Assessing the Impacts of Fractionation on Pointing-Intensive Spacecraft

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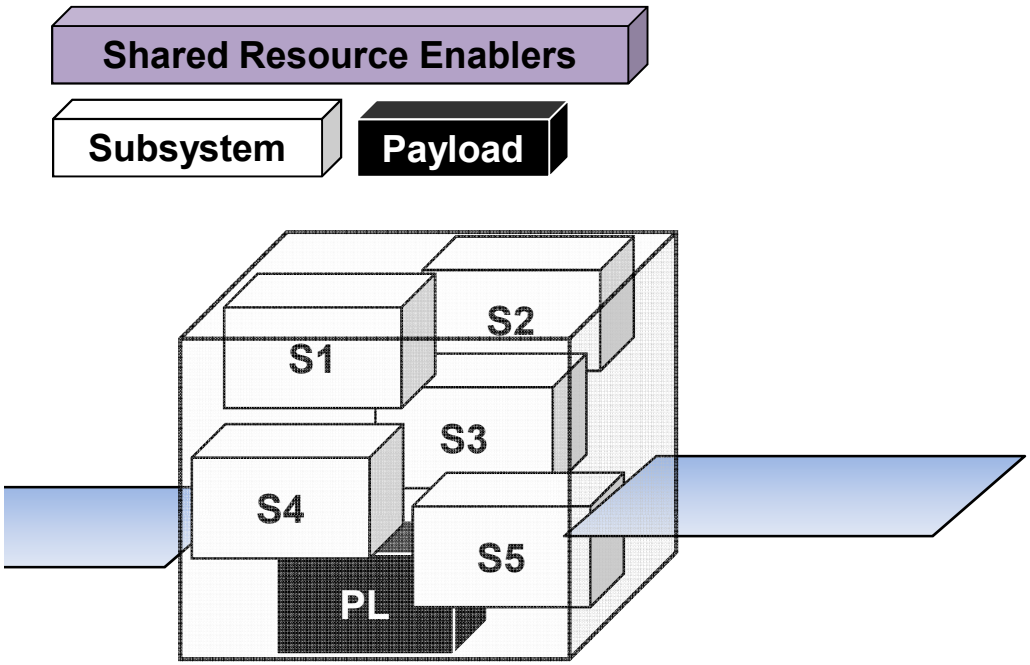
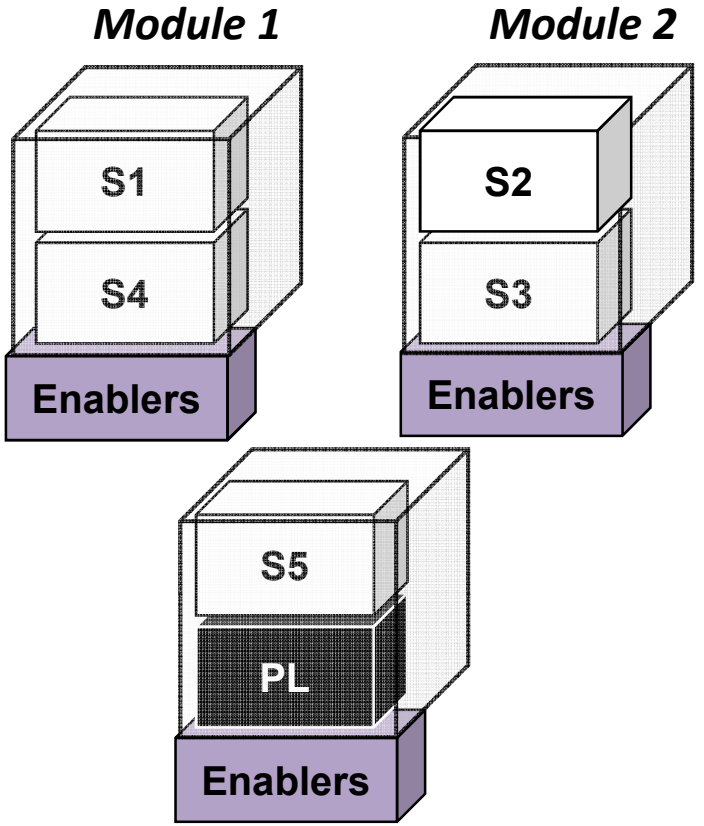
Agenda

- Problem Formulation
- Methodology & Analysis
- Synthesis
- Conclusion

Concepts & Terminology

Fractionated Spacecraft (O'Neill, 2009)





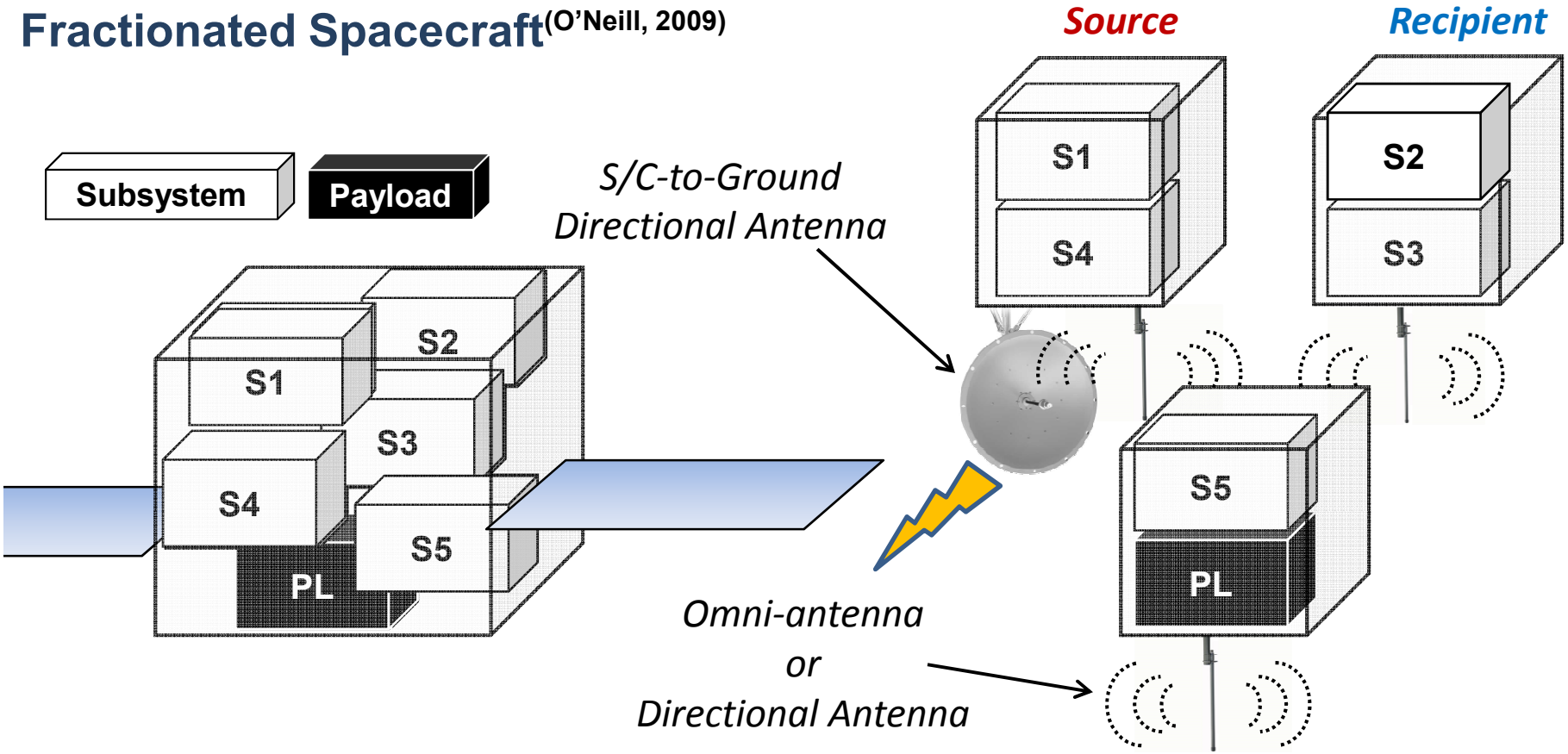
Shared Subsystem Resources (O'Neill 2009)

