PAYLOAD ADAPTOR SYSTEM FOR JAMES WEBB ADAPTER

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OVERVIEW

The James Webb Space Telescope (JWST) is a large, infrared-optimised space telescope, scheduled for launch in 2013. JWST will find the first galaxies that formed in the early Universe, connecting the Big Bang to our own Milky Way Galaxy. JWST will peer through dusty clouds to see stars forming planetary systems, connecting the Milky Way to our own Solar System.

JWST will have a large mirror, 6.5 meters in diameter and a sunshield with a size of 22x10m. Both the mirror and sunshade won't fit onto the rocket fully open, so both will fold up and open only once JWST is in outer space. JWST will reside in an orbit about 1.5 million km (1 million miles) from the Earth.

JWST is an international collaboration between NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA). The NASA Goddard Space Flight Center is managing the development effort.

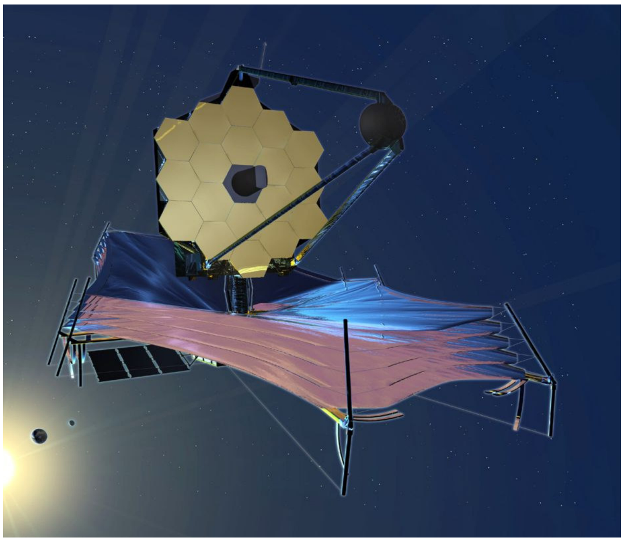

FIG 1. Artistic view of James Webb Space Telescope

EADS CASA ESPACIO has been request for the preliminary study of the Payload Adapter for the launch of the JWST with the Ariane 5 ECA launcher.

The main task has focused on searching a design concept that could satisfy the different aspects of the specification that is very exigent. The structure of the adapter has been designed taking into account that the specific topology of the I/F between the Payload and the JWST-Adapter (reduced I/F area to four bolts), in addition to the requirements of geometry, forbidden volumes, stiffness, overfluxes, stress and mass.

This has proved to be a significant design challenge as well as an important development effort. Different possible designs as been studied and calculated (including stochastic analysis and complexity management) until obtain a promising concept, quite well balanced with respect to the requirements.

When the most promising concept was chosen, it has been necessary to determine the best compromise considering all the specification aspects. To accomplish this, has been necessary to perform a Stochastic investigation and a Stochastic Design Improvement (SDI) methodology in order to determine the improved performance, determining all the possible functioning modes of the design, choosing the considered most appropriate one.

1. INTRODUCTION – STUDY LOGIC

The study of the Payload Adapter for the launch of the JWST with the Ariane 5 ECA launcher has been performed in two steps:

- **Concept quest**:

The first task has focused on searching a design concept that could satisfy the different aspects of the specification. The structure of the adapter has been designed taking into account that the specific topology of the I/F between the P/L and the JWST-Adapter (reduced I/F area to four bolts), in addition to the requirements of geometry, forbidden volumes, stiffness, overfluxes, stress and mass. This has proved to be a significant design challenge as well as an important development effort. Different possible designs as been studied and calculated (including stochastic analysis) until obtain a promising concept, quite well balanced with respect to the requirements.

- **Concept Fitness Landscape definition**:

Once the concept was defined, an arduous work of performance enhancement and design simplification has been made in order to determine the best compromise considering all the specifications. To accomplish this it has been necessary to perform a stochastic investigation by means of the execution of a large number of MSC.Nastran runs. The SDI (Stochastic Design Improvement), algorithm implemented in ST-ORM (Stochastic tool developed by EADS CASA Espacio), has been adopted in order to determine improved performance. The stochastic analysis has generated an output database that, subsequently, when processed by the OntoSpace™ tool, leads to the determination of all the possible functioning modes of a particular design option, and to choose, among the different possibilities, the most appropriate one according to our needs.

