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Efficient Trade Space Exploration

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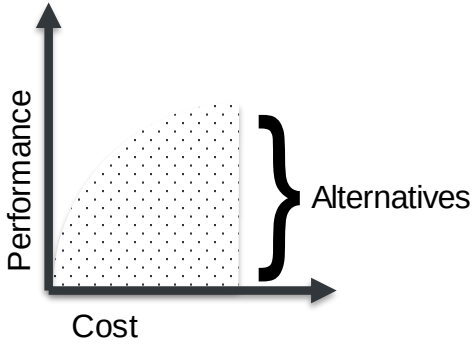
Problem

Not enough time to conduct trade studies

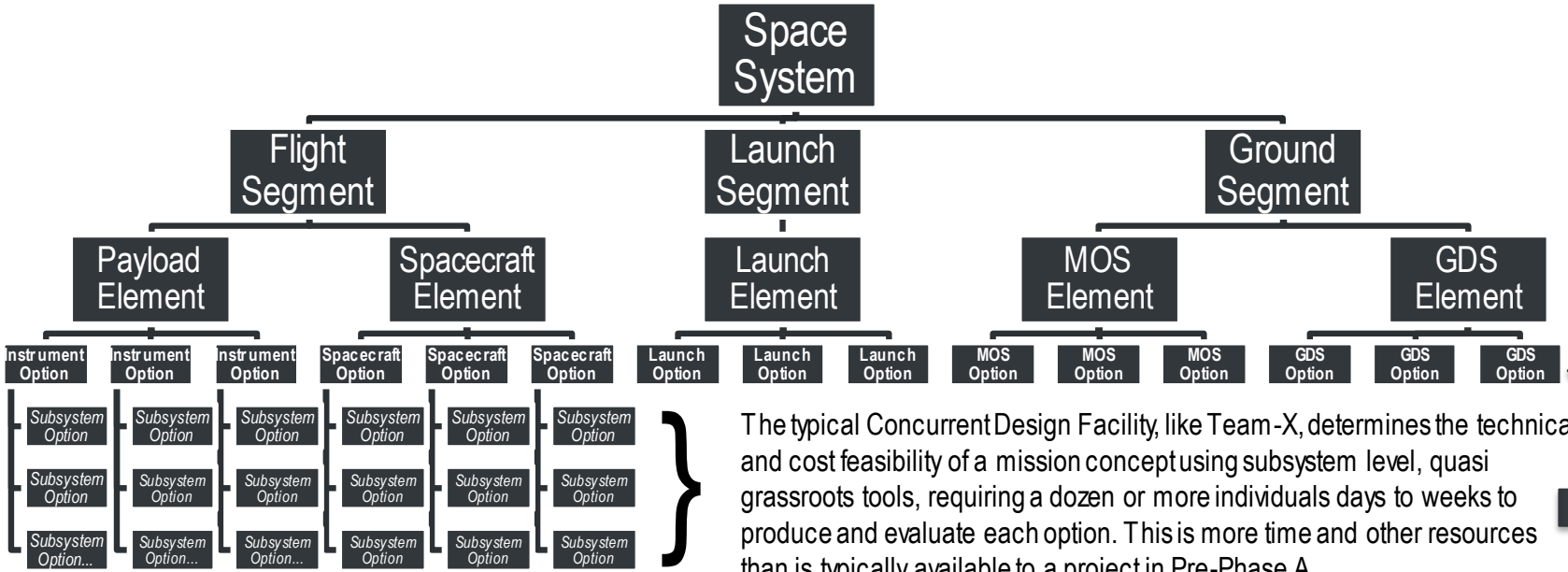


The purpose of the NASA Pre-Phase A project life cycle phase is, "To produce a *broad* spectrum of ideas and alternatives for missions from which new programs/projects can be *selected*.
[NASA Systems Engineering Handbook, NASA SP-2016-6105 Rev2, 2016, p. 9]

Two of the principal challenges in *efficient* trade space exploration are (1) quickly evaluating options, and (2) quickly convincing stakeholders to accept the results of the evaluation.

To produce a ***broad*** spectrum of ideas and alternatives

work at reduced detail – study branches, not leaves



The typical Concurrent Design Facility, like Team-X, determines the technical and cost feasibility of a mission concept using subsystem level, quasi grassroots tools, requiring a dozen or more individuals days to weeks to produce and evaluate each option. This is more time and other resources than is typically available to a project in Pre-Phase A.

