Is NASA's rocket design always right?

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Abstract

Model rockets are a much more common hobby than one may think. In the National Association of Rocketry (NAR), there are currently over 80,000 active members, and Tripoli Rocketry Association (TRA) has almost 40,000 non-NAR members. That makes 120,000 model rocket enthusiasts that belong to national organizations. You can only guess how many other model rocketeers are out there. This growing hobby is now almost being shut down because of federal court cases. The BATFE (Bureau of Alcohol, Tobacco, Firearms and Explosives) is attempting to prove that Sport Rocketry is not safe, and should be banned. They have taken the 3 main national organizations to court, the NAR, TRA and ARSA (Amateur Rocketry Society of America) who are currently working hard to keep the hobby alive. One of the main things being fought about is, of course, motors. Model Rocket motors contain one of two propellants usually. Small Estes rockets contain Black Powder, and use the atmosphere for an oxidizer, while higher-power rockets are fueled by Ammonium Perchlorate, a unique substance because it is both a fuel and an oxidizer, providing maximum thrust at minimum weight.

Model rocketeers almost always strive to get the highest altitude. Four things control how high the model goes: weather, drag, mass, and motor. Obviously, we have no control over the weather, and our rockets are using the lowest mass they can. Therefore the most easily adjustable variable is to use a bigger motor. If the BATFE prohibits this, even using the biggest available motors may not be enough. Model rocketeers will have to resort to the forth variable, drag. Drag is the phenomenon of resistance to motion through a fluid, such as air. By the time a rocket motor in a high-drag model goes out, the rocket still hasn't gotten very high. If model rocketeers want high altitude but we lose the case for high-powered motors, all rockets will have to be designed with minimal drag. Drag is created by every part of the rocket that air comes in contact with. For model rocketeers, the adjustable variables are the nosecone, body tube, fins, launch lug and surface of the rocket.

Model rocket simulators, such as WinRoc, RockSim or SpaceCAD, ask for the parts you are using, and therefore determines the mass. It then asks what motor your using, and what the weather conditions are. The only other variable that contributes to altitude, the Coefficient of Drag, is sometimes assumed to be 0.75, because this is a fairly standard number. Other software will try to predict the Coefficient of drag based on the parts you are using, but the only way to accurately determine this variable is by use of a wind tunnel. For the simulators that assume .75, model rocketeers will be able to look at their rockets based on this experiment and compare their rocket to the tests. If they use a type of part with lower drag, they know their rocket will go higher than the predicted altitude.

The engineers who created this software could also benefit from this information by designing simulators that can compare parts on the rocket to data from a wind tunnel to more accurately determine the altitude. Model rocketeers won't have to compute all of these drag force values manually.

Problem

How do the nosecone, fins, body tube, launch lug and finish of a rocket affect its aerodynamic drag at various airspeeds?

Purpose

So-called "Rocket scientists" are much more common than you may think. There are literally almost 200 rocketeers in Connecticut that enjoy launching model and high-power rockets as a hobby. They dedicate every weekend the weather permits to them for launching rockets. There are nearly 200,000 of us nationwide. However, we all have certain reasons for launching our rockets… some want to go high, while others want to go low. Still others want to achieve long or short duration of flight, which is heavily determined by altitude. Many of the goals are the results of contests, where members of national organizations can earn points that can get them into national competitions. Others have rockets that are carrying payloads, such as an air-sampling unit or a camera. They want their rockets to go high. Others want to be able to see their rocket through the entire flight, even when there are clouds. They want their rockets to stay low. Regardless of why, altitude is an important factor for rocketeers getting ready to spend hundreds of dollars on a new rocket. NASA, also, would heavily benefit from this information. The primary grudge people have against NASA is their constant need for more money, even though we already have the shuttles. This is because of the immense costs of fuel. Ammonium Perchlorate, used in high-powered model rockets and the Space Shuttle's SRBs (Solid Rocket Boosters) is an extremely expensive fuel, but is useful due to the fact that it acts as its own oxidizer. Liquid hydrogen (LH2) and liquid oxygen (LO2) are not terribly expensive, but to add to the cost of fuel for the rocket. There are three ways to reduce the amount of fuel needed – reduce the drag, reduce the mass, or increase the engine efficiency. Increasing the engine efficiency would be expensive, considering the Space Shuttle is going to be retired. The Space Shuttle was also specifically designed to have the lowest possible mass. However, the Space Shuttle has an extremely high drag. Although this, too, could add to the cost of a retiring Space Shuttle, it should be kept in NASA's minds when the design is finalized for the Crew Exploration Vehicle.

