

Non Linear Finite Element Verification Approach for Marman Fitting in Space AIT Operations

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ABSTRACT

The marman interface is widely used in space applications to fit the spacecrafts to the launch vehicle and it is the same interface that allows the integration, test and transport of the satellites (AIT). It is usually designed for launch loads with related flight design safety factors and margins, but this is not always compatible with the handling and transport environment. In particular some criticalities are evidenced during the transport of satellites, where they are mounted in the container in horizontal position therefore subjected to bending loads due to gravity and transport dynamic loads.

The study deals with a finite element analysis approach in the calculation and verification of marman clamp bands used for spacecraft AIT operations.

The paper describes the details of modeling of the clamp band parts, the involved spacecraft launch vehicle interface ring and the MGSE interface. All these parts are in contact and this configuration has been modeled adopting the most recent non linear contact analysis techniques.

It is highlighted that the elastic behavior of the parts in contact are determinant for the definition of the limit loads that can be sustained by the structural parts with enough safety margin, evidencing also the limitations of the simple geometric-analytic approach based only on trigonometric formulations with the hypothesis of high stiffness of the interface parts.

Different configurations are investigated in order to determine the contribution to the load sustainability of each involved part structural performance.

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INTRODUCTION

The marman interface has been adopted as launch rockets interface for satellite payloads since the beginning of space business for the reason that it is easy to fit, fast and reliable to separate by automatic device. Their geometric shape and inertial section characteristics have been optimized for this purpose by the launch systems companies. In their user manuals there are different versions of marman interface to be chosen in function of payload mass characteristics.

Marman fitting design in space launch application, as well described by Lazansky in [4], is commonly focused on the following points:

1. Structural fitting of the payload (satellites in our case) loaded by accelerations and vibrations induced by all the launch phases.
2. Satellite release by a command signal given by on board computer, minimization of dynamic shocks is strictly requested. Free debris to be avoided.
3. Compliance to several space standard requirements in terms of mass minimization, functional performance in thermal vacuum environment, load factors, safety, contact materials, etc.

This kind of clamp band are usually fit between launch vehicle adapter and satellite during validation test campaign in a separation shock simulation and few days before in the launch

site facility. During all the remaining time of satellite assembly, integration and testing a ground marman clamp band is used instead. This paper is focused on the 1194VS that is one of the most used interface for commercial satellites.

In [appendix](#) detailed information about 1194VS marman fitting profile and flight clamp band is shown.

MARMAN CLAMP BANDS FOR GROUND OPERATIONS

Clamp band used for satellite handling, ground testing and transport is different from the flight one because:

1. It does not have to guarantee an automatic separation.
2. It shall guarantee interface fitting during all ground operations until the satellite is fit to the launch vehicle, including handling, transport and environmental testing. This phase can have a duration of several months for each satellite unit.
3. It shall be reusable, as a standard industrial equipment, for a minimum lifetime of 10 years.
4. It shall respect satellite ground operations standards and industrial safety standards, certifications and norms; this mainly means higher load safety factors.
5. The cost of ground clamp band shall be strongly minimized, in line with MGSE budget.

Remark: In point 4 an unsafe flight hardware condition could result from combining materials of different stiffness due to the respect of different safety factors: clamping a flight interface flange with safety factor 1.4 (flight standard) using a tool that has to respect a safety factor of 3 (ground standard).

In [figures 1, 2, 3, 4](#) some example of ground clamp bands and applications are shown. They are mainly composed by:

Band: marthensitic stainless steel belt (cold forming and subsequent heat treatments to increase resistance by marthensitic transformation). Low friction treatment in the internal surface. Thickness: 3 to 5 mm, height: 60 to 80 mm

V-clamp brackets: Aluminum Alloy 7075 T651 machined blocks, low friction surface coating. Circular Extension: 18° to 29°.

Tensioning blocks: machined marthensitic stainless steel. They are connected to the band by means of shear pins.

Tensioning bolt: M16 or M20 thread pitch 1.5mm, resistance class 10.9 (typical), standard corrosion free surface treatment (compatible with clean rooms and thermal vacuum environmental requirements). Tensioning load: 45 to 90 kN. In [figures 1, 2, 3](#) some images of ground clamp bands and their details are shown.



