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Design Optimization of Fins of a Sounding Rocket for Maximum Lift-to-Drag Ratio and Minimum Radar Cross-Section Area Using ANSYS

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Abstract

The optimization of a sounding rocket's fins is a crucial part of improving its performance. The geometric optimization of a sounding rocket's fins is presented in this paper. The main goal is to optimize the geometry for the minimum radar cross-section area and maximum lift-to-drag ratio. In CATIA, a 3D model was created. The L/D ratio was maximized using the ANSYS adjoint solver, and the radar cross-section area was minimized using ANSYS optimetrics. To determine the total RCS, the RCS of each fin was determined individually and then added together. Root, leading edge, tip, and trailing edge were the four parameters that were defined for the RCS optimization. The L/D ratio was increased by 8.3 times, and the RCS was decreased by 12% after optimization. Additionally, the body surface can be optimized further. The missile industry can benefit from the paper's findings.

Keywords: ANSYS, sounding rocket, Optimization, Radar Cross Section Area, Lift-to-Drag Ratio

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1. Introduction

Companies around the world continuously seek to optimize their products and improve on their existing performance. The shape optimization process can often be time-consuming, requiring substantial manual input and multiple design iterations. In the field of aerodynamics and aircraft design, maximizing the lift-to-drag ratio is a critical objective for achieving optimal performance and efficiency. It was discovered that, utilizing the proposed technique, the drag caused by the rocket fins may be reduced by up to 29% without increasing the probability of undesirable effects leading to unstable behavior (Barbosa and Guimãraes, 2012). To achieve an optimal lift-to-drag ratio, engineers and researchers employ various optimization techniques. One powerful approach is the use of adjoint solvers, which provide an efficient and accurate means of optimizing the geometry of aerodynamic configurations. The utilization of adjoint solvers for the optimization of geometry in pursuit of the maximum lift-to-drag ratio represents a powerful tool in the field of aerodynamics and aircraft design. It was found that the rocket would have experienced a drag coefficient of 0.484 under ideal laminar and zero wind circumstances, which translates to a 13.6% increase in drag (Datye, Advisor and Zaidi, 2018). The geometry was designed in CATIA. CATIA stands for Computer Aided Three-Dimensional Interactive Application and is much more than a CAD (Computer Aided Design) software package. The CFD solution method and the optimization procedure can be applied to design or optimize for different geometries (Şumnu and Güzelbey, 2021).Adjoint Solver — a free add-on module available with Ansys Fluent — enables shape optimization in a smart and automatic way with minimal turnaround time. Using its unique sensitivity-based algorithm, Adjoint Solver helps optimize your existing design and export the morphed geometry. By leveraging the adjoint method's computational efficiency and accuracy, engineers can systematically improve the performance of aerodynamic

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configurations while considering multiple design constraints. The reduction of radar cross section (RCS) is a critical objective in the design and development of stealthy and low-observable platforms. ANSYS Electronics Optimetrics represents a cutting-edge solution for the optimization of geometry in pursuit of a minimum radar cross-section area. ANSYS Electronics Optimetrics is a state-of-the-art software tool specifically designed to address electromagnetic design challenges. Leveraging the power of high-fidelity electromagnetic simulation, it provides engineers with a comprehensive environment to optimize and analyze various aspects of antenna design, electromagnetic interference (EMI), and radar cross section reduction.

By leveraging its advanced electromagnetic simulation capabilities and optimization algorithms, engineers can systematically explore the design space to identify the optimal configuration that achieves the desired RCS reduction. Some examples of design factors include missile diameter, nose, body, and aft body length, number of fin sets, number of fins for each fin set, size and shape of each fin, and fin cross-section (Arslan, 2014). This powerful tool contributes to the development of stealthy platforms and enhances survivability and effectiveness in radar-dominated environments. The objective of this research is to maximize the L/D ratio and minimize the RCS. The experimental and numerical outcomes show that the incorporation of tubercles into engineered airfoils imparts better aerodynamic characteristics (Supreeth *et al.*, 2020). The major problem in the field of missiles is a lack of adequate research in the optimization of the geometry of fins for maximum L/D ratio and minimum RCS. In past research, the optimization of the L/D ratio and the minimum RCS were not done together. The primitive approach to the optimization of the fin geometry was done by DATCOM, which was very time-consuming and hectic. This approach is time-saving and user-friendly.

