# Surrogate-Based SmallSat Architecture Design Leveraging Integrated Parametric Mission Models

Allen Wautlet (allen.wautlet@ballaerospace.com), Greg Thanavaro, Ben Renkoski, Ball Aerospace

## MOTIVATION & RESEARCH OBJECTIVES

The modern space mission landscape requires consideration of many trade variables to meet growing cost and performance constraints. Presented is an approach to identifying promising smallsat architectures through integration of parameterized engineering and cost estimation models. The approach simultaneously explores design drivers at multiple levels of mission architecture including payload, bus, orbit, and launch vehicle by employing proven statistical, data science, and machine learning techniques. When deployed at the early stages of constellation development, this analysis approach delivers two main benefits: It informs stakeholders of mission performance and cost sensitivity to a variety of design variables, leading to better decision making earlier in the acquisition timeline; and it uncovers promising regions of large design spaces to be examined further by teams of experts, increasing the efficiency of engineering design cycles.

## METHODOLOGY

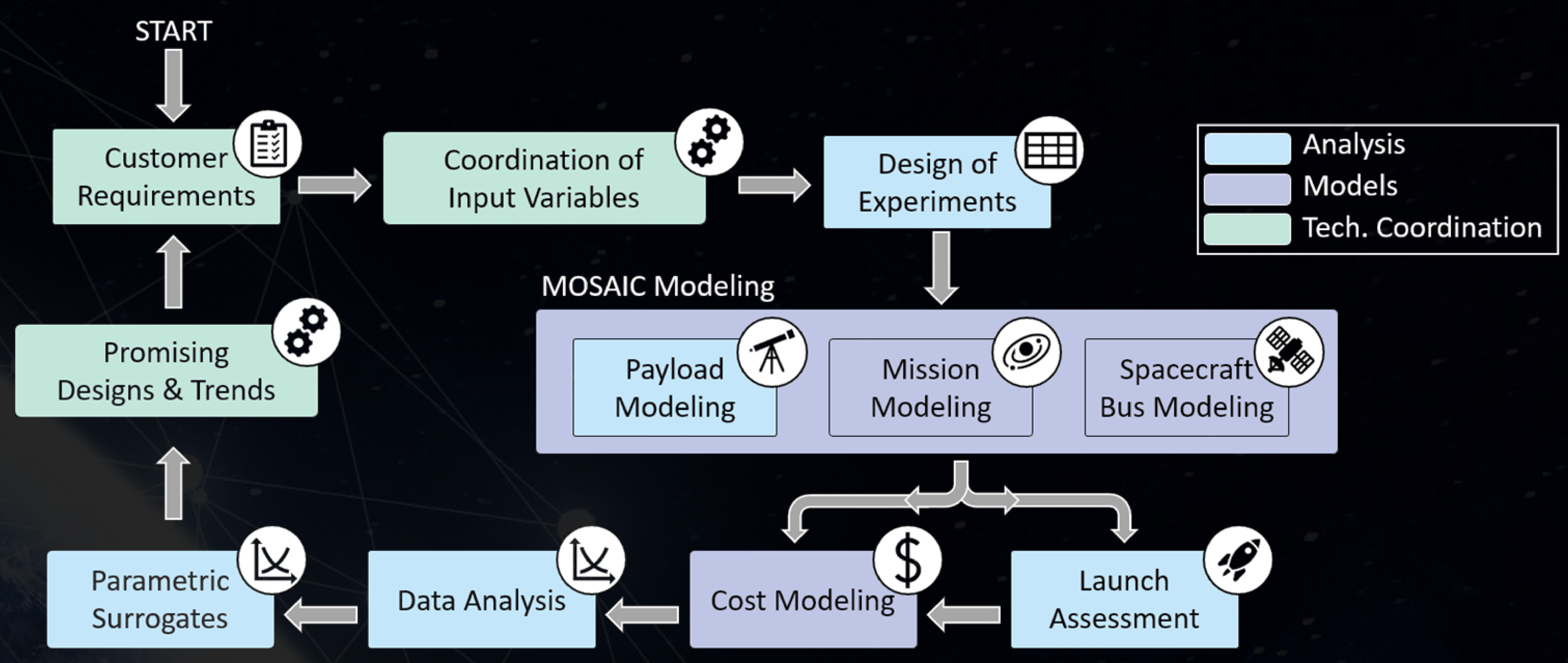


**FIGURE 1:** The constellation architecture analysis process combines design of experiments with multiple modeling capabilities to generate data, which yields surrogate models of performance, SWaP and cost.

