ANALYSIS OF A SATELLITE SOLAR ARRAY DEPLOYMENT BY MSC.ADAMS

Paper No. 2004-37

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ABSTRACT

IAI-MLM designs and manufactures solar panels. The present analysis was conducted within one of the current projects.

An array of two wings, each consisting of three panels, stowed around a hexagonal satellite, deployed by torsion and kick springs, is analyzed by MSC.ADAMS.

The analysis dealt with deployment sequence, speeds locking times and conditions as well as forces and moments developed due to the locking impacts.

The analysis has been carried out for different boundary conditions:

- Ground testing with and without gravitation relief device (zero g device).
- Deployment in space (without gravitation).
- Deployment in space with spinning increasing deployment energy.

Different deployment sequences and behavior have been found at each of those conditions, showing that only virtual analysis can simulate the real conditions existing in space without the influence of gravity or gravitation-relief device effects.

Special attention is given in the analysis to the prevention of contact during the deployment between the fragile solar cells and the satellite. A detailed locking mechanism dynamic is analyzed as well to ensure locking at the end of the deployment procedure.

Keywords: aerospace, MSC.ADAMS, satellite, solar-panels, deployment analysis

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INTROUCTION

Satellite solar arrays need to have minimal weight on one hand and a stiff structure with natural frequencies as high as possible at the deployed phase, on the other.
The presented solar system consists of two wings, each with three panels, stowed around a hexagonal satellite and deployed by torsion and kick springs. As the angle between two panels reaches the deployed state the hinge is locked by a locking mechanism. The deployment process goes on until the whole array is deployed.

Conventional deployment systems are usually kinematic. The displacements, speed and sequence are controlled and known a-priori (i.e. Ref. 1.) Unlike that concept, this system is dynamic. It is simple, small and low-weighted. However, the deployment principle is based on converting the spring potential energy into panel movement kinetic energy, which, on locking is absorbed by impact and panel oscillations. Designing such system demands the meeting of two contradicting requirements – enough energy to ensure the deployment (including factors of safety) and withstanding the impacts that arise as the movement is locked.

In addition, the deployment sequence and trajectory is not predetermined. It depends on the contact conditions between the satellite and the panel as well as panel relative energies and motions. Therefore it should be assured to have those contacts only where it has been designed for a-priory and avoid contact with sensitive components such as the fragile solar cells.

It should also be assured that the locking mechanisms do lock the panel movement and the impact and panel oscillations existing at that instant do not release the locking.

STRUCTURE AND MODEL DESCRIPTION

The structure at the deployed and stowed phases is described in Fig. 1. The panels are connected to one another and to the satellite by two hinges, each having a torsional spring and a locking mechanism. Kick springs connected to the satellite press the External panel edge and push it as the panel is released to deployment.

Since the deployment is planar, the analysis model can be reduced into an x-y planar problem, assuming infinite stiffness perpendicular to the x-y plane. A single hinge with a single torsion spring at the panel edge center, having double stiffness models the connection between adjacent panels (See Figs. 2 and 3.)

Fig. 3 describes in more details the typical connection between two adjacent panels. The satellite and the Root-panel are similarly connected with different spring parameters and deployment angles. For simplicity reasons, a spherical body represents the locking mechanism. It is connected to Panel 1 by the deployment torsional spring and by the Bistop that is activated as deployed condition achieved. Another torsional spring representing the panel flexibility connects the mechanism to Panel 2. All those components are coincident and located at the hinge.

The panel flexibility springs are matched to correlate the deployed array frequencies obtained by MSC.Nastran analysis (Ref. 2.) As mentioned above, the panel kinetic energy is converted into oscillations of the deployed array. The mechanism impact moment equilibrates the oscillations inertial loads. Those panel flexibility springs with stiffness of 1.65e5 N-m/d absorb the impact kinetic energy. This enables a better physical and practical representation of the system by allowing very high impact stiffness parameters (1.e10 N-m/d) for the Bistop, without harming the solution stability and convergence.

The Bistop activation condition shown in fig. 4 is not trivial. At the beginning it is deactivated. The activation is related to the angle between adjacent panels (or satellite and Root panel). In addition, it is conditioned that if once the Bistop is activated no deactivation is applied whatsoever, (even if the angle condition is not satisfied). The application is by an auxiliary recursive function MEA_2 initialized as 0, activated (MEA_2 = 1) as the angle measurement MEA_1>120° (for Root panel), but once reaching 1., its value does not change anymore. Multiplying MEA_2 by the Bistop determines the activation/deactivation condition.

ANALYSES AND DISCUSSIONS

The deployment simulations were carried out at three conditions:

- On ground test conditions while the satellite is fixed, with and without gravity relief (zero g) device.
- At space without gravity while the satellite is free and can move and rotate.
- In case of emergency due to malfunctioning, deployment with satellite spinning.

The MSC.ADAMS simulation followed a previous analysis carried out by MSC.Nastran nonlinear dynamic analysis with large displacement (Ref.3.), which provided similar results. Many aspects have been analyzed, evaluated and verified during the simulations. This presentation focuses mainly on several aspects where the MSC.ADAMS simulation and on-line animation capabilities enabled us to detect problems that led to design modifications.

Ground deployment - The deployment is sequential starting by the Ext. panel, while all the others are at rest, then the Mid. and finally the Root panel. . This actually happens during the ground tests, when the satellite is fixed to the ground.
High friction loads are developed in the hinges due to gravity loads and moments requiring very small time-steps in the simulations. Aerodynamic drag is taken in account as well by applying a force opposing the movement at the Ext. panel, proportional to the angular speed at the square power. Two arrays are simultaneously analyzed with and without the air-drag (Fig. 5,) resulting in deployment times 9.62 Sec. and 8.95 Sec. respectively.

