INFORMING DATA SELECTION FOR SATELLITE SUBSYSTEMS COST ESTIMATING RELATIONSHIPS

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This paper seeks to improve the cost estimating piece of the resource management function for defense satellites. It provides guidelines to facilitate data selection decisions when developing satellite Cost Estimating Relationships (CERs). Over the years, there have been transformations in satellite sizes, shapes, orbits, and mission requirements. Cost practitioners must make decisions on how to model and/or segregate data by these characteristics when developing their estimates. This paper provides a flowchart for practitioners to follow when making data decisions for their CERs. It is recommended that cost practitioners initially filter by mission or orbit types. The subsequent level of separation suggests filtering based on shape, but the loss of data points may make this infeasible in some instances. Satellite size is also considered, but not recommended.

1. INTRODUCTION

The United States has taken a significant step in addressing emerging great power competition in outer space by establishing a dedicated military branch for space operations (United States Space Force, 2019). Space assets play a crucial role as force enablers to meet national objectives. While space superiority is rightly characterized by technological and operational parameters, an often overlooked, but vital characteristic to achieving this objective is the resource management function. The resource management function focuses on efficiently managing costs and securing rapid funding to initiate new programs.

This paper seeks to improve the cost estimating piece of the resource management function by providing guidelines on data selection in satellite Cost Estimating Relationships (CERs).

An extant conundrum in satellite cost estimating is data selection for cost models. Notably, not all cost reporting is uniform, leading to a disconnect between reported data and the ideal information for cost estimating. This disconnect becomes more pervasive at lower levels of the Work Breakdown Structure (WBS). Cost analysts need the data to construct CERs, which are a common tool cost estimators utilize to estimate new capabilities, particularly in the early stages of a program. Determining which sets of data to include in the development of the CER is key for credible resource estimations.

This paper focuses on data selection criteria when developing CERs at lower levels of the satellite WBS. More specifically, we focus on Bus subsystems. While previous literature provides satellite CER guidance at higher WBS levels (Hadfield, 1974; Koelle, 1984; Rasmussen, 1998; Mabrouk, 2015), there is little to no previous analyses at the Bus subsystem level. Arguably, cost estimates are more realistic and credible when conducted with data at lower WBS levels. Thus, developing data selection criteria for these lower WBS levels is a key enabler to improving satellite cost estimations.

Lastly, this paper seeks to investigate how cost estimators should account for the unique characteristics of satellites. Data selection considerations regarding differences in satellite size, shape, orbit, mission, and contractor are also explored.

2. LITERATURE REVIEW

2.1. Space Systems

We first provide an overview of the components that comprise a Space System. This fundamental understanding of a Space System undergirds the data collection process that cost analysts utilize for their models. A Space System includes the Space Vehicle, Ground Segment, Orbital Transfer Vehicle and Launch Vehicle among others (Department of Defense, 2022). This paper is specifically focused on the Space Vehicle level (i.e. the satellite itself), which is further broken-down into two primary elements: the Space Vehicle Payload and the Space Vehicle Bus.

The Space Vehicle Bus, which is the focus of this paper, serves as the housing section for elements

that enable the satellite to fulfill its mission by carrying payloads and supporting various functions (Department of Defense, 2022). Essentially, the Bus constitutes the fundamental structure of the satellite, comprising subsystems that provide essential support. Table 1 outlines the subsystems of the Bus along with brief descriptions of their functions.

