The Effectiveness of a Turbulator on Egglofting Rockets

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NAR 35872

NARAM-31 R&D Report

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INTRODUCTION

As air flows over the surface of a wing, it will "adhere" to the wing's surface as long as conditions are favorable. This is what is referred to as a laminar boundary layer — the airflow is smooth, and it easily slips over the surface of the wing. To keep the conditions favorable for laminar flow, the pressure in front of the airflow must be lower than its current location. On most all airfoils, the pressure continues to decrease until the airflow arrives at the maximum thickness of the wing. At that point, the pressure ahead of the flow is higher, and the airflow must use its own energy to continue along its path. If the pressure is too high ahead, the airflow will not have enough energy to adhere to the surface, and it will separate from the wing (see figure 1)[1].

When the airflow boundary layer separates from the airfoil, it causes an increase in the *form drag* of the wing. At relatively high speeds, the airflow has enough energy to overcome an increasing pressure gradient until the airflow nears the trailing edge of the airfoil. At low speeds, there is not sufficient energy, and the boundary layer separates far earlier and creates a large "wake" — which increases the *profile* or *form* drag of the wing (see figure 2). This increase in drag can be avoided if the airflow is tripped from laminar to turbulent, because the turbulent airflow can "adhere" better to the airfoil when encountering an increasing pressure gradient[2] . This tripping of the airflow is done with a "turbulator" mounted near the leading edge of the airfoil[3]. A turbulator is any device that causes a disruption in the air flowing over a surface. They help in "invigorating" the flow and release some of its energy helping it through adverse pressure gradients.

Blunt bodies in an airstream are like airfoils; they have decreasing pressure gradients until maximum thickness, and then an increasing pressure gradient. But because of the shape, the increasing pressure gradient is far more severe, and the separation will occur shortly after maximum thickness (see figure 3)[4]. But like the

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[1] *Airplane Aerodynamics and Performance*, by Chuan-Tau Edward Lan and Jan Roskam. Roskam Aviation and Engineering, 1980. Page 46.
[2] *Topics in Advanced Model Rocketry*, by Gordon K. Mandell, George J. Caporaso, & William P Bengen. MIT Press, 1973. Page 376.
[3] *Model Airplane Aerodynamics*, Motorbooks International. Page 107.
[4] *Fundamentals of Aerodynamics*, by John D. Anderson, Jr. McGraw Hill Book Co., 1984. Page 36.

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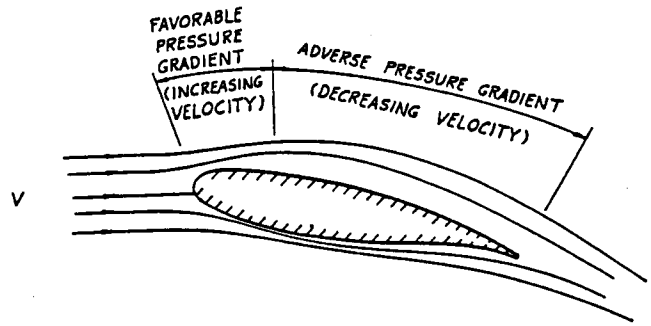

Figure 1: Velocity and pressure variation over airfoil upper surface.

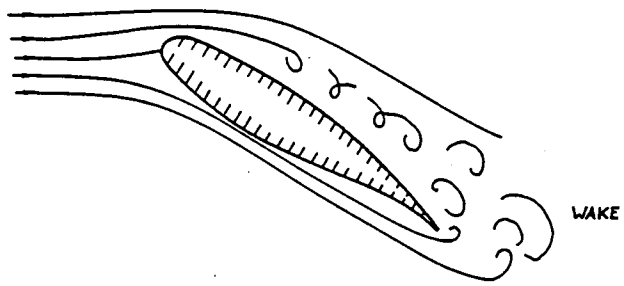

Figure 2: Example of wake induced by boundary layer separation.