Figure 1. Ground marman clamp band



Figure 2. Tensioning process (use of load cells)



Figure 3. clamp band compact tensioning joint

Marman Fitting Last Proof Test

Some anomalies have been measured last September using photogrammetry technique during the acceptance testing of a vibration test adapter MGSE, in a configuration where marman fitting was represented. See [figures 4](#) and [5](#).

The test was performed on both horizontal axes, some differences and non linearity's were noticed in the displacement behavior between the two bending axes and a certain oval distortion, even if it was within the requested tolerances and elastic behavior. In any case the test measurements were not sufficient to evaluate the phenomena and further investigation was considered necessary.



Figure 4. Marman fitting testing with a mass dummy and bending load application - photogrammetry targets.

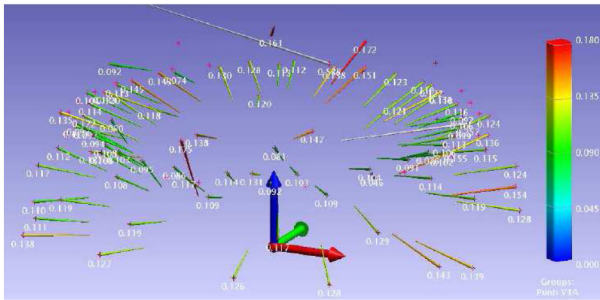


Figure 5. Photogrammetry measurements post-processing

Furthermore, during the preparation of this paper, some damages were detected by a supplier on the marman flanges during proof testing on dummies at 80 kN pretension, as shown in figure 6.

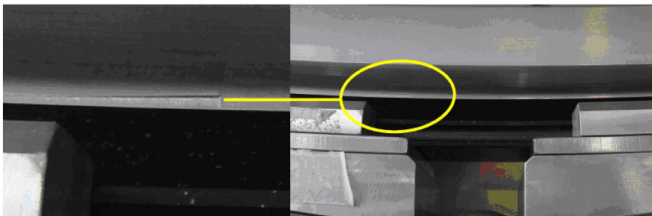


Figure 6. detected local plastic deformations

Marman Fitting Theoretical Formulations and Hypothesis

The best practice in the dimensioning of marman clamp band starts from some simple formulations by geometric considerations about the profiles shape, adding the contribution of friction effects for the determination of contact forces angle. This method is mainly referred to NASA guideline [2].

D_{cn} - Clamping contact diameter

R_b - band mean radius

F_t - band tangential load [N]

P - band bolts preload

q_{rr} - radial linear load [N/mm]

q_{ax} - axial linear load [N/mm] (i/f flow)

μ_b - band vs. v-bracket friction coefficient

μ_v - flanges - v-bracket friction coefficient

See figure 7 for geometrical profile data and forces explanation.

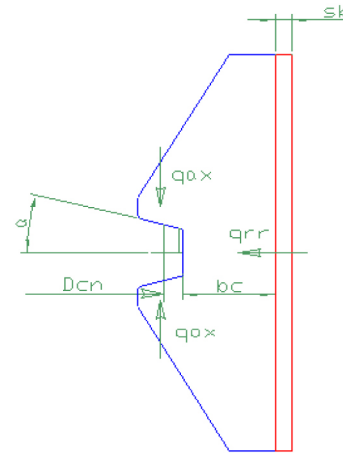


Figure 7. Typical clamp band section used for space AIT applications

Correlation between radial and axial linear loads, based on the hypothesis of a fully rigid behavior of the flanges and of the v-bracket, and of a load process that allows the friction working in favorable conditions:

$$\frac{q_{rr}}{q_{ax}} = \frac{2(tg\alpha - \mu_v)}{1 + \mu_v tg\alpha} \quad (1)$$

Correlation between band tangential load and radial linear load:

$$F_t = q_{rr} \cdot R_b \quad (2)$$

Where

$$R_b = \frac{D_{cn}}{2} + b_c + \frac{S_b}{2} \quad (3)$$

Correlation between minimum tangential load and band bolts preload for a 2 joints band:

$$P = F_t \exp(\mu_b \pi/2) \quad (4)$$

Demonstration of these formulations is omitted as not subject of this work, but it is simple to be obtained by trigonometric considerations on fitting profiles and band geometry along the circumference.

