JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

NASA Cost and Schedule Symposium

Math is EZIE: How Contracts Help Control Cost

2023 NASA Cost & Schedule Symposium

NASA Jet Propulsion Laboratory

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Background

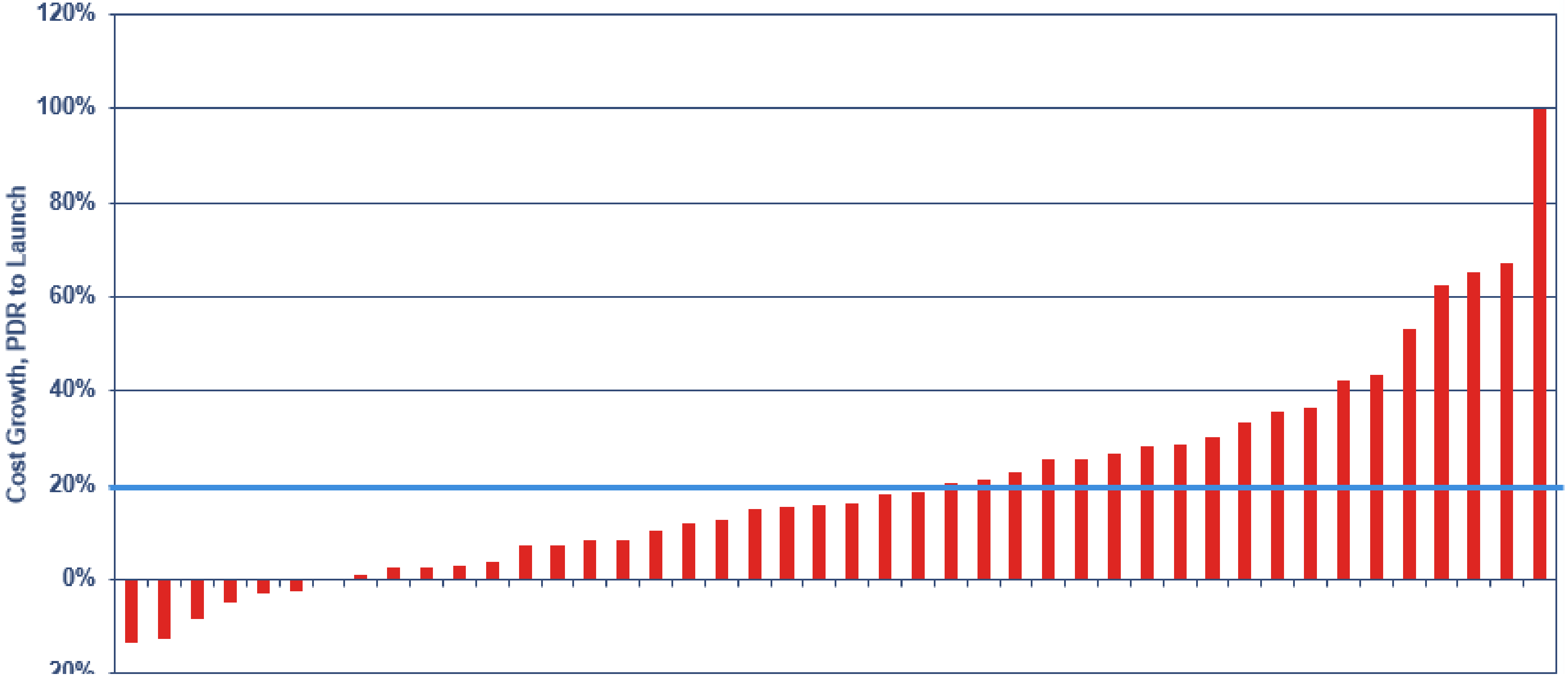
- The aerospace cost community relies on risk analyses to estimate confidence in a project's budget. At PDR, convention requires that baseline cost confidence plus project-held UFE should be around the 50th percentile and cost plus project-held UFE and HQ UFE should be around the 70th percentile of the joint distribution of total cost and schedule. But how can we test whether our approach to determining 50th and 70th percentiles for missions going into PDR is reliable?
- Our research will examine the NASA cost community's approach to project-held UFE postures, particularly when cost contracts are employed. Using the empirical dataset as our guide, how can projects approaching PDR provide cost and schedule analysis that supports the goal of achieving 70% confidence in the budget at the portfolio level?

Methodology: Data Collection & Normalization

- Cost data collected via PDR and Launch CADRes (Part C)
- Programmatic data collected via CADRes (Parts A, B)
- Looking at a total of 44 robotic missions:
  - Launch dates from 2001 to 2022
  - Total development costs up to $1B FY23
- Costs were normalized:
  - Phases A-D
  - Exclude launch vehicle costs
  - Include reserves
- Cost growth, at the mission level and at the spacecraft level, was calculated from PDR to Launch as:
  - $cost\ growth = \frac{(Cost\ @\ Launch - Cost\ @\ PDR)}{Cost\ @\ PDR}\ x\ 100\%$

