A model based approach to budget management for the Earth Return Orbiter

Lorenz Affentranger[1*], Jakob Huesing[1]

[1]MSR-ERO team, European Space Agency, Noordwijk, Netherlands

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1. INTRODUCTION

Technical budgets are an integral aspect in the design process of all mission. Most of the disciplines rely on access to the most recent accurate outputs to perform their specific analysis. Maintenance and updating of the budgets require the constant involvement of multiple stakeholders. In the case of Mars Sample Returns [MSR] Earth Return Orbiter [ERO][1], these stakeholders represent multiple agencies and numerous industrial partners. With MSR-ERO making a return trip to Mars, mass is the predominant design constraint with a high sensitivity of the overall mission design to it. A centralised tool, which offers easy and consistent access to the mass budget was thus identified as one of the highest priorities for an overall system model.

MSR-ERO has started implementing Model based Systems Engineering [MBSE] solutions to address its systems engineering challenges during pre-phase A. The work on a Digital Integrated System Model [DISM] has started after spacecraft-Systems Requirement Review [SRR] with the first issue being completed during spacecraft Preliminary Design Review [PDR] [1].

2. TECHNICAL CONTEXT

SysML was chosen as the modelling language. Cameo is the implementing tool. The modelling on Industry side is done based on the MOFL(T) [2] methodology while the ESA team has used early versions of the ESA SysML solution at the start of the activity[2]. To address the specific needs in budget management, especially concerning the effective exchange and management across teams, a specific SysML profile was developed. Furthermore, a python based

[1] The Earth Return Orbiter is an ESA mission within the Mars Sample Return Campaign. Airbus Defence & Space is the main industrial partner.

[2] A transformation to ESA SysML Solution v3.0 is forseen in the near future.

"dashboard" has been developed for the visualisation of the budgets.

The current model content organisation is depicted in Figure 1. The current content is highlighted below:

ERO-ESA DISM:

- Mission & System architecture
- Requirements
- Budgets ("needs analysis")
    - Mass budgets
    - Power budgets (work in progress)

ERO-ADS DISM:

- Operational Architecture
- Functional Architecture
- Physical/Logical Architecture
- Requirements

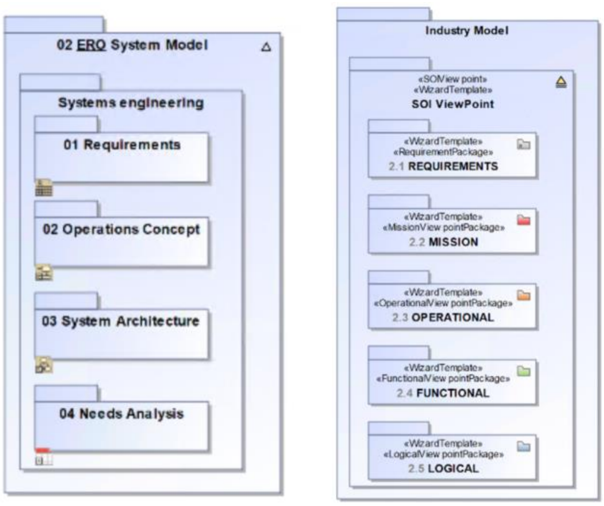


Figure 1: MSR-ERO model content. Left: ERO-ESA System Model. Right: ERO-ADS System model.

3. PHYSICAL ARCHITECTURE

The definition of a physical architecture is the first step to establish a mass budget. The previous work done by ADS has focused on this aspect. A "dummy" architecture can be seen in Figure 2. The *MOFL(T)* and *ESA SysML* methodologies use SysML *blocks* as the basis for architecture decompositions and further refine these decompositions into sub-level using association links.

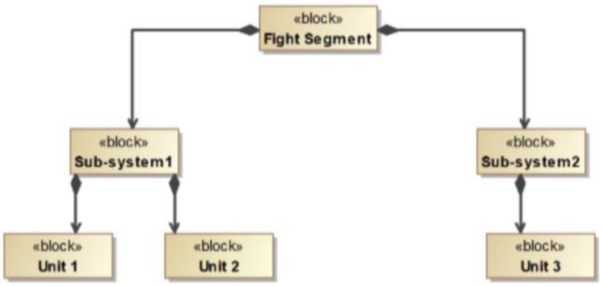


Figure 2: Example of physical architecture in SysML using "block" and associative links.

