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Spacecraft Design to a Cost Target

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Ryan Sukley

Senior Cost Analyst at Technomics, Inc.

Support to the CEMA Office at NASA GSFC

rsukley@technomics.net

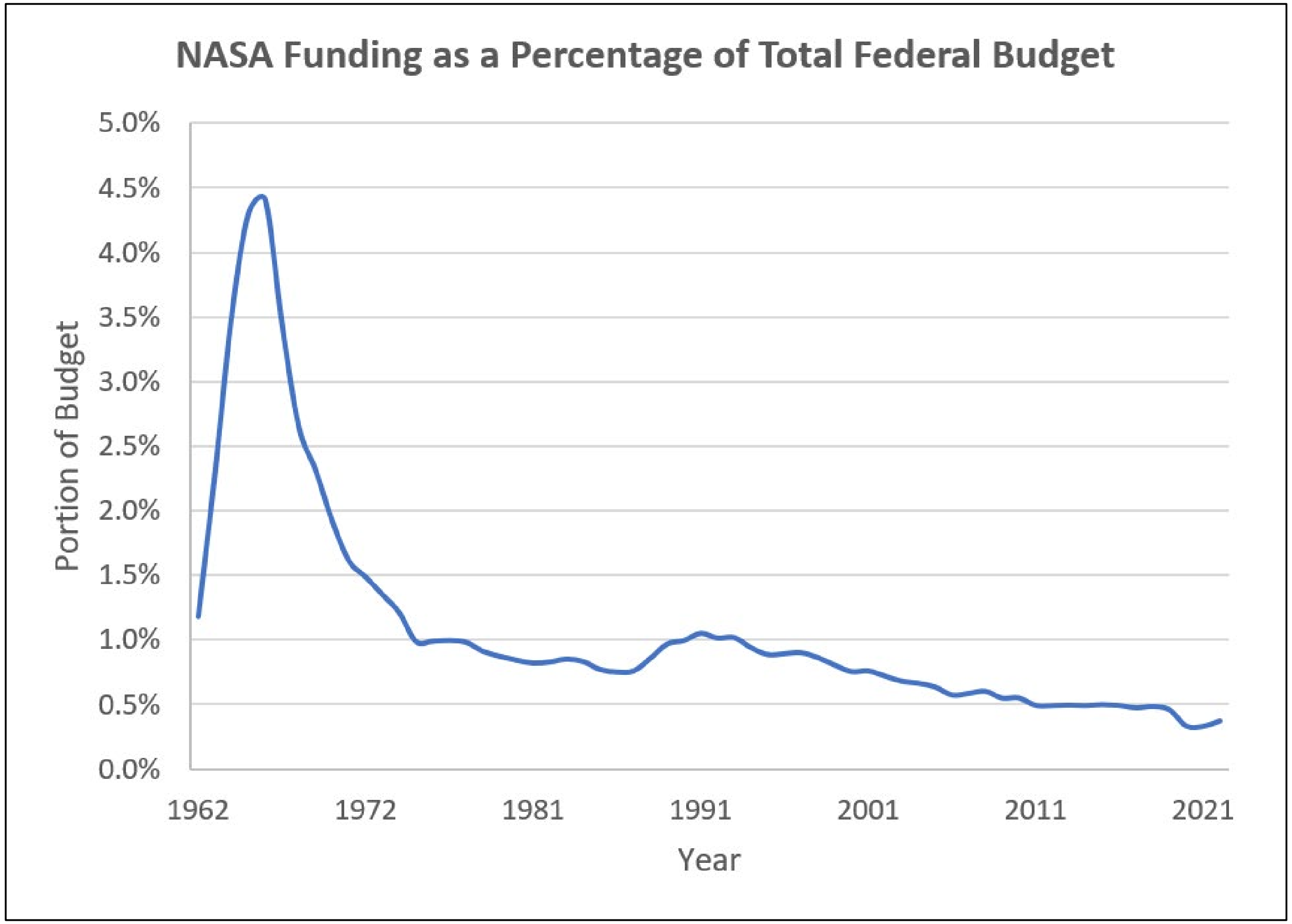
ryan.a.sukley@nasa.gov

Agenda

- Background
- The Spacecraft Mass Estimation Capability (SMEC)
- SMEC Application
- Conclusion