Module 3

Representative Enabler \ *Domain*	**Comm_CS_C&DH**	**ADS_GNS**	**Power**
Application	antenna	IMU	(receiving) solar array
Development	tasking, schedule, & control	(autonomous) relative navigation	laser diode array

Concepts & Terminology

Fractionated Spacecraft (O'Neill, 2009)



Shared Subsystem Resources (O'Neill 2009)

Recipient

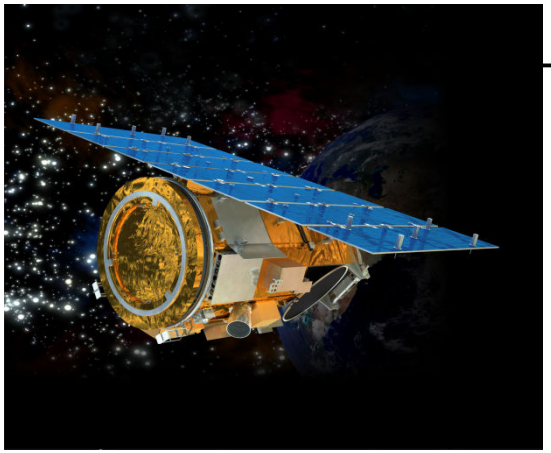
Representative Enabler \ *Domain*	**Comm_CS_C&DH**	**ADS_GNS**	**Power**
Application	antenna	IMU	(receiving) solar array
Development	tasking, schedule, & control	(autonomous) relative navigation	laser diode array

Motivation: Critical Question

Context

Mission Type	*Lifecycle Uncertainties*[(O'Neill, 2009)]	*Spacecraft Type*
Remote Sensing Mission	Launch, Technical, Environmental, Operational	Pointing-Intensive ~36 mas pointing tolerance

Monolithic Spacecraft



GEOEye-1
Source: *GEOEye*

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Value Proposition

Value Proposition

- Performance
- Lifecycle Cost
- Mission Lifetime
- Mass
- Propellant Usage

Fractionated Spacecraft

A Fractionated Spacecraft
Source: *DARPA*

Given the context, how do monolithic and fractionated spacecraft value propositions compare?

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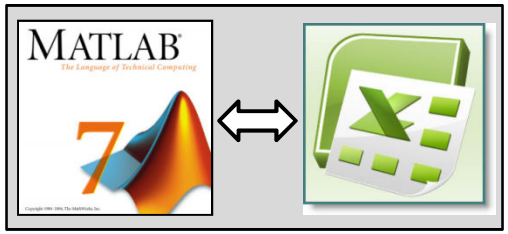
Methodology: Spacecraft Evaluation Tool

Lifecycle Uncertainties

- Market Supply & Demand
- National Security
- Technical
- Environmental
- Funding
- Operational
- Launch
- Programmatic



Operationalize via a Monte Carlo Analysis

Models and Model Processes

Spacecraft Architecture Input Group

Lifecycle & Design Input Group

Launch Vehicle Input Group

Physics-based Model

- Payload
- Subsystems
- Mass
- Power
- Size/Volume

Cost Model

- Launch Vehicle
- COCOMO II
- Parametric CERs

Dynamic Model

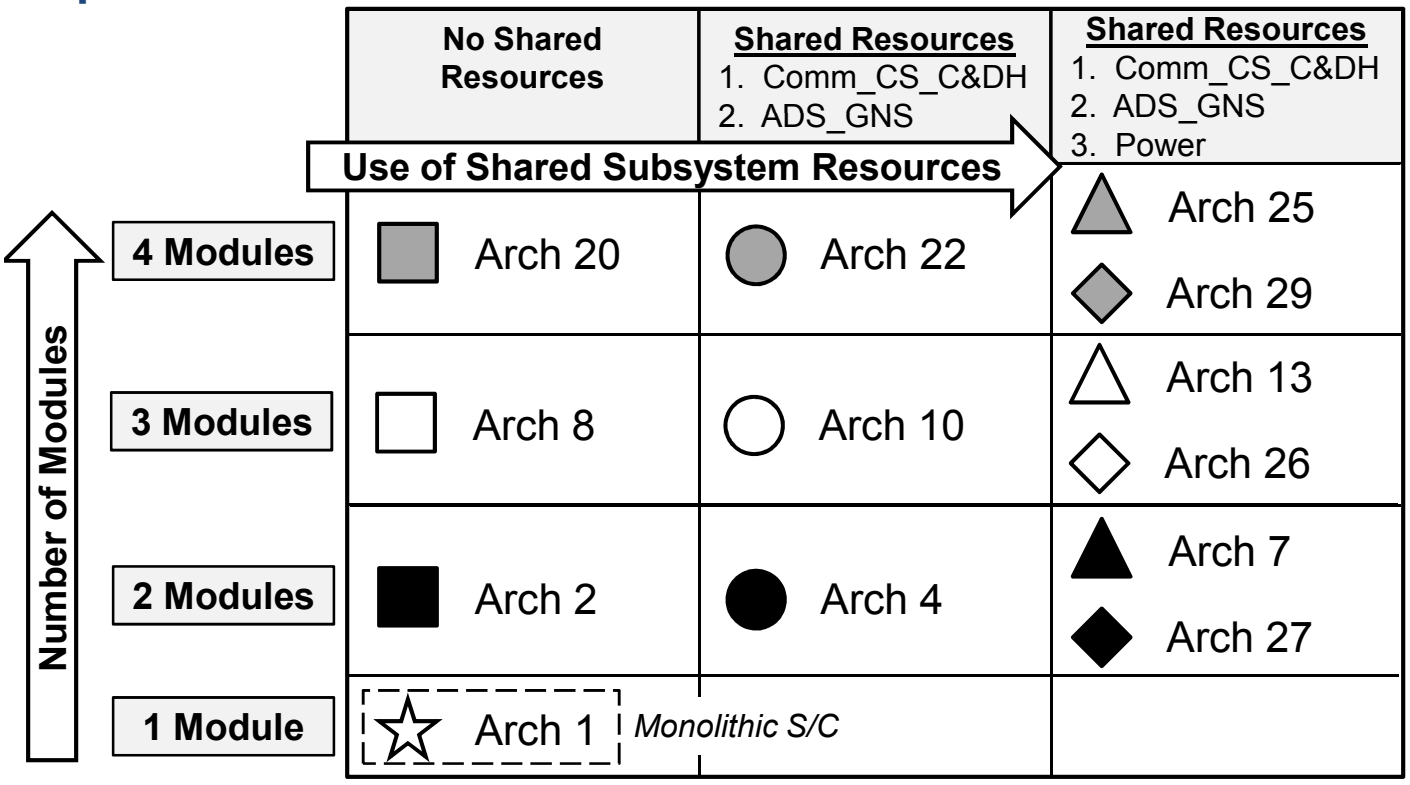
- Component-Level Outputs
- Subsystem-Level Outputs
- Module-Level Outputs
- System-Level Outputs