4. MASS PROPERTIES

A block in SysML can be further refined by given it specific attributes such as part properties, value properties and constraint properties. Native SysML introduces the concept of roll-up pattern (i.e. "parametric"). This allows to automatically create and allocate pre-defined properties to blocks which are associatively linked and apply its logic (e.g. Mathematical formulas, …) recursively. This pattern was applied to the

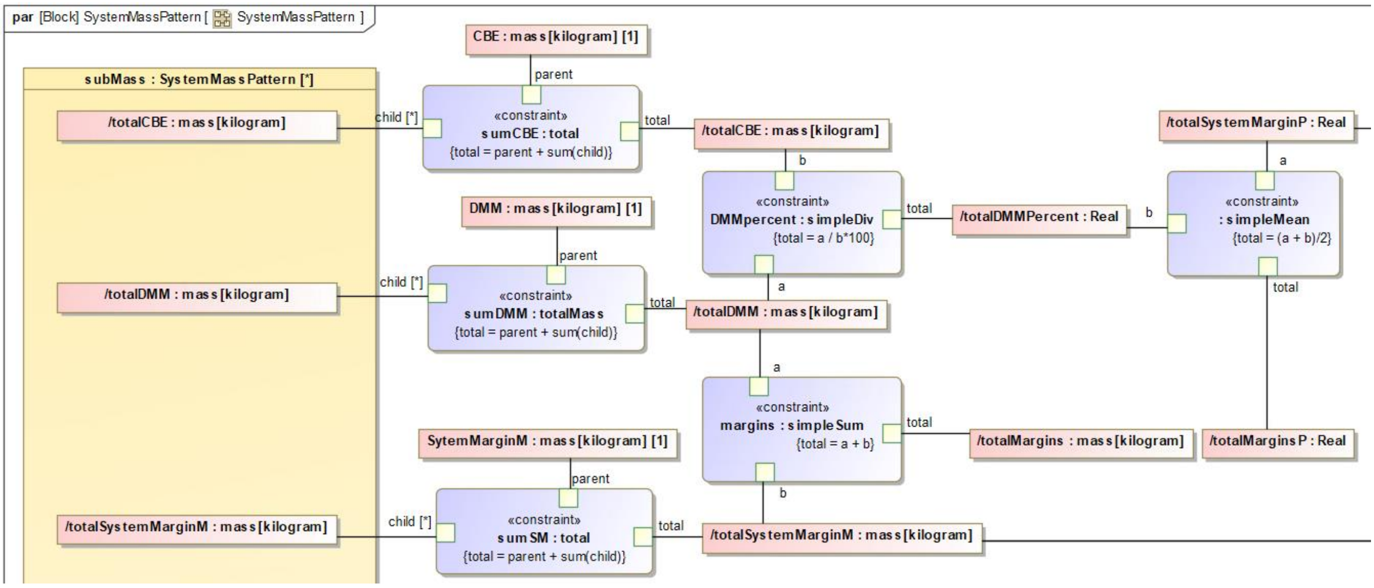


Figure 3: SysML parametric diagram representing the pattern applied for mass budgets calculation. (Note: the figure doesn't show the diagram in its entirety for the visibility convenience).

ERO architecture. Figure 3 to Figure 5 show how these were implemented.

