Preliminary design of the exhaust manifold for the 14-X Hypersonic Aerospace Vehicle.

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Abstract. *The purpose of this paper is present the preliminary design of an exhaust manifold to diverge the supersonic flow of the hypersonic experiment of the 14-X aerospace hypersonic flight experiment.*

Keywords*: hypersonic, scramjet, exhaust manifold, 14-X*

1. INTRODUCTION

Today, the only means to reach orbital speeds are by the use of rocket motors. Rockets are fifty years old technologies that have the big drawback to carry all the propellant needed. This means that a lot of energy is used to carry the propellant itself, mostly the oxidizer. Traditional air breathing engines are speed limited, mostly by the material and the need of complicated moving components. One of the preeminent future solutions to substitute the rockets and became the main propulsive technology for orbital access is the SCRAMJET engine witch is a supersonic combustion RAMJET. RAMJET is a jet engine that has no moving parts; the compression is obtained by “ramming” the air inside the engine by the movement of the vehicle itself. A RAMJET engine cycle have a combustion chamber were the flow is subsonic and at hypersonic speeds the losses to reach this operation mode are too big, leading to the supersonic combustion ramjet, SCRAMJET as an inevitable evolution to the technology. RAMJET and SCRAMJET motors are not capable of static acceleration, so they are part of a combined cycle propulsion system. In Brazil the IEAv (Institute for Advances Studies) is developing a flight experiment of a SCRAMJET engine to be used with the 14-X aerospace vehicle. Due to the static nature of the motor the experiment must be accelerated to hypersonic speeds by means of two SRM (Solid Rocket Motors) S30 and S31 from IAE (Institute of Aeronautics and Space). The flow path of the scramjet motor must be deviated from the SRM body in a way that does not interfere with the stability of the flight and the experiment itself. The main objective of this paper is the preliminary geometry of the flow path after the nozzle of the SCRAMJET engine designed for the flight experiment. The main objective is to avoid the impingement of the shockwave at the inside wall of the exit manifold, the interaction of the shockwave and boundary layer can create a high pressure and temperature recirculation area that lead to high thermal stress and possible damage, as shown in figure 1. Figure 2 shows a classical example of the problem. The impingement of a shockwave created by an experimental hypersonic engine outside USAF X-15 experimental hypersonic airplane lead to severe damage to the fuselage.

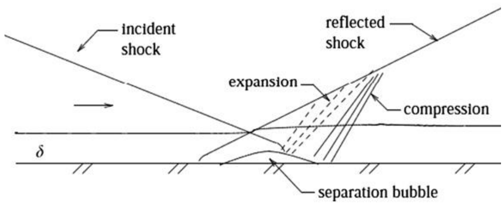

Figure 1. Impingement of a shockwave at a wall with a boundary layer. (Knight and Longo, 2012)

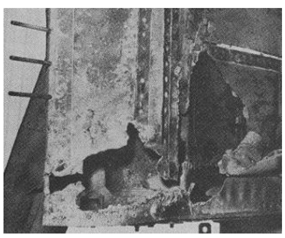

Figure 2. Damage caused by heat concentration due to shockwave impingement at a boundary layer during a X-15 flight. (NASA)

3. DEVELOPMENT

The planned flight trajectory for the first experiment is the typical trajectory of the VSB-30 rocket, the experiments will happens during the ascendant flight and the experiment will not be protected by a hoof during the acceleration part of the flight. The 14-X experimental vehicle will not separate from the second stage and will not have fuel injection. The flight conditions presented at Table 1 are from a simulation of a typical VSB-30 flight with an azimuth of 84º at launch (data from internal technical report).

Table 1. S30/S31 Simulation at 84º.

