DEPLOYMENT ANALYSIS OF SOLAR ARRAYS AND MODEL CORRELATION

A. CARPINE, G. LADUREE
Thales Alenia Space
Etablissement de Cannes
100, bd du Midi, BP 99
06156 Cannes la Bocca Cedex
France

OVERVIEW

The deployment of a satellite solar array represents a very critical phase in a satellite life. On one side, an incomplete deployment because of poor motorization can lead the mission lost; on the other side, a hard deployment dynamics because of too high motorization can lead to components damage and compromise the electrical power generation. Moreover, the deployment phase cannot be fully tested on ground, because of unrepresentative conditions. This explain why the predictions of solar array deployment behaviour are so important for solar array designers.

Since several years, THALES ALENIA SPACE use software tools, designed for multiple bodies kinematics study, to build dedicated deployment simulators and assist the development of new solar arrays concept. A home made software tool, James, is used since more than twenty years in this purpose, while a commercial tool, Adams, has been recently tested and adopted for the same kind of deployment analysis.

Thanks to this two tools, several deployment models have been built taking into account all the specificities of THALES ALENIA SPACE deployment design : panels synchronisation through stiff cables devices, deployment regulation by brushless motor, electrical cables torque, hinges motor torque and resistive behaviour ...

A very good flight correlation of our models built with the home made tool (James) has been obtained on several SPACEBUS satellites, with SOLARBUS solar arrays including four and six panels [1] [2]. The recently developed deployment simulator under Adams also gave a good correlation with flight data, on a SOLARBUS solar arrays including six panels. The correlation of this model on this rather complicated deployment (presence of two lateral panels) gave confidence to continue with the development of new design solar array. As the matter of fact, the capacity to perform accurate predictions gives us the capability to plan solar array with whatever architectures.

Therefore, a prediction model of a 7 panels solar array deployment has been developed, with the same modelling way of the six panels model. This 7 panels solar array is the first of the new THALES ALENIA SPACE solar array line based on a lightweight panel structure architecture. The predictions obtained thanks to this model have greatly helped the conception of this new generation solar array, allowing immediate dimensioning of the different components under the high loads generated by deployment dynamics and latching shocks, demonstrating the robustness of the new lateral deployment concept, and of the new transfer deployment phase with 3 panels.

1. DEPLOYEMENT OF SOLARBUS SOLAR ARRAYS

1.1. Presentation of the SOLARBUS solar arrays family

The SOLARBUS is a family of solar arrays developed by ALCATEL SPACE, which are all made with the same kind of panels and mechanisms. Those solar arrays can include from 3 to 7 panels, as shown in FIG 1.

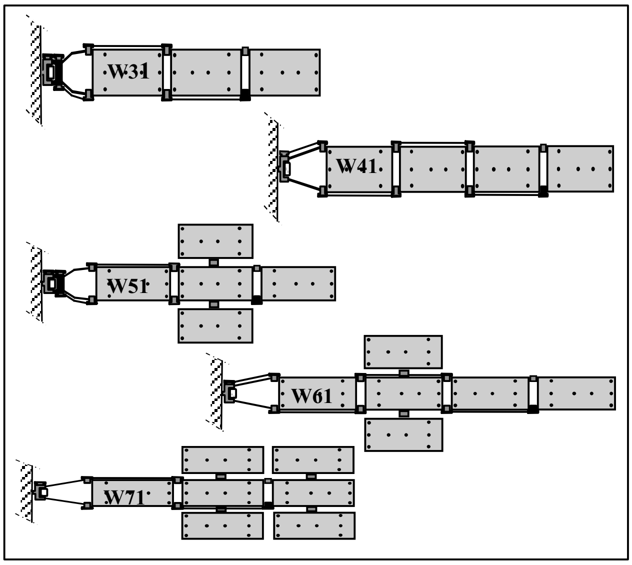

FIG 1. Different SOLARBUS Solar Arrays:
W31 with 3 in-line panels,
W41 with 4 in-line panels,
W51 with 3 in-line panels plus 2 lateral panels,
W61 with 4 in-line panels plus 2 lateral panels,
W71 with 3 in-line panels plus 4 lateral panels

The deployment of those solar arrays is done in the same way, including two different phases (FIG 2):

- **partial deployment** (also called transfer deployment):
  - deployment of the transfer panel(s): unregulated deployment of one panel (FIG 2) or three panels (FIG 3) in the W71 case
- **total deployment:**
  - deployment of the in line panels (central mast) : fully synchronized and regulated deployment
  - deployment of the lateral panels if any : unregulated deployments.

