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BRAZILIAN 14-X S HYPERSONIC UNPOWERED SCRAMJET AEROSPACE VEHICLE STRUCTURAL ANALYSIS AT MACH NUMBER 7

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Abstract. *The Brazilian VHA 14-X S is a technological demonstrator of a hypersonic airbreathing propulsion system based on supersonic combustion (scramjet) to fly at Earth's atmosphere at 30km altitude at Mach number 7, designed at the Prof. Henry T. Nagamatsu Laboratory of Aerothermodynamics and Hypersonics, at the Institute for Advanced Studies. Basically, scramjet is a fully integrated airbreathing aeronautical engine that uses the oblique/conical shock waves generated during the hypersonic flight, to promote compression and deceleration of freestream atmospheric air at the inlet of the scramjet. Scramjet is an aeronautical engine, without moving parts, therefore it is necessary another propulsion system to accelerate the scramjet to the operation conditions. Rocket engines are a low-cost solution to launch scramjet integrated vehicle to flight to the test conditions. The Brazilian two-stage rocket engines (S31 and S30) are able to boost the VHA 14-X to the predetermined conditions of the scramjet operation, 30km altitude but at Mach number 7. One-dimensional theoretical analysis, applied at 30km altitude at Mach number 7, provide the pressure distribution on the VHA 14-X S upper and lower surfaces. Structural materials for the stringers and ribs as well as coating materials for the thermal protection systems were specified based on preliminary studies. ANSYS Workbench software, which provides the Structural Numerical Analysis using Finite Element Method, has been applied to the structural analysis of the VHA 14-X waverider unpowered scramjet at 30km altitude at Mach number 7. Stress field, strains and deformations are presented.*

Keywords: *VHA 14-X, scramjet, structural analysis*

1. INTRODUCTION

Rocket and airbreathing engines (ramjet and scramjet) are the propulsion system capable to provide hypersonic speeds to aerospace vehicle to bring payloads (and astronauts) into Earth's orbit and the supersonic combustion (scramjet) may provide superior performance at higher hypersonic flight speeds than any rocket engines and any other air-breather engines at speeds about Mach number 7.

Besides that, only chemical propulsion system (rocket), at that time, was developed to carry, initially, payloads into the Earth's orbit, and lately, to bring astronauts to Earth's moon, which culminates as U.S. Space Apollo Program.

Today the access to space is done, only, by multi-stage rocket-powered vehicles, which have flown hypersonically, carrying their own propellant (solid and/or liquid, oxidizer along with fuel) to propel payloads and astronauts to Earth's orbit. Several other propulsion systems are used and in developing to outer Earth's space.

However, from 60's, several programs were created to develop a hypersonic research vehicle that include a scramjet engine to demonstrate the supersonic combustion concept. Even in the mid-1980s, the last hypersonic era began with the National Aero-Space Plane (NASP) program, developed in the United State of America, which was undertaken first

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by the Defense Advance Research Projects Administration (DARPA) in 1983. NASP was the first ambitious hypersonic aircraft project Single-Stage-To-Orbit (SSTO) reusable multi-cycle propulsion system vehicle envisioned to take off horizontally from a conventional runway, using airbreathing propulsion to accelerate to hypersonic speeds, fly into space to achieve low Earth orbit, and return for a runway landing. NASP fuselage lower front portion should operate as a shock wave compression ramp for air entering the supersonic combustion ramjet (scramjet) engines. NASP fuselage aft portion is a single expansion ramp nozzle used to expand the exhaust flow for maximum engine thrust.

The fully integrated X-30 NASP research aircraft mission should consist of three separate cycles:

- a low-speed propulsion unit to take off from a normal runway, to climb and to descent to Mach number (2 or) 3 and to land to a normal runway;
- a mid-speed ramjet engine to kick the aircraft in at Mach number (2 or) 3-5 to climb and to accelerate to sufficient altitude and velocity, and;
- a hypervelocity supersonic combustion ramjet (scramjet) engine to complete the mission and to reach speeds of 18,500 miles per hour (29,766.50 km per hour, about 8.3 km/s) or Mach number 25, and boosting the aircraft into the orbit without a rocket assist.

To reduce costs and technical risks the NASP program was re-examined in 1993, and terminated in January 1995. However, the enormous amount of ramjet/scramjet engine research generated at that time created conditions for a modern treatment of hypersonic aerothermodynamic and airbreathing propulsion analysis and design principles for the academic, industrial and government communities.

Any way, the vision of a space plane that should operate likes an airplane: take-off from a conventional runway, flies into orbit and return to ground is pursued for many countries all around the world [5-10].

The aerospace technological products have grown that one cannot conceive of putting payloads (satellites) into Earth's orbit or beyond using technologies in operation (rockets carry out solid or liquid fuel). The knowledge required to keep the current launching vehicles is already so high that if the countries do not have a technological support for their own industry, they will depend on of the supplier countries and not have independent capacity sustained.

Aerospace vehicle limitations for launching payloads into orbit or beyond require a continuous reduction in size, weight and power consumption of launch vehicles. Some solutions to these challenges require paradigm shifts, new production methods, and new technologies of strategic nature. The requirements of platforms launched satellites, high performance and reliability, as well as the strict limitations of fuel (reduction of size, weight and power consumption) for launching payloads into orbit or beyond provide the development of hypersonic aircraft using hypersonic airbreathing propulsion based on supersonic combustion (scramjet).

The recent intensification of international efforts to develop hypersonic propulsion system based on supersonic combustion, signals that this is the way of effective access to space in a not too distant future. Therefore, the field of Hypersonic Airbreathing Propulsion based on supersonic combustion, will be essential in the near future for the aerospace industry, and allow the man to build hypersonic planes, to reach other continents in hours and achieve low orbits around Earth.

The scramjet is the only airbreathing propulsion system to be able to provide the thrust needed efficiently in hypersonic flight. In addition, it has the advantage over rocket engines not lead to oxidizing substance, reducing vehicle weight. To get an idea of structural weight savings this fact, one should bear in mind that the first stage of the Saturn-1, a rocket widely used by NASA, must carry 285ton of liquid oxygen to burn 125ton of RP-1 (a type of highly refined kerosene for rocket). Aerospace vehicles using scramjet have no moving parts, and the scramjet works as follows: slows the flow into the air intake through oblique or conical shock waves until the inlet air reaches the velocity and pressure necessary to ensure that there is combustion. Thus, the gases produced in combustor with its high enthalpy and pressure is expanded in the nozzle. This cycle is then responsible for the thrust generated by the engine. Normally, the fuel chosen for the scramjet is Hydrogen, due to the fast time of ignition and high specific impulse.

