Proceedings of The National Conference
On Undergraduate Research (NCUR) 2019
Kennesaw State University
Kennesaw, Georgia
April 11-13, 2019

Effects of Shark Caved Fins on Altitude Performance of a High-Powered Rocket

Atharv Datye, Grisha Bandodkar, Sumayya Syeda, Siddharth Manchkanti
Department of Mechanical Engineering
San Jose State University
San Jose, CA, 94086, United States of America

IntelliScience Institute
San Jose, CA, 95112

Faculty Advisor: Dr. Sohail H. Zaidi

Abstract

Fins are mounted on the rocket to provide passive stabilization during the flight. Various fin designs with several primary parameters' options are readily available. Industry standard trapezoidal fins impose a major drawback in the overall stability of the rocket. Correcting the stability issue by adding weight to the nose deteriorates the rocket's speed and altitude performance, thus impacting the full potential provided by the rocket motor. As part of our research on effects of fin design at San Jose State University, a new set of fins, named Shark-Caved fins, are developed to investigate the altitude performance of the rocket. To compare the performance of Shark-Caved fins, an experimental Aerobee 150A rocket mounted with new Plexiglas fins and I280W motor was launched simultaneously with another rocket equipped with standard Trapezoidal fins in Del Norte, California. The flight data showed that the new fins helped increase the overall altitude of the rocket to 3500ft (7.69231% increase) and the Mach number 1.4 (91.78% increase) compared to the trapezoidal configuration which reached a peak altitude of 3250ft and a Mach Number of 0.73. This is because the new rocket did not need any weight addition to meet the static margin requirements. Preliminary performance on two rockets equipped with different fins was obtained using Open Rocket software. ANSYS Fluent is being used to model the flow around the fins at operating environmental conditions that existed at the launch of these rockets. Fluent was able to capture the shockwaves associated with the supersonic speed and gave full flow field around the fins providing information on drag, Mach number, and pressure distributions. Along with the experimental data, preliminary results from ANSYS Fluent are presented in this paper.

Keywords: Optimization, Altitude Performance, Fins, ANSYS Fluent

1. Introduction

The field of experimental rocketry involves experimenting with different scale rocket designs. Many flight engineers tend to optimize kit-based internal designs developed in the early 2000s to achieve upgraded performance. The problem with optimizing the internal design of the rocket is that the change in weight can severely affect the stability of the rocket, which can then lead to a massive flight path deviation or even a crash. Rockets can be stable using both active and passive control methods. At the university level, rockets that are not FAA certified class 1 with active control systems can be mistaken for guided weaponry[7], therefore, fins are installed on the rocket as a passive control system. Rocket fins provide longitudinal stability and aerodynamic efficiency. A rocket will undergo inertial forces during its flight phase which could sometimes change its flight path, thus affecting its peak altitude performance. Rockets also wobble inflight due to the inertial forces and requires excess propellant to help stabilize itself, which in turn affects speed performance. Optimal flight performance can be achieved when the drag is minimum and rocket is mostly stable throughout its flight. While other factors such as weight, drag and other aerodynamic factors were considered in this experiment, the purpose was to investigate the effect of changing the fin design on the rocket's altitude performance.

2. Design and Methodology

As a continuation of the previous paper (by Datye A, Zaidi S.H) which was primarily based on speed performance, the same procedure was conducted based on the mission guidelines with safety protocols enforced by the NFPA1127[7]. Two Aerobee 150A rockets were developed with one rocket equipped with the initial trapezoidal fin design and the other rocket equipped with the newly optimized Shark-Caved fin design. An initial preflight conducted on the initial trapezoidal configuration showed that the rocket was unstable due to the improper positioning of the Center of Gravity (CG). Upon adding weight into the nose, it was found that the rocket was within the stability criteria, however, from the flight tests it was found that the altitude and speed performance deteriorated by 4% bringing the top speed down to Mach 0.7 due to extra weight in the rocket.