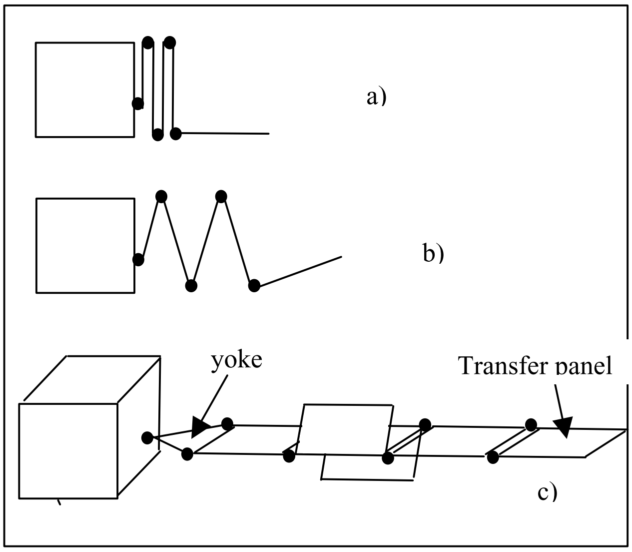

FIG 2. Deployment of a 6 panels SOLARBUS solar array
a) Partial deployment completed,
b) and c) total deployment

During the total deployment, the synchronization devices ensure a quite constant angle between the different panels of the central mast, except for satellite/yoke angle which remains twice smaller than the others (see FIG 2): the yoke rotation is 90° while the panels rotation is 180°.

Already twelve satellite with SOLARBUS solar array have been launched, with completely successful deployment of the panels :

- 2 solar arrays with three in line panels
- 8 solar arrays with four in line panels
- 2 solar array with six panels.

1.2. Deployment simulators characteristics

a)

In the last years, deployment simulators for 3, 4, 5 and 6 panels configurations, were built to predict the aperture of the solar arrays of the SOLARBUS family, using James tool. These prediction simulators were designed to predict the solar array behaviour during the total deployment phase, as the partial one can be predicted through a more simple way : only one panel opens without any regulation. They were designed to take into account all the specificities of the components:

- synchronization devices effect, including synchronization of the panels aperture angles, synchronization devices own stiffness, and induced friction torque on hinges was taken into account
- root hinge regulation motor effect was described, through electrical and mechanical behaviour equations
- hinges characteristics, including spring motor torque and friction torque, were modelled accurately
- harness effect was also carefully taken into account, through their angle dependant effect (their resistive torque changes with the deployment angle).

b)

Recently, deployment simulators for 6 and 7 panels configurations, were built (rebuilt for the 6) to predict the aperture of the largest solar arrays of the SOLARBUS family, using Adams tool.
The prediction simulator done for the 7 panels configuration was designed to predict both partial and total deployment, as partial deployment is quite complicated with 3 panels aperture (FIG 3).

The transfer deployment is proceeded as follows : the stack of 3 transfer panels deploy of 90° or a little bit more. Then the first lateral panel is released and begin to deploy. When this first lateral panel is opened of about 90°, the second lateral panel is released and deploy (FIG 3).

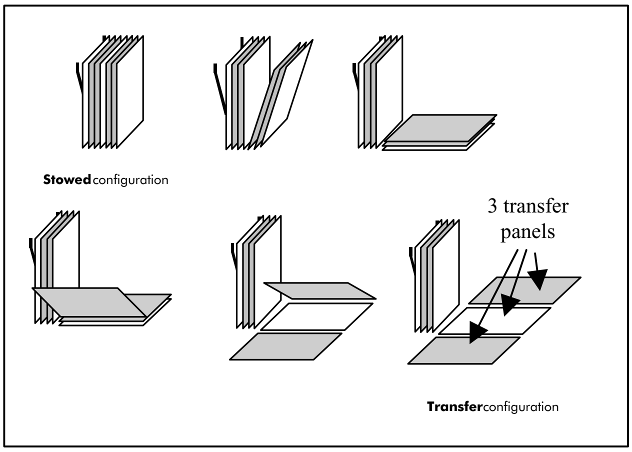

FIG 3. Transfer deployment for the 7 panels SOLARBUS solar array (W71)

The total deployment is done in the following way : the central mast is deployed. When hinges of central mast are latched at 180°, the first lateral panel is released and begins to deploy. When it reaches about 90°, the second lateral panel is released and deploys (FIG 4).