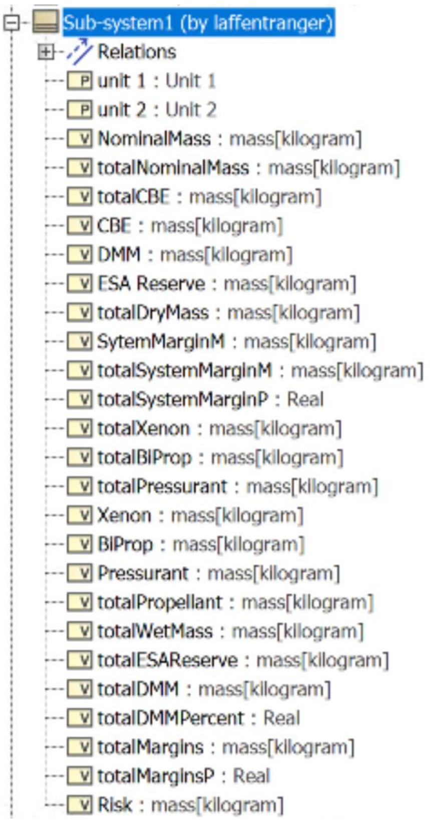
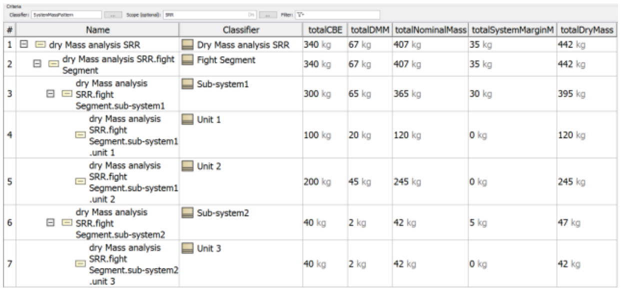


Figure 4: Containment tree in Cameo showing the value and part properties of a sub-system after SysML pattern was applied.



#	Name	Classifier	totalCBE	totalDMM	totalNominalMass	totalSystemMarginM	totalDryMass
1	dry Mass analysis SRR	Dry Mass analysis SRR	340 kg	67 kg	407 kg	35 kg	442 kg
2	dry Mass analysis SRR.fight Segment	Fight Segment	340 kg	67 kg	407 kg	35 kg	442 kg
3	dry Mass analysis SRR.fight Segment.sub-system1	Sub-system1	300 kg	65 kg	365 kg	30 kg	395 kg
4	dry Mass analysis SRR.fight Segment.sub-system1 .unit 1	Unit 1	100 kg	20 kg	120 kg	0 kg	120 kg
5	dry Mass analysis SRR.fight Segment.sub-system1 .unit 2	Unit 2	200 kg	45 kg	245 kg	0 kg	245 kg
6	dry Mass analysis SRR.fight Segment.sub-system2	Sub-system2	40 kg	2 kg	42 kg	5 kg	47 kg
7	dry Mass analysis SRR.fight Segment.sub-system2 .unit 3	Unit 3	40 kg	2 kg	42 kg	0 kg	42 kg

Figure 5: SysML table in Cameo showing mass budget (fictive values).

5. VERSION CONTROL

The cyclical nature behind the evolution of a mass budget is defined by iterations, versions, and baselines. SysML handles this by differentiating "default" and "instances" values. Defaults values are values associated to the SysML *block* itself in the physical architecture. Instances are copies of the physical architecture at a specific moment in time. Value properties can be modified and analysed accordingly without changing any default properties.

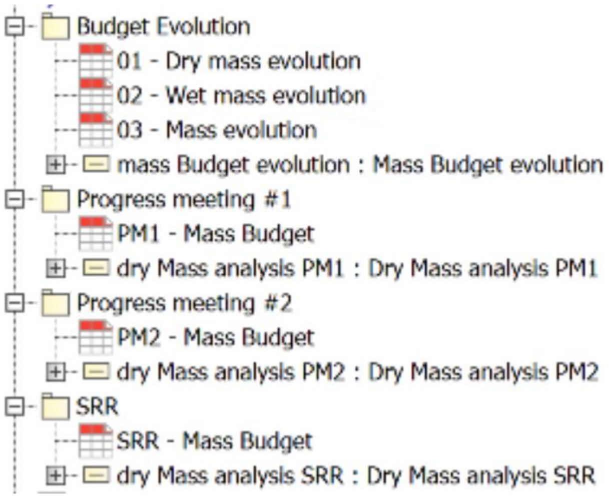


Figure 6: Containment tree in Cameo. Each milestone is stored in specific packages which also contain instance specifications and instance table for the physical architecture.

Instance tables in SysML can help visualise and simulate these instances.

6. DASHBOARD

To simplify access to the information in the overall team, a dashboard was created which reads (and writes) information between the Cameo server and an internet browser. The user can thus access and modify all the budget information in a modern and user-friendly environment, without access to the model itself.