Conventional system design proceeds typically along the following lines:

- Establish a baseline design and perform a scan of the design space in order to establish good starting points for subsequent optimisation.
- Establish performance objectives and constraints
- Optimise the design so as to satisfy the objectives (typically maximize some property, such as stiffness, strength, etc. and minimize, at the same time, for example mass.)
- Perform a robustness study in order to evaluate how the system performs in the presence of uncertainties in the environment (loading) and manufacturing tolerances.

This process is complex, requires the usage of numerous algorithms and, most importantly, requires expertise. Today, all of the above process may be simplified substantially.

The alternative process used to design the JWST adapter follows these guidelines:

- Randomly sample all the variables of a given problem using Monte Carlo Simulation (MCS). Using a uniform distribution for each variable, and sampling over the entire admissible domain of each variable yields the Fitness Landscape of the system.
- Process the Fitness Landscape using a complexity management tool (at this study, OntoSpace™, from Ontonix S.R.L.).
- Establish performance objectives and constraints using the tool, witch provides a set of alternative designs, together with a measure of complexity for each alternative.
- The least complex design will be chosen among the alternatives as it is intrinsically the most robust one.

It is important to remark that when designing complex and sophisticated systems, it is more important to favour robustness and reliability than seeking peak performance.

In each Monte Carlo simulation a relatively large variation of input variables must be adopted. The objective has been not to represent the true physical random variations (tolerances) of each variable but to generate what is known as a Fitness Landscape to determine all the possible solutions (modes of functioning of the system in question). For each solution, or mode, complexity is determined, along with other important properties of the system. Since the objective is to generate a Fitness Landscape, the results don't possess any statistical meaning.

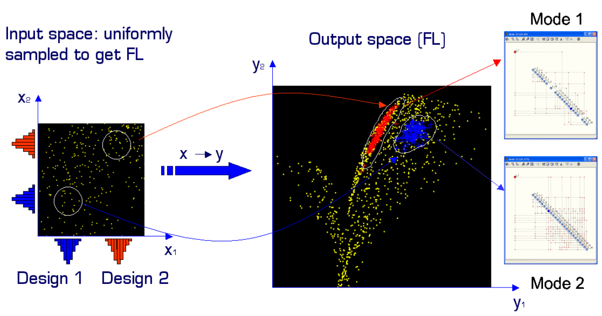

FIG 2. Example of Fitness Landscape

2. PAYLOAD ADAPTER DESCRIPTION

The JWST adapter, has the function to carry the JWST payload and transmit the thrust coming from the different stages of the launcher, to ensure a safe separation between the P/L (Payload) and the proper launcher, and to furnish the necessary electrical wiring.

It is located in the upper part of the launcher ARIANE 5 ECA, between the upper end of the conical part of the VEB (Ø 3936) and the P/L, the JWST telescope. It replaces the 3936 cone and the adapter used for the recurrent missions of Ariane 5, and is placed under a long fairing without any carrying structure.

The JWST adapter is composed of the P/L carrying structure, a separation and jettisoning subsystem and an electrical subsystem that includes the flight required instrumentation.

To contribute and facilitate the integration of P/L on the launch vehicle the JWST adapter has been designed as detachable, with two parts, the upper one with the separation, electrical and instrumentation subsystems, and the lower one to I/F with the launcher.