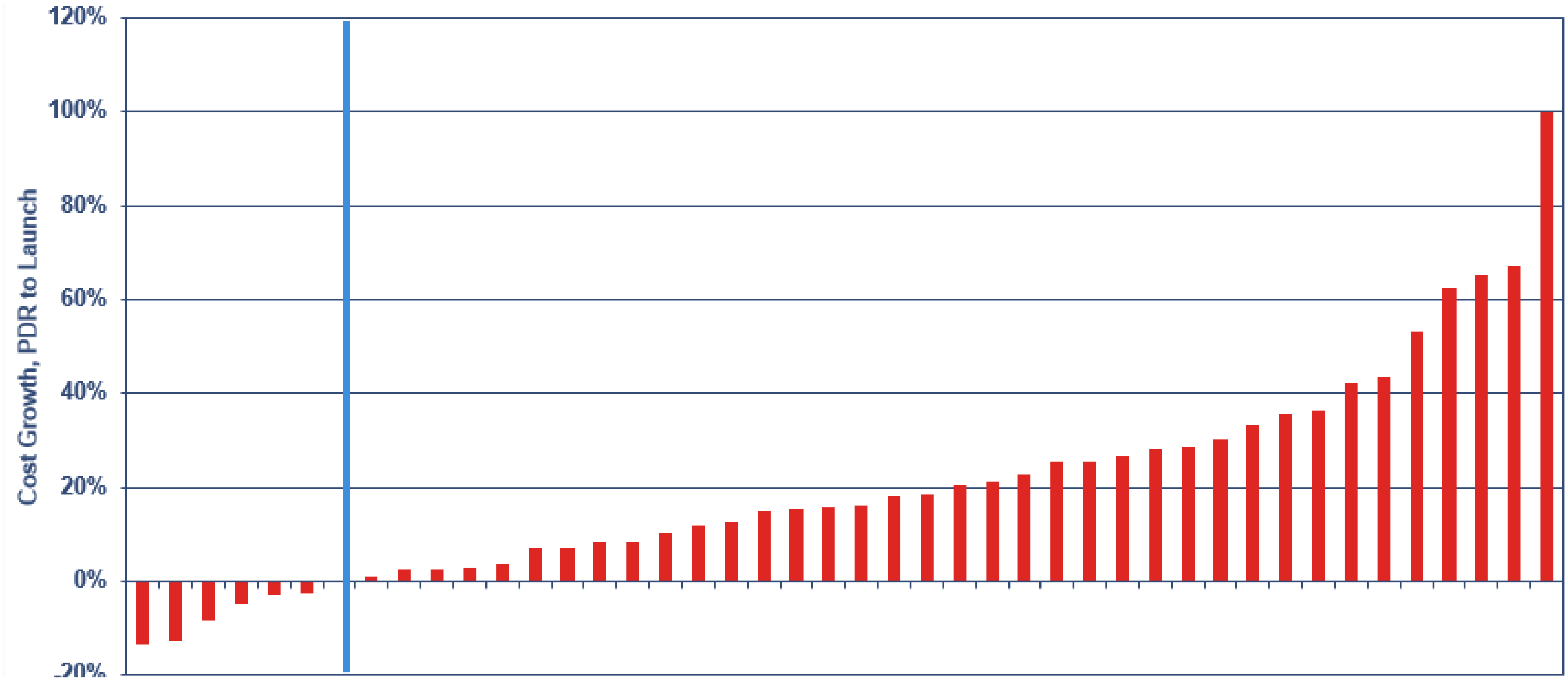
Mission Level Analysis

NASA Mission Cost Growth



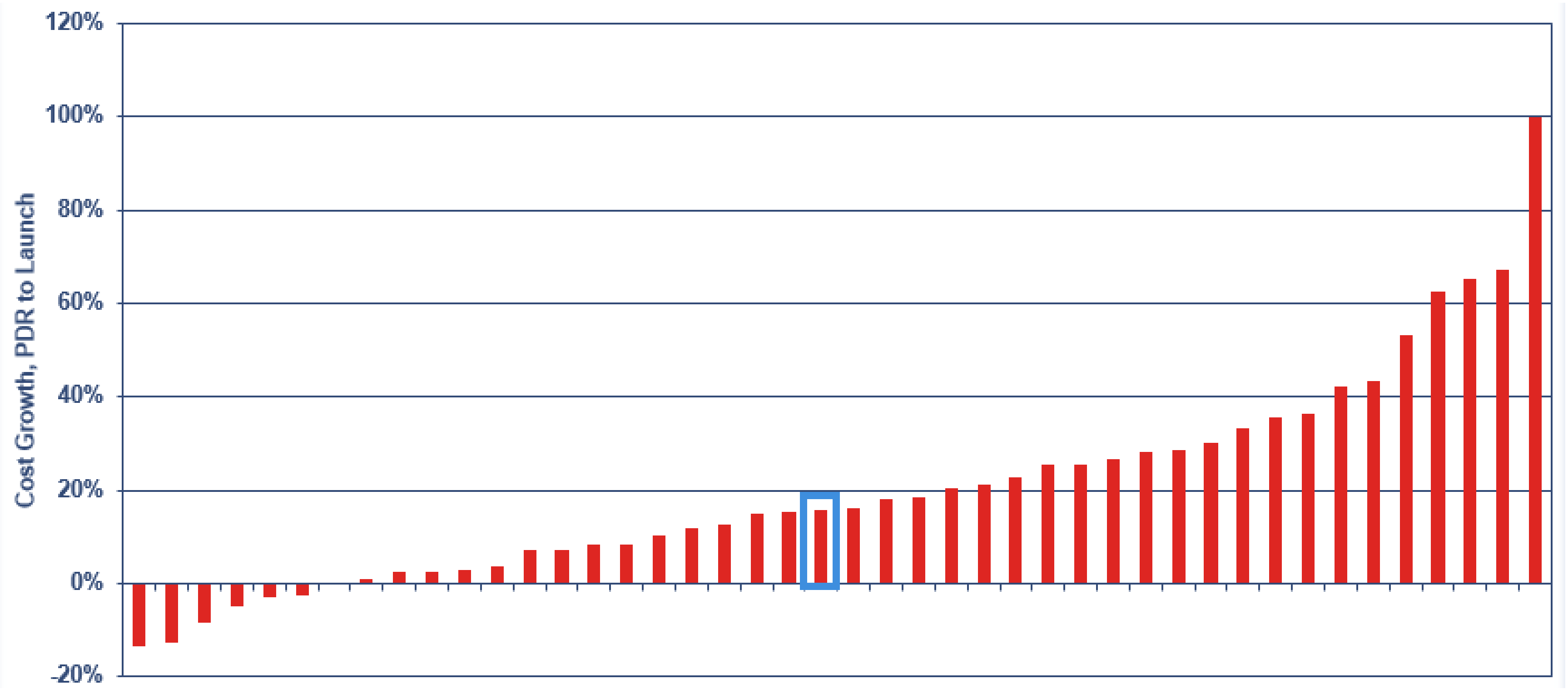
Summary Statistics	
Average Cost Growth	20%
Standard Deviation of Cost Growth	0.23

NASA Mission Cost Growth



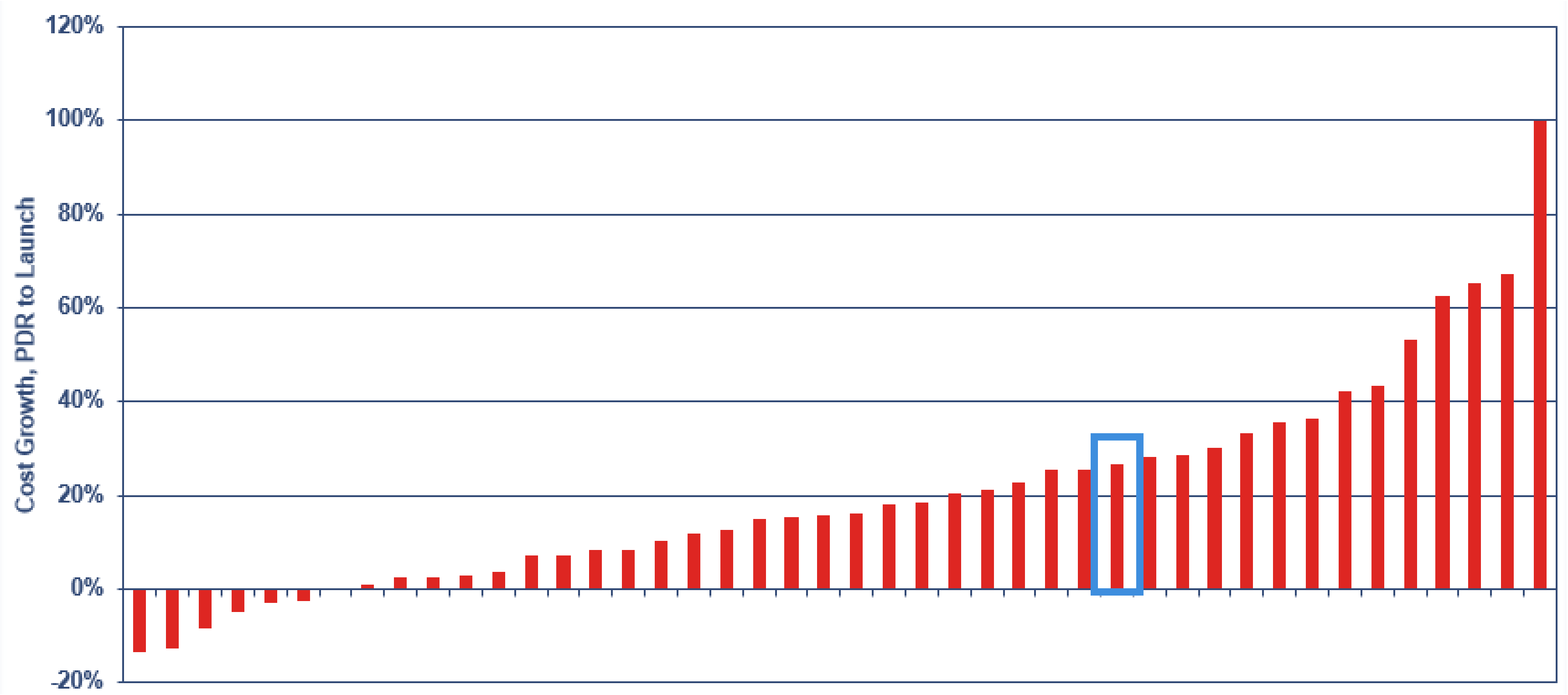
- 16% of missions did not experience cost growth
- 84% of missions experienced cost growth

NASA Mission Cost Growth



- At the empirical 50th percentile, cost growth is 16% in addition to project-held UFE

NASA Mission Cost Growth



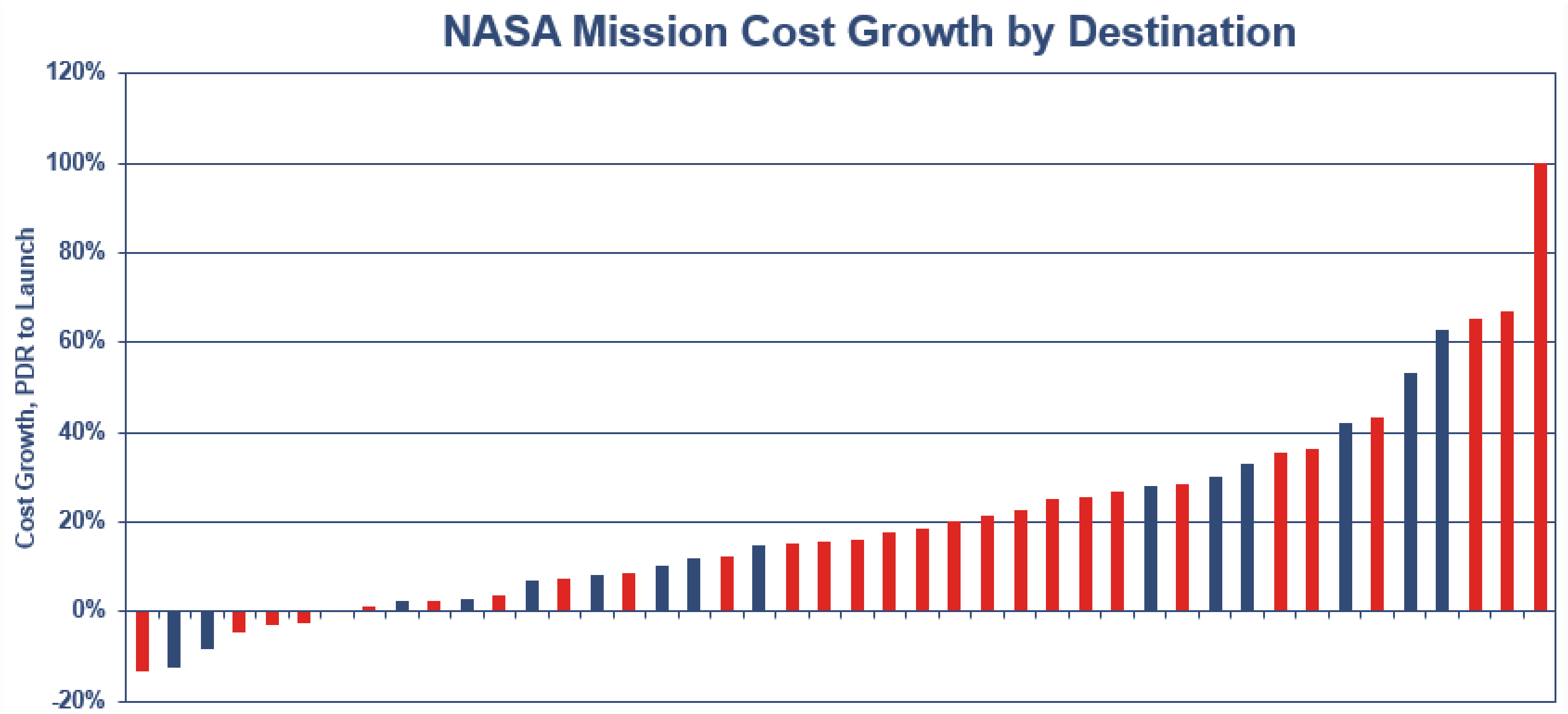
- At the empirical 70th percentile, cost growth is 27% in addition to project-held UFE

Variables

Variables	Group 1	Group 2
Destination	*Earth Orbiting*	*Planetary*
Requirements	*Pre-Version E*	*Version E*
Acquisition Strategy	*Competed*	*Directed*
Total Mission Cost	*Under $250*	*$250M+*
Mission Risk Class	*B*	*C*
Spacecraft Development	*In-House*	*Subcontracted*
Contract Type	*Cost Plus*	*Firm Fixed Price*

- We hypothesized potential drivers of cost growth and speculated if cost growth would vary based on categorical groupings
- For each of the seven variables, t-tests were run to compare the means of the two groups
  - For our hypothesis tests, an α of 0.1 was selected

Does Destination Matter?



