Deorbit Kit Design with SysML ESA Profile

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EXTENDED ABSTRACT

Introduction

SENER Aeroespacial is designing a Deorbit Kit Demonstrator mission to be launched in 2024. This activity is currently financed with 3M€ by the EC in the form of the FET-OPEN project Electrodynamic Tether technology for Passive Consumable-less deorbit Kit (ETPACK) to reach TRL4. The project involves the University Carlos III of Madrid as coordinator of the project and responsible for the mission analysis, the University of Padova as responsible for the tether deployment mechanism design, the University of Dresden in charge of the electron emitter and ATD and IKTS working on new material developments [1], [2].
The Deorbit Kit Demonstrator (DKD) will have a standard 12U form factor, a mass of less than 24 kg and will be launched in a 600 km orbit with 50º inclination. After deployment from the launcher, the spacecraft will stabilize its attitude and separate into two modules connected by 500 m of tether. The tether will be a tape of 2.5 cm width and 40micron thickness formed by a conductive aluminium tape, a PEEK segment and an insulated segment. The objective of the demonstration is to deorbit in less than 100 days, whereas the natural deorbit time would be of about 15 years [3],[4]. The consortium is currently manufacturing a fully representative satellite model for demonstrating the critical mission technologies. Each edge of the tether includes an independent satellite with its avionics and communication system (Figure 1). For the prototype, a powerful System On Chip based onboard computer using proprietary software is used to control cubesat radiation tolerant components. All avionics elements have been procured and are currently under integration, while the structure of the satellite is under manufacturing.

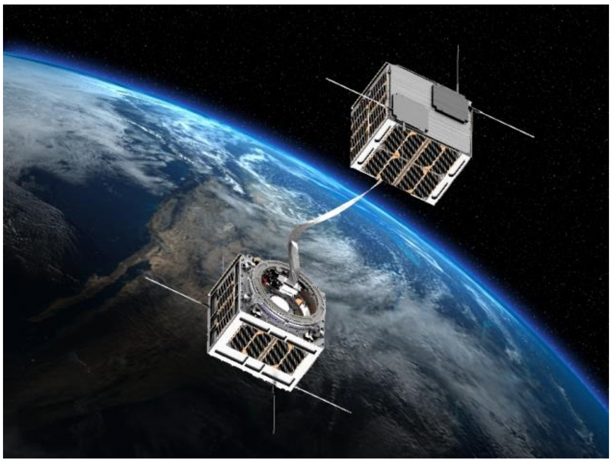
Figure 1: Deorbit Kit Demonstrator

Needs

Early in the project it was identified the need to maintain the design information updated, establish and keep the mission budgets, exchange efficiently the baseline design data among the different institutions and, finally and most importantly, ensure rapid decision making during the development of the project. The first design information exchange was based on documentation that soon demonstrated to require frequent updates. Limited budget was available for maintaining documentation and therefore SysML was selected to model the Deorbit Kit Demonstrator mission, including the mission description and the budgets. A trade off on different system engineering tools was performed and finally IBM Rhapsody was selected as baseline. The decision was mainly based on the availability of the tool, modeling skills in SENER and the possibility for universities to access to the licenses.

ESA Profile

SysML 1.3 is a rich universal language that includes several elements that can display any kind of information and results to be too generic and therefore potentially ambiguous when interpreted by different engineers. Therefore, a SysML language tailoring was required in order to design and maintain a consistent and simple model among the various institutions that were working in the project. Luckily this work was already performed by ESA engineers. ESA has defined a customized Profile to extend the SysML language, limiting the elements to be used, adopting a color code and defining new elements to differentiate the types of an element (using stereotypes) or to extend predefined (using new term stereotypes). Therefore, the ESA profile has been selected to model the DKD mission and has been implemented in Rhapsody based on the available documentation. As a result, SysML diagram tools have been customized to match the ESA profile elements. In addition, an ESA Perspective has been created in IBM

Rhapsody to define the new ESA profile stereotypes for each diagram and to adopt the ESA profile color code (Figure 2).