The JWST adapter is composed by three subsystems:

- Structure
- Separation & jettisoning
- Electrical & instrumentation

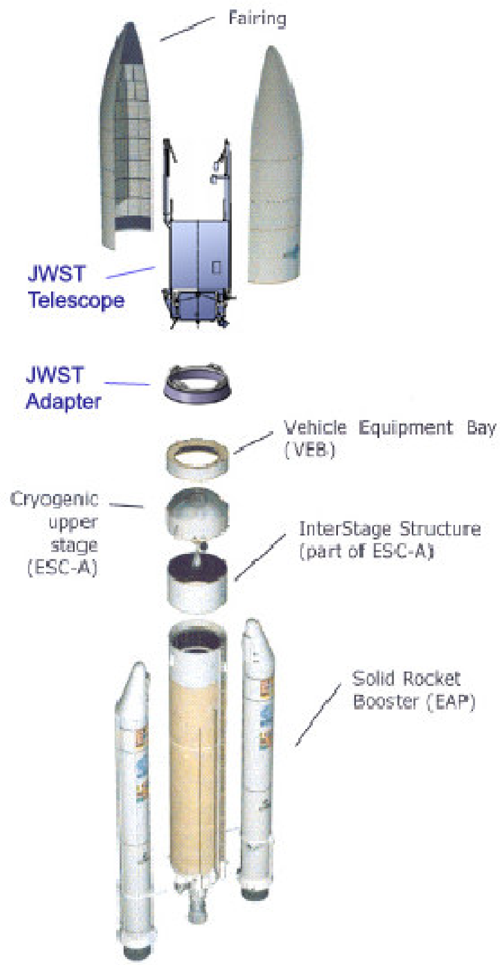

FIG 3. Launcher & Payload exploded view

The structure of the JWST Adapter, with a total height of 1.140 m, is comprised by two main elements: the lower one to I/F at Ø 3936 mm with the vehicle equipment bay of the launcher, and the upper one to I/F with the payload at Ø 3343 mm.
This short height has been a challenge in terms of overflux distribution, due to the number (4) and placement (Ø3343 mm, and radial position at 40º - 140º - 220º - 320º) of the separation subsystem pryronuts.

The main constraints and requirements for the design has been the following:

- Mass: less than 300 kg (including subsystems)
- Longitudinal/Lateral/Torsion frequency 47/10/33 Hz
- Payload mass: Max 7260 Kg at 4.2 mts
- Overfluxes: 20N/mm at level of lower I/F (Ø 3936) induced by the launcher
- Less than 10% of variation of overfluxes at lower I/F level (Ø 3936)

3. ANALYSIS STUDIES

The first approach was to define a structure preliminary concept based in alike previous adaptors with similar constrains. The problem was that no structures of this exigency of requirements exist, and the results were very disappointing.

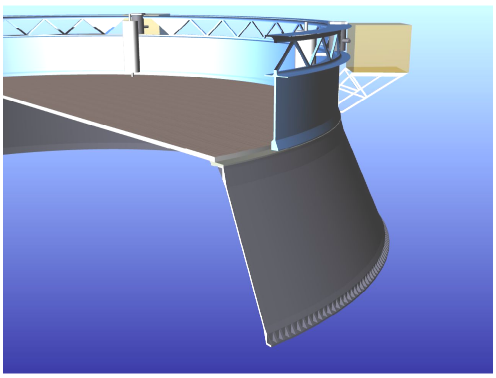

FIG 4. Previous experiences based design concept

The concept based on a detachable cylinder with variable thickness of the body, rings at different levels, upper ring of variable thickness & width, slots and/holes on the body to distribute loads, It had to be discarded due that the level of overfluxes obtained was incompatible with the requirements. After some stochastic analysis for different designs with 100 shots each, was not possible to reach reasonable values of Mass/overfluxes. Values over 40% of overflux variation implied mass over of 200% of the specified one.

The reason of this lack was that the geometric constraints was very strong for this kind of design (height/ diameter relation less than 1/3), the upper ring design was not efficient due the distance between upper I/F points (>2.5 mts), alike designs are not importable due that the geometrical relations are very different (Ø1666 versus Ø3340 in similar height), and the need to perform a detachable adaptor complicated the problem, due the impossibility to introduce holes in the lower one.

A different approach should be made after a process of convergence. In a first step, overfluxes, stress, and strength should be studied separately, in order to focus each particular requirement without disturbance. First of all was to perform a theoretical study for understand the overfluxes distribution map in thin plate (fig 5), cylindrical (fig 6) and conical (fig 7) hollered structures.