Global companies prioritize product optimization for improved performance. Aerodynamics, especially lift-to-drag ratio maximization, is vital. A technique cut rocket fin drag by 29% without instability. Adjoint solvers, like Ansys Fluent's, efficiently optimize aerodynamic geometry. CATIA aids geometry design, and CFD solutions apply to various geometries. Adjoint Solver streamlines shape optimization, enhancing aerodynamics while respecting constraints. Reducing radar cross-section (RCS) is crucial for stealthy platforms, and ANSYS Electronics Optimetrics excels in RCS area minimization through electromagnetic simulation. It aids in designing antennas, mitigating electromagnetic interference, and reducing RCS. Research focuses on maximizing L/D ratio and minimizing RCS, exploring innovative missile design methods, and departing from the time-consuming DATCOM approach towards efficiency and user-friendliness.

2. Methodology

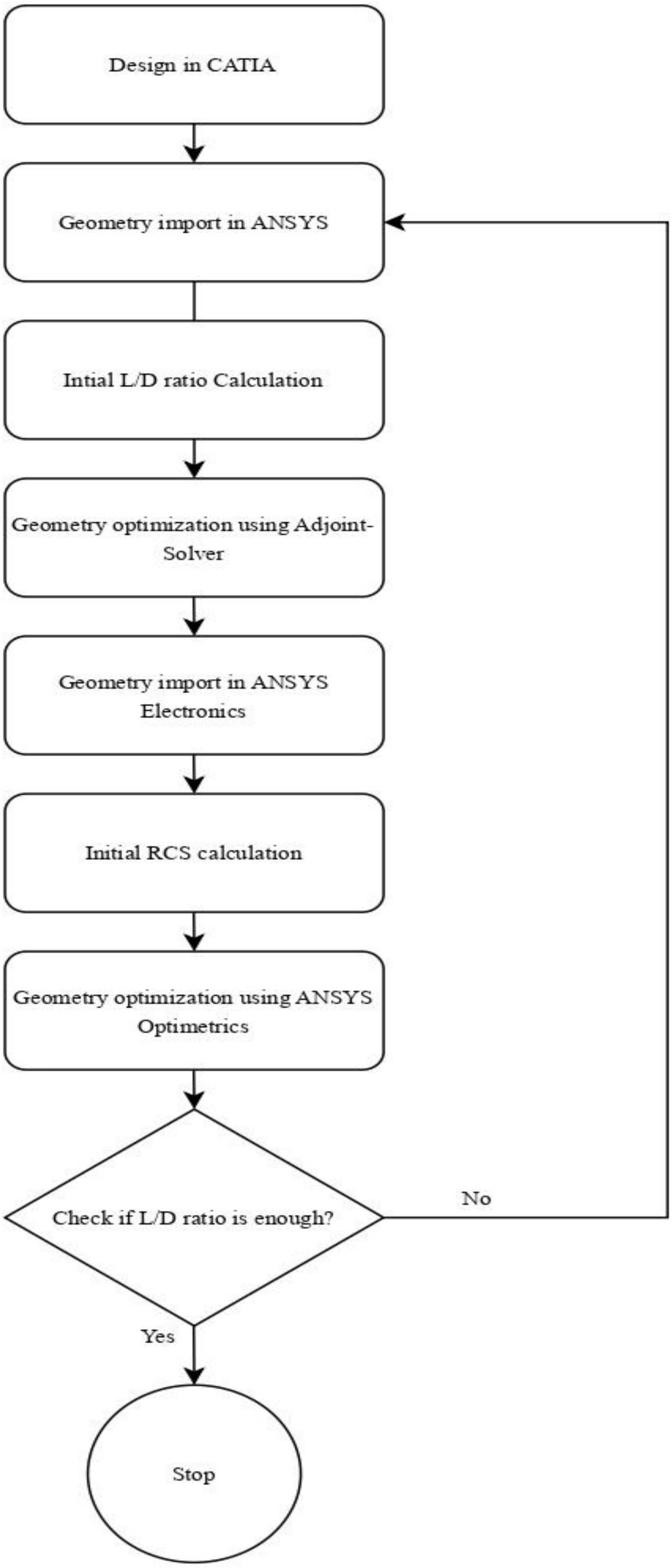

Figure 1. Methodology of project

It is necessary to calculate the value of the lift-to-drag ratio at the initial condition so that we can compare the results after optimization. Ansys Fluent was used to perform simulations to get the initial value of the lift-to-drag ratio of the geometry provided.

2.1 Geometry

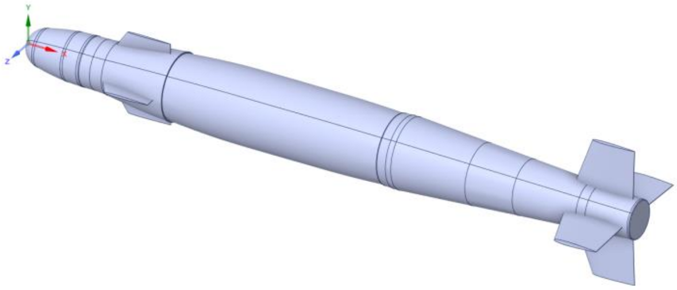

Figure 2. Rocket Geometry

This is the geometry of the rocket provided. To do the simulation in ANSYS, a fluid domain should be created. So an enclosure was created.

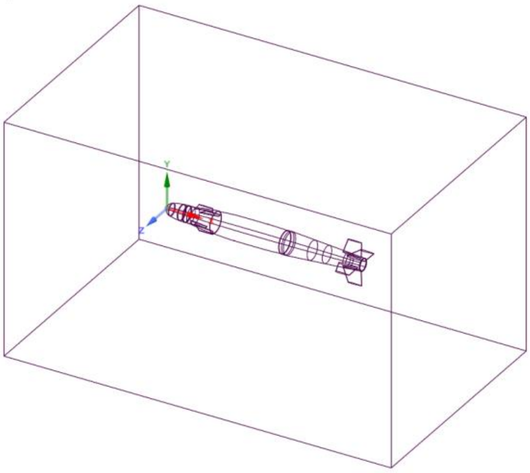

Figure 3. Wireframe model of fluid domain

The inside geometry of the rocket in the fluid domain is a cavity wall.

2.2 Mesh

Since the geometry is not more complex, creating the mesh was not a big deal.