Case Study Inputs

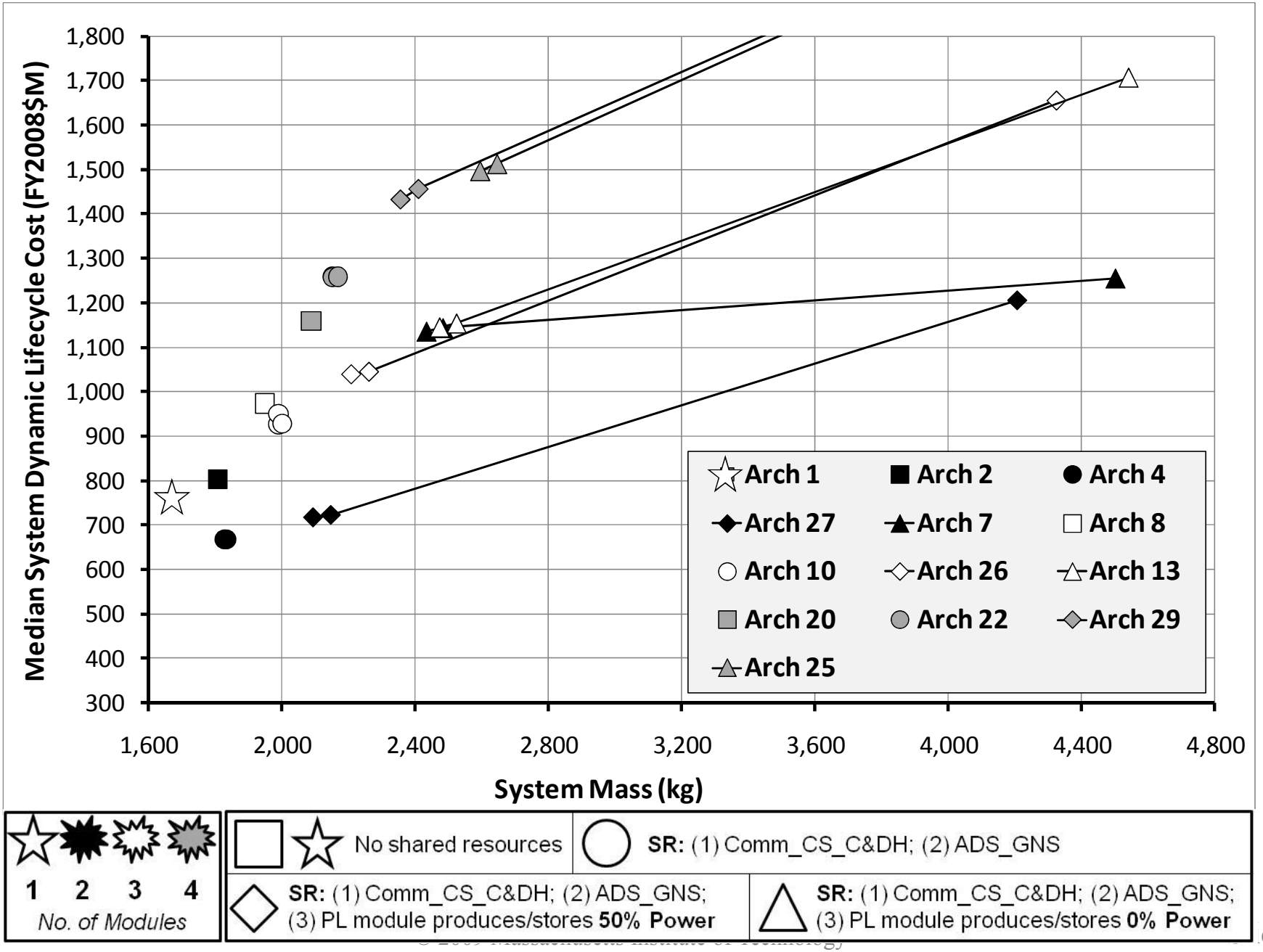
Lifecycle & Design

	Category	Input	Value	Units
Constant	Orbit	Altitude	700	km
		Inclination	98	°
	Mission	Lifetime	7	years
	Dynamic	MCA no. of Trials	2,500	-
		PoIM	1.5	%
	Payload	Resolution	0.5	m
Variable	CONOPS	Separation Distance	20, 1000, 5000	m

Spacecraft Architecture



Results: Inter-module Separation Distance



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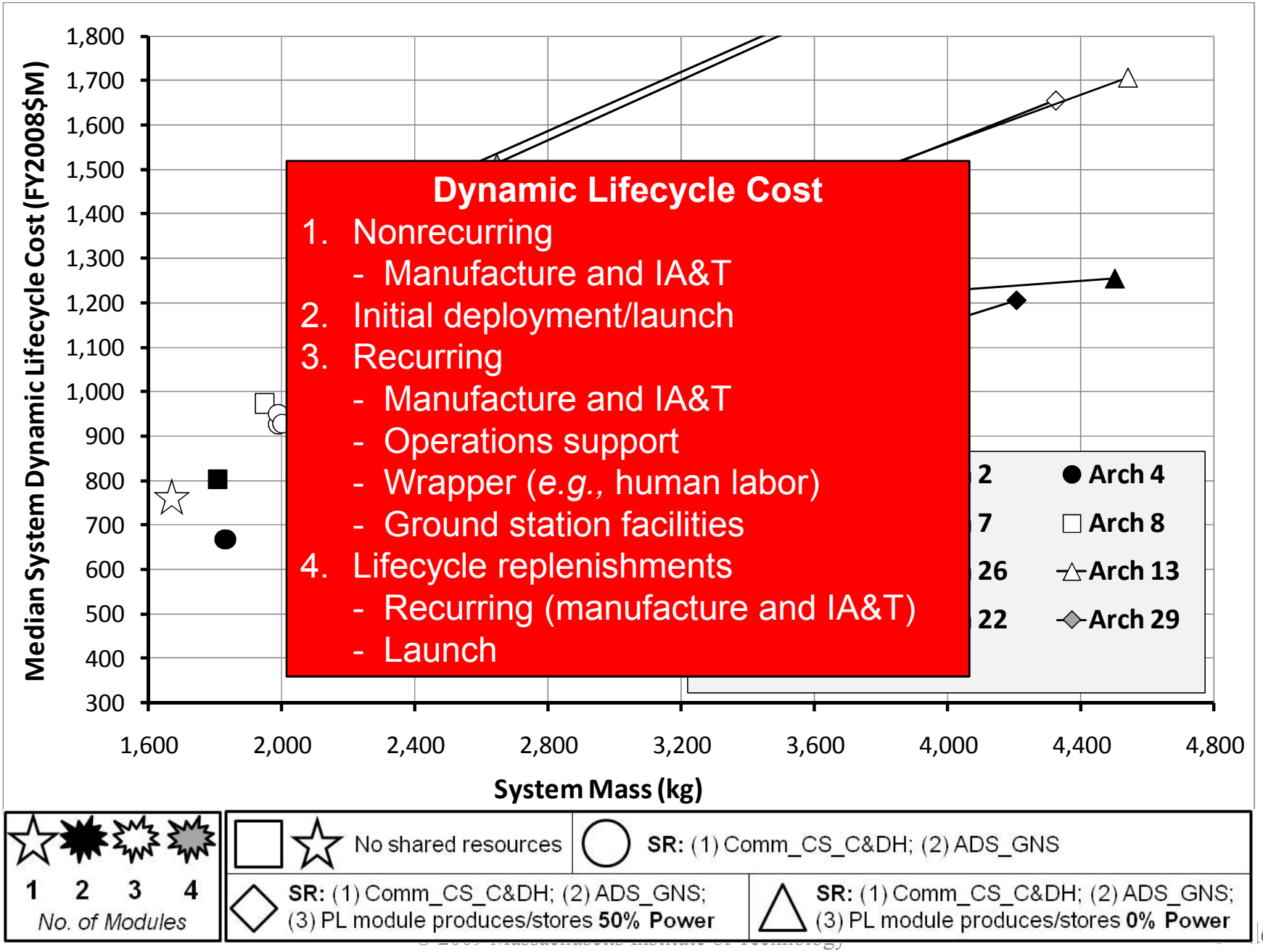