## SCENARIO & MODELING RESULTS

The methodology is applied to a generalized Earth observation mission. A customer requires a low-cost pLEO architecture hosting 5 µm IR payloads. Mission measures of performance (MOPs) are Average MTTA (≤ 240 minutes), Ground Sample Distance (GSD) (≤ 25 m), and target collection capacity (≥ 35 targets per orbit).

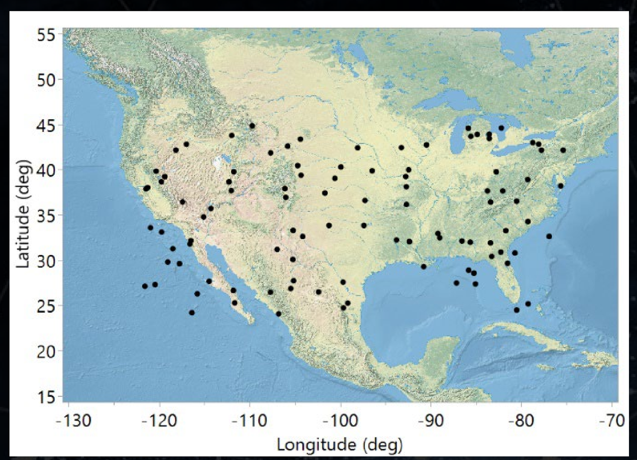

**FIGURE 2:** Target Deck for Capacity Analysis Over the US

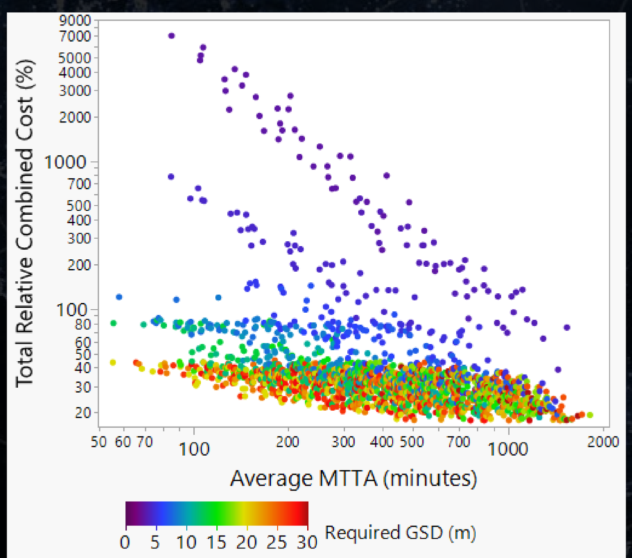

**FIGURE 3:** Average MTTA vs Relative Total Constellation Cost

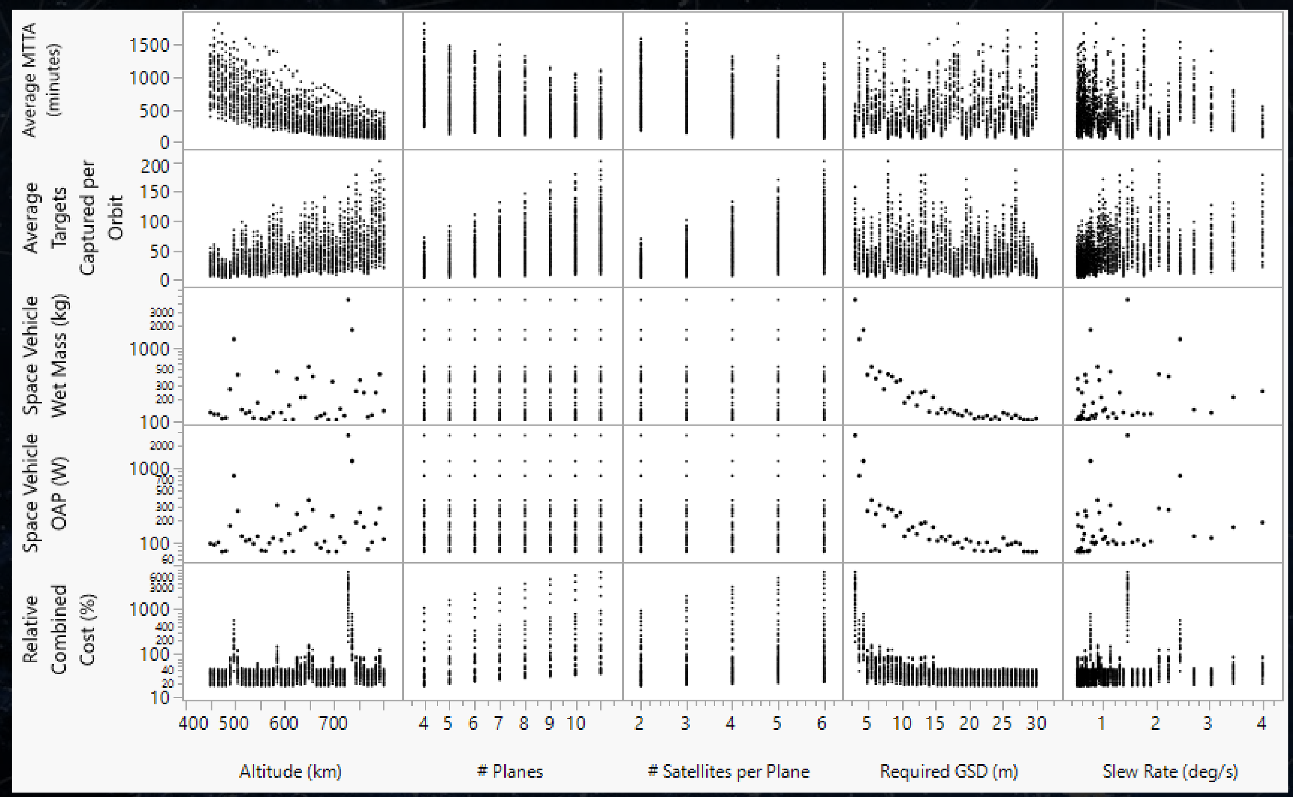

**FIGURE 4:** Mission-level outputs of interest from 1,800 simulation runs as a function of inputs of interest. Many intuitive trends are apparent, but detailed insights and optimal designs require further analysis.