An additional case taking into account the possibility of a broken root-spring (half stiffness and preload input) is analyzed simultaneously for two arrays with and without gravitation relief device (Fig. 6.) It has been found that the addition of the drag causes the deployment to stop at 66°, as observed in the ground test (Fig. 7,) whereas without it the deployment reaches its completion with all the hinges locked.

The gravity relief (zero g) device design and modeling is described in Fig. 8. It consists of a light framework mounted over the panels with correlating hinges, connected to the panels by wires and springs, having stiffness and preload calibrated to relieve the gravitation.

Deployment in space is shown in Fig. 9. The arrays are deployed in sequence, one after the other. The deployment time for one array is 5 sec, as found by Ref. 3. The deployment order is sequential, from the Ext. to the Root-panel. However, unlike the ground-test simulations, during the Ext. panel deployment, the hinge between the Root and the Mid. Panel is separated from the satellite and moves outwards. (See Fig. 9). This causes the Ext.-panel contact point to move from the hinge to the panel itself, where the fragile sensitive solar cells are installed. This phenomenon, caused by the satellite rotation equilibrating the momentum of the opening panels, becomes even more severe as the satellite rotation is increased, by spinning it up to 20 d/s and 60 d/s, in case of emergency. (See Fig. 10).

During the ground-test simulations and the ground-test itself the satellite is fixed. Therefore this phenomenon could not be observed in that condition. It has been detected only by this MSC.ADAMS analysis that simulates the conditions at space, together with on-line deployment animation.

This problem has been solved, by adding a delimiter to the Root-Mid.-panel hinge, which avoids negative angle movement above 2° (angle < -2 °). The 2° movement freedom is necessary in consideration of the production tolerances between the satellite and its panels. The delimiter is entered to the MSC.ADAMS model by a force and unidirectional contact condition. The simulation with the delimiter depicted in Fig. 11 (with 20 ° d/s spin), shows how that problem has been overcome.

Locking analysis of Root-mechanism – Fig. 12 shows several frames of Root-mechanism locking action from the stowed to the locked phase. The geometry has been imported as parasolid-structure created by the Unigraphics (UG) design program. The locker hinge and rotational spring were added in the MSC.ADAMS model and contact is determined between the cylinder and the Locker body. The deployed panel moment of inertia is simulated, by being input to the moving locker part.

This model still does not include the simulation of the array oscillations after locking. This has been done, by adding a link representing the deployed panel with the respective inertia and deployment spring. Several frames of the simulation are given in Fig. 13. It can be observed that the locker hitting the slot-cam at a flat angle may jump out. Deeper analysis shows that this behavior strongly depends on the impact energy and friction between the contact surfaces of these parts. This problem is not observed during the ground-tests however it indicates that panel-locking assurance is sensitive to slot shape, friction and other parameters. Therefore, thorough analysis and design of the locker and slot shape are required to assure that such problem will not occur.

CONCLUSIONS

Ground-testing simulations of solar arrays deployments, as well as other spacecraft components operating at a gravitational free environment are very difficult and not fully realistic. This is because any gravitation relief device is involved with side effects such as additional friction and inertia.

This presentation demonstrates how an analytic simulation can realistically simulate the space environment and help the designer to detect problems that were not previously observed during the ground-tests.

ACKNOWLDGEMENTS

The authors would like to acknowledge Mr. Daniele Catelani from MSC.software Italy, who greatly assisted us in our first steps of using MSC.ADAMS. Thanks to him we were able to complete those analyses on time.

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2. Natural frequencies and modes analysis for a deployed solar panel array by MSC.Nastran, IAI-MLM internal report, 2003.

3. Solar array deployment analysis by MSC.Nastran nonlinear large displacement dynamic analysis, IAI-MLM internal report, 2003.