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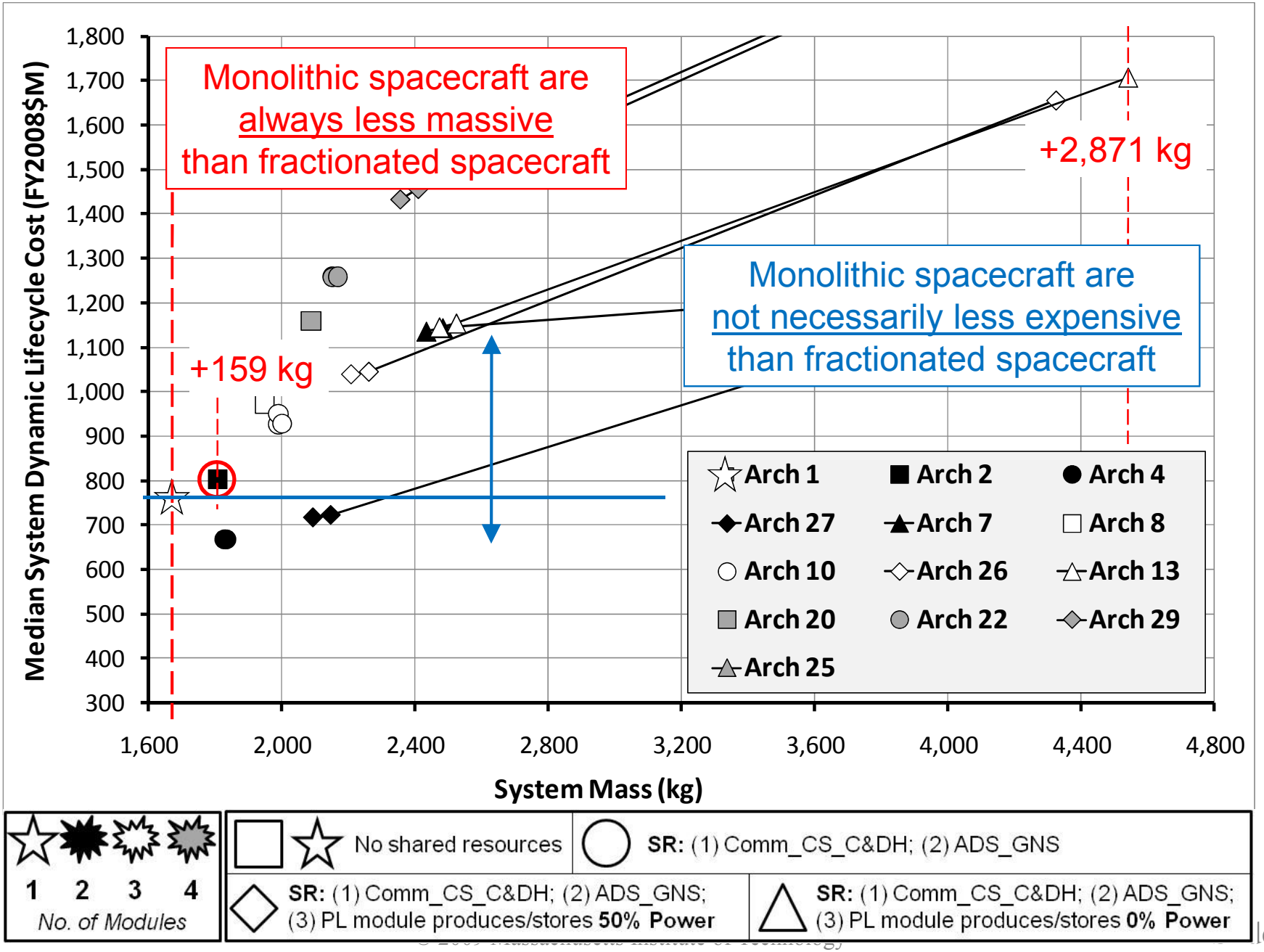

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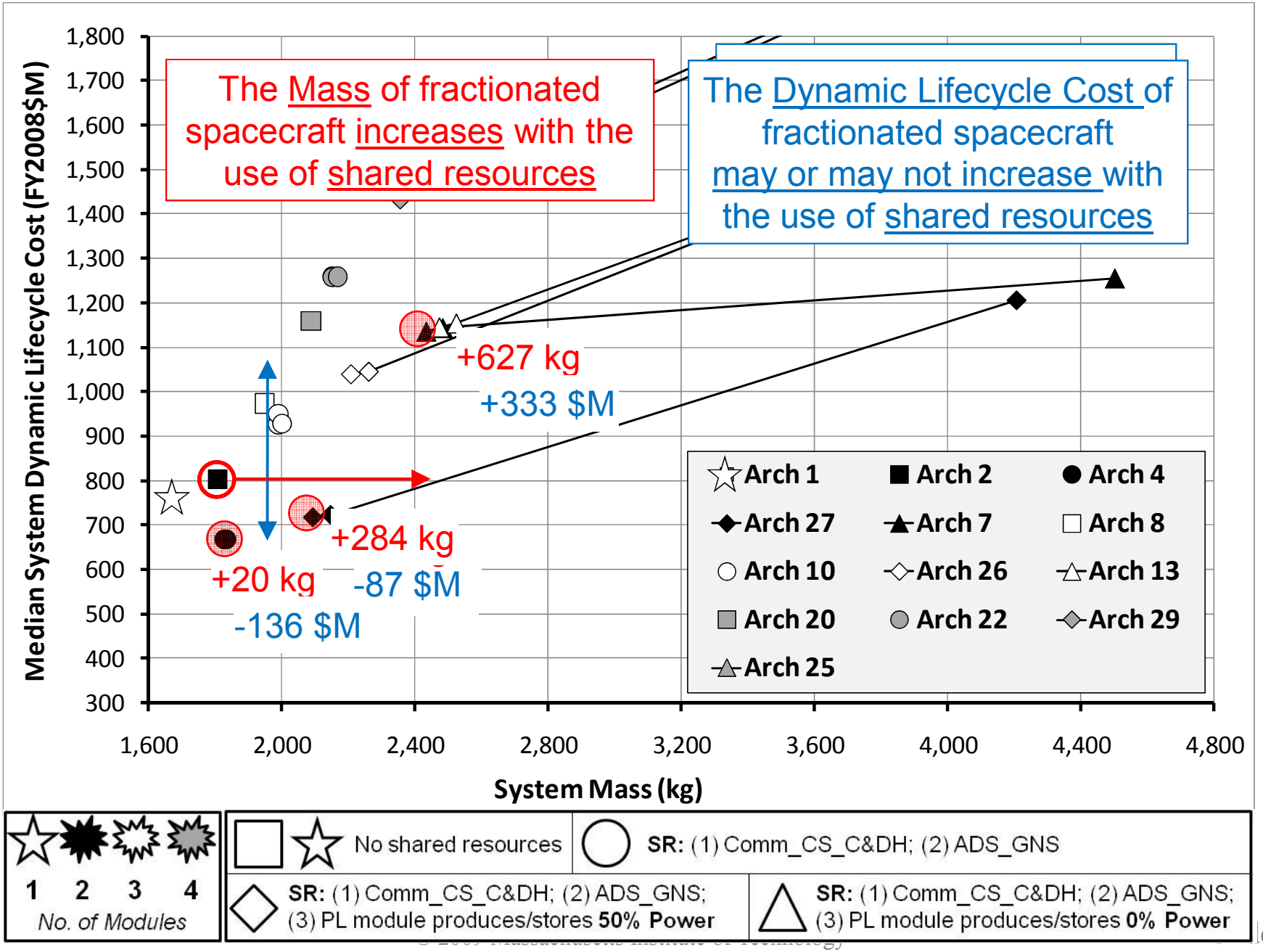