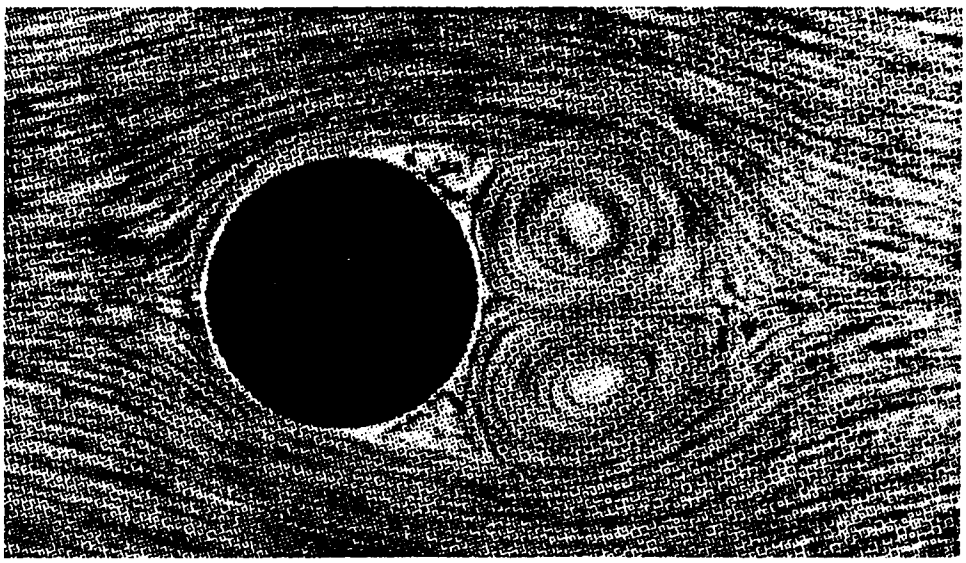

Figure 3: Flow-field picture obtained in water, where aluminum filings were scattered on the surface to show the direction of streamlines. Shows separation behind a cylinder.

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low speed airfoil, tripping the boundary layer early can reduce the overall drag of the body.

The purpose of the research presented herein is to investigate the possibilities of lowering the drag, on an egglofting rocket (which is a relatively blunt rocket), with the use of turbulators. If the drag can be lowered, then higher altitudes of travel should be attainable from egglofting rockets.

THEORY AND APPROACH

In an egglofting competition, the objective is to either obtain the greatest altitude, or achieve the longest duration aloft. Obviously, both objectives can be met by achieving the greatest altitude, because the higher a rocket travels, the further it has to fall, and that adds additional time to the model rocket's duration. Increasing the altitude on an egglofting model is harder to accomplish because the bulky size and extra mass of the egg put considerable constraints on the vehicle. Therefore, maximizing performance becomes increasingly difficult.

The two ways to achieve additional altitude are to decrease the liftoff mass of the rocket, or to reduce the aerodynamic drag on the rocket during flight.

Theoretically, one method of reducing drag to blunt bodied rockets, is to trip the boundary layer of the airflow near the leading edge (in front of the body's high point, or widest diameter). This causes the laminar airflow coming over the leading edge to turn into turbulent airflow, reducing the wake behind the model. As shown in figure 4, a sphere in a wind tunnel without a turbulator creates a large wake behind the model. With the turbulator, (see figure 5), the wake is reduced when forcing the airflow to become turbulent[1]. This is exactly the reason golf balls are dimpled; the reduction in drag allows the ball to travel further in flight.

The turbulent airflow causes an increase in *skin* or *friction* drag, but there is a considerable offset in *profile* drag of the model. The added benefit to a model rocket is that there is a smaller wake of extremely turbulent air behind the nose, and this keeps the stabilizing fins further downstream in laminar airflow: decreasing their drag, and improving their effectiveness in stabilizing the rocket.

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1 *Topics in Advanced Model Rockety*, Page 375.

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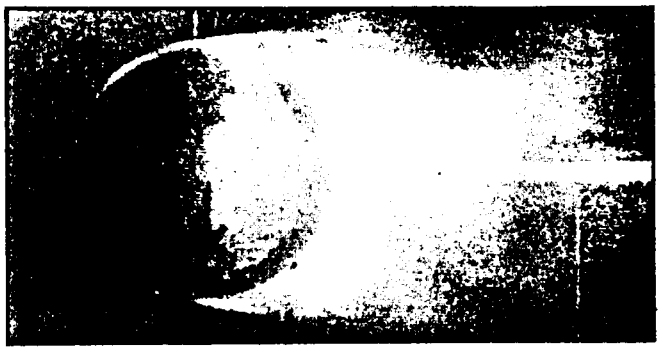

Figure 4: Airflow past a sphere without a turbulater.