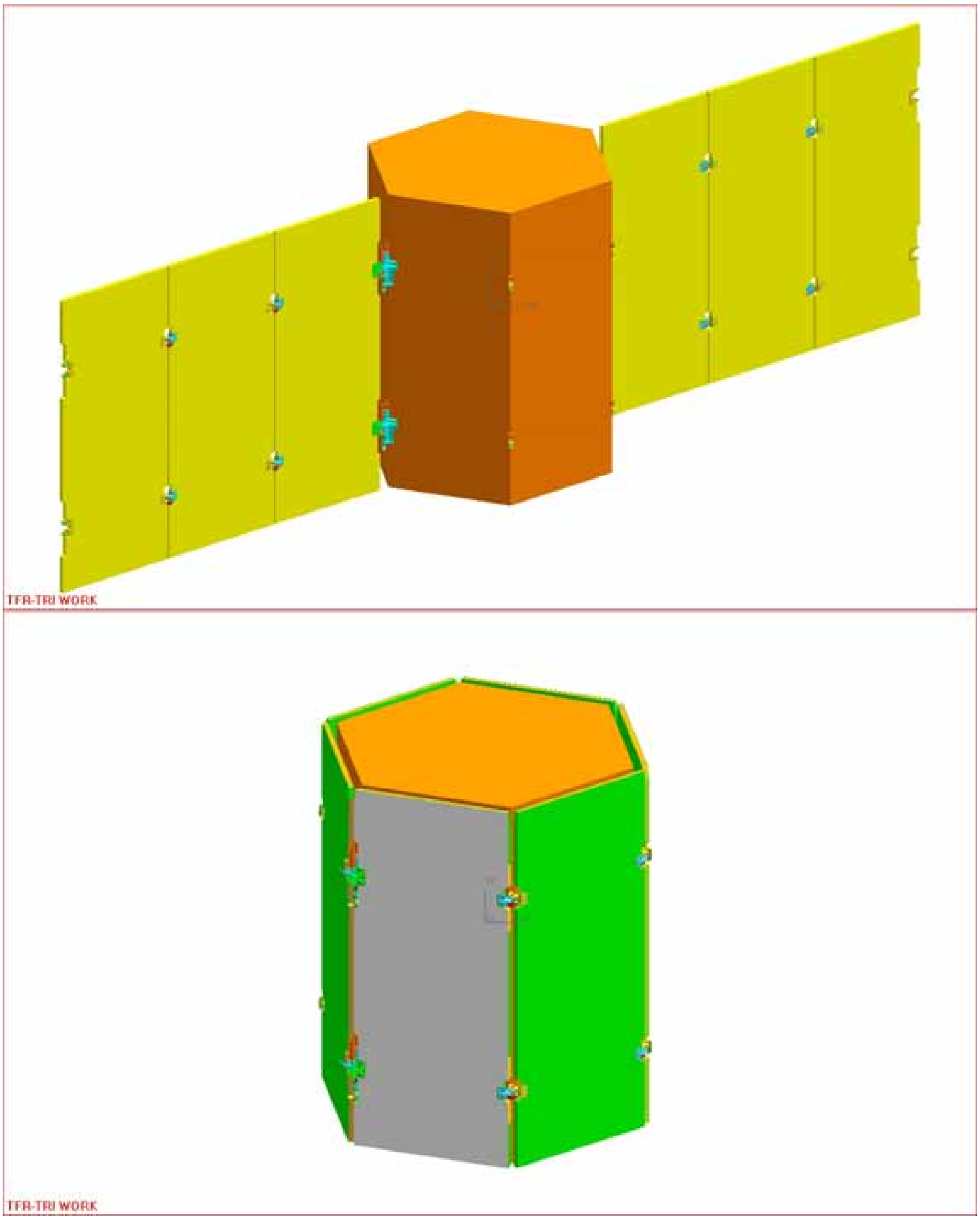


Fig. 1 – Designed solar arrays at stowed and deployed positions.

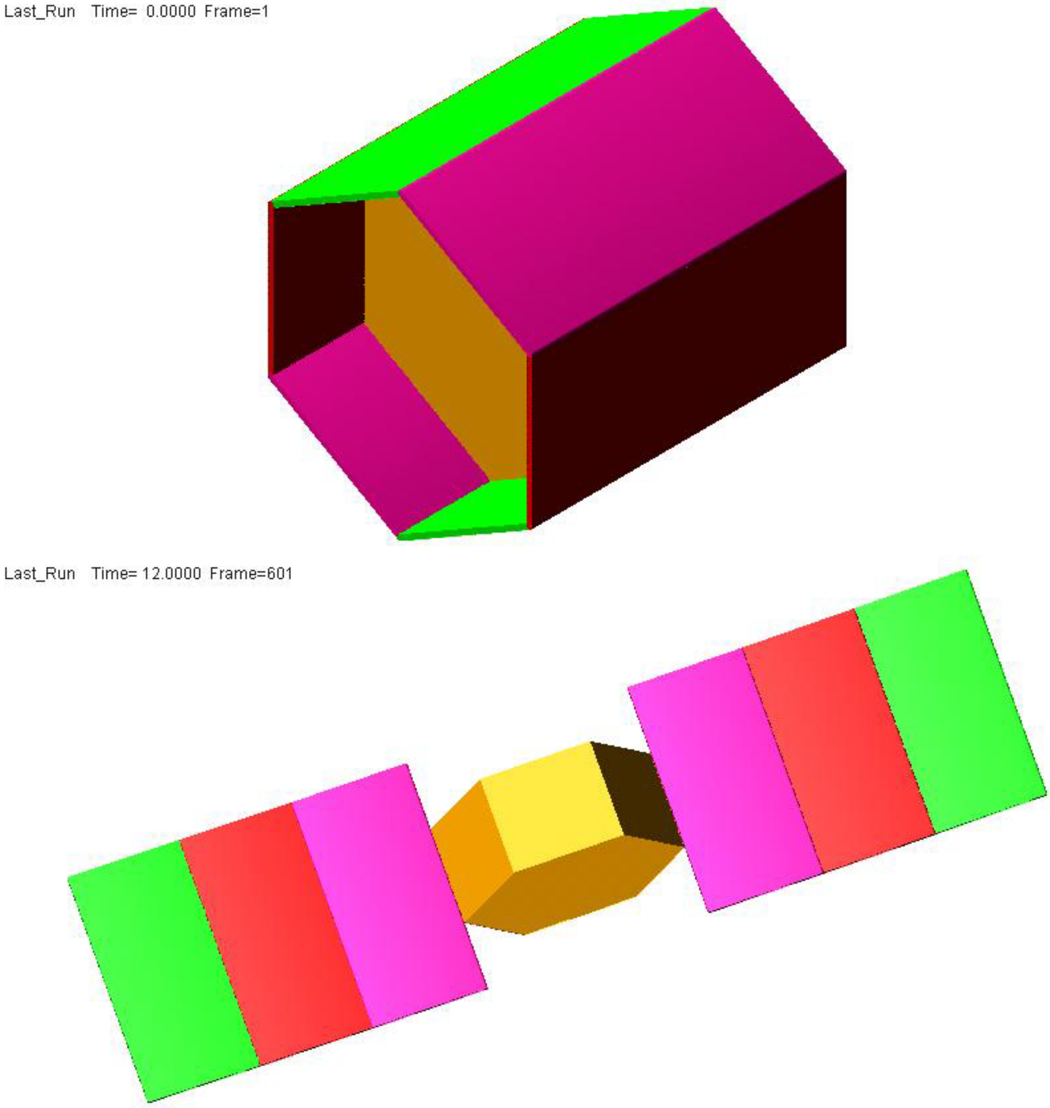


Fig. 2 – MSC.ADAMS model for solar arrays at stowed and deployed positions.
Hinges and springs connect the panel centers.