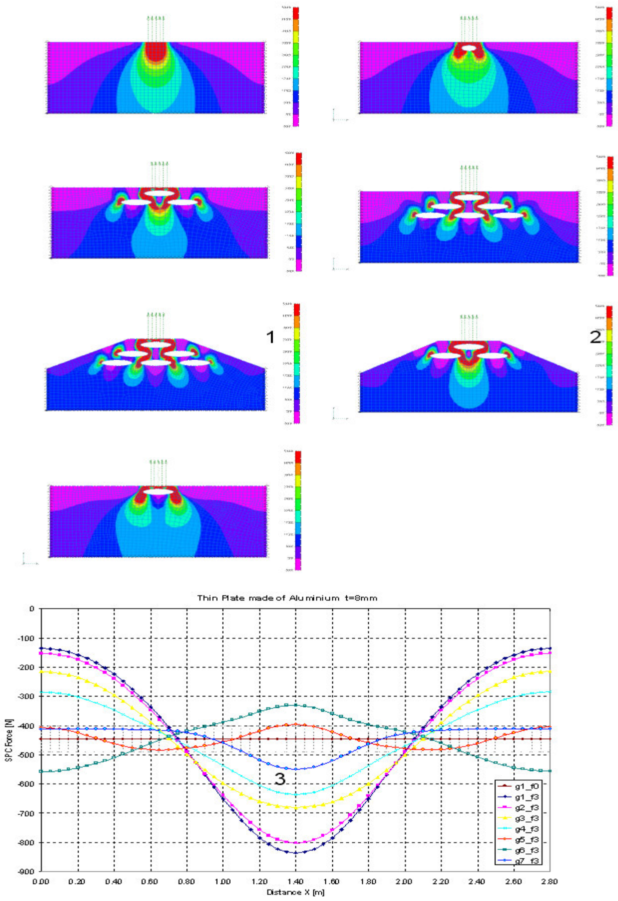

FIG 5. Preliminary analysis trade-off

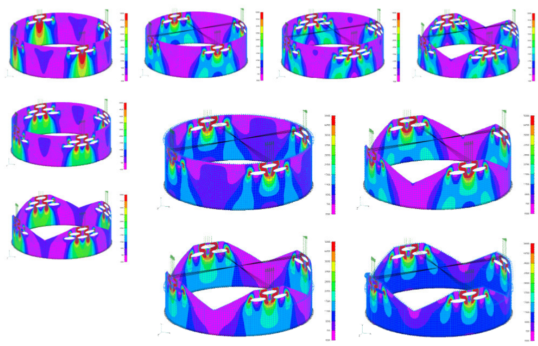

FIG 6. Cylindrical shapes analysis trade-off

The main conclusions were:

- A conical shape is more efficient than a cylindrical one in terms of overfluxes and stiffness.
- 2 lines of holes seem the best solution to spread the 4 punctual loading, but it produces stiffness poor results.
- A high torsional inertia is required at the upper and lower interfaces of the upper part.
- Dimensioning driving parameters are mass, stiffness and overfluxes.

The current overfluxes specification seemed very strong for the topology of the problem, and the mass requirement was also very exigent considering the general dimensions, and knowing previous values of existing adaptors.
A new loop a calculations, using stochastic analysis, once more was necessary to perform. Also a study the robustness of the design should be contemplated.

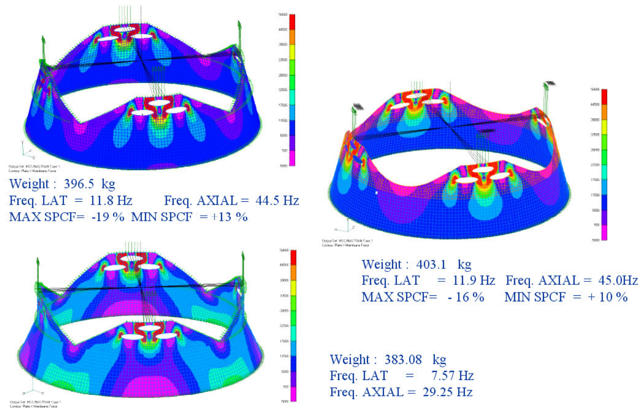

FIG 6. Conical shapes analysis trade-off

Three different configurations of the JWST payload adaptor were evaluated (Fig.7):