Table 1 Bus Subsystems and Their Function

Subsystem	Function
Attitude Control (ACS)	Counteracts gravitational pulls and keeps the antennas pointed in the desired direction
Electrical Power (EPS)	Convert, regulate, store, distribute, and switch the electrical energy to the Bus and Payload elements
Propulsion	Provides the thrust required to make corrections or reposition the satellite
Structures & Mechanisms (SMS)	Structural support, deployment, and locking functions
Telemetry, Tracking, & Command (TT&C)	Control functions to keep the satellite operating safely in orbit. Communicates with an Earth terminal facility to maintain orbit.
Thermal Control (TC)	Controls the different temperature environments and keeps it stable

2.2. Satellite CERs

Prior research in satellite CERs provides insight into potential cost drivers and other key considerations when developing modern CERs. Hadfield (1974) emphasized payload weight as a key parameter in CER development. Hadfield (1974) distinguished between nonrecurring and recurring costs, proposing that recurring cost CERs could aid in early tradeoff identification before completing the full conceptual design. [Note: non-recurring costs are one-time activities such as design engineering, while recurring costs are incurred each time a unit is produced, such as direct material.] However, he cautioned that design factors beyond payload weight might influence satellite complexity, necessitating different CERs to be developed.

Mahr and Richardson (2002) highlighted the transition from larger to smaller satellites in the 1990s as a catalyst for exploring new CERs based on payload weight. They specifically focused on satellites with a payload weight of less than 1,000 kg. They suggest that traditional cost models had been overestimating small satellite estimates and therefore advocate for bespoke small satellite CERs such as those developed by the Aerospace Corporation.

Drenthe et al. (2019) developed CERs for commercial satellites in

the early development phase, before the full design is complete. They adopted a hybrid approach, combining Koelle's (1984) three-phase approach and Mandell's (1992) use of T-1 costs to create CERs for non-recurring and recurring costs. Their novel approach allowed for CER development at the subsystem level. These prior studies all provided important insights into various aspects of satellite CER development, but they do not address how cost estimators should strategically select the data to populate the CERs.

The unique characteristics of a satellite may also impact the data selection process. Satellites have evolved over the years, each presenting unique requirements to fulfill its specific mission and objectives. The complexity of satellite designs makes the CER data selection process challenging. Previous research has identified key categories, or characteristics, that may warrant consideration in the data selection process. Table 2 outlines these categories and provides key finding from the literature.

Table 2 Categories for Consideration in Data Selection

Category	Literature Findings
Size	- Identified size as potential important cost factor (Sandau et, al. 2010; Mahr and Richardson, 2002)
Shape	- Box: Design makes it well suited for solar panels. Useful for when a satellite needs to store and produce more power (European Space Agency, 2011). - Cylinder: Low area to mass ratio, helps achieve desired stability and control during orbit (Boulton, 1984) - Hexagon: Improved structural strength and stability, useful when satellites need to withstand large operational stresses (Stough et al., 2020).
Orbit	- Geostationary Orbit (GEO): Used for communication, weather monitoring, and broadcasting purposes. Allows for continuous coverage over a specific region (European Space Agency, 2020). - Low Earth Orbit (LEO): Used for earth observation, remote sensing, and satellite constellations. (high resolution imaging or an area that requires frequent visits) (European Space Agency, 2020). - Medium Earth Orbit (MEO): Enables tracking of large aircraft and GPS on mobile devices, offers global coverage simultaneously (European Space Agency, 2020).

In summary, previous research has contributed valuable insights into satellite CER development based on payload weight. However, the extant literature is focused on the system level, with

limited examination of cost relationships at the subsystem level. Additionally, discerning whether CER development should be differentiated by the unique characteristics of the satellite (size, shape, orbit, etc.) has not been thoroughly investigated. This paper seeks to fill those gaps by delving into an exploration of the categories that should be considered in data selection for CER development, shedding light on the factors that influence the cost dynamics of satellite Bus subsystems beyond just size.

2. METHODOLOGY

3.1. Data

The data used in this paper comes from the Unmanned Space Vehicle Cost Model (USCM), which is maintained by Space Systems Command (SSC). The database contains a total of 122 programs from 1970 to 2017. The USCM database is normalized by Average Unit Costs (AUC) in thousands of dollars to Constant Year (CY) 16 using the NRO 2017 indices. Furthermore, SSC employs an algorithm to evaluate the reliability of the USCM data. This evaluation considers assumptions, completeness, and level of detail for all programs. The assessment is conducted on a scale of zero to ten. A data quality score of seven and

above is considered reliable (Kwok, 2023).