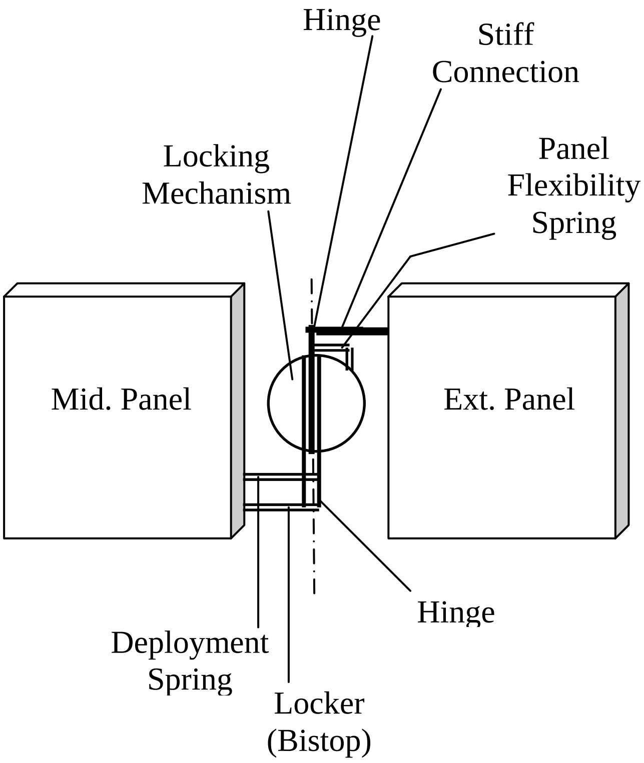
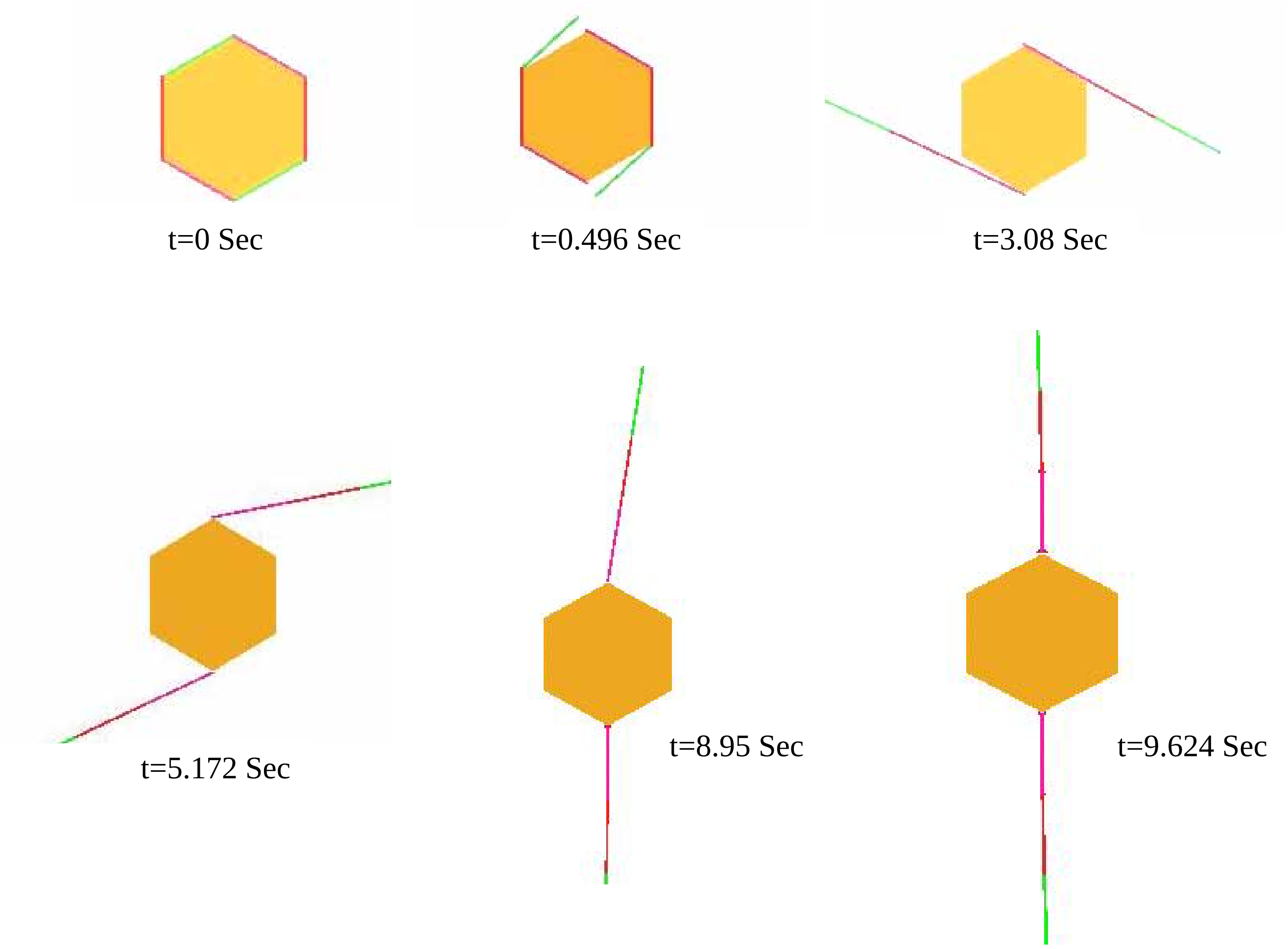


