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# A CFD-Driven Design Exploration and Aerodynamic Analysis of a Novel SR-72 Variant

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**Abstract:** Hypersonic vehicles hold significant promises for advancements in aviation and defense, yet face complex aerodynamic challenges, particularly in managing shock waves. This work presents a new version of the SR-72 that is intended to overcome these difficulties by means of an extensive Computational Fluid Dynamics (CFD) investigation. This study investigates the aerodynamic behavior of a novel SR-72 variant's diamond shaped airfoil designed for hypersonic flight using a two-stage approach. The first stage meticulously models the diamond shaped airfoil along with the aircraft geometry in OpenVSP, incorporating swept wings and optimized leading/trailing edges for shock mitigation. The second stage utilizes advanced CFD simulations across various angles of attack to analyze shock formation, pressure distribution, and their impact on aerodynamic forces. To validate these simulations and gain deeper insights into shock behavior, we conduct experimental flow visualization on a separate double wedge airfoil using schlieren photography. By comparing the measured shock deflection angle with theoretical and CFD-derived values, we assess the accuracy of simulations and identify potential discrepancies. This combined approach provides valuable insights into shock wave interaction with the optimized double wedge airfoil geometry, informing the design of the SR-72 variant. Ultimately, this research contributes to hypersonic vehicle design by offering knowledge to refine the SR-72 for minimized shock impact, leading to more efficient, stable, and maneuverable hypersonic aircraft.

### Table of Contents



## 1. Introduction

Hypersonic vehicles promise a revolution in aviation and defense, but face challenges managing shock waves that drastically impact performance [1]. This research presents a novel SR-72 variant designed to overcome these challenges through extensive CFD analysis. Our primary objective is to optimize aerodynamic performance by influencing shock wave behavior, lift, drag, and pressure distribution. This will be achieved through an iterative design process informed by latest CFD research, incorporating swept wings and meticulously designed leading and trailing edges to minimize shock wave impact [2]. Utilizing high-fidelity geometric modeling and rigorous CFD simulations, this research will comprehensively analyze the aerodynamic properties of the SR-72 variant across various angles of attack, focusing on shock wave formation and pressure distribution. The data obtained will not only identify areas requiring further development but also offer a deep understanding of the aerodynamic behavior of this specific SR-72 configuration. Ultimately, this research aims to significantly enhance understanding of hypersonic vehicle design, paving the way for the development of more efficient, stable, and agile aircraft capable of achieving exceptional hypersonic speeds.

## 2. Numerical Methodology

This research employs a two-stage computational approach to achieve a high-fidelity aerodynamic analysis of the SR-72 variant specifically designed for hypersonic flight (Mach 5). The first stage focuses on meticulous geometric modeling using OpenVSP software, chosen for its ability to create intricate 3D models while maintaining computational efficiency, crucial for complex geometries like the SR-72 with swept wings and optimized leading and trailing edges [3]. Particular attention is paid to mesh density, especially at critical areas like wing leading edges, ensuring the model accurately reflects the unique aerodynamic profile of the SR-72. Double wedge airfoil was chosen for the wing because of its ability to maintain good lift-to-drag ratios at hypersonic speeds. A thin wedge profile would help reduce drag by ensuring the formation of an (attached) oblique shockwave rather than

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a (detached) bow shockwave. Minimizing the drag would also reduce aerodynamic heating due to friction and shear stresses on the skin. The proportionate size of the wing as compared to the body was approximated by modeling the aircraft against the picture of a rendered SR-72 in the background. Further, the chord length was approximated using the method of scaling.

The second stage delves into comprehensive CFD simulations using specialized software capable of handling complex hypersonic flow phenomena. The geometric model from OpenVSP is imported into the CFD environment. Here, meticulously defined flow conditions replicate hypersonic cruise at Mach 5, a specific operating point for the SR-72. Additionally, pressure and temperature parameters are carefully adjusted to reflect real-world operational conditions. A critical aspect of this stage involves leveraging the power of adaptive meshing within the CFD software. This technique dynamically refines the mesh during the simulation, focusing computational resources on areas with high gradients like shock waves and boundary layers [4]. This ensures accurate capture of these crucial phenomena while maintaining overall computational efficiency. The selection of turbulence models specifically tailored for capturing these interactions remains paramount, and specialized models suitable for hypersonic flows are employed [5]. Finally, advanced mesh generation techniques beyond adaptation and refinement are utilized. This may include techniques like anisotropic meshing, which refines the mesh based on the flow direction, to further enhance the accuracy of the simulations, especially in the vicinity of the complex SR-72 geometry [6]. The resulting finely resolved computational domain around the SR-72 is vital for obtaining precise aerodynamic predictions and future validation against experimental data.