Our analysis began by modelling fins, using Barrowman's stability criteria to determine which configuration would maintain the stability of the rocket and increase altitude performance of the rocket. For a rocket to be stable, the static margin needs to be on or near the empennage of the rocket. This means that the Center of Pressure (CP) must be near or between the center of the of the leading edges of the fins and the center of gravity must be in front of it at a distance twice the diameter of the rocket[3]. Like the Samurai Sounder fin, the new fin was designed initially using RockSim software and was tested using the I280W motor configuration. Results for the simulations can be seen in figures 3 and 4. It was found that the shark caved fins increased the altitude performance compared to the trapezoidal fins.

The shape of a fin greatly affects the flight performance of the rocket. The worst shaped fin would have the highest profile drag; that is, more air flowing around the tip edge of the fin. Therefore, avoiding fins with a larger area near the fin tip was taken into consideration. Lifting forces are not required when the rocket is flying straight upward; however, as the rocket tends to deviate from its path due to the air turbulence and wind, the inflight lift generated by the angle of attack of the rocket due to those perturbations tends to stabilize the rocket. Theoretically, elliptical fins are ideal as they provide the best lifting force; however, they also produce enough induced drag to also provide drag stability to the rocket[1]. Clipped Delta fins are primarily used on high performance rockets to yield a low drag force[2]. The elliptical and clipped delta configurations provided more positive figures of merit compared to the other types of fins[1].

One of the factors of pinpointing an accurate design was figuring out the appropriate cross section and sweep for the fins. Most fins used in high powered experimental rocketry employ rectangular, rounded, airfoil or wedge based cross sections[6]. Most of these cross sections were studied based on theoretical data, past flights and simulations and was determined that for the nature of this mission, a combination had to be made. Rectangular fins in the past flights, though high-performing, create high drag forces which negatively impact the flight performance at higher speeds[4]. Therefore, to test the effective performance impact of the fins the rockets were initially equipped with rectangular-cross section fins with tapered ends. Figures 1 and 2 show the final rendered 3-D design of the rocket on RockSim.

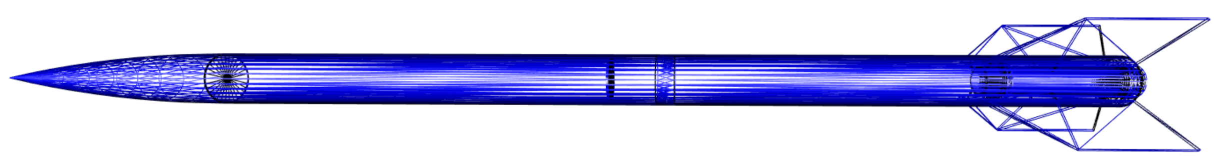


Figure 1. Industrial Trapezoidal Fin Configuration

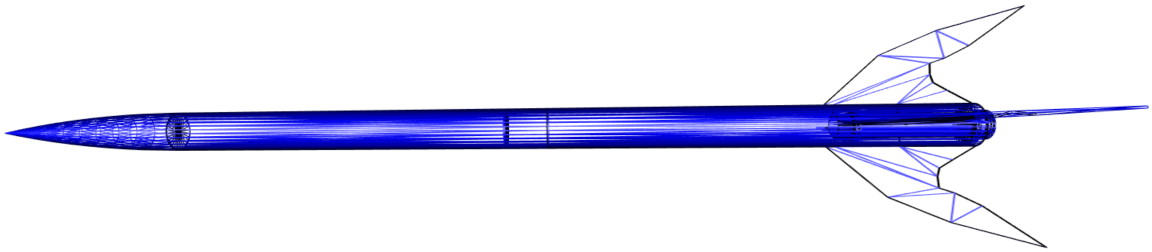


Figure 2. Shark-Caved Fins

The new fins have a lower area compared to the initial design. To reduce the effects of the shockwaves at supersonic speed and increase the altitude performance, the span, chord length and the sweep angle was further increased. Initially, RockSim indicated that the rocket equipped with the new fins would be marginally stable. However, upon investigating the different cross-sections, input in the software for this configuration, the airfoil cross-section showed that the static margin would be between 1.2 and 1.6, therefore, rocket would be well within the stability criteria.