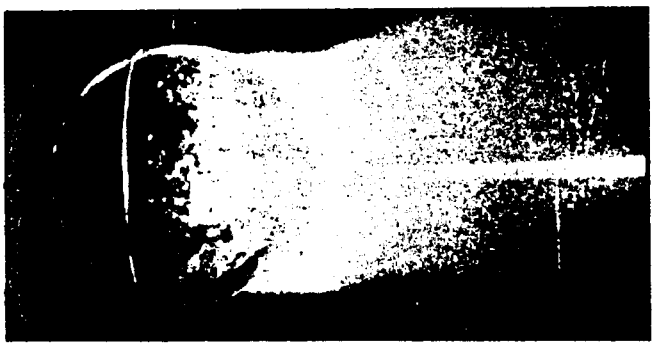

Figure 5: Airflow past a sphere with a turbulator

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Thus the intent of the experiment was to see if the application of a turbulator near the nose of the relatively blunt egglofter would decrease its drag, allowing the model to travel higher.

During the initial stages of the experiment, four models were built (see figure 6): two had gentle boattail transitions, and the other two had steeper transitions, and therefore, shorter in length. Both models of each set of rockets were identically constructed. The nose cone was made from two "large halves" of plastic Easter eggs that were glued together with cyanoacrylate (CA) adhesive. The seam was then sanded smooth until there was no visible seam line. The transition section was made from light weight cardboard. The seam that overlapped was also sanded smooth. The short straight section was made from a length of BT-20 body tube. The fins were made from 1/16-inch balsa wood. Because of possible inaccuracies that sanding an airfoil into the fins could produce, causing differences in the rocket aerodynamics, the fin's leading and trailing edges were only rounded. The wood grain was filled with CA adhesive, and then sanded smooth. After assembly, the models (except for the nose cones) were given a coat of gray epoxy primer, and then a coat of orange polyurethane paint. Figures 7 and 8 are different photographs of the rockets with turbulators.

In the flight portion of the research, it was noticed that the shorter models has less than desirable stability characteristics. Subsequently, these two models (Rockets #1 and #2) were dropped from the project. This allowed a higher number of flights of the two "longer" models. Rockets #3 and #4 were flown a combined total of 29 times.

The turbulators were made from two layers of 1/16-inch wide masking tape. On the models, they were applied circumferentially 3/4-inch behind the leading edge. This location was chosen because it is in front of the widest diameter, and far enough behind the leading edge that it would lessen the overall friction drag of the nose cone.

The models were flown in rounds with the flight proceedings following this approach: the models were prepped simultaneously, one with the turbulator, and one without. Two sheets of recovery wadding and a small amount of tracking powder were added prior to launch. These were then launched from a standard 1/8-inch launch rod with the aid of a "pop lug." The altitude of the models were then tracked using NAR approved tracking scopes set up on a 100 meter baseline.

