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# IMPLEMENTATION OF TRANSONIC AREA RULE AND SWEPT BACK DELTA WING DESIGN ON AN AIRCRAFT

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**Abstract**-The transonic area rule was first implemented in the 1950s. It is an important concept related to the drag on an aircraft or other body in transonic and supersonic flight which states that two airplanes with the same longitudinal cross-sectional area distribution have the same wave drag, independent of how the area is distributed laterally. A swept back delta wing increases the critical Mach number of the wing and performs well at low speeds, as a result of unique swirling vortices that form on the upper surface of the wing. BOOM Supersonic plans to bring back Supersonic Commercial aircrafts by implementing these modifications in the famous Concorde. In this paper two aircraft designs inspired by Concorde and BOOM Overture are compared using ANSYS Fluent. These were designed in CATIA with changes in fuselage dimensions, wing configuration and engine configuration. The lift to drag ratio of both the designs are calculated and compared. Pressure contours, velocity vectors, vector pathlines, turbulence pathlines and pressure pathlines are also compared. The results show that the design with the implementation of transonic area rule and swept back delta wing has a better Lift to Drag ratio when compared to the design with a wide fuselage and a delta wing design.

Keywords- Transonic Area Rule, Delta wing, Concorde, BOOM Overture

## 1. INTRODUCTION

### 1.1 TRANSONIC AREA RULE

Designers had found that the drag on transonic aircrafts increased substantially when the planes travelled near Mach 1, a phenomenon known as the transonic drag rise illustrated in figure 1. This increase in drag is due to the formation of shock waves over portions of the vehicle, which typically begins around Mach 0.8, and this drag increase reaches a maximum near Mach 1. Because of its source, this type of drag is referred to as wave drag.

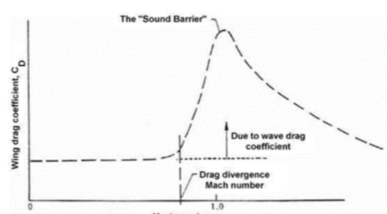


Fig.1. Increase in Wave drag [Jeff Scott, 2005]

Since the transonic drag rise was still not fully understood, the F-102's designers chose an engine they believed would provide enough thrust to reach a maximum speed of about Mach 1.2. However, initial flight tests of the YF-102 prototype indicated that the aircraft couldn't even reach Mach 1. The Convair engineers were baffled by this lack of performance until a NACA researcher named Dr .Richard Whitcomb developed the area rule. Whitcomb experimented with several different axisymmetric bodies and wing-body combinations in a transonic wind tunnel. What he found was that the drag created on these shapes was directly related to the change in cross-sectional area of the vehicle from the nose to the tail as shown in Figure 2. Whitcomb's research was a major breakthrough in supersonic aerodynamics and had an immediate effect on the design of the aforementioned F-102 fighter. Convair engineers quickly redesigned the aircraft's fuselage, taking the area rule concept into account, to create the "waisted" or "coke-bottle" fuselage. This modification, plus a new engine, allowed the aircraft to easily exceed Mach 1 and achieve a maximum speed over Mach 1.5.

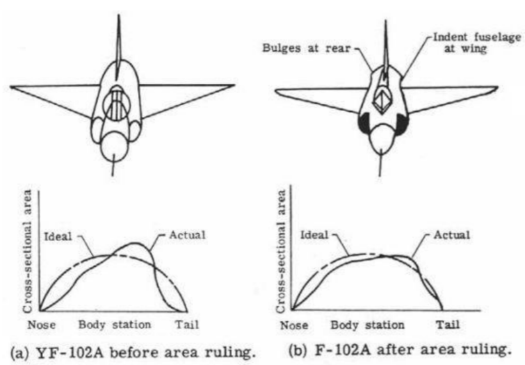


Fig.2. Implementation of Area Rule [Jeff Scott, 2005]

## 1.2 COMPARISION BETWEEN DELTA WING AND SWEPT BACK DELTA WINGS

The notable difference between the two is the location of vortex breakdown along the wing span. On the swift wing-shaped delta wing, this is governed by the width of the vortex system in relation to the local wing chord length; where the size of the vortex system exceeds that of the local wing chord, flow is no longer able to reattach and the vortex breaks down. The vortex system upstream of the point of breakdown is not significantly impacted in the cases presented. The broken-down vortex remains attached to the wing suction surface, with the proximity to the surface remaining largely unaltered, compared with that of the delta wing. The results presented confirm the sensitivity of the non-slender wing shapes to changing Re. An increase in Re results in increased coherence of the vortex system, and also a movement of the system towards the leading edge, both serving to reduce the overall width of the system. It is hypothesized that an increase in Re would also therefore delay vortex breakdown for the swift wing-shaped delta wing, as the width of the vortex system compared with the local wing chord is mediated.

