2
W:L
P:R1
W:L
P:L1