- CFRP: cone-cone configuration
- Aluminium: cone-cone configuration
- Aluminium: cone-cylinder configuration

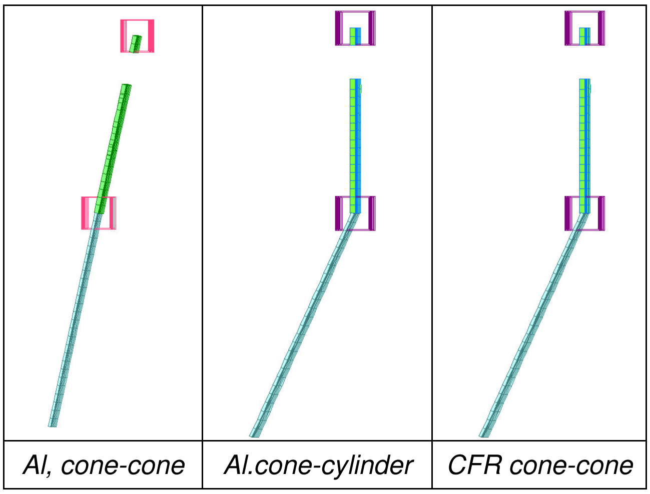

FIG 7. JWST P/L adapter configurations by parts

For each configuration a stochastic simulation has been performed using the ST-ORM stochastic code, executing simultaneously MSC.Nastran SOL 103 and SOL 101.
The objectives of the study have been to compare the three configurations in terms of robustness and complexity and verify mass, stiffness and fluxes at lower adaptor interface, selecting the most acceptable compromise.

4. ANALYSIS STUDIES

The study has been performed according to the following logic:

- Establish a configuration (e.g. Composite, AL, etc.).
- Perform a Monte Carlo Simulation, varying randomly a set of selected design variables. This is done using ST-ORM, a stochastic tool developed by EADS CASA Espacio
- Process the results using OntoSpace™, a complexity management tool developed and marketed by Ontonix S.R.L.
- Repeat for all configurations.

When the above steps have been completed for all the desired configurations, one may proceed to compare them, with focus on complexity and robustness.

The simulations were performed with 11 inputs variables and 6 outputs: weight, maximum interface flux (MAX), minimum interface flux (MIN), Lateral frequency (LAT), torsional frequency (TOR) and axial frequency (AX).

Each design exhibit different behaviour because it is located in a different portion of the Fitness Landscape. This leads to different behavioural modes. OntoSpace™ determines all the possible modes given a certain Fitness Landscape.

Which mode is best? To answer this question it is necessary to resort to complexity.

- Excessive complexity of a given design is known to be source of fragility.

- The following equation, established by Ontonix S.R.L, reflects the relationship between complexity & fragility:

$$\mathbf{C * U = F = 1/R}$$

(where C – complexity, U – uncertainty, F – fragility and R – robustness.)

- In order to guarantee acceptable levels of robustness (i.e. of fragility) in a given uncertain environment, it is paramount to keep complexity under control. In order to do this, we must be able to measure complexity.
- It two or more design options offer similar performance in the same (uncertain) environment, then the least-complex option should be selected as it will result to be less fragile (less problematic). The concept is illustrated in the following slide, where three generic configurations are indicated.

For the three candidate design options selected a stochastic simulation is performed. For each option, must be identified a design (set of input parameters) which satisfies the constraints and objectives. This is performed using the Navigation Table in OntoSpace™ (Fig 8).