Hypothesis

If a filled and glossed rocket with no launch lug, an egglofter style body tube, a plastic long ogive nosecone and three airfoiled fins is used, then you will obtain the lowest aerodynamic drag at any airspeed.

Support

Everything that protrudes from the rocket adds drag. Therefore, logic would suggest that the rocket with no launch lug is going to have less drag than the rockets with a launch lug. At first, this may seem unrealistic. How can you simply eliminate the launch lug, leaving to way to attach the rocket to the guide rail? The answer is to not use a guide rail, but instead three of them. Each is placed around the body tube between each fin and the one next to it. The rocket is fit between them, and therefore is guided through the silo-like launch pad, without being attached to it. This system is called a tower launcher, and is commercially marketed because it claims to reduce the drag of rockets by eliminating the launch lug or, in high-powered rockets, the rail button. Again, the less protrusions gives lower drag, so using fewer fins will help. Three fins instead of four will give lower drag, however it ill move the center of pressure forwards, decreasing the stability of the rocket. Only if the center of gravity is far enough forward to continue stable flight is it safe to use the method of drag reduction. The airfoiled fins are more streamlined, and therefore produce the least drag. A nosecone is necessary in a rocket to redirect the air around the rocket smoothly, preventing it from entering the body tube. The cross-sectional area also cannot change, because it has to cover the entire front of the rocket. If we increase the length of the nose cone, we increase how streamlined it is, and therefore decrease its aerodynamic drag. This leaves one more variable we can change… the cross-sectional area of the tip of the cone. The sooner the air is redirected before reaching the majority of the cone, the less drag. Therefore, the less cross-sectional area at the tip of the cone, the less drag the cone has. Since the ogive nosecone has a narrower tip, and the plastic is smoother, the long ogive plastic nosecone has the least drag. If the rocket is sanded and filled to eliminate imperfections and sprayed with smooth gloss clear coat, it should reduce the drag because the imperfections aren't inducing drag, and because the gloss coat is smooth and reduces drag. Finally, the body tube, while straight and therefore not an excessive drag creator, still does create drag. If the body tube slopes inward, the fast-moving air won't reach the body tube nearly as much. If there is less air moving over the tube, there is less force to push back on it. This means the sloping egglofter body tube should reduce drag. This is all also shown through a similar previous experiment. (See NAR R&D report: Drag Analysis in the bibliography.)

Variables

Independent Variables

Launch lug, body tube, finish, nose cone, fins, and airspeed.

Dependant Variable

Aerodynamic drag.

Control Variables

Wind tunnel, air density, parts of rocket not being tested, test bed, recording instrumentation, fan, motor, and location of wind tunnel.

Materials

1		Interactive Instruments Jet Stream 500	*
2	5 ft. minimum	9 pin data cables	*
1		Dell Inspiron 1100 Notebook	
1		Serial to USB converter	
1	Jet Stream 500	Wind Tunnel test bed with drag and wind sensors	*
6	Jet Stream 500	Testing clips	*
12	Jet Stream 500	Test Security clips	*
1	II BasicBox	Key	*
1		Interactive Instruments BasicBox	*
1	2” x 2” x 8”	Balsa Block	
1		Shop Smith or other adjustable table saw and band saw	
1	Jet Stream 500	Software Package	*
3	BT-20	15” Body Tubes	
1	Estes	BNC-20 package with Long Ogive, Short Ogive, Long Parabolic and Short Parabolic	
1	Estes	PNC-20 package with the same types of nosecones	
1	Estes	1/8” Launch Lug	
1	Estes	3/16” Launch Lug	
1	Aerotech	¼” Launch Lug	
1	Flat	Can of Clear coat	
1	Matte	Can of Clear coat	
1	Gloss	Can of Clear coat	
1	Hand-Held	Sander	
2	110 lb.	Sheets of Card stock	
1	Pair	Scissors	
1		Printer	
1	Roll	Scotch Tape	
1		Vise	
1		Pair of pliers	
1		Hot Glue gun with sticks	