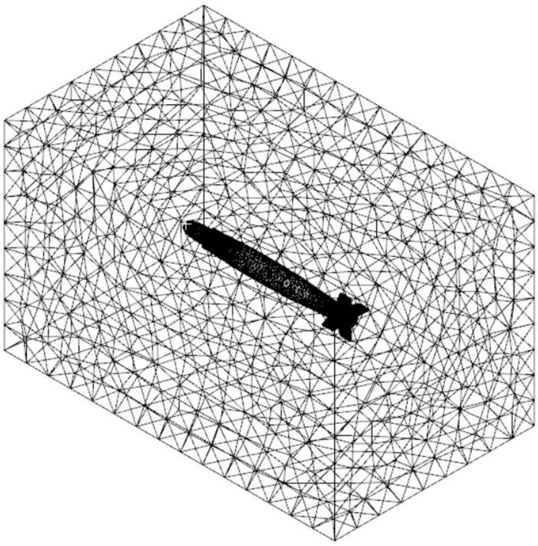

Figure 4. Wireframe model of mesh

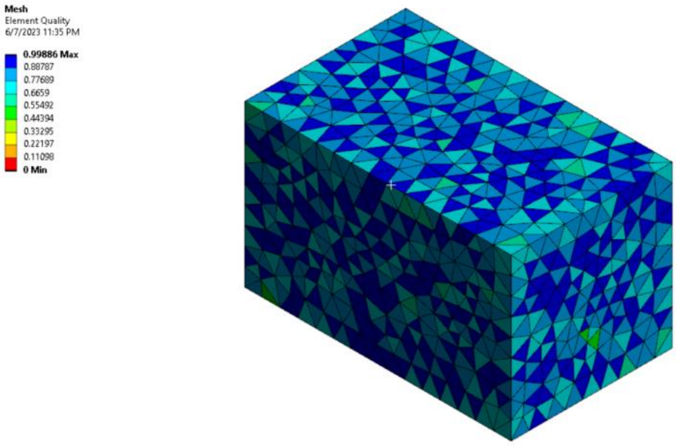

Figure 5. Mesh with element quality

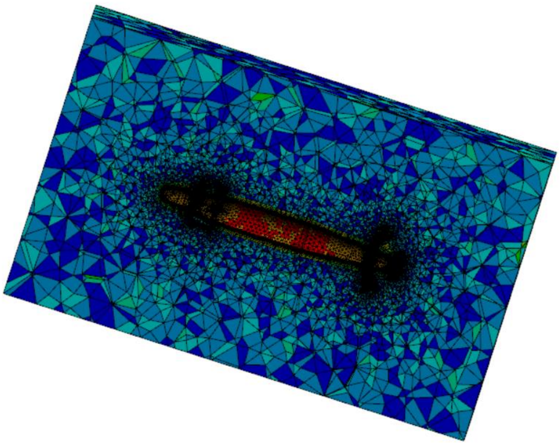

Figure 6. Section view

A structured mesh with 427023 elements was created using fluent meshing.

Table 1. Mesh statistics

Nodes	Elements
140064	427023

Table 2. Setup

Model	Viscous (SST k-omega)
Solver type	Pressure based
Velocity formulation	Absolute
Time	Steady
Initialization	Hybrid
No. of iteration	100

3. Result

After completing the solution, the lift-to-drag ratio was obtained. The value of the lift-to-drag ratio was 0.03. It is necessary to calculate the value of the radar cross-section area at the initial condition so that we can compare the results after optimization. Ansys Electronics 2023 was used to perform simulations to get the initial value of the radar cross-section area of the geometry provided.

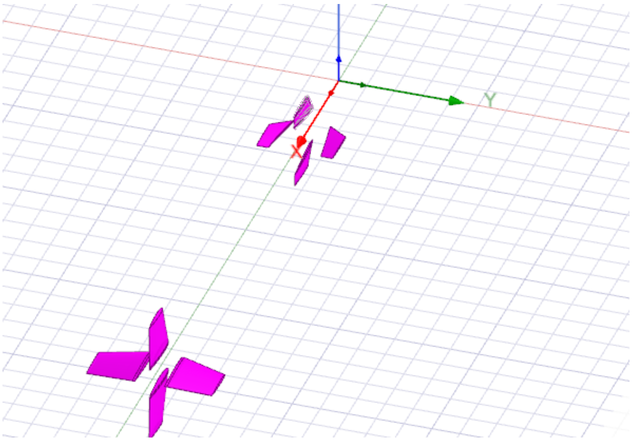

Figure 7. Geometry of initial RCS

For calculating the initial RCS, only the geometry of the wings was considered because we have to optimize the wings, and adding bodies will increase the computation cost and number of mesh elements. Aluminum was assigned as a material from the list of materials in Ansys electronics. The solution type was changed to HFSS with hybrids and Arrays from the top ribbon, HFSS->Solution type. The hybrid region was assigned to the IE region. A plane incident wave is assigned the following configuration:

After validating the simulation, the solution was started and completed successfully. A 2D plot of RCS was created. Since the number of mesh elements exceeded the limit, the calculation for each fin had to be done separately. And the total RCS was calculated by adding the RCS of each fin.

