MODELLING OF SOLAR ARRAY WING DEPLOYMENT USING A HYBRID MATLAB/SIMULINK APPROACH AND CORRELATION WITH MEASURED WING PERFORMANCES

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ABSTRACT

A deep understanding of deployment behaviour of a Solar Array Wing (SAW) is a necessity for in-orbit spacecraft operations but also for an adequate and optimized sizing of the subsystems composing the SAW itself [1]. In this paper, we are proposing a modelling method based on a hybrid model combining Simulink tools and custom-built MATLAB functions. The main advantage of this approach is the quick elaboration of a model without the need of any knowledge of advanced analysis tools allowing easy decision making in the early phase of a project. To assess the prediction accuracy of our model, simulated results have been put in comparison with measured values from test results of multiple SAWs. Our current framework, despite being still under development, already showed very satisfactory predictions, which are presented in this paper.

1 INTRODUCTION

In this paper we present a MATLAB/Simulink based modelling approach to simulate solar array wing deployments, and show a comparison between the data gathered during deployment testing of SAW with simulated output of the model of that hardware. More specifically, it focuses on SAW actuated via springs and whose synchronization is ensured through a network of dedicated synchronization cables.

The aim of the presented tool is to provide a framework allowing rapid and simple iteration on key design parameter by predicting their influence on the overall system's deployment dynamics. This flexibility is especially valuable in the early phases of a project.

It is thus to be understood that detailed and high-fidelity results are not the main point of focus in this development.

This approach utilizing fast iterations with different sets of parameters is of great help to system engineers, for example, in reviewing the torque budget and simulate failure of certain subsystems, sizing components, and predicts the expected deployment envelope.

The developed tool, in its current state can simulate SAWs with an arbitrary number of wings and number of panels per wing, including spring-actuated hinges and synchronization systems. For simulations in orbit, gravity can be set to zero, but for simulations of ground-based testing the gravity can be activated. Additionally, the framework also provides methods to model offloading equipment used in ground-based testing and therefore allows simulating the influence of this equipment on the deployment dynamics.

The correlation of the modelling parameters and measured data is mainly performed by matching key deployment data such as SAW position over time as well as its latching sequence.

2 MODELS AND METHODS

2.1 SAW Modelling

Our framework utilizes the Simscape Multibody environment to simulate the SAW as a multibody system. Using the base building blocks from this environment, we created a custom library of parametrized subsystems, such as yokes, panels, hinges, etc. model the behaviour of the real subsystems and provide interfaces to other subsystems of the library. By combining these elements in a building-block manner, a model of a simple satellite with multiple solar array wings can be assembled in a short time. All parameters of the model are defined in a separate MATLAB script, from which the simulation is then also executed. A great advantage is that most of the subsystems of the library are already equipped to log and plot relevant values, such as hinge angle, torque, synchronization cable forces, etc.

Additionally, our custom library includes models of support equipment traditionally used during on-ground deployment testing.

This approach offers the possibility to quickly assemble a SAW model based on preliminary data, without requiring in-depth knowledge of the Simulink/Simscape environment or other, traditional analysis tools.

It has to be noted that this approach doesn't provide as much details as for example an ADAMS model. Less parameters are used in general. Bodies such as panels are not implemented as flexible entities nor as volumes and the boundary conditions like the ones from the HDRM are omitted. However, it saves great amount of time for the elaboration of the model while still providing comparable results for the main parameters of interests.

Aside these technical considerations, software licence management and availability within the company is definitively an argument weighting in the decision of the software used for simulation.

2.2 Parameters implementation

The parameters required to describe the model can be categorized into several distinct categories: Geometrical envelope, Geometrical constraints, basic and advanced physical properties.

The geometrical envelope gives a shape to all the involved components such as the satellite body, the yokes, the hinges and the panels. The geometrical constraints set the positions of the objects in their reference frame but also handle the geometrical collisions between objects as for example the hinges end-stops. The basic physical properties are mainly mass and inertia which are allocated to all the present bodies. Some components have more advanced physical properties as well, such as stiffness, friction and damping. These are used for the deployment springs, the Eddy Current Damper (ECD, see Ref. [2]) and the synchronization cables.

Similarly, the models of ground support equipment are also described using geometric constraints and masses, as well as internal frictions in the case of the deployment rig, or lift forces in the case of balloons.

