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TECHNICAL AND ECONOMIC FEASIBILITY OF USING THERMAL PROTECTION SYSTEM INTEGRATED IN SARA SUBORBITAL

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Abstract. *Space and suborbital vehicles reach high speeds while flying in the atmosphere, which results in aerodynamic heating and structural loads due the dynamic pressure on the surface. High resistance materials are employed to support such requirements, increasing the spacecraft weight and launching costs. The use of an integrated thermal structural protection (TISSC) was proposed, in order to improve the overall performance, resulting in a significant reduction in weight and cost and increasing the life cycle of the vehicle. This work is aimed in analyzing the economic viability of these structures, applied to the SARA suborbital platform, which is being developed by IAE for experiments in micro-gravity environment. Possible combinations of materials to be employed, including their cost and manufacturability, were analyzed, concluding that the use of this system represents an advantage when compared to the conventional thermal protection system.*

Keywords: *SARA, Suborbital Platform, Thermo-structural Protection*

1. INTRODUCTION

Space and sub-orbital vehicles reach high velocities within the atmosphere, which results in aerodynamic heating and wall high heat fluxes. The high temperatures may negatively affect the structures mechanical behavior, the operation of on board equipment, besides the fact that payload preservation is always mandatory. These problems are solved by using an efficient Thermal Protection System (TPS). As a consequence, TPS design is a critical aspect of a rocket design, since under sizing may result loss of the payload, and the over sizing it implies in increasing mass and cost. Sub-orbital platforms are a low-cost alternative for micro-gravity research. SARA sub-orbital platform, Fig. 1, is being developed by IAE/CTA for such application. It has a total mass of 250 kg for a payload of about 25 kg, and is designed to provide 6 minutes of micro-gravity environment. SARA reaches the speed of 9300 km/h in atmospheric flight (Moraes, 1998).

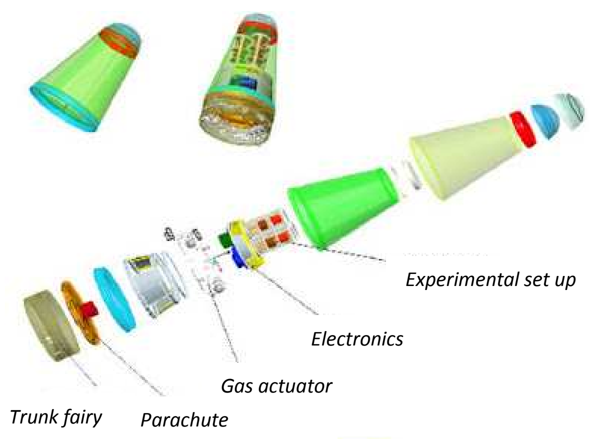

Figure 1. SARA sub orbital and its internal systems.

The current design uses a conventional cork layer as TPS to protect its lateral surface, with the trade-off of large mass. As an option, Thermally Integrated Structural Sandwich Core (TISSC) would insulate the vehicle from aerodynamic heating as well as carry primary vehicle loads (Poteet and Hsu, 2004). It consists of a structural sandwich panel in a three-layer plate with two face sheets and a core. Two thin, stiff and strong faces are separated by a thick, light and weaker core, Fig. 2. The advantages of using such a structure are that it is lightweight, multifunctional, for example offer insulation as well as load bearing capabilities, low maintenance, and low life-cycle cost. Commonly used materials for facings and core are ceramic matrix composite laminates and metals.

Figure 2. Thermally Integrated Structural Sandwich Core (TISSC) – NASA concept.

A Thermally Integrated Structural Sandwich Core (TISSC) was proposed to replace SARA´s current thermal protection system, and the results were presented in a previous work (Machado et al, 2013), Fig. 3. TPS modifying straightly results in a mass variation of SARA platform, which influences dimensioning and material choices and consequently, the final trajectory, manufacturing and launching costs. All those parameters must be selected in order to find the equilibrium point (Machado and Leite, 2010). In this work, the economic feasibility of such replacement is studied, through the comparison between the costs of the current thermal protection and the proposed TISSC configuration. Some material combinations are tested, considering their costs and manufacturing processes in order to determine the best options and its viability in replacing the current TPS design.