Does Destination Matter?

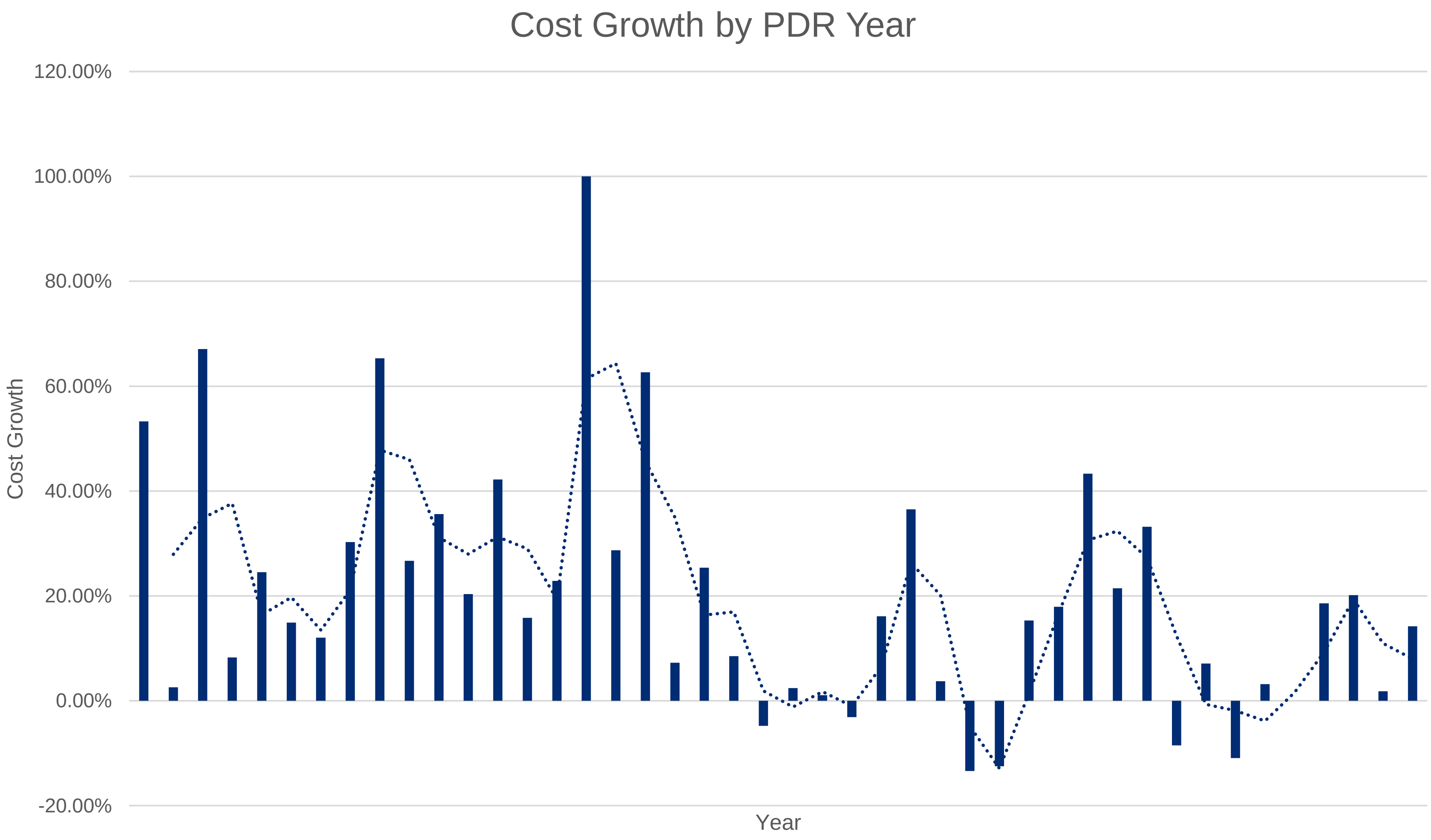
Destination	Average Cost Growth
Earth Orbiting	23%
Planetary	16%

- We looked at earth-orbiting missions compared to planetary missions
  - We hypothesized that planetary missions would experience less cost growth since they are less likely to have schedule growth due to fixed launch windows
- H_0: $\mu_{earth\ orbiting} = \mu_{planetary}$
- H_1: $\mu_{earth\ orbiting} > \mu_{planetary}$

T Test Summary	
T statistic	1.01
P value	0.16

- However, the difference is not significant

Do 7120.5E Requirements Matter?



Do 7120.5E Requirements Matter?

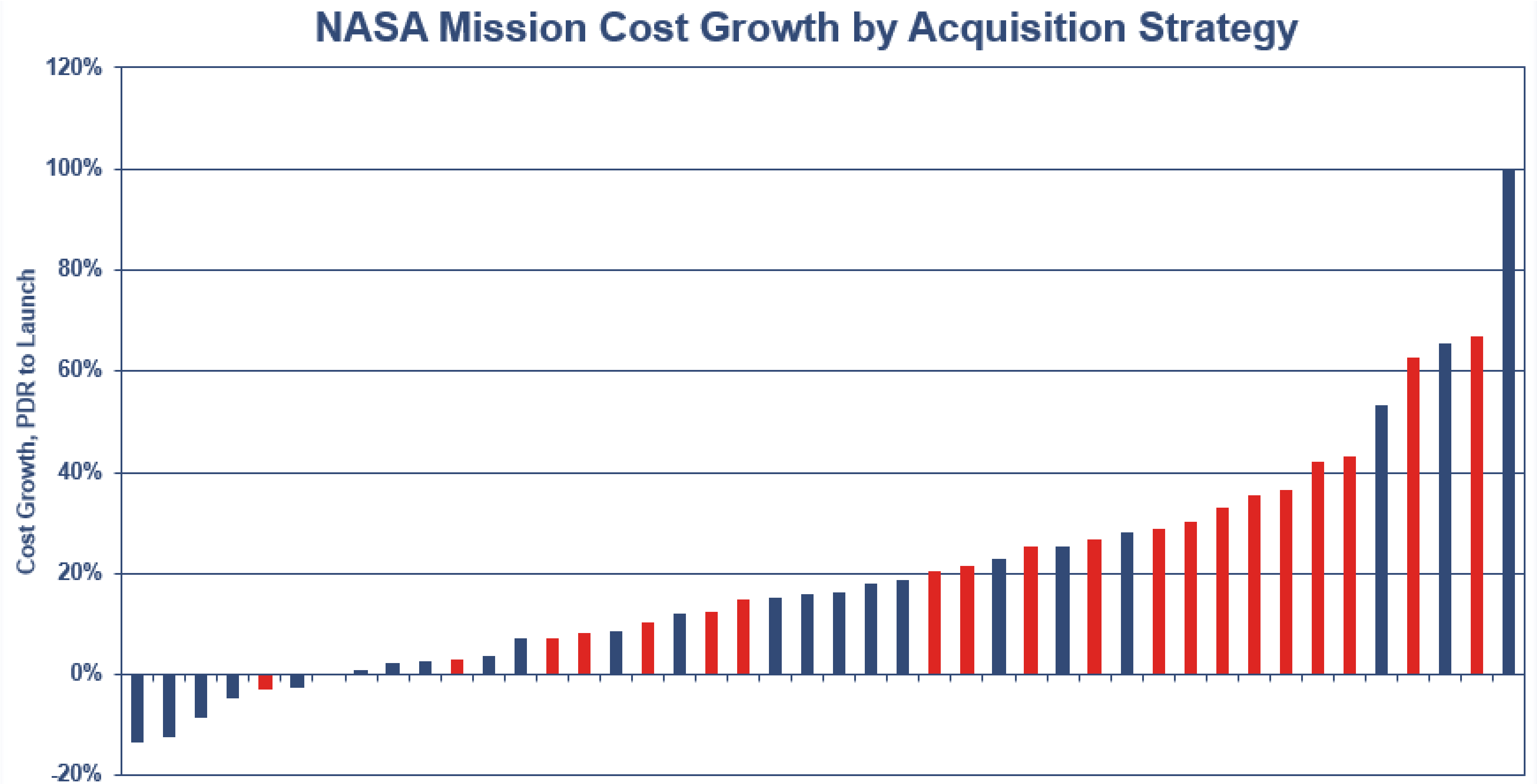
NASA Requirements	Average Cost Growth
Pre-Version E	23%
Version E	12%

- We looked at missions prior to 7120.5E requirements compared to missions with 7120.5E requirements
- H_0: $\mu_{pre\ 7120.5E} = \mu_{version\ 5E}$
- H_1: $\mu_{pre\ 7120.5E} > \mu_{version\ 5E}$

T Test Summary	
T statistic	1.69
P value	0.05

- Thus, the difference is statistically significant supporting the assertion that new programmatic requirements help NASA control costs

Does Acquisition Strategy Matter?