Background

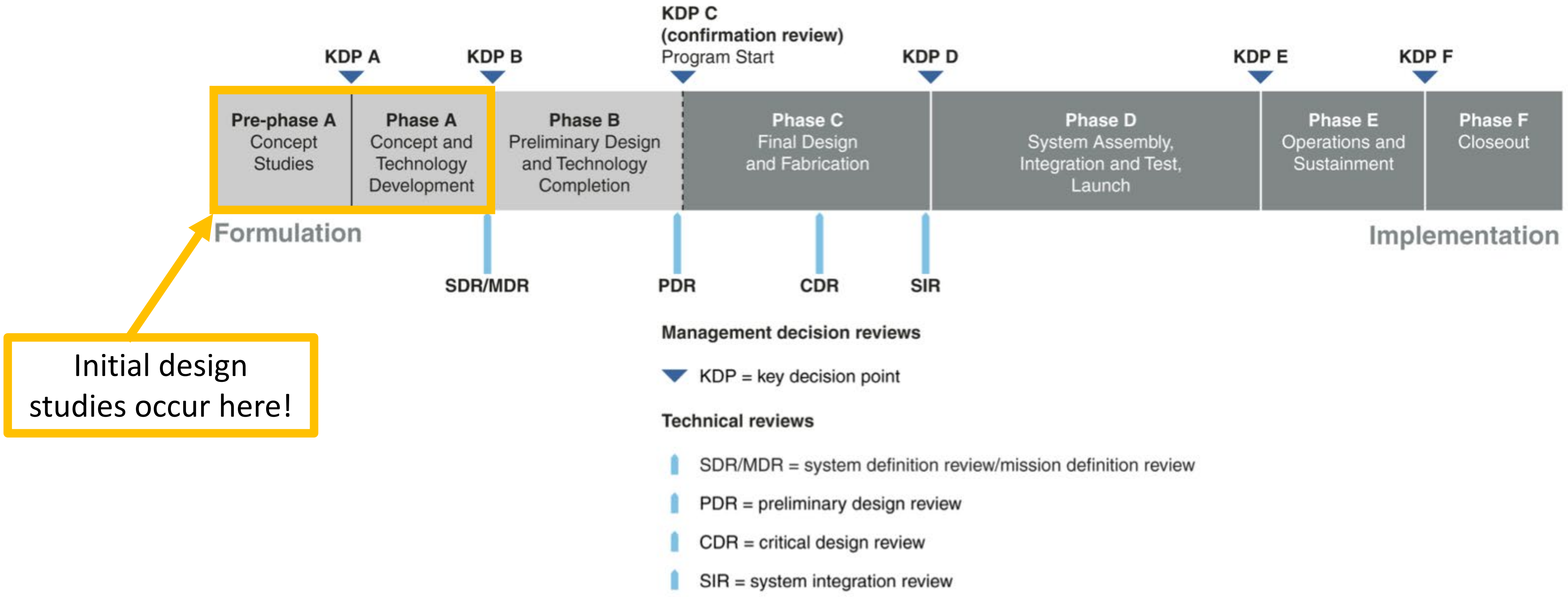
NASA's Limited Budget



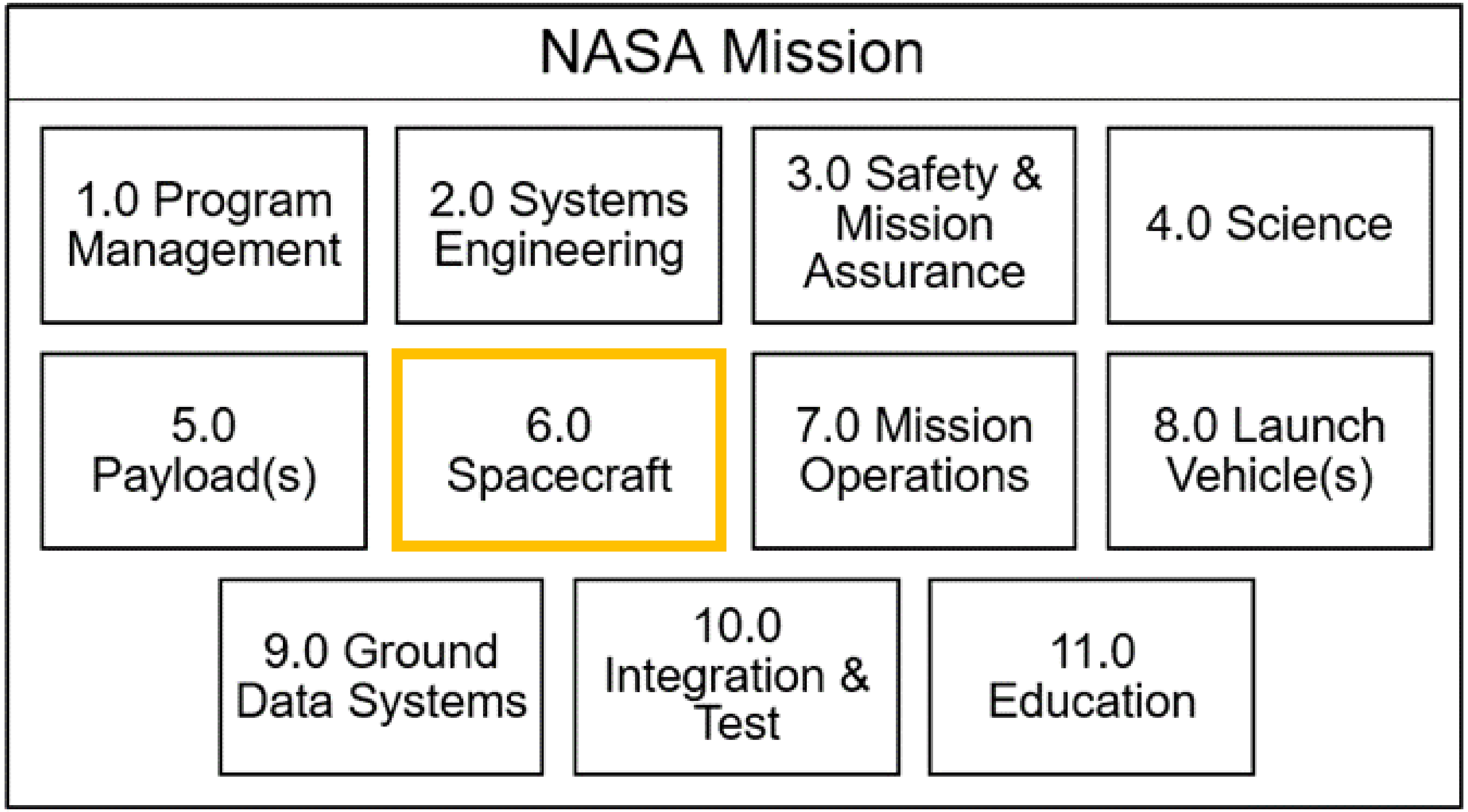
- Over the past 60 years, the percentage of the US federal budget that is distributed to NASA has decreased from ~4.5% to under 0.5%.
- Recently, NASA's funding has shrunk to its lowest level (in CY$) in several years.
- Mission budgets are as tight as ever.