To produce a ***broad*** spectrum of ideas and alternatives *work from analogy and parametric data*

There are other production and evaluation techniques than bottoms up, grassroots methods.
Amongst these are analogy and parametric based techniques.

Through its access to information about actual space missions, and its vast array of space mission studies, now numbering in the thousands, Team-X can pull the analogy based performance, technical, and cost information necessary to produce and evaluate options at this lower level of detail.
The structure of the entries in a database necessary for segment/element level trade space exploration is depicted in the tables below.

Payload Element Analogy Name	
Unit Cost ($M)	
TECHNICAL RESOURCE SUMMARY	
	ACCOMMODATION REQUIREMENTS
	HXWXL Dimensions (m)
	Mass (kg)
	(Peak) Power (W)
	(Average) Power (W)
	Data Rate (Mbps)
PERFORMANCE SUMMARY	
Radiometric	Range (J)
	Resolution (J)
Spatial	Range (FOV deg.)
	Resolution (iFOV deg.)
Spectral	Range (nm)
	Resolution (nm)
Temporal	Range (exposure sec)
	Resolution (rate sec)
Polarimetric	Range (deg.)
	Resolution (deg.)

Spacecraft Element Analogy Name	
Unit Cost ($M)	
TECHNICAL RESOURCE SUMMARY	
ACCOMMODATION CAPABILITIES	**ACCOMMODATION REQUIREMENTS**
HxWxL Dimensions (m)	HxWxL Dimensions (m)
P/L Mass (kg)	Mass (kg)
P/L (Peak) Power (W)	
P/L (Average) Power (W)	
P/L Data Rate (Mbps)	
P/L Data Storage (GB)	
PERFORMANCE SUMMARY	
ACS Pointing	Knowledge (deg)
	Control (deg)
	Stability (deg)
Propulsion	Delta V (m/s)
Telecomm	Uplink Band
	Uplink Rate (kbps)
	Downlink Band
	Downlink Rate (Mbps)

Launch Service Segment Analogy Name	
Unit Cost ($M)	
TECHNICAL RESOURCE SUMMARY	
ACCOMMODATION CAPABILITIES	**ACCOMMODATION REQUIREMENTS**
HxWxL Dimensions (m)	Launch Location(s)
PERFORMANCE SUMMARY	
ORBIT TYPE	PERFORMANCE
LEO Polar	Mass to Altitude Curve
LEO Inclined	Mass to Altitude Curve
GTO	Mass to Altitude Curve

Ground Segment Analogy Name	
Development Cost ($M)	
Cost per Data Pass ($M)	
TECHNICAL RESOURCE SUMMARY	
Station Locations	
Data Volume (TB)	
Data Product Levels (0, 1, 2, 3,…)	
PERFORMANCE SUMMARY	
Telecomm	Uplink Band
	Uplink Rate (kbps)
	Downlink Band
	Downlink Rate (Mbps)

To *efficiently* produce ideas and alternatives for missions from which new programs/projects can be selected, *avoid generating and working on ideas and alternatives that can't be selected*

$$Efficiency = \frac{N_S \times W_S}{N_S \times W_S + N_{NS} \times W_{NS}}$$

In trade space exploration, useful work output can be defined as the number of selectable configurations of the system produced, N_S, multiplied by the work (time and effort) required to produce and evaluate the selectable configurations, W_S. The total work input can be defined as the sum of the useful work and the non-useful work – the number of non-selectable configurations of the system produced, N_{NS}, multiplied by the work (time and effort) required to produce and evaluate the non-selectable configurations, W_{NS}