Table 3 shows the data exclusion criteria. First, 27 programs were removed due to a data quality score below 7. Next, 20 programs that did not have Bus data were excluded. Lastly, two programs that did not have Bus Subsystem data were removed. The final dataset for analysis is 73 programs.

Table 3 Bus's Subsystem Exclusion Criteria

Start	Removed	Remaining
122	27 under a score of 7	95
95	20 did not have Bus costs	75
75	2 did not have Bus Subsystem data	**73**

3.2. Variables

Previous research focused on weight as a primary cost driver in satellite Cost Estimating Relationships (CERs). This paper is not deriving new CERs. Rather, the goal of this paper is to inform the data selection process that populates the CERs. Our interest, therefore, is in testing differences in the data based on various satellite characteristics. To accomplish this, the data is segregated by the satellite's Size, Shape, Orbit, Mission, and Contractor.

Satellite size (small, medium, large) is annotated in the USCM database. Small satellites are less

than 600 pounds, Medium is between 600 and 1,300 pounds, and Large is anything more than 1,300 pounds (Contreras et. al, 2022). The satellite shape, orbit, and mission subcategories are also annotated in the USCM database. USCM tracks three definitive shapes and has a fourth category to encompass the ones that do not fall into the three. The four categories are box, cylinder, hexagon, and "other". The USCM database includes orbits such as Geostationary Orbit (GEO), Highly Elliptical Orbit (HEO), Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Polar Orbit, and Earth-Trailing and Interplanetary Orbits. Each orbit serves a different purpose and consequently requires distinct design specifications, leading to potential variations in costs. Finally, there are six mission types that are tracked within the USCM database that, similar to orbit, require different specifications. The six mission types are communications, environmental, experimental, navigation, scientific, and surveillance.

All of these characteristics were identified in the literature as potential variables of interest (Boulton, 1984; Mahr and Richardson, 2002; Sandau, et al., 2010; European Space Agency, 2011; European Space Agency, 2020). While contractor was not explicitly discussed in the literature, it is intuitive that contractors may have varied development processes and methods that impact costs. Therefore, the contractor variable is also explored. To maintain confidentiality, the contractor names are randomly assigned a number from 1-9. See Table 4.

Table 4 Categories for Analysis

Categories				
Size	**Shape**	**Orbit**	**Mission**	**Contractor**
Small	Box	Earth Trailing/Heliocentric	Communications	1
Medium	Cylinder	GEO	Environmental	2
Large	Hexagon	HEO	Experimental	3
	Other	Interplanetary	Navigation	4
		LEO	Scientific	5
		MEO	Surveillance	6
		Polar, Sun-synchronous		7
				8
				9

3.3. Statistical Tests

The first step is to calculate the distribution of satellite subsystem costs. The cost percentages are calculated as a ratio of the Bus subsystems AUC (which corresponds to Work Breakdown Structure Level [WBS] 3) to the Bus AUC (which corresponds to WBS Level 2). A notational example of how the cost percentages were calculated in shown in Table 5. Additionally, Table 5 delineates the six Bus subsystems that are analyzed in this paper.