= Directed

= Competed

Does Acquisition Strategy Matter?

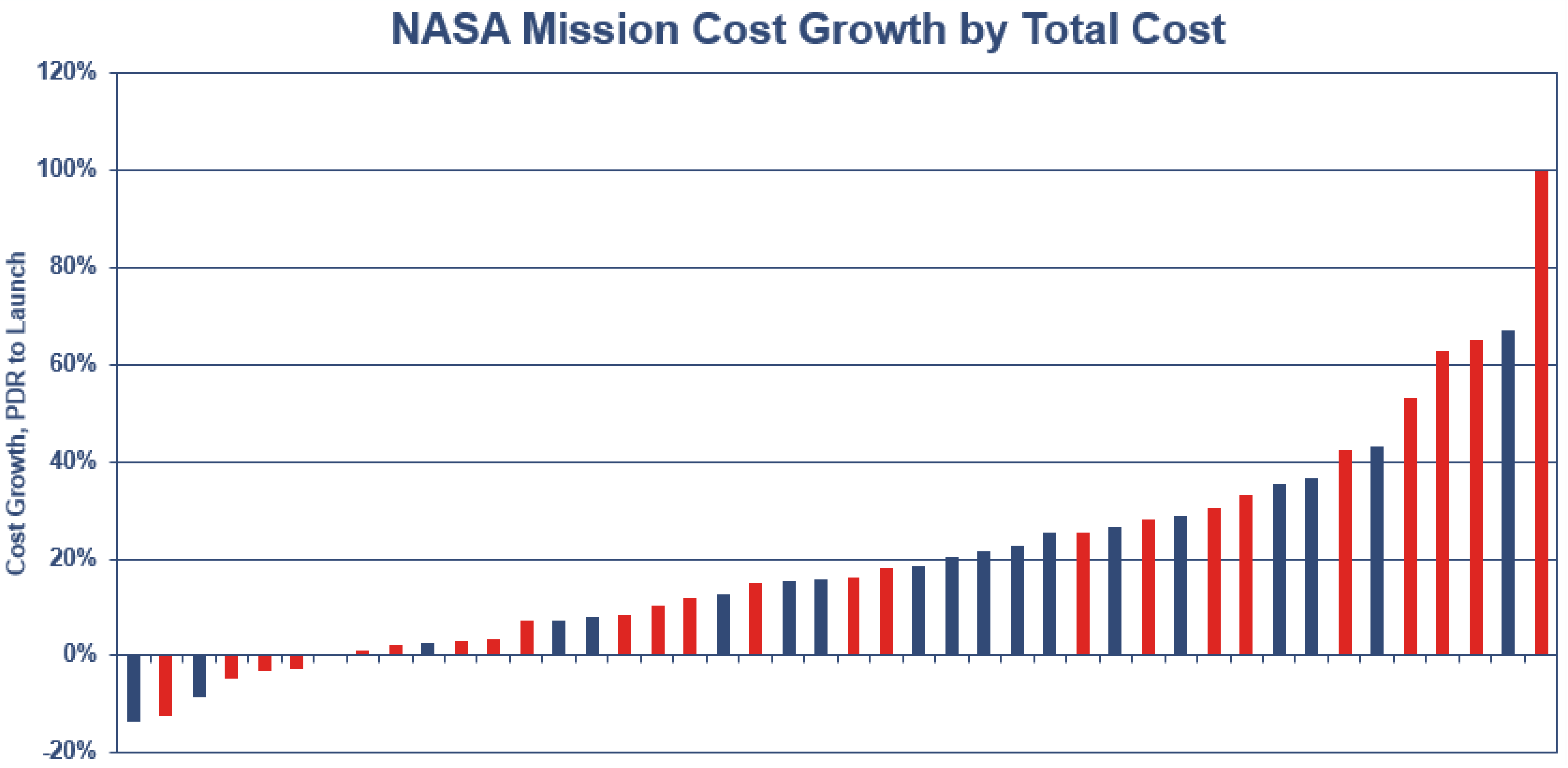
Acquisition Strategy	Average Cost Growth
Competed	25%
Directed	12%

- We looked at competed missions compared to directed missions
  - We hypothesized that directed missions would have less cost growth
- H_0: $\mu_{competed} = \mu_{directed}$
- H_1: $\mu_{competed} > \mu_{directed}$

T Test Summary	
T statistic	2.25
P value	0.01

- Thus, the difference is statistically significant
  - Potential drivers for this were explored in my presentation yesterday "How Competed Missions Might Be Experiencing More Cost Growth than Directed Missions"

Does Total Mission Cost Matter?



= Under $250M

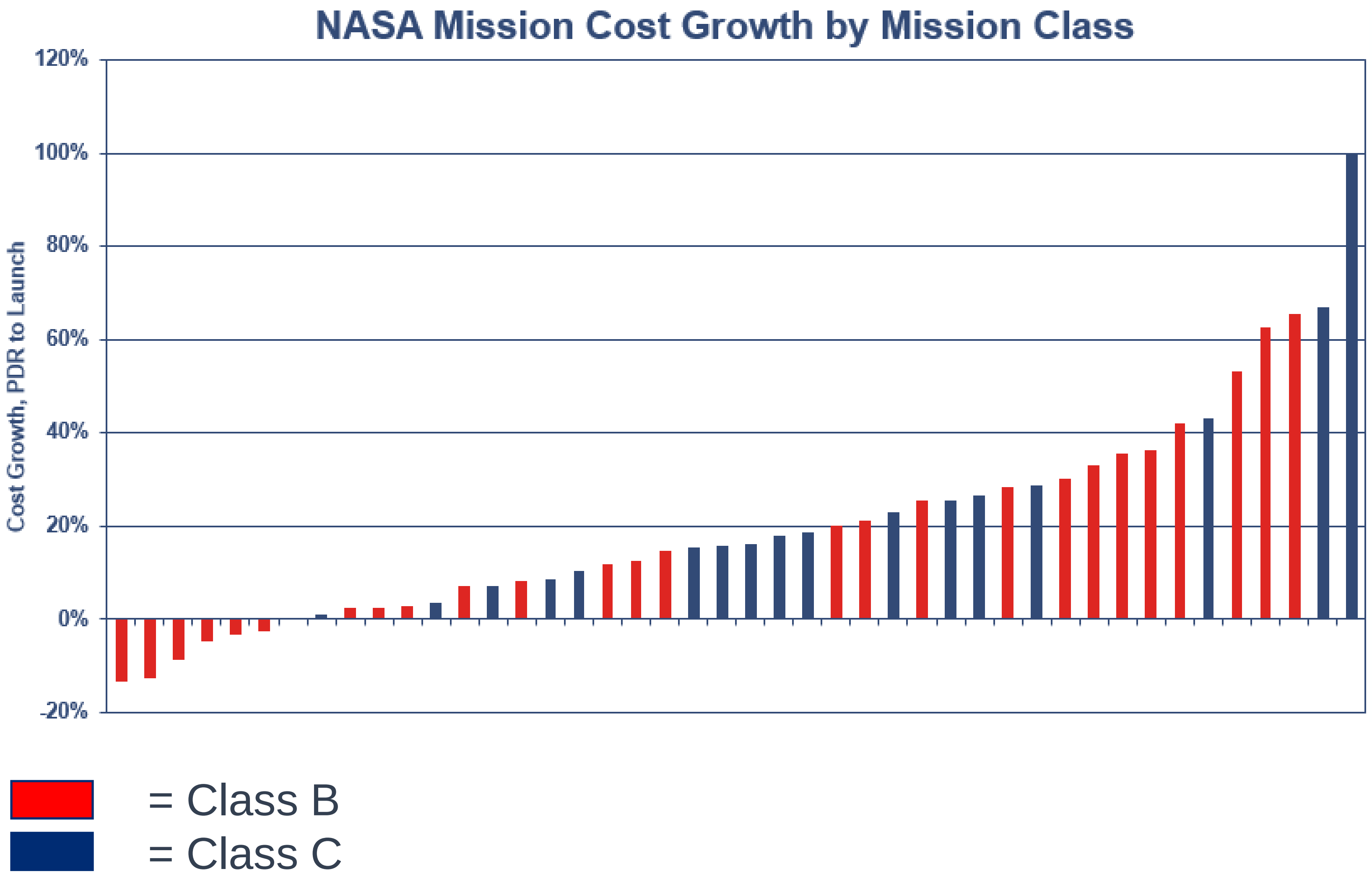
= $250M+

Does Total Mission Cost Matter?

Total Mission Cost	Average Cost Growth
Under $250M	20%
$250M+	20%

- A hypothesis test was omitted due to the equal averages

Does Mission Risk Class Matter?



Does Mission Risk Class Matter?

