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Analysis of 2-Dimensional Hypersonic Waverider

[1]S.N.Logu, [2]R.Karthika, [3]S.Gowtham, [4]B.Arunkumar & [5]V.Janani
[1]Assistant professor, Dept. of Aeronautical Engg, SNS College of Technology
[2,3,4,5]UG Scholar, Dept. of Aeronautical Engg, SNS College of Technology

Abstract: *In aerospace technology, hypersonic waverider plays one of the important roles in increasing the lift of the aerospace vehicles. Aerospace vehicle using the "Waverider" technology that obtains lift using shockwave, formed during supersonic/hypersonic flight through the Earth's atmosphere, which originates from leading edge and is attached to the bottom surface of the vehicle, generating a region of high pressure resulting in high lift and low drag. This paper describes about the design and analysis of hypersonic vehicle which flies at Mach number more than 6 and the analysis will be carried out on ANSYS based on the design of Brazilian 14-X hypersonic waverider which follows the osculating cone methodology. Waverider geometries are consider amongst the most promising in making hypersonic flight viable due to the high lift to drag ratios they exhibit at high speeds. This accomplished by keeping the shockwave greatly increasing the lift generated by the oncoming hypersonic flow attached to the entire leading edge of the lifting body. The design goal of compression system is to provide the desired pressure and velocity for the supersonic combustion over the entire flight range with minimum loss.*

Keyword: Design of wave rider, Hypersonic, Osculating, Supersonic, Wave rider.

1. Introduction

In 1950s onwards, various designing approaches have been proposed for the designing of waverider geometries. In Early, the waverider design is based on the inverse design methods of planar and axi-symmetric shockwave flow-fields, both of the methods were limited by the poor balance of L/D [Lift/Drag] ratios, volumetric efficiency and ease of engine inlet integration. A more flexible design method that departed from the motion of having a single shock generating body is the osculating cones method. The concept of wave rider as a lifting system generated from streamline flow behind the known Shockwaves. In Theoretical point of view a waverider is a conically-derived lifting system, the system that is always behind the shockwave generated by it. By practically, the waverider is a wing, an aircraft and a propulsion system at the same time therefore it requires a multi-disciplinary integrated design. The wave rider technology using scramjet engine flies at a hypersonic speed more than 6 Mach number. The aerodynamic advantage of the waverider is that high pressure behind the shock wave under the vehicle does not "leak" around the leading edge to the top surface, so that the L/D for the waverider is considerably higher than that for the conventional aerodynamic vehicle. The propulsion system in the waverider is based on scramjet engine propulsion system which has no moving component inside the engine.

2. Base Design

In order to get good performance of the waverider, the design configuration is important to attain good L/D characteristics. The design is taken from the waverider of Brazilian 14-X whose design configuration is based on the osculating cone method whose experimental investigations at the Hypersonic Shock Tunnels along with non-intrusive diagnostic techniques, CFD [Computational Fluid Dynamics] codes as well as Theoretical Analysis have been used to design the 14-X Hypersonic waverider scramjet Aerospace Vehicle. Experimental data of the waverider and scramjet configurations obtained with the T3 Hypersonic Shock Tunnel have been used to compare with the CFD codes. The analysis is carried out on the ANSYS with 2D-design specification which was already verified experimentally in the test section using aluminium sheet with some specification for Mach number 10 at Brazil during the year 2013 which was taken as reference [2] and attached in this paper for analysis work.

3. Design Specifications

The complete design of Brazilian 14-X waverider is shown in Figure.1 and the design specification is tabulated in Table 1.

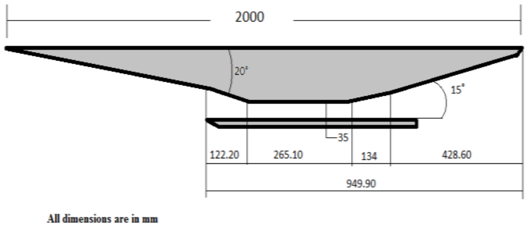

Figure 1: Design of Brazilian 14-X waverider

Table I: Design Specifications of Brazilian 14-X Waverider

S.No	Specification	Values
1.	Length of the waverider	2 m
2.	Inlet area of the waverider	0.12 m
3.	Throat area of the waverider	0.035 m
4.	Outlet area of the waverider	0.4 m

4. Boundary Conditions

From Isentropic Equation, the pressure value is calculated for various Altitude and Mach number 6-10.

$$\frac{P}{Pt} = \left\{1 + \frac{\gamma - 1}{2} * M^2\right\}^{\gamma/\gamma+1}$$

