ABSTRACT
Micro-satellites concept requires various mechanisms optimized in cost and mass. To enhance number of parts reduction several functions are integrated in the same compliant device, CNES and 01dB-METRAVIB have developed a self actuating, guiding and locking hinge for space appendices deployment (antenna, mast, solar array, baffle, cover plate…). This flexible hinge named “Maeva” consists in a particular arrangement of three Carpentier curved elastic strips.

The present paper details results of a twos years R&T program ended last year also new 2009 developments. Research aim was to develop a numerical simulation tool in order to improve the prediction of appendices kinematics deployments with such a hinge.

Because of 3D non symmetric movement, breakthrough consists in performing a global model of the compliant 3D mechanism. The non-linear dynamic model is computed through the stand-alone non-linear FEA code, SAMCEF Mecano from SAMTECH. This approach takes into account the complexity of strips real deployment kinematics in full 3D. This enables to achieve most accurate motion prediction of the entire compliant mechanical system.

Micro-gravity tests have been performed during zero-g flights on a mock up of solar array. Comparisons between numerical simulation and experimental results confirmed validity of the presented methodology.

This paper will conclude with new possibilities offered by the tool and more precisely recent developments performed to define and qualify a lighter hinges intended for smaller deploy light appendices (m < 0.5 kg).

1. INTRODUCTION
The micro-satellites policy requests specific mechanisms design for optimum efficiency in cost and weight. Therefore combine multi integrated functions in a same device, based on reliable generic technologies approved, is the optimum strategy for long term performance are successful and reproducibility for several missions. Following this philosophy, CNES and 01dB-METRAVIB have developed and qualified a self actuating, guiding and locking hinge for appendices deployment [1], [2]. First real conditions application was DEMETER microsatellite program, launched in June 2004 [3]. Today, this flexible hinge named “Maeva” composes standard feature of Myriade satellite platform.

After presentation of hinges basic principle, the present paper details method and tool used to model 3D deployment kinematics. It shows progress in numerical simulations to improve the prediction of appendices deployments. Also comparison will me made with tests performed during zero-g flight on mock up of solar array.

Goal is to evaluate, with a high level of confidence, existing collision risk between appendices parts or satellite structure frame during deployment. If necessary, hinge physical parameters could be adjusted, as strips thicknesses, curvatures arrangement, number of hinges fixing the appendices…) to prevent from collisions and obtain compliant appendices deployments once in orbit.

These results are issued from a two-years R&T program ended early 2008 and new 2009 developments.

2. MAEVA HINGES BASIC PRINCIPLE
The concept used is an application of Carpentier Joint principle, which consists in an elastic steel or composite material strip with a curved cross section.
By reducing number of components, it avoids sliding / moving interfaces and combine guiding (anisotropic stiffness), actuating (spring effect) and locking device (high stiffness contrast due to post buckling behavior). In MAEVA design, specific arrangement of a three Carpentier strips (Fig. 1) module, were selected to provide a quasi centre - pin guiding behavior. Compared to a single Carpentier Joint, such a geometry provides high stability versus twist during opening, and increases both driving torque and stability after locking (holding torque and forces, and stiffness). Both size and relative position in the plane of strips mounting enhance adjustment for an optimized combination of flexibility and twist stability.

3. PROBLEMS OF MODELING

3.1. Limits of the model called "equivalent"

To obtain models for behavior kinematics deployment prediction, models called "equivalent" were developed by the past. The models are considered as "equivalent" to the extent that the general dynamic model includes a fictional representation of the hinge by a matrix of stiffness. Equivalent driving torque and selected modal basis are implemented in Multi Body Dynamics code to generate a global equivalent model. To determine stiffness matrix and the model behavior with respect to the complex Carpentier joints hinges, simplified assumptions based on experimental observations were needed. Despite acceptable results, simplified assumptions could be subject to discussion as directly involved in accuracy and so credibility of the model. To improve behavior representation of curved strip in the overall model, a non-linear code is used.

3.2. Method and tool for 3D non linear calculation

SAMCEF™ code is specifically designed to match those issues mixing dynamic analysis and nonlinear large rotations. Therefore it has been implemented to remove the limits described above. It is an implied general structure calculations based on the finite element method.

