

Space Mission Concept Design

at the NASA Ames Mission Design Center (MDC)

Stanford University

David Mauro, KBR / NASA Ames Research Center



Agenda



- Space Mission Concept Design at NASA Ames
 - What the Ames MDC is
 - A framework for space mission ideas – The Concept Maturity Levels
 - Aeolus: an example of a mission concept study for Mars
 - Lessons learned and tips
- Overview on how to design a spacecraft telecommunication subsystem
 - Overview on the main design considerations
 - The Link Budget
- Summary & Conclusion

Mission Design Center - What is it?

About the Mission Design Center



The Mission Design Center (MDC) is a facility within the Spaceflight Division that specializes in conceptual mission design. While experienced in multiple levels of design and mission implementation, the MDC focuses on low-cost, small spacecraft missions.

The MDC possesses full, end-to-end mission design capability with sophisticated analysis and simulation tools in a collaborative concurrent design environment. Services include:

- Concept Maturity Level (CML) progression
- Spacecraft design and trade studies
- Scientific instrument selection
- Feasibility assessments
- Proposal support and partnerships

These capabilities allow the MDC to support the Ames Engineering Directorate's ability to support all phases of engineering and project management for flight and mission projects from research and development to close-out.

Point of Contact:

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Ryan.Vaughan@nasa.gov
 650-604-2109

Examples of MDC-supported projects

2019 | 2018 | 2017 | 2016 | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007

2019

Luna Lynx

Preliminary feasibility assessment for a small spacecraft lunar communication relay with a Lunar South Pole asset.



Mission Concept Study report for the Dark Ages Polarimeter Pathfinder (DAPPER)

Mission concept study report designed to search for deviations from the standard cosmological model by measuring the global 21-cm spectrum.



Miniaturized Distributed Occulter Telescope (mDOT)

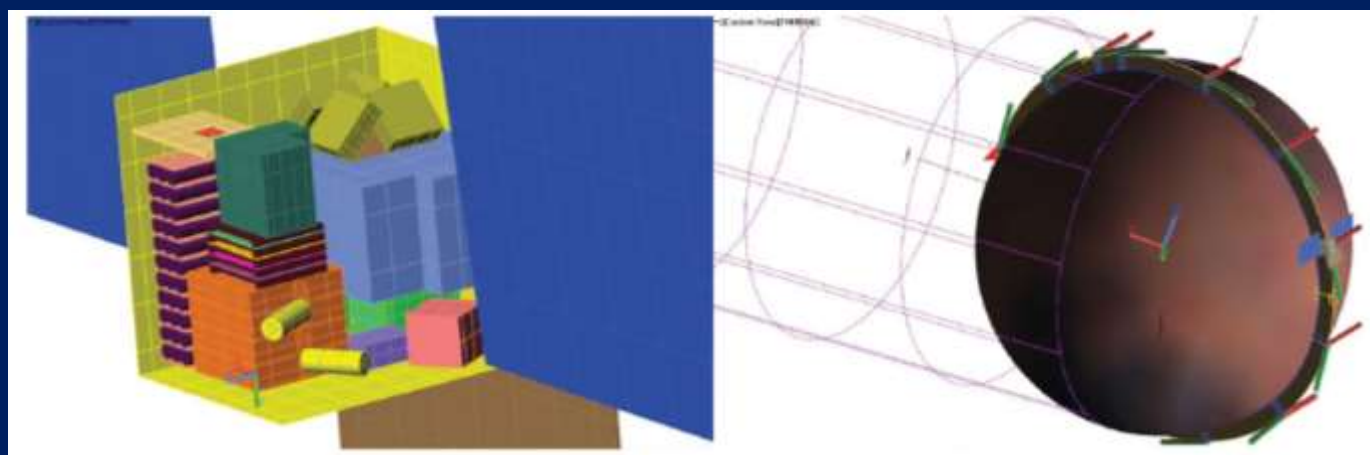
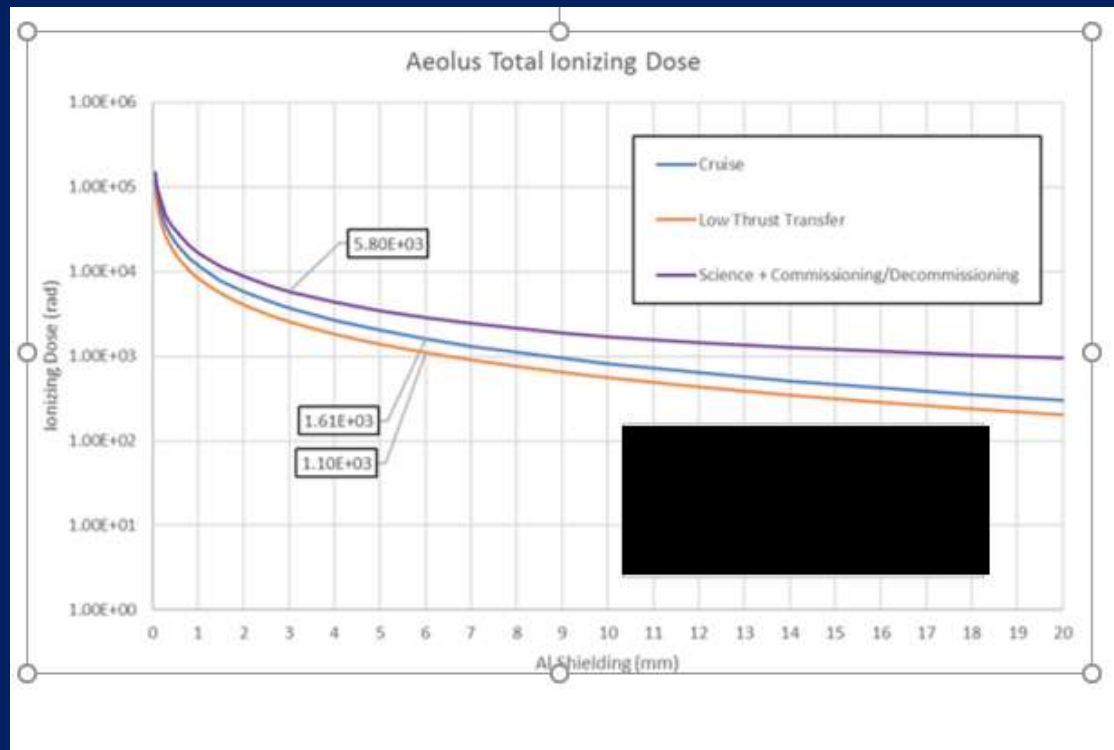
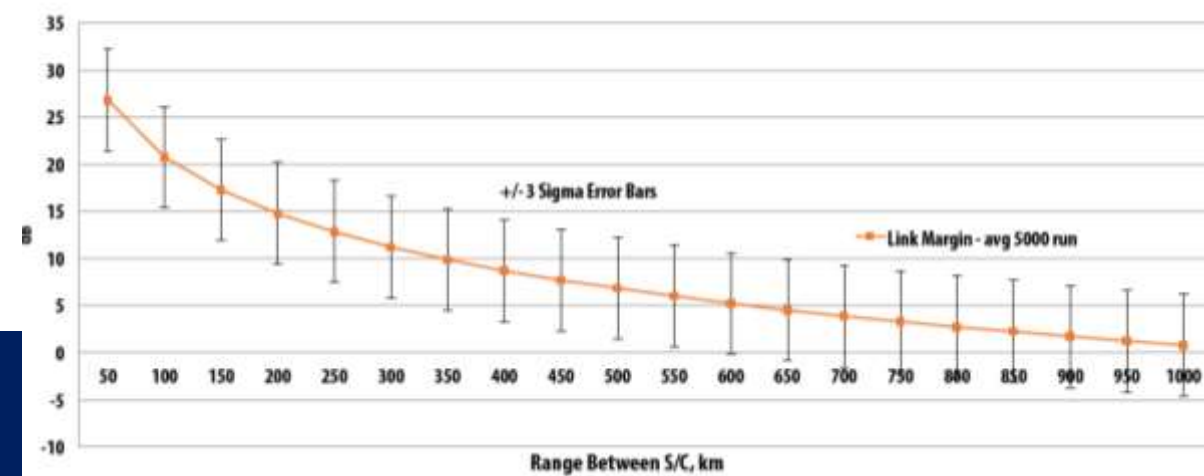
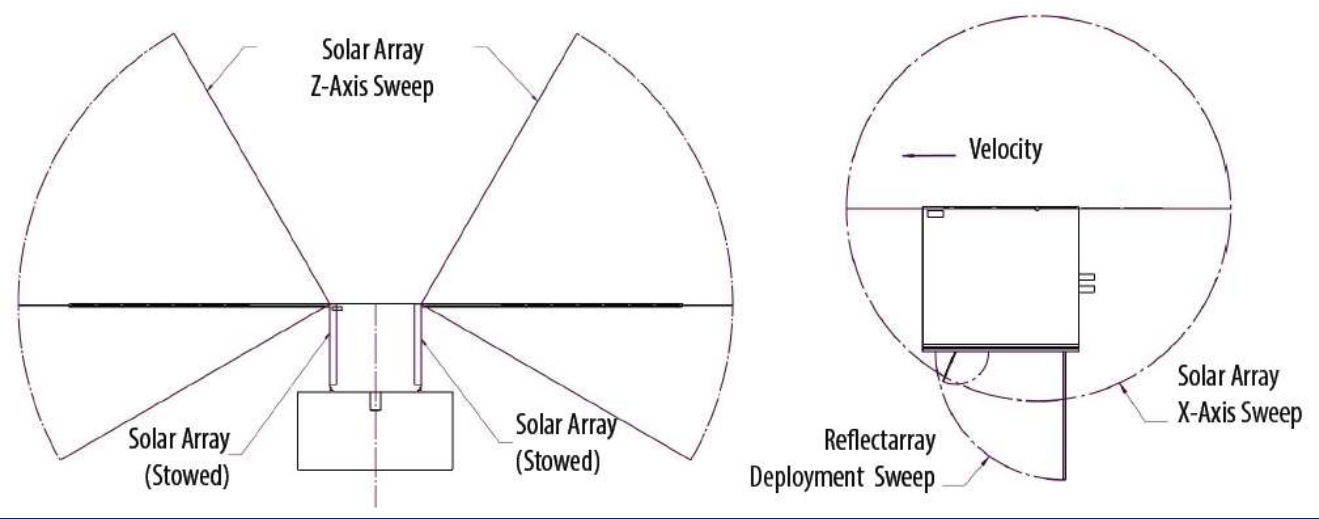
Mission concept study to provide unprecedented detection and direct measurements of brightness of extragalactic dust disks visible to ultraviolet wavelength using a small spacecraft starshade and a 6U telescope spacecraft. mDOT was selected as part of the Astrophysics Science SmallSat Studies solicitation.



<https://www.nasa.gov/centers/ames/engineering/mission-design-center/about>

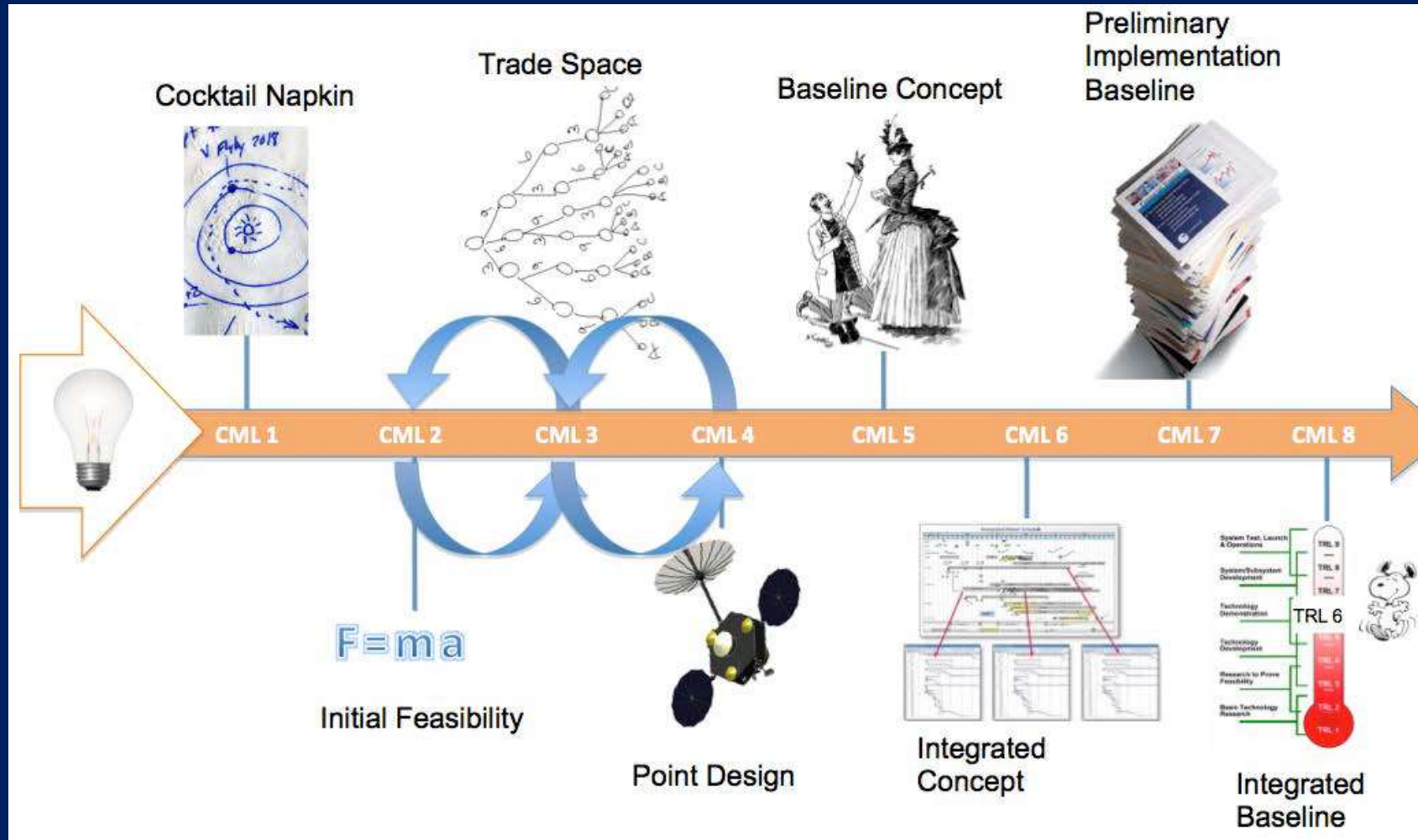






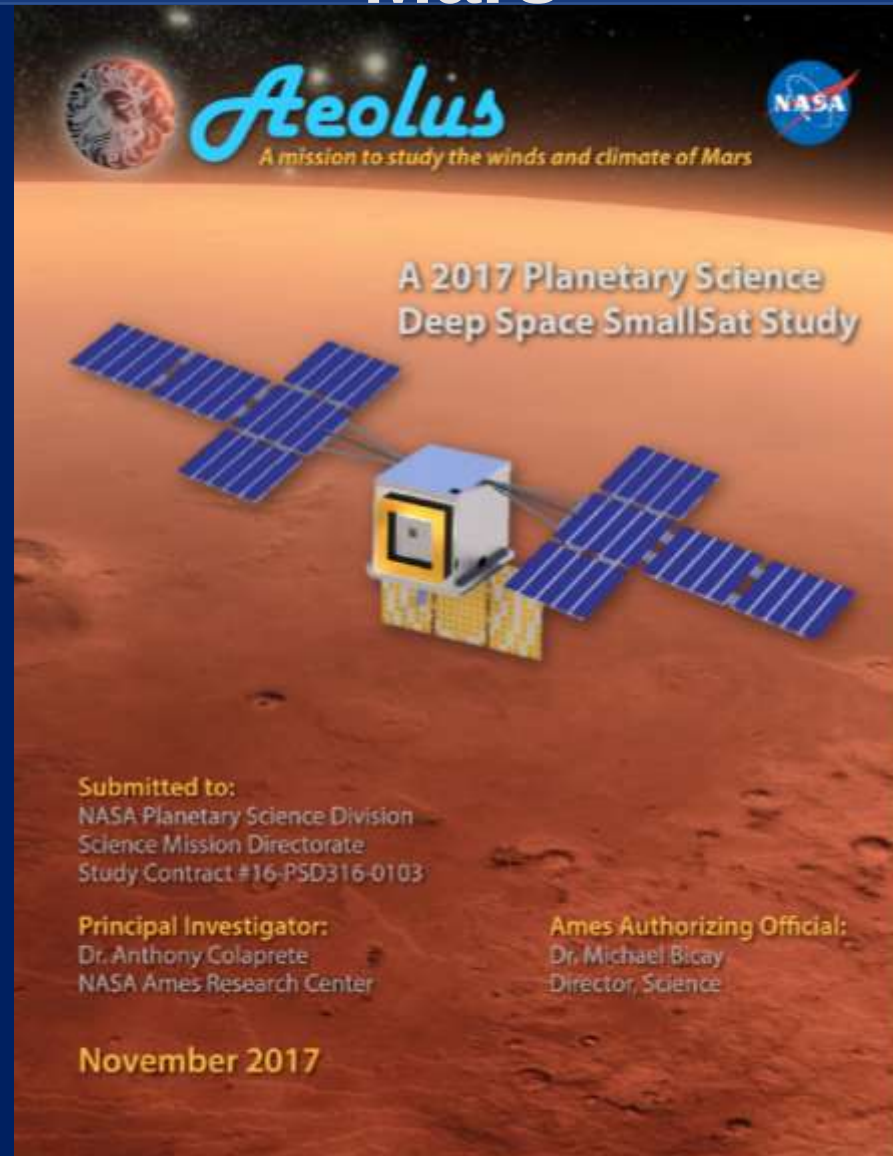
A framework for space mission ideas

The Concept Maturity Levels



From: Space Mission Concept Development Using Concept Maturity Levels, Wessen et al., 2013

Aeolus: an example of a mission concept study for Mars



Aeolus: an example of a mission concept study for Mars



CML 1
“Cocktail Napkin”

Aeolus: an example of a mission concept study for Mars



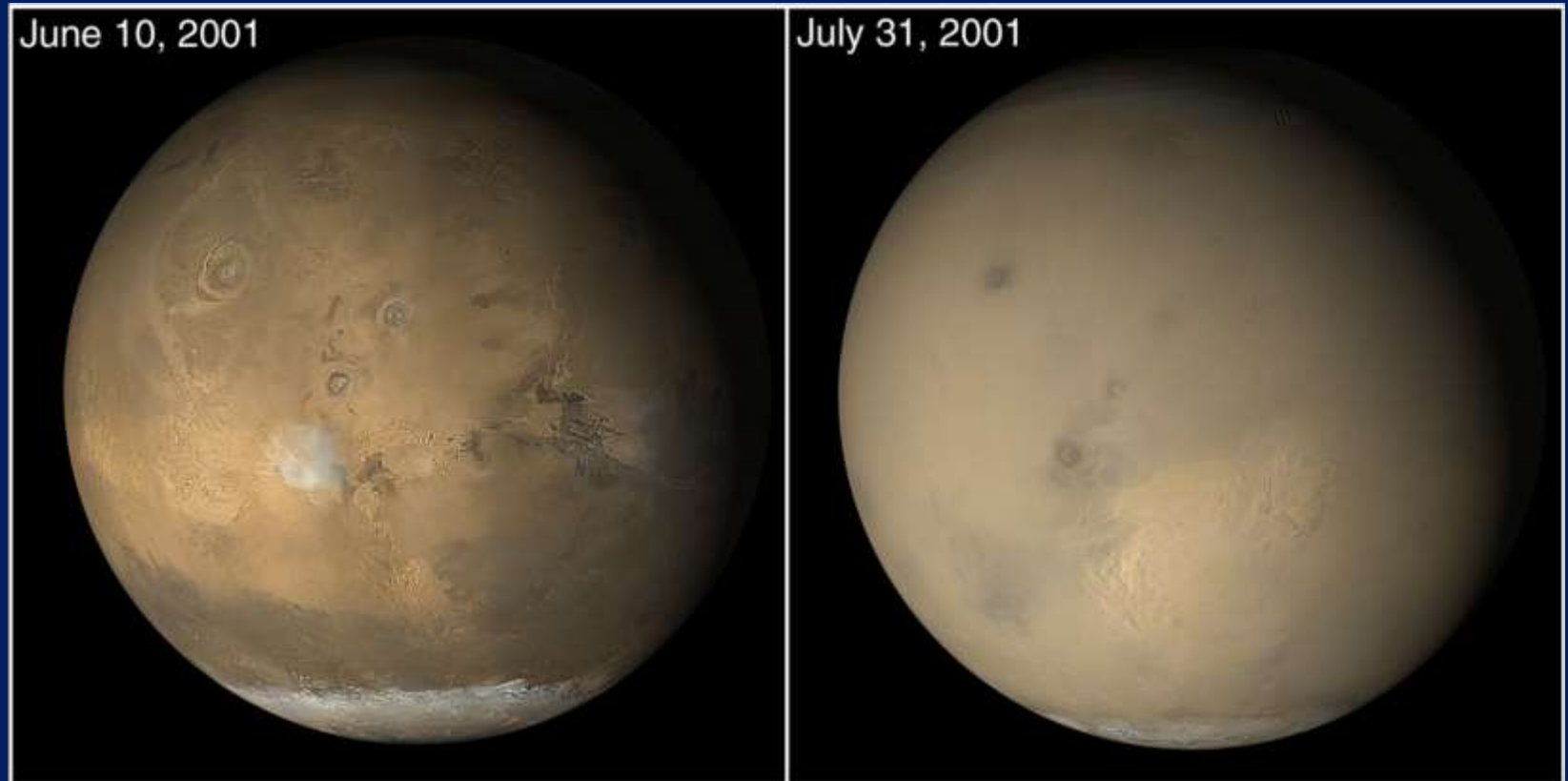
CML 1
“Cocktail Napkin”