## SURROGATE MODELS

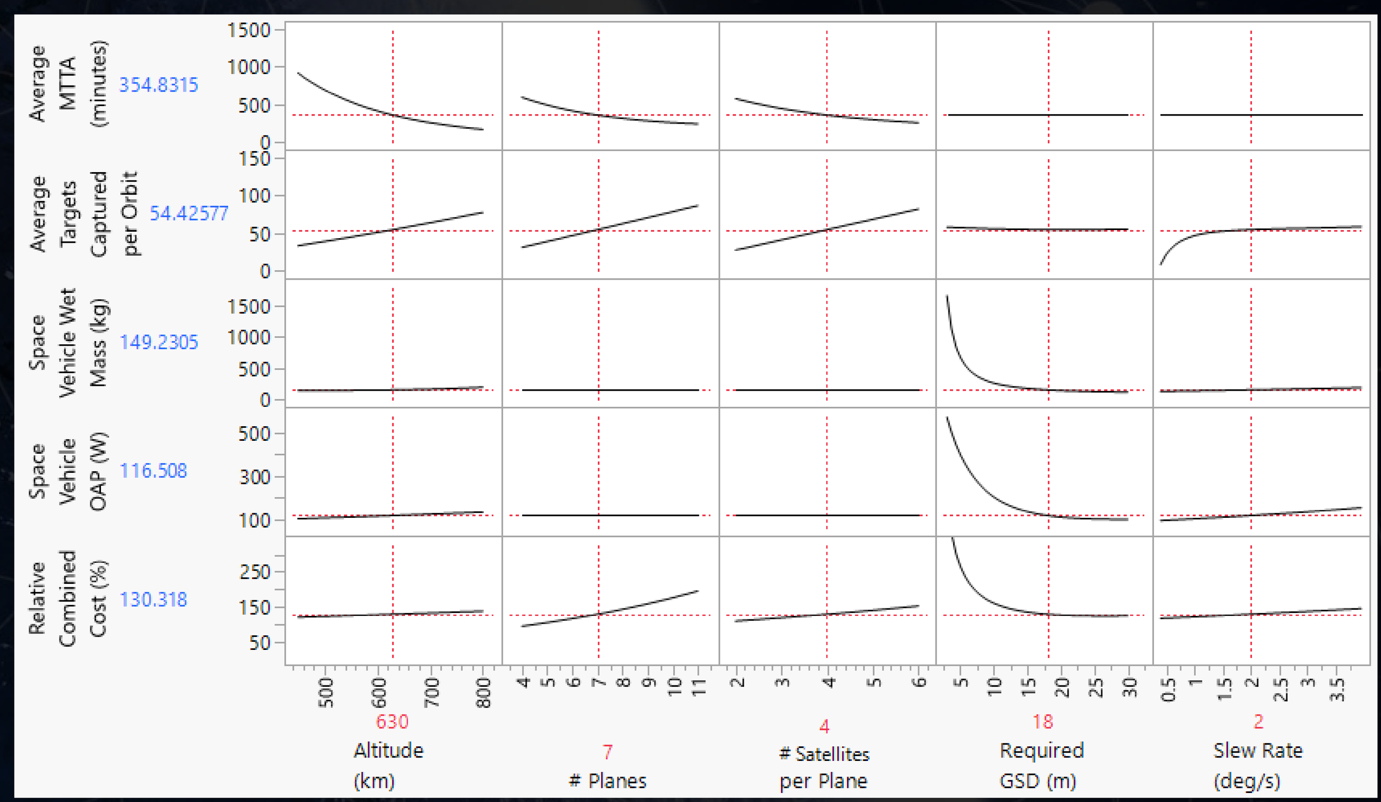

**FIGURE 5:** The surrogate models depict complex interactions between mission, space vehicle design, and cost in terms of inputs of interest. Relationships developed help identify promising mission architectures across a wide trade space and provide insight into architecture sensitivities.

While many surrogate modeling approaches exist, the phenomena contained within this data can be easily interpreted using simple relationships without the risk of overfitting.

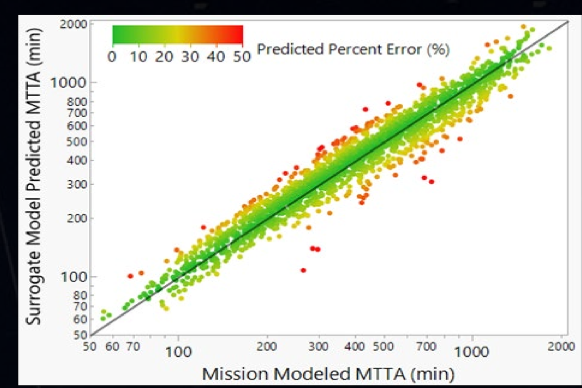

**FIGURE 6:** Predicted vs Expected Variance in Surrogate Models Show Suitable Model Fits

## ALTERNATIVE SOLUTIONS

Beyond the baseline solution, alternative architectures can be identified with the surrogate models using different evaluation criteria.

| | | ALTERNATIVE ARCHITECTURE SOLUTIONS | | | | |
|---|---|---|---|---|---|---|
| Constellation Parameter | Baseline Arch. Solution | Improved GSD and Agility + Minimize Cost | Better MTTA + Minimize Cost | Better MOPs for Lowest Cost | Better GSD and Agility + Maintain Cost Baseline | Minimize Planes + Maintain Cost Baseline |
| Altitude (km) | 800 | 752 | 732 | 780 | 798 | 741 |
| Number of Planes in Constellation | 5 | 5 | 7 | 7 | 4 | 2 |
| Number of Satellites per Plane | 4 | 5 | 5 | 6 | 4 | 4 |
| GSD (m) | 25 | 12.6 | 25 | 19 | 17.2 | 10 |
| Slew Rate (deg/s) | 0.56 | 1.2 | 0.5 | 1.1 | 1.5 | 2 |
| Average MTTA (minutes) | 240 | 240 | 180 | 120 | 300 | 600 |