The recent success to demonstrate the supersonic combustion concept, through the (2004 about 10s burnt hydrogen scramjet-powered at Mach 7 and 10) X-43 Aerospace Vehicle flights and the (2010 about 140s burnt hydrocarbon scramjet-powered at Mach number 6+) X-51 Aerospace Vehicle flight provided by the new U.S. hypersonics strategy formulated (after NASP program) by NASA, U.S. Government agencies (Air Force, Army and Navy) and DARPA for the next generation of space transportation systems under NASA Marshall Space Flight Center's Advanced Space Transportation Program (ASTP) gave a fresh renaissance in hypersonic flight.

Basically, the scramjet is a fully integrated airbreathing aeronautical engine (that has no moving parts) that uses the oblique/conical shock waves generated during the hypersonic flight, to provide compression and deceleration of freestream atmospheric air at the inlet of the scramjet. This atmospheric air at supersonic speed is mixed and burned with an on-board fuel suitable for the production of thrust. Therefore, the combustion process occurs in supersonic regime. When the combustion process occurs in subsonic regime, it is called subsonic combustion or ramjet, the predecessor of the scramjet, which already finds many applications. The total pressure loss that occurs through normal shock wave (which slows the flow in ramjets) makes use of these engines impractical at hypersonic speeds.

An important feature of the scramjet is a highly integrated system, where engine and vehicle are indistinguishable. This tight integration is caused by the fact that the front section of the vehicle contributes to the compression of atmospheric air, while the rear contributes to the generation of thrust. The net thrust produced by the scramjet is the

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difference between the thrust (force that propels the vehicle) generated by the expansion of exhaust gases from the rear of the engine and the total drag (force that resists the movement of the vehicle). These forces may produce thrust to the flight of the vehicle or not depending on the balance of these forces in engine design in question.

Thus, aerospace vehicles propelled by scramjets carry only the fuel, usually Hydrogen, using atmospheric air as an oxidant itself by acquiring most of the kinetic energy required to reach Earth orbit during atmospheric flight. As a result of self-propulsive nature of the reactors, they are unable to produce thrust while standing still. The static thrust is zero. Accordingly, they must be accelerated to a speed such that the shock waves produced by the air intake are able to compress the atmospheric air. This velocity is approximately four times the speed of sound, Mach 4, considering scramjet.

2. SCRAMJET RESEARCH AT THE INSTITUTE FOR ADVANCED STUDIES

2.1 The Brazilian 14-X Projects

The Brazilian 14-X Hypersonic Aerospace Vehicle, VHA 14-X, project (Fig. 1) named after 14-Bis developed by aviation pioneer Alberto Santos Dumont, is being designed at the Prof. Henry T. Nagamatsu Laboratory of Aerothermodynamics and Hypersonics, at the Institute for Advanced Studies (IEAv) since 2007 (Ricco et al., 2011; Toro et al., 2012).

Today, the VHA 14-X is a strategic project of the Department of Aerospace Science and Technology (DCTA), where the goal is to design, to develop, to manufacture and to demonstrate, in free flight at 30km altitude at Mach number 10, a technology demonstrator using ”scramjet” as an hypersonic airbreathing propulsion system based on supersonic combustion.

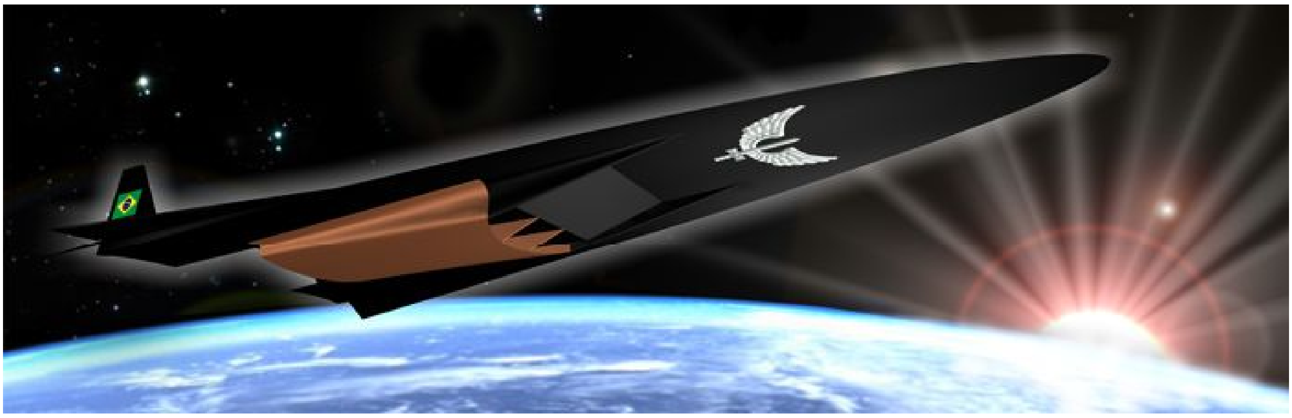

Figure 1: Brazilian 14-X Hypersonic Aerospace Vehicle, VHA 14-X.

In March 2012, the coordination of the VHA 14-X proposed new versions based on the VHA 14-X (Toro et al., 2013), where the VHA 14-X S (Fig. 2) has been designed to demonstrate the axisymmetrical two dimensional scramjet technology at 30km altitude with Mach number 7.

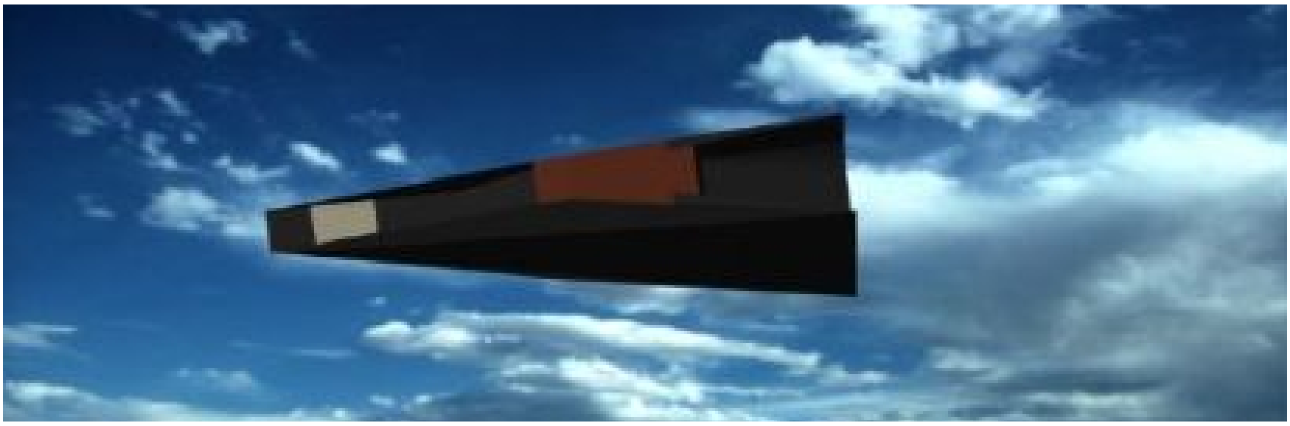

Figure 2: VHA 14-X S.