- The performance objectives were at this case:

– Interface fluxes: 277 N +/- 20%, i.e. (221; 332)
– Axial frequency: > 47 Hz
– Lateral frequency: > 10 Hz
– Mass: < 350 kg

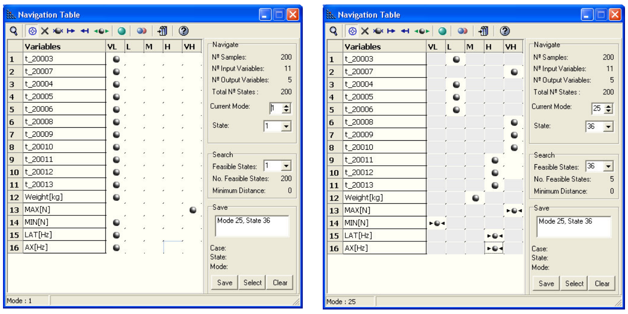

FIG 8. OntoSpace™ Navigation Table

In the sequel, each design configuration has been analyzed, and the basic output-output relationships, provide interesting information of the problem topology.

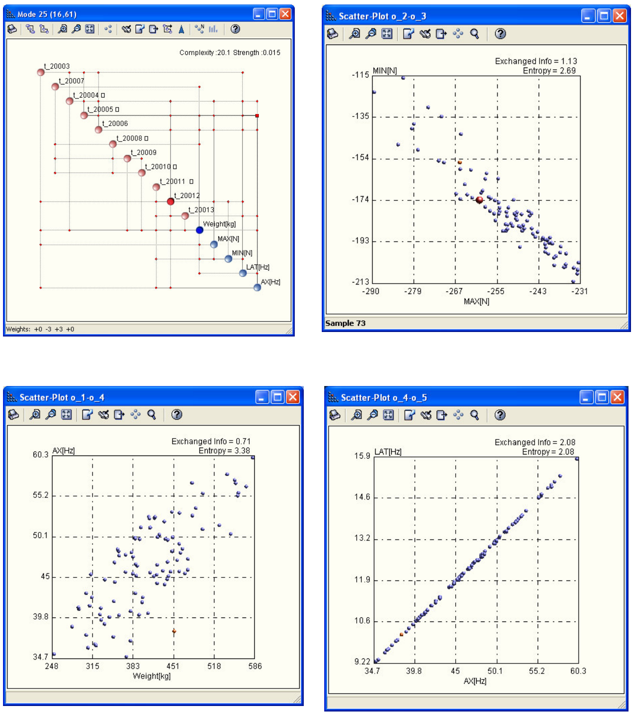

FIG 9. OntoSpace™ Modes Table & Decision maps

Analysing the decision maps (Fig 9), one observes that, with differences among the different configurations, some clarifier conclusions could be extracted:

- The fluxes are strongly correlated:
  when MAX increases, MIN decreases
- Strong correlation between Weight and AX frequency both increase or decrease
- The AX and LAT freq. are also strongly correlated both increase or decrease
- When MAX increases, AX decreases
  the relationship is also strongly correlated
- The Weight is not related to any of the fluxes.

The above statements imply that they are outputs strongly correlated, with all correlations having a linear tendency. This means that all outputs are dependent and changing any one will invariably change all the others. It is therefore necessary to resort to compromises.

The fluxes are not related to any the other variables. The weight is related to both the frequencies and these, in turn, are very strongly related. Essentially, there exist in this design option two separate groups of outputs.

Working with the Table of Modes and the Navigation Table we can identify the feasible solutions and to define our compromise objectives:

- None of the solutions in aluminium satisfy the performance objective and constraints. However, the cone-cone solution is substantially better than the cone-cylinder one. At least in terms of satisfying flux constraints.
- The CFRP solution provides the best alternative for the JWST payload adaptor, but for manufacturing reasons the upper cone must be performed in aluminium alloy.
- In the given Fitness Landscape two candidate solutions have been established – mode 25 and 42. Mode 42 results less complex (by approximately 20%) and therefore it is taken as the baseline design. Body text, body text.