Aeolus: an example of a mission concept study for Mars



CML 1
“Cocktail Napkin”



Aeolus: an example of a mission concept study for Mars



CML 1
“Cocktail Napkin”

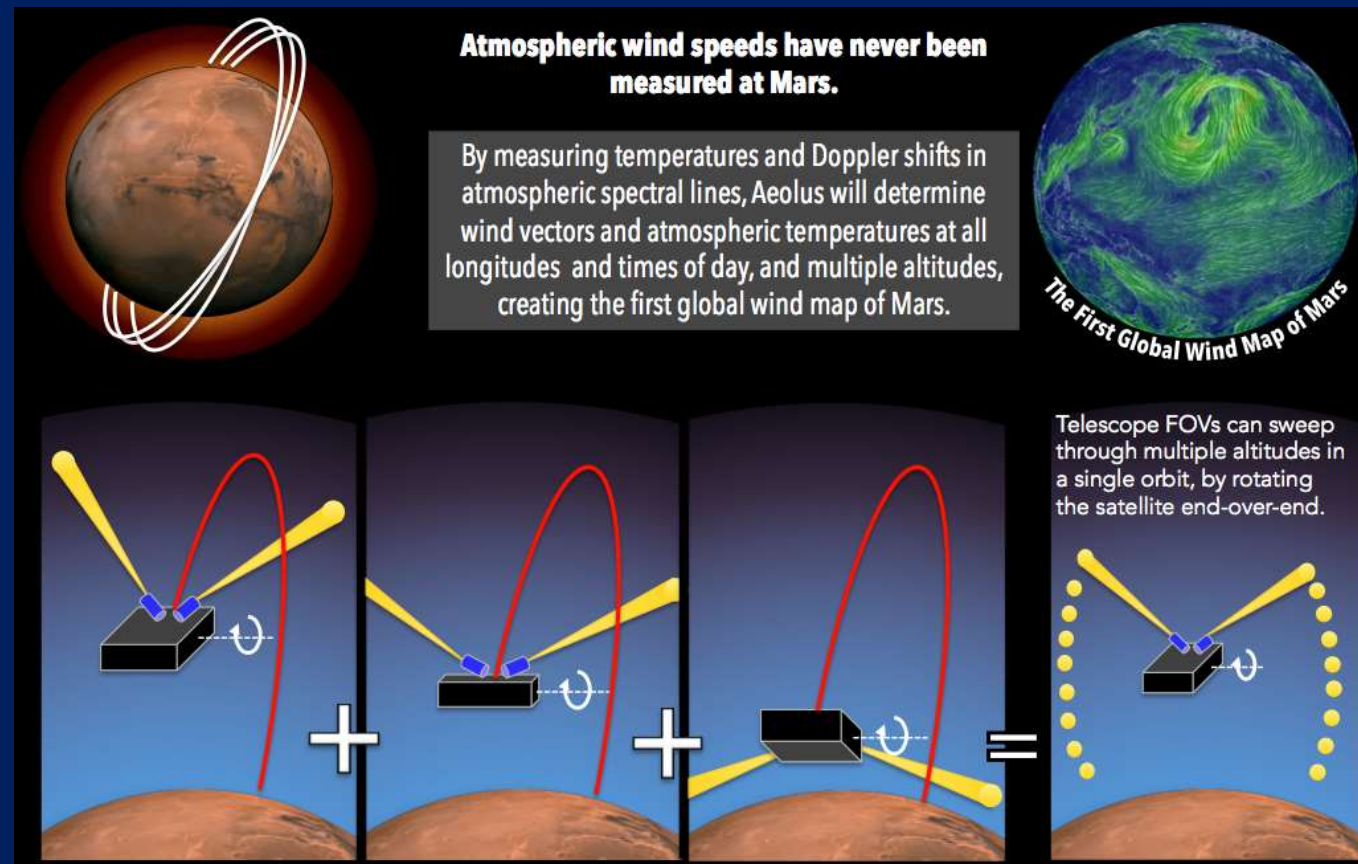


Opportunity December 2011 (Credit NASA)

Meaningfulness & Uniqueness
Identify Knowledge Gaps

State Broad Science Objective

One-sentence description of measurement(s)



Aeolus: an example of a mission concept study for Mars



CML 1
“Cocktail Napkin”



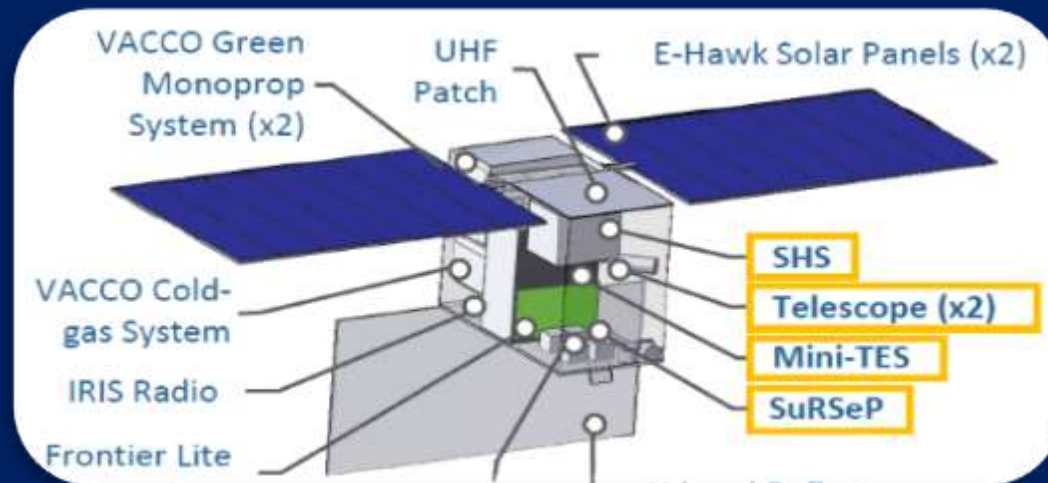
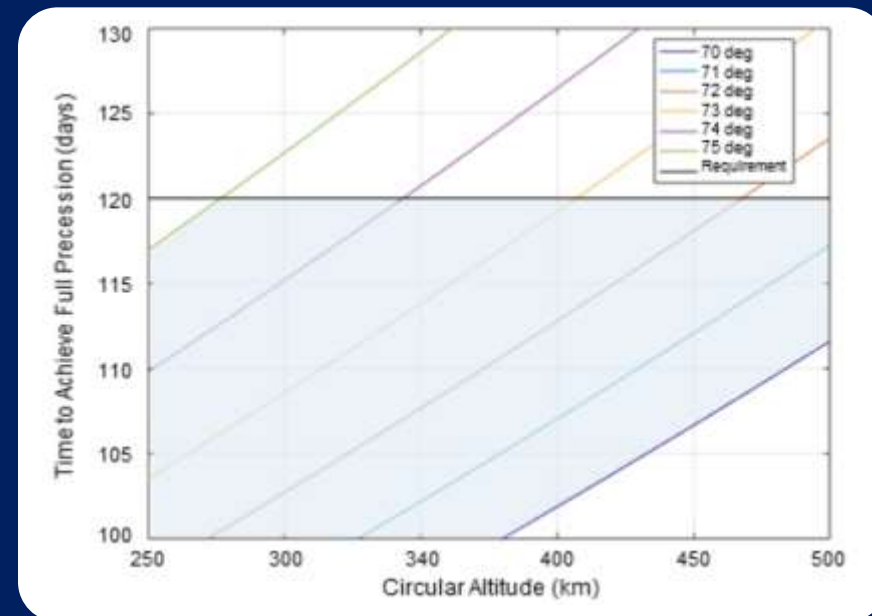
CML 2
Feasibility

Does any
solution
exist?

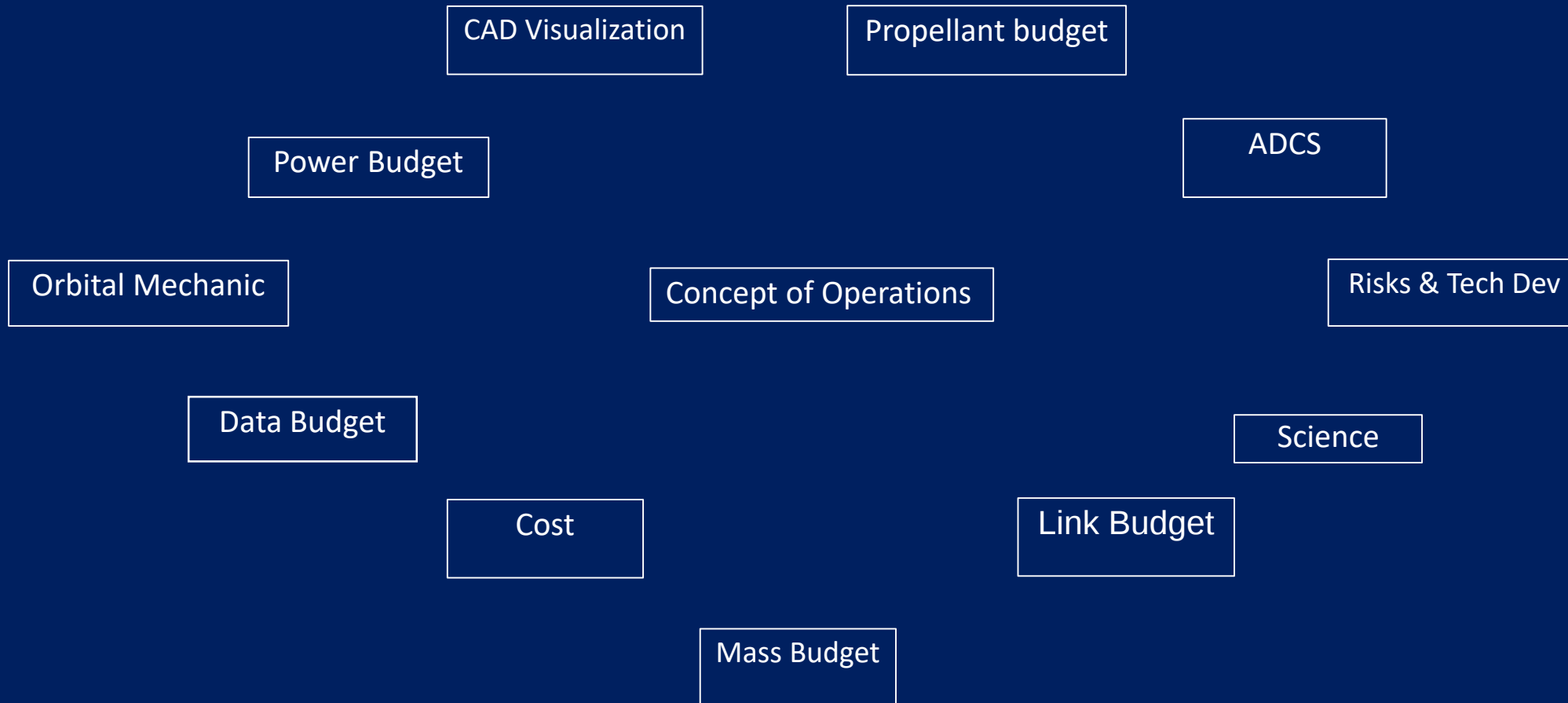
CML 2: Feasibility Study

Draft of Science Traceability Matrix
 Mission Architecture – main elements
 Environmental driving parameters
 Identify required tech development
 Launch opportunities
 Delta-V calculations
 Orbital solutions
 Mission ops
 Spacecraft CAD model
 Rough cost estimate
 Rough schedule
 Initial risks & mitigation identified
 Future trades identified

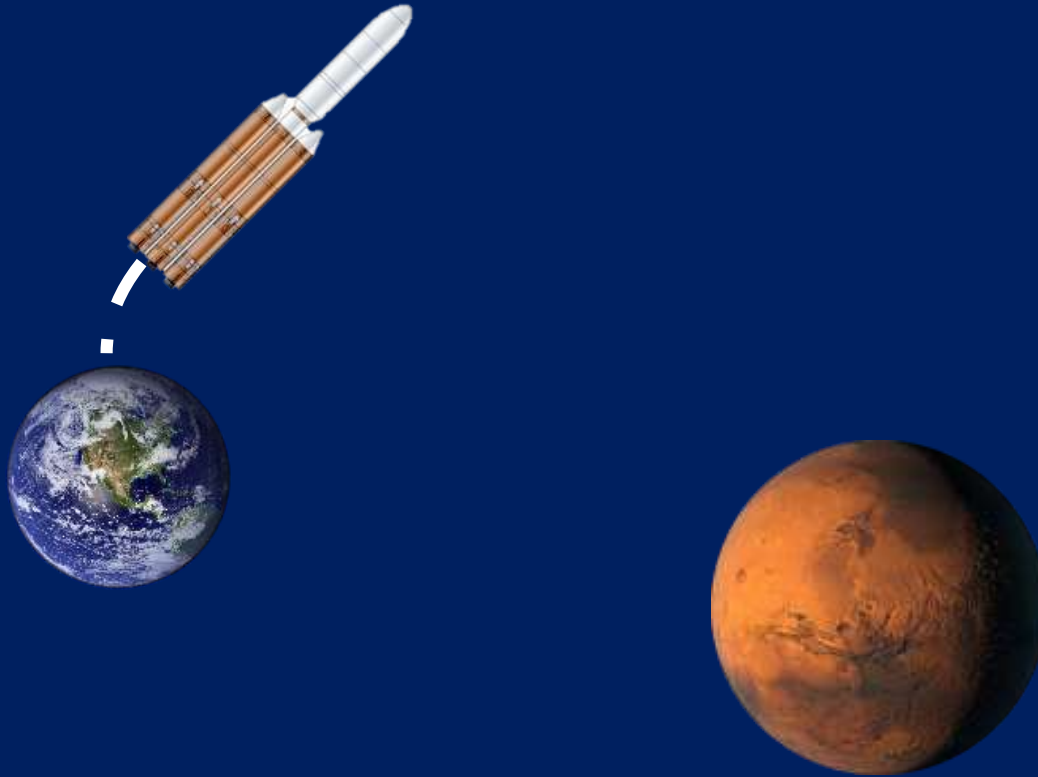
Resource	CBE
Volume	45 x 35 x 52 cm
Total Launch Mass	37.6 kg
Total Power	53 W
Spacecraft Delta-V	237.5 m/s
Solid State Data Storage (Vol)	8GB
Data Throughput (UHF Downlink)	1Mbps