Since, the scramjet is a fully integrated airbreathing aeronautical engine (that has no moving parts) the VHA 14-X SA will be operational only on hypersonic speeds, and a hypersonic accelerator vehicle will be needed to take the VHA

14-X SA at 30km altitude at Mach number 7. As a low-cost solution to launch scramjet integrated vehicle to flight test conditions (30km altitude at Mach number 7) is to use rocket engines based on solid propulsion, in ballistic trajectory. Such approach may provide an affordable path for maturing Brazilian hypersonic airbreathing components and systems in flight.

3. THE BRAZILIAN 14-X S HYPERSONIC AEROSPACE VEHICLE

The 14-X S Hypersonic Aerospace Vehicle, VHA 14-X S, (Fig. 2) has been designed to flight at 30km altitude at Mach number 7 for the first experimental flight, in Brazil, based on VHA 14-X waverider (Rolim, 2009; Rolim et al., 2009; 2011) and scramjet engine (Romanelli Pinto et al., 2013) experimental data as well as on the one-dimensional theoretical analysis, based on oblique shock wave flow and Prandtl-Meyer expansion wave flow theories (Anderson, 2003) applied to the external and internal compression surfaces and to the internal and external expansion surfaces, respectively. The cross-section of the VHA 14-X S (Fig. 2) consists of a double cross-section of the VHA 14-X B (Fig. 3), where in the upper and lower contours are identical (Fig. 4).

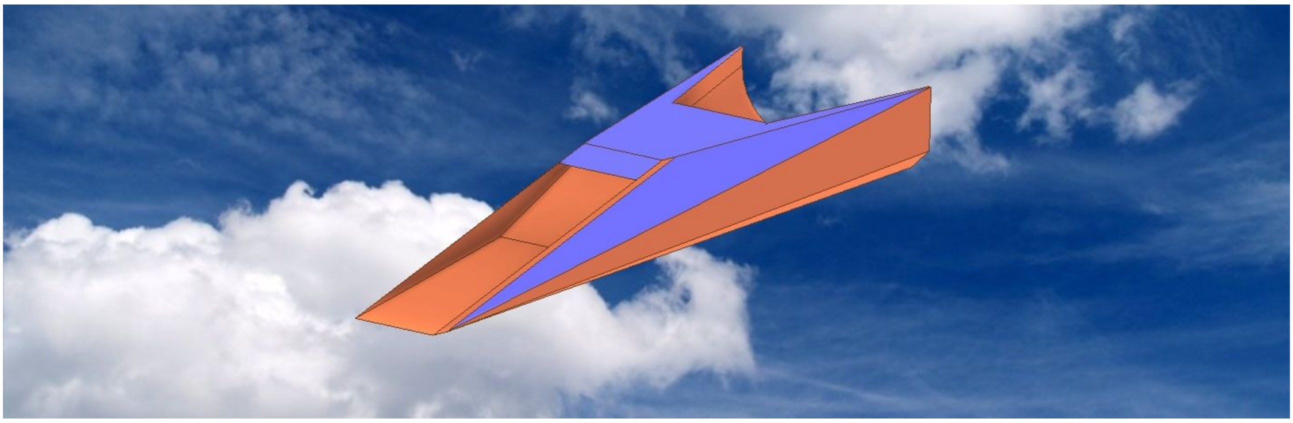

Figure 3: VHA 14-X B.

The lower surface of the 1-m. long VHA 14-X S (Fig. 4), taken from the VHA 14-X waverider external configuration (Rolim, 2009; Rolim et al., 2009; Rolim et al., 2011; Costa, 2011; Costa et al., 2012; Costa et al., 2013) consists of a frontal surface with a leading edge angle of 5.5^o, compression ramp angle of 14.5^o (related to the angle of the leading edge), the internal expansion chamber combustion angle of 4.27^o and external expansion angle of 10.73^o (related to the angle of internal expansion). The cross-section height is 224.35-mm. The combustor chamber 129.32-mm. long with constant area, following by 67-mm. long with 4.27^o (to accommodate the boundary layer and expansion due H_2 and O_2 combustion) was defined by research of the Hyslop (1998) and Kasal et al. (2002), respectively. The constant area combustion chamber is 7.5-mm. high (to accommodate the airflow captured by the VHA 14-X B frontal area).

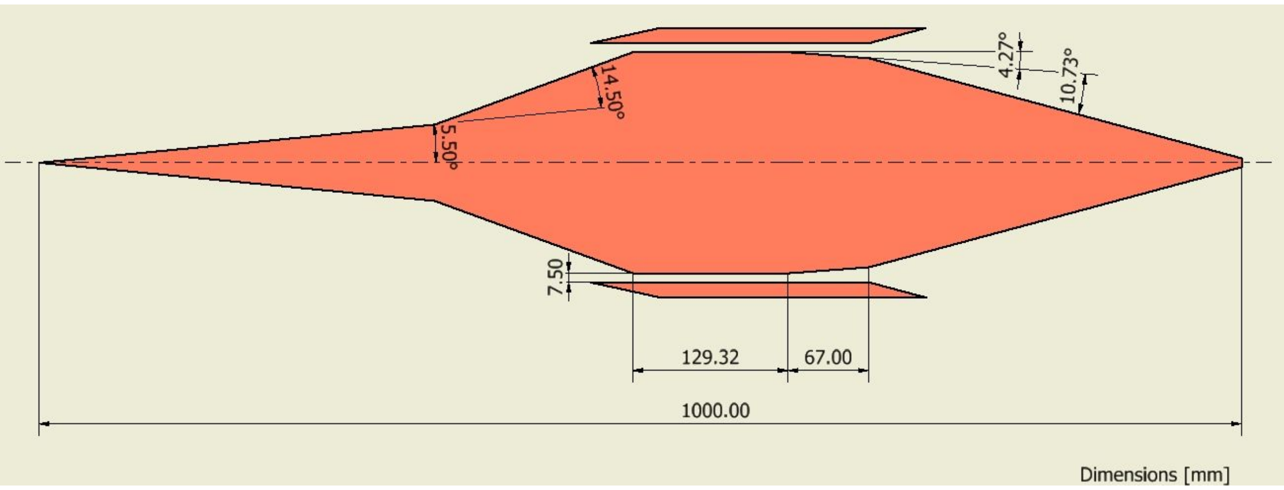

Figure 4: A side view of the plane VHA 14-X S.