Considering what makes an option selectable…

According to Design Thinking*

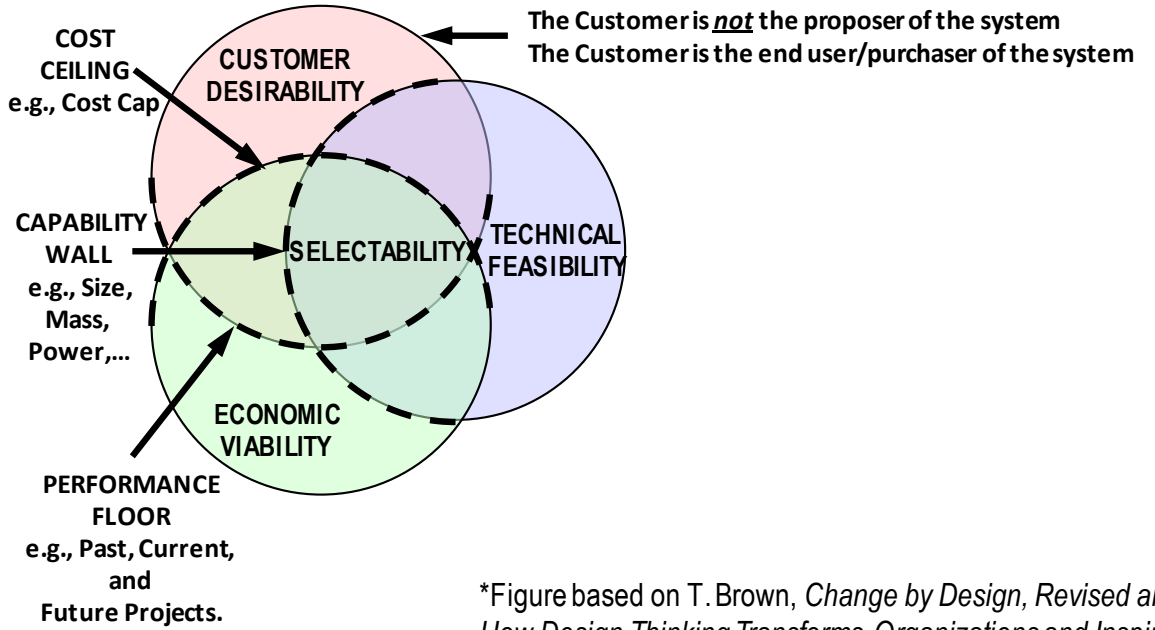
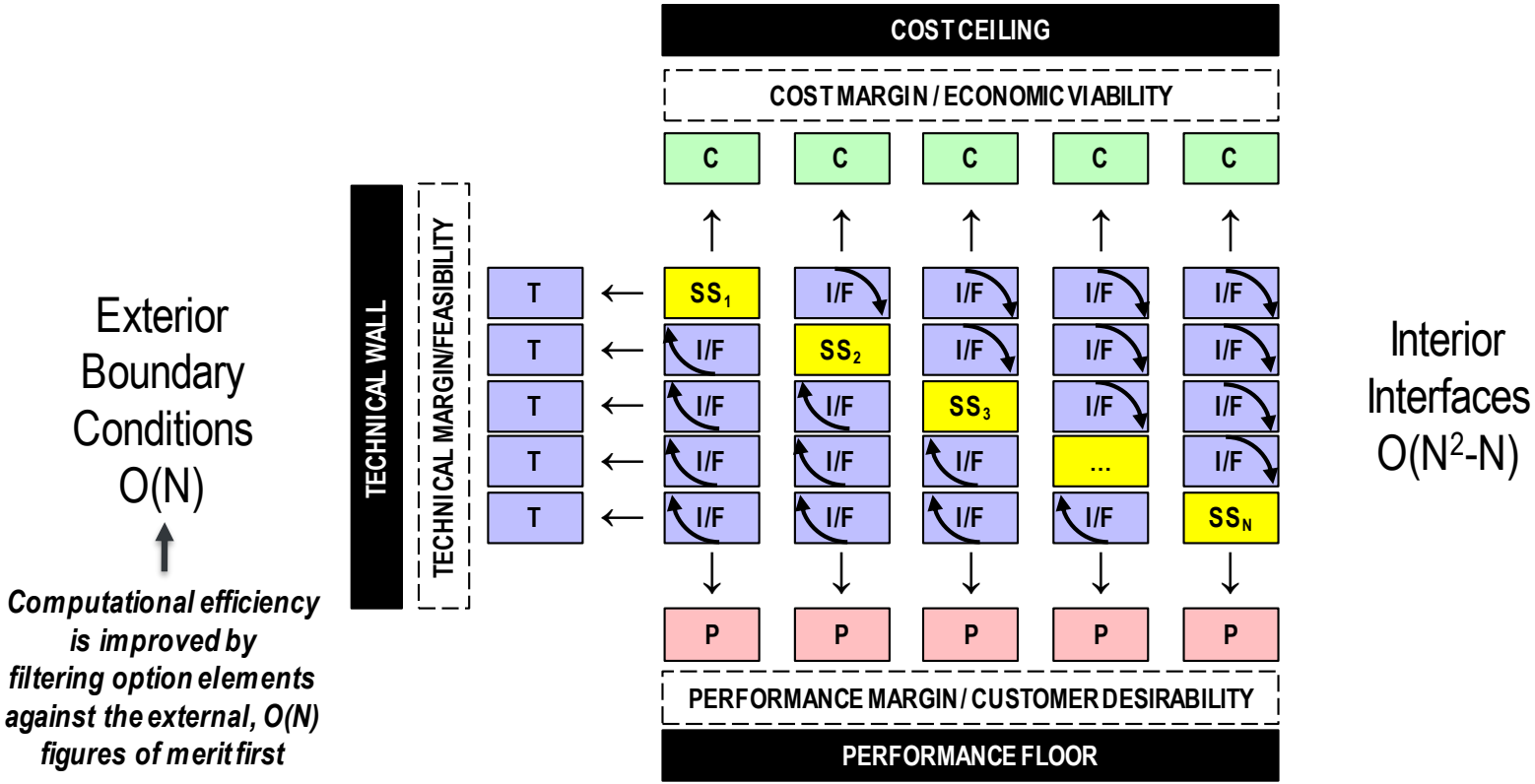