Table 5 Cost Percentage of Bus Subsystem to Bus Example

WBS Level 2	WBS Level 3	AUC (Level 2)	AUC (Level 3)	Cost Percentage (Level 3) to (Level 2)
Bus	Attitude Control (ACS)	$59,459	$9,037	15.20%
Bus	Electrical Power (EPS)	$59,459	$20,941	35.22%
Bus	Propulsion	$59,459	$4,548	7.65%

Next, hypothesis testing is utilized to determine whether there are differences in the Bus subsystem cost percentages when the data is separated by the subcategories of Table 4. Due to the small sample, we use the rank-based nonparametric Kruskal-Wallis test. The Kruskal-Wallis test determines whether there are statistically significant differences between two or more groups of independent variables on a continuous dependent variable (McClave et al., 2018). Having small sample sizes makes it hard to state if the distributions are the same or different. As a result, we utilize the term distribution of responses (location) versus median. An alpha of 0.05 is used. The specific Kruskal-Wallis hypothesis tests are:

H_o: *The responses are equivalent between the groups*

H_a: *One or more groups have statistically different responses*

Lastly, the Steel-Dwass multiple comparison test is used to identify which rank orders of the tested groups are statistically different for each sub-category comparison. This test assists in determining the specific sub-category comparisons that exhibit statistically significant differences compared to the other sub-categories. An alpha of 0.05 is used.

By employing these statistical tests, this paper aims to identify and analyze significant differences and relationships among the categories and sub-categories under investigation. Each category started with the 73 programs from Table 3 and has further exclusion for any sub-category that had an N less than five. The Kruskal-Wallis test

requires a sample size of five, hence the sub-category exclusions.

4. RESULTS

The first analysis explores how different satellite characteristics may affect the subsystem cost percentages. The literature review identified three categories that may exert influence on variations in subsystem cost percentages: Size (Koelle, 1984, Sandau et al. 2010, Rasmussen, 1998; Mabrouk, 2015), Shape (Boulton, 1984, European Space Agency, 2011, Stough et al., 2020), and Orbit (Hadfield, 1974, Campbell, 2017, European Space Agency, 2020, Space Foundation, 2023). Additionally, mission type and contractor are hypothesized as potential variables that may impact future data selection choices.

The Kruskal-Wallis tests rejected the null hypothesis (that all responses are equivalent across the groups) for all six Bus subsystems and found that each of the satellite characteristics indeed has varying degrees of impact on cost percentages. Individual Steel-Dwass tests were then run to identify where those differences occur (see Appendix A for the individual Kruska-Wallis and Steel-Dwass test results). Table 6 provides a visual representation of the significant variables within each dataset. An "X" in the table indicate that data from that subcategory should not be combined together.

Table 6 Steel-Dwass Subsystem Results at 0.05 Significance

Category	Size			Shape			Orbit			Mission					Contractor				
Subsystem	Small	Medium	Large	Box	Cylinder	Hexagon	LEO	MEO	GEO	Scientific	Communications	Environmental	Experimental	Navigation	Three	Four	Seven	Eight	Nine
Attitude Control (ACS)								X	X	X	X			X		X		X	X
Electrical Power (EPS)	X		X	X	X		X	X	X	X	X		X	X					
Propulsion							X	X	X	X	X	X		X				X	X
Structures & Mechanisms (SMS)								X	X	X	X			X					
Telemetry, tracking & Command (TT&C)	X	X	X	X	X		X	X	X	X	X			X	X		X	X	X
Thermal Control (TCS)					X	X	X		X									X	X

4.1. Subsystem Significance

Size is identified as significant in a limited number of instances. The recurring theme is the Small satellite size displaying significance. The results imply that cost practitioners should segregate out the Small satellite data for any CERs being developed for the TT&C subsystem. The EPS finding is more nuanced. Only the Small-Large comparison was statistically significant. Practitioners are therefore advised that Medium satellite EPS data can be combined with either the Small or Large, but the Small and Large satellites should not be combined in future EPS CERs. While Size can be a consideration in data selection, its overall association with cost percentages appears to be relatively minor. Thus, the benefit of breaking down data by Size may not outweigh the loss of data points.

Next, shape shows three Bus subsystems demonstrating significance, and identified the Cylinder and Box shapes as key differentiators. This result implies that cost practitioners should consider segregating out Cylinder and Box satellite shape data for any CERs being developed for the EPS, TT&C, and TCS subsystems. Practitioners are therefore advised that Hexagon satellites for EPS, TT&C, and TCS data can be combined with either the Box or Cylinder, but the Box and Cylinder satellite data should not be combined in future EPS, TT&C, and TCS CER developments.