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Firstly, a nomenclature was defined to be used in the analytical theoretical analysis. Following Heiser and Pratt (1994) the VHA 14-X S may be divided in three (Fig. 5) main components: external and internal compression section (inlet), combustion chamber (combustor) and internal and external expansion section (outlet). Also, the hypersonic vehicle with airframe-integrated scramjet engine lower surface may be divided by several stations (Fig.5).

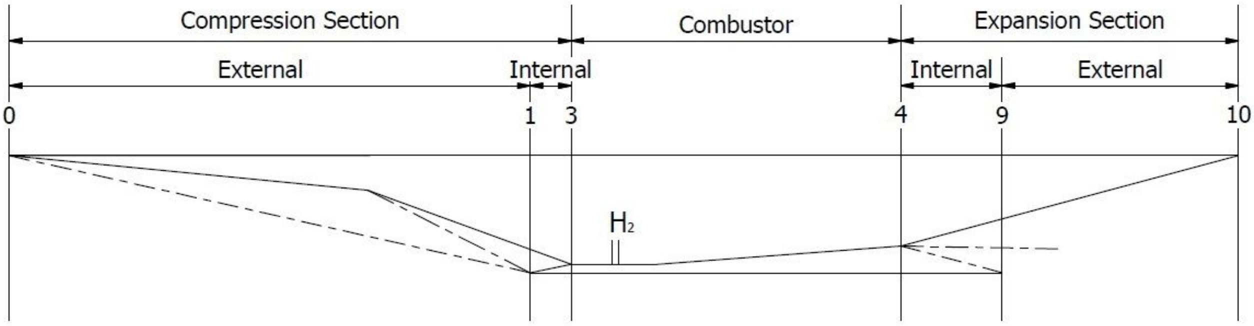

Figure 5: hypersonic vehicle with airframe-integrated scramjet engine stations and reference terminology.

Analytical theoretical analysis (Fig. 6), using the reference terminology (Fig. 5), applied to the nose-to-tail VHA 14-X S flying at 30km altitude at Mach number 7 (Cardoso, 2012, Cardoso et al., 2013), where at the lower surface was considering the simplest case, i. e., no viscous flow, calorically perfect air ($\gamma = 1.4$) and scramjet engine with power off. The standard atmospheric properties at 30km geometric altitude (U.S. Standard Atmosphere, 1976) are given as $p = 1197(Pa)$, $T = 226.5(K)$, $\rho = 0.01841(kg/m^3)$, $a = 301{,}7(m/s)$, where a is sound velocity.

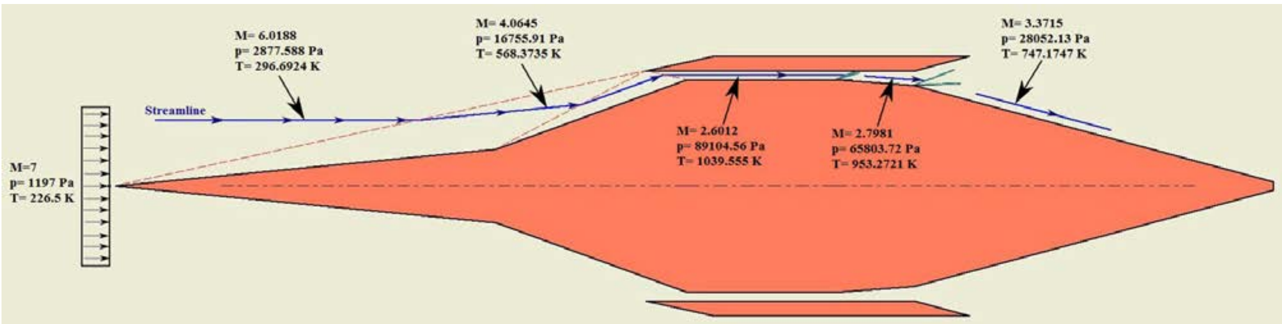

Figure 6: Analytical Theoretical Analysis applied to the VHA 14-X S at 30km altitude Mach number 7.

Note that, the incident shock waves generated at the 5.5° attached leading-edge deflection angle and at the 14.5° deflection (following the leading-edge deflection) hit the cowl leading-edge. The reflected shock wave generated at the cowl leading-edge hits the entrance of the combustor station (Fig. 6).

Also, the flow from the external and internal compression section are deflected to the combustor entrance (Fig. 6) at supersonic speed (constant pressure, constant density, constant temperature and constant Mach number) and remains constant at the exit of the combustor.

Finally, the closed form of the thermodynamic property (pressure, density and temperature) ratios and Mach number across the oblique shock waves and expansion waves are applied to the external and internal compression section and the internal and external expansion section (Fig. 6), respectively.

In general, analytical theoretical analysis, computational fluid dynamics simulation and experimental investigation are the methodological tools used to design a technological demonstrator, before flight throughout Earth’s atmosphere.

Analytical theoretical analysis provides simplified mathematical models; which are able to obtain a fast and reliable set of optimal parameters to be used on the nose-to-tail hypersonic vehicle with airframe-integrated scramjet engine preliminary design.

4. DIMENSIONAL DESIGN OF THE VHA 14-X S AT 30KM ALTITUDE AT MACH NUMBER 7

Dimensional Design of the VHA 14-X S has been developed to demonstrate at 30km altitude at Mach number 7 for the first experimental flight atmosphere (in Brazil) the scramjet technology.

6-mm. thickness (Fig. 7) of coating materials (Fig. 8) used for the thermal protection systems (which define the internal volume) and structural materials (Fig. 8) for the stringers and ribs (Fig. 9) as well as structural materials for the scramjet engine (Fig. 8) were specified (Cardoso, 2012, Cardoso et al., 2013) based on preliminary studies of the VHA 14-X waverider scramjet Mach number 10 at 30km altitude (Costa, 2011; Costa et al., 2012; Costa et al., 2013) to

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support the aerodynamic loads during the atmospheric hypersonic flight. 77.44-mm. long of the 5.5^o leading edge will be made from Carbon-Carbon material following by 108.35-mm. long Tungsten SD 180. The rest of the 5.5^o ramp, the 14.5^o ramp and the external expansion section while the scramjet engine will be made using Carbon-Carbon and Inconel 718, respectively (Cardoso, 2012).