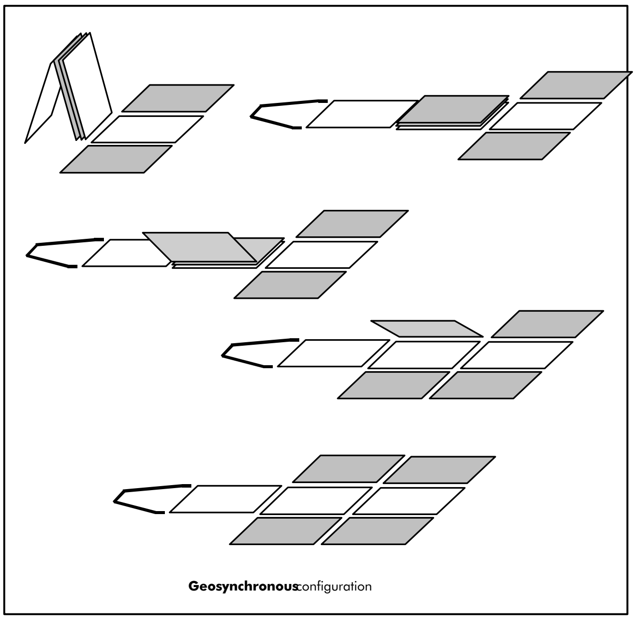

FIG 4. Total deployment for the 7 panels SOLARBUS solar array

The 7 panels simulator, built with Adams, was designed to take into account all the specificities of the components as previously:

- synchronization devices effect
- root hinge regulation motor effect
- hinges precise characteristics
- harness effect.

1.3. Design with deployment simulators

Once built, these simulators brought to the designers a decisive assistance to determine the right balance between the wing motorization and the components safety in terms of loads and shocks. If the wing mechanisms has to provide a sufficient energy to ensure a proper motorization ratio, the loads on components during deployment must remain low enough for safety reasons and the final latching shocks shall not be destructive !

Then, the deployment design begins with the choice of hinges able to ensure a proper motorization ratio. After this preliminary step, the deployment simulators are used to evaluate the loads on the different components : maximal torque on regulation motor output shaft, maximal motor current, maximal load on synchronization devices, maximal shock torque on hinges and panels structure.

The simulators also allow the designers to secure the deployments kinematics, i.e. to eliminate the risk of any interference between panels or between spacecraft and panels. This point is particularly important when the solar array has several lateral panels. Indeed, the design of the lateral panels deployment sequence (when to release the lateral panels in relation with the central mast and with the lateral panels of the opposite side) can easily be validated using the prediction tool.

This point was particularly important when designing the 7 panels solar array deployment. Indeed, during the transfer deployment, the lateral panels are deployed in the same half-space of the wing, so the risk of interference is real. Moreover, the release of the first lateral panel occurs while the central transfer panel is still oscillating, just after its latching. So, the risk of interference between the lateral panels which are deploying and the stack of panels still latched on the hold-points, is important. And the risk of interference between the two lateral panel is high, as the oscillation of the central panel may generate back rotation of the lateral panels.
The use of a deployment simulator was primordial in this optics. In the absence of ground tests, the only way of securing the 7 panels deployment kinematics was to develop a precise dedicated simulator.

It must be emphasized that the results obtained from those representative predictions lead to specifications on wing components:

- regulation motor specifications
- synchronization devices specifications
- hinges specifications
- panels specifications.

Thanks to simulators predictions, the design of the SOLARBUS solar arrays deployment has been fully secured and the design phase duration has been considerably decreased.

2. CORRELATION WITH FLIGHT MEASUREMENTS

Correlation between predictions from James made simulators and real flight measurements have been done on several SOLARBUS programs. All were telecommunication satellites: two of them were similar solar arrays with four in-line panels (W41), while the third one was composed of six panels (W61), four in-line panels plus two lateral panels. Very good correlation was obtained for theses three programs [1] [2].

More recently, a correlation between predictions from an Adams made simulator and real flight measurements has been done on a six panels SOLARBUS solar array.