RockSim also demonstrated that the CP was a bit closer to the CG. Therefore, we decided to take off some weight of the fins by reducing the thickness by 6.8%. Theoretical simulations performed in RockSim for altitude performance showed that the new configuration would reach an average peak altitude above 3200 ft. Sounder rocket has the capability to fly at a speed more than Mach 1.2. However, as the speed of the rocket increases, the drag force also increases, impacting the altitude performance of the rocket. Therefore, Shark Caved Fins were developed so that the speed performance will be negatively impacted due to a larger span to reduce the drag and increase its altitude performance. A more in-depth simulation was performed using the ANSYS Fluent software to investigate the flow profile of the fin which will be further expanded in the upcoming section.

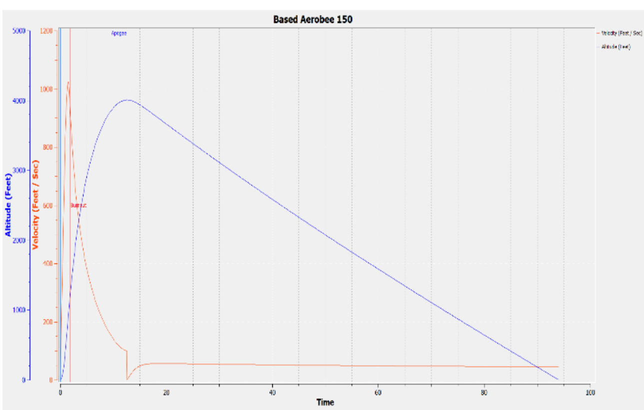


Figure 3. Preliminary Data for Trapezoidal Fin

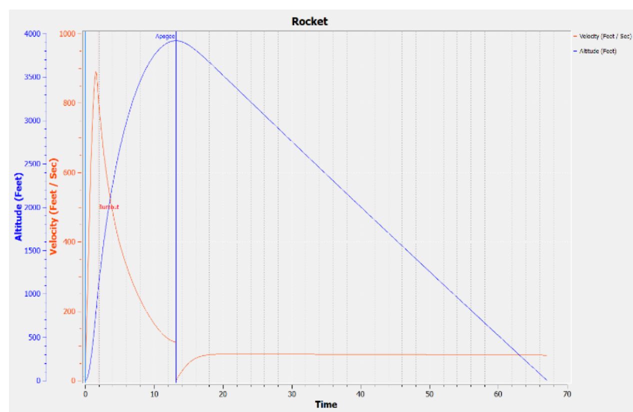


Figure 4. Preliminary Data for Shark Cave Fin

Table 1 summarizes the simulation results for the altitude, speed and drag force for each configuration from the simulations performed in RockSim as seen in figures 3 and 4

Table 1. Simulation Results

Configuration	Altitude	Speed	Drag Force
Initial Trapezoidal Configuration	3300ft	1,500 ft/sec	700N
Shark-Caved (optimized configuration)	3850ft	1,850 ft/sec	350N