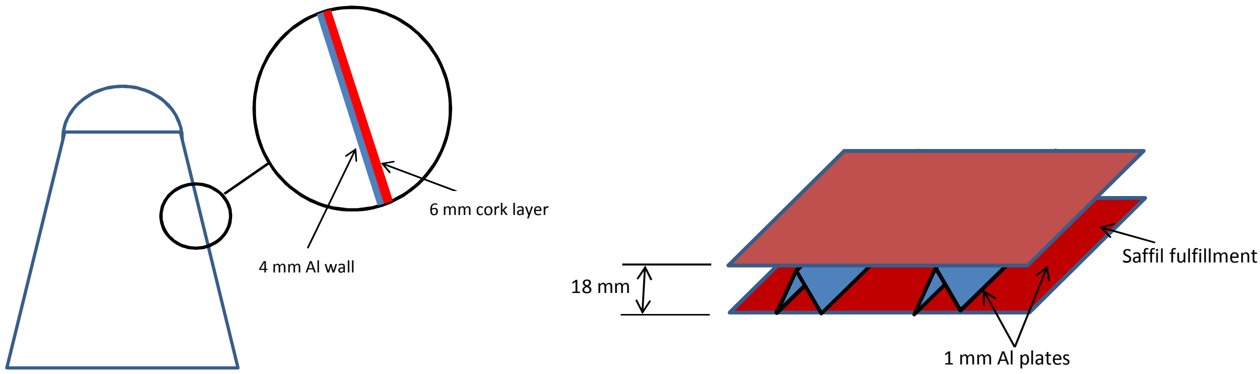

Figure 3. Schematics of current TPS (right) and proposed arrangement for the integrated thermal protection (left).

Behind the mass, the cost is also influenced by the time available for the experiment performing within the payload. The corresponding costs for several micro-gravity facilities are showed in Fig. 4 (Côrrea, 1999). In this work, the benchmark adopted was the sounding rocket value, with a microgravity cost of US$ 10,000 for kg.h, resulting in a total amount of US$ 250,000 for a whole SARA mission (25 kg payload during 6 minutes of microgravity environment).

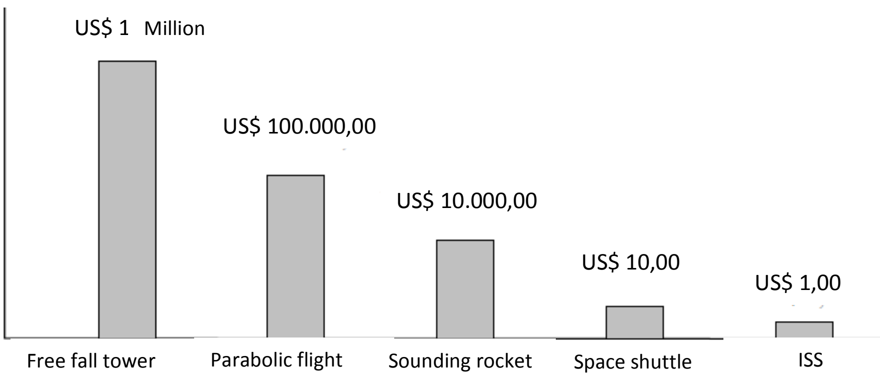

Figure 4. Microgravity cost - kg.h

2. METHODOLOGY

The global methodology used in engineering design and applied to SARA project and its components, including TPS, is divided in three steps, which can describe all work phases. Figure 4 shows the organization flux of time steps since planning the mission to platform assembling (DefesaNET, 2014):

- Engineering development: study, simulations and calculations of the system that comprehends thermo-structural behavior (Machado et al, 2013), pressure load and aerodynamic warming (Machado and Villas Boas, 2006; Machado et al., 2012), ballistic atmospheric reentry simulation (Schulz and Moraes, 2004), etc.
- Qualification: prototype assembling and testing.
- Flight: all studies are concluded and a real flight is to be performed.