Orbit finds the most differences of all the satellite characteristics. The recurring theme of the Steel-Dwass tests is that LEO and GEO are different in four subsystems and MEO and GEO are different in three subsystems. The MEO and LEO combination displayed significance in only two subsystems (ACS and TT&C). The results imply that cost practitioners should be aware of the Orbit for any CERs being developed for all subsystems but especially for EPS, Propulsion, and TT&C as there was only one possible Orbit combination for these subsystems that did not show significance.

Mission finds the second most differences of all the satellite characteristics. Communication stands out because it is different than at least one other mission in five subsystems. Similarly, Navigation and Environmental have at least one difference with another mission in four subsystems. The results imply that cost practitioners should be cognizant of the mission during CER development.

Lastly, contractor has two notable findings. First, TT&C has four instances of contractor combinations flagging as statistically significant. Second, the 9-8 contractor combination is statistically significant in four separate subsystems. However, more in-depth analysis may be needed before proceeding with these contractor results. Previous statistical differences within earlier categories (e.g. Orbit, Shape, etc.) might serve as potential explanations for variations among contractors, making it advisable to conduct additional multi-variate analysis. We explore this possibility in the next section of the paper.

In summary, there are four key findings from the categorical analyses in Table 6. First, subsystem cost percentages do not appear to be frequently influenced by Size. Second, while Shape has some minor effects on cost percentage, it is not a frequent differentiator. Third, Mission, Orbit and Contractor all significantly influence the cost percentage of a subsystem. Finally, the differences in subsystem cost percentages related to Contractors warrant further investigation.

4.2. Confounding Variables – An Exploration of Contractor

The previous analyses suggested that Mission, Orbit, and Contractor are important differentiators in the data. However, it is possible that the Contractor variable demonstrated statistical significance because it is really capturing a "Mission type" or "Orbit" effect, rather than a unique aspect attributable to the contractor itself. To investigate, the Contractor variable was introduced as a binary variable in contingency table analyses to shed light on potential associations between contractors and the different categories.

Contingency tables are a tabular representation of categorical data that displays the frequency or count of occurrences corresponding to specific combinations of categories from the variables. From these tables, the Pearson Chi-squared test can be used to assess if the outcomes in the table are associated with each other. They compare the observed frequencies of occurrences to the expected frequencies given independence, which tests if the variables are related or if the observed distribution is significantly different from what would be expected by chance (McClave et al., 2018). Additionally, variables

compared in a contingency table have an odds-ratio, which quantifies the strength and direction of the association. Table 7 illustrates the categories that emerged as significant and exhibit dependencies with their respective variables (i.e., Size, Shape, Orbit, and Mission) at a 0.05 significance level.

Table 7 Dependency Contractor Results at 0.05 Significance

Category / 0.05 Significance	Size			Shape			Orbit			Mission				
Contractor	Small	Medium	Large	Box	Cylinder	Hexagon	LEO	MEO	GEO	Scientific	Communications	Environmental	Experimental	Navigation
Contractor 3							X		O	O				
Contractor 4				X	X			O		X				O
Contractor 7				X	O			X					O	X
Contractor 8	O			X		O	O	O	X	O	X			O
Contractor 9	X													

In Table 7, an "X" denotes significance with an associated odds ratio, although it's important to disclose that all the odds ratios had confidence intervals with wide ranges. (See Appendix B for full dependency results between Contractor and the different categories. Dependency results between Orbit and Mission are included as well). An "O" indicates a significant Pearson value, but the odds ratio was not applicable (N/A) as it did not occur. For example, contractor eight was significant for all three orbits, but contractor eight was only used in GEO orbit and not used in LEO or MEO, hence the N/A odds Ratio. Our primary focus was on identifying the dependency rather than the specific odds ratios.