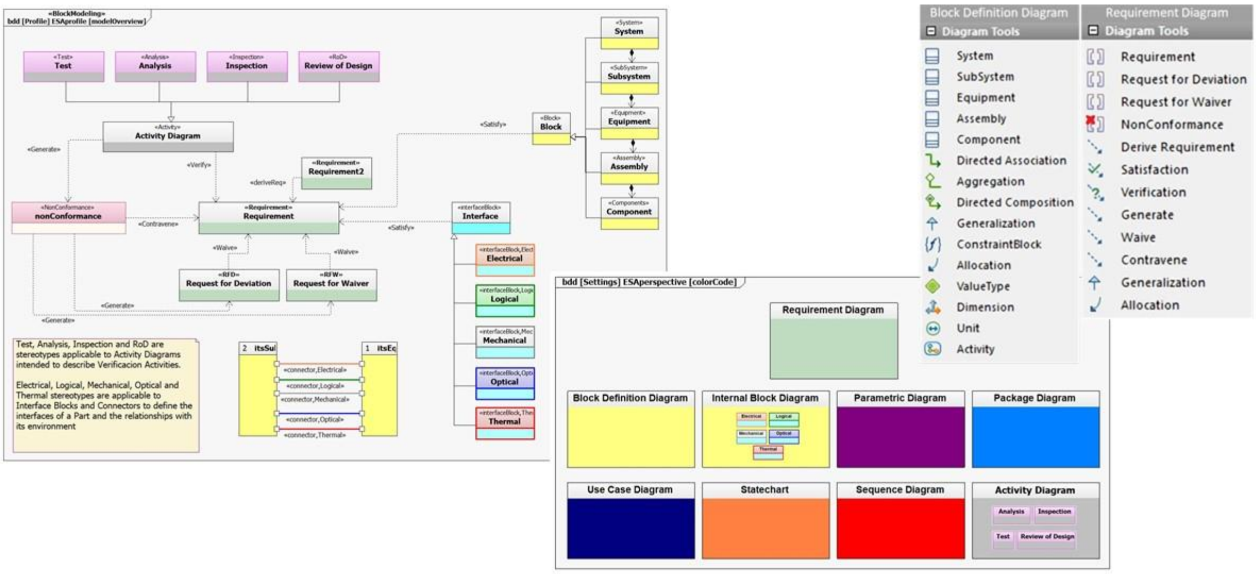

Figure 2 ESA Profile New Elements, Toolboxes and Color Code

To assist the DKD team to model, a Value Types library collecting the most used ones and diagrams displaying the new elements and its interaction with the environment have been added within the profile.

DKD Model Overview

Using the improved ESA profile, the ETPACK team is currently designing the deorbit kit mission. The DKD model is divided into 4 main packages for describing requirements, budgets, the model (including the product tree, use cases and interfaces) and assembly integration and test sequence. This structure is represented in a Package Diagram that appears at the top of the browser and from which the user can access the different packages using quick navigation (Figure3). The set-up of a SysML project with thousands of graphical elements was soon identified as a very complexity task with conflicting needs. The hierarchical structure of the tool browser would suggest nesting elements inside others (e.g. subsystems inside the system) but when the model contains several layers up to component level, the navigation through the browser to find the elements becomes very time consuming. Another important consideration is the fact that during a concurrent work session an engineer working on a part of the system needs to "lock it" to prevent editing from other users. The database therefore shall be organized to allow the concurrent work limiting the "locking" to the strictly needed model elements. After several iterations it was finally decided to organize the model in a package for each upper level element (System, Subsystem, Equipment and Assembly) and include all the Components of a parent Assembly within a package.

