AIR BRAKE DEPLOYME

by Thomas Salverson

In October of 2013 I had an idea to precisely control a rocket's apogee. Two years later I found myself standing in The Plains, Virginia, for the 2015 TARC National Fly-offs (Figure 1)! The idea I had was to use an onboard control system to accurately guide a TARC rocket to an exact apogee, every time. This system is called the Air Brake Deployment System (ABDS) and it was my goal to design and implement it in a TARC rocket.

For those who are unfamiliar with TARC (Team America Rocketry Challenge) it is a program that challenges students to build and design a rocket to accomplish the season's challenge. The 2015 season's challenge guidelines were as follows: rocket must fly to an apogee of 800 feet; rocket must have flight duration of 46 to 48 seconds; and rocket must carry one raw chicken egg without breaking it during flight. Scoring of a TARC flight is as follows: every one foot the rocket's apogee is off compared to the perfect standard of 800 feet is 1 point. For every second the flight duration is off from 46 to 48 seconds is worth 4 points. The winning TARC team is the team with the lowest number of points. So the purpose of the ABDS was to exactly guide the rocket to 800 feet and cause the rocket to land within 46 to 48 seconds.

In October of 2013 I began a long process of designing. After dozens of drawings and numerous prototypes, I developed the first ABDS. The ABDS opens and closes a pair of flaps by rotating a stationery screw with a servo. As the stationery screw rotates, a non-rotating float rides up and down on it, depending on which direction the screw is rotating. As the float rides up and down, it is linked to the flaps with levers. These levers are directly attached to the flap arms that cause the flaps to open or close (Figure 2).

The ABDS was initially made of balsa wood (Figure 3). The key element to the strengthening the balsa wood ABDS was the addition of metal supports laminated into the balsa wood structure. I took pieces of paper clips and smashed them between two pieces of balsa wood. Even with the metal "rebar" in the balsa wood, the ABDS would never be strong enough to hold up in a rocket crash. This was a serious problem since it took four weeks to build the ABDS by hand, and in the case of a crash there was also no way to easily fix it since

Figure 1. Thomas Salverson (circled) at the 2015 TARC Nationals.
Photo by Dan Stohr.

the entire ABDS was glued together.

The balsa wood version was developed throughout the first year of the ABDS project and the ABDS had only made a few test flights in the TARC rocket. Since the design for the ABDS worked, it just needed a stronger frame to resist crashes.

Once the 2014-2015 TARC season started, I was ready to finish the ABDS project. The first thing I set about to do was creating a stronger ABDS frame. To do this, I began 3D printing all of the ABDS parts just like the balsa wood parts. I used Autodesk Inventor (Figure 4) to design all of the parts and a Maker Gear M2 3D printer to print the parts. Originally, all

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the 3D printed parts were very strong, but also very heavy! The parts also required a long assembly time, just like the balsa wood model, since they all had to be glued together. The next step was to make the ABDS parts "snap" together for easy assembly.

So one part at a time, I added small grooves and retaining ears that allowed each part to slide and snap into the adjoining piece. To further simplify the ABDS, the nylon bolt that had been used to move the float was replaced with a 3D printed bolt and the float had threads printed directly into it. Once the ABDS was simplified, it was completely "snap" together and ready for use immediately after printing. The only thing left to do was to lighten the ABDS. So I began thinning the parts as well as adding weight relief holes. Once completed, the ABDS weighed a fraction of what it started out as, and now was flight worthy (Figure 5).

After designing, prototyping, constructing, 3D printing, and refining the ABDS, the ABDS was now in need of a control system. The control system had to have the ability to rotate the servo, which opened the flaps, based on the projected altitude of the rocket. The first thing I needed to do for the control system was to find some electronics. I originally used an Arduino Uno, BMP180 barometric pressure sensor, micro SD card reader, and a 9 volt battery to power the system. The Arduino Uno was easy to use since it required minimal soldering; however, it weighed way too much for the TARC rocket. With the Arduino Uno and 9 volt battery the rocket only flew to 600 feet! That was 200 feet away from its target altitude of 800 feet! To overcome the weight issue I chose to use the Arduino Pro Mini and an old MP3 player battery, which was very lightweight (Figure 6). This setup weighed 60 grams less than the Arduino Uno and 9 volt battery.