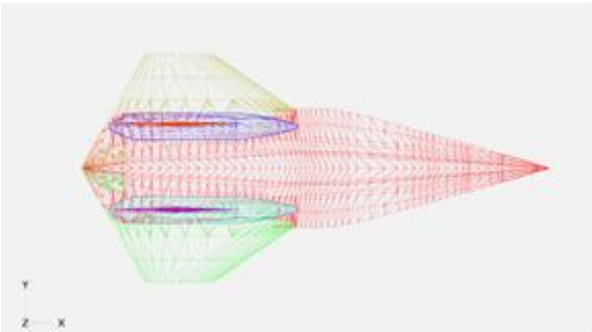

**Figure 2.1 Top View of SR-72 designed in OpenVSP Figure 2.2 Isometric view of SR-72 in OpenVSP**

## 3. Results and Discussion

### 3.1 Simulations

The CFD simulations employed a two-pronged approach utilizing OpenVSP and Simcenter Floefd to capture the aerodynamic behavior of the diamond shaped airfoil across different angles of attack (0°, 4°, and 8°). OpenVSP provided valuable qualitative insights through pressure distribution contours obtained on the wing. Analyzing these contours revealed how pressure changes across the wing surface at different attack angles, offering crucial information for understanding how lift and drag forces are generated and impacted by shock wave formation. Simcenter Floefd delved deeper, generating detailed quantitative data through contour plots of pressure distribution and Mach number across the aircraft at various attack angles. This data allowed for a comprehensive understanding of shock wave formation and propagation around the diamond shaped airfoil. Additionally, Simcenter Floefd calculated lift and drag coefficients at each angle of attack, providing valuable data for assessing the overall aerodynamic efficiency of the design.

### 3.2 Analysis

The analysis focused on establishing a link between shock wave formation, pressure distribution, and the resulting aerodynamic forces acting on the SR-72's airfoil. Pressure distribution contours obtained on the wing at angles of attack of 0° and 4° provided valuable qualitative insights. Analyzing these contours revealed how pressure changes across the wing surface at different attack angles. Areas with significant pressure variations, particularly sudden jumps or drops, could indicate the presence of strong shock waves. By correlating these pressure variations with the corresponding angles of attack, we can understand how shock wave formation is impacted by the angle of attack.

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### 3.2.1 At 0-degree angle of attack