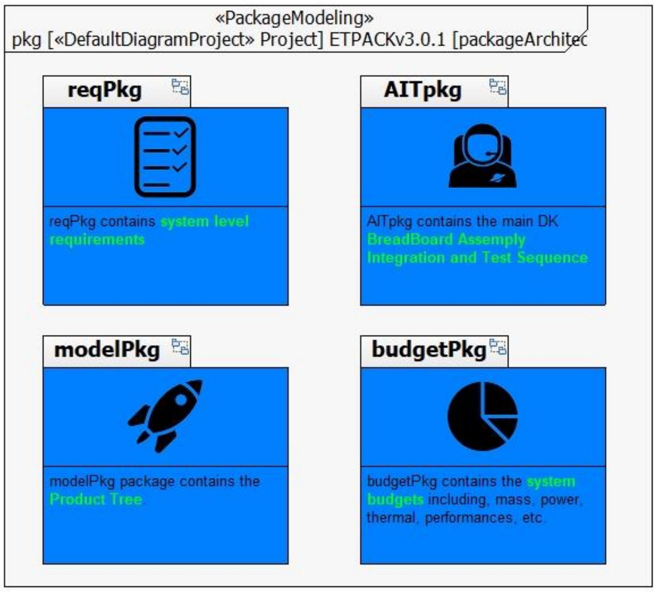

Figure 3 Package Diagram representing the Model Structure

This structure enables to maintain an organized browser with a limited number of elements at first level, lock, make changes and unlock the desired packages in concurrent work, reuse elements to display in different diagrams and ensure not duplicated elements (Figure 4).