In [3] a detailed description of a trigonometric approach for the computation of v-band joint is well described, but in any case these methods are based on the following hypotheses:

- fully rigid behavior of the flanges and of the v-brackets assuming higher order buckling effects neglectable and a very good load path.
- Perfect load process that allows the friction between flanges and v-brackets working in favorable conditions.
- Linear behavior of friction between band and v-brackets along the circumference.
- High manufacturing accuracy of band, flanges and v-brackets contact profiles.

These assumptions can be acceptable for small diameters stiff flange profiles as we could see in many automotive applications, as described in [3], but for dimensions used in launch vehicle interfaces they need further investigations.

Satellite Interface Ground and Launch Loads

In the following [tables 1](#) and [2](#), the quasi-static accelerations induced to payload CoG are shown, in the different situations, during launch and during ground AIT operations (including assembly, integration and transport to the launch site).

Tab. 1. Arianespace Soyuz launch vehicle mechanical induced loads (complete version in [appendix](#)).

Load event		QSL (g) [+ = tension; - = compression]	
		Lateral	Longitudinal
0	Ground transportation on launch vehicle	± 0.3	min -1.3 max -0.7
1	Lift-off	±1.8	min -1.6 max -0.4
2	Flight with maximum dynamic pressure	±1.1	min -2.8 max -2.0
3	First stage flight with maximal acceleration	±0.9	min -5.0 max -3.6
4	Separation between 1 st and 2 nd stages	±1.1	min -4.3 max -0.6
5	Second stage flight	±1.2	min -4.0 max -0.6
6	Separation between 2 nd and 3 rd stages	±0.8	min -3.3 max +1.3
7	Beginning of 3 rd stage flight	±0.8	min -2.9 max +0.9
8	3 rd stage engine cutoff	±0.4	min -4.0 max +1.8

Tab. 2. Induced mechanical loads during handling and transport of satellites (as in [figure 8](#)).

OPERATION	fd Vertical	fd Lateral
Handling: (according to DR 15)		
Standing, on ground trolley ops.	1+/- 0.2 g	+/- 0.25 g
Hoisting	1+/- 0.2 g	+/- 0.25 g
Transport:		
Suspended/insulated HW	1+/- 2.0 g	+/- 1.5 g



Figure 8. Satellite installation in the shipping container

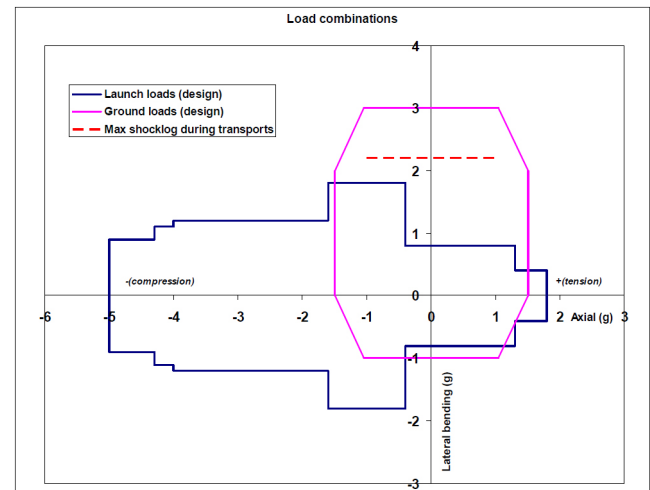


Figure 9. Load summary chart

I/F flow (q): it is the induced line load from bending and axial load combination distributed on the interface contact circumference. Bending moment (B_m) and axial load (F_a) are computed for a satellite of 2200 kg, cog at 1650 mm from the separation plane.

$$q = \frac{F_a}{\pi \cdot D_{cn}} + \frac{4B_m}{\pi \cdot D_{cn}^2} \quad (5)$$

Load combination expressed as I/F flow is shown in the following chart: [figure 10](#).

