PEAK OF FLIGHT NEWSLETTER

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APOGEE COMPONENTS

PEAK OF FLIGHT

Testing Drag Brakes on TARC Rockets

By Dr. Martin Cwiakala and the RocCATS

The Start of a TARC Team

In 2020, the Center for Advanced Technical Studies (CATS) began its first year in 'The American Rocketry Challenge' (TARC). Starting from the ground up, the team began their education not only by designing a rocket for the competition but also by designing the supporting launch system. The stand selected for the launcher was a Rockwell JawStand Portable Work Support Stand. A unique feature of this stand concerns the legs attachment. They mount to the side of a triangular tube. This made mounting and hinging of the legs a simple matter. See Figure 1.

FIGURE 1: SIDE-MOUNTED LEGS INSPIRE A FIN MOUNTING SCHEME.

This unique leg mounting feature led to the question of whether or not rocket fins could be mounted in the same manner.

Mounting fins on the side of a rocket has a number of advantages. Since the fins would be glued to the side, longitudinal orientation is assured. The fins will be straight relative to the rocket body. By boxing the fins, each fin will not only be glued to the body tube, but to two other fins as well, making for a strong mount. Assuring fins are aligned 90-degrees to each other can be easily accomplished with a square. The only question that arose is, will it fly? It seemed as if it should, so a small prototype was built to test in the local multi-purpose school field. See Figure 2.

FIGURE 2: INITIAL BOX FIN DESIGN WITH 3D PRINTED TAIL ASSEMBLY.

Initial stability tests where the rocket was suspended on a 4-foot string and twirled showed an increase in fin size was needed. Balsa fins were attached to the existing fins. The flat areas provided by the box fin design inspired the idea of grid fins that could be extended to adjust drag and therefore altitude. See Figure 5. The lower portion of the rocket was also tested in a Pitsco vertical wind tunnel to determine the effect of the grid fins on the drag force. Three tests were performed for each of the four grid fin extension settings. See Figures 3 and 4.

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FIGURE 3: TESTING FIN CONFIGURATIONS IN A WIND TUNNEL.

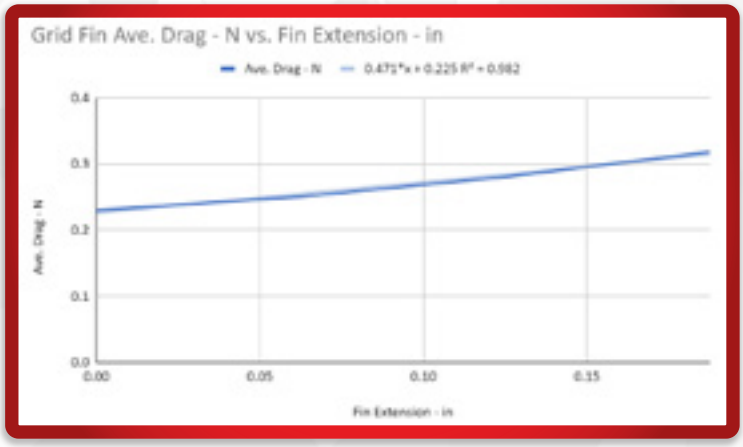

FIGURE 4: GRID FIN DRAG VERSUS FIN EXTENSION WITH TREND LINE EQUATION.

FIGURE 5: INITIAL BOX FIN WITH GRID FINS TO ADJUST THE DRAG. NYLON SCREWS FLARE FINS TO INCREASE DRAG.

The grid fins were 3D printed and designed to accept nylon nuts and bolts for adjustment. The grid fins were hinged using Gorilla tape. The detent on the hinged grid fins was accomplished using rubber bands. Initial tests of the box fin/grid fin design proved promising, so it was incorporated into the TARC rocket design. See Figure 6.

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FIGURE 6: FIRST 2021 TARC ROCKET DESIGN WITH BOX FINS, GRID FINS AND CLUSTERED ENGINES USING FOUR EXTERNAL MOUNTS. FROM LEFT TO RIGHT: SAMUEL, ASHLEY, AND ZAC.