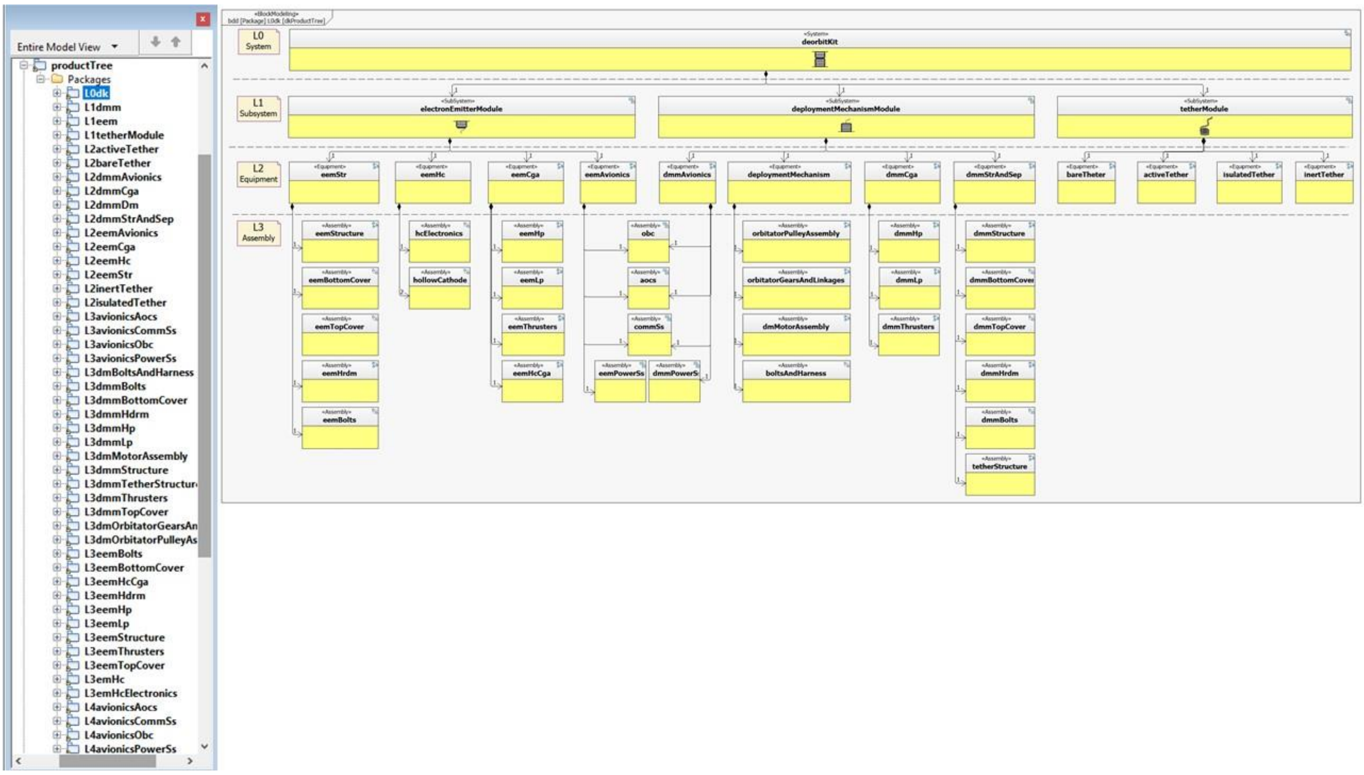

Figure 4 Product Tree Diagram and Browser

One of the most critical decision in the setup of the SysML database is to establish a clear, functional and maintainable naming convention. Since the graphical object are of reduced size, names shall be as short and as precise as possible. In the DKD model the element level (L0, L1, L2, L3 and L4) is part of the name of the package to clearly organize the elements in the browser according to the system decomposition. Moreover, elements related to elements from the product tree include the name of the latter. Users can locate elements in the browser depending on the level decomposition and check if elements have been previously defined in that level, preventing duplicate elements. This is particularly useful when modeling Internal Block Diagrams, where the structural elements are not displayed but only the part defined inside the parent element. The naming convention and the model architecture is currently being tested in the frame of the preparation of the avionics electrical and logical interface diagrams (Figure 5). Since SysML diagrams display exclusively the relevant information for that diagrams and not all the information available for the shown elements, the organization of the diagrams in a "navigable" architecture is of paramount importance for describing the system.

The DKD models currently include the mission product tree including main value properties for each element selected from the profile's Value Types library. At present, mass and cost budgets are being modelled using Parametric Diagrams and MAXIMA plugin has been used to evaluate the constrain expressions. With the aim of maintaining diagrams as simple and readable as possible, it was decided to create a diagram for each element from Assembly to System and nest those diagrams to ensure easy updating when the value of a property would change. Finally, navigability throughout the model has been enabled to handle the complexity more effectively by accessing graphical elements from others linked. This feature is especially useful for maintaining nested Parametric Diagrams updated. From the Parametric Diagram of an element one can access to the diagrams one level below and above by clicking the quick navigation icon (Figure 6).

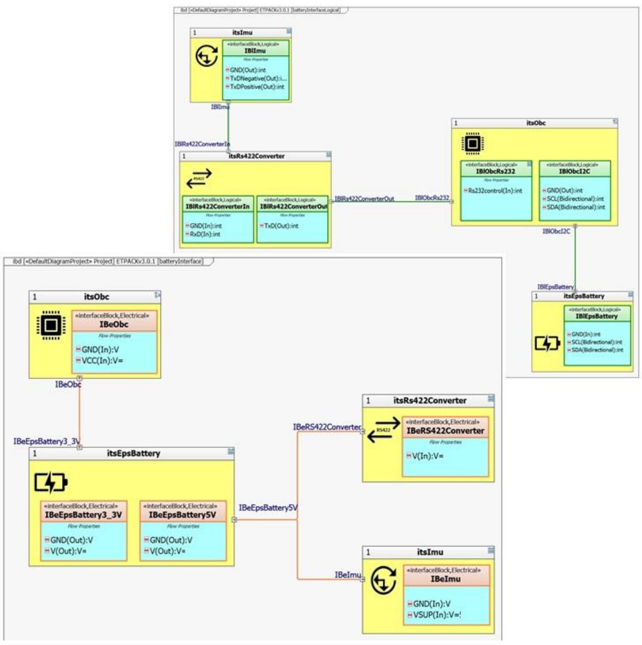

Figure 5 IBD displaying the relevant Proxy Ports of an element for each type of interface