The next step for the ABDS was to program the electronics. I wanted the ABDS to be able to variably control the flaps' position during the rocket's flight, i.e., open the flaps if the rocket is going to overshoot the target and close if the rocket is going to undershoot the target. To do this, I developed an algorithm that calculated the rocket's apogee, based on the rocket's current flight trajectory. The calculated apogee is then used to determine if the rocket will overshoot or undershoot the target. If the projected apogee is greater than the target apogee of 800 feet, the Arduino sends the command to the servo to open the flaps; if the projected apogee is less than the target, it sends the command to close the flaps. Now, as the rocket is flying and the flaps begin to open, the drag on the rocket is increased and it changes the projected apogee. As the drag increases and the projected apogee decreases, the Arduino continuously monitors the projected apogee and if it goes under the target apogee, the Arduino closes the flaps to decrease the rockets drag. By doing this cycle of continuously opening and closing the flaps the ABDS is able to accurately guide the rocket to 800 feet.

Once the rocket reaches apogee and begins descending, the ABDS begins calculating the landing time of the rocket based on its current flight trajectory. The flaps work the same way in the decent as they did in the ascent, as they open they cause more drag and as they close they decrease the added drag. During the decent, the rocket's parachute size determines the rough landing time and the ABDS is able to tune the landing time by 1 to 2 seconds.

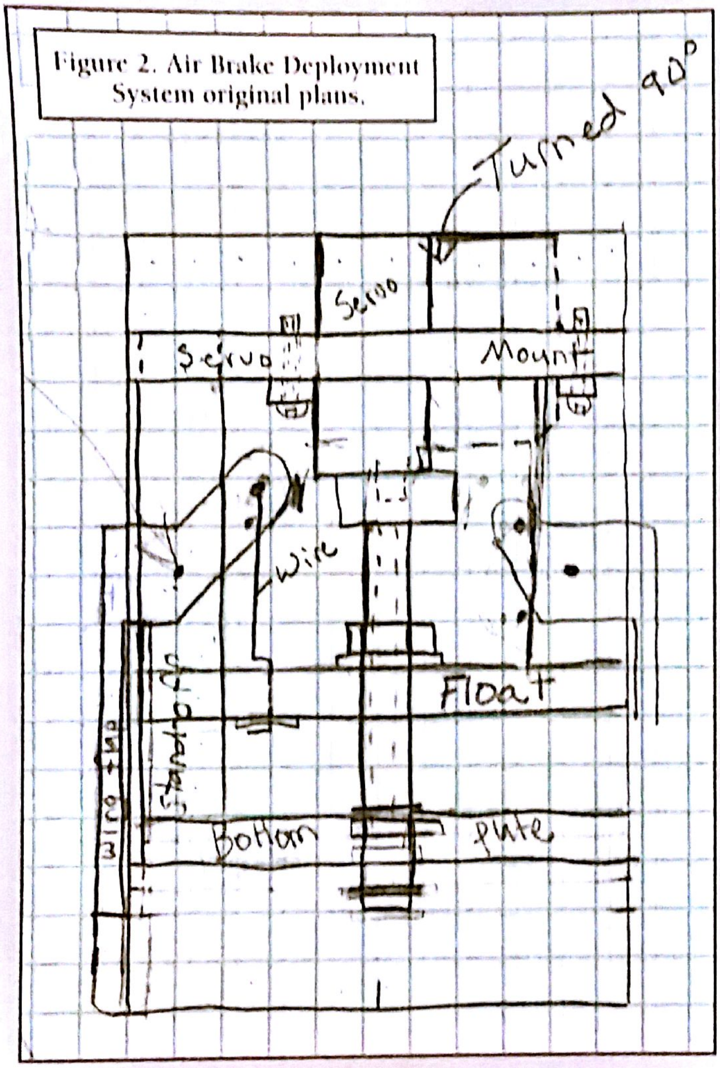

Figure 2. Air Brake Deployment System original plans.

By using the ABDS to control both the ascent and decent of the TARC rocket, it scored a 5.22 point qualification flight score. The flight hit exactly 800 feet and landed 1.3 seconds too early due to a small parachute.