* Comes with Wind Tunnel

Procedure

1. Obtain a Jet Stream 500 wind tunnel from Interactive Instruments. If you are buying the wind tunnel, you also will need to order the software package and an accessory kit. If you are renting the student tunnel, it comes with these things.
2. While waiting for the wind tunnel to arrive, gather the rest of the components (The items without stars).
3. On each of the three body tubes, mark them at 6” intervals, starting at either end (There will be 2 6” sections and 1 3” section.)
4. Set up your shop smith or band saw with a level platform.
5. Carefully cut each body tube on the lines from step 3. Discard the 3” sections.
6. Mark each of the 6 new body tubes at their mid point.
7. Print the fin pattern you will use for your experiment. (To use my fin pattern, see Appendix A)
8. Tape the fin pattern over the 2x2 side of the balsa block such that all parts of the fin are on the block.
9. Place the block on the band saw with the paper-covered side facing the saw. Tilt the table so that the root edge of the fin is parallel with the band saw, and then align the two.
10. Carefully cut the block lengthwise along this line. Repeat steps 9-10 for the leading edge, fin tip and trailing edge.
11. Now place the block on the table (angle does not matter) such that the 8” section is perpendicular to the saw.
12. Use a clamp to attach a scrap of wood from the above steps to the table such that if the block is pushed against it, 3/16” of the wood is on the clamped side of the blade.
13. Cut the 3/16” segment, then push the block against the wood again and cut once more. You should have 2 identical fins that are 3/16” thick.
14. Repeat step 13 until you have 21 fins. (You may wish to cut some spares.)
15. Divide the fins into three piles of 7. Leave one pile alone. (These will be the Square fins.)
16. Stack the second pile of fins together in the same orientation and carefully sand the corner between the fin tip and leading edge to make it round. (See Appendix A.) These are your Round fins. Set these next to the square fins.
17. Use your hand sander to round the leading edge of one of the fins in the third pile laterally, and to taper the trailing edge so that the fin tip looks like an airfoil. Repeat for these seven fins. These will be the Airfoiled fins.
18. Divide the body tubes into three groups of two, and place the piles in front of each pile of fins. One body tube in the pile while get three of the type of fin it is in front of, while the other gets four.
19. Using the hot glue gun, attach the fins to the proper body tubes such that they are equally spaced around the body tube and are perpendicular to the body tube.
20. While they are drying, clamp the 6 wind tunnel clips in a vise and use pliers to round up the sides so they will wrap around the body tube.
21. When the fins have dried, place a clip over the mid point line on each body tube and use the screws to secure them in place. Cover in scotch tape for security.

22. Open the small rectangular box from the wind tunnel case and remove the software and manuals. Read the manuals thoroughly and install the software using the directions in the software manual.
23. Remove the basic box from the same box and set it up where you will run the experiment. Use the 9-pin data cable from the tunnel case and USB to serial adapter to connect the box to your computer.
24. Use the power cord in the tunnel case to supply power to the basic box from a circuit rated at 15 amps or more. Using the tunnel key, unlock the keypad and turn the basic box on.
25. The box should perform and pass a test, then display 0 wind speed, lift, drag and Lift/Drag. Now shut the box off.
26. Remove the wind tunnel from the case. Place on level ground and follow the manual to level the tunnel.
27. Use the other 9-pin data cable to connect the test bed of the wind tunnel to the control box. Connect the wind tunnel power cable (attached to the wind tunnel) to the control box as well.
28. Start the laptop, then the control box. Start the wind tunnel software and click OK. Make sure the keypad is unlocked.
29. Type, "W, 5, ENTER". The wind tunnel should start. Now press "S" to stop the tunnel. On the Test menu, choose configure and select metric for the Units. Click OK.
30. Remove the test bed and use the clip adjuster in the accessory kit to loosen the clip attach point. Insert the rocket with four square fins. Secure the clip and add a Long Ogive plastic nosecone. Attach the test bed to the wind tunnel testing area.
31. Type, "W, 50, ENTER" to start the wind tunnel. Make sure you are wearing ear protection. If the rocket is secured well and does not move, type "W, 80, ENTER" and record the number next to "Drag" on the status bar.
32. Repeat step 31 for 100 and 120 km/h tests.
33. Type "S" then repeat steps 31 and 32 twice more to check for accurate results.
34. Repeat steps 31-33 for the 4 Round, 4 airfoiled, 3 square, 3 round and 3 airfoiled.
35. Remove the test bed and replace the nose cone with a plastic short ogive. Repeat steps 31-33 for this nosecone.
36. Repeat step 35 for each nosecone type.
37. Remove the test bed and hot glue the 1/8" launch lug against a fin. Repeat steps 31-33 for this launch lug.
38. Remove the test bed and snap off the launch lug and replace it with a 3/16", then ¼", and repeat steps 31-33 each time. Then remove the ¼" launch lug.
39. Remove the test bed and spray your rocket with flat clear coat. Repeat steps 31-33.
40. Repeat step 39 for the matte and then the gloss clear coats
41. Remove the test bed. Carefully sand your rocket wherever there are angles in order to make the rocket uniform. If there are indentations, fill them. Then respray the rocket with gloss clear coat and repeat steps 31-33.
42. Use the sanded to roughen the body tube again, and repeat steps 31-33 to make sure have not affected the drag of the standard rocket.