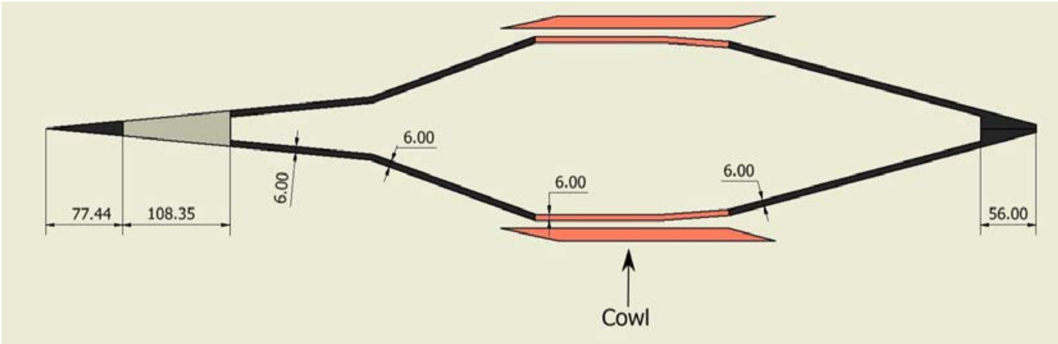

Figure 7: VHA 14-X S scramjet internal configuration.

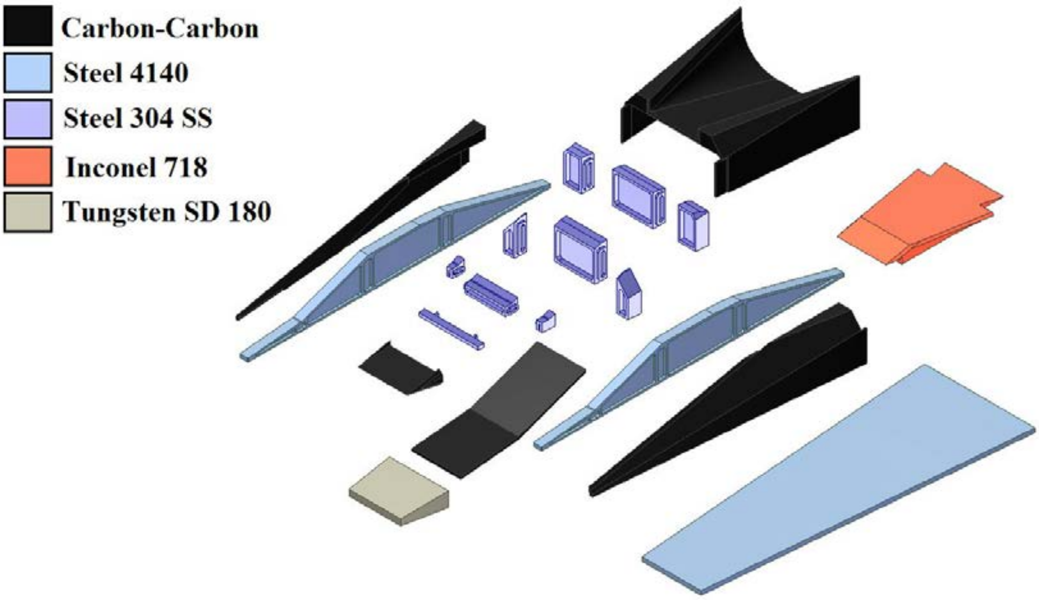

Figure 8: Material specification for the VHA 14-X S.

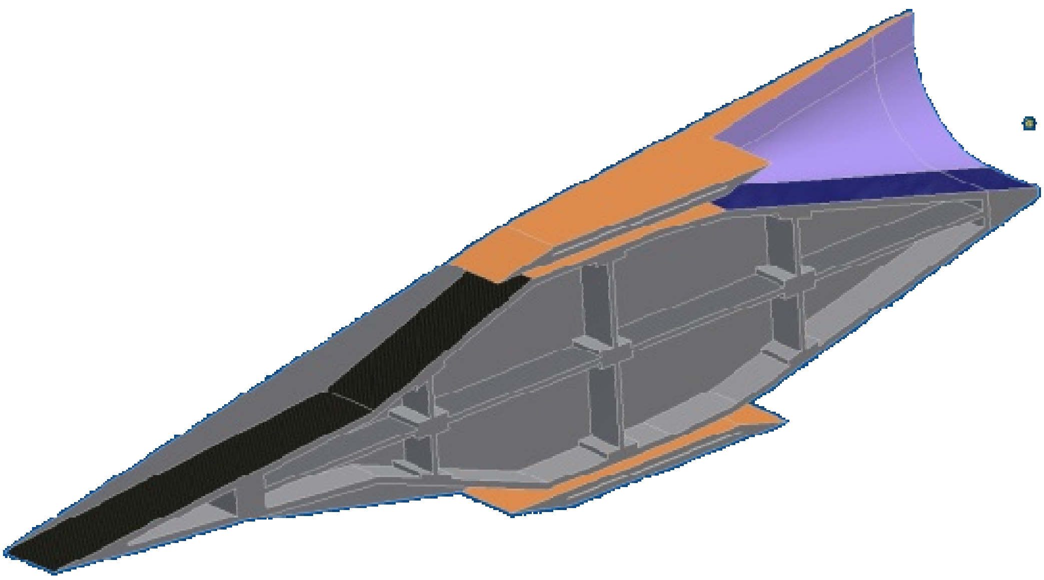

Figure 9: Internal view showing the stringers and ribs for the VHA 14-X S.

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5. STRUCTURAL NUMERICAL ANALYSIS

The present structural numerical analysis applied to the VHA 14-X S follow the same procedure as the structural numerical analysis applied to the VHA 14-X (Costa et al., 2013), therefore some of the introduction of the structural analysis applied to VHA 14-X S (Fig. 2) is the same as the VHA 14-X (Fig. 1).

Due to the high complexity of aerospace structures, which consist of a combination of different structural elements (stringers, ribs, panels, etc.) and of different types of materials, these structures cannot be described neither approximated by a mathematical equation, invalidating the use of classical methods of structural analysis. Therefore, it is necessary the use of the Finite Element Methods (FEM) to describe of high complexity structures into simpler and easier algebraic equations (Lage 2009). Additionally, numerical methods should be used due to the high degree of programmability of the FEM, to obtain greater speed and accuracy in calculations of the matrix associated.