To test this seemingly elaborate program, I made a small vacuum jar. I used one of my mom's jelly jars (don't worry, I asked) and a small plastic syringe to suck the air out of the jar (Figure 7). Using the jar, I was able to test the electronics before ever flying them. I simply took the electronics that I was going to put in the rocket and put them in the jar. Then to simulate the flight, I sucked the air out while watching the ABDS's reaction. By testing the ABDS this way, I was able to remove programming bugs and other errors that would have wasted a good rocket launch.

After testing was done with the vacuum jar, it took many months and dozens of launches to adequately tune the ABDS programming to work perfectly. The key to the testing was the ABDS's onboard flight recorder. During the rocket's flight, the flight was sampled 20 times per second and each sample recorded the rocket's flight time, current altitude, calculated projected altitude, and the percentage the flaps were open. It recorded all of this data onto a micro SD card using the card reader. Once the flight was over, I simply slipped the micro SD card into my computer and analyzed the data with Microsoft Excel. Using Excel, I created graphs of the flight data so that I could determine if the flaps were opening too soon, too late, or simply not enough. So by comparing multiple

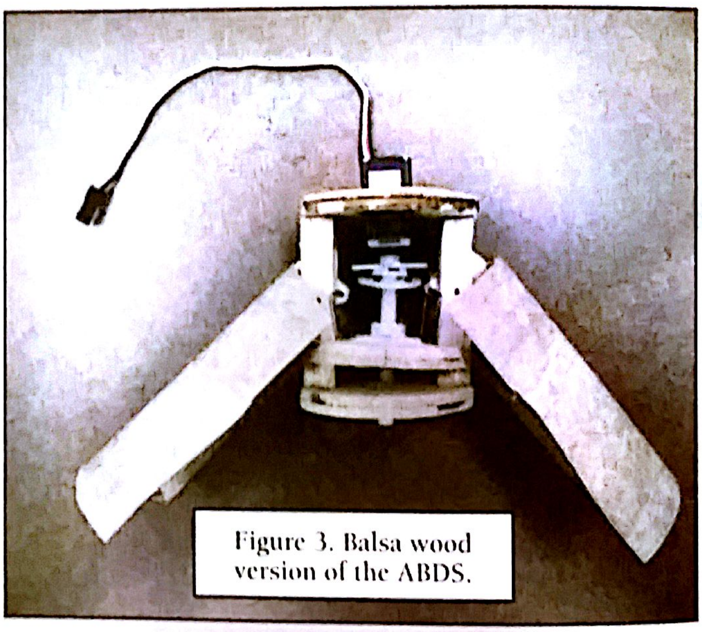

Figure 3. Balsa wood version of the ABDS.

rocket flights to each other and to a control flight (a flight without the ABDS so I could see what an uncontrolled flight looked like) I was able to make small adjustments and tweaks to my program to increase the rocket's performance.

The Excel graph of the perfect apogee flight mentioned previously is shown in Figure 8. In the beginning of the flight at 2.7 seconds, the projected apogee (green line) goes over 800 feet and the flaps on the ABDS began to open (purple line). At the same

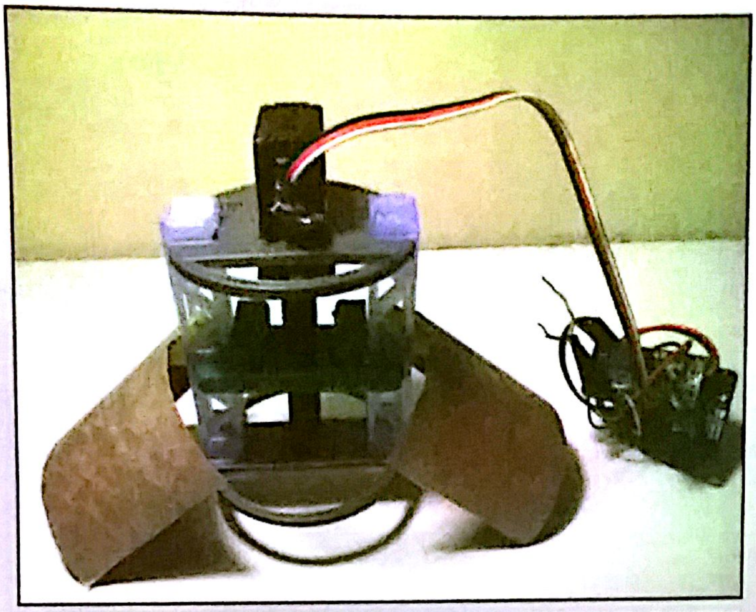

Figure 5. 3D printed version of the ABDS.