Mission Type	Average Cost Growth
Class B	17%
Class C	24%

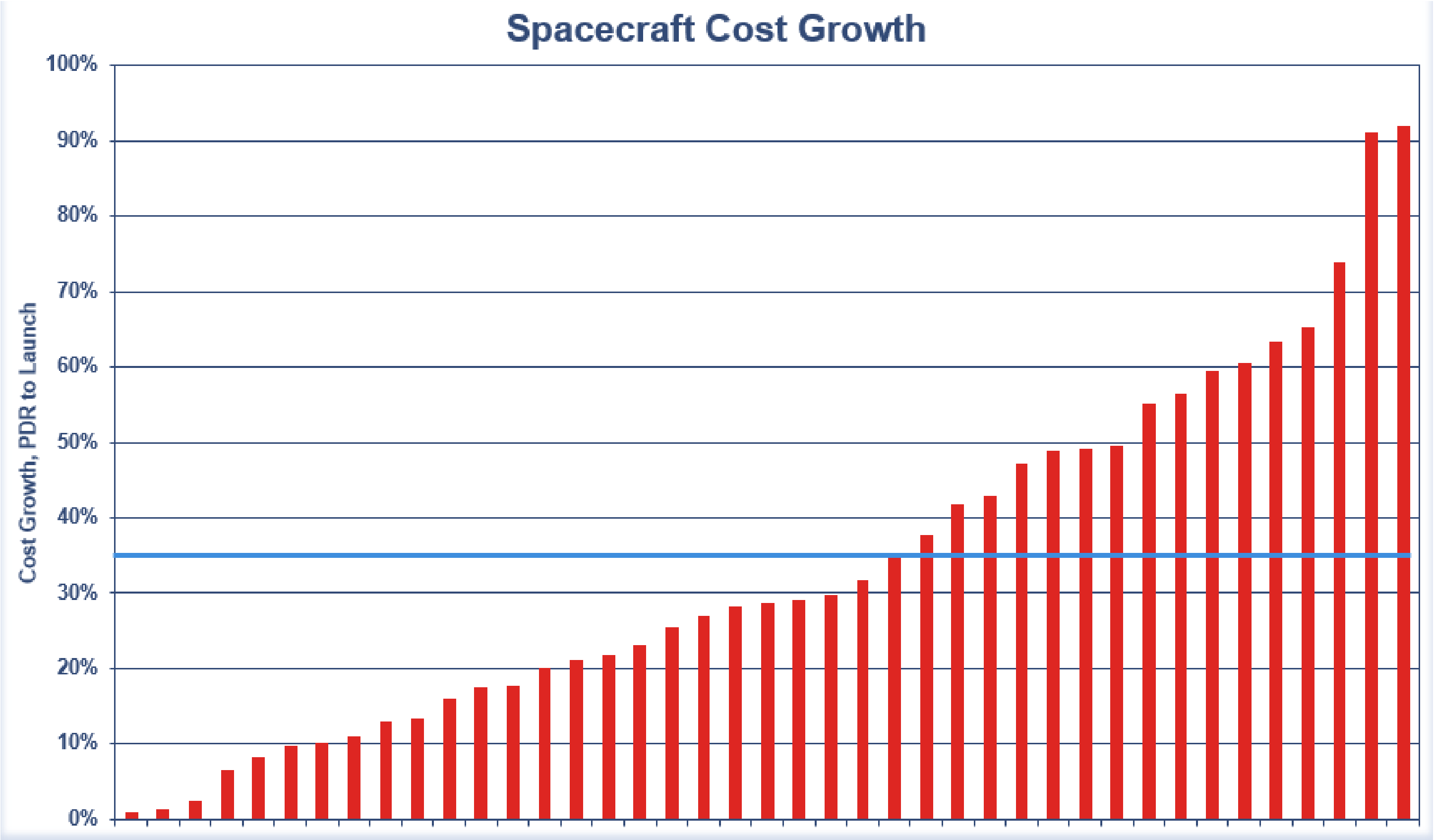
- We looked at Class B missions compared to Class C missions
- H_0: $\mu_{Class\ C} = \mu_{Class\ B}$
- H_1: $\mu_{Class\ C} > \mu_{Class\ B}$