Therefore, Structural Numerical Analysis using Finite Element Method (ANSYS Workbench software, 2011) has been applied to the VHA 14-X waverider unpowered scramjet flying at 30km altitude at Mach number 7, considering the dynamic pressure during the ballistic trajectory of the S31 and S30 unguided, rail launched, solid rocket engines.

First, methodology for pre-processing and post-processing were defined to maximize efficiency in achieving the results of structural analysis of VHA-14 X coupled to rocket engines (S31 and S-30) flying at the altitude of 30km altitude and reaching at speed corresponding the Mach number 7. The pre-processing consists of the following steps: addition of materials (to be used in this project) at the software ANSYS library, application the APDL module for the carbon-carbon parts, definition the geometry of the VHA 14-X into ANSYS database, generation the mesh by ANSYS, optimization of the mesh by analyzing the quality of the generated mesh, dimensional parameterization, adding bond structures, determination and application of pressure loads. The post-processing is made by analyzes of stress field and total displacement field together with the numerical error (APDL) of the mesh in order to optimize the thickness and weight reduction in the areas of low stress in the stringers as well as in the ribs. If necessary, propose changes in the geometry and again performing pre-processing and post-processing to obtain an appropriate solution.

The mesh generated by ANSYS Workbench (automatically) for the VHA 14-X S showed the presence of distorted elements, which it is characteristic of structured mesh, and can generate results that do not match reality.

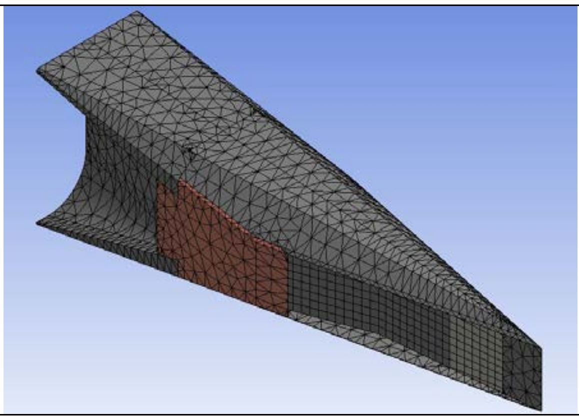


Figure 10: Automatically generated mesh for the VHA 14-X S.

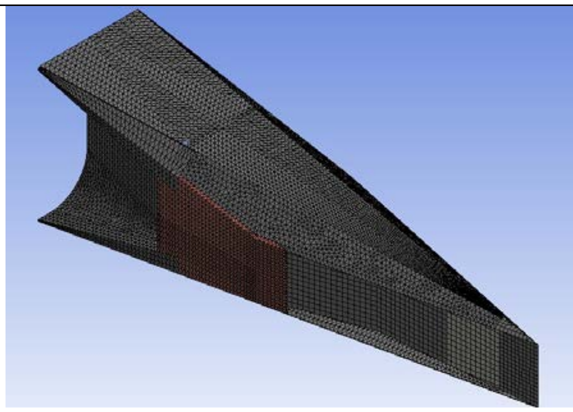


Figure 11: VHA 14-X S optimized mesh.

Appropriate tools of the software ANSYS Workbench were used to structure the mesh. The optimized mesh (Fig. 11) containing 184632 nodes and 61619 elements (quadrangular and tetrahedral) was obtained using the geometry of VHA 14-X S at the Mach 7 (Figs. 4, 7 and 9) implemented in the software ANSYS.

Next, the isotropic (Table1) and non-isotropic (Table 2) material mechanical properties specified by Costa (2011) and used at the VHA 14-X waverider (Costa et al., 2013) were used at the structural and thermal protection systems of the VHA 14-X S and were inserted into ANSYS Workbench material database. The mechanical properties of the CRFC 3D orthogonal (Table 2) were obtained from Gonçalves (2008).

Table 1: Mechanical properties for isotropic materials.

MATERIAL	ρ [g/cm³]	E [GPa]	υ	σ_e [MPa]	σ_r [MPA]
Steel 4140	7.85	20.5	0.29	415	655
Stainless Steel 304	8	20	0.29	215	505
Inconel 718	8.19	20.49	0.284	980	1100
Tungsten	17.75	40	0.28	552	827

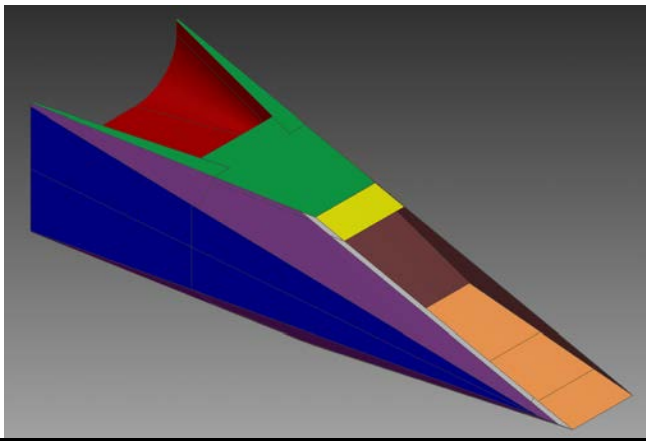
Table 2: Mechanical properties for CRFC 3D orthogonal Gonçalves (2008)..

Properties	CRFC 3D orthogonal	Properties	CRFC 3D orthogonal
Ex [GPa]	31.8	Gxy[GPa]	7.8
Ey [GPa]	31.8	Gxz[GPa]	5.0
Ez [GPa]	38.5	Gyz[GPa]	5.0
		υxy	0.1306
		υxz	0.0670
		υyz	0.0670

The boundary conditions for pressure load (Table 3) evaluated for VHA 14-X S flying (with no attack angle) at 30km altitude at speed correspondent to Mach number 7, as well as the inherent bonds (VHA 14-X coupled to the 2nd stage of the rocket engines) of the structure to each region (and components), which were applied to the VHA 14-X S model used for FEM. Additionally, it was inserted the acceleration of 14g's, being 13g's correspondents to the acceleration reached during the atmosphere flight and 1g's to the Earth's gravitational acceleration.

Along the present analytical theoretical analysis the subscripts u and d will be used to identify the upstream (inlet) and the downstream (outlet) conditions, respectively, of the each station of the hypersonic vehicle with airframe-integrated scramjet engine lower surface, VHA 14-X S.

Table 3: VHA 14-X S Analytical Theoretical Analysis at 30km altitude at Mach 7.