*Figure based on T. Brown, *Change by Design, Revised and Updated: How Design Thinking Transforms Organizations and Inspires Innovation*, New York, New York: Harper Business, 2019.

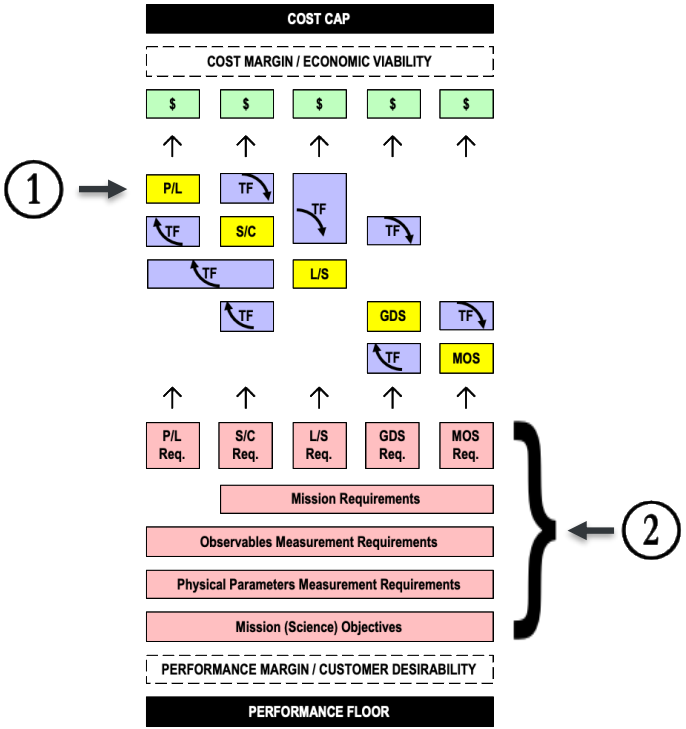
…leads to recognizing there are *two* types of figures of merit

one with *external* constraints O(N), and the other with *internal* interfaces $O(N^2-N)$



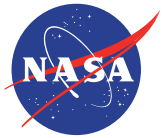
Increase Stakeholder Cognitive Efficiency

by highlighting how (1) internal option choices affect the selectability of the options, and (2) by aligning stakeholder requirements *in* the trade space



Findings and Recommendations

- These principal processes and tools, which enable the production and evaluation of a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected – i.e., **analogy based tools for detail reduction**, **prefiltering of options for selectability**, and a **concurrent figures of merit dashboard** to enhance stakeholder cognition
  – **have led to a factor of nine improvement in the efficiency of trade space exploration of space systems in Team-X at the Jet Propulsion Laboratory** – from a nine hours per option to one hour per option.
- While these processes and tools lack the ***precision*** of a typical subsystem level concurrent design facility study, they have had enough ***accuracy*** to enable dozens of explorations of broad trade spaces within the limited time and other resources typically available to projects in Pre-Phase A.
- While these processes and tools have to date only been applied to Astrophysics, Earth Science, and Planetary Science mission concepts, **this general approach should be applicable to a broad range of Space Missions**.



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