Develop Feasible Mission Architecture

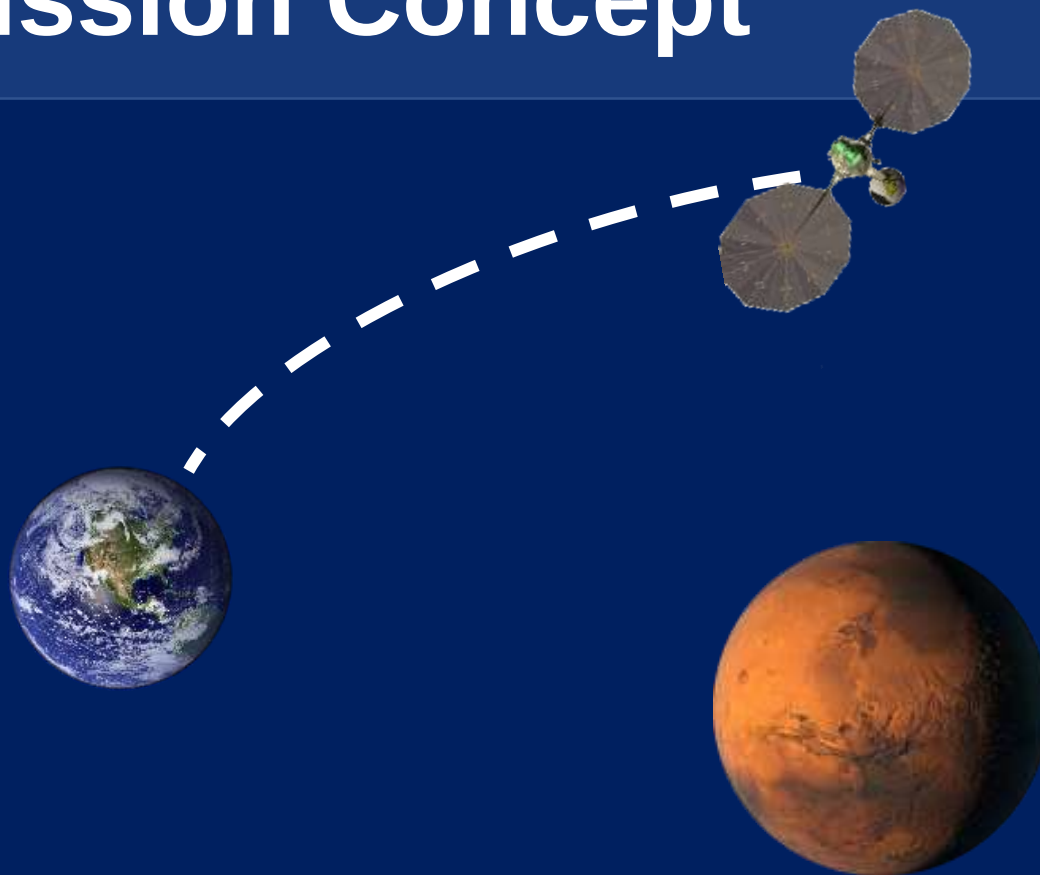


Mission Concept



Launch

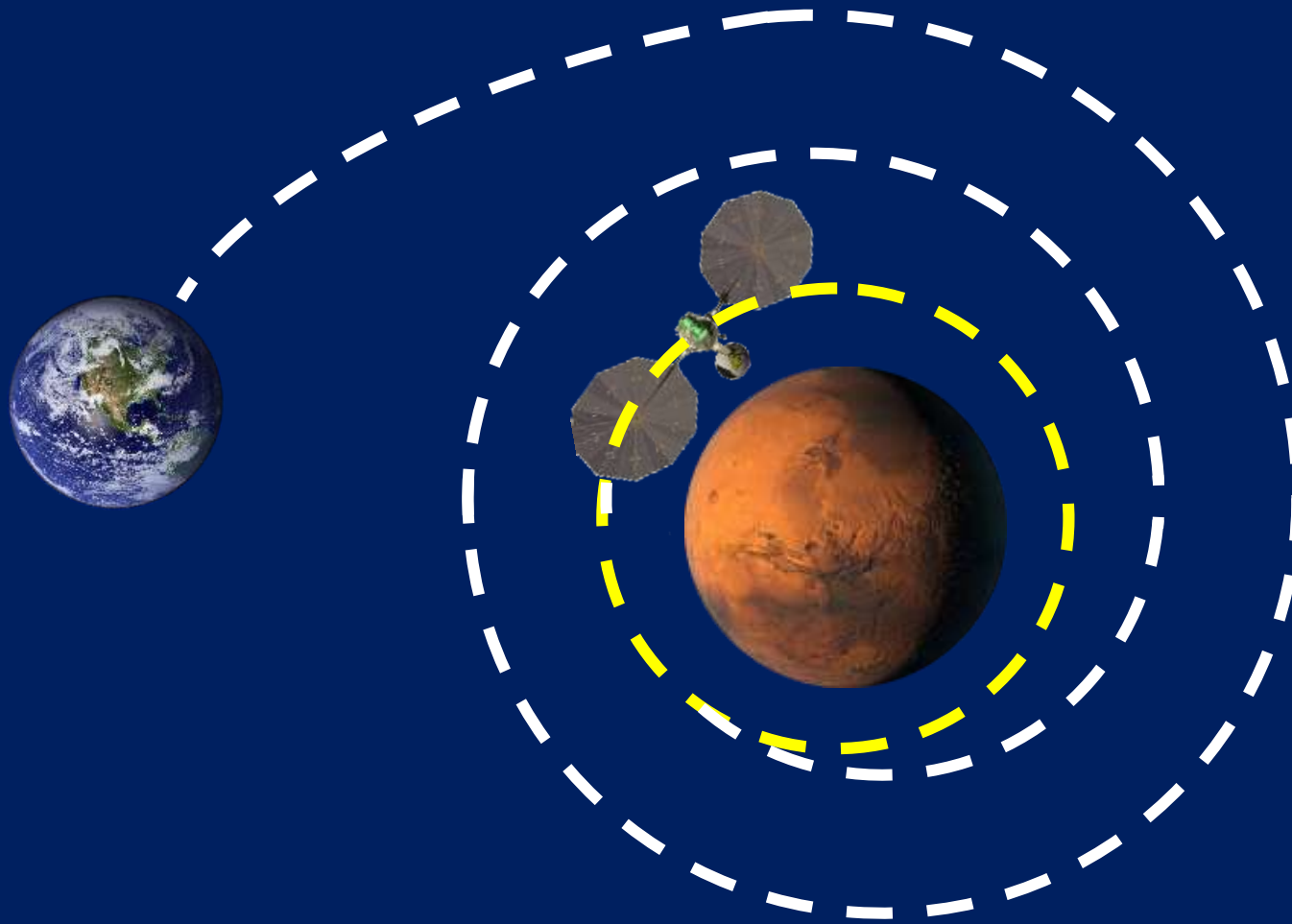
Mission Concept



Launch

Cruise
15 months

Mission Concept

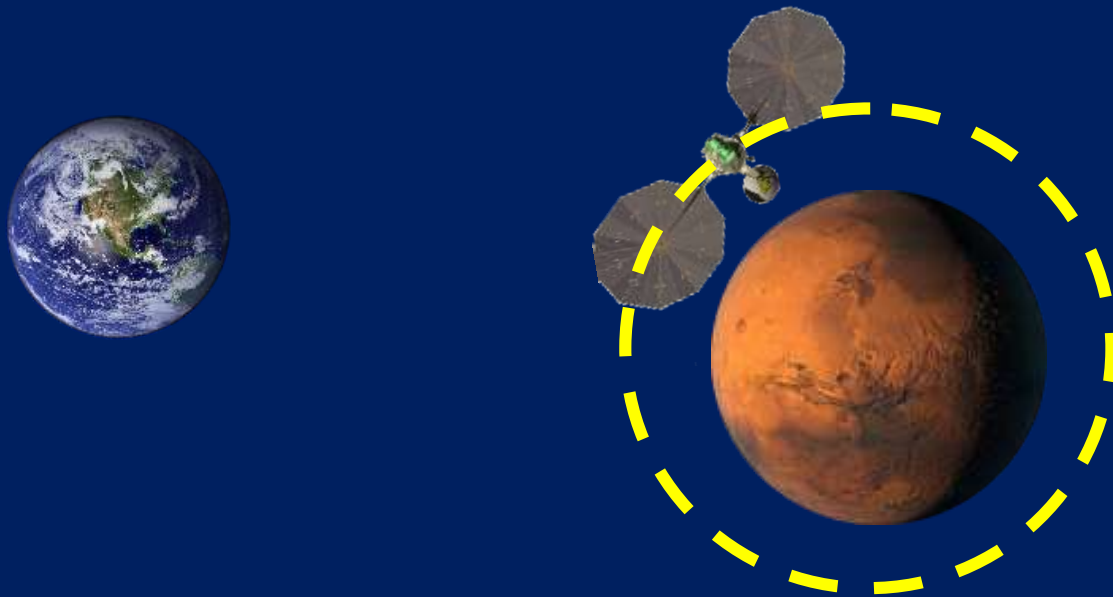


Launch

Cruise
15 months

NeMO LTT
10 months

Mission Concept



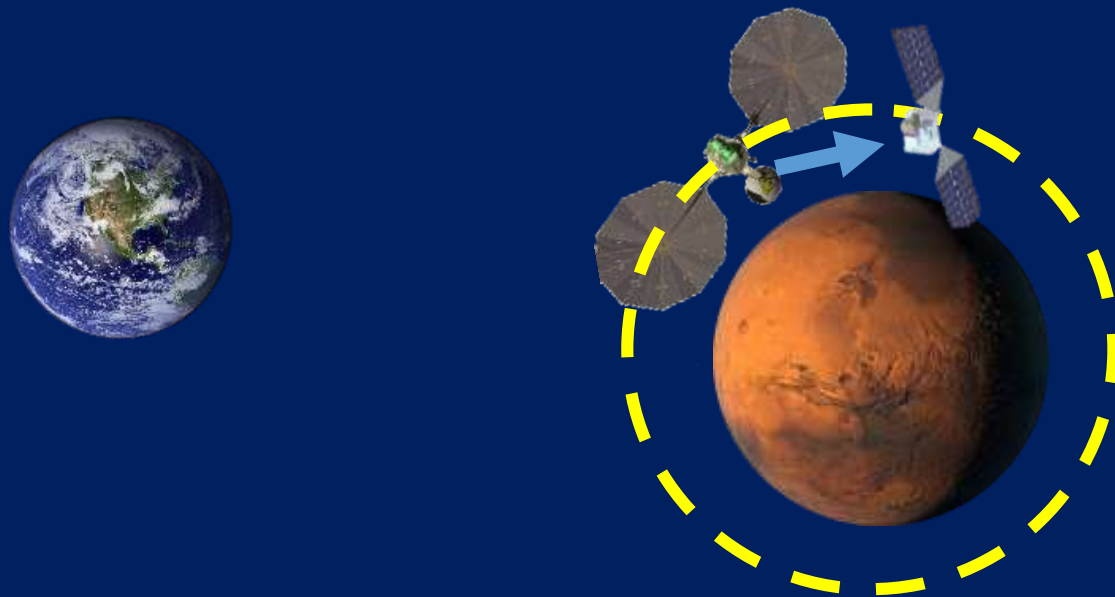
Launch

Cruise
15 months

NeMO LTT
10 months

Aeolus
Stowed

Mission Concept



Launch

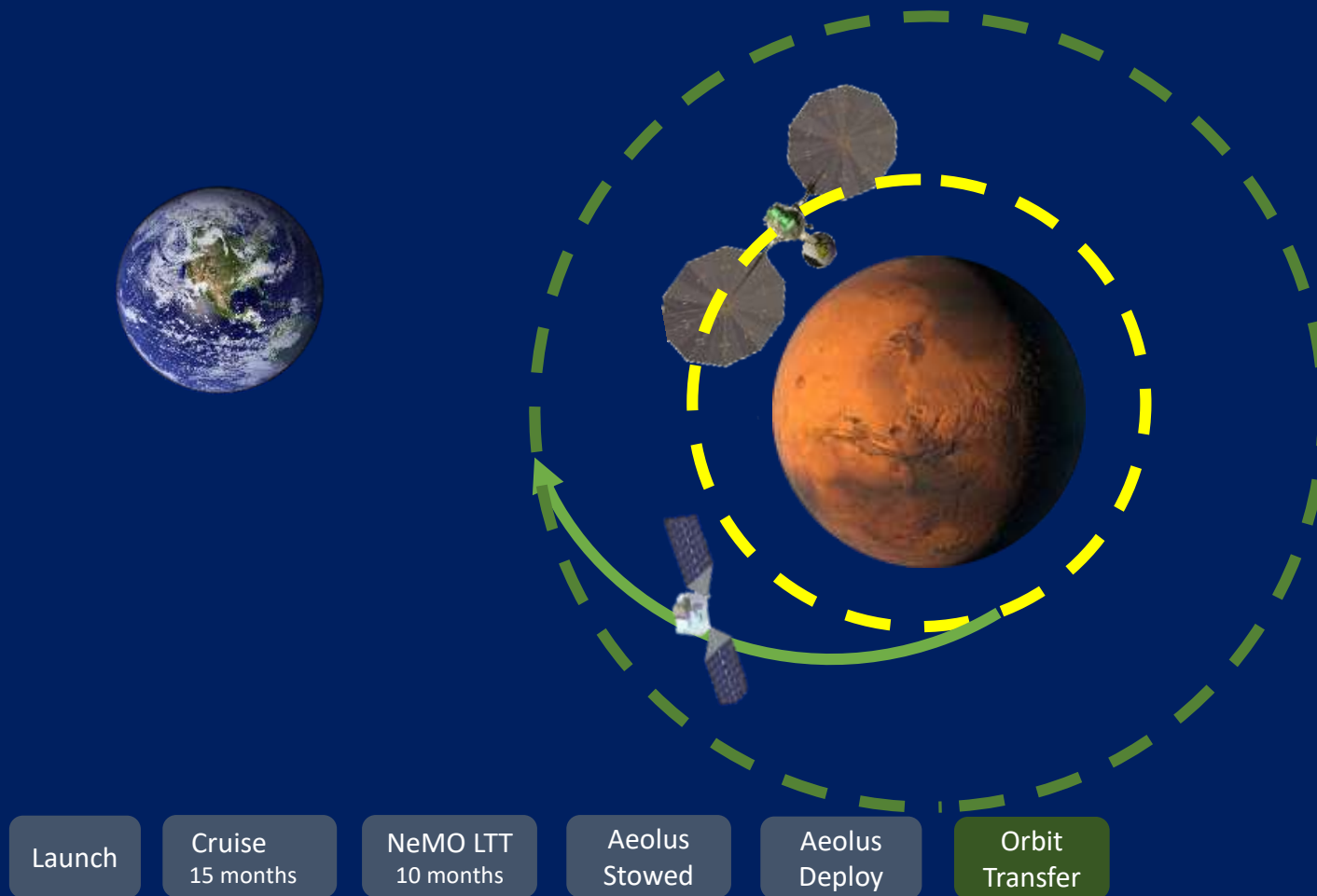
Cruise
15 months

NeMO LTT
10 months

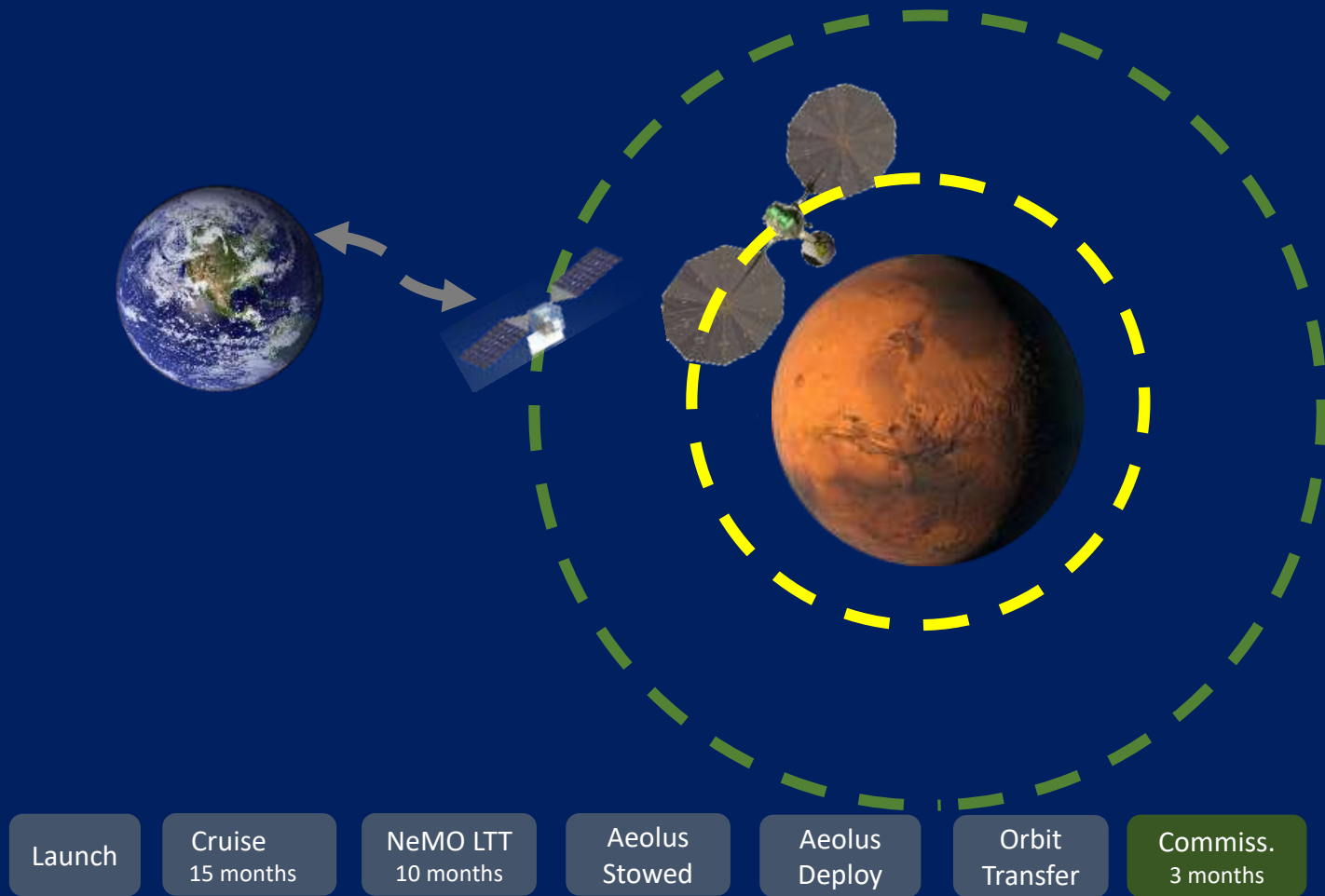
Aeolus
Stowed

Aeolus
Deploy

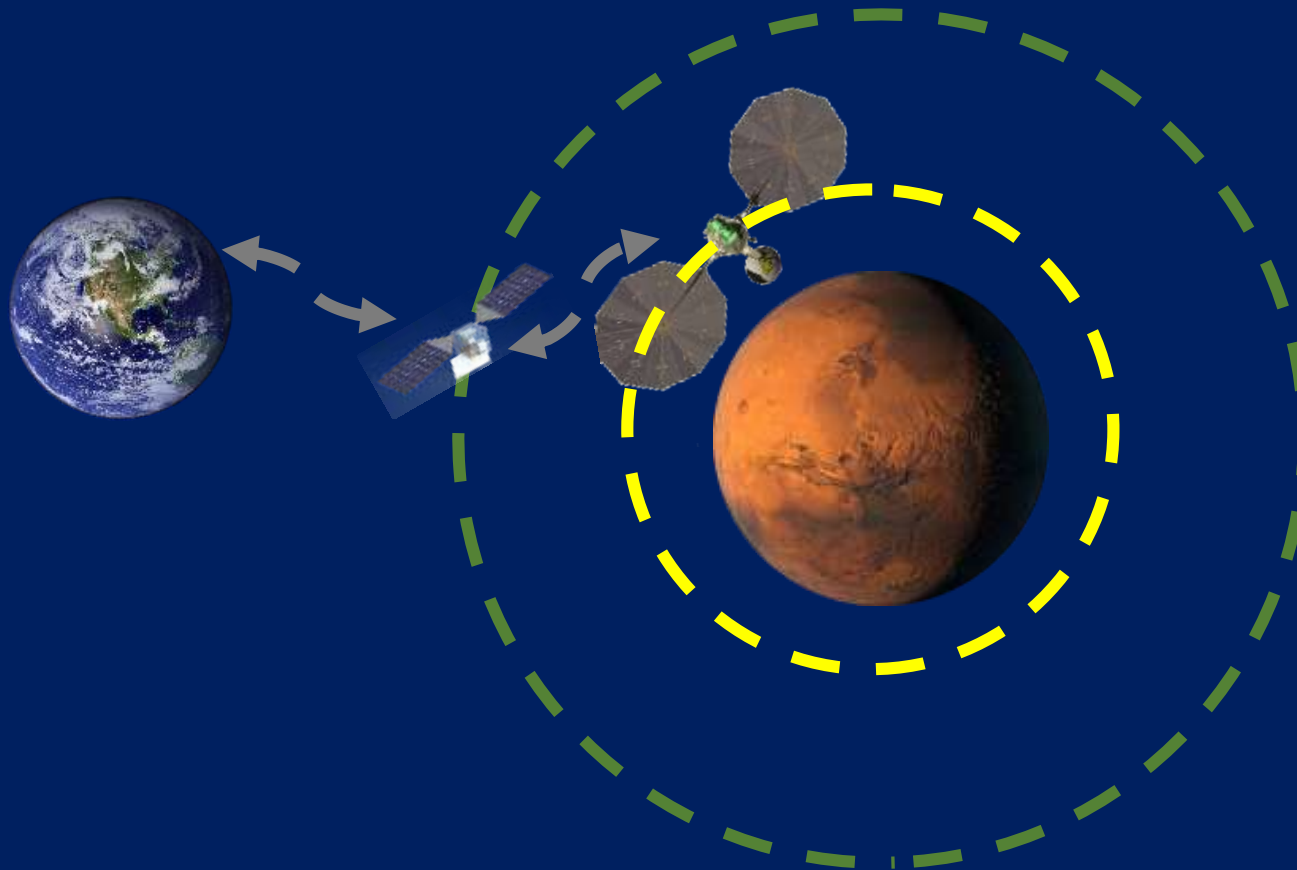
Mission Concept



Mission Concept



Mission Concept



Launch

Cruise
15 months

NeMO LTT
10 months

Aeolus
Stowed

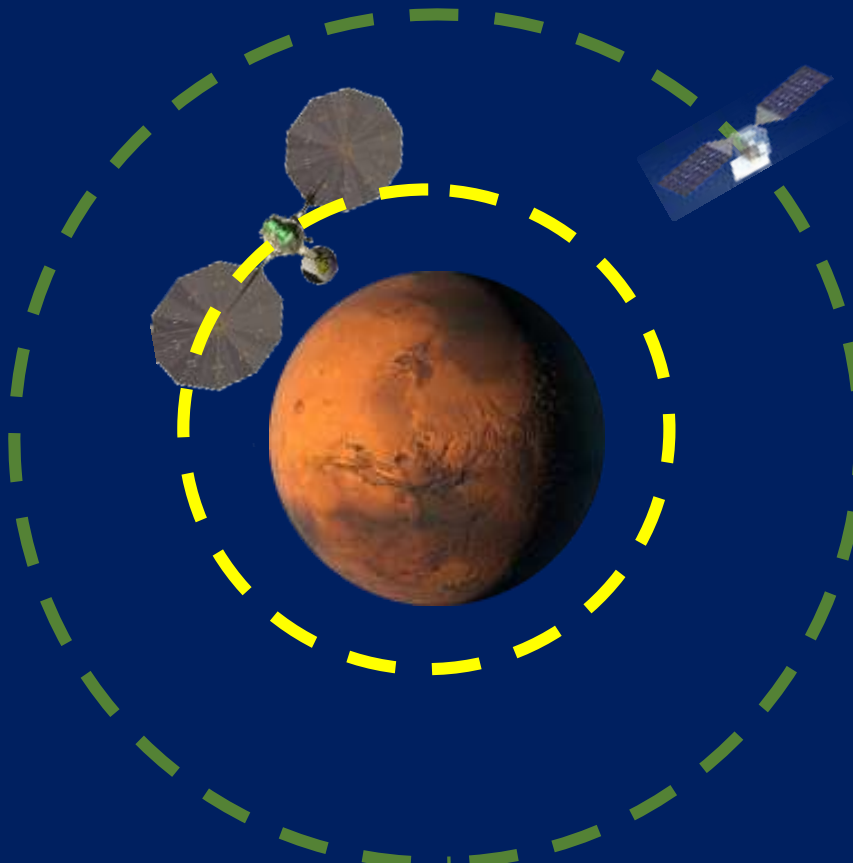