	M_u	δ [°]	θ [°]	M_d	T_d[K]	P_d [Pa]
Gray	7	8.62	15.05	5.47	349.94	4412
Purple	7	7.83	14.31	5.61	335.19	3979
Blue	7	4.78	11.64	6.15	286.07	2588
Orange	7	5.5	12.24	6.02	296.69	2877.6
Brown	6.02	14.5	22.11	4.06	568.4	16755.9
Engine (20°)	4.06	20	32.24	2.6	1039.55	89104.56
Engine (4.27°)	2.6	4.27	μ_1 = 22.61 μ_2 = 20.94	2.8	953.27	65803.72
Red	2.8	10.73	μ_1 = 20.94 μ_2 = 17.25	3.37	747.17	28052.13
Yellow	7	12.24	18.65	4.85	428.38	6799.8
Green	4.85	12.24	μ_1 = 11.9 μ_2 = 8.95	6.43	263.92	1247.76

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The equivalent stress σ_e, named as von Mises stress (Fig. 12) is related to the main stress $\sigma_i,\ where\ i = 1,2,3$ (Eq. 1), which used to quantify the ductile material fail model (Shigley et al, 2005).

$$\sigma_e = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} \right]^{1/2} \tag{1}$$

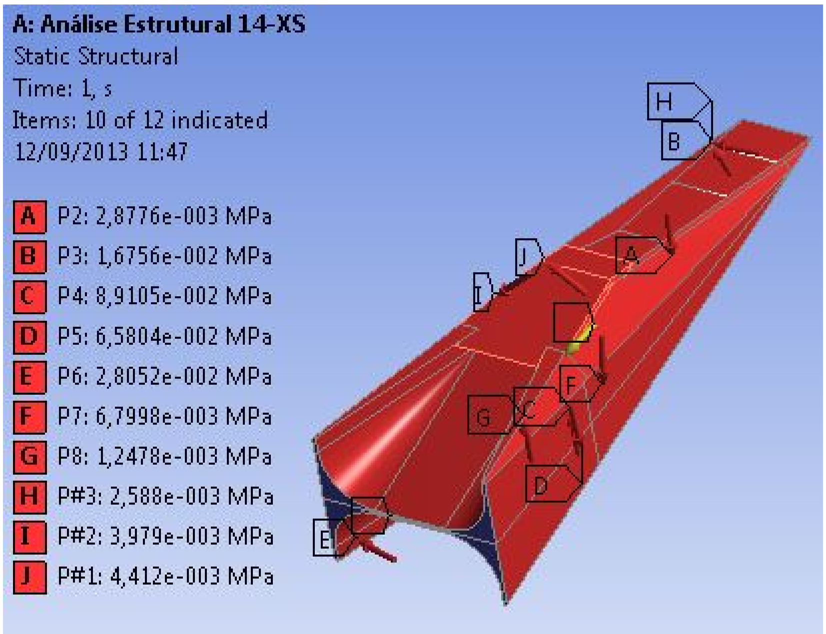

Figure 12: Equivalent stresses (von Mises) fields of the VHA 14-X S.

Considering the boundary conditions of the aerodynamic load (Table 3), acceleration of 14g's and inherent bonds as well as the isotropic materials (Table 1) and non-isotropic materials (Table 2) the maximum and minimum equivalent stresses (von Mises) are 8.66 MPa and 7.4 10^{-4} MPa at the leading-edge of the cowl (red) and the rest (blue) of the VHA 14-X (Fig. 13), respectively. Both maximum and minimum equivalent stresses found in the present evaluation are lower than any equivalent stress of the materials (Tables 1 and 2) used. Note the VHA 14-X S is symmetrical related to the leading-edge of the vehicle.

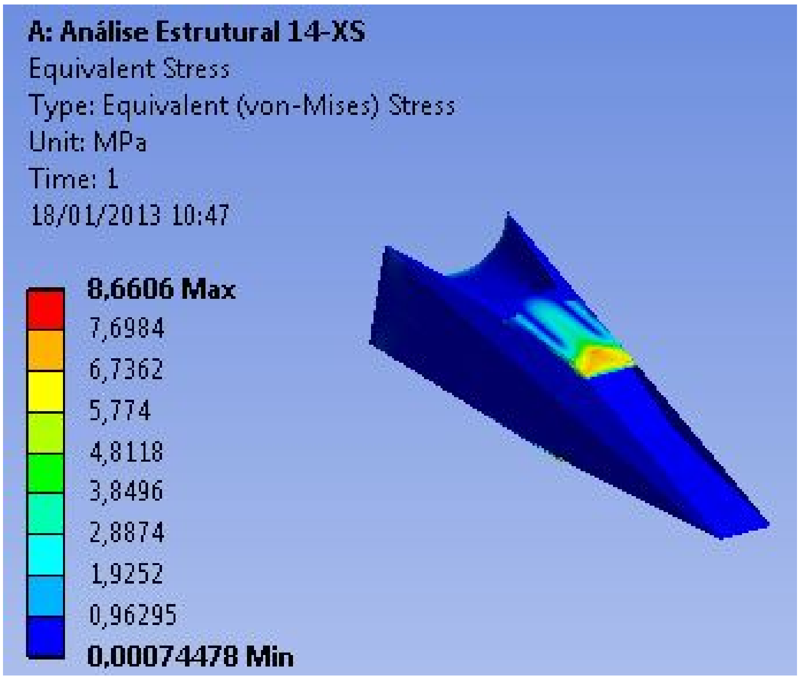

Figure 13: Equivalent stresses (von Mises) fields of the VHA 14-X S.

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The "Fixed Support" bond used in the present structural analysis, do not allows the deformation between two adjacent components related to the initial position. Therefore, the deformation is related to the global coordinates.

Figure 14 shows the total deformation is 2.5 10^{-2}mm and it is occur at the cowl leading-edge of the VHA 14-X S, considering the boundary conditions of the aerodynamic load, acceleration of 14g's and inherent bonds as well as the isotropic materials (Table 1) and non-isotropic materials (Table 2).