Fig. 3 – Schematic description of hinge and locker modeling between two panels

```
measure modify function&
 measure_name = .model_1.FUNCTION_MEA_1&
 function = "AZ( .model_1.PART_3.MARKER_2, .model_1.satelite.MARKER_1)*rtod"
!
measure_display create&
 mea_display = .model_1._model_1_FUNCTION_MEA_1_1&
 measure_name = .model_1.FUNCTION_MEA_1
!
measure modify function&
 measure_name = .model_1.FUNCTION_MEA_2&
 function = "IF((time-.1):0.,0., IF( (.model_1.FUNCTION_MEA_1-120) :
IF(.model_1.FUNCTION_MEA_2: 0.,0.,1.) , IF(.model_1.FUNCTION_MEA_2: 0.,0.,1.) , 1.))"
!
measure_display create&
 mea_display = .model_1.FUNCTION_MEA_2_display&
 measure_name = .model_1.FUNCTION_MEA_2
!
force modify direct single_component_force&
 single_component_force_name = .model_1.SFORCE_7&
 function = ".model_1.FUNCTION_MEA_2*BISTOP(
az(.model_1.PART_3.MARKER_2,.model_1.satelite.MARKER_1) ,
wz(.model_1.PART_3.MARKER_2,.model_1.satelite.MARKER_1,.model_1.satelite.MARKER_1),
.120  d , 120.01d , 1.e10 , 2.2 , 3500. , 1.d")
!
```

Fig. 4 – Bistop load and activation modeling


t=0 Sec

t=0.496 Sec

t=3.08 Sec

t=5.172 Sec

t=8.95 Sec

t=9.624 Sec

Fig. 5 – Ground test deployment with and without aerodynamic drag

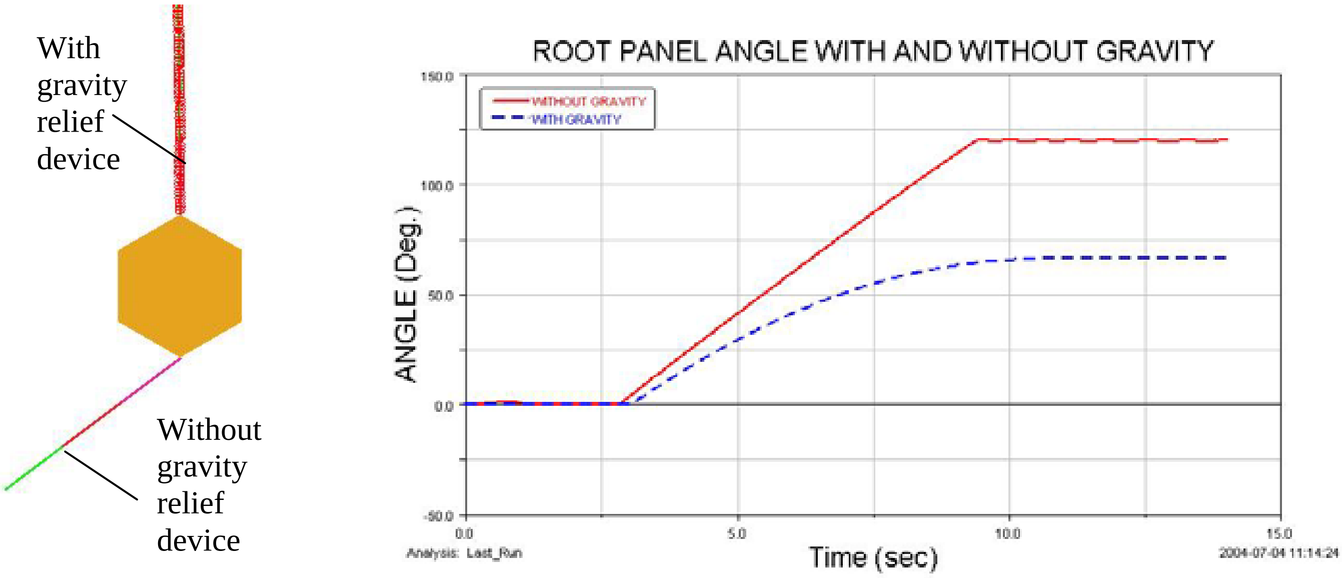
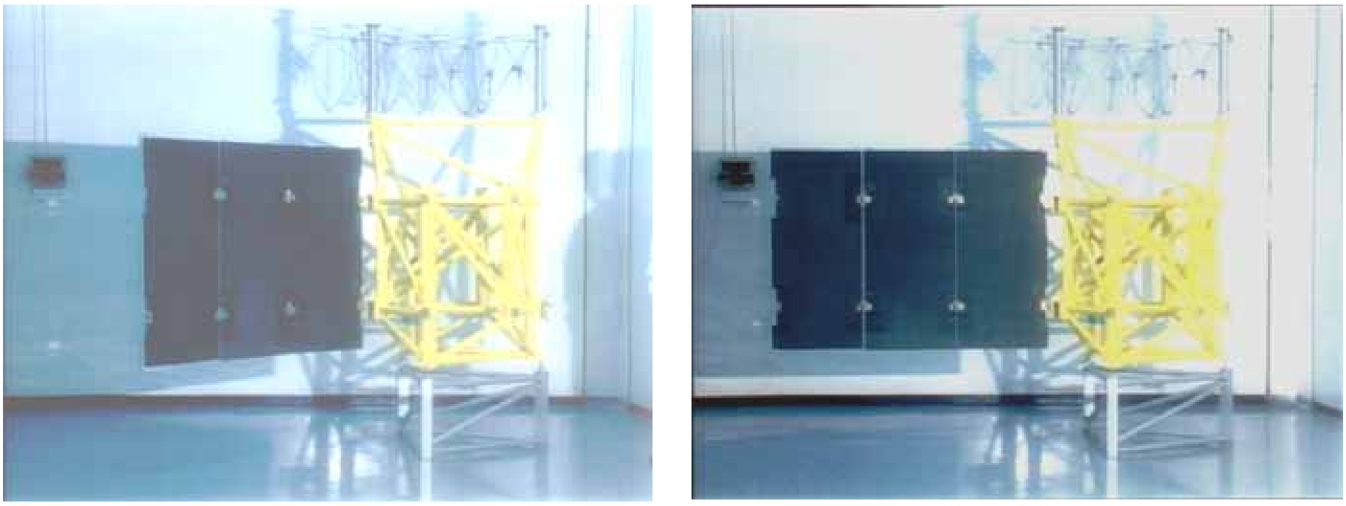