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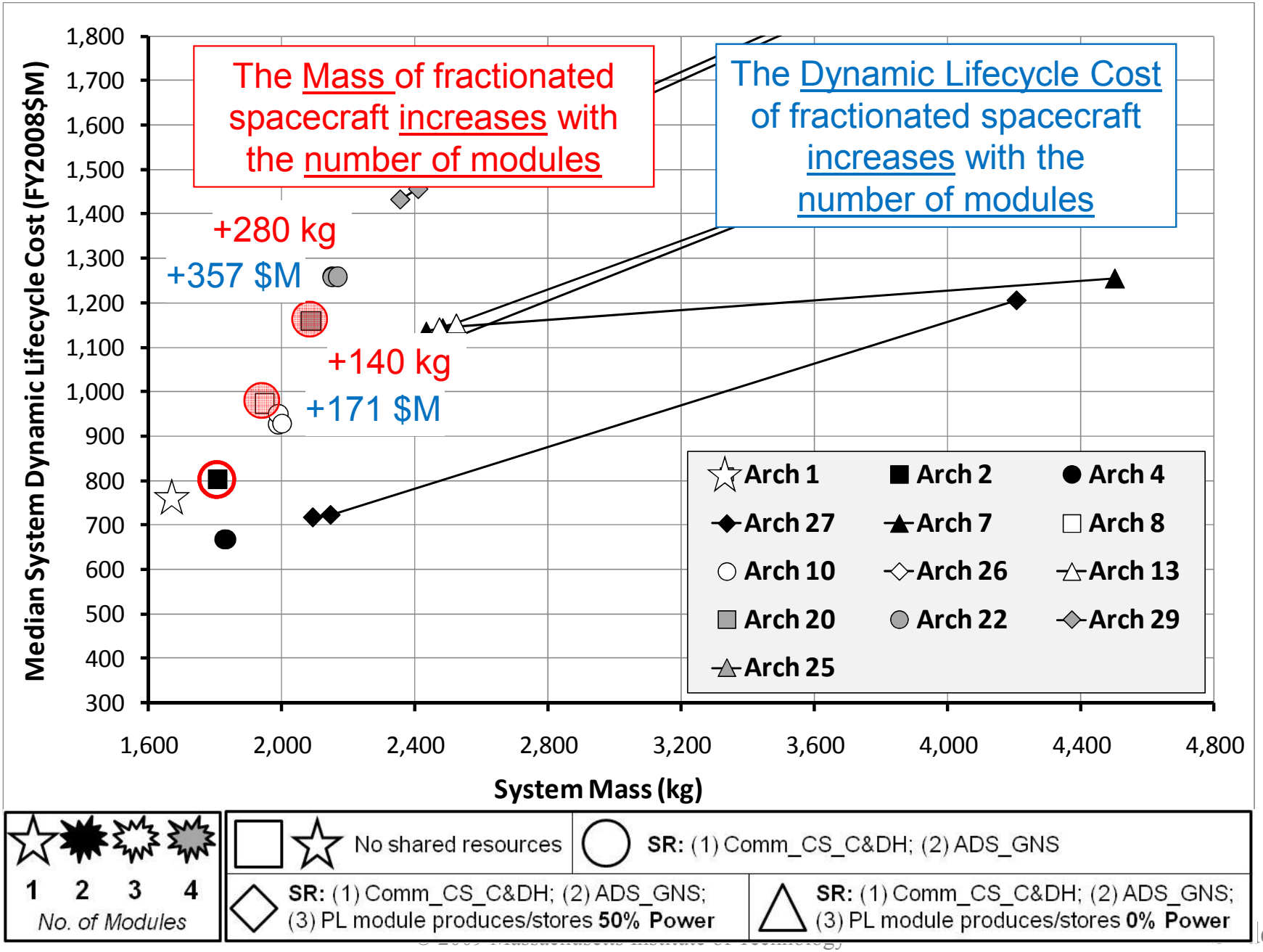
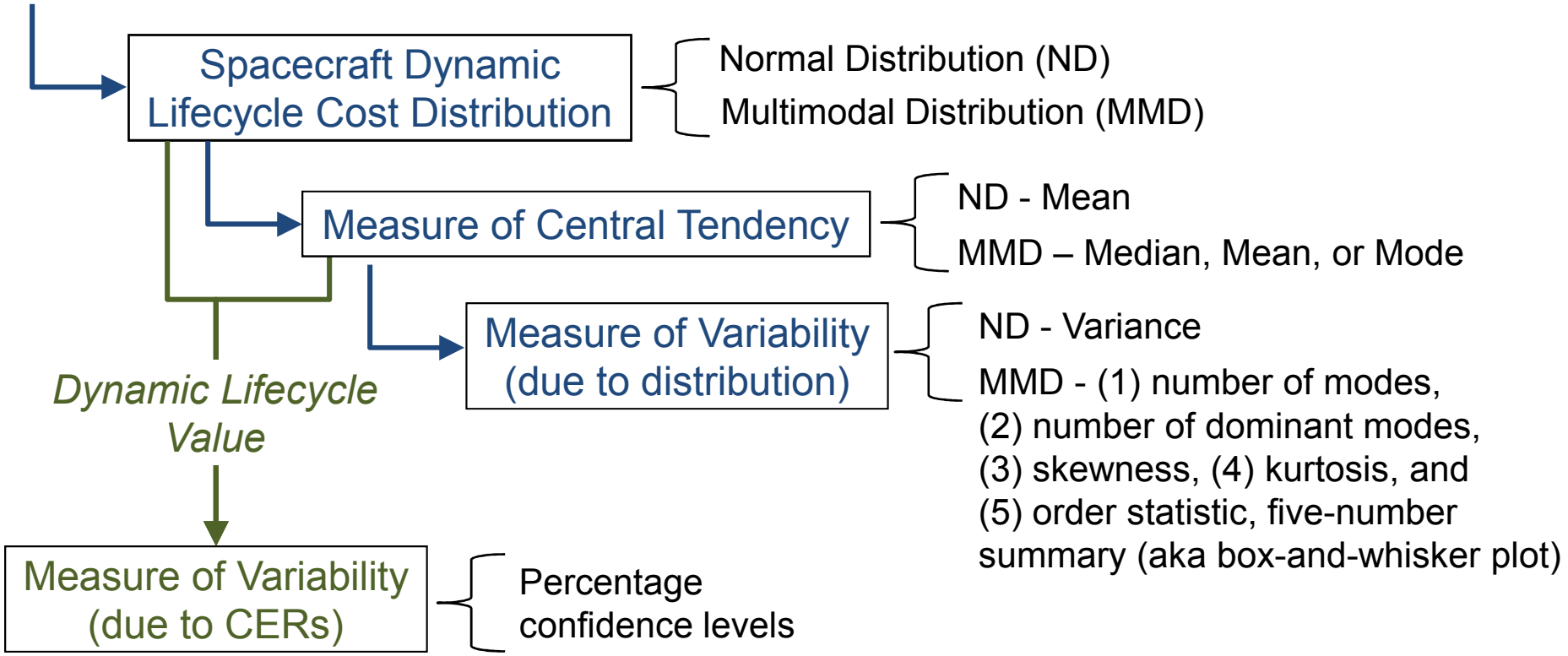