Aeolus
Deploy

Orbit
Transfer

Commiss.
3 months

Science
24 months

Mission Concept



Total Mission
Duration
52 months

Launch

Cruise
15 months

NeMO LTT
10 months

Aeolus
Stowed

Aeolus
Deploy

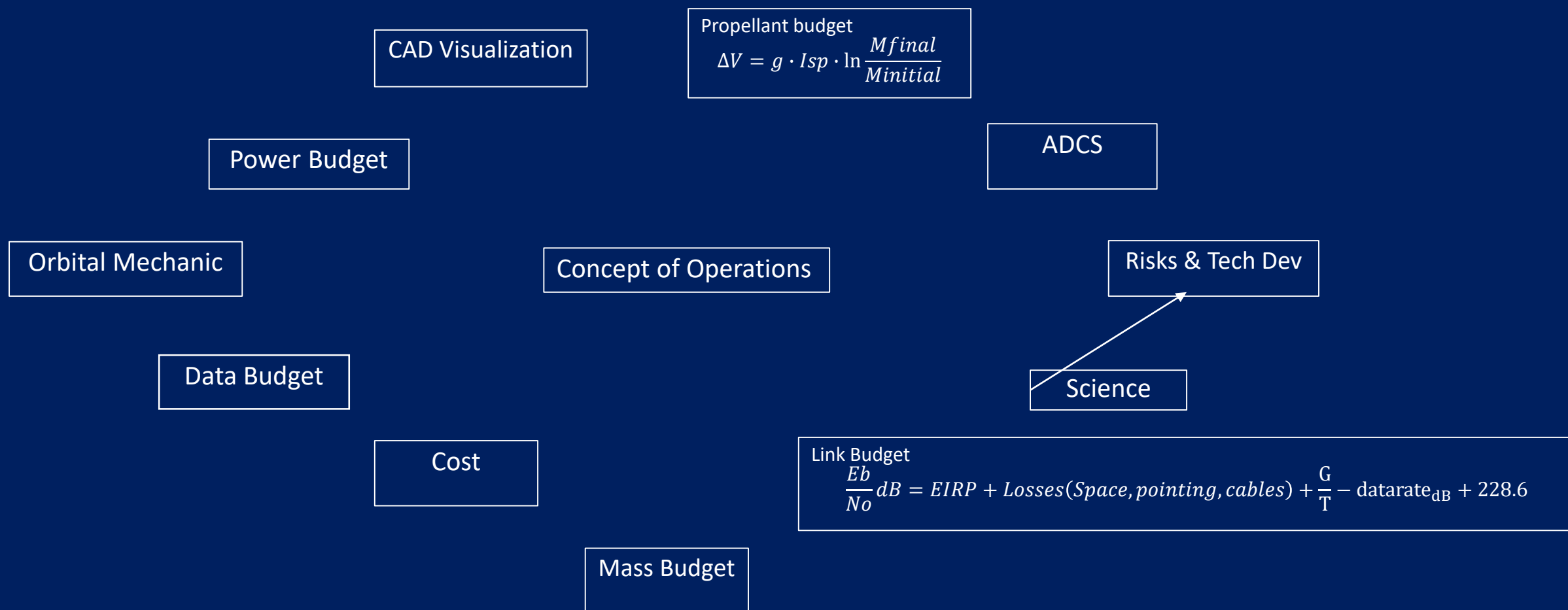
Orbit
Transfer

Commiss.
3 months

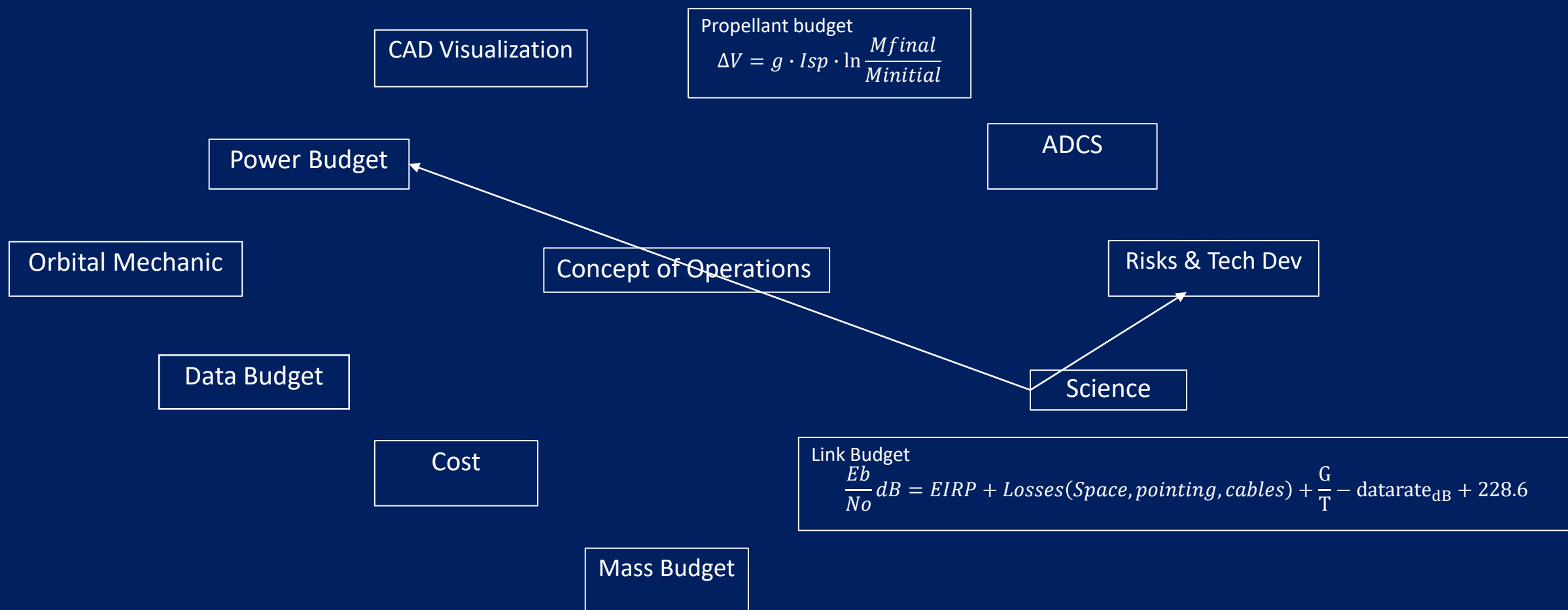
Science
24 months

Decommission

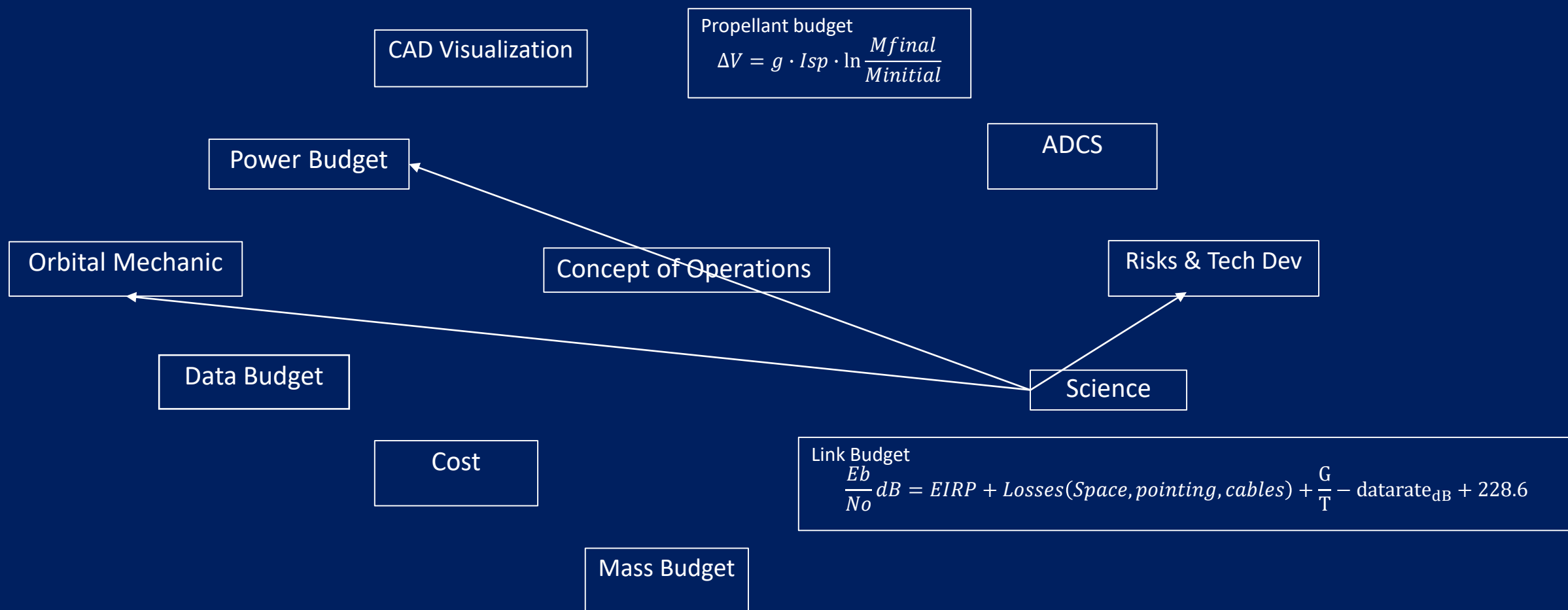
Develop Feasible Mission Architecture



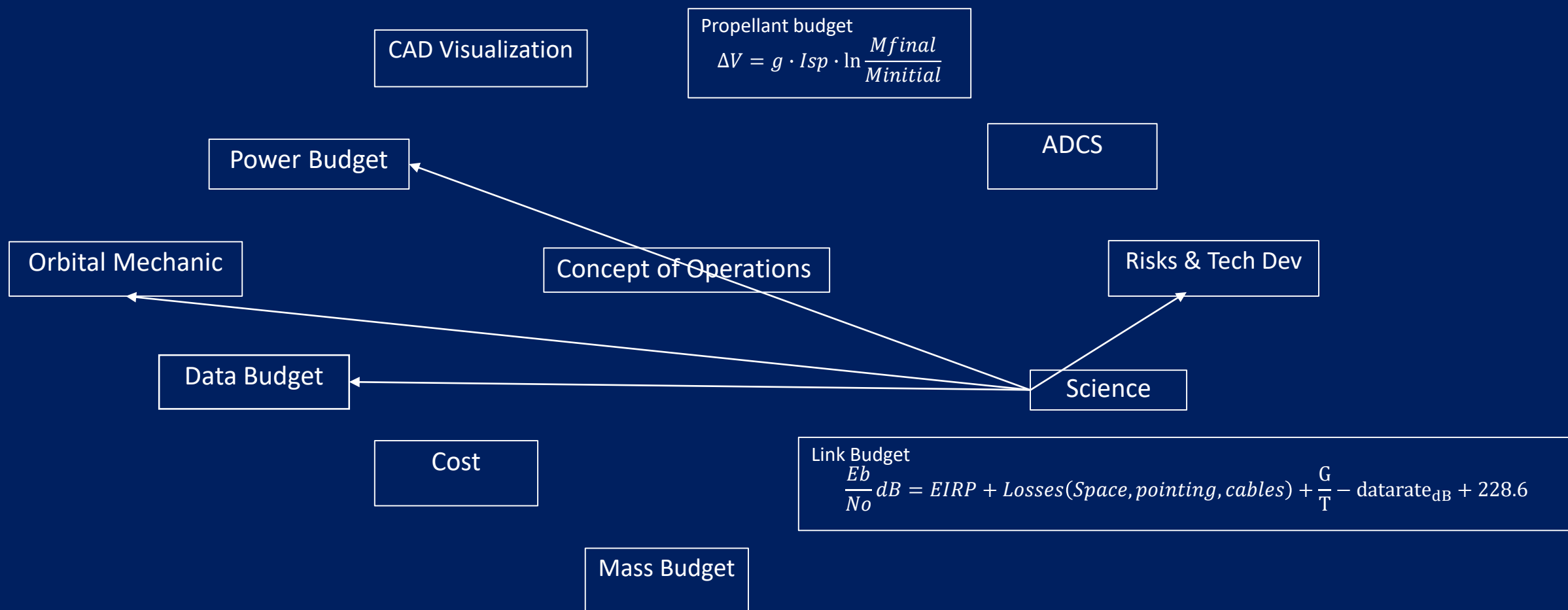
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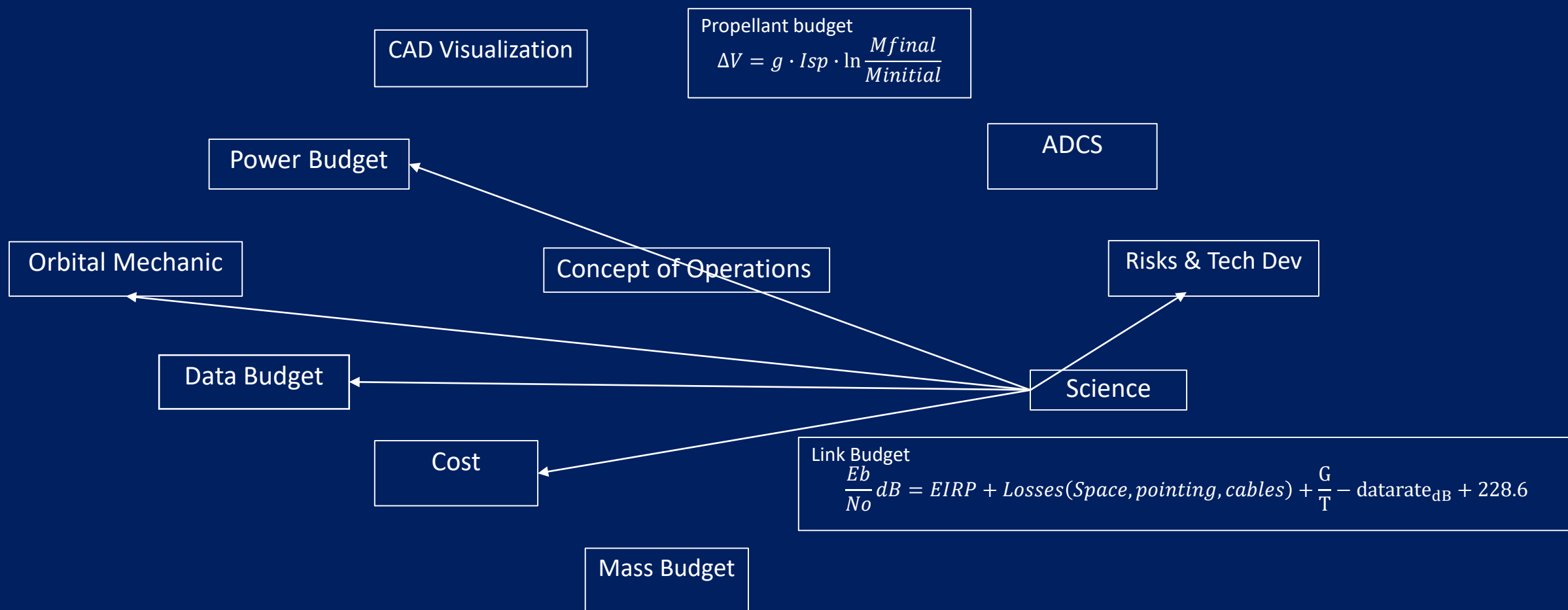
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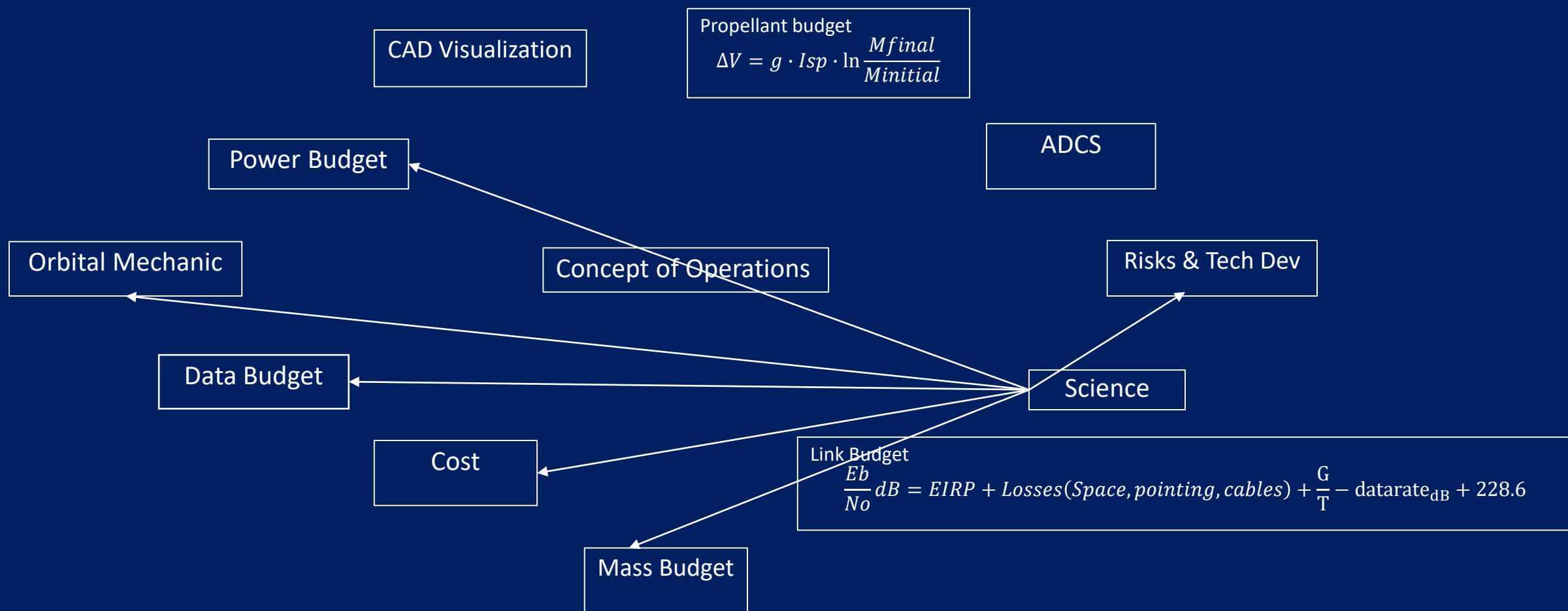
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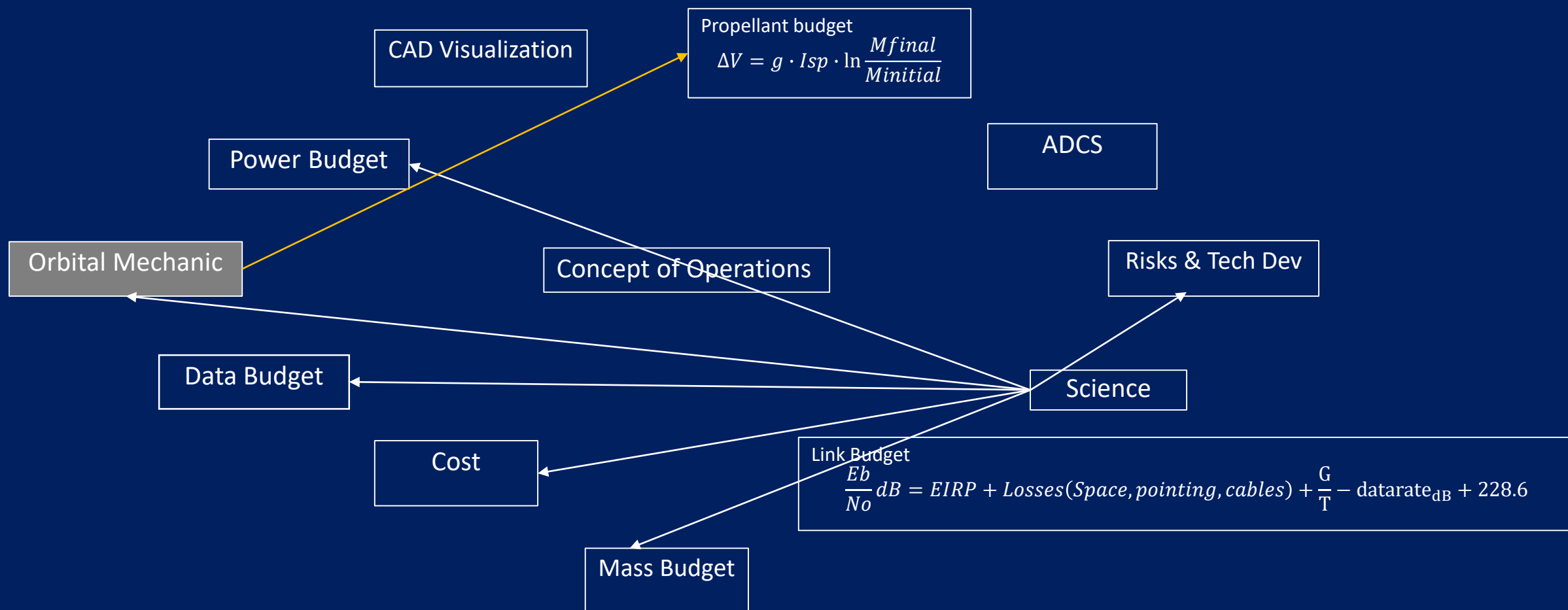