NASA Mission Phases

- A NASA mission is divided into several distinct phases, each of which contain major milestones and are outlined by decision reviews.



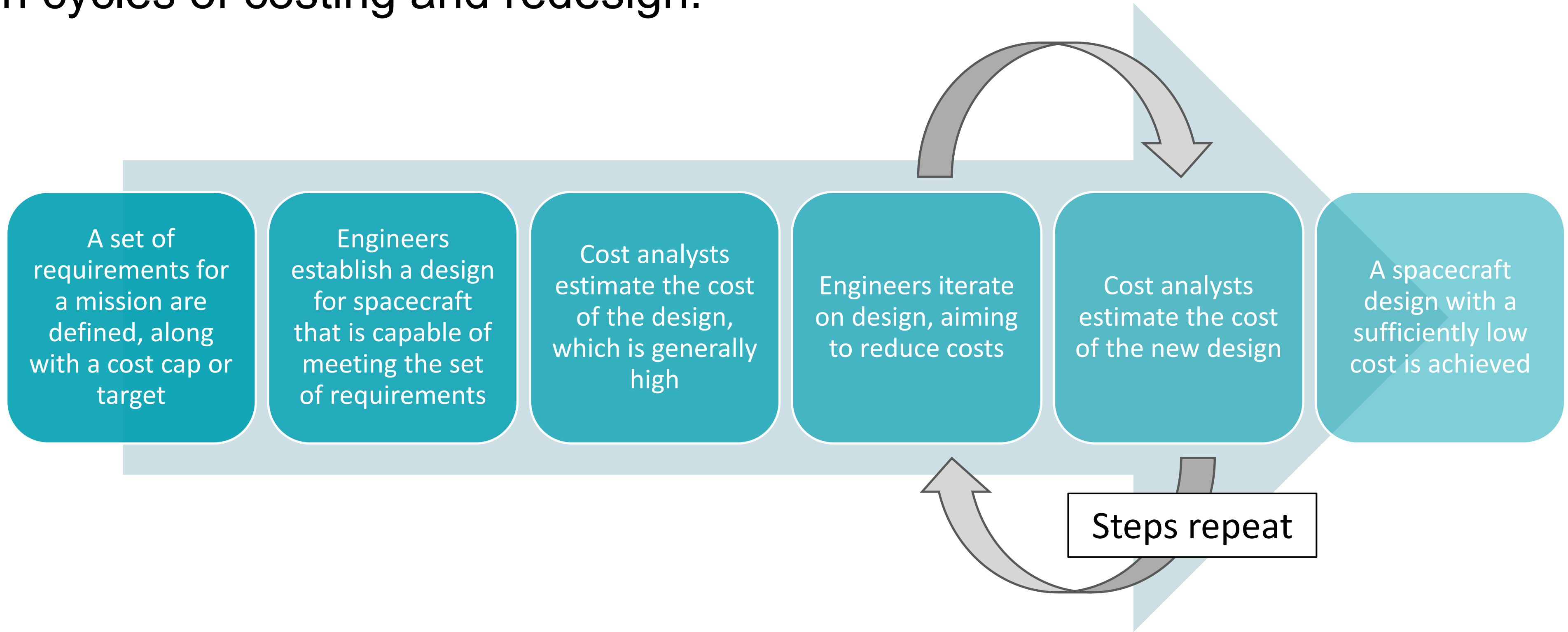
Anatomy of a NASA Mission



- A significant portion of a mission's budget is designated to WBS 6.0 Spacecraft – the platform for carrying scientific instruments and other essential equipment.