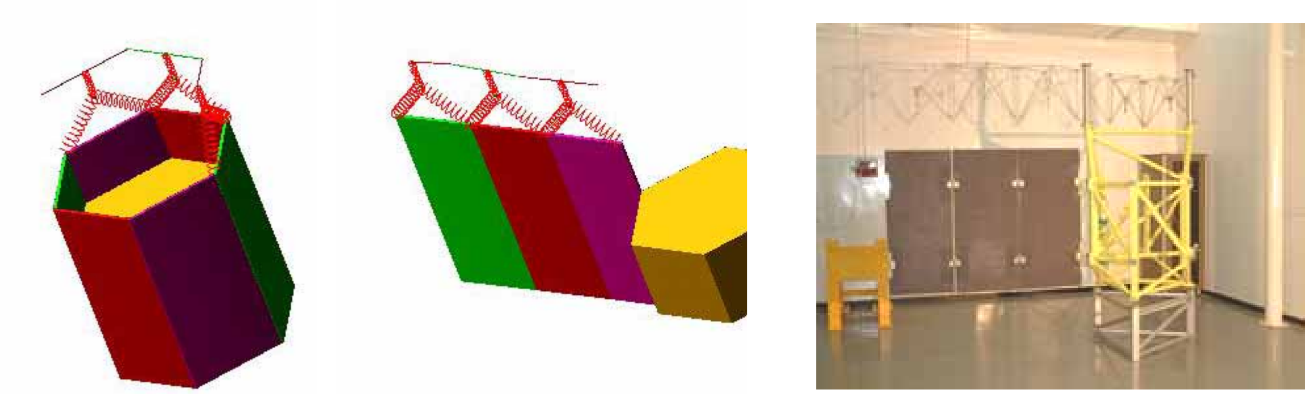
Fig. 6 – Ground test deployment with a single Root-panel spring, with and without gravity relief device



Deployment stopping position

Deployment final position

Fig. 7 – Ground test deployment with a single spring taken from a video photograph. The deployment without gravity relief device stops before the final position.



Initial position

Final position

Testing unit

Designed unit

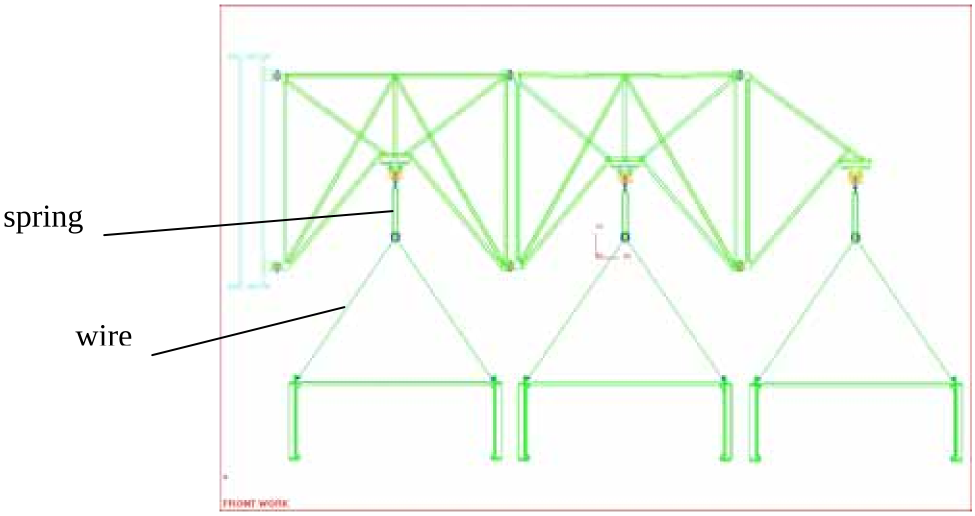
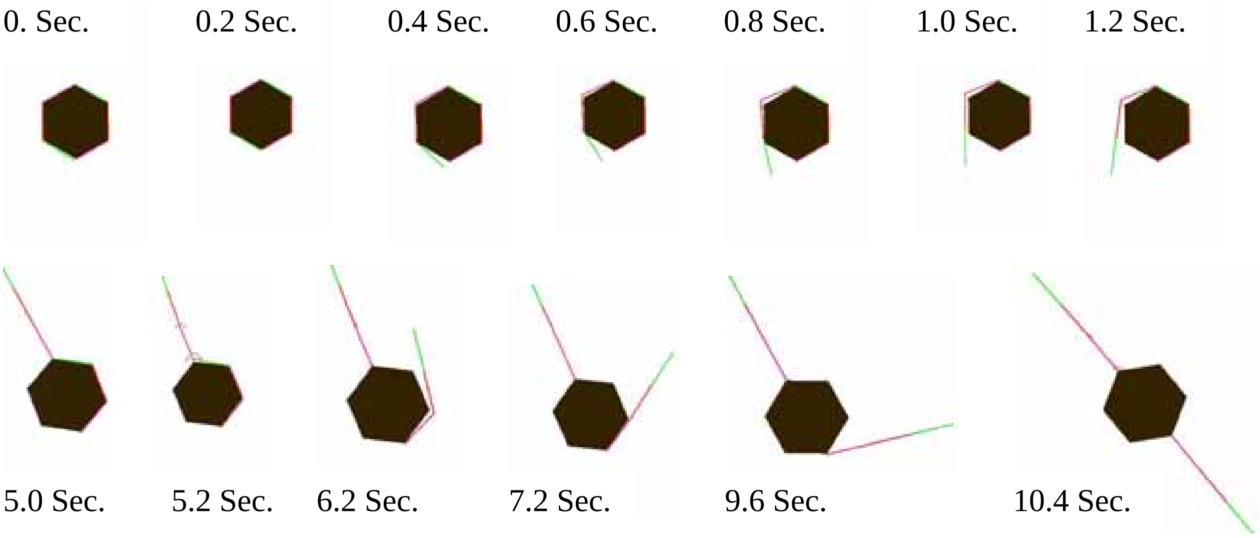
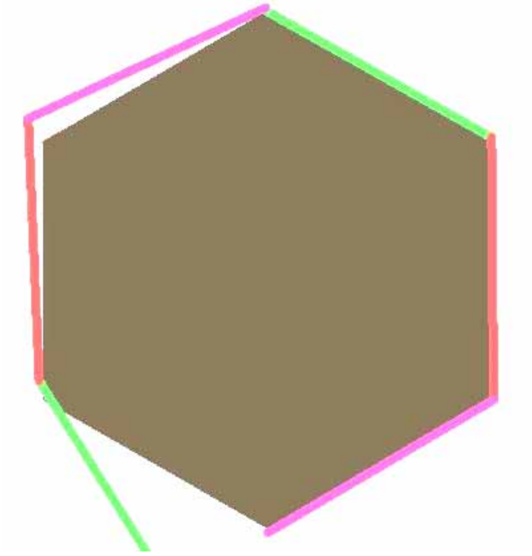