out yet. After 9 seconds, the flaps opened all the way to slow the rocket down more than the parachute normally would. The flaps remained open until the end of the flight. After the rocket landed, the flaps closed to reset for the next flight (This is not visible on the graph since the flight recorder stops recording at touchdown).

The other method of testing I used was flight replays. Using the data collected from the flight recorder, I could replay the flight. Instead of the ABDS collecting data and recording it, the ABDS reads the data back from the micro SD card and re-opens and closes the flaps, just like it did in the recorded flight. This was great since I was able to physically see how much the flaps were opening and closing (Figures 9, 10, and 11).

After using the ABDS for the 2015 TARC season, the results of the ABDS are evident. The TARC rocket scored 27.4 points as a combined qualification score. The rocket made it to the TARC National Fly-offs and placed 12th in rocket performance out of 700 teams across the Nation. For the upcoming 2016 TARC challenge the ABDS is going to be further improved, so that is able to control the rocket's flight even better than it does now.

For more information, please visit https://sites.google.com/site/tsalveengineeringprojects/air-brake-deployment-system. On this website I have my ABDS engineering paper and videos of the ABDS in action. If you have any questions feel free to contact me at t2salve@gmail.com.

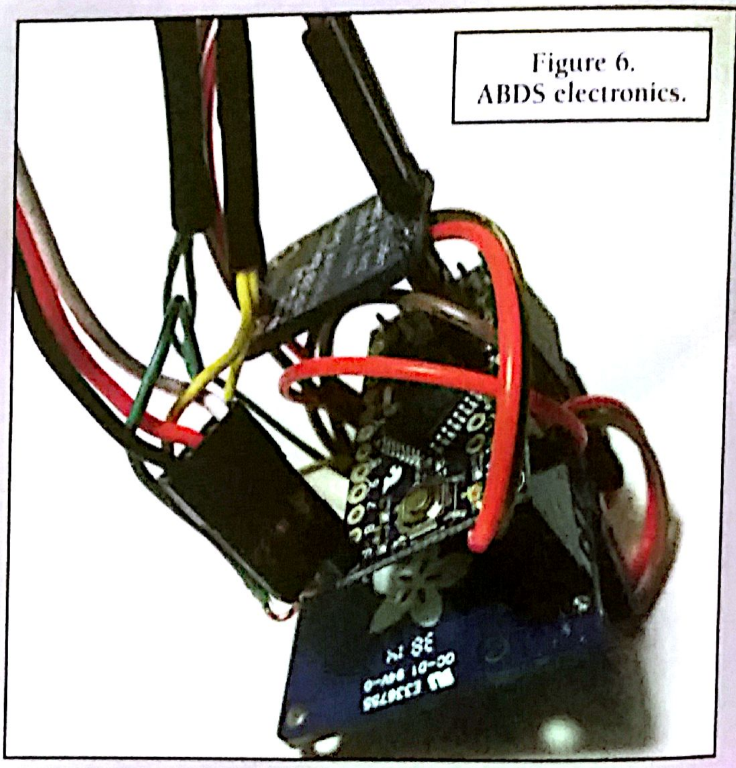

Figure 6. ABDS electronics.