T Test Summary	
T statistic	-0.946
P value	0.175

- However, the difference is not significant

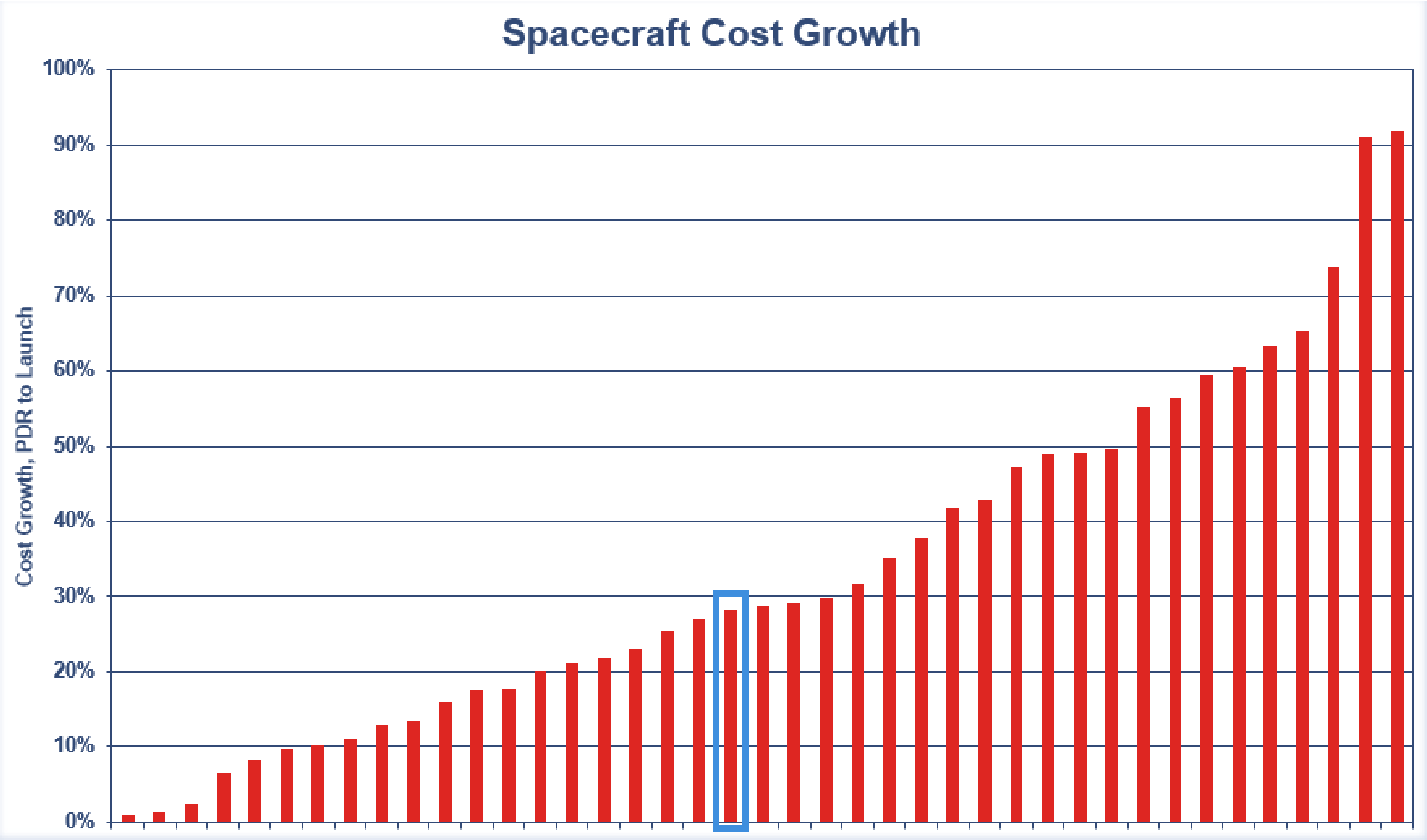
Spacecraft Level Analysis

NASA Spacecraft Cost Growth



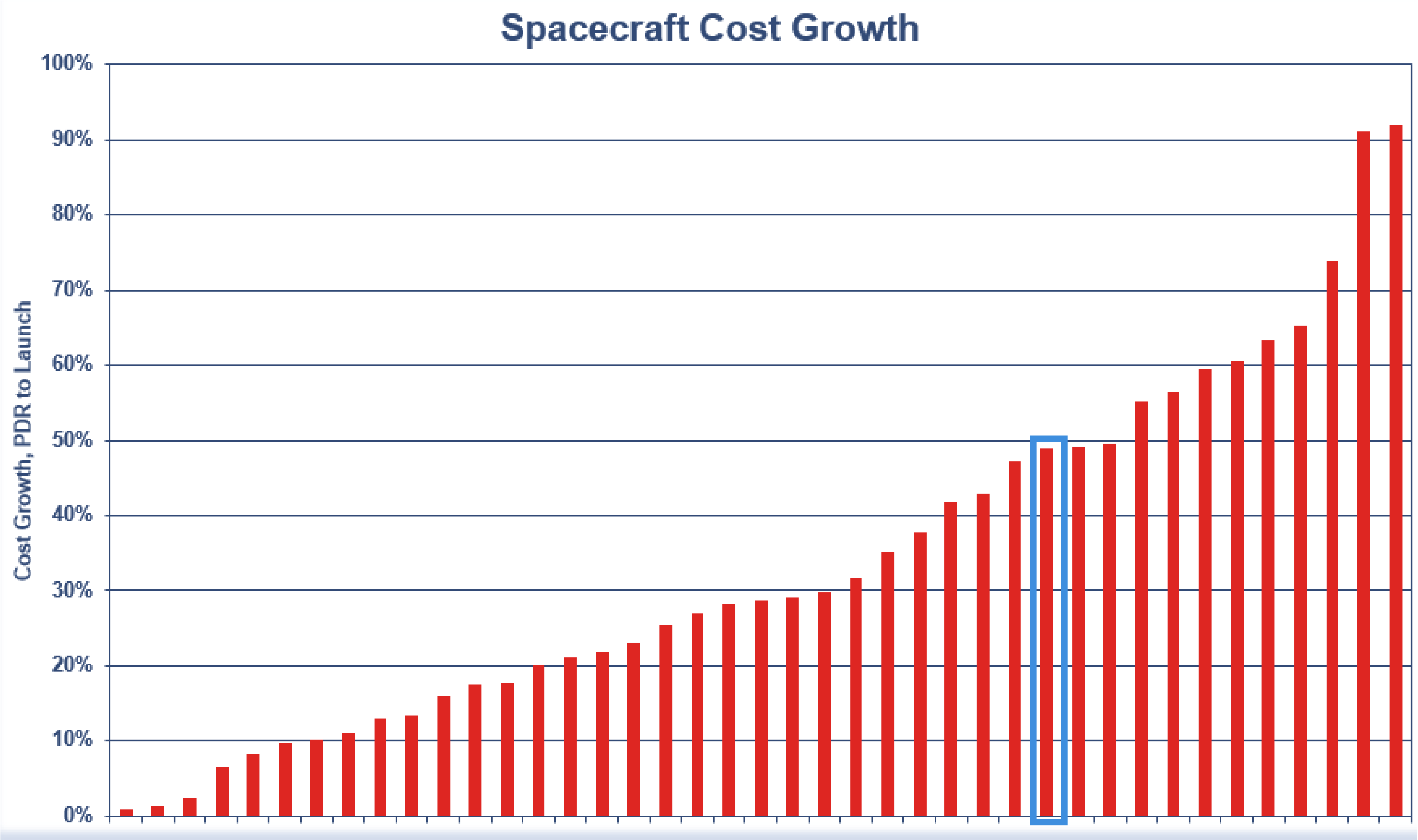
Summary Statistics	
Average Cost Growth	34%
Standard Deviation of Cost Growth	0.23

NASA Spacecraft Cost Growth



- At the empirical 50th percentile, cost growth is 28% in addition to project-held UFE

NASA Spacecraft Cost Growth



- At the empirical 70th percentile, cost growth is 49% in addition to project-held UFE

Spacecraft Bus Developer

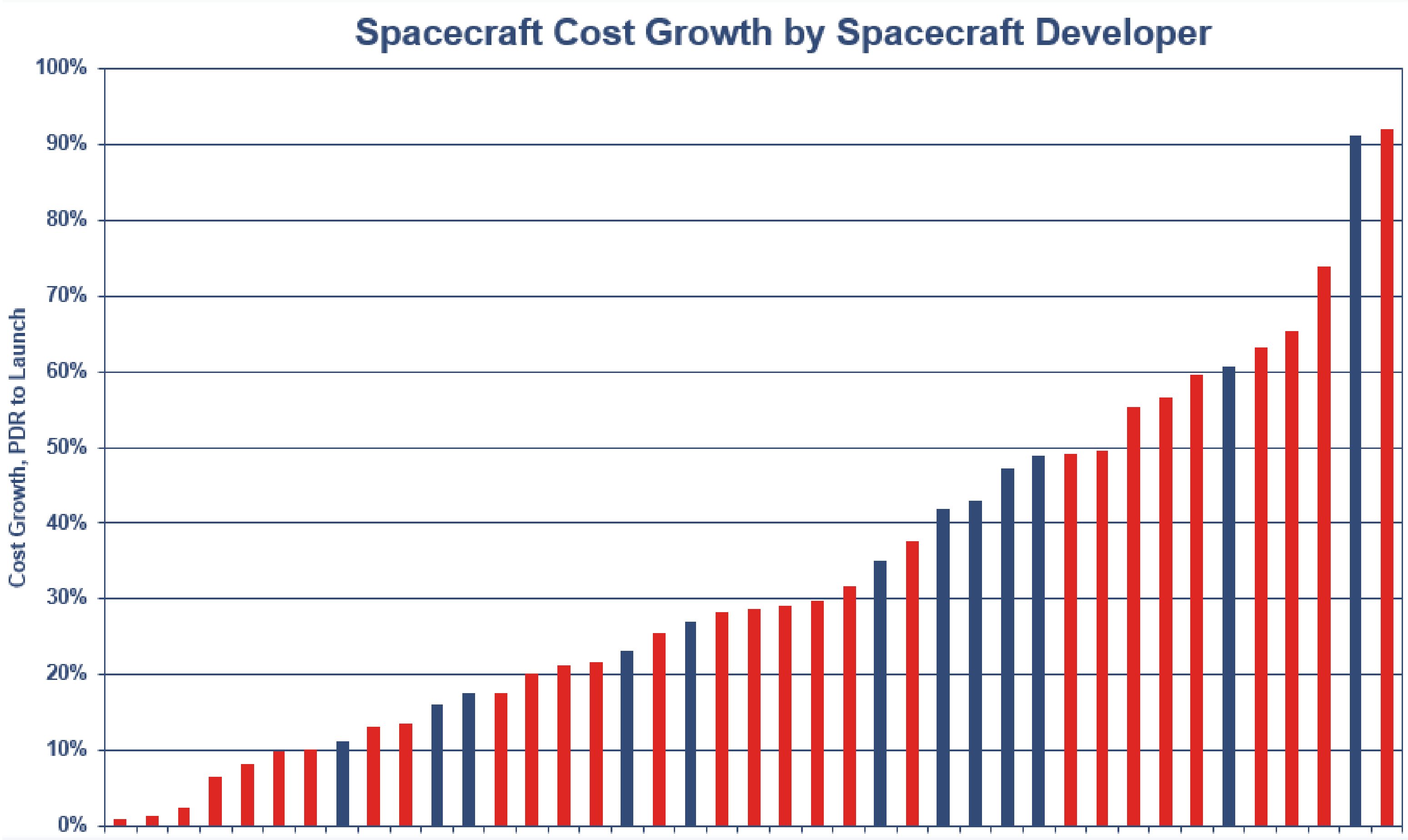
- As more commercial hardware options become available, NASA missions have relied on various cost contracts, particularly cost-plus (CP) contracts and firm-fixed-price contracts (FFP). With CP contracts, NASA covers the original planned cost as well as any cost growth experienced due to labor or material costs. With FFP contracts, NASA covers a fixed price and the contractor is responsible for any incurred costs. NASA administrator Bill Nelson noted the dramatic shift to FFP contracts in a continued effort to control cost growth and make space exploration more affordable.

Nelson criticizes "plague" of cost-plus NASA contracts

by **Jeff Foust** — May 4, 2022

NASA Administrator Bill Nelson criticized traditional cost-plus contracts at a May 3 Senate hearing, calling them a "plague" on the agency. Credit: NASA/Bill Ingalls

Does Spacecraft Bus Developer Matter?



= In-House Build
= Subcontracted

Does Spacecraft Bus Developer Matter?

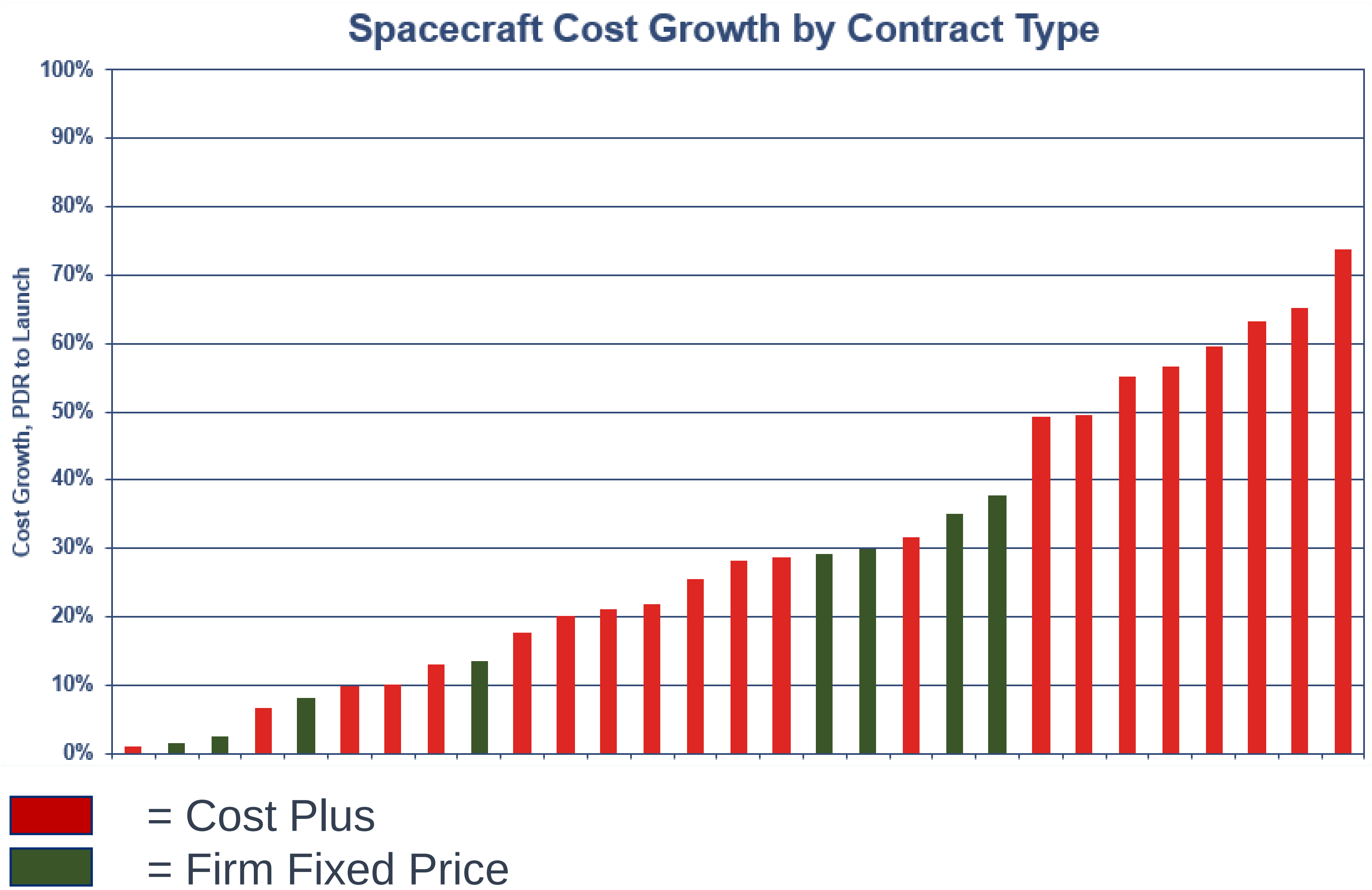
Spacecraft Developer	Average Cost Growth
In-House Builds	39%
Subcontracted Bus	32%