Fig. 8 - Gravity relief device at one panel – MSC.ADAMS model, designed and testing unit



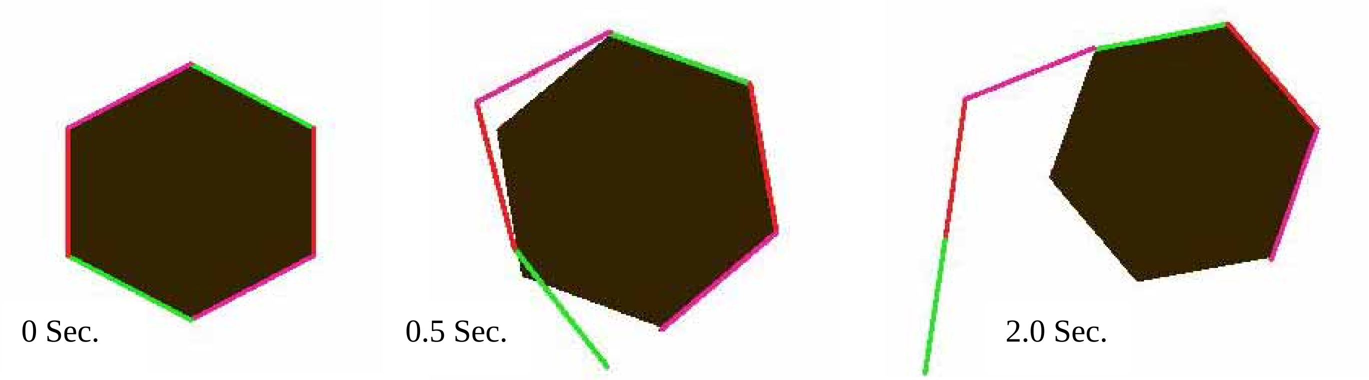
0. Sec. 0.2 Sec. 0.4 Sec. 0.6 Sec. 0.8 Sec. 1.0 Sec. 1.2 Sec.

5.0 Sec. 5.2 Sec. 6.2 Sec. 7.2 Sec. 9.6 Sec. 10.4 Sec.



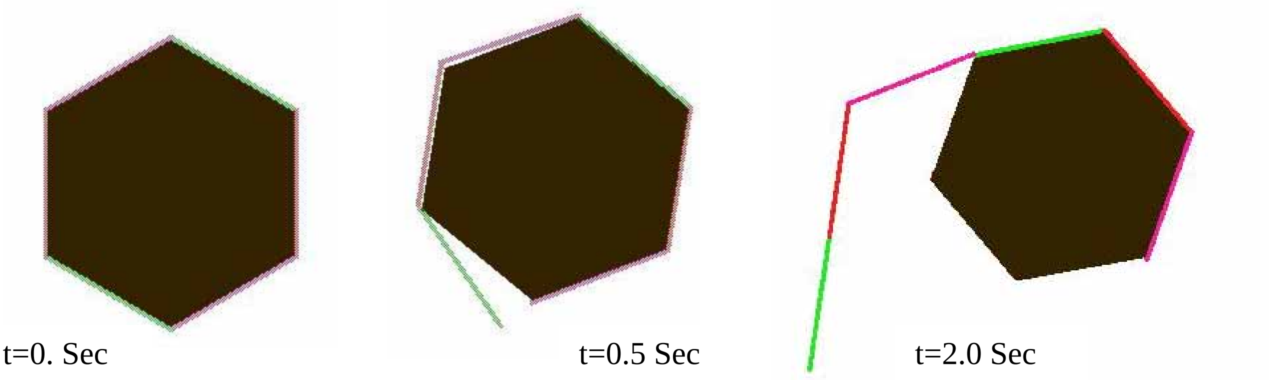
Detailed view at t=0.6 Sec.
Showing the interference between the panels and Satellite

Fig. 9 – Space deployment phases simulation.



0 Sec. 0.5 Sec. 2.0 Sec.

Fig. 10 –Deployment simulation in space with 20 d/s counter-clockwise spinning.



t=0. Sec t=0.5 Sec t=2.0 Sec

Fig 11 – Deployment after mechanism modification, illustrated for the case with 20° d/s spin.