At this point, SARA was considered to be at the first step (engineering development).

Figure 4. SARA Project methodology.

The sequence considered in this work is showed in Fig. 5, through a flux diagram, where one can see the material selection and the cost analysis. Obtaining this cost was the first obstacle to go ahead with the work, since some uncommon materials were selected. After the simulation the proposed configuration for TPS was considered validated, and showed lower cost, lower mass and a better performance than the current TPS design.

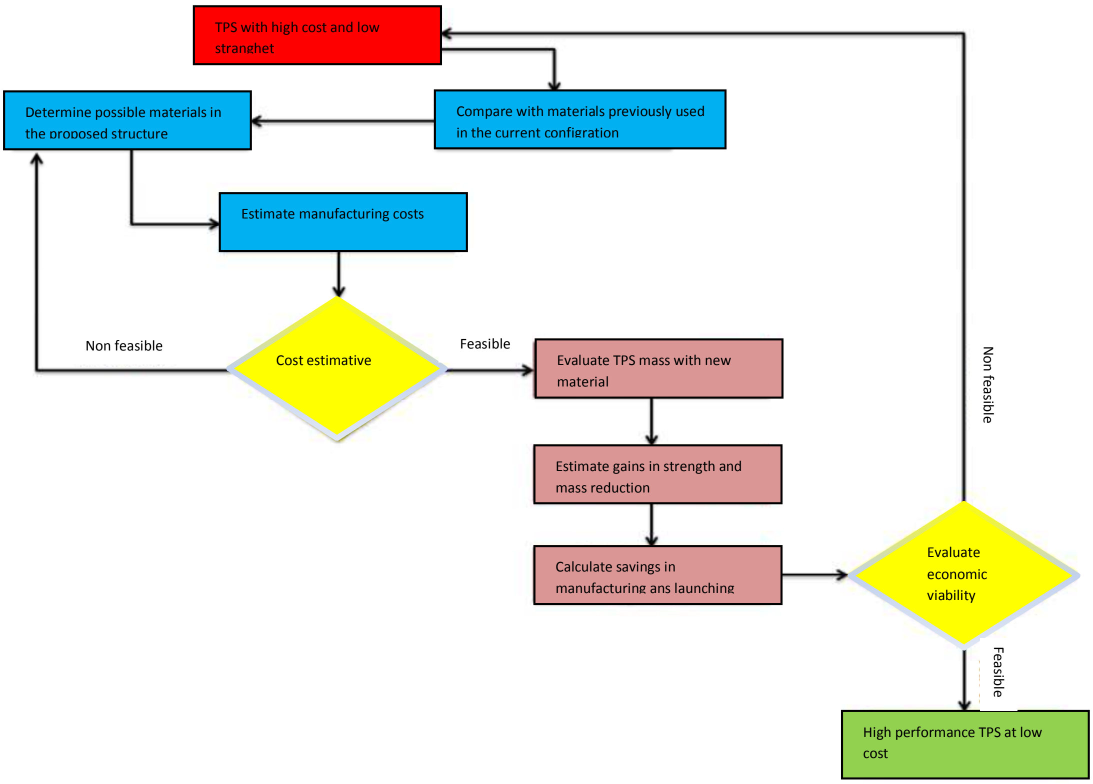

Figure 5. Flux diagram for material selection and analysis.

The software for simulation used in the economic viability analysis was built in *Visual Basic for Aplications* (VBA). Its interface is showed in Fig. 6, where the inputs considered are listed (structure material, internal/external cover layer and TPS dimensions). The material densities used were extracted from the commercial software CATIA V5, and the platform geometry modeled in three dimensions as showed in Fig. 7.