Results: Confidence in Dynamic LCC

Spacecraft Cost Modeling



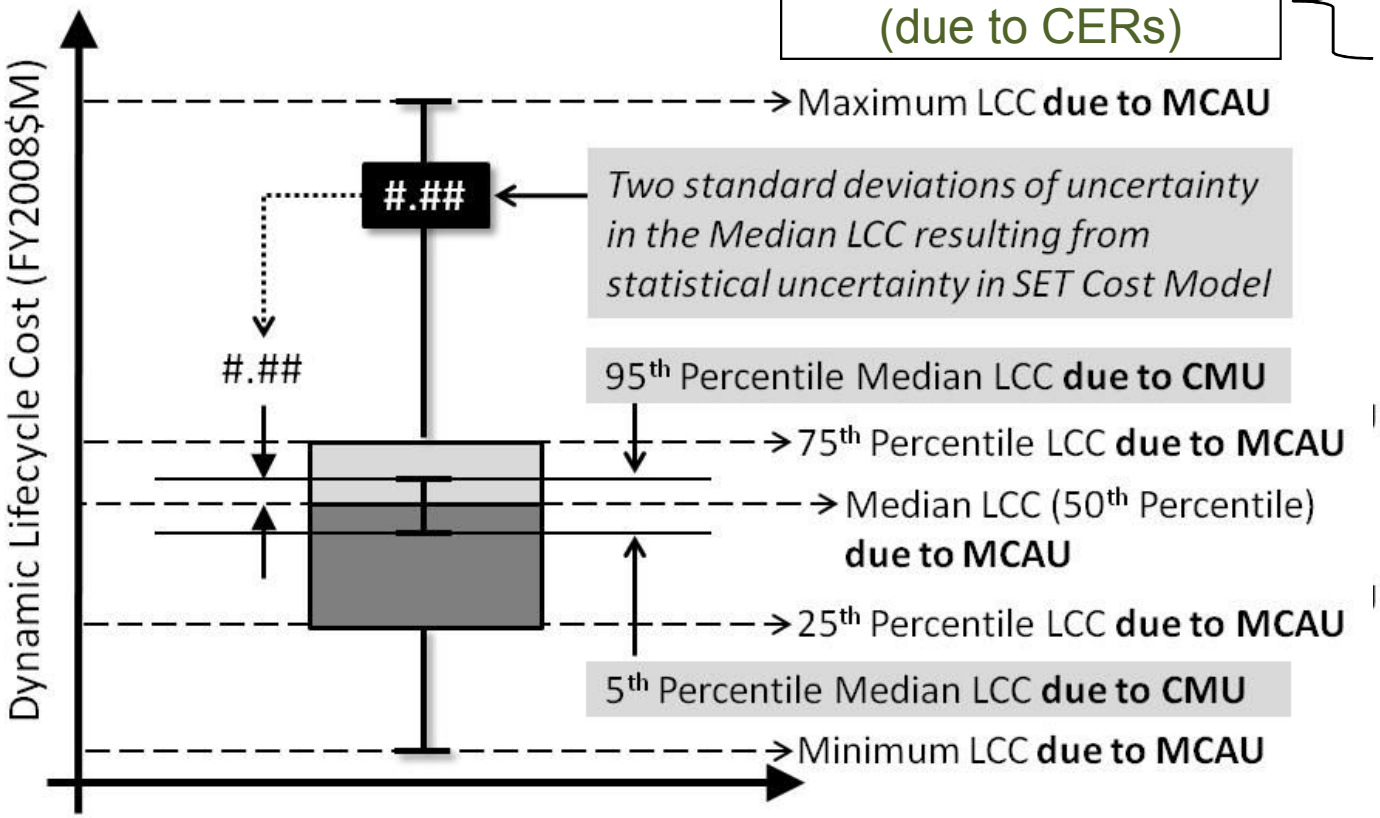
Results: Confidence in Dynamic LCC

Spacecraft Cost Modeling

Measure of Central Tendency — MMD – Median

Measure of Variability (due to distribution) — (5) order statistic, five-number summary (aka box-and-whisker plot)

Measure of Variability (due to CERs) — Percentage confidence levels



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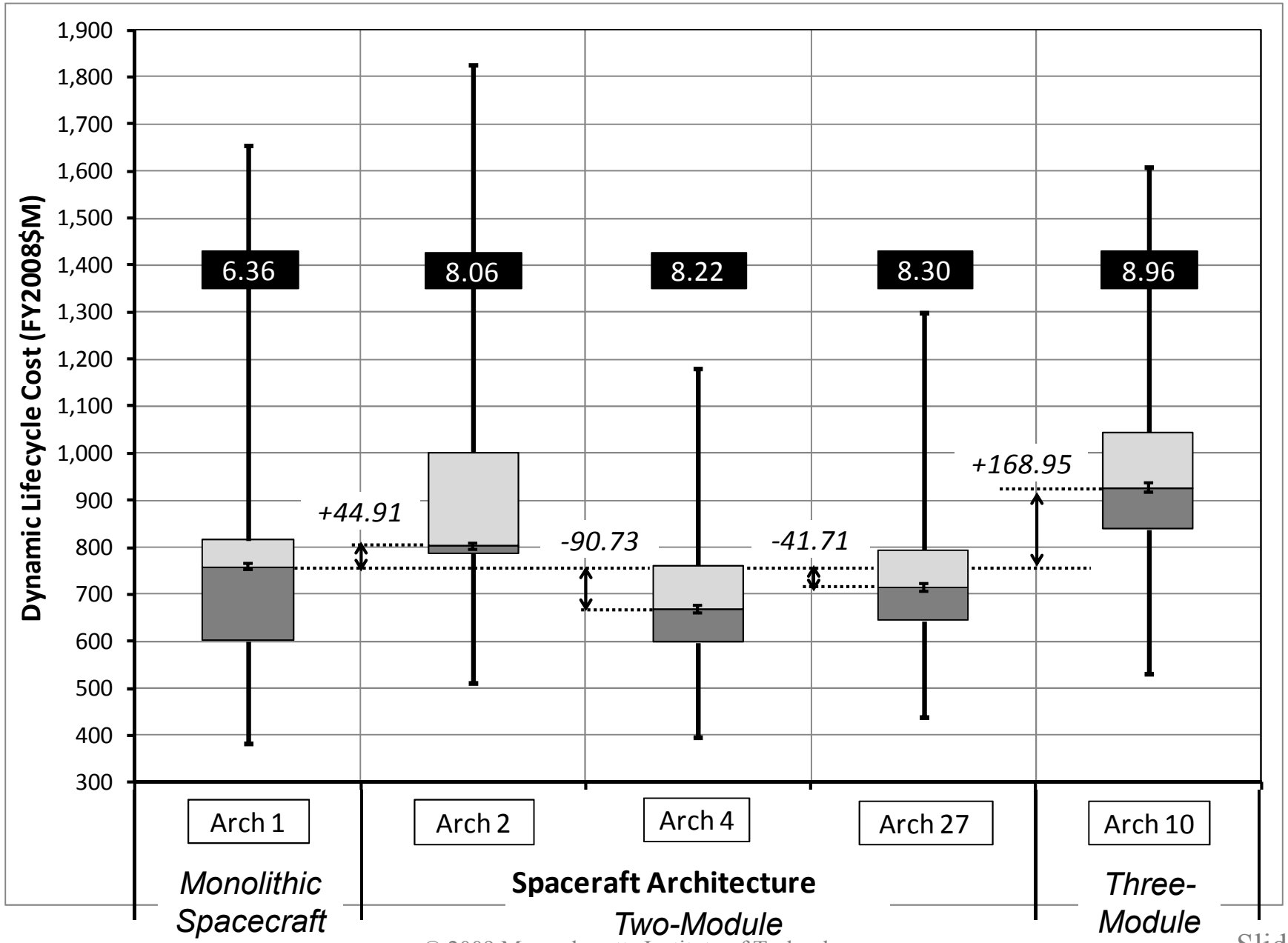