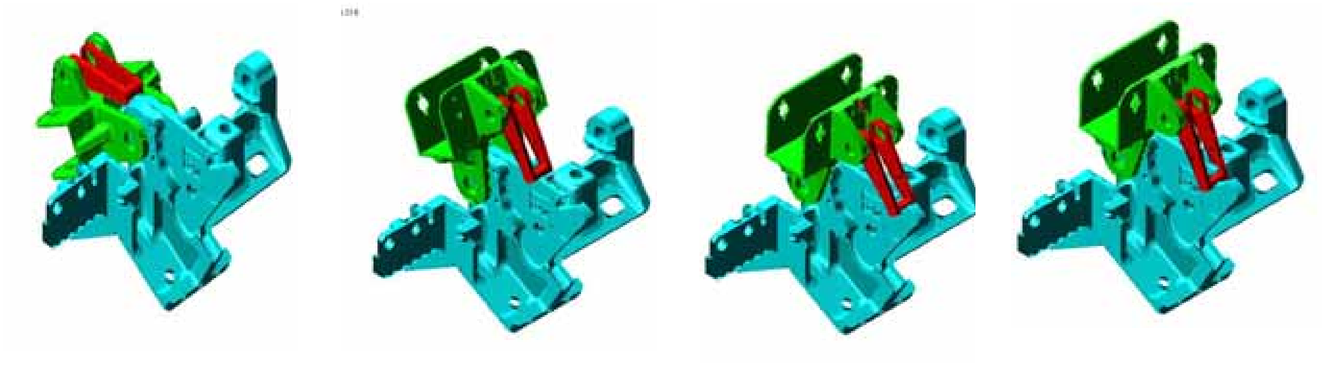


Fig. 1**2** - Root mechanism deployment without array flexibility

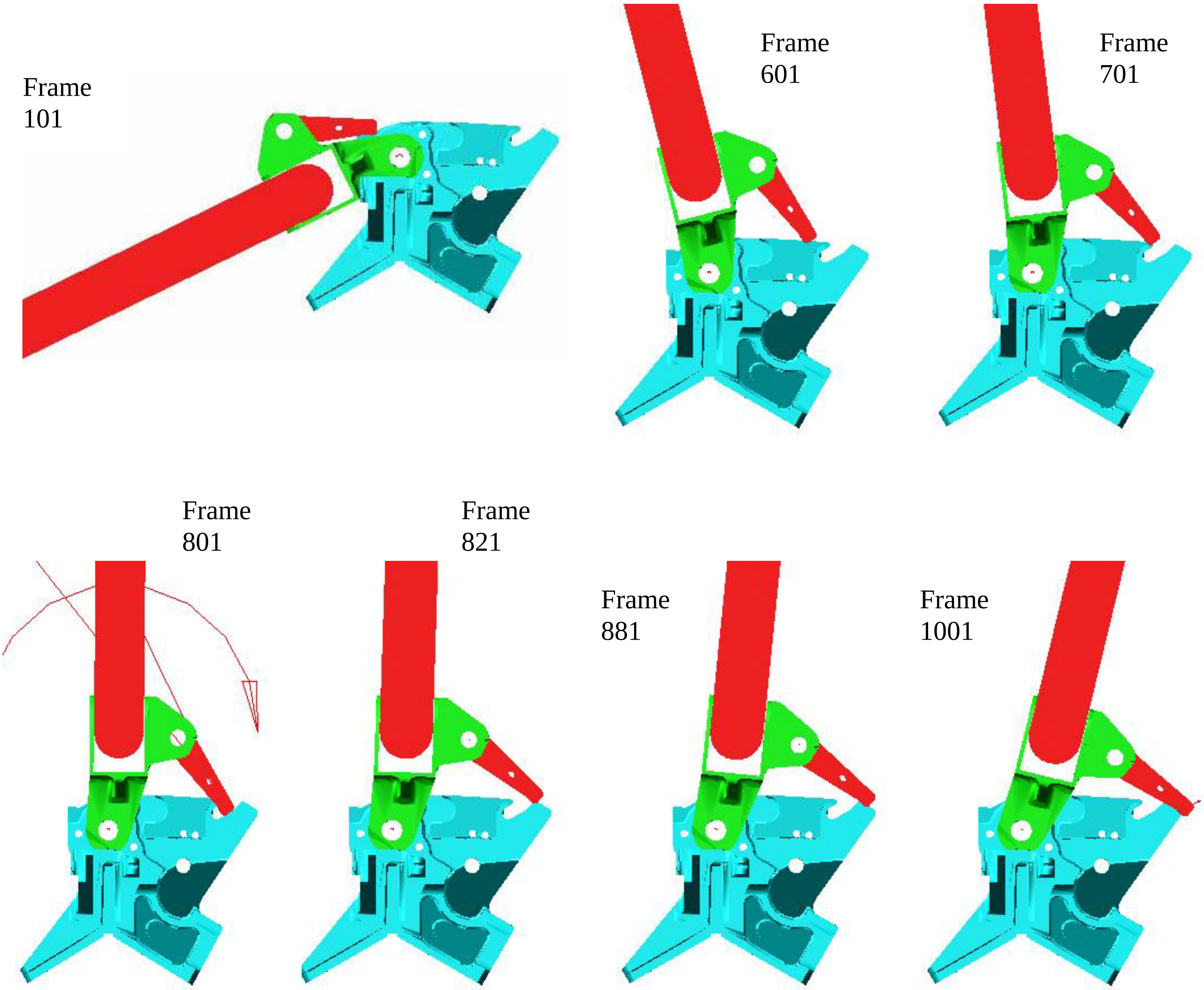


Fig. 13 – Root mechanism deployment with array flexibility.
Panel oscillations cause the locker to ricochet out.