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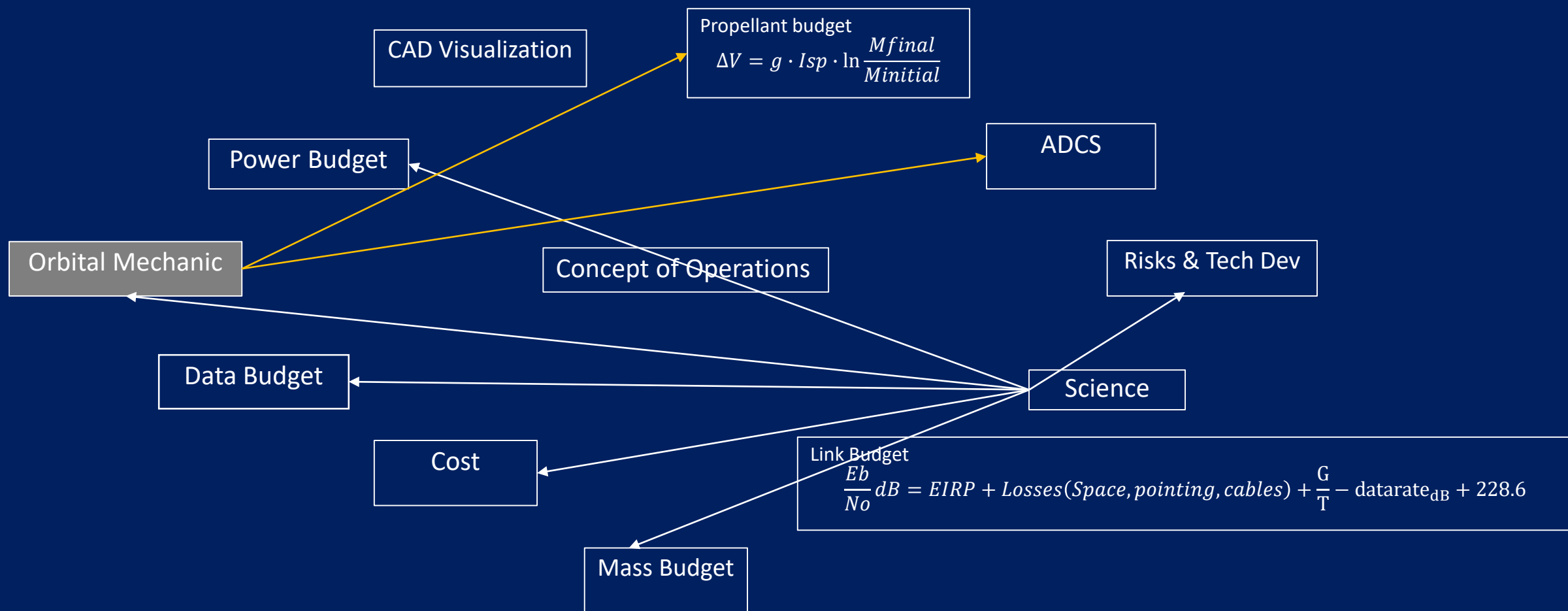
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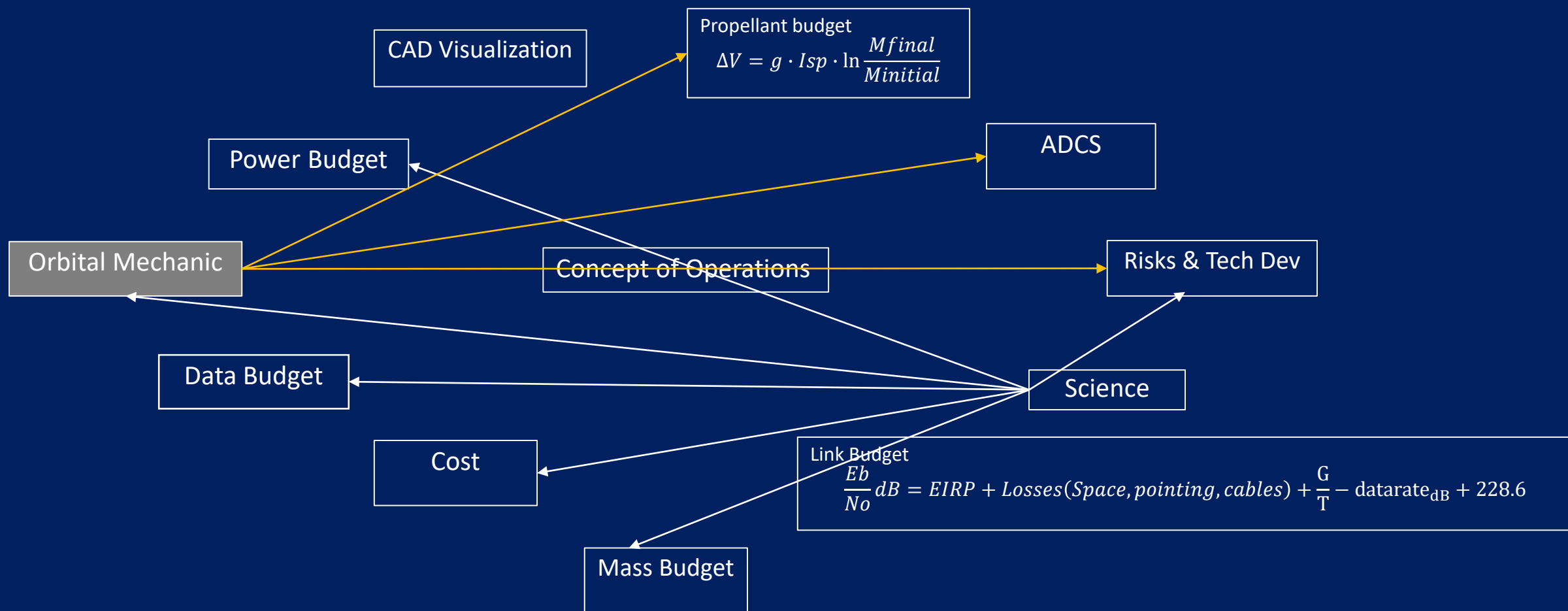
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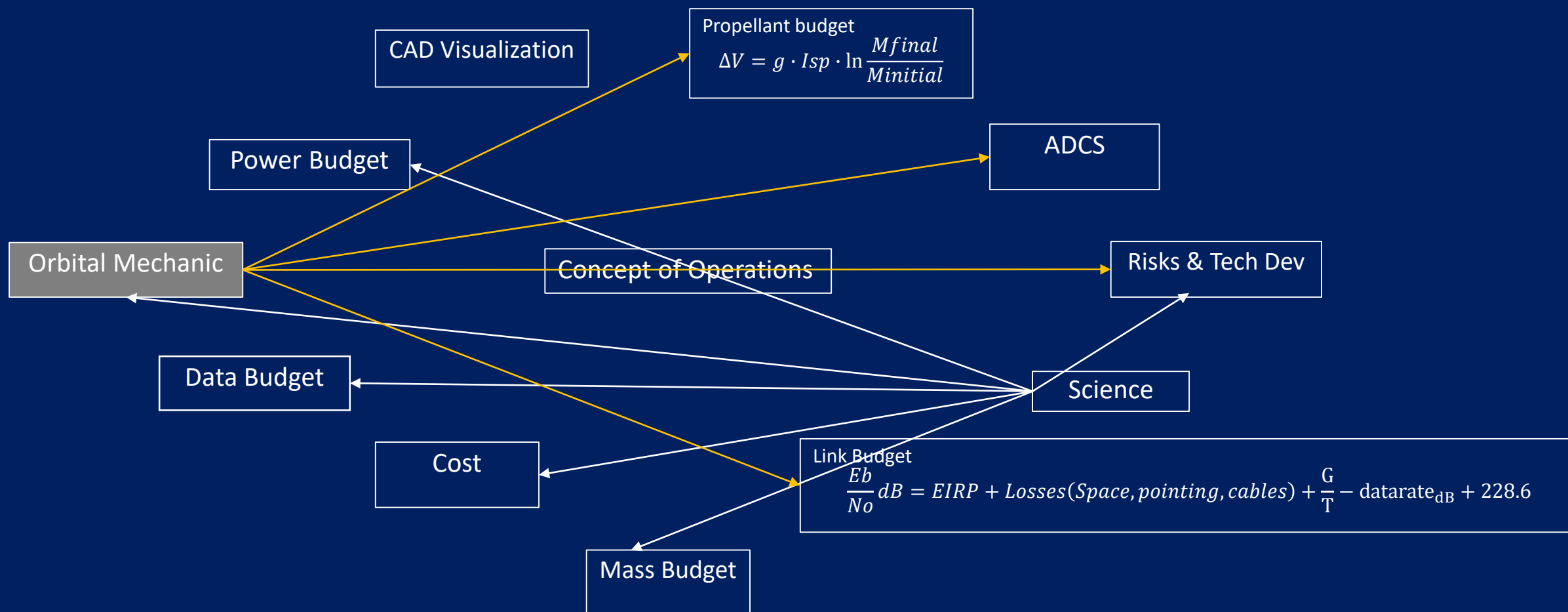
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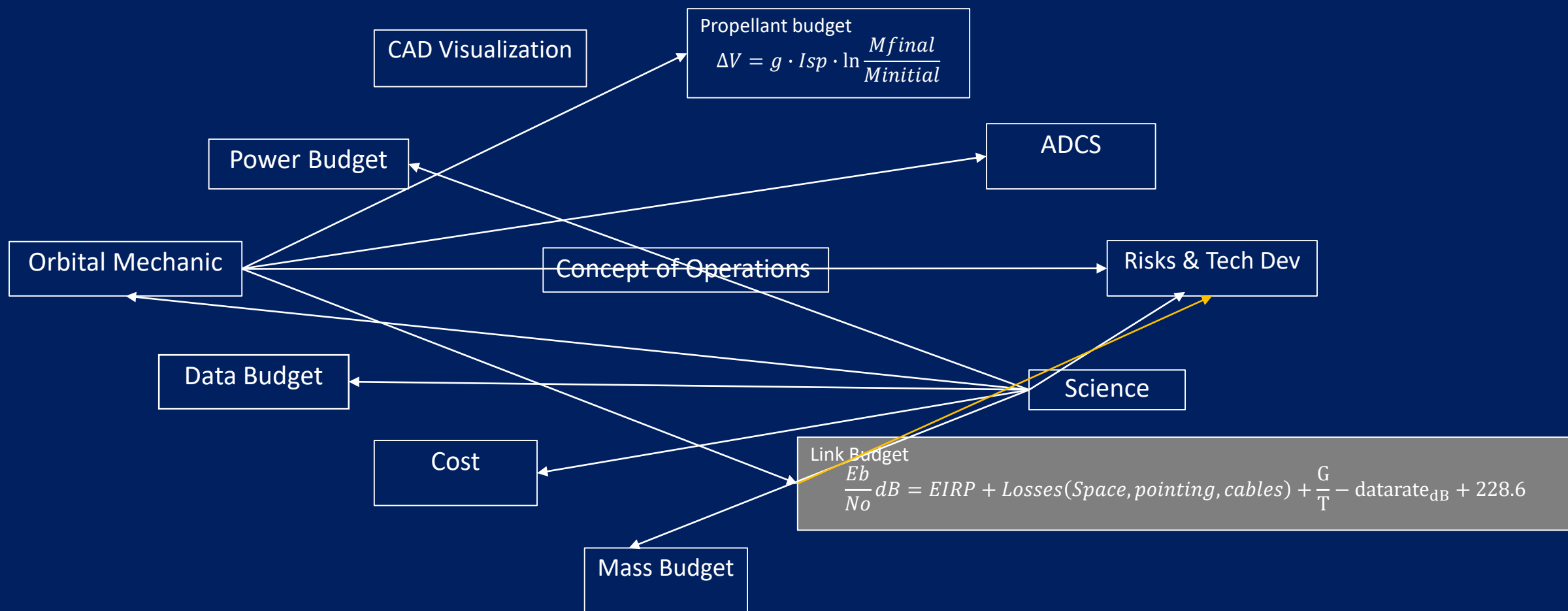
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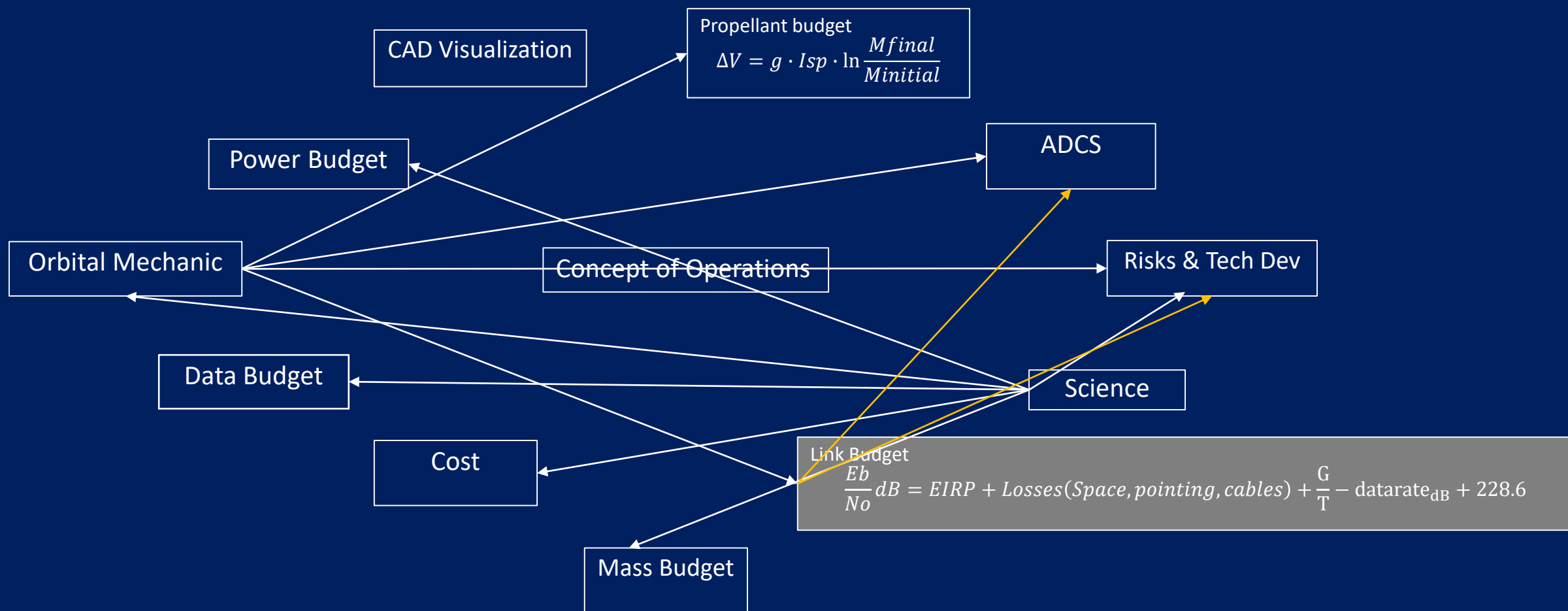
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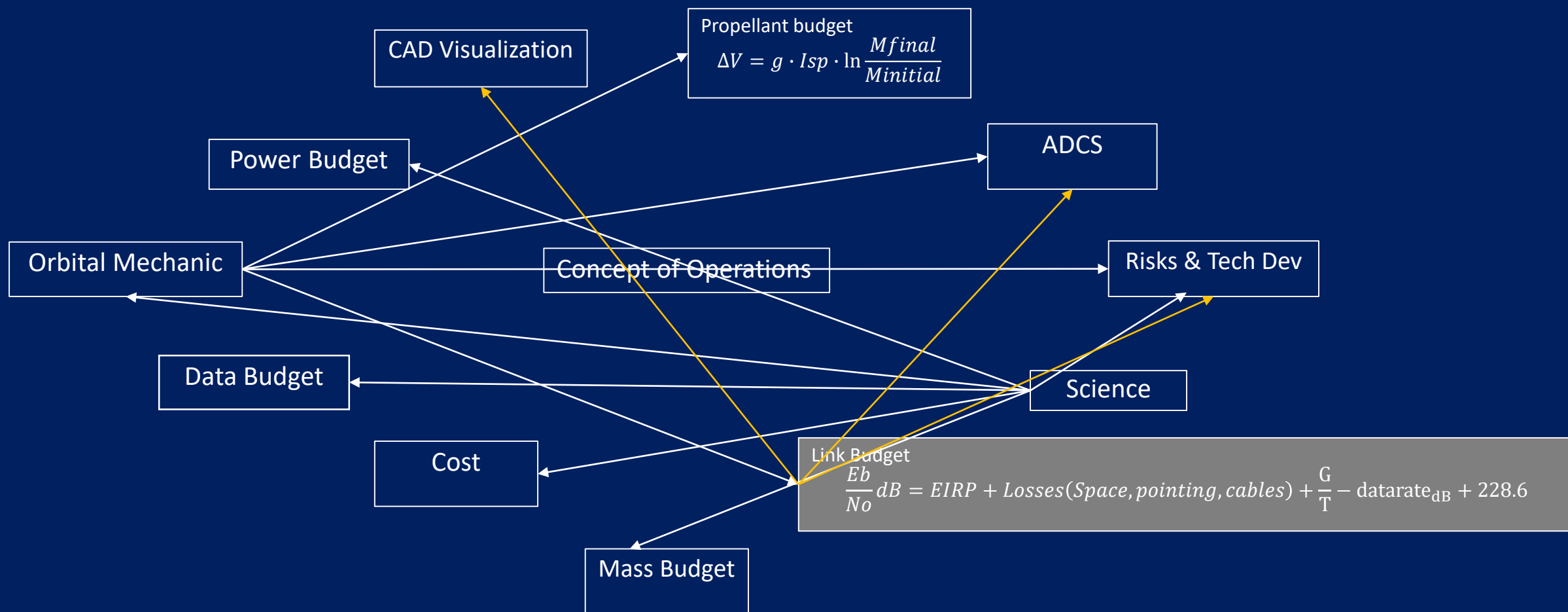
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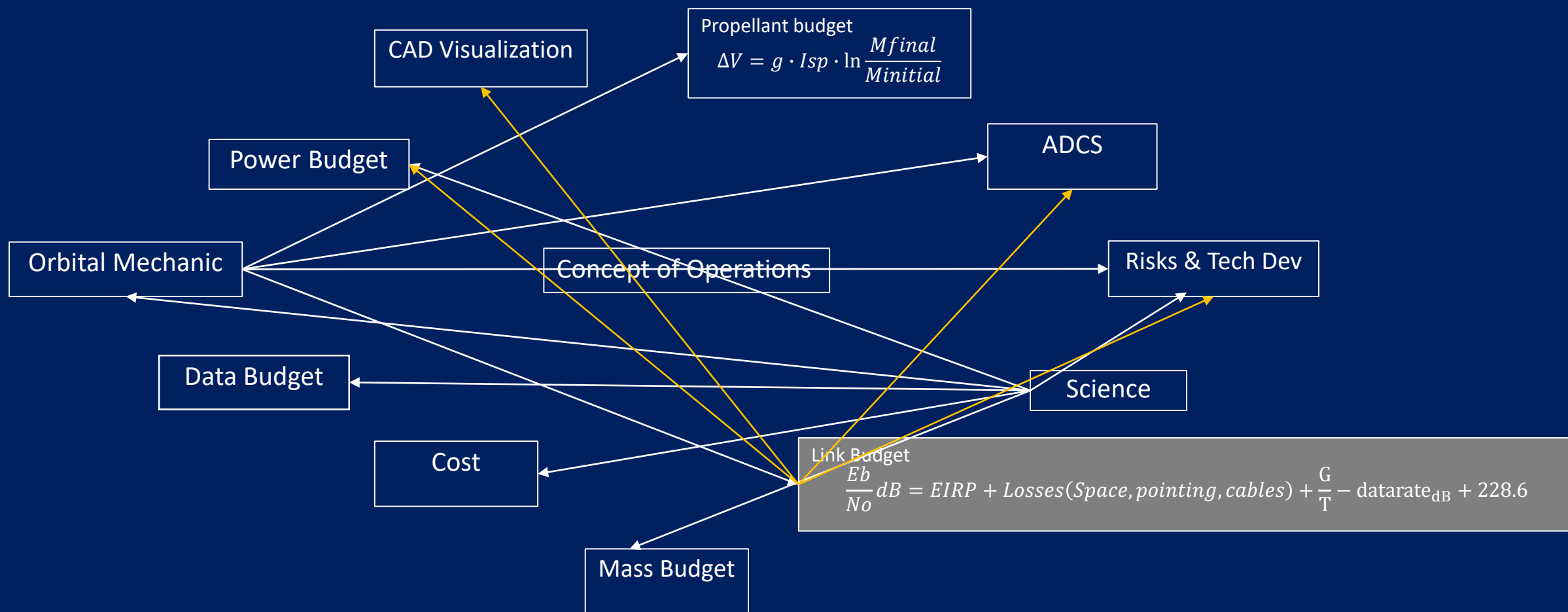
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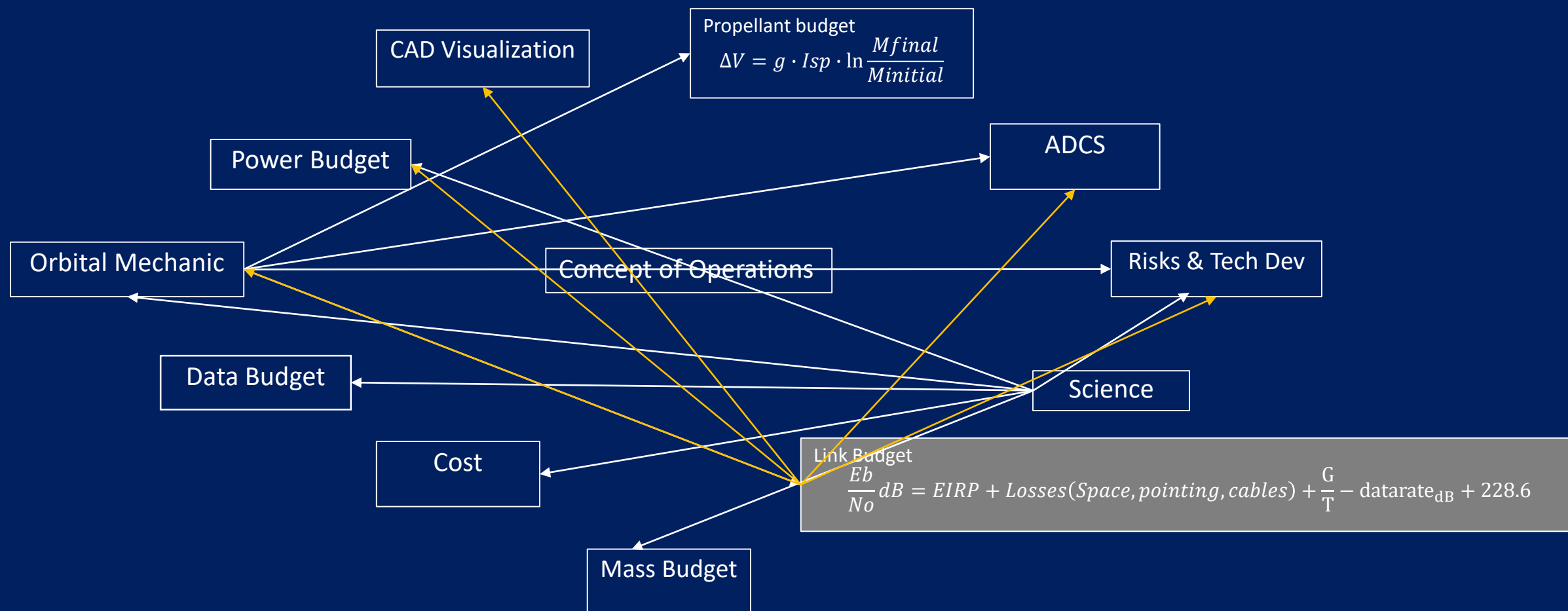
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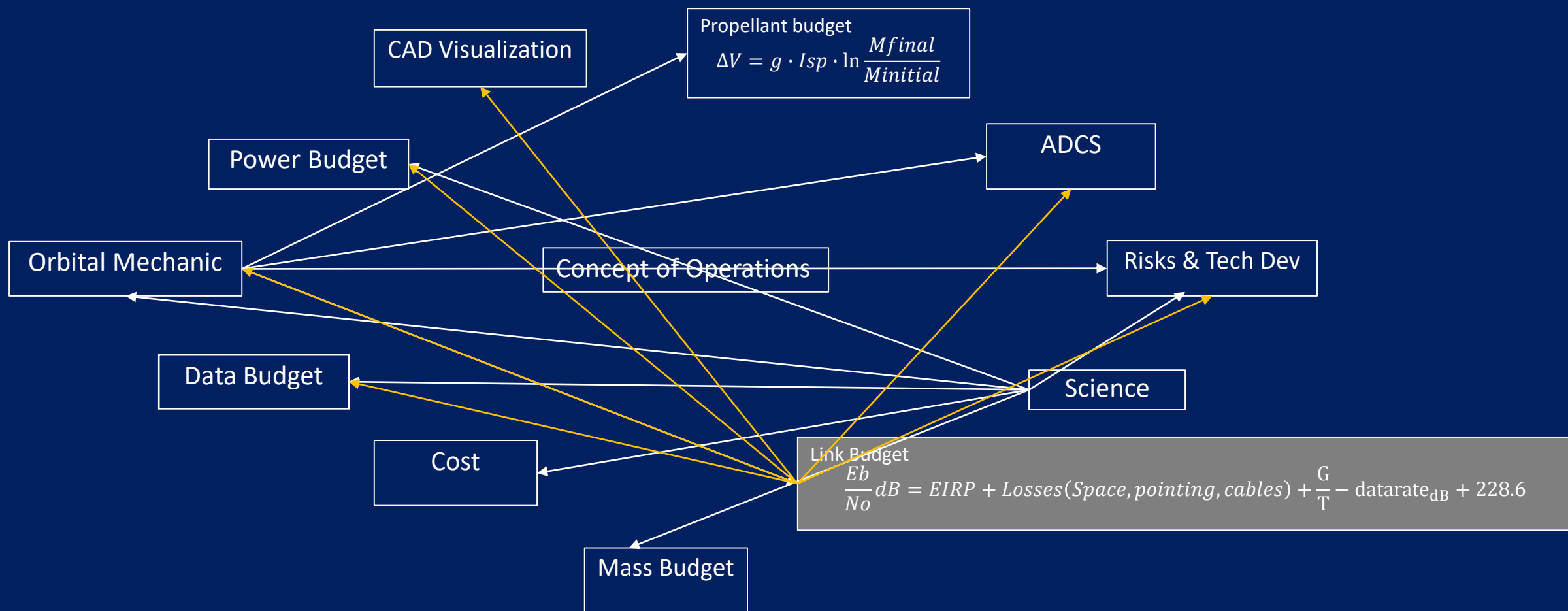