Because we were a new team that had not established a good field for official flights, a cluster engine approach was used to allow for testing in the small multipurpose school field. Three B4-2 engines were utilized for the first flight - one engine on center with the two others on the diagonal.

The first flight went well, however, one of the fins cracked on landing. The fin was quickly fixed with instant glue and a second flight with three C6-3 engines was performed and we gained experience.

After the rocket cleared the launch rail, it was obvious that something was wrong. C6 engines should be outperforming the B4, and they were not. The rocket made it to about 100 feet, hit apogee, and then crashed into the ground without deploying the recovery system. Initial thoughts were that the center engine did not fire, which was true. The ignitor was still in the center engine. On further inspection, we realized that the ignitor did fire. A spent engine had made its way into the good engine box! Four people inspected the rocket and nobody thought to look at the other end of the rocket engines. This is a mistake that will never happen again. The bad news was that we broke our rocket one week before scores were due. The good news was that the fins stayed attached, and we did not break our egg! See Figures 7 and 8.

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FIGURE 7: CRASH CAUSED LOWER BODY TUBE TO COLLAPS BUT FINS REMAINED SECURED.

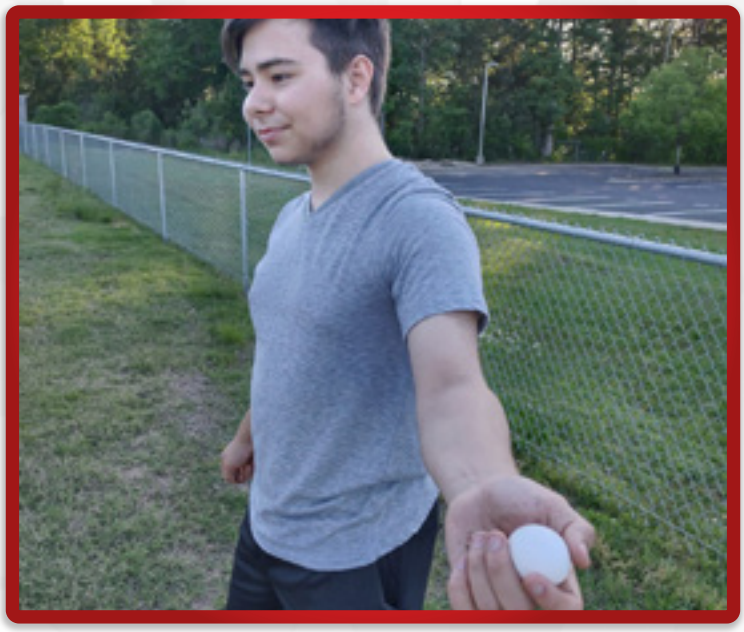

FIGURE 8: ZAC SHOWS THE UNBROKEN EGG AFTER THE CRASH.

With a broken rocket and one week before final attempts were due, the rocket was rebuilt to utilize a single F-size engine. We had made contact with Rocketry South Carolina for an appropriate launch site, and our next flights would have to be test flights and then official ones.

Our performance was less than stellar. Utilizing an F15 engine did not provide the necessary altitude and the delay resulted in deploying the plastic parachute far past apogee at high speed, stripping it from the shroud lines. Another rocket crashed, but much more experience and resources, like an appropriate flying field for next year's work, were gained.

Second Year TARC Team

The 2022 TARC competition was approached in a much different way. Early registration and purchasing materials early allowed for many more meaningful test flights. The 2022 challenge required two eggs mounted sideways lofted to 835 feet in a flight time of 41-44 seconds. Big payload sections with more weight required components to be made as light as possible while still maintaining strength. This resulted in a dramatically simplified and lightweight grid fin design.

Early design of the grid fins involved a stationary portion, a hinge (Gorilla tape), and a moveable grid fin that incorporated two nylon screws and nuts for adjustment. All of these components were plywood which resulted in significant weight. The new design utilizes 1/16 inch plywood grid fins which are zip-tied to the box fins. A single nylon nut was superglued to the thin grid fin. The flexibility of the plywood replaced the hinge function of the earlier

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design. This design resulted in each grid fin weighing less than 3 grams mounted. See Figure 9.