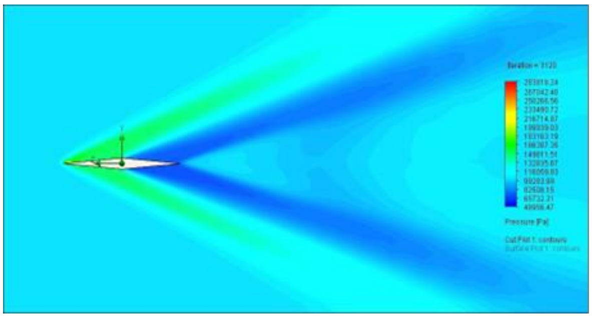


**Figure 3.2.1.1 Pressure Contour at Mach 2.5**

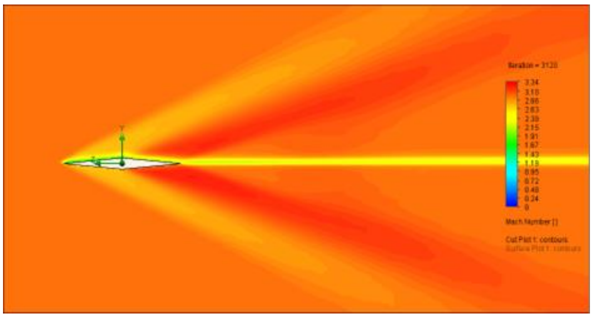


**Figure 3.2.1.2 Mach Number Contour at Mach 2.5**

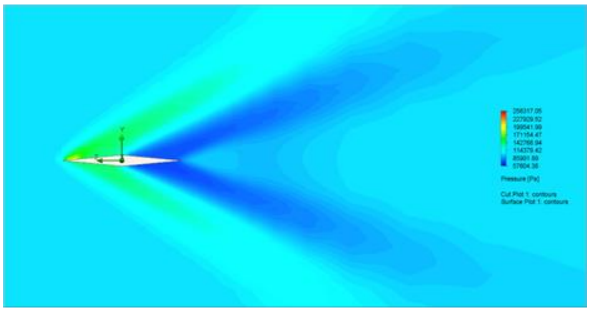


**Figure 3.2.1.3 Pressure Contour at Mach 3**

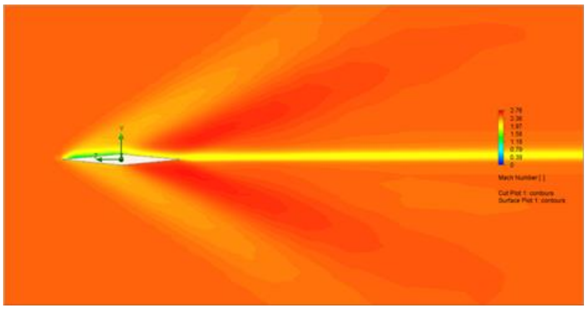


**Figure 3.2.1.4 Mach Number Contour at Mach 3**

### 3.2.2 At 4-degree angle of attack

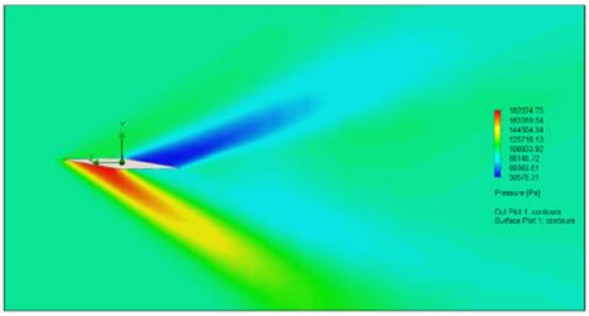


**Figure 3.2.2.1 Pressure Contour at Mach 2.5**

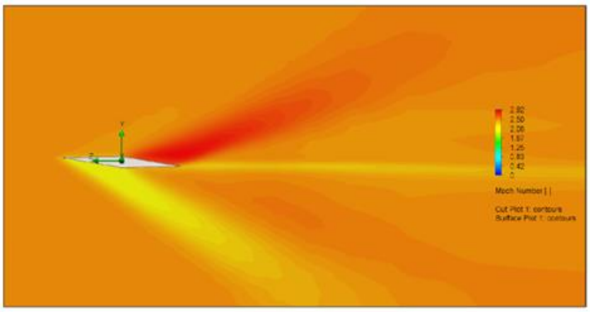


**Figure 3.2.2.2 Mach Number Contour at Mach 2.5**

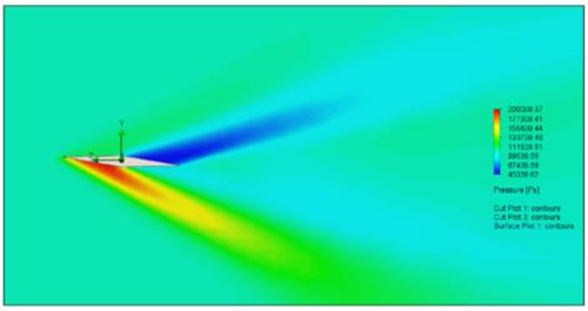


**Figure 3.2.2.3 Pressure Contour at Mach 3**

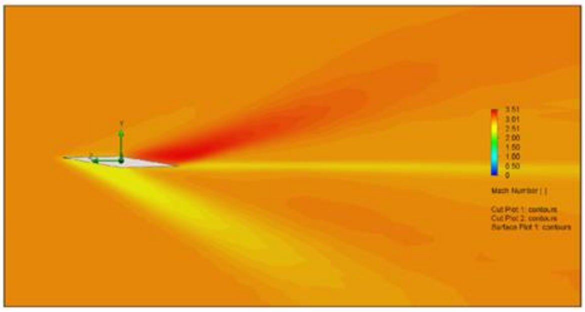


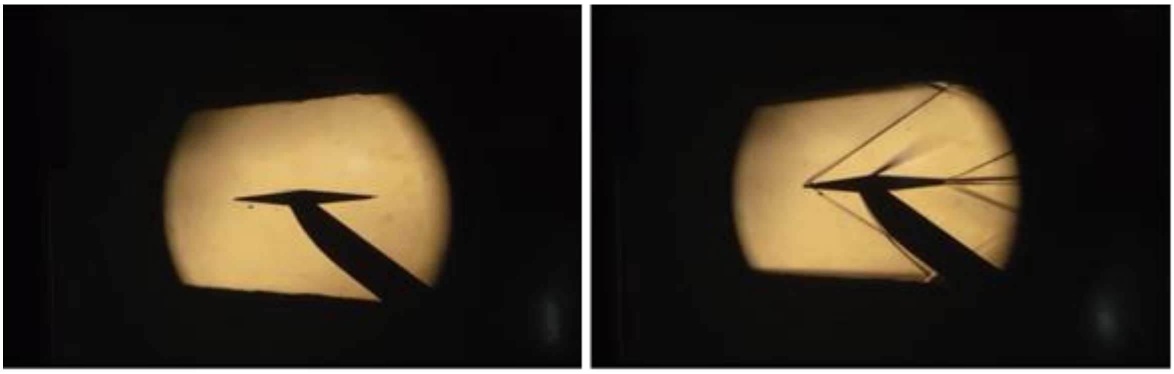
**Figure 3.2.2.4 Mach Number Contour at Mach 3**

This analysis is further strengthened by incorporating quantitative data on pressure distribution and Mach number across the aircraft at the investigated angles of attack. While the specific software used for these simulations is not mentioned, the analysis highlights the importance of these plots for understanding shock wave formation, propagation, and their impact on the aircraft's aerodynamics. By combining these findings with the lift and drag coefficients obtained at each angle of attack, researchers can gain a comprehensive understanding of how shock waves affect the overall aerodynamic performance of the SR-72 variant. This knowledge will be instrumental in guiding further design refinements and operational optimizations aimed at mitigating shock wave effects and enhancing the aircraft's stability, efficiency, and maneuverability at hypersonic speeds.

### 3.3 Shock Wave Visualization

Schlieren photography is a valuable technique for visualizing shock waves around airfoils at supersonic speeds. It exploits the deflection of light rays caused by density variations in the flow field. This deflection is particularly pronounced around shock waves, allowing Schlieren photography to capture these features as dark or bright regions on a screen.

Figure 3.31 and 3.32 shows an example of a Schlieren image obtained for a diamond-shaped or double wedge airfoil at Mach 2.5 and zero angle of attack. The distinct dark wedge-shaped region in front of the airfoil represents the attached oblique shock wave. The angle of deflection (θ) caused by the shock wave can be measured from this image.