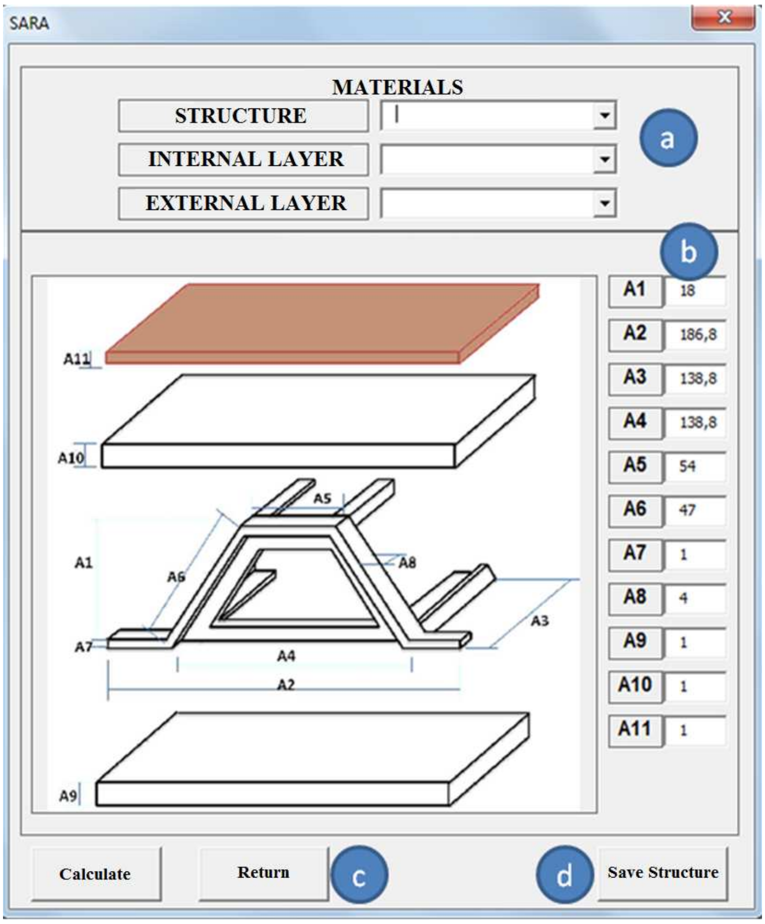

Figure 6. VBA software interface built for the analysis.

Figure 7. 3D model of the proposed TPS configuration.

Materials considered for use in the proposed structure were Aluminum 2024 (Al 2024), Aluminum 7075 (Al 7075), Aluminum-Beryllium (Al-Be) and the composite Carbon fiber-Phenolic resin (CF). Such materials present excellent strength/weight ratio. Figure 8 presents material properties (Callister, 2010).

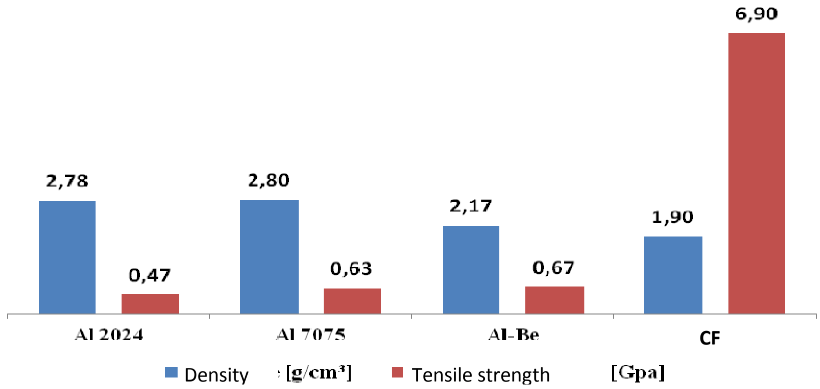

Figure 8. Material properties.

Thermal insulation was provided by cork in the current configuration and Saffil® (alumina fiber) in TISSC. Both materials present low density and low thermal diffusivity. According with the previous work of Machado et al (2013), their properties are 0.0242 g/cm³ and 0.9-0.12 W/m.K for Saffil® and 0.140 g/cm³ and 0.039-0.045 W/m.K for cork (UNIFRAX®, 2014; Gil, 2008).