## 1.3 APPLICATION OF THIS THEORY BY BOOM SUPERSONIC

The design and technology applied in BOOM Overture is inspired by Concorde's. Boom believe that a 30% increase in fuel efficiency would reduce operating costs sufficiently. The transonic area rule is applied by narrowing the fuselage and the wing are swept back. This design feature is essential to allowing the wing to function at both subsonic and supersonic speeds. The drag force on an object increases with the square of the velocity, so creating a streamlined aircraft is incredibly important for supersonic aircraft, especially when fuel efficiency is paramount. Intuitively we want to minimise the cross-sectional area of the aircraft to reduce drag, but we also want to minimise the changes in cross sectional area along the length of the plane to reduce the wave drag. The Delta wing performs well at low speeds too, as a result of unique swirling vortices that form on the upper surface of the wing. On a traditional aircraft's wing a swirling vortex is formed only at the wing tips. On a delta wing they form on nearly the entire wing surface and produce a considerable amount of lift.

## 2. METHODS AND MATERIALS

### 2.1 DESIGN

Two models were designed in CATIA (Fig. 3, 4, 5, 6, 7, and 8) to do analysis and find the change in L/D ratio and performance of an aircraft when the transonic area rule is applied and the wing configuration is changed to a swept back delta wing configuration. The first design is inspired by the Concorde and the second design is inspired by BOOM Overture. The second design has modifications in the wing configuration, fuselage width, and engine design.

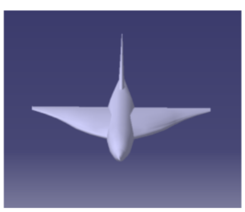

Fig.3. Top View of Design 1

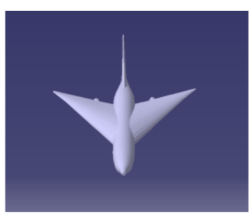

Fig.4. Top View of Design 2

Fig.5. Side View of Design 1

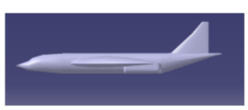

Fig.6. Side View of Design 2

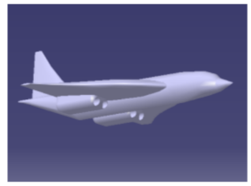

Fig.7. Iso View of Design 1

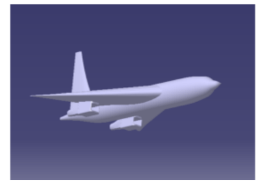

Fig.8. Iso View of Design 2

#### 2.1.1 MODIFICATIONS

Engine Modification- The same engine used is design 1 could not be used in design 2 because of the inlet area. The size of the engine was generating a lot of drag and had to be modified to reduce the inlet area as the wing span in the second design is less when compared to the first design.

Wing configuration- The sweep angle of the delta wing in the second design is 72°.

Fuselage width- The diameter was changed from 4 cm in the first design to 3.7 cm in the second design.

#### 2.1.2 SPECIFICATIONS

Specifications of both the designs-

| Specification | Design 1 | Design 2 |
|---|---|---|
| Length(cm) | 58 | 59 |
| Wing Span(cm) | 30 | 24 |
| Diameter of fuselage (cm) | 4.5 | 3.7 |
| Aerofoil used in wings | NACA 64A210 | NACA 64A210 |
| Aerofoil used in vertical stabilizer | NACA 0010 | NACA 0010 |

## 2.2 ANALYSIS

### 2.2.1 Operating Conditions

| Variable | Operating Condition |
|---|---|
| Altitude | 15000 m |
| Velocity | 343 m/s |
| Temperature | 216.5 K |
| Pressure | 12110 Pa |
| Density | 0.1948 kg/m^3 |

### 2.2.2 METHODS

#### 2.2.2.1 GEOMETRY

1. CATIA file was imported in the Geometry section in the Fluent workbench and edited using Design modeller (DM). In DM an ideal enclosure was created in which there was sufficient space behind the model for drag formation. After creating the enclosure I created a Boolean Operation (subtract). Then the boundaries were named used Named selection-Inlet, Outlet, Walls, Aircraft.

#### 2.2.2.2 MESHING

Mesh influences the accuracy, convergence and speed of a simulation. One of the purposes of meshing is to actually make the problem solvable using Finite Element as illustrated in Figure 9... By meshing, you break up the domain into pieces, each piece representing an element.

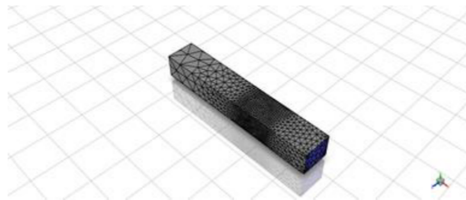

Fig.9. The generated mesh of the two designs.

#### 2.2.2.3 SETUP

The time used was transient. The viscous model was selected as the Shear Stress Transport (SST) Model. The SST model performance has been studied in a large number of cases. In a NASA Technical Memorandum, SST was rated the most accurate model for aerodynamic applications. Reference values were computed from the inlet and the pressure was considered from the specifications table. The solution was then initialized by the Hybrid Initialization method

## 3. THEORY/CALCULATION

### 3.1 THE LENGTH vs CROSS SECTION AREA GRAPH OF TWO DESIGNS

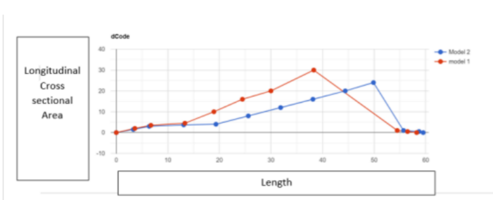


Fig.10. Graph

### 3.2 LIFT AND DRAG CALCULATIONS FOR DESIGN 1

```
                          Lift                  (n)
-------------------------------- -------------------
                      aircraft            33.862797

                          Drag                  (n)
-------------------------------- -------------------
                      aircraft            22.939175
```

Fig.11. Lift and drag values for Design 1

The L/D ratio we get is 1.47.