43. Using WinRoc, select Boattail for type, D1 should be the diameter of the rocket, and D2 should be about 1cm. Set a length of 1 in. and print out the file on cardstock.
44. Cut along the solid lines and curl the paper to form a truncated cone. Hot glue the two ends together.
45. Hot glue the larger side of the cone to the bottom of the body tube. Repeat steps 31-33.
46. Go back to WinRoc and use the same settings, except use 6 in. as the length. Repeat step 44.
47. Carefully remove the fins from the body tube, and reattach them around the narrow side of this new cone. Hot glue the plastic long ogive nosecone in place.
48. Using the same procedure as for the other body tubes, attach a security clip to the cone at the 3" point.
49. Secure this rocket to the tunnel test area and repeat steps 31-33.
50. Remove the rocket and repack the wind tunnel exactly how it came. Dismantle the wind tunnel by the instructions in the manual and send it back to Interactive Instruments if it was a rental. Now clean up your work area.

Airspeed Test #

Results

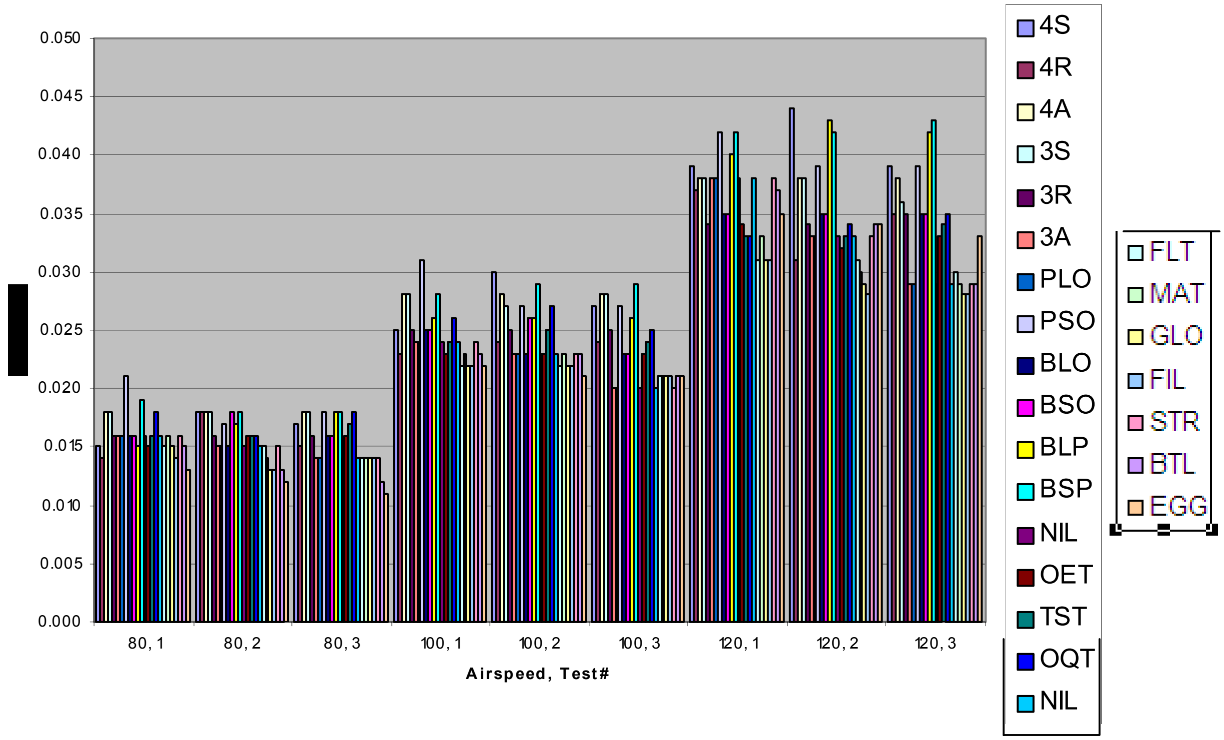
Data

Type	Part	80, 1	80, 2	80, 3	100, 1	100, 2	100, 3	120, 1	120, 2	120, 3
Fins	4S	0.015	0.018	0.017	0.025	0.030	0.027	0.039	0.044	0.039
	4R	0.014	0.018	0.015	0.023	0.024	0.024	0.037	0.031	0.035
	4A	0.018	0.018	0.018	0.028	0.028	0.028	0.038	0.038	0.038
	3S	0.018	0.018	0.018	0.028	0.027	0.028	0.038	0.038	0.036
	3R	0.016	0.016	0.016	0.025	0.025	0.025	0.034	0.034	0.035
	3A	0.016	0.015	0.014	0.024	0.023	0.020	0.038	0.033	0.029
NC	PLO	0.016	0.015	0.014	0.024	0.023	0.020	0.038	0.033	0.029
	PSO	0.021	0.017	0.018	0.031	0.027	0.027	0.042	0.039	0.039
	BLO	0.016	0.015	0.016	0.025	0.023	0.023	0.035	0.035	0.035
	BSO	0.016	0.018	0.016	0.025	0.026	0.023	0.035	0.035	0.035
	BLP	0.015	0.017	0.018	0.026	0.026	0.026	0.040	0.043	0.042
	BSP	0.019	0.018	0.018	0.028	0.029	0.029	0.042	0.042	0.043
LL	NIL	0.016	0.015	0.014	0.024	0.023	0.020	0.038	0.033	0.029
	OE	0.015	0.016	0.016	0.023	0.023	0.023	0.034	0.032	0.033
	TS	0.016	0.016	0.017	0.024	0.025	0.024	0.033	0.033	0.034
	OQ	0.018	0.016	0.018	0.026	0.027	0.025	0.033	0.034	0.035
Finish	NIL	0.016	0.015	0.014	0.024	0.023	0.020	0.038	0.033	0.029
	FLT	0.015	0.015	0.014	0.022	0.022	0.021	0.031	0.031	0.030
	MAT	0.016	0.014	0.014	0.023	0.023	0.021	0.033	0.030	0.029