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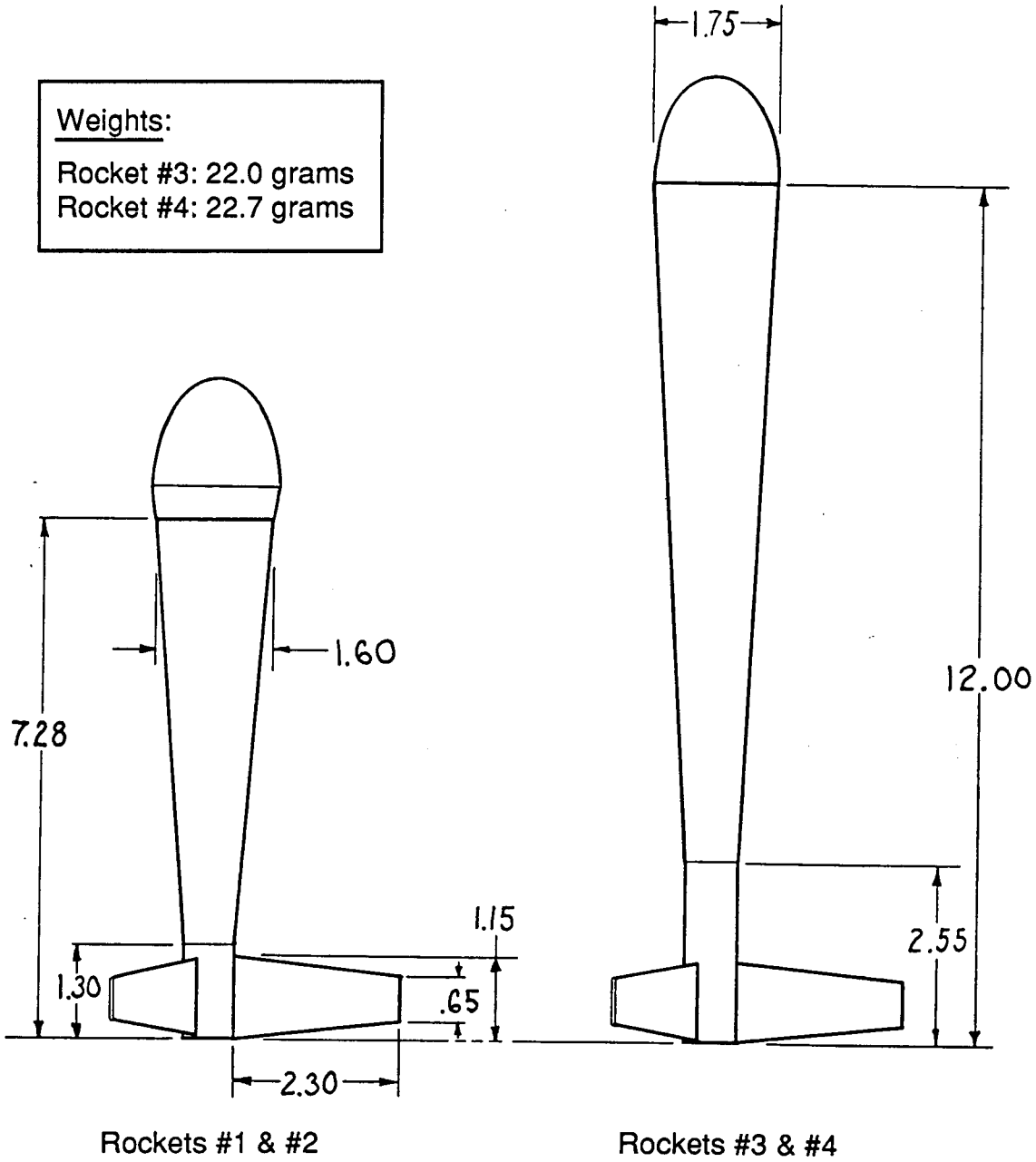

Figure 6: Basic rocket dimensions

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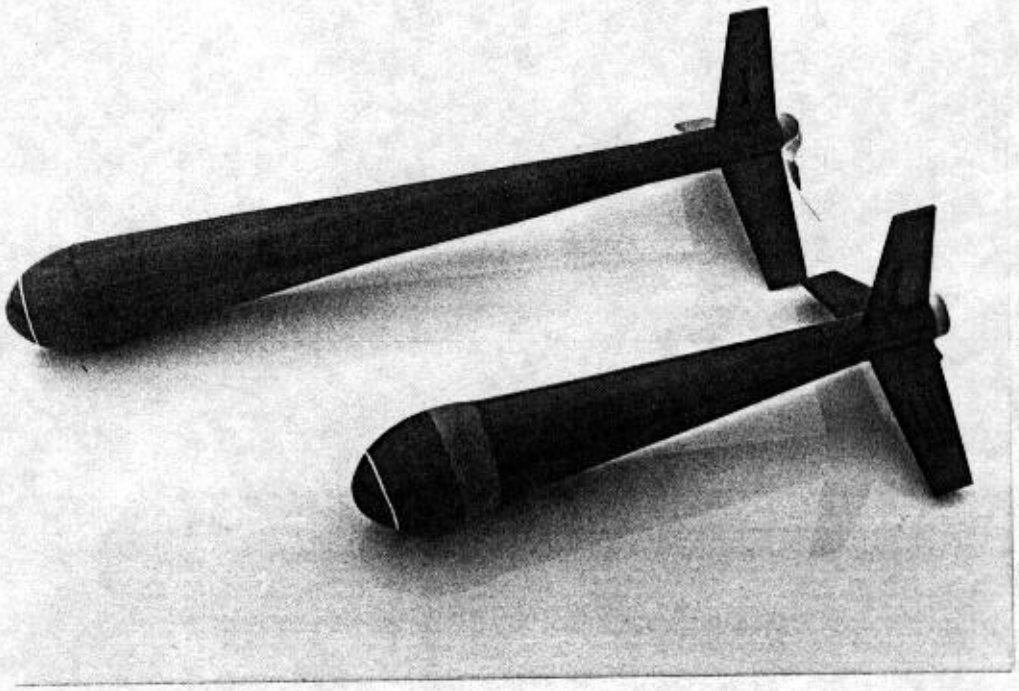