- We looked at in-house spacecraft builds compared to subcontracted builds
  - We hypothesized that subcontracted buses would experience less cost growth than in-house builds
- H_0: $\mu_{in-house} = \mu_{subcontract}$
- H_1: $\mu_{in-house} > \mu_{subcontract}$

T Test Summary	
T statistic	0.85
P value	0.20

- However, the difference is not significant

Does Contract Type Matter?



Does Contract Type Matter?

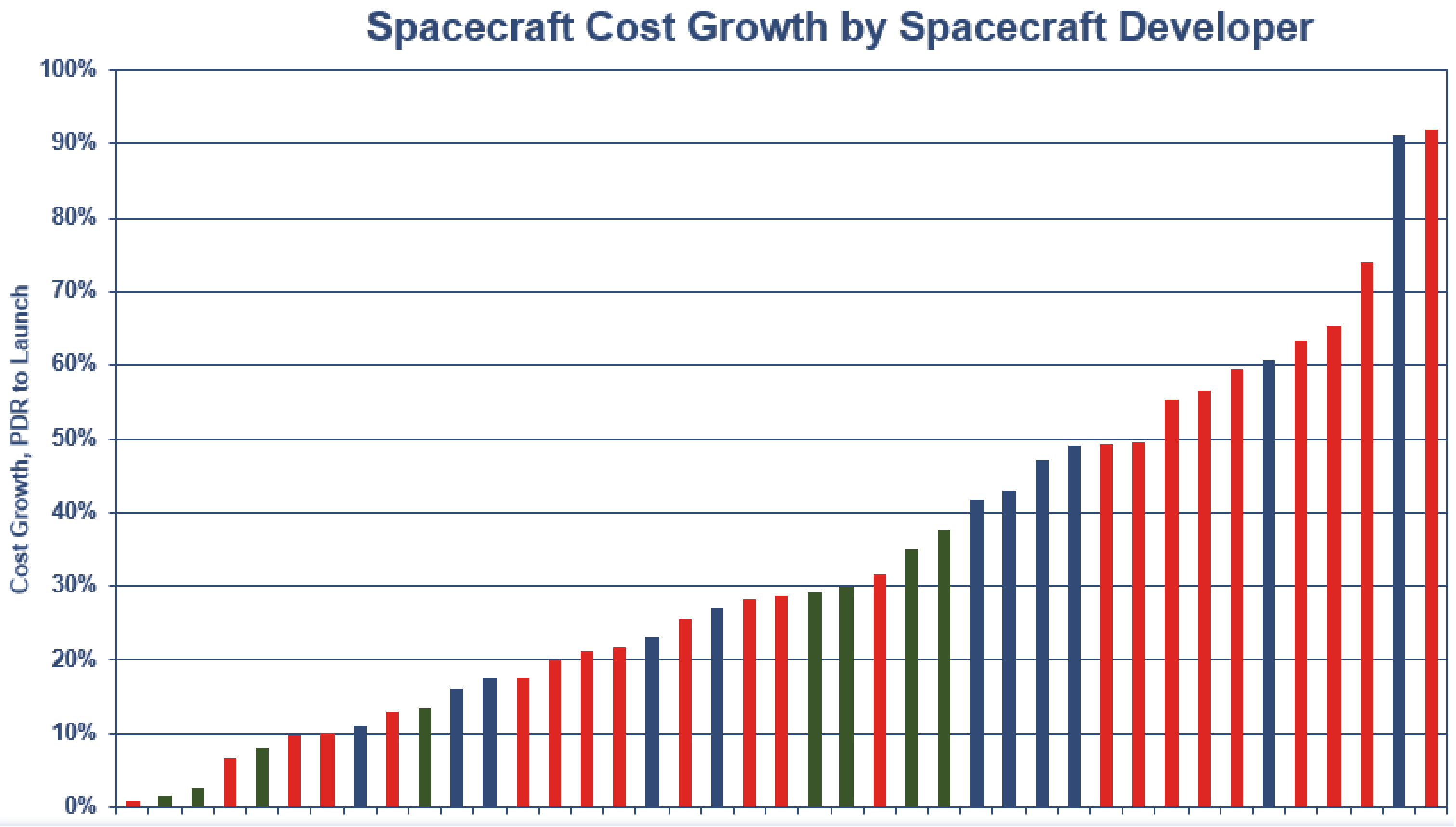
Contract Type	Average Cost Growth
Cost Plus Contract	36%
Firm Fixed Price Contract	20%

- We looked at in-house spacecraft builds compared to subcontracted builds
  - We hypothesized that CP contracts would experience more cost growth than FFP contracts
- $H_0: \mu_{CP} = \mu_{FFP}$
- $H_1: \mu_{CP} > \mu_{FFP}$

T Test Summary	
T statistic	2.20
P value	0.02

- The difference is statistically significant

What about In-House vs. CP vs. FFP?



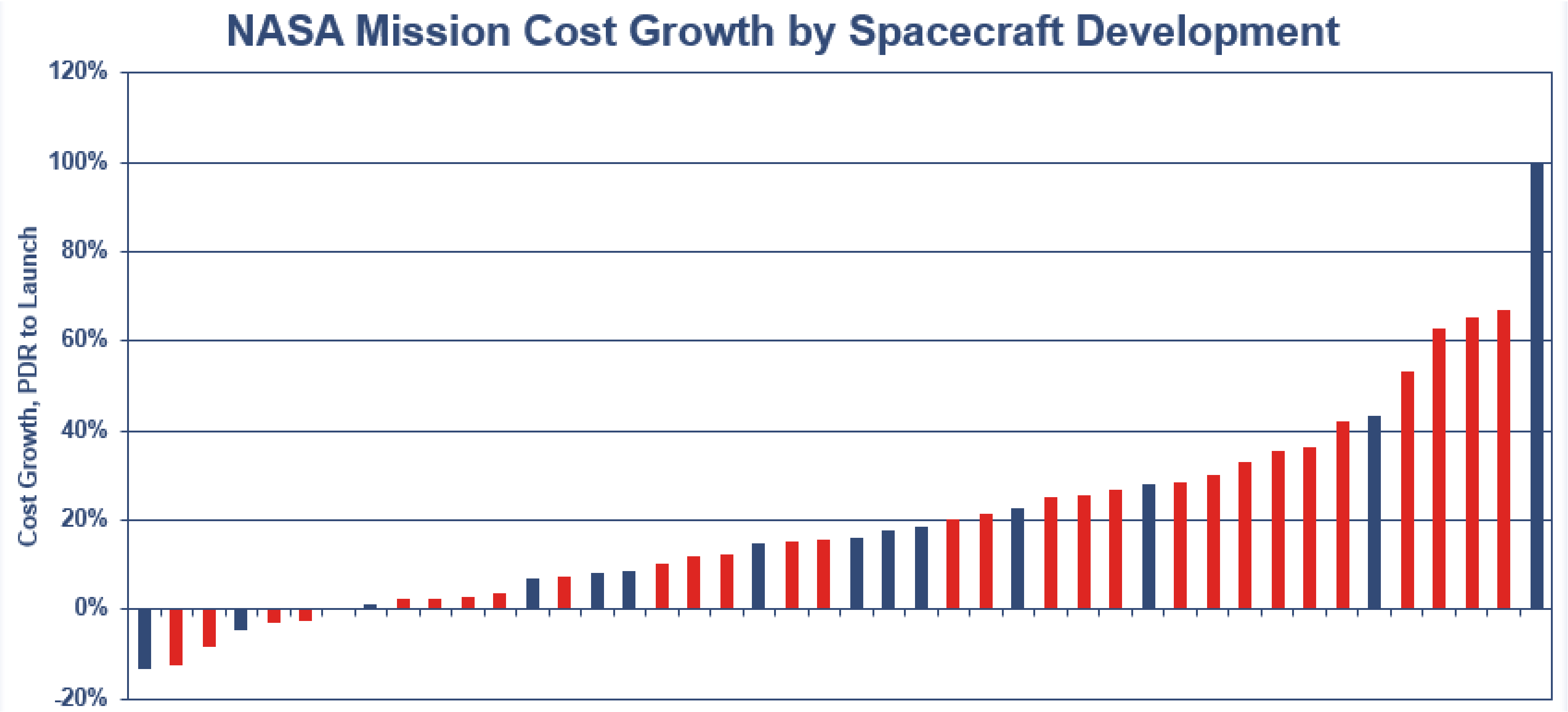
= In-House Build
= Cost Plus
= Firm Fixed Price

What about In-House vs. CP vs. FFP?