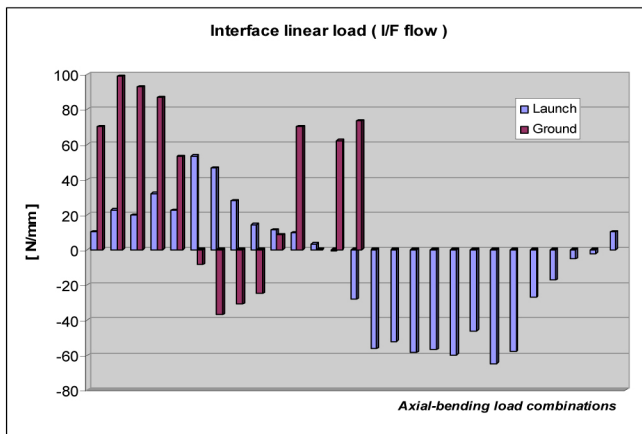


Figure 10. Interface line load (I/F flow)

The induced ground loads are more critical for the satellite structure for the following main reasons:

1. The high compression load during launch increase structural stability of the interface, and combination of tension-bending during launch phases does not induce high values of interface linear loads.
2. The axial loads during handling and transport are within the launch loads, but the bending loads are higher. This is due to the transport loads because the satellites usually are transported in horizontal position and fit by the only structural interface available for this situation, that is the marman interface.

The following sections describe the FE modeling and analysis results that investigate the highlighted points about theoretical hypotheses and ground operations overloads. This job is also to be intended in continuity to what still done for the design and verification of flight marman separation systems, described in [4].

Marman Fitting FE Model

A FE model has been developed in order to evaluate the marman fitting interface performance of existing clamp bands. For this purpose, it has been used MSC SimXpert® 2012 tool.

Dimensional data are an average among the most used 1194VS clamp bands for ground operations. In figure 11 the FE model of the clamp band is shown. In figures 12 and 13 the details of flanges modelling and in figure 14 the complete model are shown.

For each part, the cross section geometry has been imported, meshed and then extruded for the required extension to obtain CHEXA8 solid elements for V-clamp brackets and flanges, CQUAD4 shell elements for the band.

The different parts are modeled as separate deformable bodies, then touch contact parameters are defined in order to simulate the mutual frictional sliding. For parts modeled with

shell elements, thickness has been taken into account to define the contact deformable body.

Remark: tensioning blocks and bolts have been neglected, substituted by RBE and LBC respecting load eccentricity to obtain a not heavy model, because not relevant for the purpose of this analysis. In any case they can be included in a subsequent phase to evaluate design solutions for manufacturing.

Planar symmetry in the load application plane has been adopted to reduce dimensions. The model has been defined using millimetres scale, so the T-mm-N reference system have been adopted. Z axis is referred to vertical-up direction, corresponding to the satellite launch reference direction, x axis is referred as normal direction to symmetry plane (Y-Z plane).

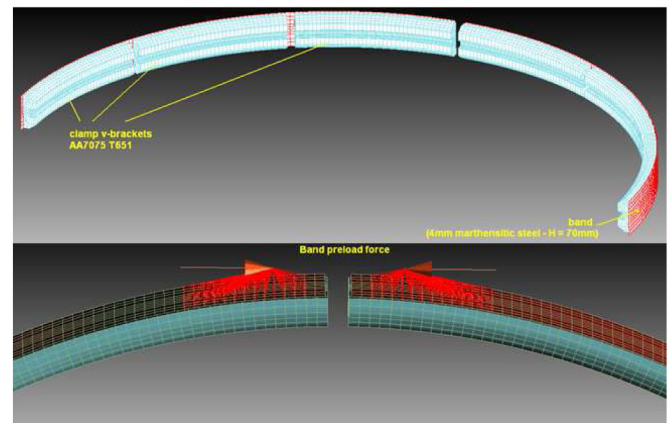


Figure 11. Marman clamp band modeling

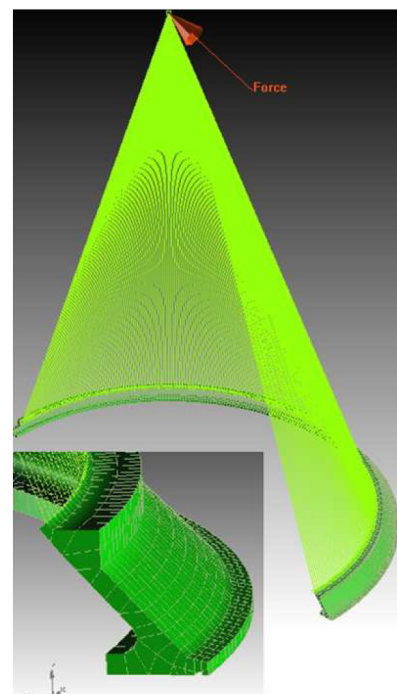


Figure 12. Satellite Launch Vehicle Interface SLV (material : AA7075 T651)