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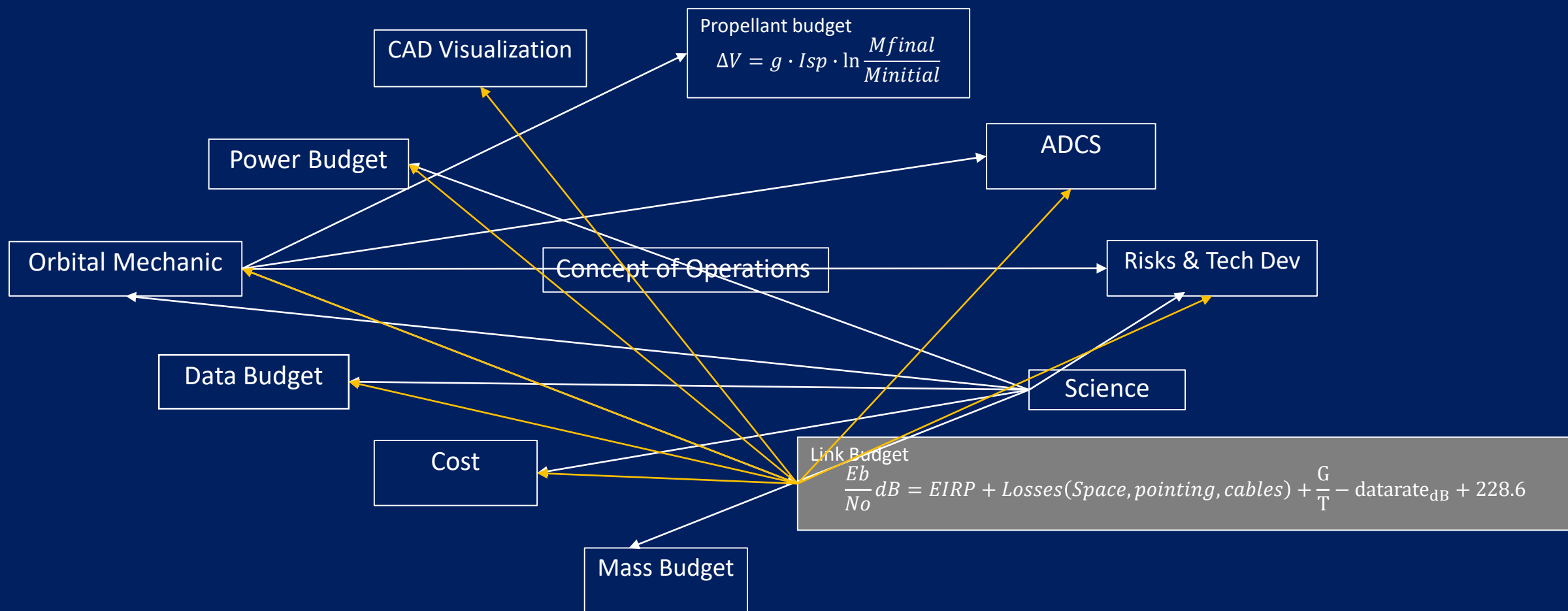
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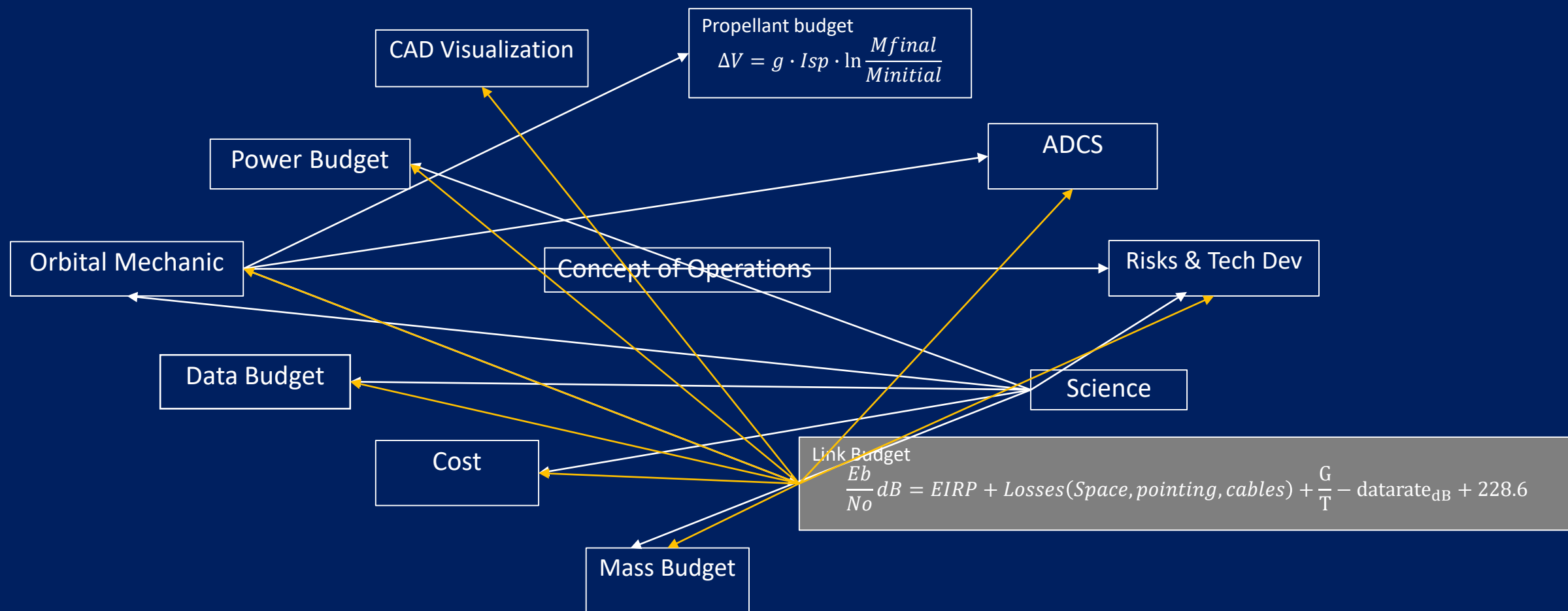
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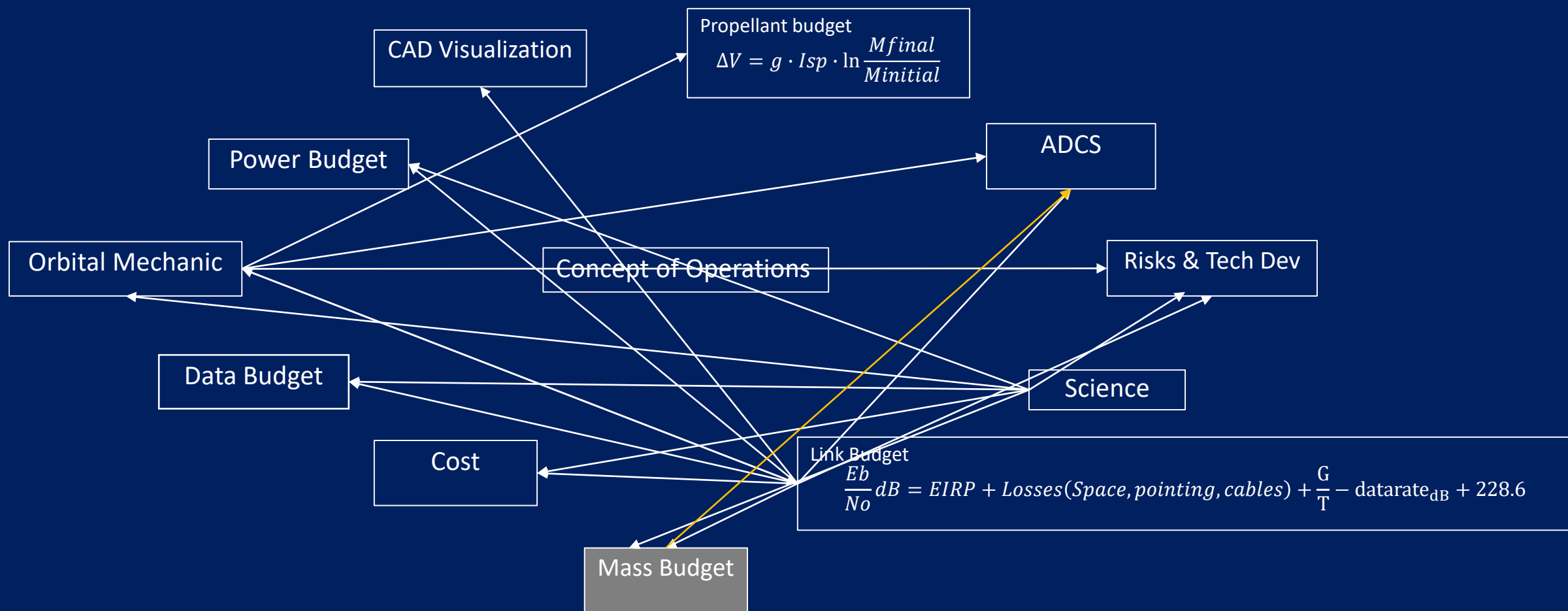
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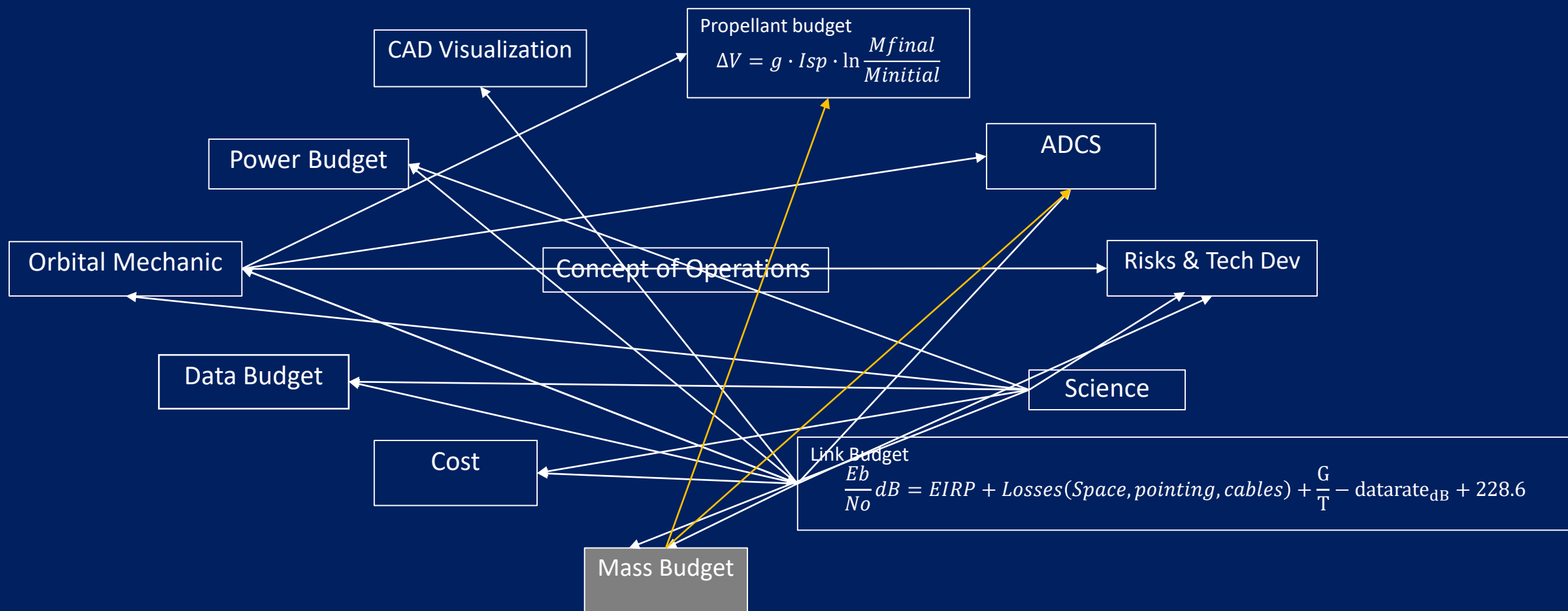
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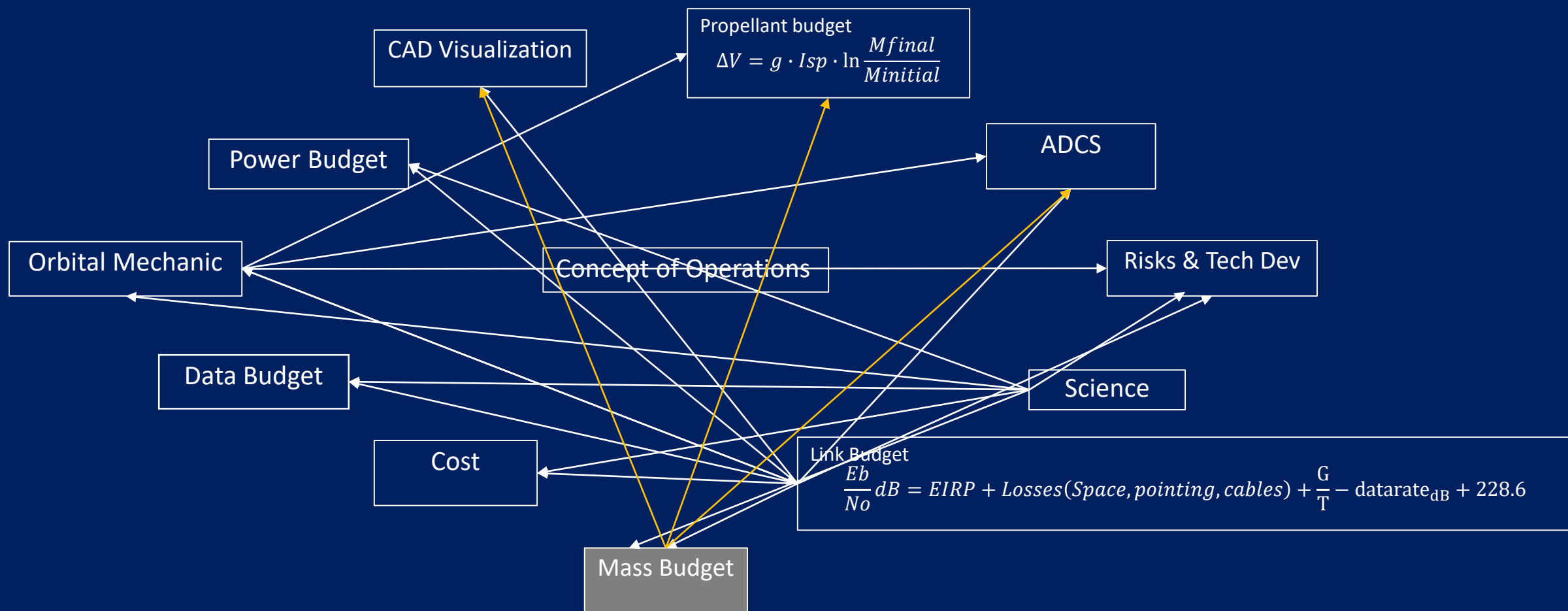
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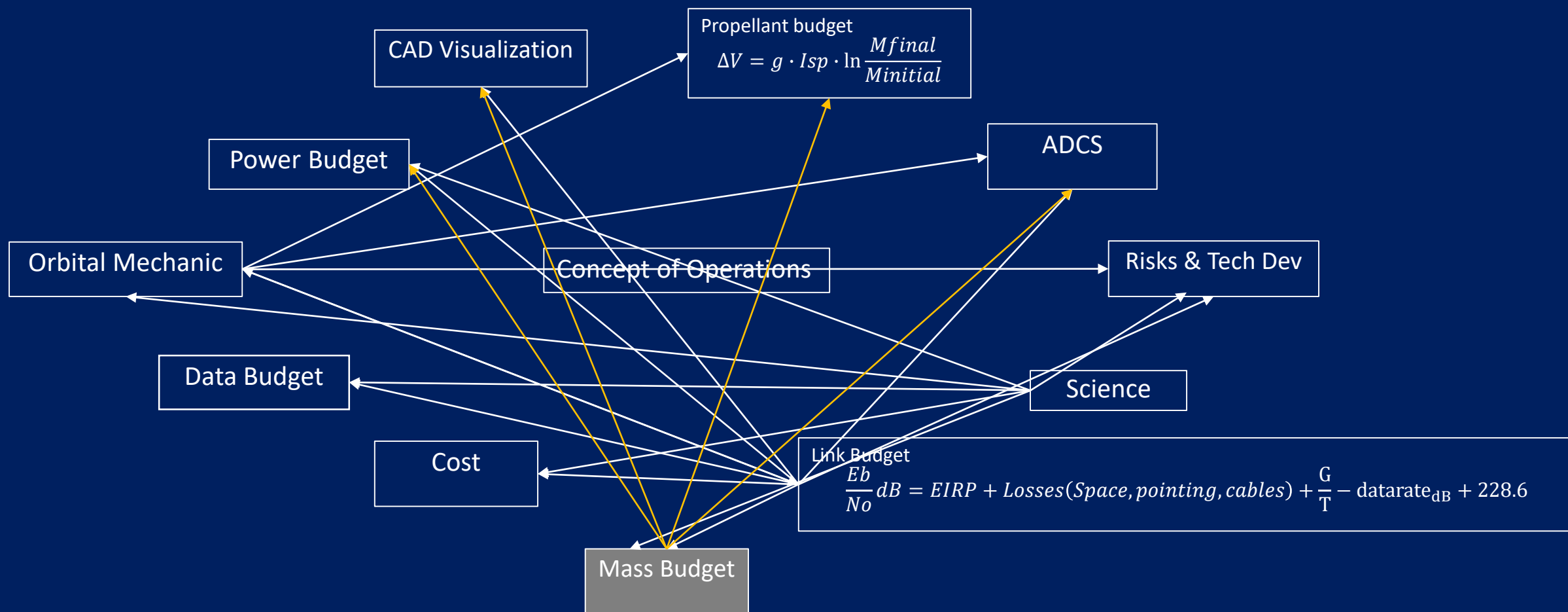
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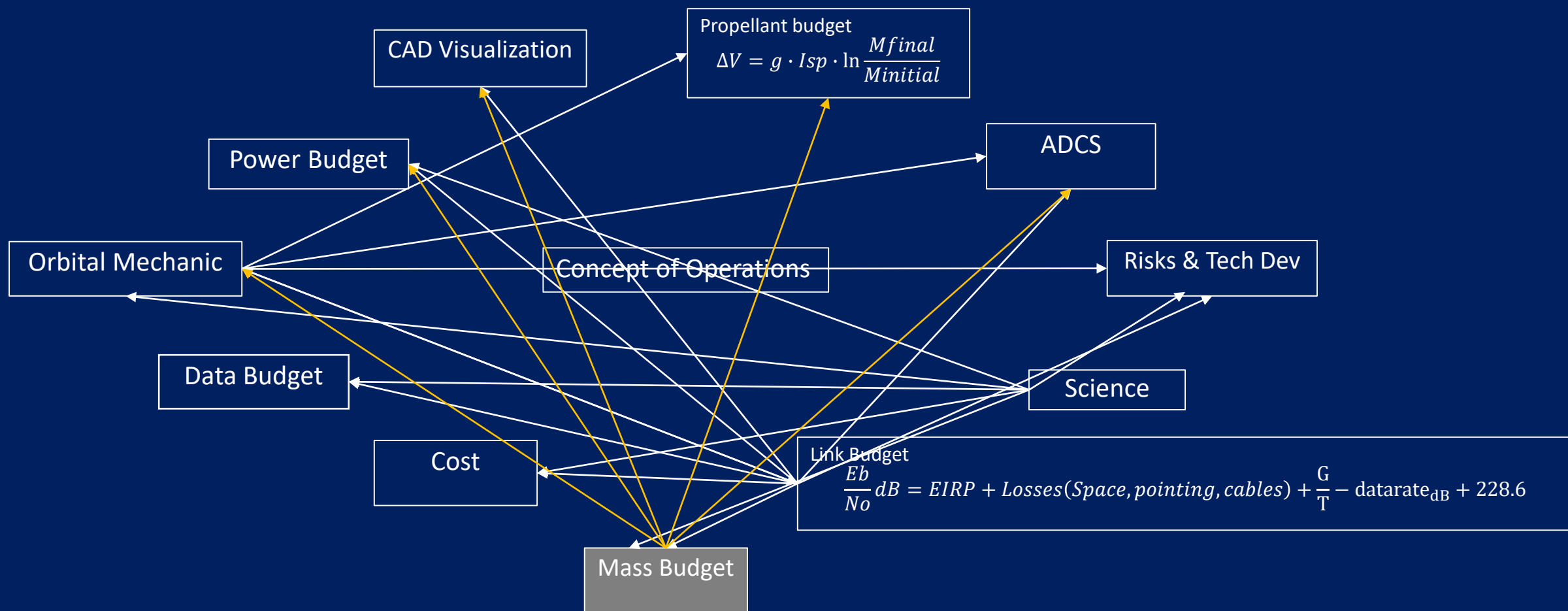
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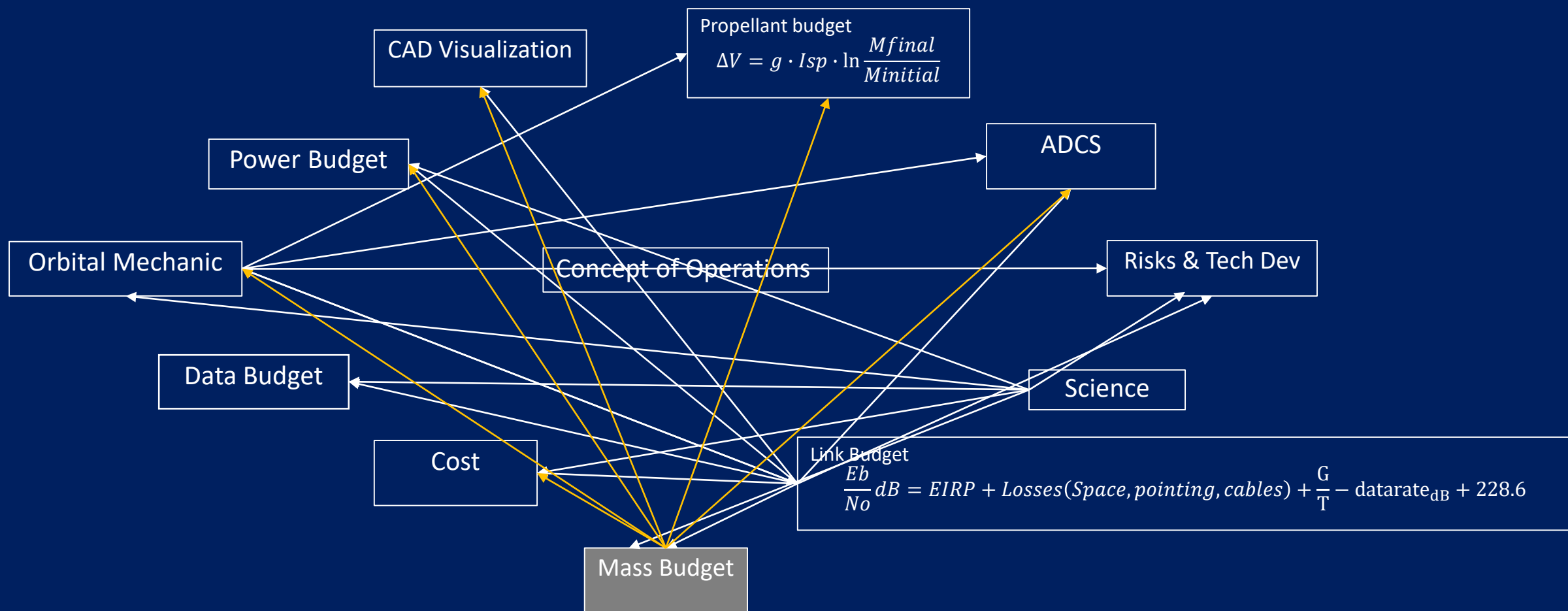
Develop Feasible Mission Architecture