| Average Targets Captured per Orbit | 35 | 59 | 43 | 102 | 43 | 20 |
| Space Vehicle Wet Mass (kg) | 133 | 216 | 118 | 160 | 186 | 296 |
| Space Vehicle OAP (W) | 94 | 156 | 88 | 111 | 130 | 221 |
| Relative Combined Cost (%) | 100 | 133 | 125 | 151 | 100 | 101 |

**Table 1:** Multiple promising mission alternatives are identified using the surrogate models that improve performance with similar cost. MOP tradeoffs are rapidly assessed allowing for extended "what-if" analyses.

## CONCLUSIONS AND FUTURE WORK

The surrogate modeling capability shown demonstrates an efficient and powerful approach to developing mission and space vehicle architectures, especially at the concept level. Surrogate models developed from validated modeling and simulation tools offer a proven approach to reducing design cycles. Rapid design cycles are invaluable during the early phases of a program. The generation of data and development of the surrogate models presented here was completed in two weeks utilizing four standard laptops. The implementation of this process is made possible by flexible, rapid, integrated, and validated modeling tools currently being employed at Ball Aerospace.

The approach demonstrated provides engineers with the opportunity to begin design maturation from relevant points of departure, and to rapidly adapt architecture concepts as customer requirements evolve. The benefits in both scope and efficiency enable the rapid discovery of highly capable, low cost, future space architectures.