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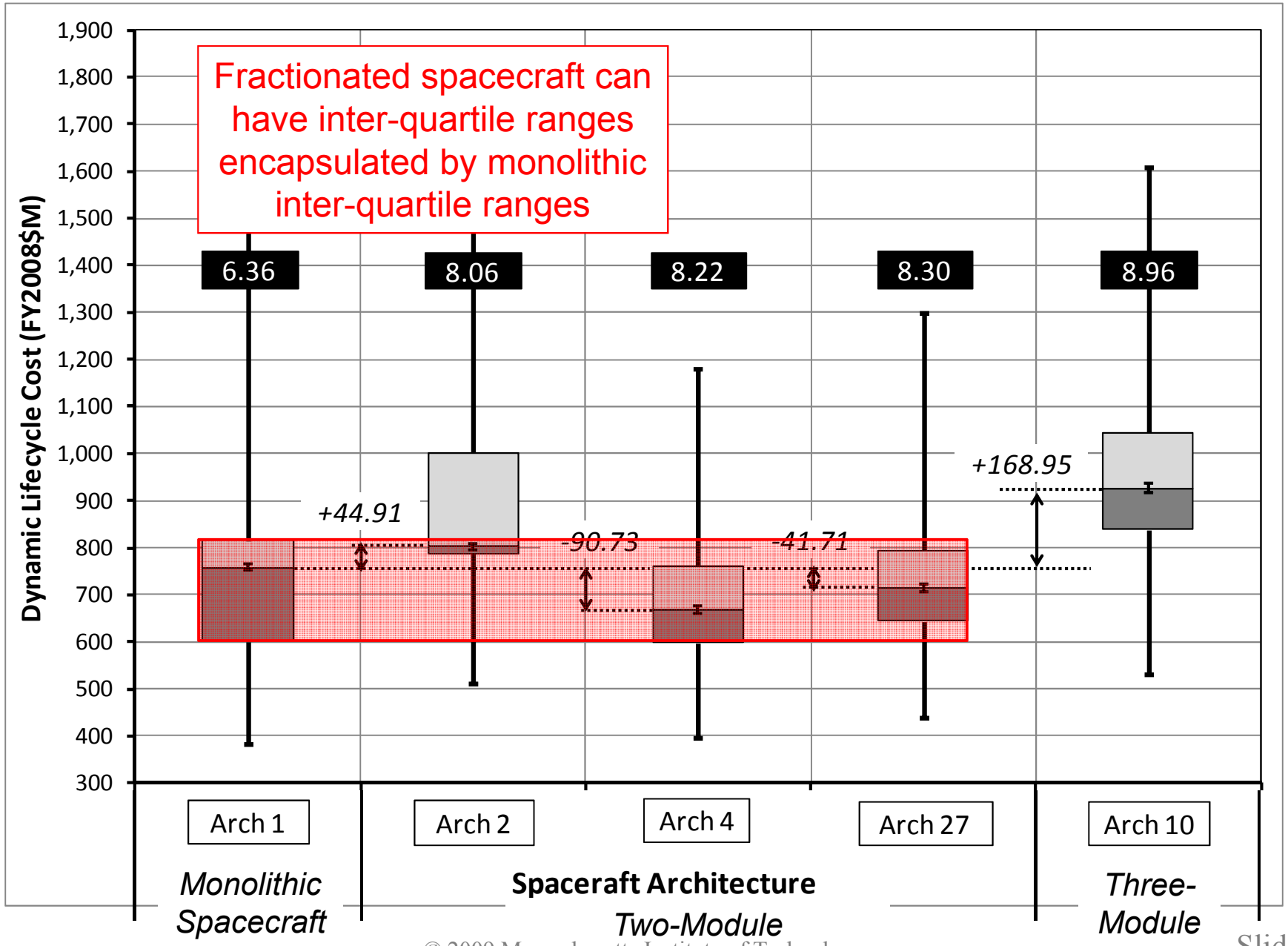

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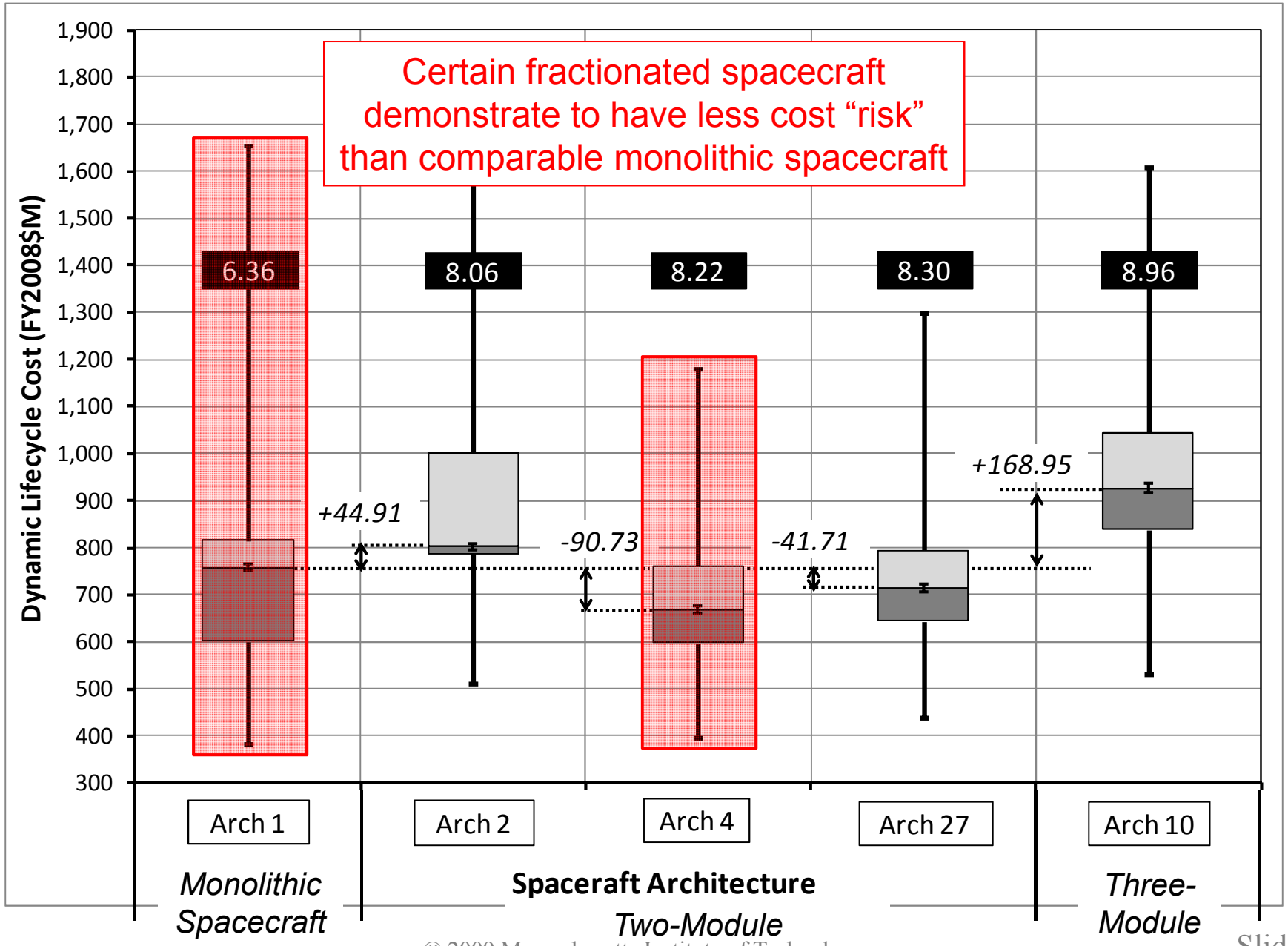

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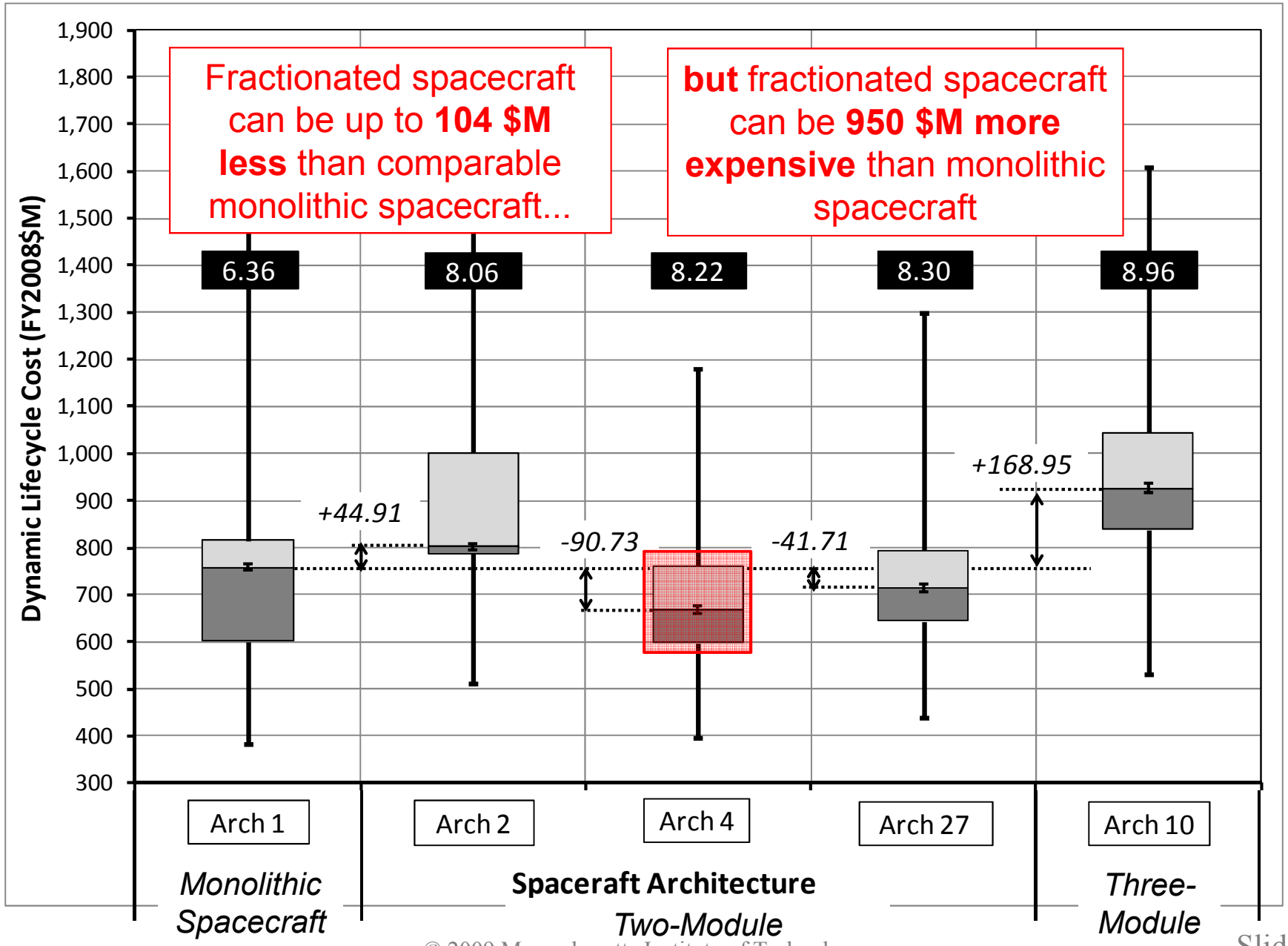