Where,

- P → unknown pressure for known altitude,
- P_t → known pressure,
- γ → Ratio of Specific heat (1.3)
- M → known Mach number

Table II: Pressure Values for Various Altitudes at Mach Number 6-10

S.No	Altitude (Km)	Mach No.	Temperature (K)	Initial Pressure (Pa)	Pressure (Pa)
1	15	6	216.5	12044.6	37286504.2
		7	216.5	12044.6	117949151.4
		8	216.5	12044.6	331410892.5
		9	216.5	12044.6	842831757.8
		10	216.5	12044.6	1970751685
2	20	6	216.5	5474.89	16948633.3
		7	216.5	5474.89	53613953.9
		8	216.5	5474.89	150643290.9
		9	216.5	5474.89	388110370
		10	216.5	5474.89	895807471.5
3	25	6	221.65	2511.02	7773372.1
		7	221.65	2511.02	24589664.9
		8	221.65	2511.02	69091491.5
		9	221.65	2511.02	175710891.2
		10	221.65	2511.02	410856059.7
4	30	6	226.65	1171.87	3627761.4
		7	226.65	1171.87	11467251.4
		8	226.65	1171.87	32220427.01
		9	226.65	1171.87	81941782.08
		10	226.65	1171.87	191600403.8

5. Analysis carried out on ANSYS

Case 1.Altitude 20km-Mach 10

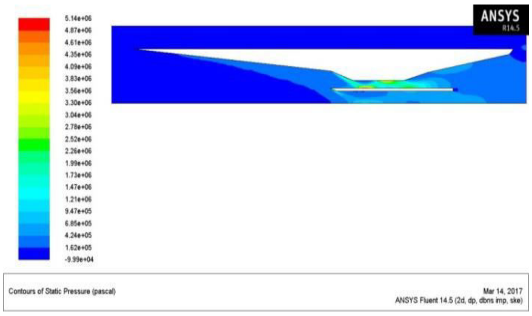

Figure 2.1: Pressure

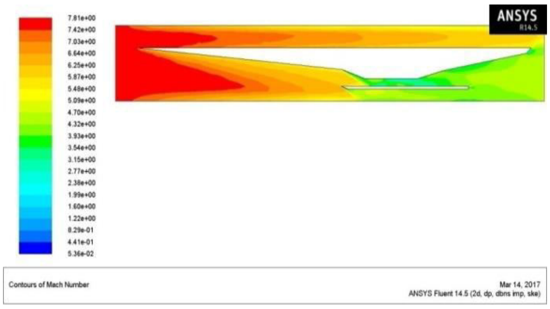

Figure 2.2: Velocity in terms of Mach

From the Figure 2.1 and Figure 2.2 it shows that at an Altitude 20km, the maximum Pressure is obtained only at a Mach number 10 and obtained velocity flow in terms of Mach number is 1.94 M whose inlet flow was 5.87 M and outlet flow was 3.93 M.

Case 2.Altitude 25km-Mach 10

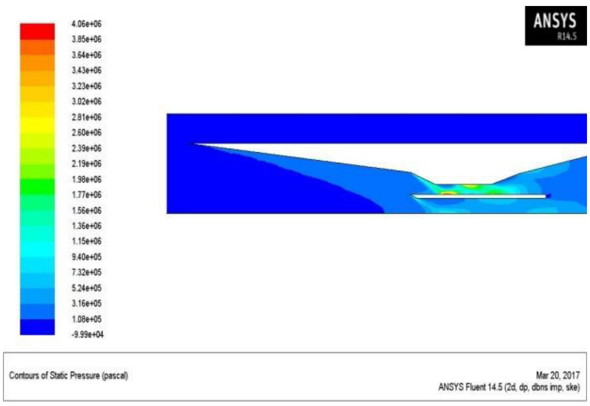

Figure 3.1: Pressure

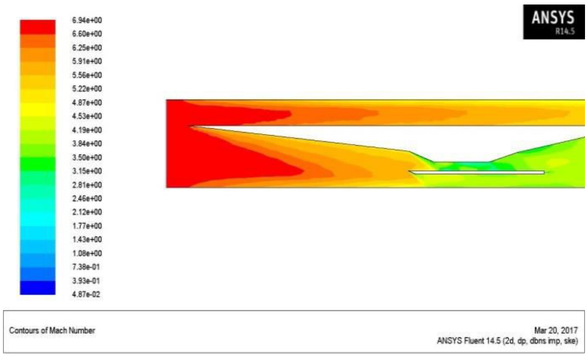

Figure 3.2: Velocity in terms of Mach

From Figure 3.1, Figure 3.2 it shows that at an Altitude of 25km, the maximum Pressure is obtained only at a Mach number 10 and obtained velocity flow in terms of Mach number is 1.72 M whose inlet flow was 4.87 M and outlet flow was 3.15 M.