FIGURE 9: NEW FLEXIBLE GRID FINS ARE ZIP-TIED TO THE BOX FINS. THE POD HOLDS THE ALTIMETER IN A WEIGHT CONSERVATIVE FASHION.

The pod holds the altimeter in a weight conservative fashion.

Notice in Figure 9 that the sweep back fin design has been replaced by a fin design that does not extend past the bottom of the rocket. This year's design evolved three times. Fins that are the first part to hit the ground break. The motor mount retainer is a much tougher component. After including the elliptical fin design, no further issues with fin breakage occurred.

This year, like last, we were still taking official flights on the last Sunday before flight scores were due, but this year, things are looking much better. During the previous weekend, 17 mph winds were present and an official flight was attempted. It wasn't a great flight and the lower portion of the rocket was damaged during the landing and by subsequent dragging due to the high winds. Schedules were changed to be available the following Sunday so that repairs could be made and the remaining two official flights could be taken.

Cut to the last Sunday before scores are due. With only four engines remaining, the first practice flight resulted in the rocket flying to 860 feet with a flight time of 49 seconds. With altitude and duration high (target at 835 feet and 41-44 seconds) the decision to add nose weight was made. Adding 9 grams, and then taking our last practice flight, an altitude of 845 feet with a flight time of 46 seconds was achieved! Every 3 grams took altitude down by 5 feet and reduced duration by 1 second. We are now about to take our second official flight.

An additional six grams should bring us to the target altitude of 835 feet with a time of 44 seconds - a perfect score of 0 is within reach! The six grams are added and an official flight is called. The countdown commenced, the ignition button was pressed and the rocket streamed

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upward in a beautiful straight flight. Hearts were racing, and we thought: this is going to be THE FLIGHT! At apogee the recovery system deploys and to everyone's dismay, the parachute, payload section, and booster section all descended on different paths!

On recovery of all components, (after Seth ran a mile to recover the parachute) it was discovered that the tie-wrap which connected all the sections of the rocket became undone. Using a tie wrap is usually a solid lightweight way to make a fast connection that does not depend on anybody's knot-tying skills. All season this approach was used with success. The 19 flights before this did not show this problem. Samuel, one of the team members said: "This shows a one in twenty failure rate, we should add a second tie wrap, and that will bring us down to one in four hundred." (Good math Samuel, we will do that in the future!) Flight attempt two was a disqualification and we broke the eggs and then some.

We took 5 minutes to lick our wounds and regain our composure. With only one engine left, repairs were made and an official flight attempt was taken. With an altitude of 818 feet and a duration of 49 seconds (we hit a thermal), the season was finished. We did not make qualifications. So close though.

Post Season Testing

Due to overweight, fin breakage, and damage to the booster section, the design of the 2022 TARC rocket went through three redesigns. This year's design required two different body diameters, so the team opted to utilize a slender lower section which performed better in simulation. What the simulation did not show was the slender body was prone to buckling on hard landings due to the time constraint. The final design utilized a 38 mm engine mount tube for the body which eliminated the buckling problem. All of the redesigns resulted in less scientific testing of the grid fins during the season since time was of the essence.

Some strange observations occurred when attempting to utilize grid fin adjustment. See Figure 10 and Figure 11 for some flight data relating to grid fin adjustment.

Flt #	Adjust -Turns	Alt-ft
1	0	843
3	4	860
4	8	796
5	6	872

Rocket Weight - g 836
Date 3/13/2022
Engine F40-7 Aerotech

FIGURE 10: DATA TABLE OF GRID FIN ADJUSTMENT FOR TARC ROCKET

From Figure 10, you might ask the question, where is flight number two? The altimeter, which was mounted in the small pod just above the fins, was ejected from the rocket due to a tape failure. It made for a very interesting altitude versus time plot as it fluttered down attached to the small nose cone to which it was mounted.