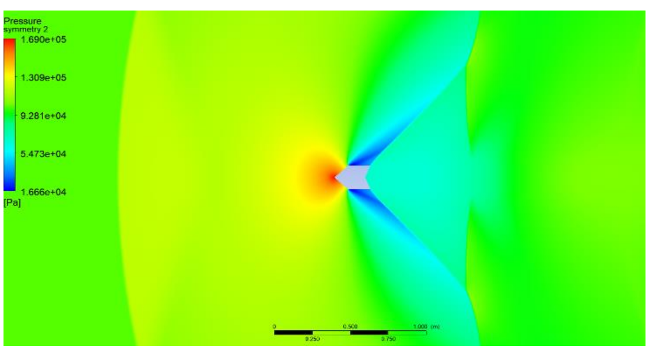
3. CFD Fluent Simulations

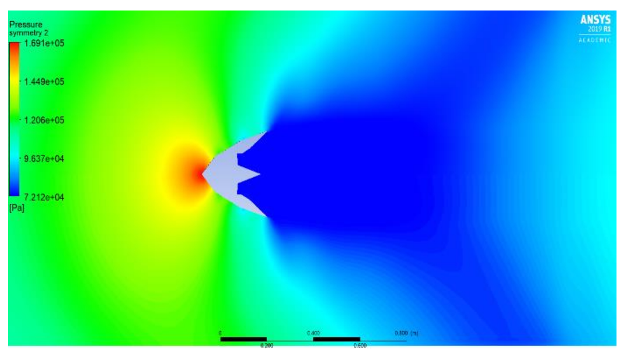
CFD Simulations were conducted on ANSYS Fluent to determine the Velocity, Pressure and Turbulence Kinetic Energy criteria which will determine the overall drag performance. For this analysis, as the flight will be operated well within the troposphere, the atmospheric conditions up to 10,000ft will not be changing that much. Therefore, this simulation will be conducted in steady state and pressure based conditions. Based on the preliminary results from RockSim, higher order discretization was not considered for the initial simulations as the operating speeds of the rockets based on the I280W motor yielded below Mach 1.5. For the both the fins, Quad-Multizone meshing techniques was used to mesh the area containing the fin. The mesh size was selected to be between 0.02cm and 0.05cm. This is because mesh sizes under 0.02 yielded errors during the meshing process and delayed most of the simulation result time. Boundary conditions were operated with energy equations and Transitional SST scenario as these rockets have the potential to surpass Mach speed. Table 2 shows the operating and the boundary conditions used to perform the simulations and the following figures depict the Pressure, Velocity and Turbulent Kinetic Energy profiles.

Table 2: List of Boundary Conditions

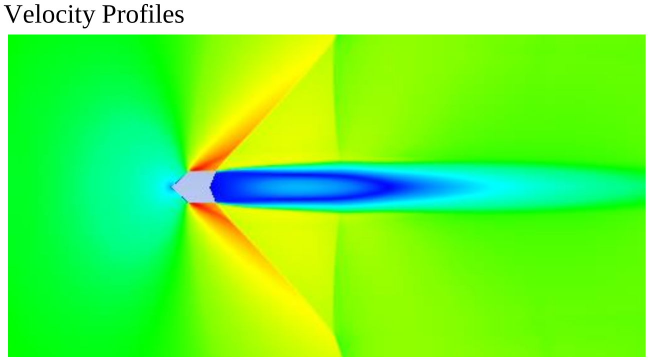
Description	Trapezoidal Fin	Shark Caved Fin
Operating Pressure	0 Pa	0 Pa
Gauge Pressure	101325 Pa	101325 Pa
Mach Number	0.9	1.4
Temperature	292K	292K

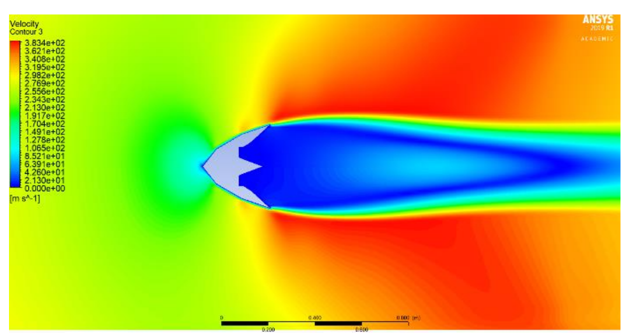
Pressure Profiles:



