SysML Customization for Assisted Low Earth Orbit Design Space Exploration

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Abstract— This study addresses workshop objective O2; **limitations of current MBSE approaches and ways to circumvent or resolve these.** Exploration of the design space and performing trade-offs can be complex and time consuming. While MBSE has been shown to effectively address communication issues between engineers, most MBSE tools focus only on describing a baseline design with little provision for the variability modelling that is required for rapid iteration and exploration. This study has explored the use of a new SysML profile for design space exploration that assists the designer in generating and assessing new designs through interactive visualizations and analysis. The profile makes use of different techniques to assist the designer such as surrogate modelling and generative design. The profile can be used in traditional MBSE models and currently makes use of Cameo Simulation Toolkit to evaluate many different design alternatives and visualize the design space. Preliminary results of the study show that the profile can provide assistance in selecting parameter values for a system design and visualise multi objective optimisation problems with suggestions of optimal design points. Currently the profile is limited to only parameter value variation, but further work will extend this to higher levels of variability. It is hoped that this work will provide a valuable extension to the way MBSE is used in allowing it to become a design space exploration tool.

1 Introduction

- The aim of this study was to provide improved semantics **and toolset for design space exploration with SysML.**
- The toolset is based on the following techniques:
  - **Surrogate modelling**
  - **Generative design**
- Dassault Systems's **Cameo Systems Modeller** © was used as the MBSE tool

2 Design Space and Robustness SysML stereotypes

- Created new SysML stereotypes to describe variability for **design space exploration and design sensitivity**, fig. 1 and table 1.

Table 1 Design Space and Robustness SysML Stereotypes

Stereotype	Use Case	Example
Design Variable	Elements of the system to be actively varied during the design space exploration	Orbit parameters Solar array areas
Dependant Variable	Elements of the system that should be constrained	Data latency Size of data storage
Objective Variable	Elements of the system that have some goal related to them	Revisit time Mission lifetime
Noise Factor	System parameters to be perturbed during the sensitivity analysis	Any system parameter with uncertainty
Response Parameter	System parameters to be recorded for sensitivity calculations	Similar to dependant variables

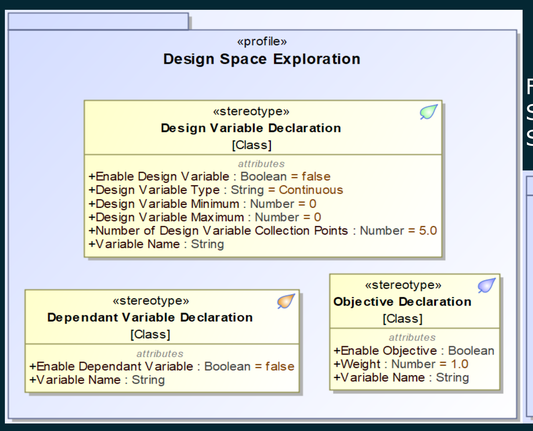

Figure 1: Design Space SysML Stereotypes

3 Workflow Diagrams

Four **workflow** diagrams were created for the toolset and are shown in fig.2, an is shown in fig.3

Generative Design Exploration: Basic using uniform sampling used across each design variable to generate new design options

Optimisation: MATLAB genetic algorithm to optimize the surrogate model and suggest an optimal design point

Surrogate Model Creation: Builds mathematical approximation of the model using radial basis functions

Design Sensitivities: Uses a gradient based method to assess design sensitivity

figure 2 Workflows implemented in the toolset

4 Design Space Visualisations

- Fig.s 4-7 show examples of **interactive visualisations**, generated using the toolset during a design space exploration using a model of a notional **Earth observation satellite** (Fig.8) in Cameo Systems Modeller.