2.1. Correlation method

The flight deployment data have demonstrated a great similarity between North and South wings deployment. South wing deployment was chosen to be correlated.

Two kind of parameters had to be defined in order to simulate the deployment :

- solar array parameters: hinge characteristics, synchronisation stiffness and damping, …
- electrical motor parameters: torque sensitivity, internal losses, efficiency, wiring resistance.

a) Solar array parameters

Solar array parameters, which were known with a slight incertitude through components acceptance tests and which are known to be slightly dependent of temperature, were adjusted to fit the flight curves.

b) Electrical motor parameters

The deployment motor parameters (torque sensitivity, resistive torque, efficiency) can be calculated exclusively from the flight data (motor torque, current, voltage, and speed).

From these set of parameters, it was possible to perform correlations with flight data of South wing deployment.

2.1.1. Motor torque

The following curves (FIG 5) stand for the measured and simulated motor torque. The simulation begins exactly when the pyro has been fired.

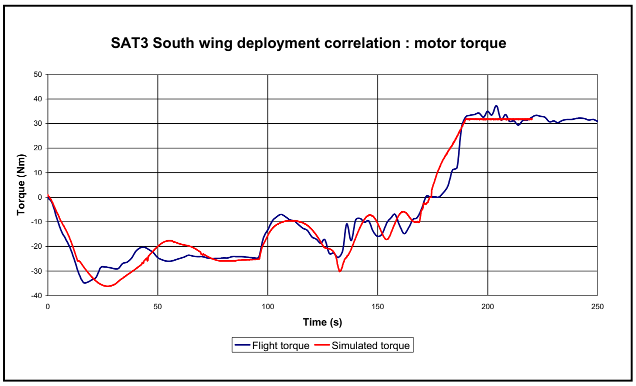

FIG 5. Measured and predicted motor torque

The correlation is quite accurate and put into evidence the different phases of the deployment :

- The wing's release is just followed by an active braking of the motor which acts as a generator (between 20 and 30 s).
- Then the wing stabilises under the friction torque of the regulator, until time = 96 s.
- At 96 s, the motor is powered ON, allowing thus a release of the wing that can pursue its deployment.
- The wing acceleration necessitates a strong active braking of the regulator (around 130 s), generating some oscillations after.
- The motor ends the deployment by applying a positive motor torque that facilitates the hinges latching (after 180 s).

2.1.2. Motor current

The following curves (FIG 6) stand for the measured and simulated motor current.

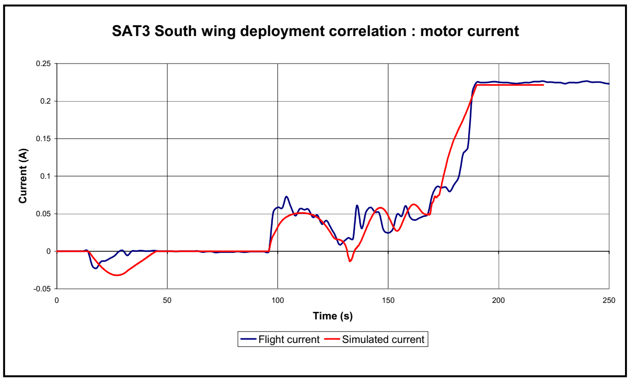

FIG 6. Measured and predicted motor current

Here again, the correlation is quite accurate.

2.1.3. Motor voltage

The following curves (FIG 7) stand for the measured and simulated motor voltage.

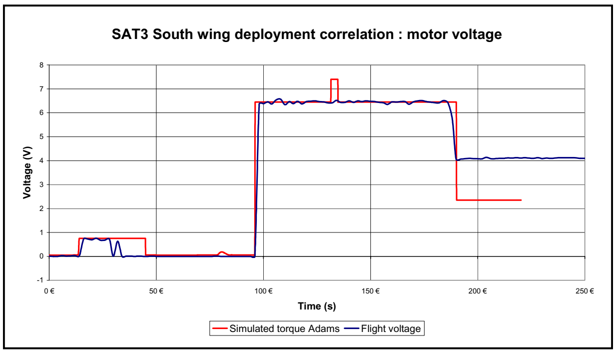

FIG 7. Measured and predicted motor voltage

It can be noted that the simulation predicts longer dissipation phases than the real ones seen during the flight deployment.

2.1.4. Wing total current

The following curves (FIG 8) stand for the measured and simulated current generated by the cells of the wing.