Traditional Spacecraft Design Process

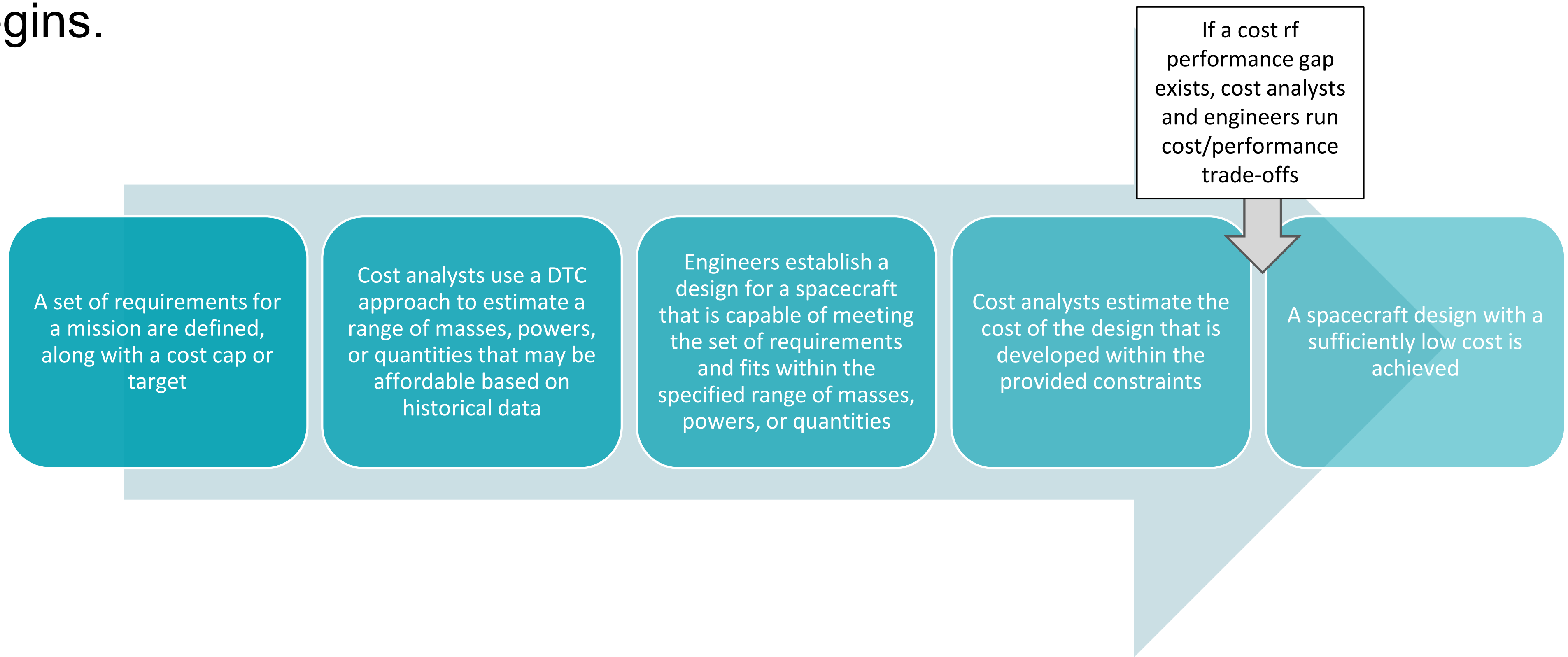
- Cost is not traditionally included as a variable early in the design process. Generally, the initial effort focuses on identifying a functional but non-optimized design, which then goes through cycles of costing and redesign.



- **Challenge:** This can be time intensive, requiring multiple iterations of design!

Spacecraft DTC Process

- With Design to Cost (DTC), leadership sets a target cost. This value is used to estimate an upper limit on a technical parameter (e.g., mass, power, quantity) before the initial design run begins.



- **Benefit:** This cost-conscious approach can bring an initial design closer to desired costs!

CAIV Overview

- DTC can be performed using parametric relationships with CAIV.
- CAIV is an acquisition philosophy that treats operational requirements and cost objectives as equal. This turns cost into a factor that influences decisions rather than an outcome of decisions made for other reasons (technical, political, etc.).
- One of the key tenets of CAIV is running trade-offs.
  - Cost/Requirement Trade-off
  - Cost/Performance Trade-off
- It is most effective when applied early in development, when decisions are being made that will impact a mission throughout its duration.

The Spacecraft Mass Estimation Capability (SMEC)

NASA CEMA Office Application

- The CEMA Office is implementing CAIV for spacecraft design by using a model called SMEC.

- SMEC leverages a dataset of historical NASA missions with analogy and parametric methodologies to estimate a range of potentially affordable masses, incorporating uncertainty.

- Mass was selected as the performance parameter to estimate due to:
  - High correlation to cost in space hardware.
  - Tradition of limiting mass in spacecraft design (to fit within launch vehicle).

SMEC Development Process

- Developing SMEC required four steps:

1. Collect and normalize cost and technical data to obtain the inputs and outputs that drive the methodology.
2. Develop methods to obtain a Spacecraft Cost Target from a Mission Cost Target, using analogy, and to estimate a range of values for Spacecraft Mass, using parametric Mass Estimating Relationships (MERs) with the general formula:

$$Spacecraft\ Mass = A * Spacecraft\ Cost\ Target^{B}$$

3. Validate the MERs using visual checks and goodness-of-fit statistics.
4. Design an interface for the capability.

Here, we'll look mostly at the inputs and outputs shown in the interface. For details of the data and methods, please see the technical paper!

Model Inputs

Insert Cost Data

Mission Cost Target ($K):
Fiscal Year $:

Pass-Throughs ($K)
Phase A:
Payload (WBS 5, Phase B-D):
Phase E:
Phase F:

Select Parameters

Mission Risk Class:
Destination:
Spacecraft Type:

# of Identical Spacecrafts:
% Non-Recurring Engineering:

Choose Method Settings

WBS Allocation %:
MER Includes Constant:
MER Uncertainty Distribution:

- The SMEC interface requires input data for a number of different fields.
- Pass-through costs are required for some elements that are not estimated by the tool (Payload, Mission Ops, etc.).
- Parameters and method settings are used to select the correct analogy missions and MERs from the model's library.
- All fields must be completed to obtain results.

Model Outputs: Numbers and Pie Chart

- Results are displayed numerically and visually.
- One visualization is a pie chart, which shows the proportion of the Mission Cost for Phases B-D that is designated to each element.