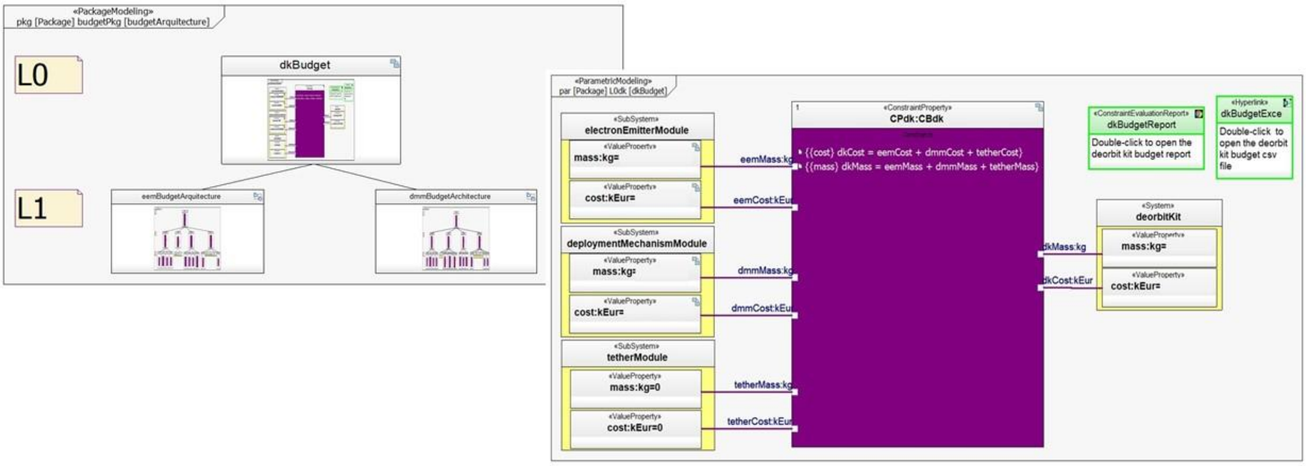

Figure 6 Parametric Diagrams for budget structure with Quick Navigation enabled

Team formation

Mastering SysML is not easy, the learning curve is very steep, software is expensive and little training material is available online. SENER AE prepared a 16-hour intense training program for kickstarting the consortium in the use of the DKD SysML Rhapsody model. A total of 13 engineers from SENER, UC3M, TUD and UniPD received the SysML training and started modeling their subsystems. The feedback received so far has been very positive, but it is still too early to draw final conclusions since the real collaborative work on the model has not started.

Roadmap and future plans

The DKD demonstration mission is the first step for the development of a commercial system product that will have many differences with the initial design. The potentiality of the tether technology allows deorbiting, re-orbiting and station keeping missions. A business development study is currently ongoing to determine which will be the most promising application of the technology. SysML will allow to maximize the design reuse and moreover to support independent development "branches" for each deorbiting product foreseen. Furthermore, the SysML implementation in the DKD is the pilot project in SENER AE to evaluate to possible ramp up of the design approach to other projects.

Conclusions

This extended abstract introduces the Deorbit Kit Demonstrator mission currently in development under the umbrella of the E.T.PACK EC project. In the frame of this project a clear need to maintain an updated system description, avoiding static documents, has been identified and SysML has been selected for describing the design. In order to overcome the SysML ambiguity, the ESA profile has been adopted, implemented into IBM Rhapsody and tailored for the DKD project. The DKD mission design has been modelled following an effective structure that allows to find each Product Tree element easily. The key for efficient model organization is establishing a clear naming convention and straightforward modeling rules. The DKD team formation results to be fundamental to lower the steep SysML learning curve and start a real concurrent process. Finally, the investment in the project is considered limited with respect to the future benefit it could bring.

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