	GLO	0.015	0.013	0.014	0.022	0.022	0.021	0.031	0.029	0.028
	FIL	0.014	0.013	0.014	0.022	0.022	0.021	0.031	0.028	0.028
BT	STR	0.016	0.015	0.014	0.024	0.023	0.020	0.038	0.033	0.029
	BTL	0.015	0.013	0.012	0.023	0.023	0.021	0.037	0.034	0.029
	EGG	0.013	0.012	0.011	0.022	0.021	0.021	0.035	0.034	0.033

Units are km/h (airspeed) and kg (drag).

Fins – 3 or 4 = # of fins, S, R, and A mean type of fin
Nosecone – B or P = Balsa or plastic, S or L = Short or long and O or P = Ogive or parabolic
Launch lug – Nil=None, OE=1/8, TS=3/16, OQ=1/4
Finish – Nil=None, Flt=Flat, Mat=Matte, Glo=Gloss, Fil=Filled and glossed
Body Tubes – Str=Straight, BTL=Boattail, Egg=egglofter style

Graph



As you can see, the graph forms a 3-stair staircase. Each stair, representing a different airspeed, has increased drag proportional to the airspeed. This makes sense, since increased airspeed should increase the drag logically. In addition, each step is roughly level, because the tests should have been about equal.

Conclusion

My hypothesis was indeed correct. For fins, the rockets with 3 fins outperformed the others, and the airfoiled fins did the best. My analysis for these numbers is taken by the average of the 120-km/h test results (which are closer to the speed the rocket would actually travel) and from the average of all the numbers. This makes it clear this rocket outperformed the rest significantly. The plastic nosecones, as I predicted did better than the balsa cones. I also correctly predicted that the ogives did better than the parabolics, and the long nosecones beat the short ones. This supports my hypothesis in that the plastic long ogive preformed the best. For launch lugs, my hypothesis is supported by the average of all the numbers, in which the rocket with no launch lug preformed the best. However, with the 120-km/h averages, the 1/8" launch lug beat the rocket with no launch lug. This is likely due to a mismeasurement or other minor error, as the numbers are very close. The filled and glossed rocket performed the best for finishes, with the rocket with no finish performing the worst. The straight body tube preformed the worst, with the egglofter body tube doing the best, also supporting my hypothesis. Evidently, my predictions were correct.