The solution SAMCEF Mecano, non-linear module of the range of solvers SAMCEF™ was developed in the late 1980s, with the aim of simulating the dynamic behavior of flexible mechanisms. The originality of this solution is to integrate a multi-body approach in a global non-linear solver. System components flexibility must be considered in the global structure dynamic model to evaluate behavior, and so determinate stress and strain for each component. Technical condensation in super-elements are available in SAMCEF™ to reduce computing time and can be integrated into the general model, mixing elements and flexible, rigid, super-elements, joints and kinematics (rigid or flexible, perfect or friction). However, proceed in this way performs providing condensed component maintains a linear behavior. In case of non-linear phenomenon (contact, plasticity ...), a flexible modeling component would be required.

The mixed approach mechanism / structure SAMCEF Mecano solver allows it, as demonstrated in this case, for a better understanding of dynamic behavior and deformable systems observing a non-linear and undergoing large rotation [4].

4. SOLAR PANEL DEPLOYMENT APPLICATION

4.1. Non linear dynamic model

The original methodology of FEA simulation has been implemented in the case of solar panels. Because of the 3D non symmetric movement, the breakthrough consists in performing a global model of 3D mechanisms made up of mixed models of components: the strips are modeled with shell non-linear geometric finite elements; the panels are modeled with Craig Bampton super-elements (modal basis) and some small other parts with rigid components (kinematical constraints). This non-linear dynamic model is then computed once through the stand-alone non-linear FEA code, SAMCEF Mecano. This approach takes into account the complexity of the strips real deployment kinematics that is fully 3D and cannot be described with simple revolute joint.
4.2. Deployment kinematics

As presented in Figure 2, the system (spatial hinge + appendix), during the deployment, oscillates around its equilibrium position before lock. Indeed, depending on the inertia of deployed appendix, several "locking / unlocking" of the hinge can occur, during deployment before stabilizing.

Figure 2. Deployment kinematics

4.3. Structures presentation: Solar Panel mock up

Below are presented the various assemblages (Figures No. 3, 4 and 5) models of studied solar generators. The models were designed to have equivalent representation in mass, inertia and elasticity of solar panels, while minimizing the effects of friction in the air, during the multiple tests in micro-gravity.

Figure 3. Deployment of one panel with one hinge

Figure 4. Deployment of one panel with two hinges in parallel

Figure 5. Deployment of two panels with two hinges in series

Micro-gravity tests have been performed during zero-g flights (Figure 6).

Figure 6. 0g flight: deployment of two panels with two hinges

The comparisons between numerical simulation and experiments are shown hereafter to illustrate the validity of the presented methodology.

Figure 7. Comparison for three deployments of one panel with one hinge

Curves show that calculation is a good evaluation of the real test. To obtain such a result, model needs to take in account the initial conditions. Here, it needs to introduce the residual micro-accelerations curves in each direction measured during the 0g flight.

Next figure presents very good correspondence between measurements and calculation, as the mounting device is
physically much more stable than the previous “one hinge” configuration.

**Figure 8. comparison for a deployment of one panel with two hinges in parallel**

Despite more unstable mounting than two previous configurations, next figure presents a good correspondence between measurement and calculation.

**Figure 9. comparison for a deployment of two panels with two hinges in series**

Calculation delays are directly linked to complexity and the physical stability of the structures to be deployed.

5. CONCLUSION

A numerical simulation tool in order to improve the prediction of appendices deployment kinematics with MAEVA hinge has been developed. This non-linear dynamic model, computed through the stand-alone non-linear FEA code, SAMCEF Mecano takes in consideration of real deployment strips kinematics in 3D environment.

Micro-gravity tests have been performed during zero-g flights on mock up of solar array representative in mass, inertia, centre of gravity and elasticity. Comparisons between numerical simulation and experimentations illustrate the validity of this methodology.

This shows motion prediction accuracy of entire compliant mechanical system and progress to get a better view of the reliability margins, when submitted to combinations of static and dynamic stresses. Moreover, it allows identifying and viewing of critical cases.

This new tool offers new possibilities for appendices deployment prediction with MAEVA hinges. Furthermore, it allows developing new hinges ranges, specifically designed to appendices dimensions. This new tool has been used by 01dB-METRAVIB to design new hinges for a light antenna (m < 0.5 kg) and to comfort technological choices for components and deployment mechanism (Figure 10).

**Figure 10. Development of a new hinge for antenna**

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