2.3 Model of the tested SAW

In this paper, two different SAWs are presented, a small and a large one (HERA SAW).

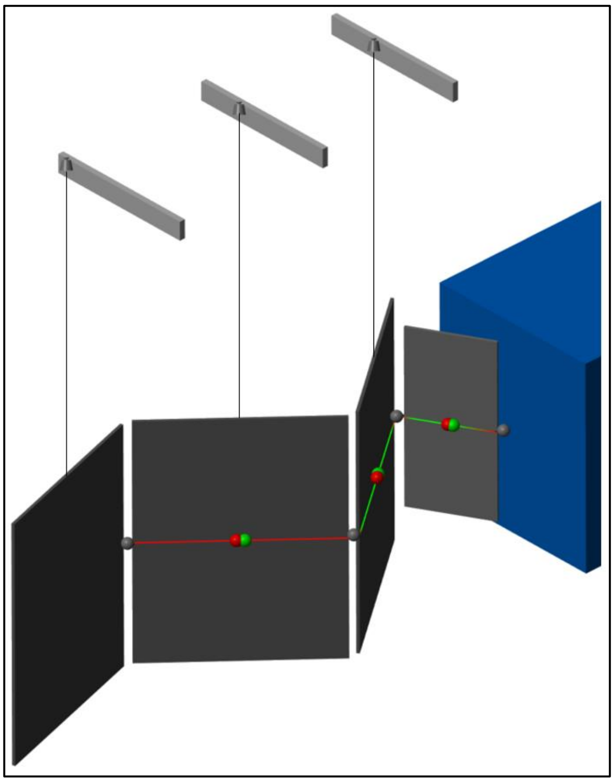

Figure 1. Large SAW model

They have been chosen for both their variety in design which is interesting to model in our framework and because they are related to recent BGC projects. This also means that corresponding hardware has been built and thus test data could be collected. The larger of the two solar array wings (see Figure 1) consists of a yoke and three panels, connected via hinges and all linked using synchronization systems between two adjacent hinge-lines. A damping system is provided at the root hinge only. The smaller solar array wing (Figure 2) consists of two panels. One synchronization system links the root hinge-line with the panel hinge-line. A damping element is also present at the root hinge.

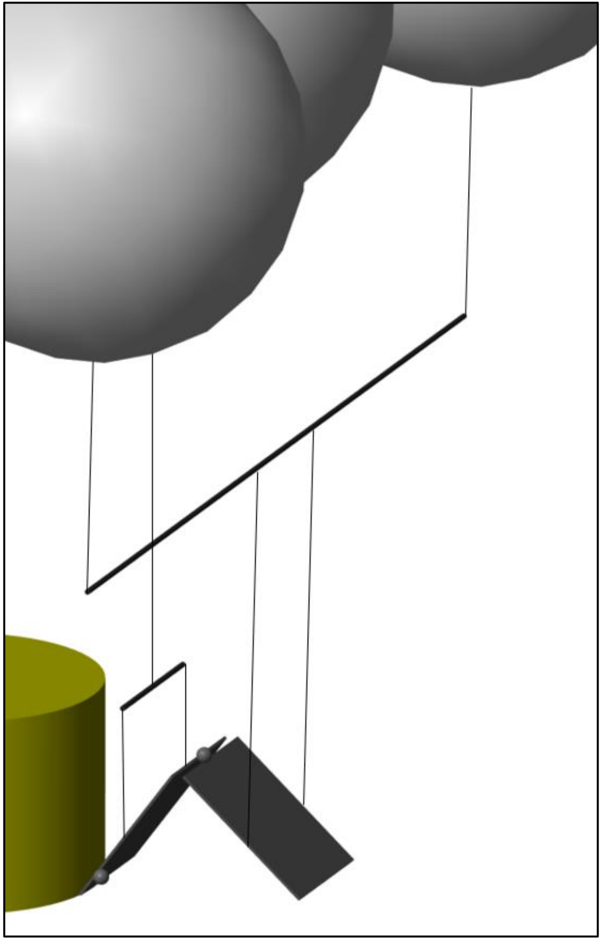

Figure 2. Small SAW model

In the case of the Large SAW, the synchronization system model using physically modelled cables and pulleys can be seen in Figure 1. A different cable modelling approach has been implemented in the Small SAW model in order to compare both approaches as well. It calculates the interactions between two hinge-lines via a mathematical function rather than modelling the synchronization system physically. While this second method models the system in a simpler manner, it also requires less geometric constraints entered in the tool as parameters. This allows it to be used at a project stage where these parameters might still be unknown (e.g. if the design is not yet mature).