But what went wrong? Was this a perfect experiment? Of course not. For example, the test bracket, tape, and support arm have their own drag. However, these should have consistent drag because they do not change. Therefore, they should have affected each design equally. This means that while the numbers may not be entirely accurate, the comparison between them should be correct. Also, with several designs, the drag was rapidly switching between 2 drag readings. These values were then estimated by seeing where the drag was precisely at the airspeed being tested. These should also not have affected the results too much, because they were each tested three times. All in all, there really were not many problems with this experiment, because the wind tunnel keeps everything not being tested control.

Now why is this all important? NASA can't possibly care about what 8 inch tall rockets do, now would they? Actually, they do. Wind tunnels are amazing because they can represent upscaled rockets or airfoils for aircraft. One way of doing this is to test individual components, such as in this experiment. If an 8" tall rocket with airfoiled fins has less drag than one with square fins, then a 363-foot tall Saturn V rocket with airfoiled fins will outperform one with square fins. The other way of upscaling information involves finding the Coefficient of Drag. Why does NASA want to minimize drag? Because it is easier to push a rocket with less drag through the atmosphere, allowing them to use less Ammonium Perchlorate in the Solid Rocket Boosters and therefore save money. The same applies on a smaller scale for model rocketeer. While igniting an Ammonium Perchlorate-fueled model rocket is not as expensive as igniting a solid rocket booster, the smaller rockets are not government-funded. NASA and model rocketeers both want to minimize drag because then they get the same performance for less money, and therefore they can launch more rockets.

Recommendations

Although this experiment went well, and the only bugs were accounted for, there are still some things that may have made this experiment run more smoothly:

- Try to keep the glass test chamber clean. Otherwise its drag will increase and cause the air to move faster in one place than in another.
- Avoid the use of scotch tape if possible. Not only does it increase the drag, it also gets stuck around the sensor and prevents the support rod from moving. Thus the drag reads 0. When the tape is removed, some of the sticky substance remains behind.
- Position the clip such that the secured rocket roes not have any fins pointing straight up. This puts the fin tip on the roof of the chamber and gives a 0 drag reading. To correct this, the rocket must be rotated, which removes it from the center of the chamber, where the air is moving at a different speed.

Observations

Only a few things were observed that could have been potential flaws, the solutions for which are under "Recommendations." They include:

- The glass chamber, particularly the mirror, got dirty towards the beginning of experimentation when I was attempting other methods of getting results. There was scotch tape on the mirror itself. These also caused problems when they blew off during experimentation, blocking the exhaust.
- The scotch tape securing the clip on the rocket became a problem as well. If it were attached to anything other than the clip and rocket, such as the security arm, it would pose a problem for the drag sensor. This would result in a reading of 0.
- Lastly, the rockets were often secured with a fin pointing straight up. This resulted in that fin getting stuck on the glass roof of the testing chamber. The rocket would not move, so there was no drag measured. After observing this to be the cause of the measurement errors, this was corrected on later tests.

Application

This could be applied for great use in two main areas:

- NASA can use this research to design more fuel-efficient rockets, allowing them to possibly reduce the high cost of space travel.
- Model and high power rocketeers can use this information to help them to obtain their goal, higher altitude and space. See the resources on the bibliography for details.

NASA is currently competing against Burt Rutan at Scaled Composites, because if they begin to provide low cost space flights, NASA's funding may be cut, and the civilians may take over. With cheaper flights, they may be able to stay a large section of the government.

Model rocketeers can use the information to reach space and beyond. Actually, they already have. A small team of individuals formed a group and created the first civilian rocket to reach space. They all had one thing in common – a passion for model rockets.

Bibliography

Book Resources:
Second Stage: Advanced Model Rocketry, Second Edition Compiled by Michael Banks and Tim Miligan
The PinkBook (Model Rocket Sporting Code) Compiled by The National Association of Rocketry

Web Resources:
CSXT- the Civilian Space eXploration Team; (http://www.civilianspace.com/)
Model Rocket Drag Analysis – NAR R&D Report; (http://web.syr.edu/~smdemar/rocketdrag.html)

Acknowledgements

I would like to extend my sincerest thanks to Interactive Instruments, Inc. for allowing me to borrow their Jet Stream 500 Wind Tunnel. This experiment would have been impossible if they had not come to the rescue. I would also like to thank the Connecticut Humane Society for allowing me to use their docking facility so the wind tunnel could be shipped somewhere close. Both organizations volunteered their goods and services free of charge.

Pictures

POTENTIAL FOR PHYSICAL INJURY AND HEARING
LOSS EXISTS. REFER TO OPERATOR MANUAL
PRIOR TO TESTING