	Mach [M]	Alt. [m]	Temp. [Cº]	P [Pa]	Dens. [kg/m3]	V. som [m/s]	P. Din. [Pa]
1	1,2	2325,0	273,0	76350,0	9,74E-01	331,2	76933,7
2	2,0	6093,0	248,6	46620,0	6,53E-01	316,1	130513,1
3	3,3	10700,0	218,7	23790,2	3,79E-01	296,4	185503,0

The conditions at the exit plane of the nozzle will be calculated considering some simplification hypothesis:

- Ideal gas
- Inviscid flow
- Specific heat ratio 1,362

The flow path will have series of compression shockwaves. Starting with a ramp with 5.5º angle (0 to 1) then another ramp of 14.5º (1 to 2) to the flow direction and finally "reflected" by 20º by the cowl (2 to 3). The flow will pass by an expansion ramp of 4º (3 to 4), which represents the combustion chamber without combustion, and finally a 15º expansion ramp of the nozzle (4 to 5). As shown in Figure 1 below.

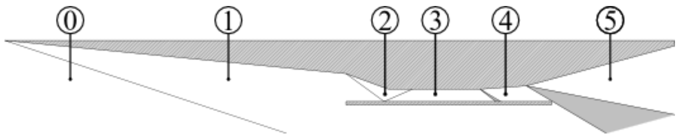

Figure 3. Diagram of the flow path.

A computer program, based on Anderson equations (1990) for oblique shocks and Prandtl-Meyer expansion, was written in MatLab® for the calculation using a Newton-Raphson method for convergence. The entry conditions 1 and 2 from the Table 1 leaded to subsonic flow at region 2 and 3 respectively due to the turning angle at those conditions lead to dethatched shock waves. Those entry conditions will be neglected as no shockwave will appear at the exhaust manifold due to subsonic flow. Considering that shockwaves have a smaller angle at higher speeds (Anderson, 1990) only the condition 3, table 1, will be considered and higher mach numbers will be neglected at this stage of development. That is the condition where the shockwave will have the maximum angle and could impinge the inner wall of the manifold. Table 2 shows the result of the calculation for that condition.

Table 2. Calculated flow path conditions

	0	1	2	3	4	5
M [Mach]	3,30	3,01	2,33	1,54	2,22	2,84
Temp. [K]	218,60	245,91	328,27	454,00	342,57	264,00
Pressure [Pa]	23723	36625,00	98259	291380	100990	378980
Density [kg/m3]	0,3781	0,5188	1,0427	2,2359	1,03	0,5001

Considering the diameter of the booster, as seen on figure 4, one can calculate the shockwave angle that will impinge at the outer wall of the manifold:

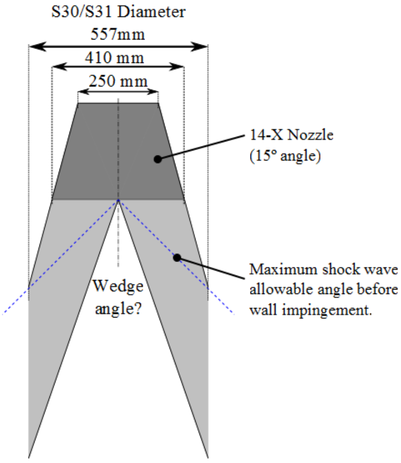

Figure 4. Schematic of the exhaust manifold.

$$\text{atan}\left[\frac{278{,}5 \times \tan 15°}{73{,}5}\right] = 45{,}44° \qquad (1)$$

Considering the calculated air conditions at the nozzle exit one can calculate the wedge angle that generate a shockwave angle smaller than 45,44º. Using a wedge half angle of 25º will result in a shockwave angle of 44,95º. A preliminary manifold was designed using a 3D CAD tool for future CFD investigation, as shown in figure 5.

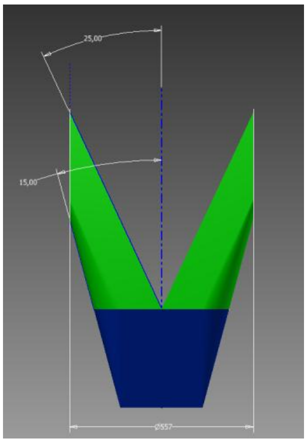

Figure 5. Resultin preliminary exhaust manifold design for future studyes.

4. REFERENCES

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