Table 7 shows a clear dependency between Orbit-Contractor and Mission-Contractor. Additionally, Contractor-Shape exhibits a dependency, primarily with Box-shaped satellites, which represents the majority of shapes within our dataset. We also examined the relationship between Orbit and Mission. Although the results are not presented here, Mission and Orbit showed themselves to be highly associated with one another. These results suggest that there are multiple associations that need to be considered in the data selection process.

Next, Figure 1 presents a descriptive 3D graph illustrating the three-level dependency with

the Mission type, Orbit, and Contractor variables. Increased point density within a specific region indicates heightened interaction among the three variables. The key observation is that Contractor appears to be a confounding variable with Mission and Orbit. For example, contractor eight's points are all in a singular area, suggesting that contractor eight is exclusively utilized in one specific mission and orbit type. While the other contractors exhibit a broader distribution between orbit and mission, there still are some clustering points that overall indicate diverse connections between orbit and mission type for the majority of contractors.
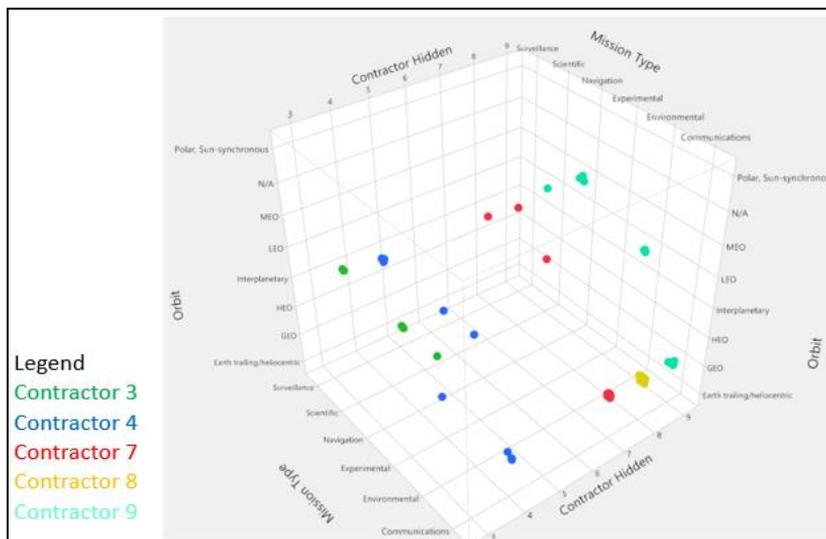

Fig.1 3D Scatterplot of Mission, Orbit, and Contractor

5. CONCLUSION

One way to improve resource management is through the cost analysis process. This paper focused on making the CER data selection process for Satellite Bus subsystems better. Our findings emphasize that there isn't a single, universally applicable recommendation for selecting data categories when developing CERs for estimating Bus subsystem cost percentages. Therefore, we propose a three-tiered approach to guide practitioners. See Figure 2.

The green boxes on the right signify recommended levels of filtering while the yellow boxes represent additional levels of filtering that may be pursued if the data sample size allows.
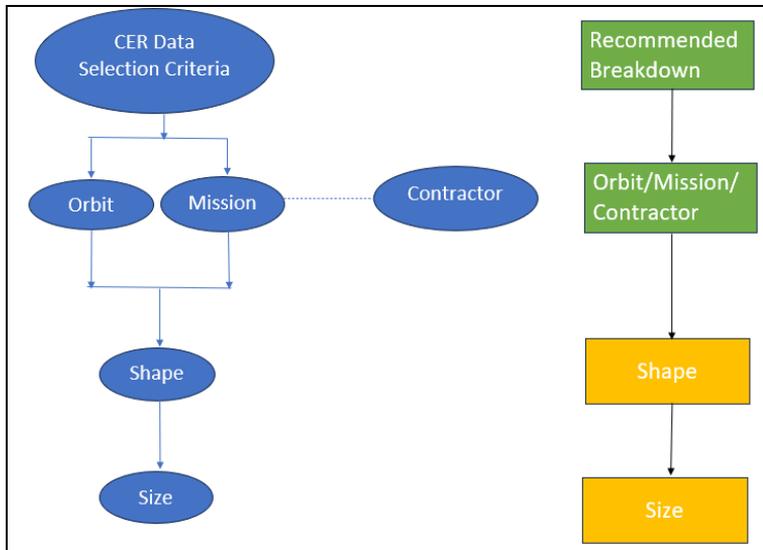