Risk Opportunity

Overview Detailed

#	Module	System	Unit	CBE [kg]	CBE ev. [kg]	DMM [kg]	DMM ev. [kg]	Nominal mass [kg]	Nominal mass ev.
0				12.64	0.18	1.33	0.02	13.97	8.95
1				5.67	0.1	0.44	0.01	6.11	4.99
2				1.04	0	0.02	0	1.06	0
3				1.18	0	0.06	0	1.24	0
4				0.79	0	0.04	0	0.83	0
5				0.63	0.04	0.05	0	0.68	1.98
6				0.6	0	0.12	0	0.71	0
7				0.12	0	0	0	0.13	0
8				1.31	0.06	0.15	0.01	1.46	3.02
9				0.27	0	0.02	0	0.3	0
10				0.27	0	0.02	0	0.3	0
11				0.96	0.02	0.18	0	1.14	1.19
12				0.96	0.02	0.18	0	1.14	1.19
13				5.25	0.06	0.63	0.01	5.88	2.76
14				4.38	0.06	0.46	0.01	4.84	2.77

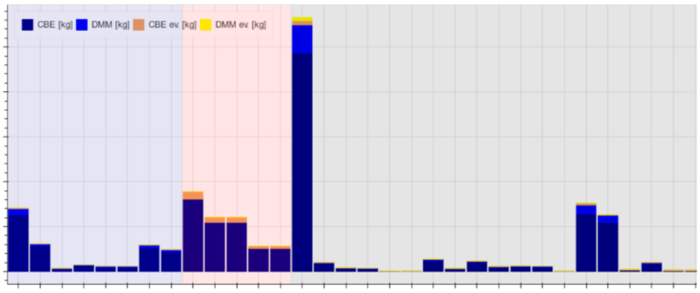


Figure 7: Insight into MSR-ERO mass budget dashboard – Risk & Opportunities (specific module, system, unit names & axis label have been redacted and values are fictive). Top: Table view of current risks. Lower: Graphical bar plots of risk based on table values (y-axis = mass, x-axis = unit names). CBE: Current best Estimates, DMM: Design Maturity Margin.

7. CONNECTIVITY

CAMEO tables have the options to be synched with Excel and thus offers the possibility for users to use this format. The python dashboard requests data directly from the Cameo model and as such has always the most up to date data when being launched.

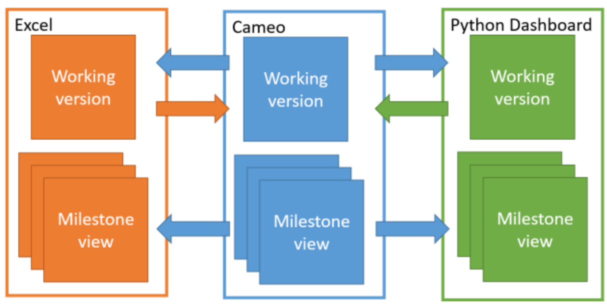


Figure 8: Interfaces between tools used in the mass budget management. Milestone versions are centralised within Cameo while working (e.g. current) version are synchronised.

8. CONCLUSION & OUTLOOK

An effective mass budget management system was developed and extended to the current MSR-ERO DISM. It uses existing SysML functionalities where possible and only minimal extensions ("stereotyping") were necessary. Some effort was required in developing an external viewer (i.e. "dashboard") but it was justified by the potential to view the mass budget in a simple bowser also serving users without CAMEO licenses. Version control is ensured by the usages of SysMLs built in instances system.

While this work was focused on mass, many more budgets (e.g. power budgets, …) could benefit greatly from a centralisation of information and from the interconnectivity that a model base environment presents.

References

[1] Affentranger, L. Huesing, J.(2021). Incorporating Model Based Reviews into the life cycle of the Earth Return Orbiter¶. *MBSE 2021.* Noordwijk: The European Space Agency, ESTEC.

[2] Bernaudin, J.-B. (2021). MBSE on MSR ERO: a use case. *MBSE 2021.* Noordwjik: The European Space Agency, ESTEC.