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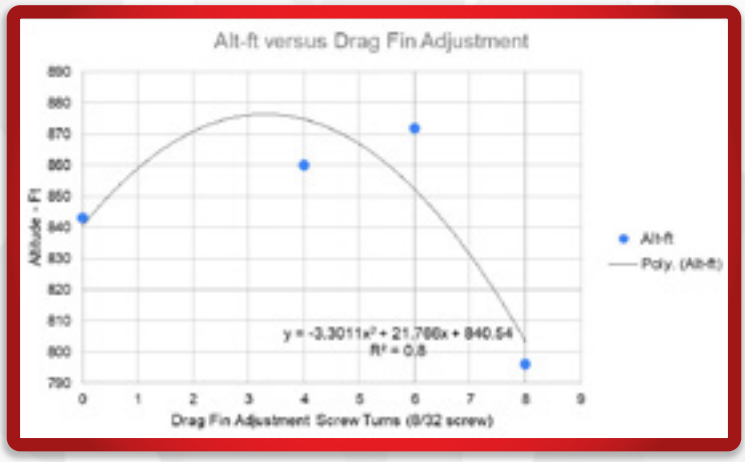

FIGURE 11: GRAPH OF ALTITUDE VERSUS GRID FIN ADJUSTMENT.

The team was surprised during testing of the grid fins when extending them resulted in higher altitudes! The general testing approach was fins close (0 turns), fins midway (4 turns), and fins at maximum extension (8 turns). Six turns were attempted, which resulted in the highest altitude. With only four flights, there was not enough data to make a good curve fit. It was obvious from the four points that linear curve fit was not appropriate. A third-order equation has four coefficients, which can be defined using four points. A third-order equation can fit through four points exactly. A second-order fit was selected since some adjustment between zero and max should provide maximum altitude. It was obvious that these grid fins warranted more investigation, but with F-size engines at approximately $20 per flight, a more economical investigation would need to take place.

Prior to the tests on the TARC rocket, a grid fin test rocket was developed to allow for tests to be performed in the local school field. This rocket utilized the trapezoidal fin design of the earlier TARC rocket design. Since the rocket was started, we continued with the design. See Figure 12.

FIGURE 12: TEST GRID FIN ROCKET UTILIZES FIN ASSEMBLY FROM TARC ROCKET.

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The grid fins were constructed from 1/16-inch birch plywood with an array of 5 rows by 5 columns of 0.16" diameter holes intended to make drag. They were laser cut and attached to the box fins using small tie wraps. Figure 13 shows a drawing of the grid fin.

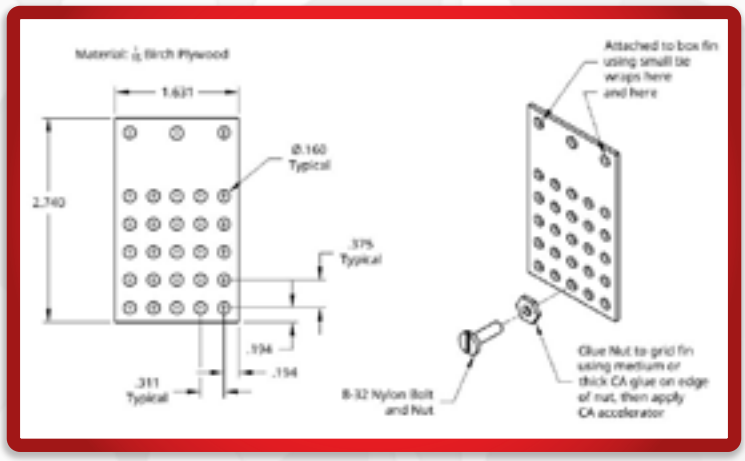

FIGURE 13: GRID FIN DRAWING AND ASSEMBLY. ADJUSTMENT IS ACCOMPLISHED USING 8-32 NYLON BOLTS AND NUTS.

Adjustment (outward deflection) is accomplished using an 8-32 x ½ nylon bolt and nut. The nut is CA glued to the bottom center of the grid fin. To glue the nut to the grid fin, thread it on the bolt until 1/16" or more is extending beyond the nut. Using medium or thick CA glue, place a bead of glue around the outside edge of the nut that will be connected to the grid fin. Using the protruding bolt as an alignment jig for the nut, insert it into the lower middle grid fin hole. Immediately apply the CA glue accelerator to secure the nut and to prevent CA glue from bleeding onto the bolt. Figure 14 shows the grid fins retracted and Figure 15 shows them fully extended.