Table 3.Initial RCS

Fin	RCS (dB)
Rear up	-19.57
Rear Left	-15.79
Rear Down	-15.81
Rear Right	-19.587
Front Up	-19.39
Front Left	-24.97
Front Down	-24.9379
Front Right	-19.35
Total	-159.4

For the optimization of geometry to get the maximum L/D ratio, an adjoint solver was used, which is a built-in module available in ANSYS.

Table 4. Setup of adjoint solver

Observable	Lift-to-drag ratio
Target	10% increase
No. of design iteration	14
No. of flow iteratio0n	25
No. of adjoint iteration	25
Convergence criteria	0.005
Zones to be modified	Front fins and rear fins
Region	X: [-1,2] Y: [-1,1] Z: [-1,1]
Region condition	Symmetric in X and Z direction
Design condition	Translation along x-direction

After setting up the adjoint solver, we began the optimization. After 14 successful iterations, we were able to get a lift-to-drag ratio of 0.249, which is 8.3 times the original value.

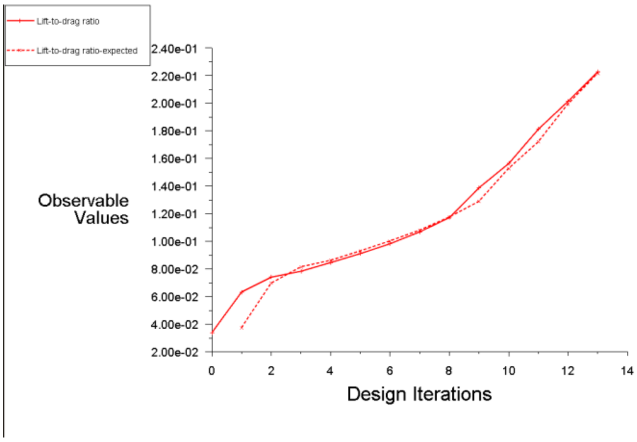

Figure 8. L/D ratio vs Design iteration

The change in shape or size is very small, i.e., 10–4 mm for each design iteration. The optimized geometry was then exported in STL format from Fluent.

Figure 9. Optimized geometry

For the design optimization of the geometry for minimum RCS, Ansys electronics was used. In order to perform optimization using optimetrics, it is necessary to parametrize the geometry because in Ansys electronics, we get the optimized parameters in the output rather than the geometry. The parameters selected for optimization were root chord, Tip chord, Leading edge, and trailing edge.

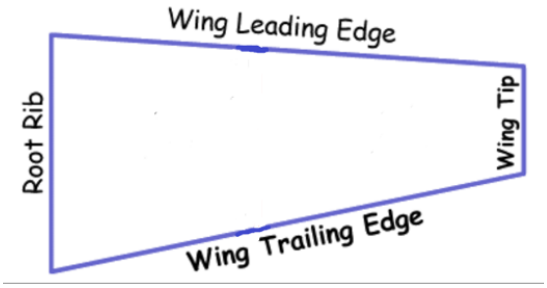

Figure 10. Parameters for optimization

The initial geometry didn’t have the parameters, so the cross-section of wings was created using rectangles in order to parametrize the wing. The optimization has to be carried out twice, i.e., once for the front fins and once for the rear fins.

Table 5. Setup for optimization of RCS

Optimizer	Adaptive single objective (Gradient)
Calculation	Monostatic RCS
Target	<= -22 dB
Variables	Leading edge, root, tip, Trailing_edge

After completing the setup, the solution was started, and finally we got the optimized parameters for the target RCS.