**Figures 3.31 and 3.32: Shock Wave Formation on Double Wedge Airfoil at Mach 2.5 and 0° Angle of Attack**

**Table 1: Shock Wave Angle Comparison**

| Sl. No | Mach Number (M) | Deflection Angle (θ) | Theoretical Shock Wave Angle (β theoretical) | Experimental Shock Wave Angle (β experimental) |
|---|---|---|---|---|
| **1** | 2.0 | 5.3 | 35 | 34.3 |
| **2** | 2.5 | 5.3 | 32.42 | 27 |
| **3** | 3.0 | 5.3 | 25 | 23.13 |

Comparing the measured deflection angle (θ) with the theoretical shock wave angle (βtheoretical) calculated from gas dynamics equations for the specific Mach number, we can assess the accuracy of theoretical predictions. We can also determine the experimental shock wave angle (βexperimental) by measuring the angle of the shock wave relative to the airfoil leading edge in the Schlieren image. This comparison of theoretical and experimental shock wave angles helps validate the CFD simulations used to analyze the SR-72 variant and identify any discrepancies that require further investigation.

## 4. Conclusions

This research employed a two-stage computational approach to analyze the aerodynamic behavior of a novel SR-72 variant designed for hypersonic flight. The first stage meticulously modeled the SR-72's geometry in OpenVSP, emphasizing swept wings and optimized leading and trailing edges for shock wave mitigation. The second stage leveraged advanced CFD simulations in Simcenter Floefd to analyze the variant across various angles of attack (0° and 4°). Analysis revealed a vital link between shock wave formation, pressure distribution, and the resulting aerodynamic forces. Pressure contours from OpenVSP displayed how pressure changes across the wing surface at different attack angles, affecting lift and drag generation. Quantitative data from Simcenter Floefd, including pressure distribution, Mach number plots, and lift and drag coefficients, provided a comprehensive understanding of shock wave behavior and its impact on the SR-72 variant's aerodynamics. These findings significantly contribute to hypersonic vehicle development. By understanding shock wave interaction with the SR-72 variant's design, researchers can refine the design to minimize shock wave impact, leading to more efficient, stable, and maneuverable hypersonic aircraft. This research paves the way for further exploration of design modifications and the development of next-generation hypersonic vehicles capable of achieving exceptional performance at hypersonic speeds.

## 5. Acknowledgement

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## 7. Conflict of Interest

The author declares no competing conflict of interest.

## 8. Funding

No funding was issued for this research.