Case 3.Altitude 30 km-Mach 10

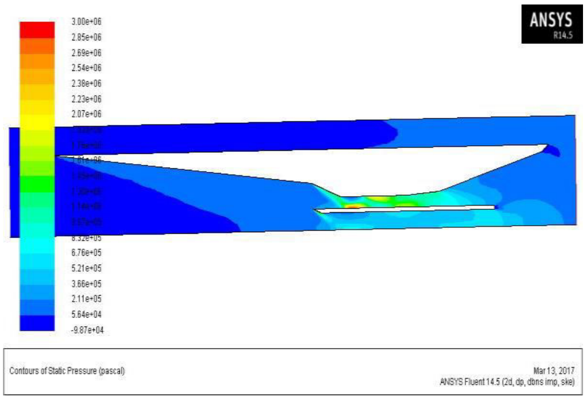

Figure 4.1: Pressure

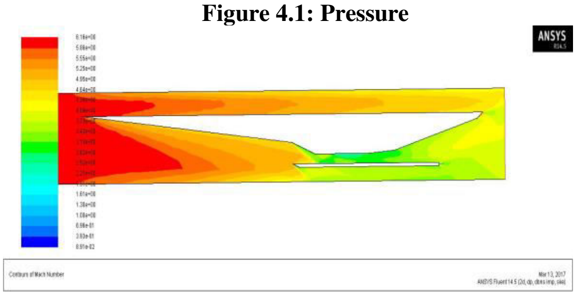

Figure 4.2: Velocity in terms of Mach

From Figure 4.1, Figure 4.2 it shows that at an Altitude of 30km, the maximum Pressure is obtained only at a Mach number 10 and Obtained velocity flow in terms of Mach number is 1.51M whose inlet flow was 4.64 M and outlet flow was 3.13 M.

The following Table III shows that the amount of pressure inlet and outlet for various Mach number and various altitudes is tabulated with velocity inlet and outlet.

Table III: Comparison of Pressure Inlet/ Outlet and Velocity Inlet / Outlet

S.No	Altitude (Km)	Mach No.	P_{in} (Pa)	P_{out} (Pa)	$V_{in\ in}$ (Mach)	$V_{out\ in}$ (Mach)	P_{in}-P_{out} (Pa)	V_{in}-V_{out} (Mach)
1	20km	6	1.91E+04	9.61E+05	3.25	1.86	9.42E+05	1.39
		7	3.09E+04	1.08E+06	3.98	2.52	1.05E+06	1.46
		8	6.35E+04	8.81E+05	4.43	2.98	8.18E+05	1.45
		9	1.08E+05	1.15E+06	5.14	3.1	1.04E+06	2.04
		10	1.62E+05	1.73E+06	5.87	3.93	1.57E+06	1.94
2	25km	6	1.32E+05	1.04E+06	2.47	1.62	9.08E+05	0.85
		7	1.32E+05	1.06E+06	3.7	2.21	9.28E+05	1.49
		8	1.68E+05	9.71E+05	3.92	2.64	8.03E+05	1.28
		9	2.33E+05	8.99E+05	4.56	3.36	6.66E+05	1.2
		10	1.08E+05	1.15E+06	4.87	3.15	1.04E+06	1.72
3	30km	7	1.27E+05	9.11E+05	2.98	2.01	7.84E+05	0.97
		8	1.33E+05	1.06E+06	3.67	2.55	9.27E+05	1.12
		9	1.61E+05	5.50E+05	4.31	2.72	3.89E+05	1.59
		10	5.64E+04	9.97E+05	4.64	3.13	9.41E+05	1.51

6. Conclusion

By the Analysis of 2D modal of Brazilian 14-X hypersonic waverider it states that when altitude increases the pressure value decreases according to the amount of flow in terms of Mach number. By the analysis, we conclude that maximum Pressure value is obtained only at the Mach number 10 at an altitude of 20km, 25km and 30km which also has a condition of C_L increases and C_D decrease and the altitude of 15km is neglected because of less in amount of L/D ratio. The change in pressure value will depends on the layer by layer in atmosphere and the amount of airspeed to the engine in terms of Mach number.

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