Material prices in USD/kg were obtained from diverse suppliers in Europe, Asia and USA. Three-five quotations for each material were considered, and used to obtain average values, showed in Table 1. In this work, taxes, political conditions for acquisition and depreciation were neglected.

Table 1. Average quotations for selected materials.

Material	Saffil®	Cork	Al 2024	Al 7075	Al-Be	CF
Quotation (USD/Kg)	22.50	1.05	4.43	4.77	10.10	24.00

3. RESULTS

After analysis, total mass and cost of the current configuration and the proposed configuration of TPS were compared, as showed in Figs. 9-10.In the proposed TISSC configuration, a cork layer with 1 mm thickness was kept, in order to assure the external temperature to be within the maximum limit allowed.

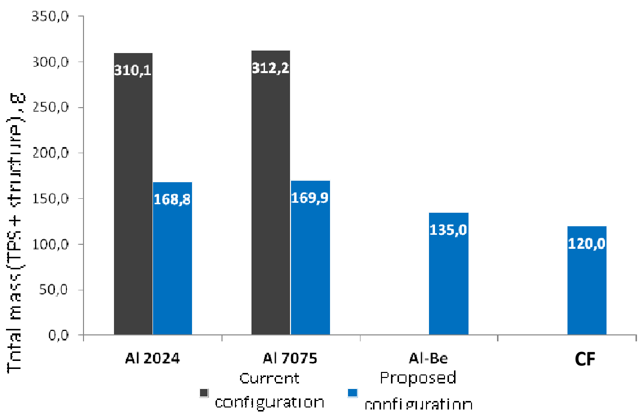

Figure 9. Mass variation according with the configuration proposed for every selected material.

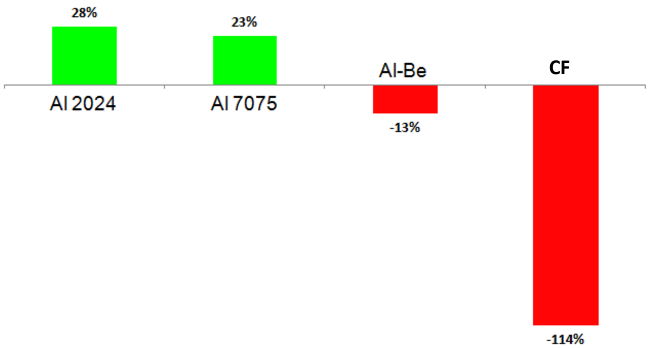

Figure 10. Cost reduction according with the configuration proposed for every selected material.

According wiht results, a reduction of 45.56 % was obtained keeping the original materials (Al) and modifying the structure layout to the proposed configuration. When Al-Be and Carbon Fiber are used, the mass reduction rises to 56.46% and 61.30, respectively. These reductions can be straight converted in cost reductions. However, when the final costs are compared, these materials present difeent results. Keep on using Al 2024 and Al 7075 results in a total cost reduction of 29% 23%, respectively. These costs can be amortized with a higher quality manufacturing process, although this procedure could yield a higher initial cost.

Use of Al-Be results in a rising cost of 13 % when compared with the current configuration, even neglecting any aditional cost related to manufacturing processes. Altough Carbon fiber presented highest mass reduction, this material prsentes the highest cost, with an increment of 114 % when comapred with the current configuration. This cost shall be even higher, considerind that the manufacturing processes for this composite is more complex than the previous materials.

The mass reduction can be converted in payload increment, adding 15 to 20 kg plus to the 25 already available. According with Corrêa (1999), the mass reduction can also extend the time available for microgravity experiments, adding 23 to 32 seconds. If such parameters (payload and microgravity environment time) were kept constant, the mas reduction can be converted in cost reduction, resulting in an economy of USD 15,000, which assures the economic viability of the proposode TPS configuration. Figure 11 sumarizes the possible gains in every parameter according with the material selected. Such gains can be considered alone or in combination, according with the mission demands.