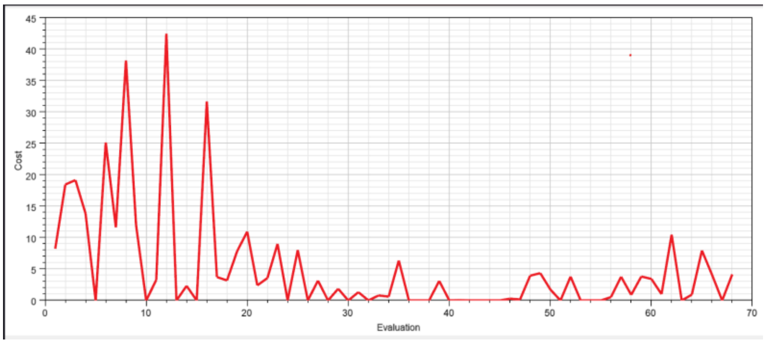

Figure 11. Cost chart for front fins

The cost chart for the front fins is shown above in the figure. We have to choose the parameters whose cost is the least possible to get the RCS as the targeted value. The cost chart for the front fins shows that while doing iterations, there are 23 possible configurations where the cost is zero, i.e., the RCS is the same as the targeted RCS. Any configuration can be chosen. Similarly, simulation was done for the rear fins, and results were obtained.

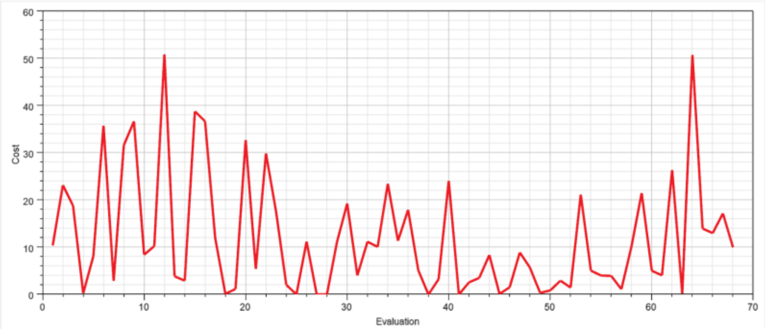

Figure 12. Cost chart for rear fins

The cost table for the rear fins is displayed in the above figure. To achieve the RCS as the desired value, we must select the parameters with the lowest possible cost. According to the cost chart for the rear fins, there are five configurations that can be achieved through iterations in which the cost is zero and the RCS is identical to the desired RCS.

Finally, after analyzing the optimized parameters, a suitable parameter was selected, and then RCS was calculated to validate the optimization. The results of RCS after optimization are shown below in the table.

Table 6. Result of RCS after optimization

Fin	RCS (dB)
Rear up	-22.518
Rear Left	-19.44
Rear Down	-19.44
Rear Right	-22.55
Front Up	-21.66
Front Left	-25.63
Front Down	-25.61
Front Right	-21.68
Total	-178.528

4. Conclusion

In this paper, the geometric optimization of the fins of a sounding rocket is presented. The primary objective is to optimize the geometry for the maximum lift-to-drag ratio and the minimum radar cross-section area. For that, a 3D model was designed using CATIA. The radar cross-section area was minimized using ANSYS optimetrics, and the L/D ratio was maximized using the ANSYS adjoint solver. Four parameters were developed for the RCS optimization: the root, leading edge, tip, and trailing edge.

The RCS decreased by 12%, while the L/D ratio increased by 8.3 times. It is easy to see that the ideal surface forms dimples when it is closely examined, exactly like a golf ball's surface does. It is always up to us how much we want the design to be optimized. We might have further optimized the design by merely increasing the solver's iterations. Optimization is achievable as long as the geometry makes sense and doesn't cross the limits of the design. It can be helpful to the missile industry to develop more stealthy and efficient missiles. This paper presents a new approach to optimizing the geometry of the fins of a sounding rocket that is less complex than the primitive methods.

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