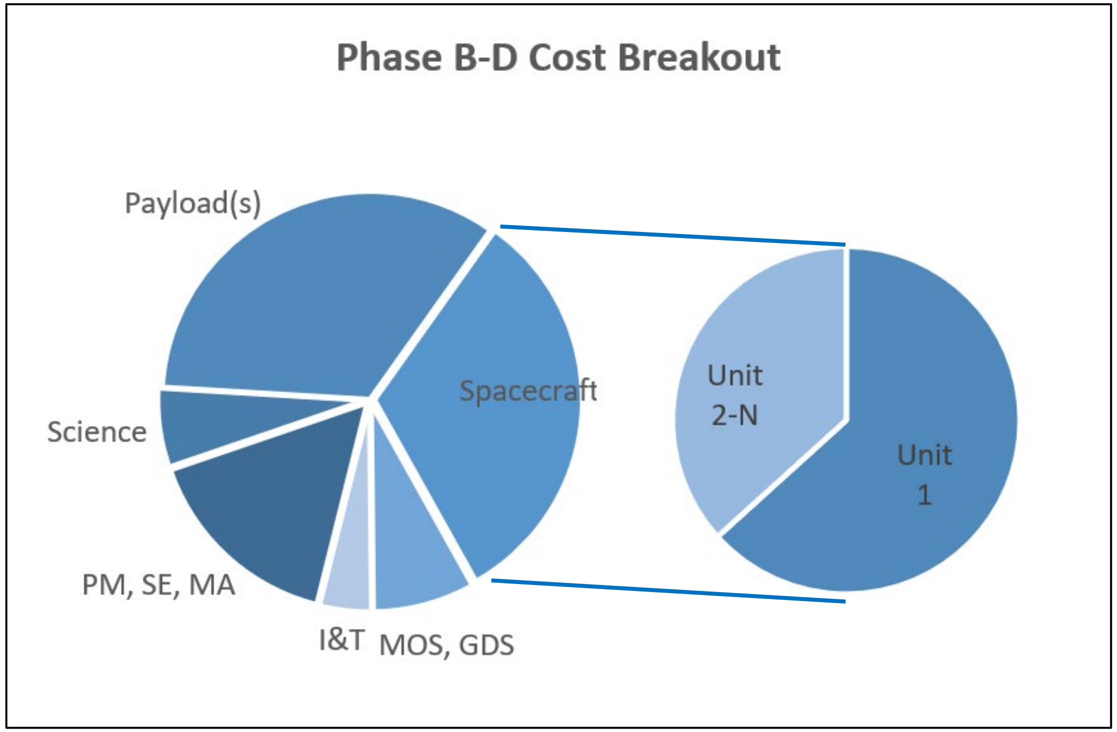
Results

Total Cost Phase B-D (FY24$K): $600,000

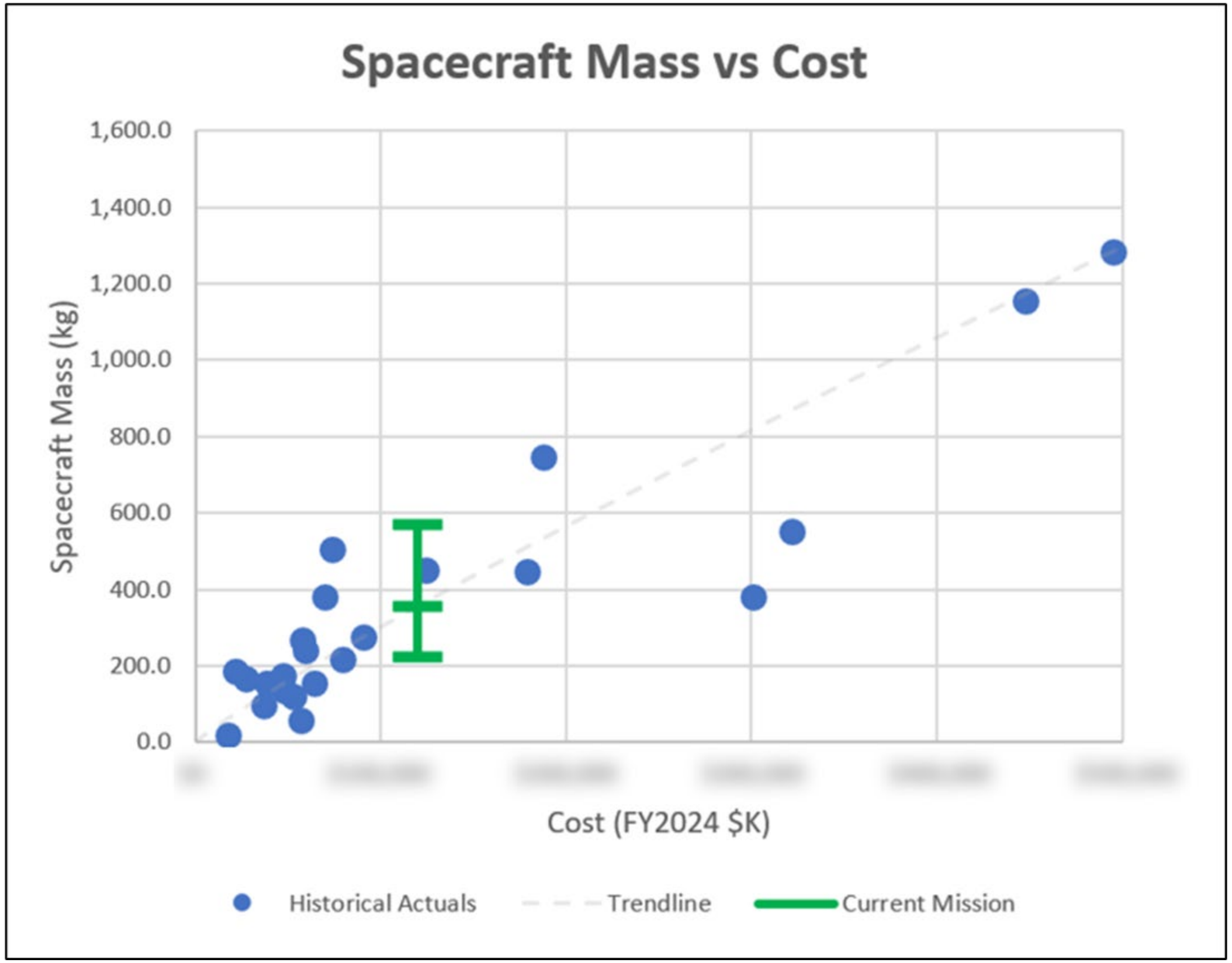
WBS	Name	% Mission Cost	ROM Cost (FY24$K)
1, 2, 3	PM, SE, MA	17.5%	$105,000
4	Science	7.5%	$45,000
5	Payload(s)	31.0%	$186,000
6	Spacecraft(s)	30.5%	$183,000
7,9	MOS, GDS	8.5%	$51,000
8	Launch Services		
10	I&T	5.0%	$30,000
11	E&PO		