Tables 2-4 summarizes results for all materials.

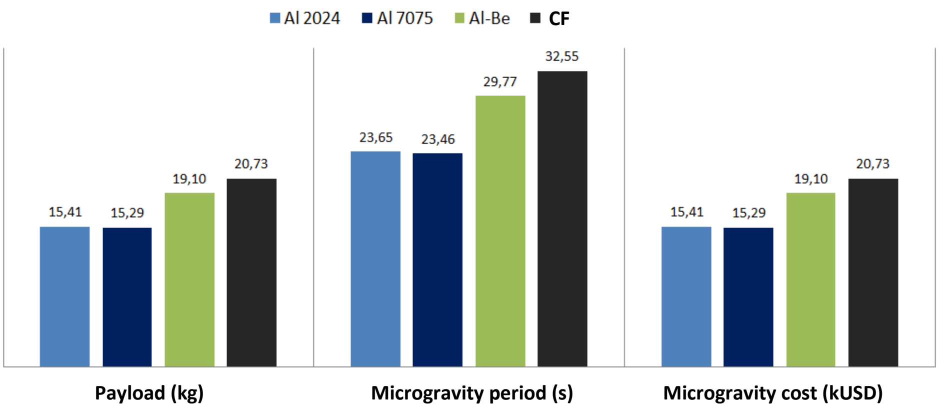

Figure 11. Summary of gains in every parameter.

Table 2. Mass variation according with material.

	Al 2024	Al 7075	Al-Be	CF
Mass of current configuration (kg)	33.82	33.82	33.82	33.82
Mass of proposed configuration (kg)	18.41	18.53	14.72	13.09
Mass reduction (kg)	15.41	15.29	19.10	20.73
Total payload (kg)	40.41	40.29	44.10	45.73
Payload gain (%)	61.65%	61.17%	76.39%	82.91%

Table 3. Microgravity period according with material.

	Al 2024	Al 7075	Al-Be	CF
Microgravity cost	10,000	10,000	10,000	10,000
Period of microgravity (min)	6.39	6.39	6.50	6.54
Increase in microgravity period (s)	23.65	23.46	29.77	32.55
Gain in time (%)	6.57%	6.52%	8.27%	9.04%

Table 4. Cost variation according with material.

	Al 2024	Al 7075	Al-Be	CF
Cust of current configuration (USD)	1.30	1.30	1.30	1.30
Cust of proposed configuration (USD)	0.94	1.00	1.47	2.78
Cust reduction (USD)	0.36	0.30	-0.17	-1.48
Relative cust saving	28%	23%	-13%	-114%
Total cust saving (USD)	15,412.94	15,292.17	19,096.87	20,727.47

4. CONCLUSION

In this work, the economic viability of the use of a TISSC configuration to replace the conventional TPS of SARA sub orbital platform was studied. Since the technical viability was already verified and the dimensions to be considered were obtained from previous works, it was possible to estimate the gains due the mass reduction. These gains may consist in cost reduction or increasing of the payload or microgravity environment time of the mission. In all cases, the manufacturing costs were not accounted.

If Aluminum is kept as structural material, both types used (Al 2024 and Al 7075) provide reduction in cost and mass, which confirms the economic viability of the proposed configuration. The best material seems to be Al-Be, since even considering the manufacturing costs (due the fact this material is toxic when being processed) a reduction of 56.46% in mass was obtained, increasing the payload in 76.39 % when compared with the current configuration, resulting in USD 19,096.87 savings in the microgravity total cost. It should be emphasized the better processing characteristics of this material, when compared with both types of Al and the CF composite.

The Carbon Fiber composite shall provide a high mass reduction but also a high cost increase, when manufacturing is accounted the cost rises greatly, since it can reach 1,000 EU/kg in an aerospace application. As an alternative, a re-dimensioning of the structure for CF composite could reduce the dimensions, and consequently, the cost for the use of this material, considering its high strength/weight ratio.

5. ACKNOWLEDGEMENTS

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