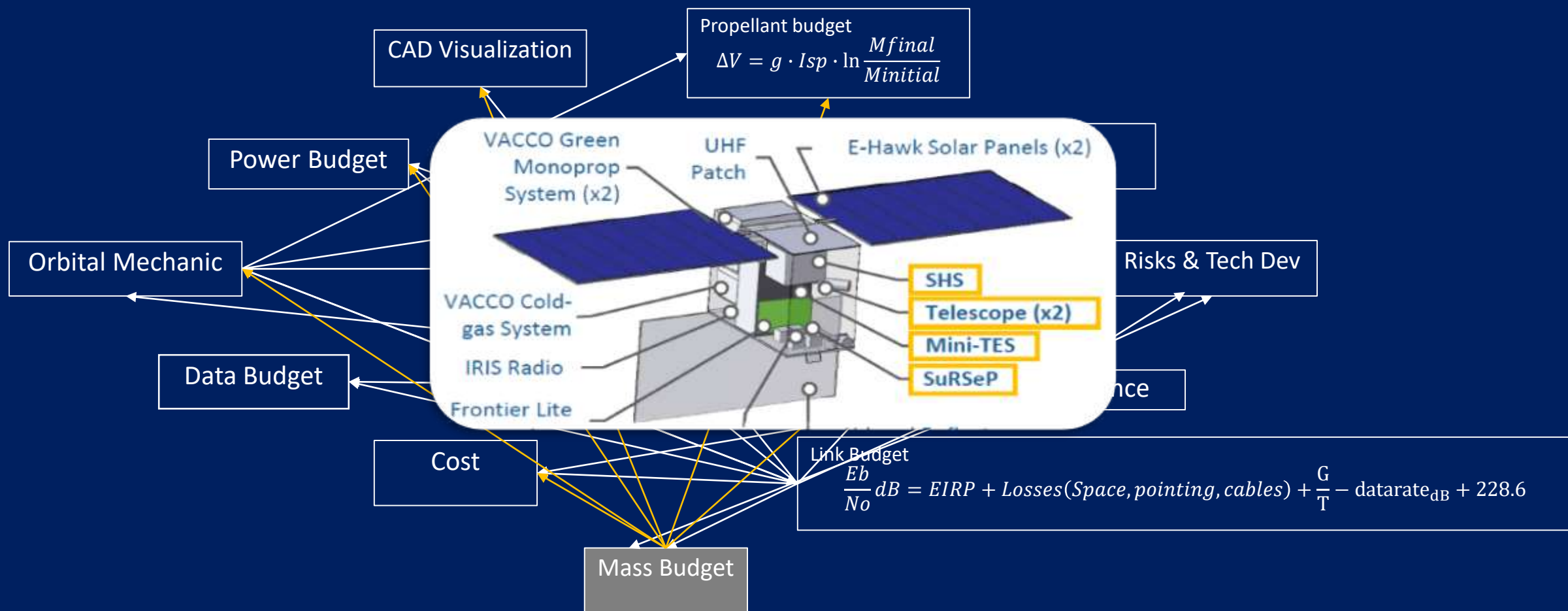
Develop Feasible Mission Architecture



Develop Feasible Mission Architecture



Develop Feasible Mission Architecture



Aeolus: an example of a mission concept study for Mars



CML 1
“Cocktail Napkin”



CML 2
Feasibility
Does any
solution
exist?



CML 3
Expanded Trade
Space
What other
solutions
exist?

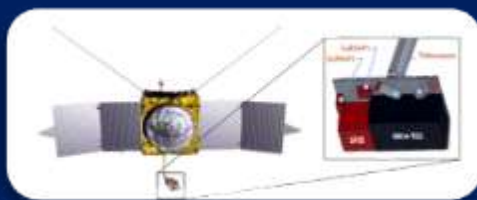
CML 3: Expanded Trade Space

Divergent Phase:

Explore different mission architectures
primary vs. secondary
launch options
number of spacecrafts
et cetera

Convergent Phase:

Identify rejection criteria & pick
architectures to pursue.



Iteration:

Repeat CML 2 as needed on
selected architectures

Trade Dimensions	Tradable Options					
Mission Type	Primary	Secondary				
Approach Type	Flyby	Atmospheric Entry	Orbit	Landing on Phobos		
Measurement						
Surface	Lander	Rover	Impactor			
Atmospheric	Balloon	Dirigible	UAVs	long probe		
On-orbit	Single fixed	Single Variable	Swarm	Constellation		
Primary Power	Nuclear	Solar	Battery			
Drop-off	Earth	Helio	Outside Earth SOI	Intermediate Mars drop-off	Direct to final orbit	
Prop System	Solar sail	Solar EP	Chem	Nuclear EP		
Orbit Characteristics	Circular	Elliptical				
Periapsis/Altitude	Low Mars Orbit 200-600 km	~1000 km	≥17000 km			
Inclination	0 deg	1-60 deg	60-89 deg	90 deg		
Instruments	SHS	SURSeP	Mini-TES	Lidar	Imager	Radio (occultation)
Mass/Size	6U	12U	24U	ESPA (<180 kg)	>180 kg	
Science Pointing	rotating optics	Rotating SC	Imaging Array (fixed)	gimbaled instrument platform		
Ops and Data Return Technology	Direct to Earth	Relay				
Launch Vehicles/Options	Mars 2020	Mars 2022	EM-2	Dedicated		
Science Duration	3 Earth Months Full Surface Coverage (<1 Martian Season)	6 Earth Months 1 Martian Season	12 Earth Months 2 Martian Season	1.5 Earth Yrs 3 Martian Season	2 Earth Yrs 1 Martian Year (4 Martian Seasons)	4 Earth Yrs 2 Martian Yrs

LEGEND

	Elements selected in at least one architecture
	Technical rejection
	Science rejection
	Programmatic rejection
	Allowable but not selected (white), e.g. out of scope

Aeolus: an example of a mission concept study for Mars



CML 1
“Cocktail Napkin”



CML 2
Feasibility
Does any
solution
exist?



CML 3
Expanded Trade
Space
What other
solutions
exist?



CML 4
Point Design
What is a good
approach, given our
circumstances?