ROM First Unit Spacecraft Cost (FY24$K): $115,823

	MEV	Margin	CBE Target
Spacecraft Mass (kg):	355.6	30%	273.6

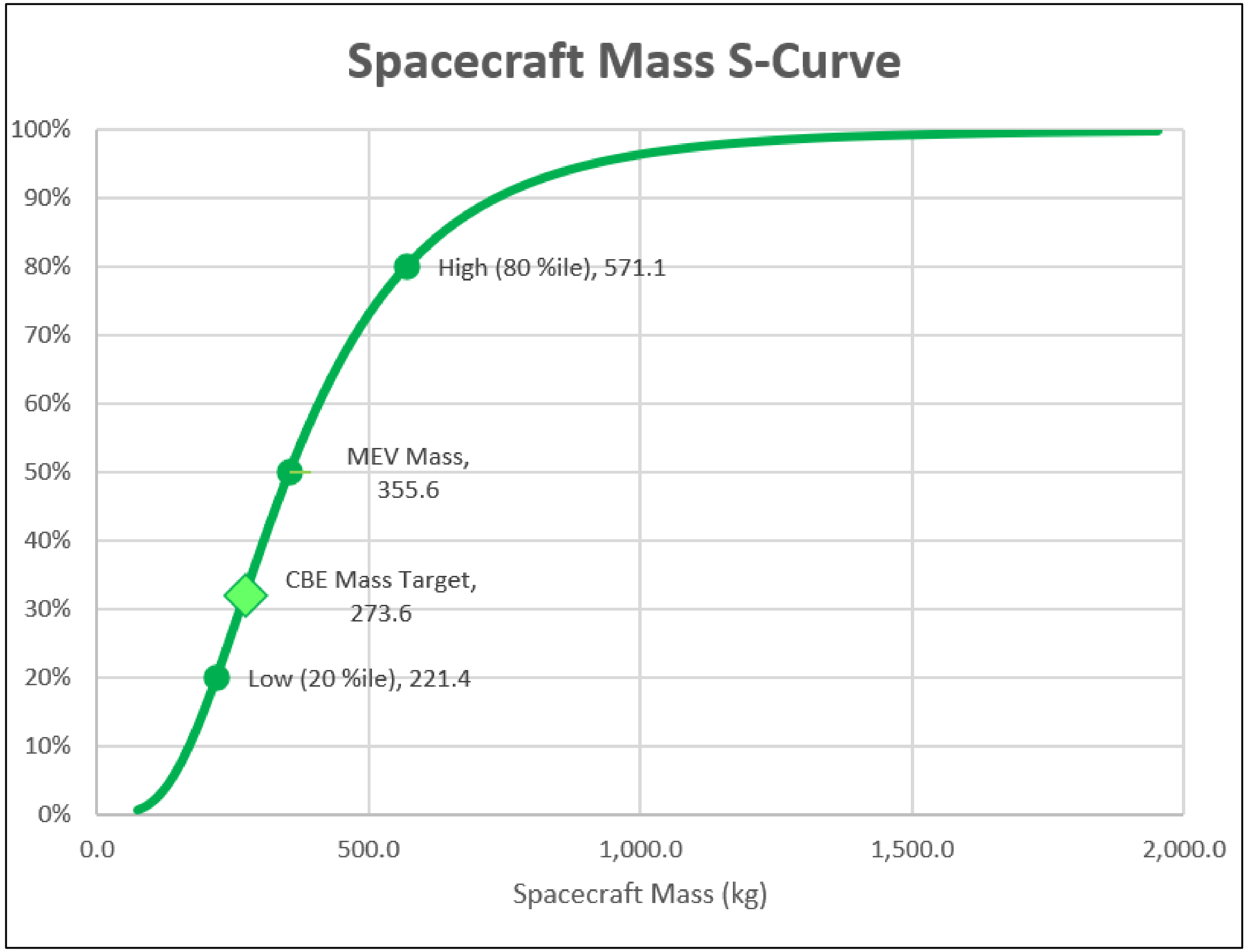


Model Outputs: Scatter Plot



- In this plot, the green line shows a range of potentially affordable masses (20th to 80th percentile) and identifies the Maximum Estimated Value (MEV) mass produced by the MER.
- The blue points add context by showing the costs and masses of similar spacecraft from historical missions.