Fig. 2 CER Data Selection Flowchart Recommendation

First, we recommend segregating the data by Mission or Orbit. Both Mission and Orbit were consistently found in our analysis to be differentiators. While Contractor was also found to be a frequent differentiator, it is likely confounded with Orbit and Mission as previously discussed in the paper. The dashed line for Contractor on the flowchart is meant to convey that fact. The reality that Contractor is likely confounded with other variables makes it a less desirable approach and as a result it is not recommend.

Second, we recommend practitioners consider segregating data by Shape in some instances. This recommendation primary applies to Box and Cylinder shaped satellites and is contingent upon an adequate sample size. Lastly, Size can be considered as a final level of filtering. We caution, however, that Size only mattered in a small number of cases. The benefit of filtering by Size may not outweigh the loss of data points.

The importance of space assets to national defense is undoubtedly enduring. Our contribution supports the space frontier from

the resource management angle. The recommended data selection flowchart can inform future CER development and lead to more realistic and credible cost estimates. Future research should improve upon this study as more data becomes available.

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Appendix A Kruskal-Wallis and Steel Dwass Test Results

Significance Levels	*0.05	**0.01	***0.001

Steel-Dwass Test Results – Size

Element	Observational Level	*P*-Value
Electrical Power (EPS)	Small-Large	0.0148*
Telemetry, tracking & Command (TT&C)	Small-Large	0.0014**
Telemetry, tracking & Command (TT&C)	Small-Medium	0.0072**

Steel-Dwass Test Results – Shape

Element	Observational Level	*P*-Value
Electrical Power (EPS)	Cylinder-Box	0.0041**
Telemetry, tracking & Command (TT&C)	Cylinder-Box	0.0006***
Thermal Control (TCS)	Cylinder-Box	0.0006***

Steel-Dwass Test Results – Orbit

Element	Observational Level	*P*-Value
Attitude Control (ACS)	MEO-GEO	0.0195*
Electrical Power (EPS)	MEO-LEO	0.0057**
Electrical Power (EPS)	LEO-GEO	0.0052**
Propulsion	MEO-GEO	0.0062**

Propulsion	LEO-GEO	0.0023**
Structures & Mechanisms (SMS)	MEO-GEO	0.0053**
Telemetry, tracking & Command (TT&C)	LEO-GEO	<0.0001***
Telemetry, tracking & Command (TT&C)	MEO-LEO	0.0034**
Thermal Control (TCS)	LEO-GEO	0.0054**

Steel-Dwass Test Results – Mission

Element	Observational Level	*P*-Value
Attitude Control (ACS)	Environmental-Communications	0.0052**
Attitude Control (ACS)	Navigation-Communications	0.0334*
Electrical Power (EPS)	Navigation-Environmental	0.0334*
Electrical Power (EPS)	Navigation-Experimental	0.0052**
Electrical Power (EPS)	Experimental-Communications	0.0282*
Propulsion	Scientific-Communications	0.0455*
Propulsion	Navigation-Communications	0.0060**
Propulsion	Environmental -Communications	0.0023**
Structures & Mechanisms (SMS)	Environmental-Communications	0.0171*
Structures & Mechanisms (SMS)	Navigation-Communications	0.0060**
Telemetry, tracking & Command (TT&C)	Experimental-Communications	0.0074**
Telemetry, tracking & Command (TT&C)	Scientific-Communications	0.0201*