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Key Lessons Learned

System (Aggregate) Mass and Shared Subsystem Resources

- System mass increases
  - With increase in the use of shared resources
  - With increase in the number of modules via system-wide redundancy

NRE and RE Costs

- Dynamic Lifecycle Cost is dependent on NRE and RE costs
  - NRE and RE costs correlate positively with mass

Number and Cost of Replenishments

- Aggregate number of replenishments increases with number of modules
  - Aggregate cost of replenishments increases

Launch Vehicle Usage and Costs

- Fractionation decouples subsystems and payloads into modules
  - New spacecraft deployment strategies
    - Fractionated spacecraft may fit into a smaller launch vehicle or set of smaller launch vehicles
      - Reduces the launch costs (significantly)

Fundamental Reason for Selected Trends

Mass: monolithic spacecraft are less massive than fractionated spacecraft

- Number of modules and shared resource usage

Dynamic Lifecycle Cost: monolithic spacecraft are **less expensive** than fractionated spacecraft. Fractionated spacecraft have **higher**...

- Number of modules and shared resource usage
  - System mass (and size)
    - NRE and RE costs
    - Launch costs
  - Aggregate number of replenishments
    - Aggregate cost of replenishments (launch + RE costs)

Dynamic Lifecycle Cost: monolithic spacecraft are **more expensive** than fractionated spacecraft. Fractionated spacecraft have **higher**...

- Number of modules and shared resource usage
  - System mass (and size)
    - NRE and RE costs
  - Aggregate number of replenishments

Fractionated spacecraft have **lower**...

- Aggregate cost of replenishments (due to launch costs)

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Are Fractionated Spacecraft Viable?

Are fractionated spacecraft a suitable, if not "better", alternative to monolithic spacecraft in the current spacecraft paradigm?

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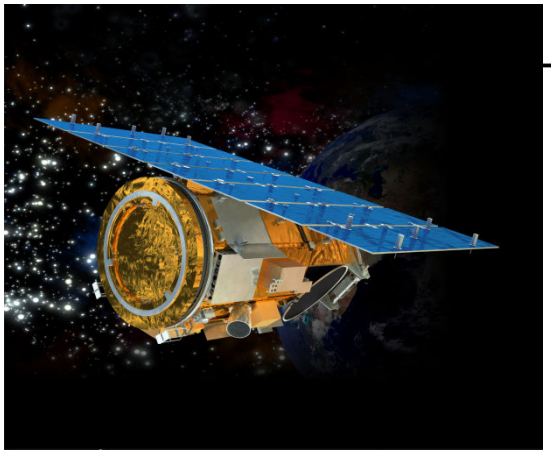

GEOEye-1
Source: *GEOEye*

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Value Proposition

Value Proposition

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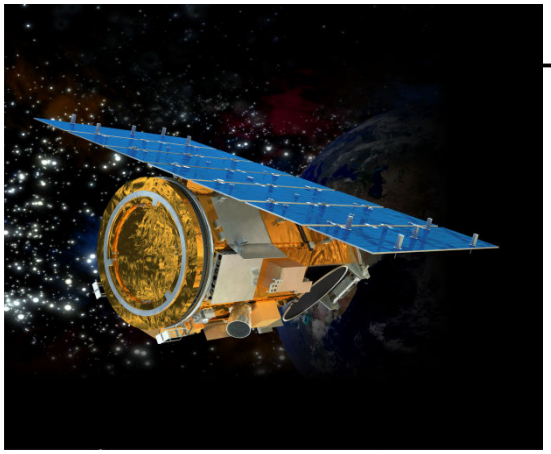

GEOEye-1
Source: *GEOEye*

Mass

+159 kg
+2,871 kg

Mass

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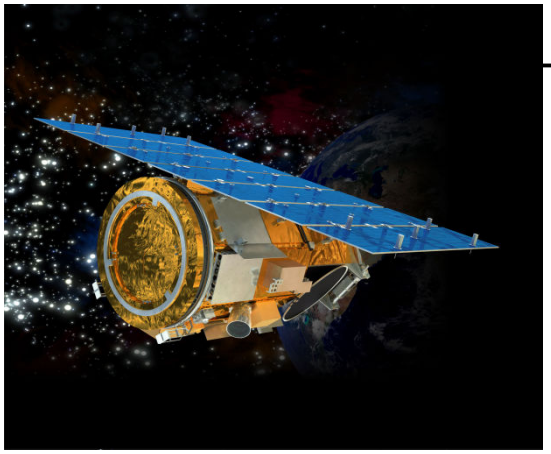

GEOEye-1
Source: *GEOEye*

Lifecycle Cost

-104 $M
+950 $M

Lifecycle Cost

Fractionated Spacecraft

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Further Exploration of the Value Proposition

O'Neill, M. G. (2009). *Assessing the Impacts of Fractionation on Pointing-Intensive Spacecraft*. SM Thesis, Aeronautics and Astronautics, Massachusetts Institute of Technology. www.seari.mit.edu

Addressed

Include other cardinal measures of effectiveness in the Value Proposition

What about the benefits of fractionation?

- Analysis of the mission lifetime benefits of fractionation

Discussed

Investigate alternative wireless power distribution systems

- Radically change the value proposition
  - Radio and microwave power transmission (O'Neill, 2009; Kerslake, 2008)
  - **Laser power beaming** (O'Neill, 2009; Kerslake, 2008)
  - Concentrated, reflected sunlight (Turner, 2006)
  - Electromagnetic formation flight (EMFF) (MIT Space Systems Lab)

What about other benefits of fractionation?

- Remote sensing mission, fractionated spacecraft interferometers

References

O'Neill, M. G. (2009). *Assessing the Impacts of Fractionation on Pointing-Intensive Spacecraft*. SM Thesis, Aeronautics and Astronautics, Massachusetts Institute of Technology.

Kerslake, T. W. (2008). Lunar Surface-to-Surface Power Transfer. In *University of New Mexico's Institute for Space and Nuclear Power Studies: Space Technology and Applications International Forum*. Albuquerque, New Mexico.

Turner, A. E. (2006). Power Transfer for Formation Flying Spacecraft. In *American Institute of Astronautics and Astronautics: Space 2006 Conference and Exposition*. San Jose, California.