Figure 7

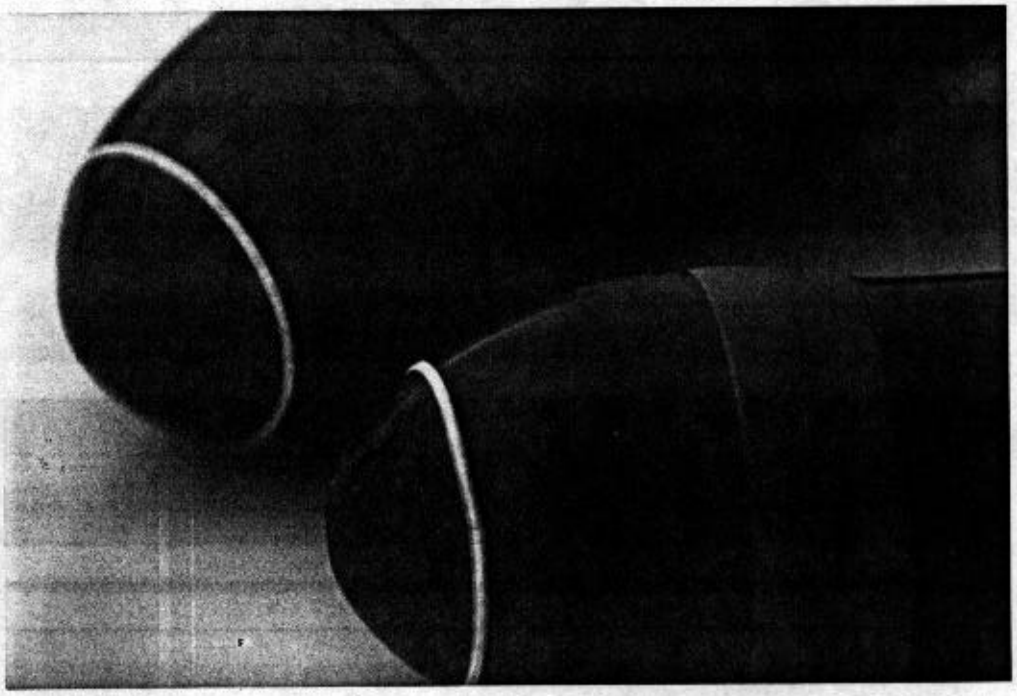

Figure 8

Recovery of the rockets was via a two inch wide by approximately 46 inch long tracing paper streamer (weight 2.0 grams).

Once the data was taken, it was reduced using the standard geodesic method listed in the back of the NAR "pink book.[1]" Between flight rounds, the turbulator would be switched from one model to the other to even out any subtle aerodynamic and weight differences between the models.

EQUIPMENT USED

The following equipment was used in this project:

- Launch pad
- Launch firing system
- Pop lug
- Two tracking scopes (owned by Space Coast Rocket Association)
- HP-28C hand-held calculator
- Two custom built rockets
- 28 Estes B4-4 rocket motors
- One Estes B4-2 rocket motor

DATA

The data shown in the following tables is in both its raw and its final form; meaning the tracking data has been reduced to yield the altitudes of the rockets' flights.

Table 1 shows the basic rocket data in the order in which it was obtained.

Table 2 takes the data from table 1 and divides it into two categories; flights that used the turbulator and those that didn't.

Graph 1 is the basic rocket data from table 1 only in graphical form (to see if any trends were developing).

Finally, table 3 shows the average altitude of the flights with turbulators, and those without.

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1 *United States Model Rockety Sporting Code*, 1988 Edition. National Association of Rockety. Page 53.