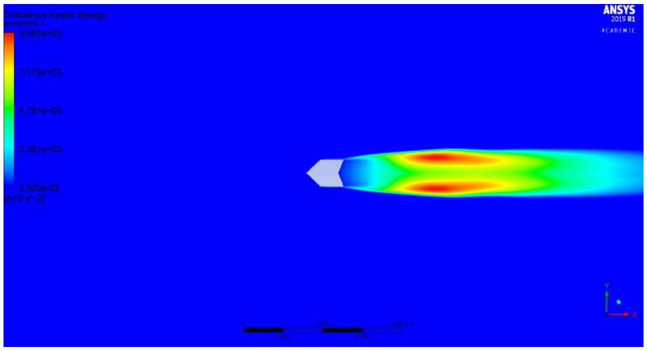


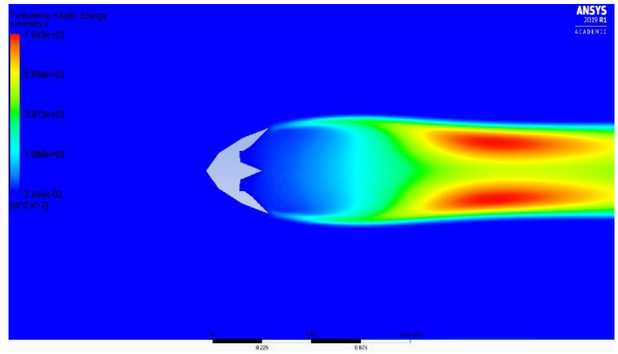
Velocity Profiles





Turbulence Kinetic Energy Profile





4. Flight Test

Targeted ideal flight conditions of a high powered rocket for this mission was warmer temperatures with light and variable winds. The experiment took place during the summer season, and the following Table 3 shows the translated METAR data of the launch area (Fresno, CA, meteorological identifier KFAT) at the time of launch.

Table 3: Flight Parameters at the time of launch

Temperature	88.9 F
Pressure	30.16 in
Launch Time	12:20 P.M.
Winds	3.2 mph
Humidity	30%

Preflight checks determined the departure weight of the modified rocket to be 12 lbs. and 15.25 oz., much lighter than the original rocket (15 lbs.) Installation of the motor before the launch sequence yielded a CG imbalance for the original design. This was rectified by placing additional weight into the nose cone of the rocket to bring the CG forward. This increased the weight of the rocket, which ultimately increased the drag forces and thus hampered its overall altitude performance. As the CP shifted towards the tail end of the rocket for the second design, the position of the CG after the motor installation provided a good static margin. The visual representation of the flight showed that the rocket was very stable. Figure 8 demonstrates the flight data from the initial configuration and Figure 9 from the optimized configuration.