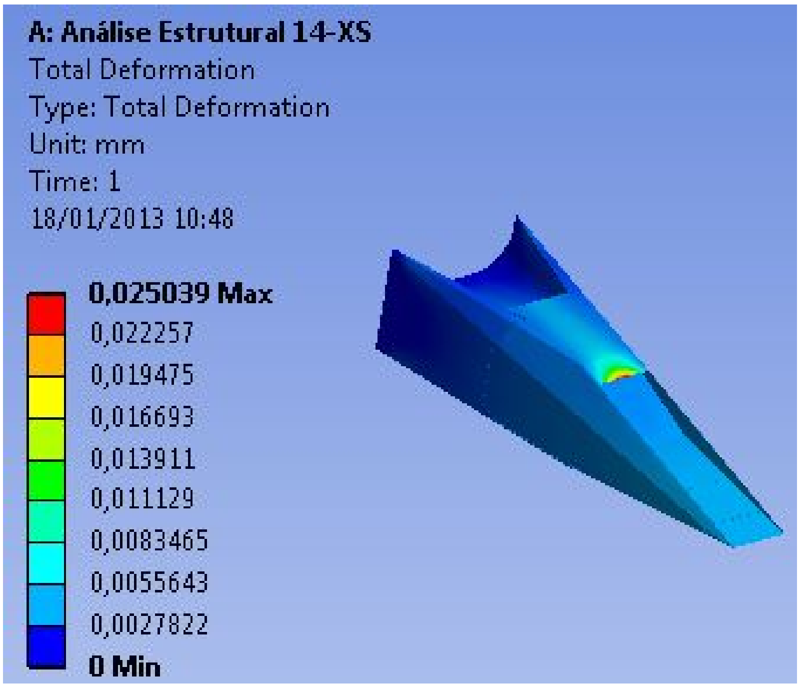

Figure 14: Total deformation of the VHA 14-X. S.

Also, the X-direction deformation (Fig. 15) reaches the maximum of 5.5 10^{-3}mm and minimum of -2.3 10^{-5}mm. The Y- and Z- direction deformations (not presented in this work) show the same very low deformation when one consider the application of the boundary conditions of the aerodynamic load (Table 3), acceleration of 14g's and bonds as well as the isotropic materials (Table 1) and non-isotropic materials (Table 2) under the equivalent stresses (Fig. 13).

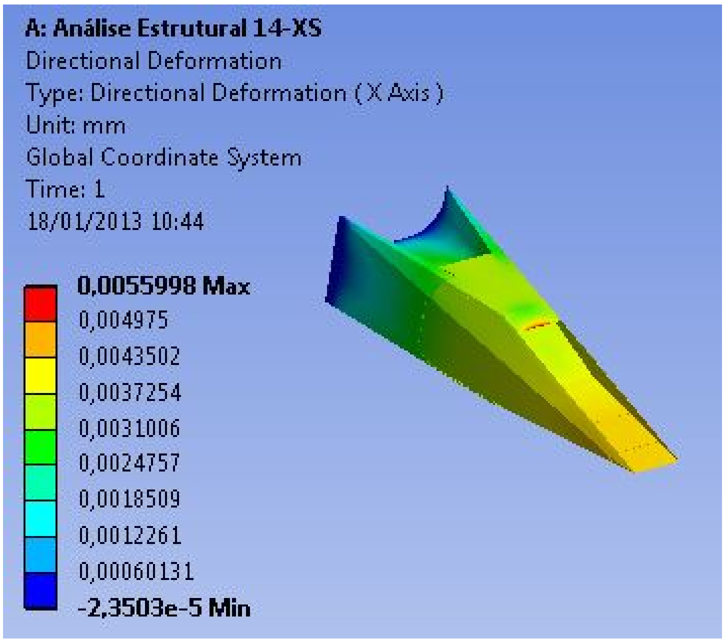

Figure 15: X-direction deformation of the VHA 14-X S.

Also, the equivalent deformation, which the origin is from the von Mises theory, may be evaluated by the Eq. 2.

$$\varepsilon_e = \frac{1}{1+\nu}\left(\frac{1}{2}\left[(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2\right]\right)^{1/2} \quad (2)$$

Finally, the principal elastic strain shows the equivalent deformation occur in the elastic region of the used material at the each components of the VHA 14-X S. The maximum of 1.5 10^{-4}mm/mm and minimum of -1.1 10^{-7}mm/mm (Fig. 16) is found for the principal elastic strain.

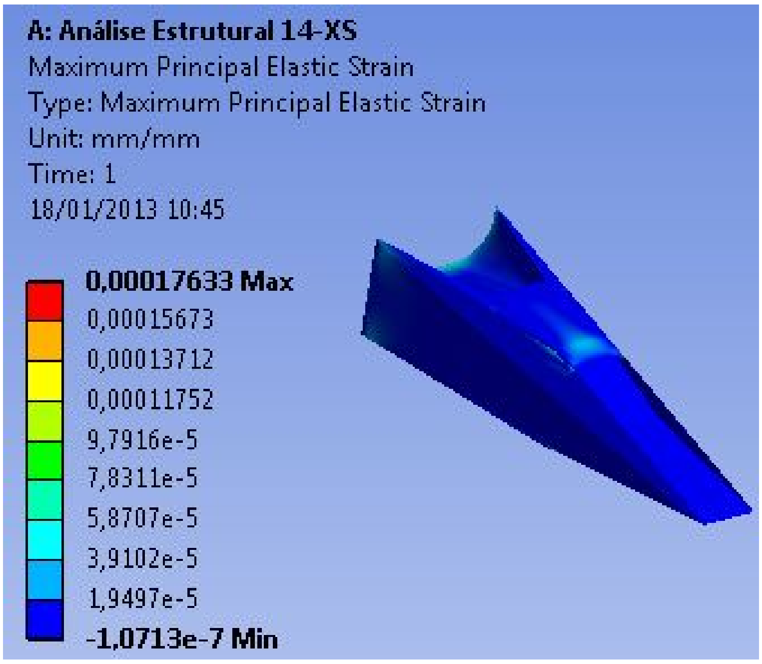

Figure 16: Principal elastic strain at lower surface of the VHA 14-X.

6. CONCLUSION

The primary objective of this work is to present the structural analysis (stress, deformation and elastic strain) using the von Mises theory applied to the VHA 14-X S, considering the aerodynamic load, acceleration of 14g's and bonds as well as the isotropic and non-isotropic materials.

VHA 14-X S is being designed as an option of a new generation of scientific aerospace vehicle to replace not in a too distant future the conventional multi-stage rocket-powered vehicles, which have flown hypersonically, carrying their own propellant (solid and/or liquid, oxidizer along with fuel) to propel payloads and astronauts to Earth's orbit.

Experimental data as well as analytical theoretical analysis of the waverider and scramjet configurations allowed to obtain the dimensional design of the VHA 14-X S. Isotropic and non-isotropic materials were specified using based on the scramjet demonstrators flying at 25-35 km altitude at Mach number 5 to 10 through Earth's atmosphere.

ANSYS Workbench software, which provides the Structural Numerical Analysis using Finite Element Method, has been applied to the structural analysis of the VHA 14-X S unpowered scramjet at 30km altitude at Mach number 7. Preliminary investigations show the maximum stress is lower than the stress of the isotropic and non-isotropic materials used in the structural analysis. Also, total and direction deformations and elastic strain are acceptable for the stress evaluation.

7. ACKNOWLEDGEMENTS

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