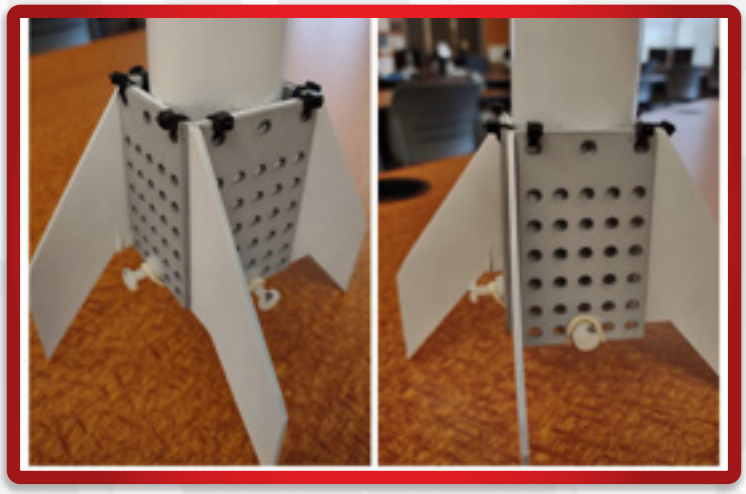

FIGURE 14: GRID FINS WITH 0" DEFLECTION, FULLY RETRACTED.

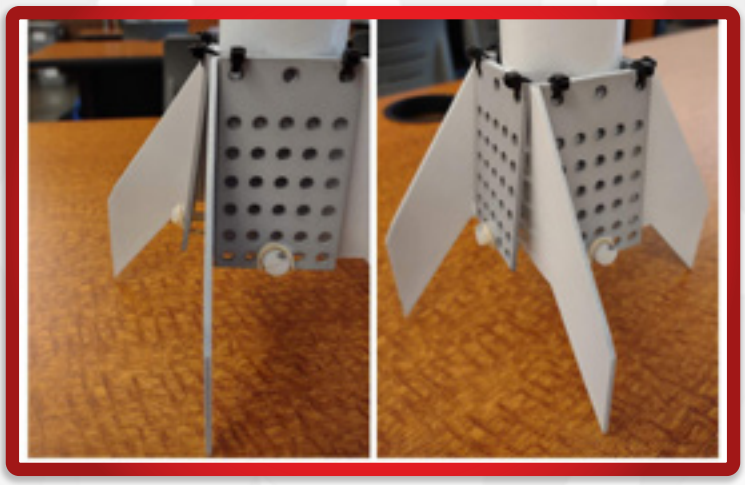

FIGURE 15: GRID FINS WITH 0.25" DEFLECTION (8-TURNS OF ADJUSTMENT SCREW), MAXIMUM EXTENSION.

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The test grid fin rocket was flown on Estes C6-3 engines. Simulations estimated the altitude for traditional trapezoidal fins within the range of 315 feet. From experience, this is about the maximum altitude that practically works on a field of 400 x 500 feet.

Six flights were taken: two with fins at 0-turns, two with fins at 4-turns, and two with fins at 8-turns (maximum deflection equaling a ¼ inch). See Figure 16 and Figure 17 for the results.

Altitude Versus Drag Fin Adjustment

For Experimental Rocket with C6-3 Engines

Flight #	Drag Fin Extension - in	Altitude - ft	Comment
1	0	217	
2	0	244	Cracked Fin Repaired after flight
3	4	248	Rocket rolls during flight (RR)
4	4	283	RR
5	8	266	RR. Fin Breaks & Repaired
6	8	241	RR

Weather Report by Weather.gov for Columbia, Columbia Metropolitan Airport

Date	Time (edt)	Wind (mph)	Vis. (mi.)	Weather
4/28/22	16:56	Vrbl 3	10	Fair

Sky Cond.	Temperature (°F)		Relative Humidity	Heat Index (°F)
	Air	Dwpt		
CLR	76	39	26%	77

Pressure	
altimeter (in)	sea level (mb)
30.09	1018.7

FIGURE 16: FLIGHT DATA AND CONDITIONS FOR TEST GRID FIN ROCKET

As can be seen from the notes in Figure 16, the problem with fin damage occurred with the test rocket. A redesign using elliptical fins would resolve this problem. Having damaged fins that were repaired might have affected the results, however, the trends seen with the TARC rocket were confirmed with the test one. See Figure 17.