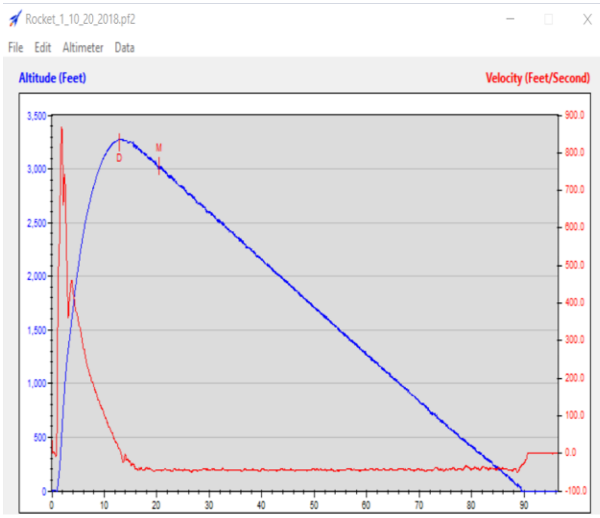


Figure 8. Flight Data from Trapezoidal Fin Rocket

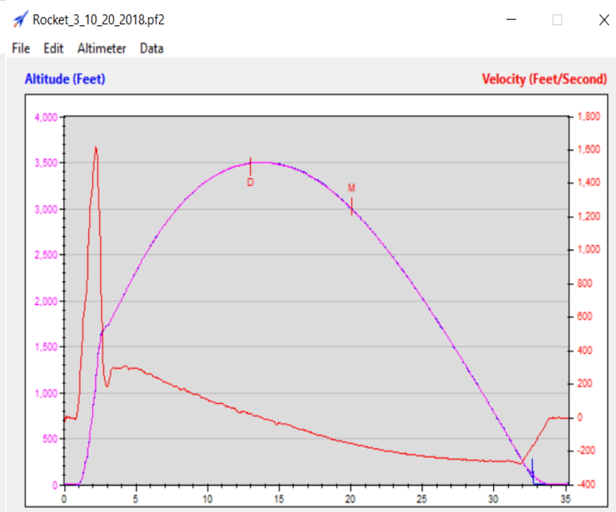


Figure 9. Flight Data from the Shark-Caved Fins Rocket

5. Discussion

The availability of ANSYS Fluent and RockSim software provided an ideal viewpoint of the rockets behavior during its flight. The rocket was stable and had an uneventful flight, and was later certified as a successful test flight by Tripoli Area Prefecture (TAP) officials. The resulting simulations on Rocksim showed that the newly optimized rocket experienced a 23% reduction in the overall drag force, thus reducing the drag coefficient and the flight time. The peak altitude increased by a factor of 1.2%. Attaining the proper static margin without affecting the rocket's weight contributed to the decrease in drag forces acting on the rocket. The simulations revealed a 10% error in the static margin readings. The sounding rocket's main body design dictated that the static margin of the rocket had to be more than twice the diameter of the rocket. The static margin determined at the time of the preflight was exactly twice the diameter. The first configuration, however, took on an additional 2lb 12oz to meet the appropriate static margin requirement. Inflight experimental data showed that the first configuration reached a peak altitude of 3250ft with a max velocity of Mach 0.7. The optimized configuration reached a peak altitude of 3500ft with a maximum velocity of Mach 1.4. The speed performance for the newly optimized rocket increased by a fraction and the altitude performance of the rocket increased due to lower drag at supersonic speeds. The first rocket, due to the additional 2.3lbs weight, experienced more drag than predicted from the simulations, which negatively impacted the altitude performance by 50ft.

6. Conclusion and Future Work

The flight test conducted showed that the proposed optimized fin design, which has a lower fin area but a larger fin span, successfully improved the rocket's altitude and speed performance. The rocket's overall weight decrease showed that optimizing the fins can impact the overall rocket's physical and flight parameters. The shark cave fins designs undergo further testing where the fins will be manufactured using both fiberglass and carbon fiber composite.

7. Acknowledgements

Support from the San Jose State University Rocketry Club for their provision of work station and transportation to the launch site is greatly appreciated. Funding, support and manufacturing of fins from IntelliScience Institute is also greatly appreciated.

8. References

1. Anderson, J. D. (2016). *Introduction to flight*. New York, NY: McGraw-Hill Education.
2. Bohrer, T. W., Humphries, M. J., Hendricks, T. G., Johnson, P., and Dormody, K., "Design and Development of Amateur Rocket for NASA USLI Competition," *AIAA Region VI Student Conference*, Mar. 2017.
3. Box, S., Bishop, C. M., and Hunt, H., "Estimating the dynamic and aerodynamic parameters of passively controlled high power rockets for flight simulation," Feb. 2009.
4. Datye A., S.H. Zaidi, "Design and Development of a High-Powered Rocket to Achieve Supersonic Speed", *Southern California Conference of Undergraduate Research (SCCUR)*, Los Angeles (CA), 2017
5. Hernandez, R. N., Singh, H., Messimer, S. L., & Patterson, A. E. (2017). Design and Performance of Modular 3-D Printed Solid-Propellant Rocket Airframes. Retrieved from http://www.mdpi.com/journal/aerospace
6. Nakka, Richard A. "SIMPLIFIED METHOD FOR ESTIMATING THE FLIGHT PERFORMANCE OF A HOBBY ROCKET." Feb. 2007.
7. Safety Code for High-Power Rocketry, *Tripoli Rocketry Association* § NFPA1127 (2016).