Model Outputs: S-Curve



- The curve displays the range of estimated spacecraft masses to illustrate the impact of uncertainty within the MER.
- The MEV result from the MER is reduced by a percentage to obtain a Current Best Estimate (CBE) mass, which serves as a "target" for the design process.

SMEC Application

SMEC for Engineering Studies

- SMEC or a similar CAIV model can be leveraged during the period before the formal design process begins.

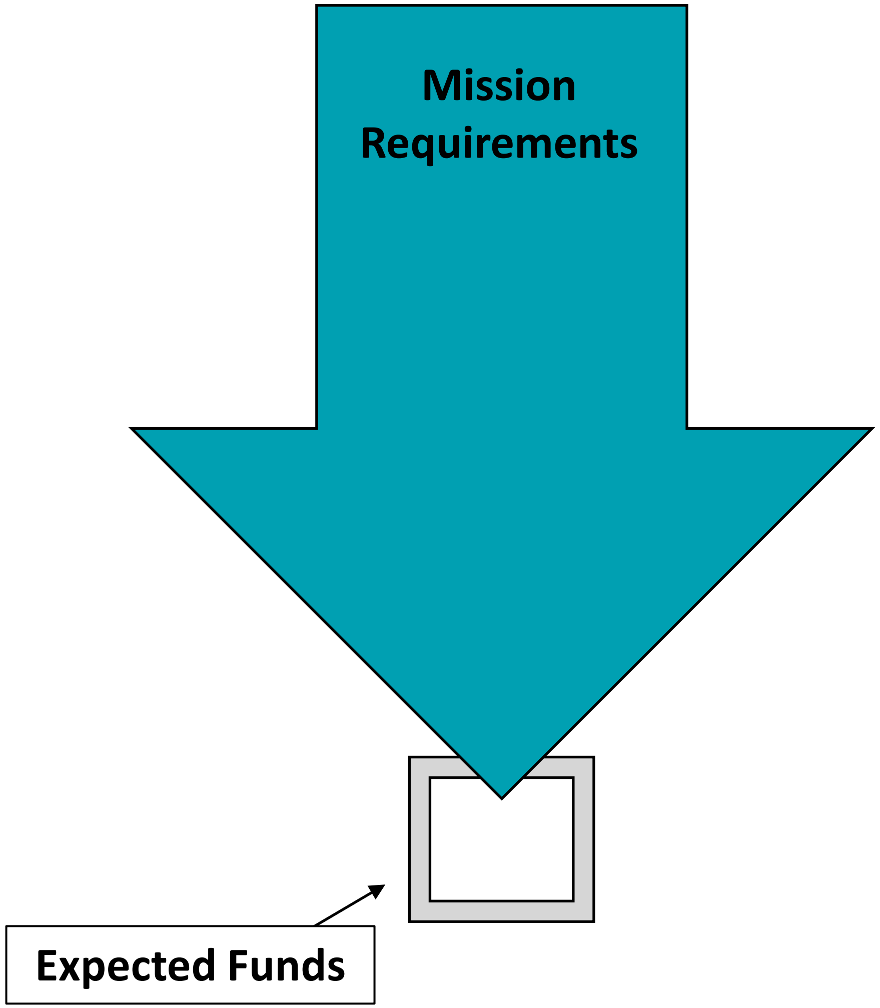
- Consider a theoretical scenario:
  - A proposal team approaches an Engineering Team Lead to request a design for a spacecraft. This spacecraft will enable a mission with a cost cap defined in a NASA Announcement of Opportunity (AO).
  - The Engineering Team Lead provides the necessary details to a Cost Analyst, who would take the steps identified:

Impacts on Design

- After the Cost Analyst delivers numerical results for spacecraft mass, along with visualizations, the Engineering Team Lead can:
  - Communicate overall constraints to subsystem engineers to emphasize the importance of monitoring spacecraft size.
  - Designate specific mass limits to subsystems based on engineering judgment.
  - Flag areas where cost/performance trade-offs are worthwhile.

- This enables cost-conscious decision-making that brings an initial design closer to a reasonable cost.

Unworkable Constraints



- What if the requested configuration is likely unworkable at a given cost?
- This information can be communicated to stakeholders before design starts, in order to:
  - Establish expectations.
  - Jointly consider solutions, such as modifications to the mission architecture (e.g., reducing the number of satellites in a constellation).
- These early conversations ensure that requirement changes are considered early.

Conclusion

Summary

- As the NASA CEMA Office has demonstrated with SMEC, the CAIV approach is an intuitive way to add cost as a consideration early in the process of designing new spacecraft.
- SMEC shows numerical and visual results to illustrate cost constraints and the feasibility of simultaneously meeting cost and performance objectives.
- This equips an Engineering Team Lead with the tools to communicate their expectations and concerns both internally and externally.
- The result is a reduction in the time and effort spent by all parties involved in design.