Table 2 Example design space exploration setup

Variable	Model Element/Property
Design Variables	Orbit semi-major axis Orbit Inclination
Dependent Variables	Data Latency (3 days max) Downlinked Data Volume (15 data packets min)
Objective Variables	Data Latency (Minimise) Downlinked Data Volume (Maximise)
Noise Factor	Payload data packet size Imaging passes per downlink Orbit semi-major axis
Response Parameter	Data Latency Downlinked Data Volume

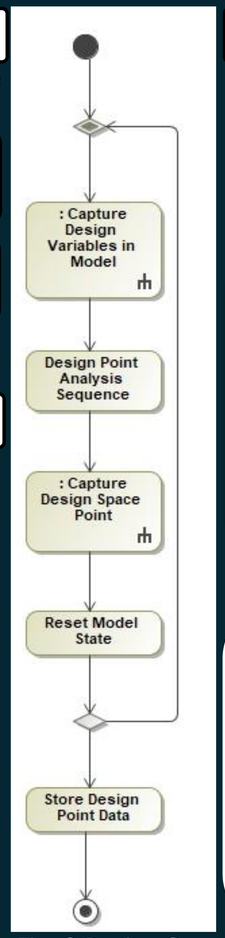

Fig. 3 Design Space Exploration Custom SysML Workflow Diagram

Figure 8: Orbit model of the notional Earth observation satellite in STK

5 Discussion and Next Steps

- Upcoming **ESA TRUTHS mission** case study, with Airbus Space and Defence.
- The design sensitivities could be used in a **first order reliability method**, to measure system robustness
- The custom SysML stereotypes are currently only able to describe **continuous parameter variability**, this should be expanded to higher levels of variability

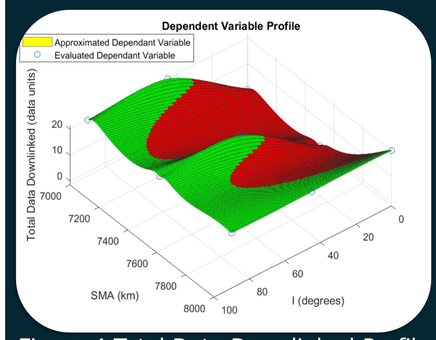

Figure 4 Total Data Downlinked Profile

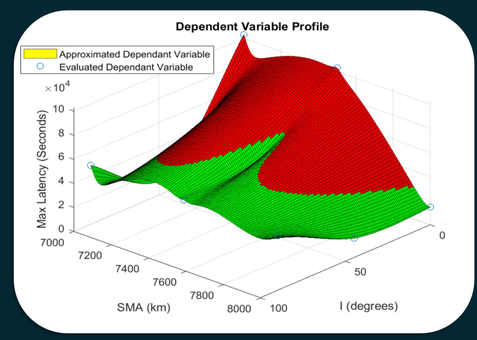

Figure 5 Max Latency Profile

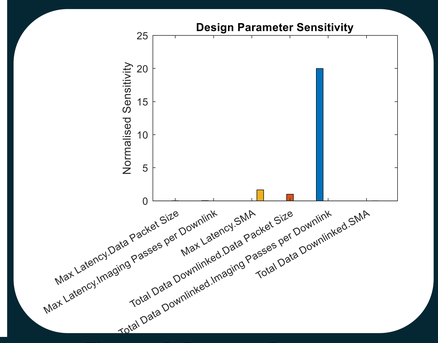

Figure 6 System Response Parameter Sensitivities to Various Noise Factors

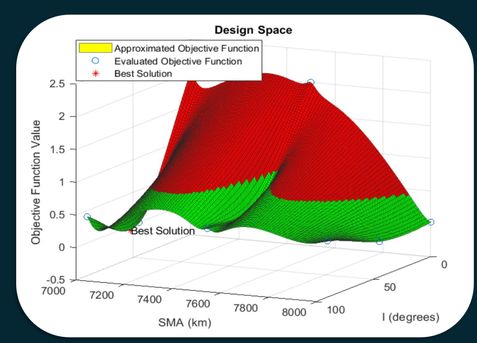

Figure 7 Design Space and Suggested Best Design Point

6 Conclusion

- The foundation of a design space exploration SysML profile and toolset has been laid. It can provide an understanding of the underlying relationships that exist in a given design space.
- The **applicability** of the profile is being widened and assessed via real life use cases.
- Design space explorations can be performed with many design, dependent and objective variables, and interactive design space visualisations can be rapidly generated.