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Table 1: Raw flight data

Rocket Number	Turbulator	Engine	East Az.	East Elev.	West Az.	West Elev.	Geo. Altitude	Closure
3		B4-4	87.5	48.5	55.0	42.5	150.81	.0075
4	YES	B4-4	70.0	58.5	51.5	53	147.48	.0120
4	YES	B4-4	73.0	52.0	58.0	34.0	not closed	
4		B4-2	78.0	32.5	60.0	27.0	77.89	.0929
3	YES	B4-4	83.0	48.5	60.0	44.0	160.58	.0185
3	YES	B4-4	61.0	56.0	66.5	57.5	172.12	.0049
4		B4-4	53.0	61.0	58.0	64.0	168.68	.0267
3	YES	B4-4	68.0	35.5	65.5	36.0	91.13	.0292
4		B4-4	61.0	45.0	89.0	51.3	201.33	.0567
4	YES	B4-4	36.0	53.0	90.0	67.0	164.48	.0169
3		B4-4	50.0	36.5	101.5	45.5	152.14	.0512
4	YES	B4-4	65.0	47.0	72.5	50.0	154.64	.0347
3		B4-4	60.0	47.0	76.0	52.0	152.88	.0390
4	YES	B4-4	67.0	43.5	74.0	47.0	149.22	.0539
3		B4-4	44.5	65.0	47.5	64.5	152.14	.0249
3	YES	B4-4	77.0	45.0	58.5	43.5	126.61	.0617
4		B4-4	28.0	43.0	105.5	62.5	123.86	.0016
3		B4-4	77.0	57.0	59.0	54.5	194.09	.018
4	YES	B4-4	64.5	64.5	49.5	63.0	183.94	.038
3		B4-4	77.0	57.0	61.5	56.0	211.84	.034
4	YES	B4-4		LOST TRACK				
3	YES	B4-4	94.0	52.3	50.5	46.0	176.83	.020
4		B4-4	47.5	55.5	91.5	67.5	216.70	.085
3	YES	B4-4	90.0	46.5	60.5	45.5	197.76	.070
4		B4-4	79.0	42.0	73.5	44.0	193.40	.068
3	YES	B4-4	64.0	32.0	57.5	29.0	180.05	.0465
4		B4-4	60.0	35.0	52.0	30.5	171.25	.0619
3		B4-4	52.0	31.0	55.0	19.0	113.30	.5182
4	YES	B4-4	41.0	32.0	55.0	30.0	132.88	.2348

Table 2: Flight data categorized

Flights without Turbulator

Flight Number	Rocket Number	Altitude	
1	3	150.81	
4	4	77.89	early ejection
7	4	168.68	
9	4	201.33	
11	3	152.14	
13	3	152.88	
15	3	152.14	
17	4	123.86	old engine
18	3	194.09	
20	3	211.84	
23	4	216.70	
25	4	193.40	
27	4	171.80	
28	3	119.8	not closed

Flights with Turbulator

Flight Number	Rocket Number	Altitude	
2	4	147.48	
3	4	92.65	not closed
5	3	160.57	
6	3	172.12	
8	3	91.13	nose seperation
10	4	164.48	
12	4	154.64	
14	4	149.22	
16	3	126.61	old engine
19	4	183.94	
21	4	lost track	
22	3	176.83	
24	3	197.76	
26	3	180.4	
29	4	134.3	not closed