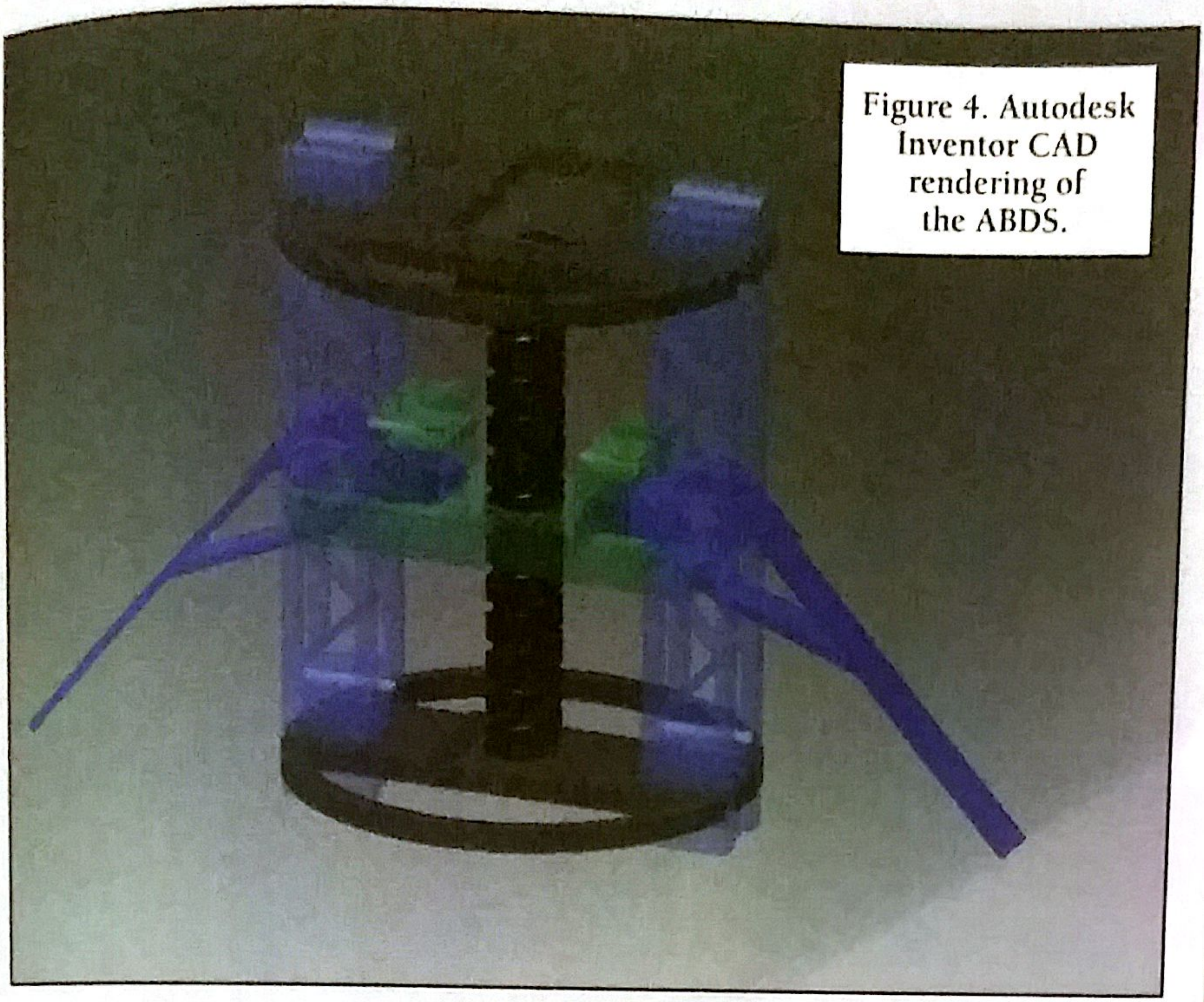

Figure 4. Autodesk Inventor CAD rendering of the ABDS.

time, the altitude (red line) begins to taper off more quickly. The altitude tapering off like this is in direct relation to the flaps opening, since when the flaps opened it increased the rocket's drag and slowed the rocket down. Between 2.7 and 5.4 seconds the flaps fluctuate as the projected apogee fluctuates, this fluctuation was able to guide the rocket to exactly 800 feet. At 5.4 seconds, when the rocket reached apogee, the ABDS flaps were constantly opening since the parachute had not come