Steel-Dwass Test Results – Contractor

Element	Observational Level	*P*-Value
Attitude Control (ACS)	8-4	0.0291*
Attitude Control (ACS)	9-8	0.0411*
Propulsion	9-8	0.0459*
Telemetry, tracking & Command (TT&C)	9-8	0.0001***
Telemetry, tracking & Command (TT&C)	8-3	0.0056**
Telemetry, tracking & Command (TT&C)	7-3	0.0315*
Telemetry, tracking & Command (TT&C)	8-7	0.0024**
Thermal Control (TCS)	9-8	0.0038**

Appendix B Contractor Dependency Results

Significance			*0.05	**0.01

Contractor by Size Dependency Analysis

Comparison	X² *P-*Value	Odds Ratio	Lower Bound	Upper Bound	Interpretation
Contractor 9					
Small	0.0299**	3.6364	1.1419	11.5798	Contractor 9 is 3.63 times more likely to be used in Small satellites

Contractor by Shape Dependency Analysis

Comparison	X² *P-*Value	Odds Ratio	Lower Bound	Upper Bound	Interpretation
Contractor 4					
Box	0.0004**	0.1015	0.0250	0.4114	Contractor 4 is 9.85 times less likely to be found in Box shape satellites
Cylinder	0.0036**	10.3704	2.1041	51.1147	Contractor 4 is 10.37 times more likely to be found in Cylinder shape satellites
Contractor 7					
Box	0.0122*	4.6897	1.2264	17.9326	Contractor 7 is 4.69 times more likely to be found in Box shape satellites
Contractor 8					
Box	0.0381*	4.4118	0.9055	21.4942	Contractor 8 is 4.41 times more likely to be found in Box shape satellites

Contractor by Orbit Dependency Analysis

Comparison	X² *P-*Value	Odds Ratio	Lower Bound	Upper Bound	Interpretation
Contractor 3					
LEO	0.0010**	22.9167	2.4494	214.4055	Contractor 3 is 22.92 times more likely to be found for LEO
Contractor 7					
MEO	0.0022**	8.9744	2.0350	39.5730	Contractor 7 is 8.97 times more likely to be found for MEO orbits
Contractor 8					
GEO	<0.0001**	N/A	N/A	N/A	Contractor 8 only used in GEO

Contractor by Mission Dependency Analysis

Comparison	X^2 *P*-Value	Odds Ratio	Lower Bound	Upper Bound	Interpretation
Contractor 4					
Scientific	0.0158*	6.0	1.4411	24.9815	Contractor 4 is 6 times more likely to be found in Scientific
Contractor 7					
Navigation	0.0022**	8.9744	2.0352	39.5730	Contractor 7 8.97 times more likely to be found in Navigation
Contractor 8					
Communications	<0.0001**	N/A	N/A	N/A	Contractor 8 only did Communication

Orbit by Mission Dependency Analysis

Comparison	X^2 *P*-Value	Odds Ratio	Lower Bound	Upper Bound	Interpretation
LEO					
Scientific	0.0064**	7.0910	1.7096	29.4114	LEO is 7.09 times more likely to be found in Scientific
Environmental	0.0110*	7.3611	1.5430	35.1176	LEO is 7.36 times more likely to be found in Environmental
Experimental	0.0040**	11.25	1.9451	65.0685	LEO is 11.25 times more likely to be found in Experimental
MEO					
Navigation	<0.0001**	N/A	N/A	N/A	MEO is only used in Navigation
GEO					
Communications	<0.0001**	N/A	N/A	N/A	Communication is only used in GEO
Experimental	0.0234*	0.1228	0.0140	1.0783	Experimental is 8.14 times less likely in GEO