The deployment direction of each of the modelled wing has been adapted in their respective model to reflect the deployment configuration during testing. Thus, the Large SAW has its hinge-lines perpendicular to the ground while the Small SAW has it hinge-lines parallel to the ground (applicable only for the gravity offloaded deployment).

In both models a gravity offload system is present. Including the on-ground deployment jigs into the models allows a characterization of their influence onto the deployment dynamics and easier correlation with test results. Thus, it increases the confidence of in-orbit deployment behaviour as the correlated model can then be run again without the offloading system. For the Large SAW, the gravity offloading system is rail-based and thus modelled with corresponding trolleys. For the Small SAW, the gravity offloading system is modelled with balloons. Parameters for modelling of the trolley or balloons are taken directly from measured values such as mass, friction or lift.

3 TESTING

3.1 Test Set-up

Figure 3 shows the Large SAW on the mobile deployment rig. The deployment rig is a standard rail-based deployment system with longitudinal and transversal trolleys which provide the lifting force in order to offload the panel masses.

Figure 3. Large SAW in mobile deployment rig – HERA SAW by Beyond Gravity, ESA project

The smaller solar array wing, not shown here for confidentiality reasons, was tested in two different configurations: with hinge-lines parallel to the ground using an offloading system and perpendicular to the ground without any offloading system. Test set-ups are mounted in cleanroom and the ventilation is turn off for the deployment time to limit disturbances on the wing. However, no deployment is performed in vacuum.

3.2 Monitored parameters

In order to limit the disturbances on the SAW during deployment, all the parameters are extracted from videos taken during deployment. A special attention is given to the hinges position and behaviour over time. Their opening angle as well as their latching sequence are values which can later be compared with simulated data. Valuable data such as cable forces are thus extrapolated from hinge torques and angles. This is achieved making use of the asynchrony between two adjacent hinges-lines as it is related to the synchronization cable elongation. With this, the instantaneous cable properties can be extracted.

The parameters required to build the model, such as geometric constraints, masses, hinge spring torques, friction coefficients, etc., are not extracted from the deployment test but were acquired beforehand. In that regards, dedicated test campaigns were run to provide the needed information to build the simulation framework.

3.3 Findings

Despite the two very different wings and deployment set-ups used, deployment testing highlighted common behaviour and finding.

The main one is concerning the synchronization system, which is as well the core of the deployment dynamics. Indeed. Its influence on the deployment showed to have a lot more impact than any other subsystem taking part into the deployment. More specifically, it addresses the synchronization cable. It is observed that the synchronization system is, as expected, not behaving linearly. However, it is not behaving in the same fashion as the synchronization cable itself, whose behaviour was measured during cable-level testing. The non-linearity is thus greater than originally foreseen.

Additionally, the synchronization system shows an important damping behaviour aside to its stiffness. This effect being also larger than anticipated.

Aside the findings on the behaviour of the components of the SAW, it has also been noted that both gravity compensation methods have a non-negligible effect on the deployment despite the efforts to minimize their impact. This finding confirmed the importance of modelling these deployment jigs into the simulation to be able to understand fully the deployment.

4 MODEL AND TEST CORRELATION

4.1 Correlation results

Using the data acquired during testing, our simulation tool can be correlated in order to provide more reliable prediction once a new SAW configuration is built. Because two different cable modelling approaches have been presented into this paper, this also results in the need of two different correlation.

The results for the Small SAW present tests and simulated values are presented in Figure 4. Comparing the two orange curves together and the two blue curves together, it can be noted that their overall shape are very similar. Simulated and tested deployment time are also matching well. One can note that the influence of the offloading balloons is visible on both simulated and tested plots.