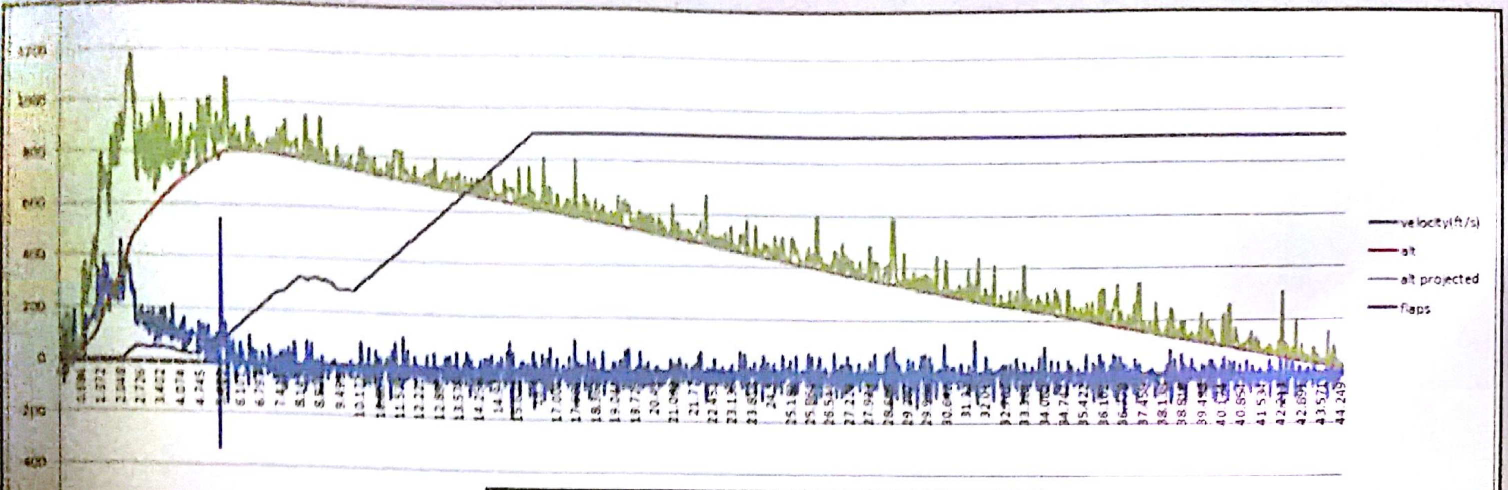

Figure 8. Graph of a perfect ABDS flight.

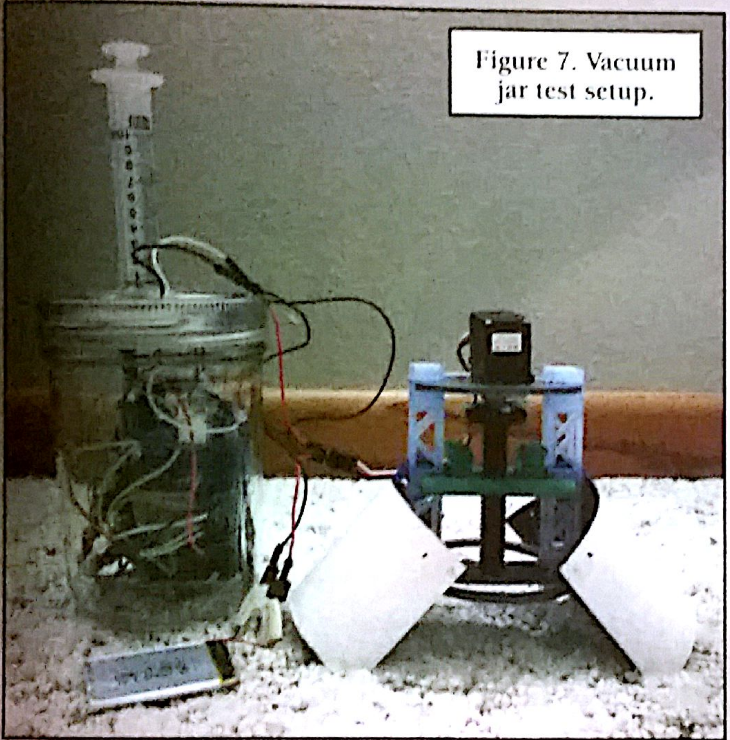

Figure 7. Vacuum jar test setup.

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Figure 9 (Left). TARC rocket with flaps closed.
Figure 10 (Center). TARC rocket with flaps halfway deployed.
Figure 11 (Right). TARC rocket with flaps fully deployed.