### 3.3 LIFT AND DRAG CALCULATIONS FOR DESIGN 2

```
                            Lift                  (n)
-------------------------------- -------------------
                        aircraft             179.8964
                            Drag                  (n)
-------------------------------- -------------------
                        aircraft            53.895017
```

Fig.12. Lift and drag values for Design 2

The L/D ratio we get is 3.33.

### 3.4 SCALED RESIDUALS

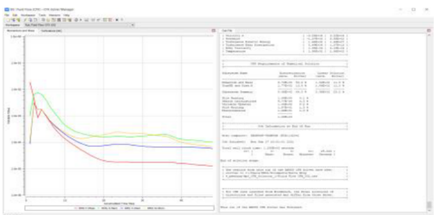

Fig.16. Scaled Residuals

## 4. RESULTS

### 4.1. VELOCITY VECTORS

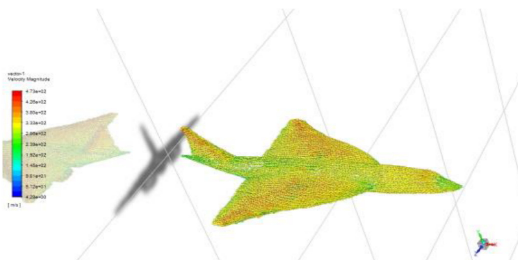

Fig.17. Velocity vectors of Design 1

From the velocity vectors of Design 1 we can see that the velocity is not uniform and is very high, this would create wave drag at high velocities which will make it harder for the aircraft to break the sound barrier.

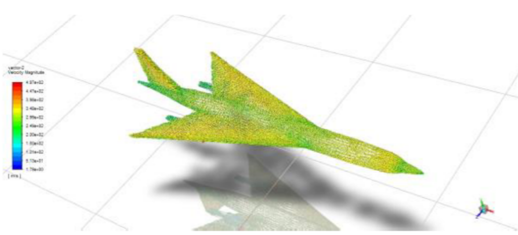

Fig.18. Velocity vectors of Design 2

From the velocity vectors of Design 2 we can see that the velocity is uniform and in the right velocity range, this would delay the wave drag at high velocities which will make it easier for the aircraft to break the sound barrier.

### 4.2 TURBULENCE PATHLINES

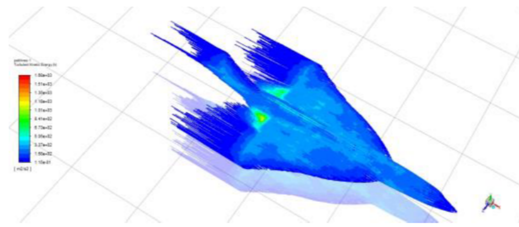

Fig.19. Turbulence pathlines of Design 1

From the turbulence pathlines we can observe that Design 1 creates more turbulence after flow separation because of its large wing span.

Fig.20. Turbulence pathlines of Design 2

The reduction of fuselage width also reduced the turbulence created near the fuselage, which indicates the flow is better in Design 2.

### 4.3 PRESSURE PATHLINES

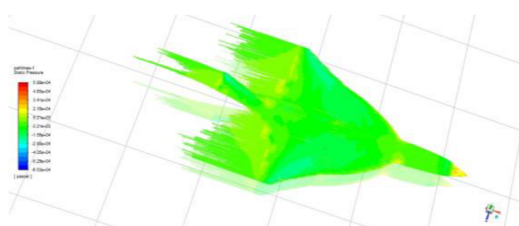

Fig.21 Pressure pathlines of Design 1

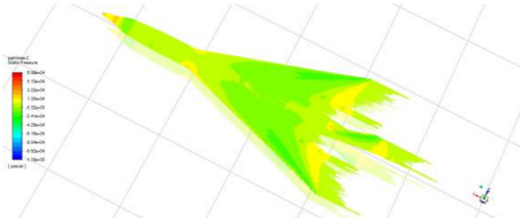

Fig.22 Pressure pathlines of Design 2

## 5. CONCLUSION

1. Design of both the aircrafts was done successfully using CATIA V5 and all the analysis were done using ANSYS Fluent 2020 R1.

2. The cross sectional area graph plotted shows the change in cross sectional area over length.

3. The application of the transonic area rule increased the L/D ratio from 1.47 to 3.33.

4. The increase in the L/D ratio shows that the second design will have better performance at high velocities.

5. The swept back delta wings reduced turbulence at high velocities.

6. These modifications could be implemented in designs in improve performance and fuel efficiency.

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