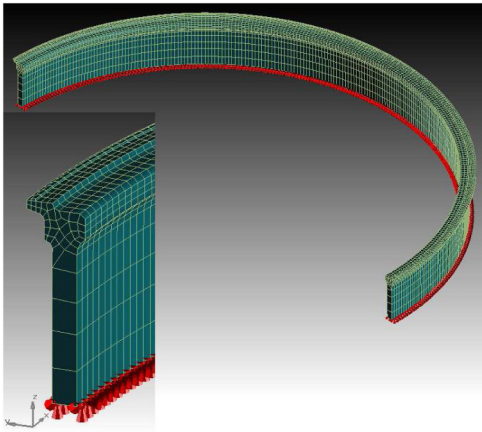


Figure 13. MGSE adapter SCA (material : AA7075 T651)

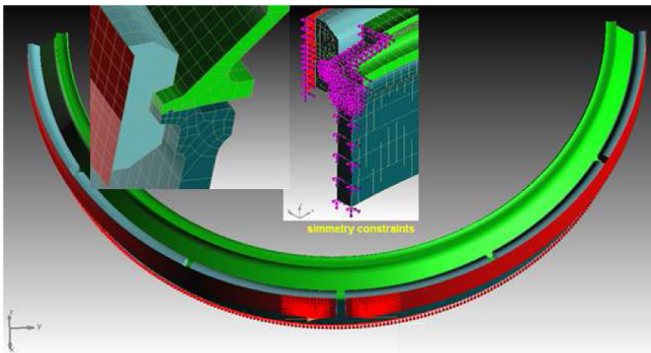


Figure 14. Complete contact assembly model

Applied pretension: $P = 53.2 \text{ kN}$

According to formulations (1), (2), (3), (4), the fitting would theoretically sustain a maximum interface flow of:

$$Q_{\max} = 251.5 \text{ N/mm}$$

The applied load force has been applied by the two components : axial and lateral at the given satellite cog, 1650 mm from the marman interface plane.

Satellite mass considered: 2200 kg.

Accelerations: 3g lateral combined with 1.1g lateral. Resultant interface flow: $Q_{\text{tot}} = 99 \text{ N/mm}$ (theoretical safety factor: 2.5).

The sliding contacts among the parts has been considered as the contact table resume (table 3).

Remark: a particular model refinement phase has been done in order to obtain the optimal contact distribution among the parts and minimize numerical spikes. This operation consisted in numerical calibration of contact tolerance and detection parameters.

Tab. 3. Contact data

	LVI	SCA	Band	Vclamp-1	Vclamp-2	Vclamp-3	Vclamp-4	Vclamp-5	Vclamp-6
LVI		T_1	-	T_2	T_2	T_2	T_2	T_2	T_2
SCA			-	T_2	T_2	T_2	T_2	T_2	T_2
Band				T_3	T_3	T_3	T_3	T_3	T_3

T_1 : Solid to solid touch sliding contact, $\mu = 0.15$

T_2 : Solid to solid touch sliding contact, $\mu = 0.12$

T_3 : Surface to solid, thickness included, touch sliding contact, $\mu = 0.1$

Non Linear Contact Static Analysis

FE analysis has been executed by MSC Nastran® 2012, Sol400 module for non linear static analysis, including touch sliding contact analysis behavior.

Hypothesis and limitations:

The analysis has been performed assuming the following main hypothesis:

Structural performance of the parts remains in linear elastic field

Pretension and loads are applied in quasi-static mode, dynamic or transient effects are considered negligible.

Geometry of deformable bodies are within the best practice usual manufacturing tolerances, and no stresses concentrations due to manufacturing mistakes are present.

The following non linear main steps have been configured:

STEP-1: $P = 6\%$

STEP-2: $P = 100\%$

STEP-3: $P = 100\%$, $F = 100\%$

Where P is the band pretension and F the resultant applied load at satellite CoG.

Each main step is subdivided in several analysis incremental sub-steps to guarantee non linear computation accuracy.