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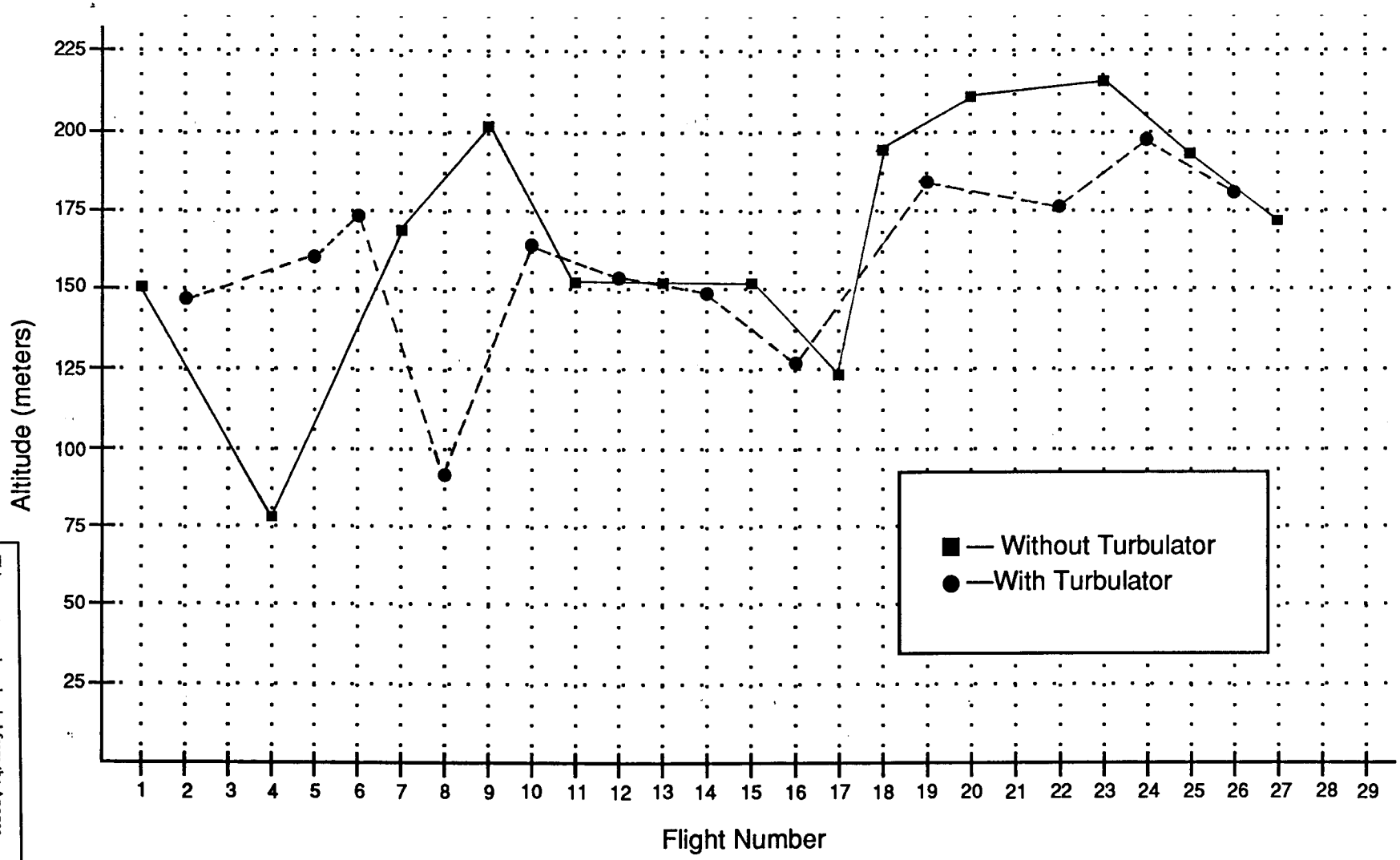

Graph 1: Altitude of each flight

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Table 3: Flight data summary

Flights without Turbulator		Flights with Turbulator	
Total Flights:	14	Total Flights:	15
No. of "Reliable Flights:	11	No. of "Reliable Flights:	10
Avg. Altitude of "Reliable Flights":	**178.71 m**	**Avg. Altitude of "Reliable Flights":**	**168.74 m**
Standard Deviation	25.60	Standard Deviation:	16.34
No. of Flights (Rocket #3):	6	No. of Flights (Rocket #3):	5
Average Altitude (Rocket #3):	168.98 m	Average Altitude (Rocket #3):	177.53 m
Standard Deviation:	26.92	Standard Deviation:	13.55
No. of Flights (Rocket #4):	5	No. of Flights (Rocket #4):	5
Average Altitude (Rocket #4):	190.38 m	Average Altitude (Rocket #4):	159.95 m
Standard Deviaton:	20.23	Standard Deviation:	14.96

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DATA INTERPRETATION AND RESULTS

Of the 29 flights flown, tracking was "closed" on 21. The final results used the 21 "reliable" flights. The other eight data points were excluded, but are listed for completeness.

Those flights of those thrown out are as follows. Flight #3 experienced tip-off from the pop lug, and the flight ended up unstable, and therefore not closed. Early on in the experiment, in an attempt to get the ejection charge to release the recovery system as close to peak altitude as possible, a "B4-2" motor was used on flight #4. The delay time turned out to be too short, and the altitude attained was only 77.89 meters.

The nose cone in flight #8 was apparently not snug enough, because following engine burnout, the nose cone separated from the rocket before reaching apogee. This flight was not "closed."

Flights #16 and #17 used "older" engines that had been lying in the bottom of the range box for the past few years, and consequentially, the performance of those two flights were "out-of-family" (and inferior) compared to the newer engines (this is one good reason for using engines of the same lot number).

Rocket flight 21 experienced a small amount of tip-off from the launch rod causing it's trajectory to carry it directly over one tracker. Because of this, he was unable to get a fix on the rocket's position.