Spacecraft Developer	Average Cost Growth
In-House	39%
Cost Plus Contract	36%
Firm Fixed Price Contract	20%

- We looked at in-house spacecraft builds compared to CP spacecraft compared to FFP builds
- H_0: $\mu_{in-house} = \mu_{CP} = \mu_{FFP}$
- H_1: $\mu_{in-house} \neq \mu_{CP} \neq \mu_{FFP}$
- While t tests were used for all other comparisons, a Tukey statistical test is utilized for this three group comparison in order to test every possible pair of all groups. Based on the results, we can conclude:
  1. The difference between in-house builds and CP contracts is not statistically significant
  2. The difference between CP and FFP contracts is statistically significant
  3. The difference between in-house builds and FFP contracts is statistically significant

Does Spacecraft Bus Developer Matter at the Mission Level?



= Missions with In-House Builds
= Missions with Subcontracted Buses

Does Spacecraft Bus Developer Matter at the Mission Level?

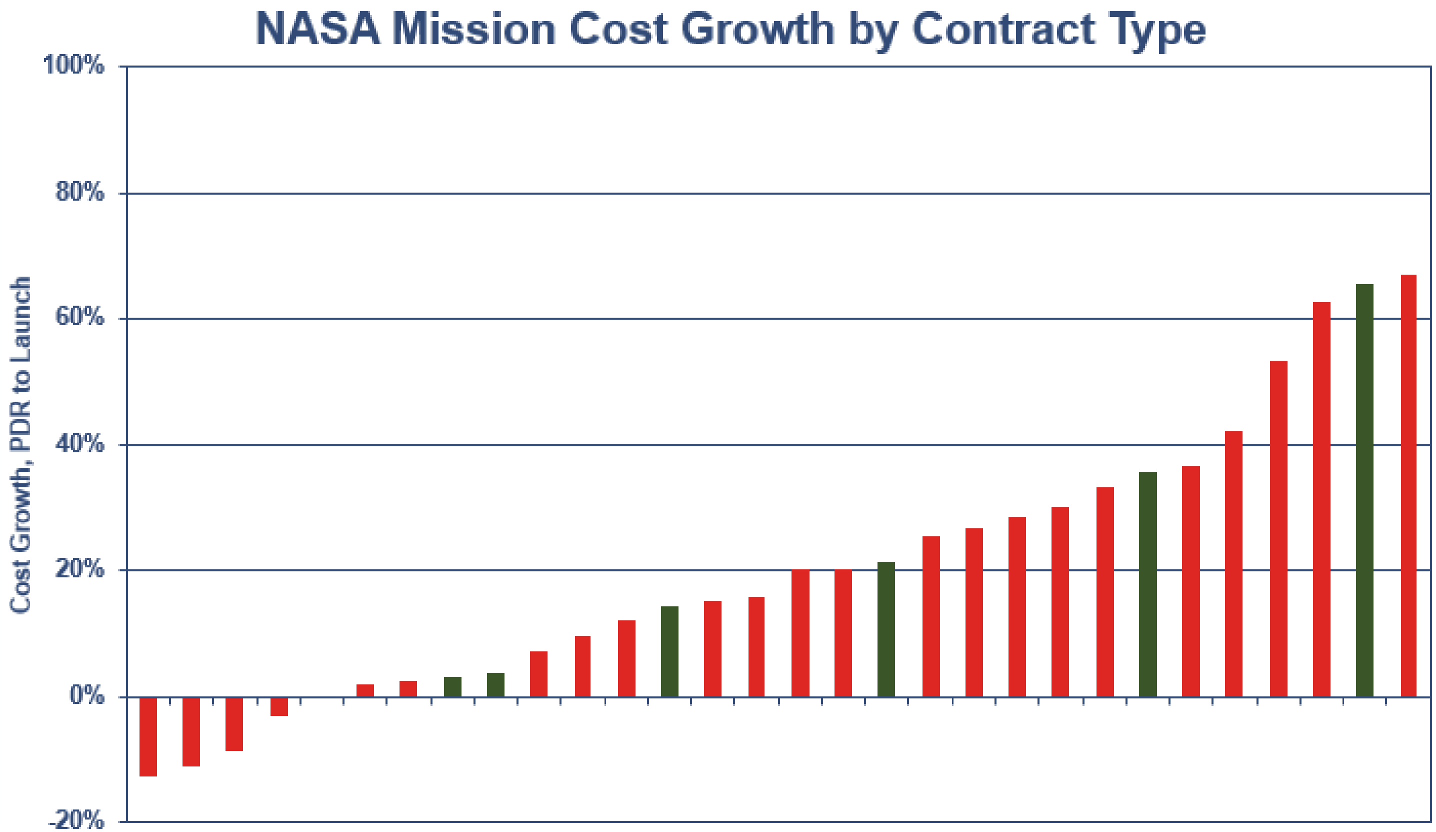
Spacecraft Developer	Average Cost Growth
Missions with In-House Builds	13%
Missions with Subcontracted Buses	21%

- We looked at in-house spacecraft builds compared to subcontracted builds
  - We hypothesized that subcontracted buses would experience less cost growth than in-house builds
- H_0: $\mu_{missions\ with\ in-house\ builds} = \mu_{missions\ with\ subcontracted\ builds}$
- H_1: $\mu_{missions\ with\ in-house\ builds} > \mu_{missions\ with\ subcontracted\ builds}$

T Test Summary	
T statistic	-1.41
P value	0.08

- Thus, the difference is significant and the opposite of what we see at the spacecraft level

Does Contract Type Matter at the Mission Level?



= Missions with Cost Plus Contracts
= Missions with Firm Fixed Price Contracts

Does Contract Type Matter at the Mission Level?

Contract Type	Average Cost Growth
Missions with Cost Plus Contracts	21%
Missions with Firm Fixed Price Contracts	21%

- A hypothesis test was omitted due to the equal averages
- Thus, contract type matters at the spacecraft level, but not at the mission level

Mission Level versus Spacecraft Level

Spacecraft Developer	Average Cost Growth
Missions with In-House Builds	13%
Missions with Subcontracted Buses	21%

Spacecraft Developer	Average Cost Growth
In-House	39%
Subcontracted Bus	32%

Contract Type	Average Cost Growth
Missions with Cost Plus Contracts	21%
Missions with Firm Fixed Price Contracts	21%

Contract Type	Average Cost Growth
Cost Plus Contract	36%
Firm Fixed Price Contract	20%

- At the mission level, missions with in-house spacecraft builds experience less cost growth than missions with subcontracted buses.
- But, at the spacecraft level, in-house builds experience more cost growth than subcontracted buses
- At the spacecraft level, FFP contracts experience less cost growth than CP contracts.
- But at the mission level, they experience the same amount of cost growth

Do Cost Contracts Help Control Costs?

- Cost implications of both CP and FFP contracts are often experienced outside of spacecraft costs due to subcontracted spacecraft accommodations at the mission level
- In terms of mission system optimization, engineering flexibility is lost with a subcontracted bus, particularly a FFP bus, and can consequently affect the payload interface, concept of operations, etc.
- Benefits from in-house spacecraft builds and CP contracts can be seen in oversight cost savings from design to requirements
- Benefits from subcontracted buses can be seen with commercial entities using production lines to produce larger quantities of low mass, cheap spacecraft

EZIE

Electrojet Zeeman Imaging Explorer

A Case Study

Conclusions

- 84% of NASA missions experienced cost growth post-PDR
- The average NASA mission cost grew 20% from PDR to Launch
- Missions with in-house spacecraft builds experienced 13% cost growth on average compared to missions with subcontracted builds at 21%
- This contrasts with what is seen at the spacecraft level with in-house spacecraft builds growing 39% compared to CP builds at 36% and FFP builds at 20%
- Benefits of in-house builds versus subcontracted spacecraft should be analyzed on a case by case basis to optimize cost savings and efficiency
- Future analyses of cost growth by WBS may help explain cost growth differences seen at the mission versus spacecraft level

Conclusions

- At the empirical 50th and 70th percentiles, assuming 30% project-held UFE, NASA missions were spending their full budgets plus 16% and 27%, respectively
- Historically, in order to achieve a 50% chance of coming in on budget, missions would have had to hold 46% project-held UFE in order to be 50% confident
- If missions had held 46% project-held UFE, then 50% of missions would come in on budget compared to 16%
- Given that missions continue to hold 30% project-held UFE against their baseline cost estimates, NASA needs to be holding an additional 27% against its mission portfolio in order to be at the empirical 70th percentile
- If missions had held 46% project-held UFE and NASA had held 11% UFE, then NASA would have been 70% confident
- Sometimes, math is hard, sometimes math is easy, and sometimes math gives us answers we either don't like, or that surprise us. But it's worthwhile to do this work!

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