The correlation is very accurate until the lateral panels latch and induce a global wing rotation. Indeed, when lateral panels latch, the torsion torque generates a global rotation of the wing and therefore a current decrease. The wing rotation is only braked by the solar array drive mechanism internal friction torque, because this mechanism is in OFF mode. So, this correlation shows that our model of the solar array drive mechanism behaviour could be enhanced.

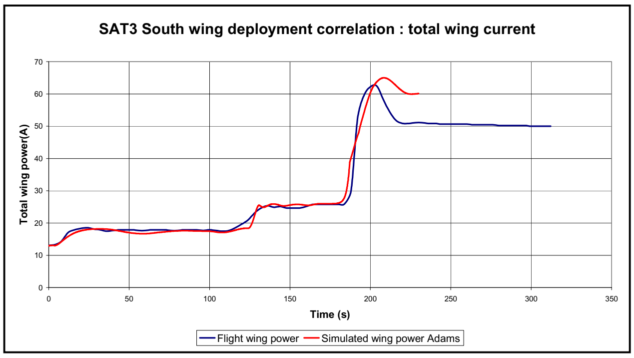

FIG 8. Measured and predicted wing total current

3. DEPLOYMENT PREDICTIONS OF FUTURE SOLAR ARRAYS DEPLOYMENT

The correlation, on several programs, of our deployment simulators made from both James and Adams tools gives confidence to continue with the development of new design solar arrays. The capacity to perform accurate predictions gives us the capability to develop solar array with completely new architectures.

Thus, recently, deployment predictions have been performed for a 7 panels solar array (including 4 lateral panels), based on an innovative light weight architecture with thin lateral panels and a completely new deployment phase with 3 panels. The development of this last born SOLARBUS solar array has been simplified, and greatly secured thanks to the dedicated simulator built.

Other innovative deployment, like deployment with blade made hinges, are currently under development and the corresponding deployment simulator are under construction to help and secure the design. Indeed, those very particular hinges induce several latching/unlatching sequence before the final one, so that the deployment kinematics is quite complex and the risk of interference between panels or between panels and satellite are real if non studied.

4. CONCLUSION

In order to evaluate the behaviour of new design solar arrays, deployment simulators are regularly built, using, formerly the home made James tool, and more recently the commercial Adams tool.

Solar array deployment using synchronization devices, different regulation systems (motors, fluid regulators, shape memory alloy regulation devices...), lateral panels, are currently modelled, with a wholesome effect on the duration of the design phase.

The dynamic predictions allow to evaluate the deployment duration, the loads on wings components during deployment, the shocks at latchings, the absence of interference between panels. It allows to anticipate many problems such as too high dynamics leading to destructive loads on components, too large panels oscillations leading to interference..., problems that cannot be evidenced by a simplified analysis. The results obtained from those representative predictions lead to specifications on wing components (regulation motor, synchronization devices, hinges, panels...).

A very good correlation of this two tools predictions has been obtained on several satellites of the SPACEBUS family already launched. These satellites included four in line panels solar arrays and four in-line plus two lateral panels solar arrays, with regulated and synchronized motion. Flight data as regulation motor parameters and wing current have allowed to correlate the deployment dynamic predictions of these three programs with a good accuracy. Motor torque, current and voltage, total wing current have been correctly correlated, showing that the regulation system has been efficient and well predicted.

The correlation of this tool with flight data gives confidence to continue with the development of new design solar arrays. The capacity to perform accurate predictions gives us the capability to secure the deployment of solar array with completely new architectures.

Thus, 7 panels solar array (including 4 lateral panels), based on an innovative light weight architecture has been very recently developed with a great confidence with regards to deployment aspects. Other innovative deployment, like deployment with blade made hinges, are currently under development with the help of dedicated simulators.

Finally, the control of the deployment analysis gives to THALES ALENIA SPACE the confidence in developing completely new design solar array with innovative architecture and innovative deployment sequence.

5. REFERENCES

[1] Innovative light weight mechanical architecture with thin lateral panels deployed with shape memory alloy regulator, L. D'Abrigeon, A. Carpine, 7th European Space Power Conference, Stresa, May 2005

[2] Deployment analysis of very large advanced structures for solar arrays and model correlation, A. Carpine, G. Ladurée, 23rd ICSSC, Rome, September 2005