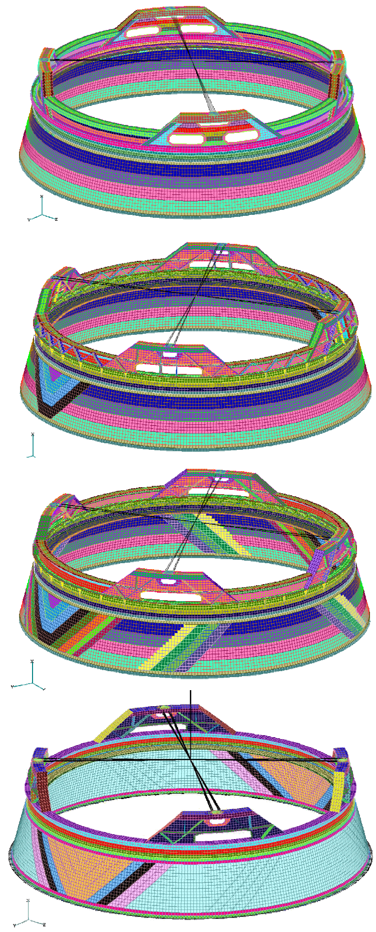

FIG 10. JWST P/L adapter structure final trade-off

To accomplish the overflux requirements has been necessary to define a particular topology of the adaptors with horizontal slots. The position and size of this hole was demonstrated quiet sensible for the final result.
The over thickness in some areas of the lower cone is necessary to homogenize the overfluxes at lower interface level.
A final loop of calculation to assure the best structure global performance, emphasizing the best overfluxes behaviour, varying stiffness, shape and number of holes in the handles (Fig 10) was performed to fix the most balanced compromise solution.

The final design (Fig 11 & 12) was based in:

- Upper Adapter, a cone made in aluminium alloy, supporting the I/F with the P/L
- Lower Adapter, a cone completely CFRP made with variable thickness to assure the overflux distribution, to I/F with the launcher

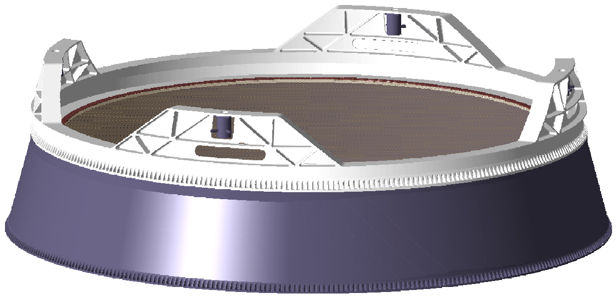

FIG 11. JWST P/L adapter final design

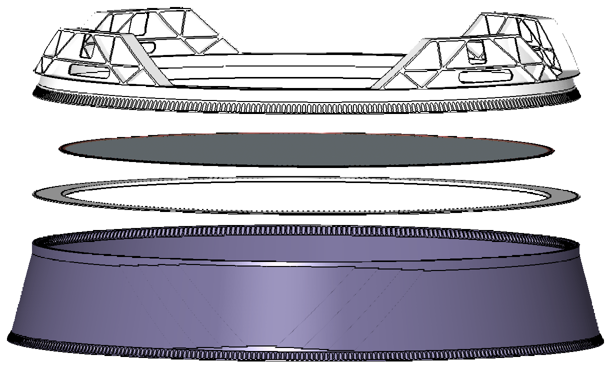

FIG 12. JWST P/L adapter exploded view

5. CONCLUSIONS

Independently of the conclusions related with the final proposed design aspects, from the analysis point of view the use of stochastic analysis and robust management seems a good approach, to assure the performances of the design, due that the conventional system design constraint a lot the knowledge and possibilities of the design.

Summarizing we can state that the use of stochastic analysis is valid to:

- Establish performance objectives and constraints
- Optimise the design so as to satisfy the objectives
- Perform a robustness study in order to evaluate how the system performs in the presence of environment uncertainties and manufacturing tolerances.

And the Robust & Uncertainty management approach to:

- Randomly sample all the variables of a given problem using Monte Carlo Simulation (MCS) to yield the Fitness Landscape of the system.
- Process the Fitness Landscape using a complexity management tool.
- Establish performance objectives and constraints providing a set of alternative designs, together with a measure of complexity for each alternative.
- To choose the least complex design among the alternatives as it is intrinsically the most robust one.

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