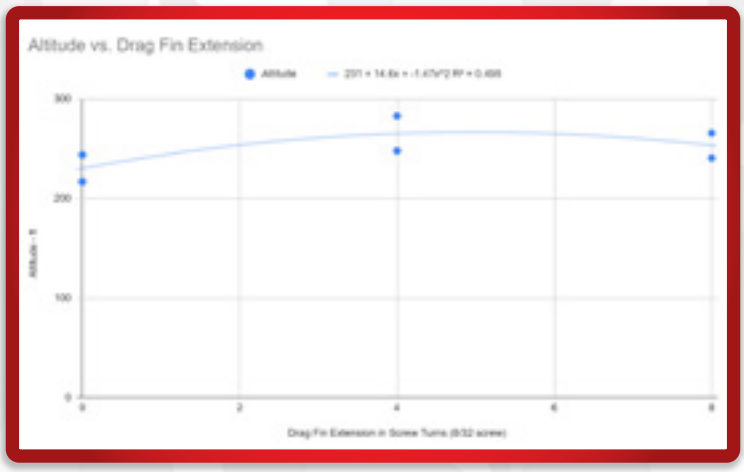

FIGURE 17: GRAPH OF ALTITUDE FOR FIN ADJUSTMENT FOR TEST GRID FIN ROCKET.

It can be seen that the results from the test rocket show an increase in altitude with grid fin extension. Not what anybody expected! What can be causing this?

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A relevant article in terms of aerodynamic analysis, entitled: “Drag reduction by application of aerodynamic devices in a race car,” indicates that spoilers and diffusers reduce the overall drag of a car. See (Nath, et al.). We posit that perhaps the deflected grid fins, with their rows of holes, are acting as a spoiler or diffuser. The article talks about a numerical modeling technique known as CFD or computational fluid dynamics. There are a number of CFD resources, some of which are web-based and have free accounts, which may help shine some light on this phenomenon. Looks like work for next season.

Further investigation is warranted on this observation.

Conclusion

This year the team experienced an overweight rocket, three redesigns, delays due to weather, and flying in 17 mph winds. We learned how to use reloadable engines, and we were on the verge of the perfect flight. Some practice flights, if called official, would have made results that would have brought the team to the finals. Post-season tests verified that the drag fin concept could actually be reducing drag! Welcome to competition rocketry - we learned a lot.

All of this year’s team members were seniors. In an effort to pass on lessons learned, these members will be writing their thoughts for next year’s TARC team. Three of the students who have been with the team for two years will be achieving their High Power Level 1 Rocket certification at the National Sport Launch at the end of May.

FIGURE 18: TEAM MEMBERS AT FINAL TARC FLIGHTS. LEFT TO RIGHT: SETH, SAMUEL, AND ZAC

Resources

If you are interested in trying the CATS box fin design, a resource is available which utilizes Onshape online CAD. Onshape is a fully functional parametric CAD program that can be accessed through the web. If you sign up for a free account, you can use a parametric model that allows you to create trapezoidal or elliptical box fin patterns. The full-size patterns can be printed for traditional hand fabrication or downloaded in DXF format for import into a laser.

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Access to the Onshape document is provided in the link below along with an instructional video.

CAD Resource: TinyURL.com/BoxFins
CAD Resource Video: TinyURL.com/BoxFinsVideo

FIGURE 19: SETH IS PREPARED FOR A DUSTY DAY!

References

Nath, D.S., Pujari, P.C., Jain, A. et al. Drag reduction by application of aerodynamic devices in a race car. Adv. Aerodyn. 3, 4 (2021). https://doi.org/10.1186/s42774-020-00054-7