Future Work: CAIV for Spacecraft Subsystems

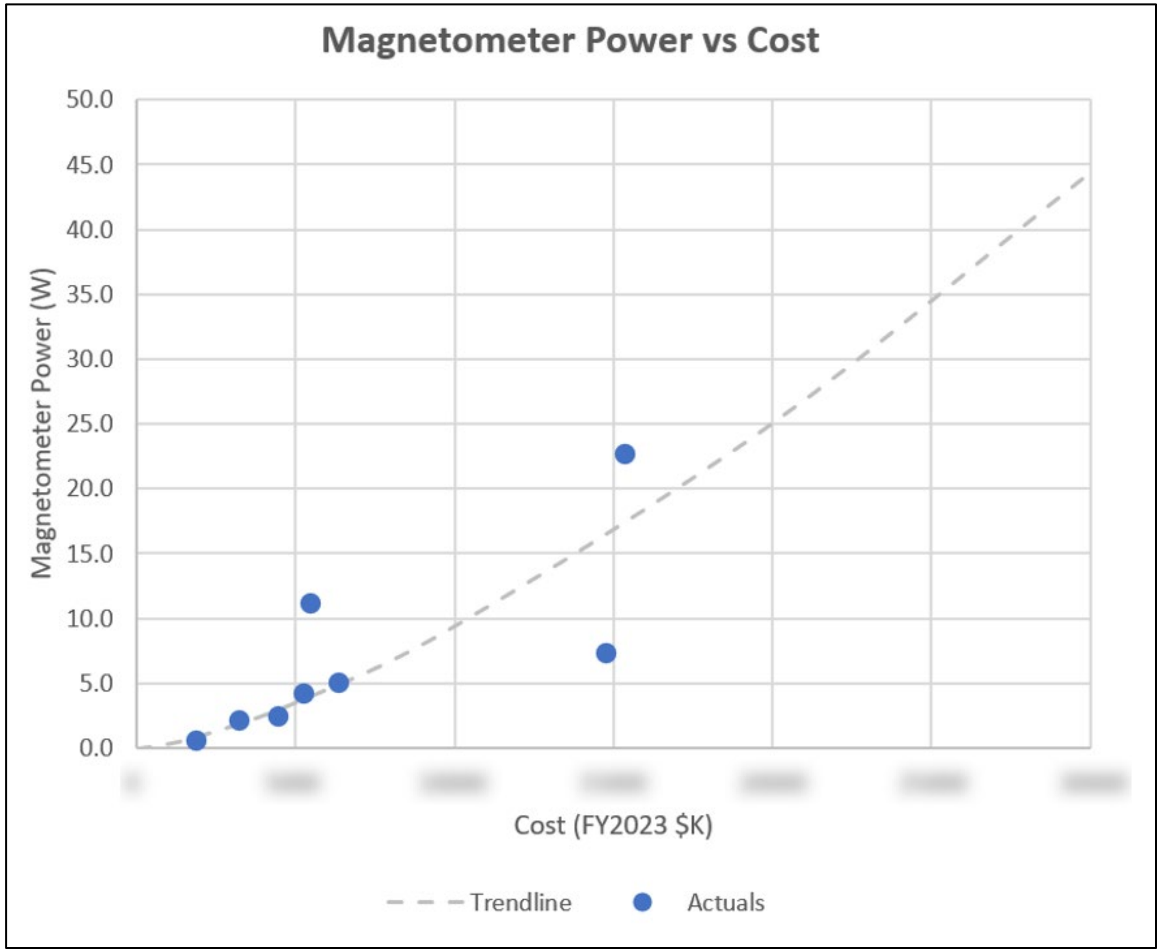
- Further research into CAIV for spacecraft could examine the relationships between cost and technical parameters in different subsystems.
- Subsystem-level MERs would enable a Cost Analyst to trade mass changes in one subsystem versus another.
- Could answer questions like:

"If I reduce the mass of the Power subsystem by 10 kg, can I increase the Structures by more than 10 kg while remaining affordable?"

"If we want to ensure that our design comes in on cost, is it more important to optimize the size of our Thermal Control or Communications subsystem?"

Future Work: Instrument Applications

- CAIV has applications to other types of hardware (e.g., scientific instruments like a magnetometer).
- Mass may not be the only appropriate parameter to limit.
  - For example, power is a parameter that can be controlled during the design process.
- The performance of an MER or Power Estimating Relationship (PER) based on cost can be evaluated visually.



Methodology Limitations

- There are limitations to the CAIV methodology based on:

Quantity of Similar Systems

- **Question:** How many systems are of a similar type to the one being estimated?
- **Impact:** If very few historical examples exist, it may not be possible to develop a credible estimating relationship. Any estimates generated using these formulas would have significant uncertainty.

Applicability of Similar Systems

- **Question:** How similar is the new system to the ones that are considered a “similar type”?
- **Impact:** If the new system is not particularly similar to historical examples, it may be necessary to flag any estimates generated as potentially non-applicable.

Details on data collection and normalization, method development, and validation for SMEC are available in the technical paper “Spacecraft Design to a Cost Target”.

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Thank You!

Ryan Sukley
rsukley@technomics.net
ryan.a.sukley@nasa.gov

Backup

Acronyms

- NASA – National Aeronautics and Space Administration
- GSFC – Goddard Space Flight Center
- CEMA – Cost Estimating, Modeling, and Analysis Office
- AO – Announcement of Opportunity
- DTC – Design to Cost
- CAIV – Cost as an Independent Variable
- CY$ – Constant Year Dollars
- MEV – Maximum Estimated Value
- CBE – Current Best Estimate
- MER – Mass Estimating Relationship
- PER – Power Estimating Relationship
- SMEC – Spacecraft Mass Estimation Capability

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