Flights 26 through 29 were tracked using a 300 meter baseline (compared to 100 meter baseline used on all previous flights) at *VANGUARD 1,* a competition in West Palm Beach, Florida on July 22, 1989. Because of the longer baseline, and greater distance of trackers from the pad, the trackers were unable to spot the rocket, and consequently, two of those four flights were not "closed."

The remaining flights were taken on three separate days June 27, July 8, and July 15. The weather conditions being in the same range: temperature 85 - 90° F, 80% humidity. Except for the noted flights above, all the flights were very stable and nearly vertical.

Damage did occur to the models on some flights when the models landed on hard ground. The noted damage was broken fins at the root edge. Repairs were made by gluing the fins back in place, and reinforcing all the fillets with CA soaked

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graphite mat. Both rockets received comparable damage during the course of the flight program.

The quality of the data can be inferred from the flight summary data in table 2. The table breaks down the performance of each individual rocket. In the case of the flights without turbulators, Rocket #4 flew higher by 12.66%. When the turbulator was added, Rocket #3 flew higher by 10.99%.

The results from this project seem to indicate that the use of the turbulator was ineffective causing the average altitude to decrease from 178.71 meters to 168.74 meters.

I do believe, even with only 21 good flights, that the data presented is typical of the trend that would eventually appear with more flights.

CONCLUSION

For the flight configuration tested, the data indicates that for maximum altitude, do not fly the rocket with a turbulator. The key thing said in the above sentence is "the flight configuration tested." For a different flight configuration, the results might be different, and it is conceivable that the shorter rocket (that needed to be re-balanced), might have flown higher with a turbulator.

Also not tested, because of money and time constraints, is how the total impulse of the rocket motor plays in turbulator effectiveness. Although all rockets begin flight with zero velocity, and end at apogee with zero vertical velocity, larger motors reach higher velocities in the middle. At these higher velocities, the turbulator might become more (or less) effective.

The ideal, and the quickest way, to test these hypotheses is to conduct the research in a wind tunnel, and actually measure the drag coefficients of the two different configurations. Then it would be easy to vary the velocity of the airflow, the location and thickness of the turbulator. Much more meaningful data would result from this approach. But because I didn't have the use of a wind tunnel, flight testing was my only available means of gathering the data.

Finally, to be worth the trouble of adding a turbulator, a change of at least 5% in increased altitude would have to be attainable (this is what I was looking for in the data). For a rocket that averages 160 meters each flight, the extra 5% performance increase would allow it to coast another 8 meters. This experiment gave a -5%

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change in average altitude, which is why I believe that this particular configuration does not warrant the use of a turbulator.

PROJECT COST

The total cost of this project was approximately $56. This was broken down as follows: engines - $35.35, models - $12.00 (a comparable retail value), photographs - $6.00, misc. items (wadding, igniters, glue) - $5.00.

ACKNOWLEDGEMENTS

Thanks to: Pat McCarthy, Robert Koenn, Mike Myrick, and Rick Boyette for the excellent aid they provided in tracking the flight models in the unbearable heat and humidity of Florida.

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APPENDIX

Formula for Geodesic Altitude Determination (from the NAR "Pink Book")

$$f = \sin E_1 \sin E_2 - \cos E_1 \cos E_2 (\cos A_1 \cos A_2 - \sin A_1 \sin A_2)$$

$$d_1 = B \frac{\cos E_1 \cos A_1 + f \cos E_2 \cos A_2}{1 - f^2}$$

$$d_2 = B \frac{\cos E_2 \cos A_2 + f \cos E_1 \cos A_1}{1 - f^2}$$

$$A = \frac{d_1 d_2}{(d_1 + d_2)} (\sin E_1 + \sin E_2)$$

$$C = B \left| \frac{\cos E_2 \sin E_1 \sin A_2 - \cos E_1 \sin E_2 \sin A_1}{A\sqrt{1 - f^2}} \right|$$

- B is the length of the tracking baseline
- A1 and E1 are the azimuth and elevation angles reported by tracking east.
- A2 and E2 are the azimuth and elevation angles reported by tracking west.
- A is the final, reduced altitude.
- C is the closure, expressed as a fraction of the altitude.
  Closure ≤ 0.1 denotes a closed track.
- Other symbols denote common subexpressions, and are used solely for purposes of clarity.

Formula for Standard Deviation (from Kenkel, page 63)

$$S^2 = \frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n - 1}$$

n = sample size

$\overline{X}$ = average value

X_i = value of the i member

S = standard deviation

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