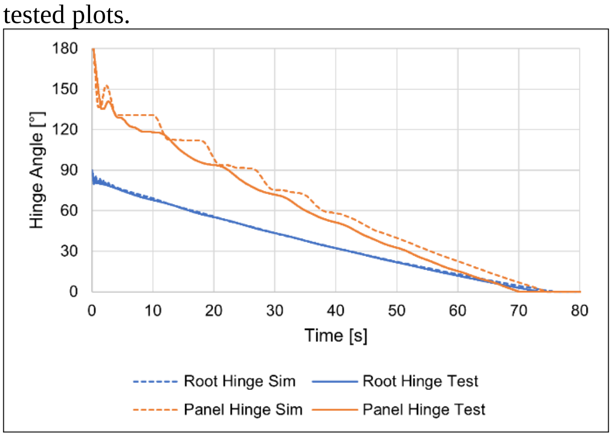

Figure 4. Small SAW deployment comparison

Remembering that the aim of the tool is to offer an approximate estimation of key parameters such as deployment time, hinges and panel CoGs position, the prediction accuracy achieved with the tool is very satisfactory.

The results for the Large SAW are presented on Figure 5. One can see that the general trend is visible. However, the differences between the predicted behaviour and the tested one is significantly larger than for the Small SAW.

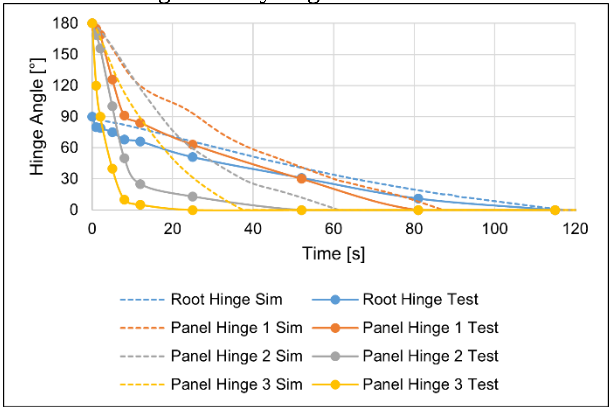

Figure 5. Large SAW deployment comparison

This clearly shows that more correlation work needs to be conducted. Nevertheless, the testing of this particular SAW being still on-going at the time of this publications, not all the results are yet available.

4.2 Discussions on discrepancies

Unlike initially assumed, the correlated parameters of the Small SAW can't be transposed directly to the large one. The reason lies in the fact that the two SAW have different cable braiding angle while keeping the same material. Accounting for the easily characterizable changing properties between these two cable types such as cable stiffness and length is not sufficient to achieve good results.

In addition, some on-ground effects which can be neglected while simulating a SAW with a small panel area have to be considered more carefully for larger SAW. These effects are mainly related to general air resistance as well as air flow in the cleanroom.

4.3 Correlation conclusion

Two different modelling approaches have been chosen for the two different SAWs but, from a hardware point of view, they also both had different synchronization cable properties. Despite these differences, a few common conclusions can be extracted from this correlation exercise.

Firstly, it has been made clear that each synchronization cable type is requiring its own correlated model. Meaning that an in-depth characterization of the used cable type is as well needed to reach good predictions.

Secondly, this exercise highlighted the fact that the smallest the wing, the easiest the correlation exercise. Indeed, the correlation of a SAW with multiple synchronisation systems is more challenging. These systems interact together, and their interdependencies make the tuning of the parameters more difficult as the influence of a single parameter is spread throughout the whole SAW. Ideally, a two panels SAW with only a single stage state of synchronization system can be used for the initial correlation, as the Small SAW presented in this paper.

In conclusion, the impact of the synchronization cable modelling has a large impact on deployment dynamics and thus predicted results.

5 CONCLUSION

We have seen that the presented approach provides a very convenient rapid way to set-up a model for a new SAW and that it can provide exploitable results. We have also seen that the synchronization system drives the deployment dynamics, this is the place to put the maximum effort in order to get a good prediction.

The current state of our framework does not allow us yet to have an extremely precise idea of the deployment dynamics of any new configuration we would run with it. However, it already offers a good first glance of the general direction to be expected. Anyhow, by finalization of the test campaign of the Large SAW, the remaining uncertainties will likely be reduced.

In order to improve the current building blocks of our framework, it may be very interesting to build a test SAW offering the possibilities to vary numbers of parameters but keeping the same base components, ensuring representative testing. The parameters to be tested over a full range could be the number of panels, spring torque, different configuration of synchronization system, cable tension, ECD settings, etc. Such test SAW would allow isolation of the specific contributors to the deployment dynamics and thus an optimized correlation approach.

6 REFERENCES

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