CML 4: Point Design

Science Traceability Matrix

Mission Architecture

Driving environmental parameters

Launch vehicle

Delta-V calculations

Orbital solution

Radiation Analysis

Mission ops

Identify required tech development

Spacecraft CAD model

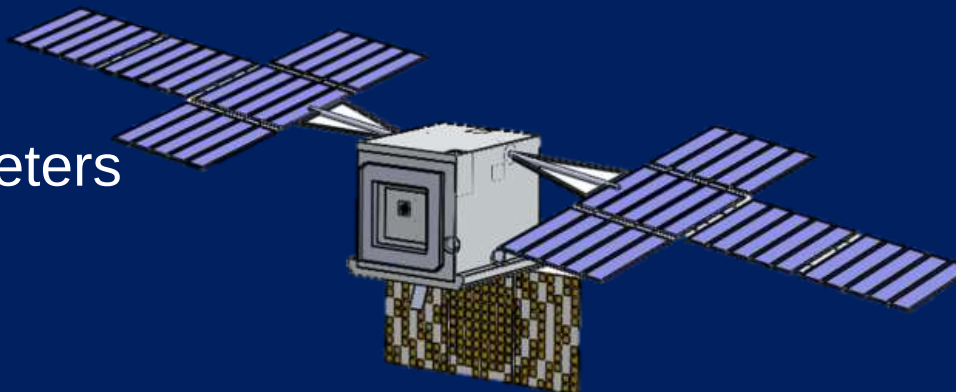
Power Analysis

Thermal Analysis

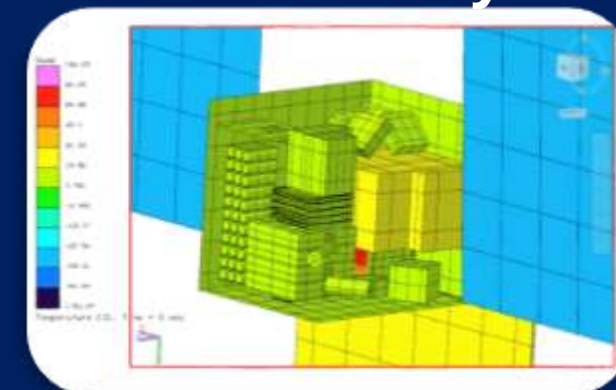
Better Cost Estimate

Refined Schedule

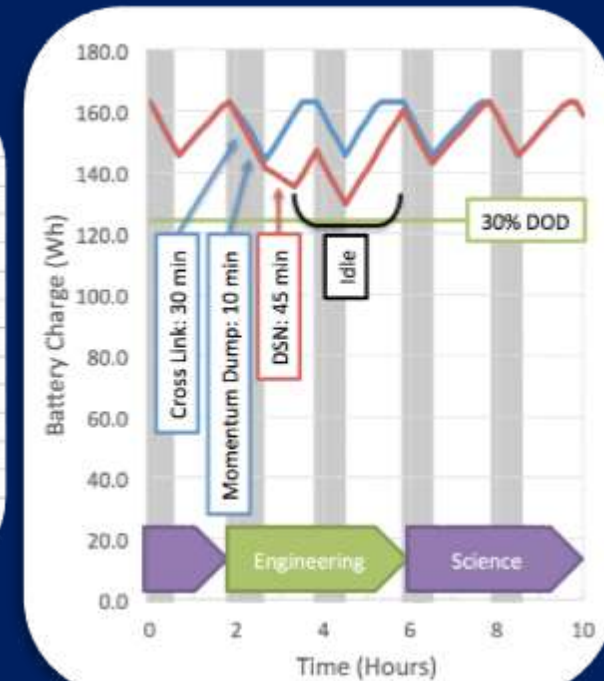
Risks Matrix & Mitigation



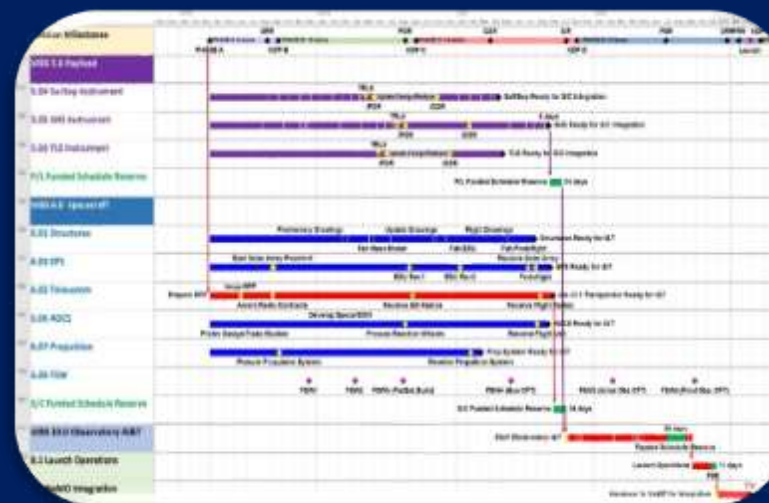
Thermal analysis



Power analysis



Schedule



Science Traceability Matrix

Mission Architecture

Driving environmental parameters

Launch vehicle

Delta-V calculations

Orbital solution

Radiation Analysis

Mission ops

Identify required tech development

Spacecraft CAD model

Power Analysis

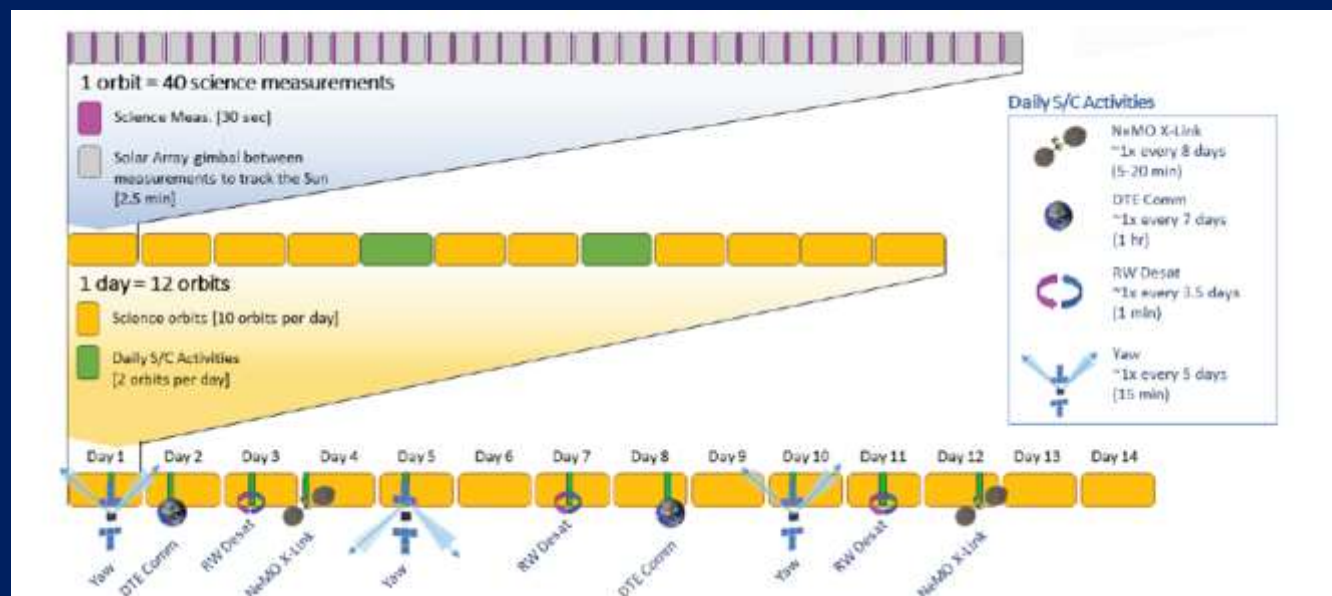
Thermal Analysis

Better Cost Estimate

Refined Schedule

Risks Matrix & Mitigation

2 weeks operational cycle



Science Traceability Matrix

Mission Architecture

Driving environmental parameters

Launch vehicle

Delta-V calculations

Orbital solution

Radiation Analysis

Mission ops

Identify required tech development

Spacecraft CAD model

Power Analysis

Thermal Analysis

Better Cost Estimate

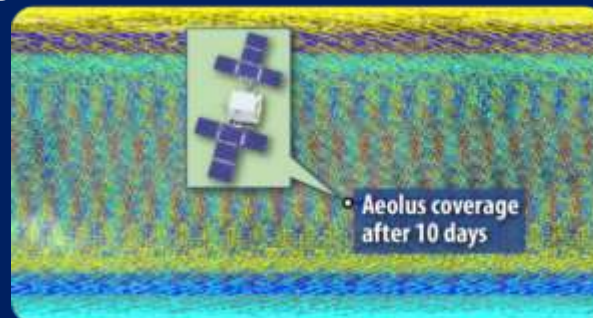
Refined Schedule

Risks Matrix & Mitigation

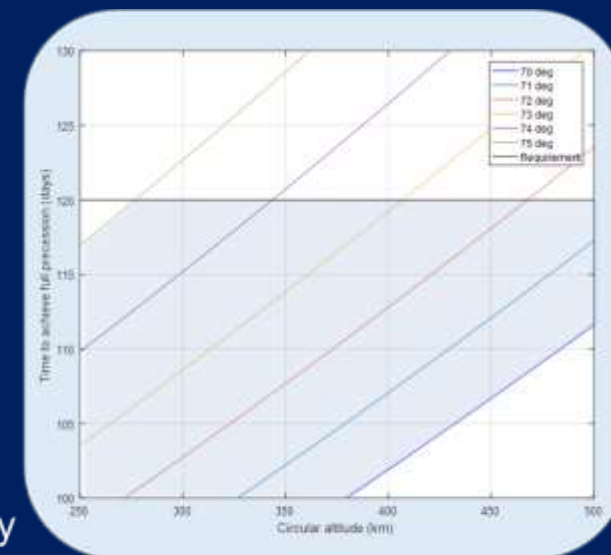
Refined orbit design



Orbit precesses
over all *local*
times within 2
months



Global spatial
coverage every
10 days



Science Traceability Matrix

Mission Architecture

Driving environmental parameters

Launch vehicle

Delta-V calculations

Orbital solution

Radiation Analysis

Mission ops

Identify required tech development

Spacecraft CAD model

Power Analysis

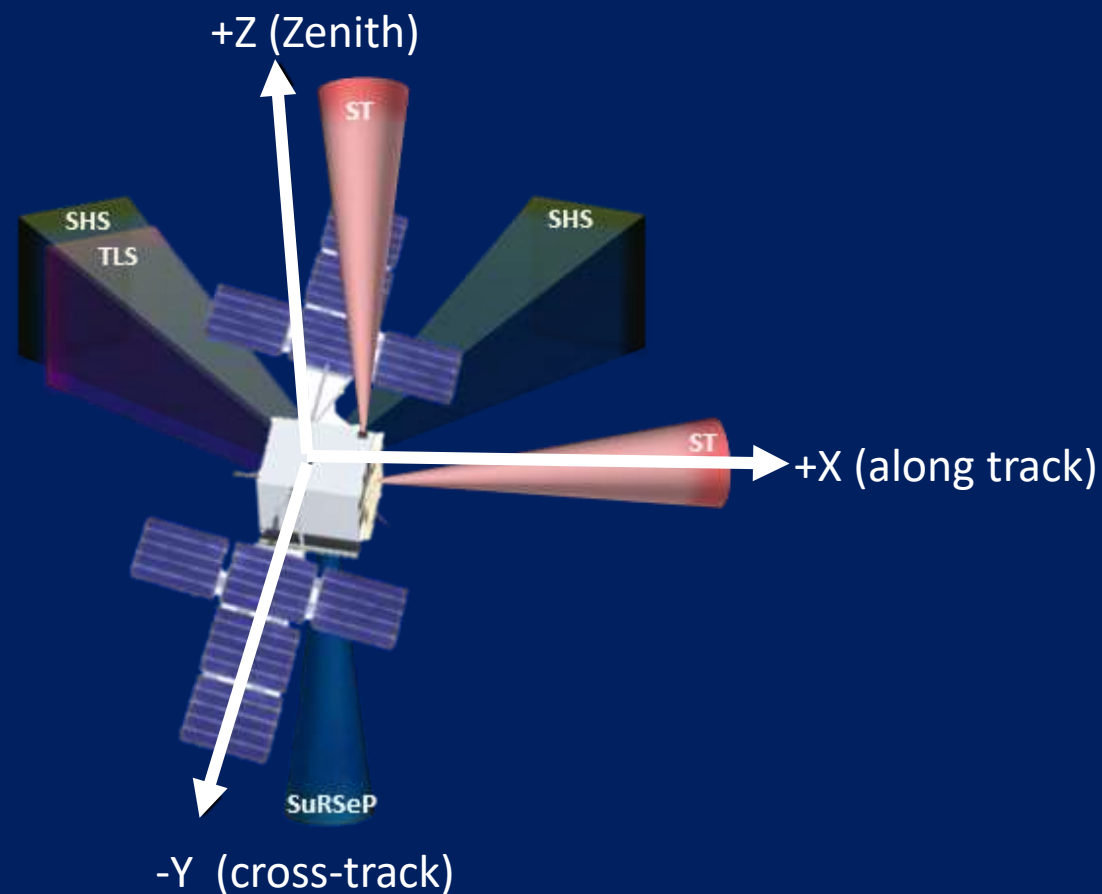
Thermal Analysis

Better Cost Estimate

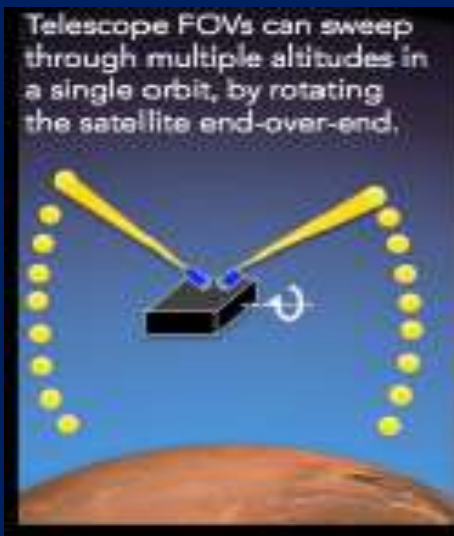
Refined Schedule

Risks Matrix & Mitigation

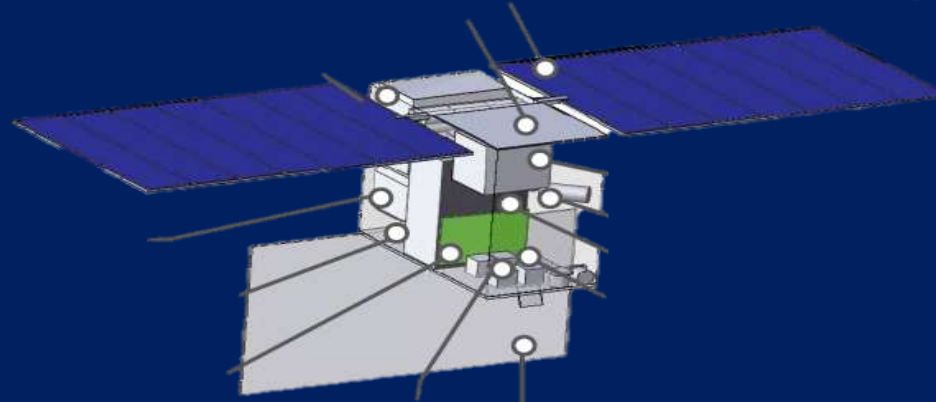
Refined Flight system capabilities



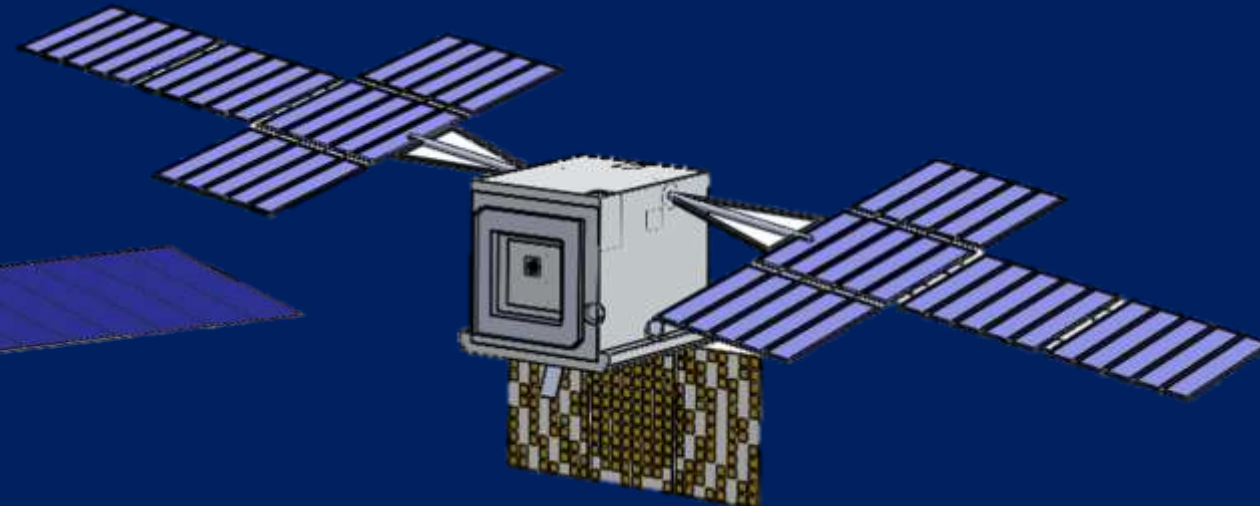
CML 1



CML 2



CML 4





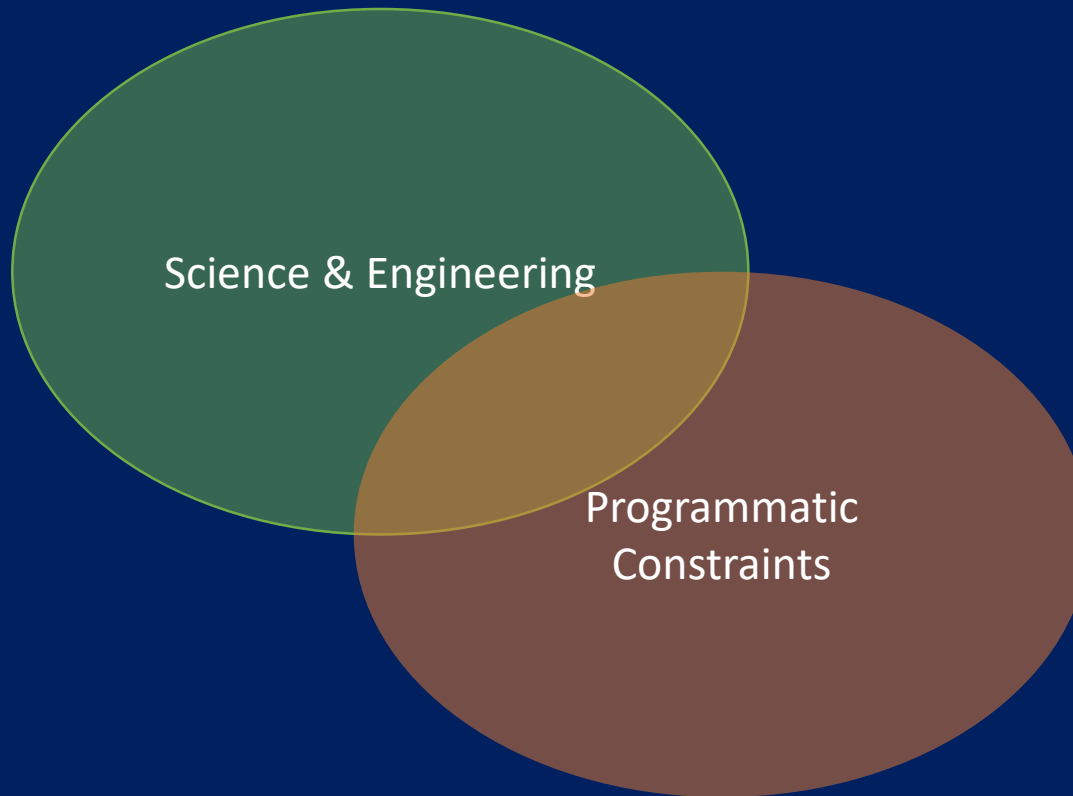
Lessons learned



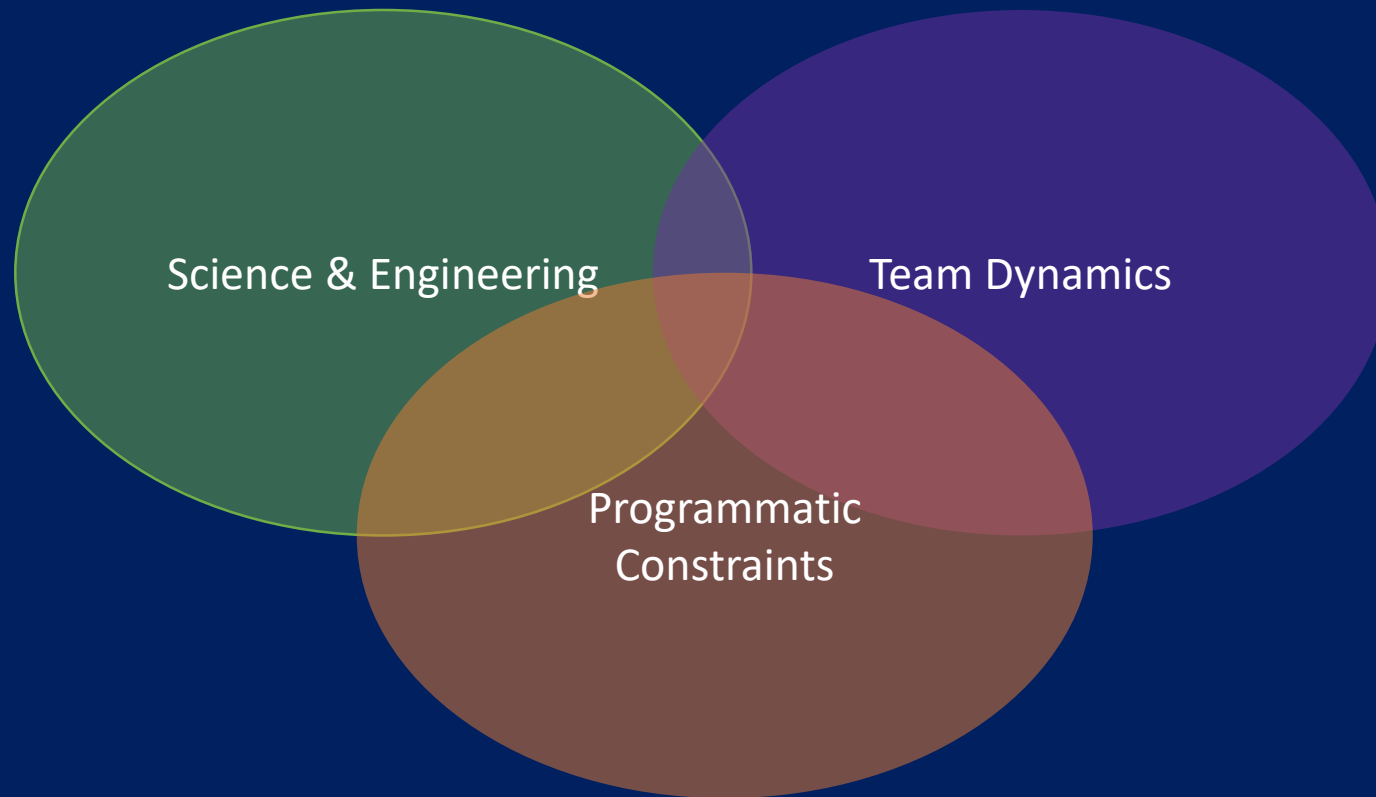
Lessons learned

Science & Engineering

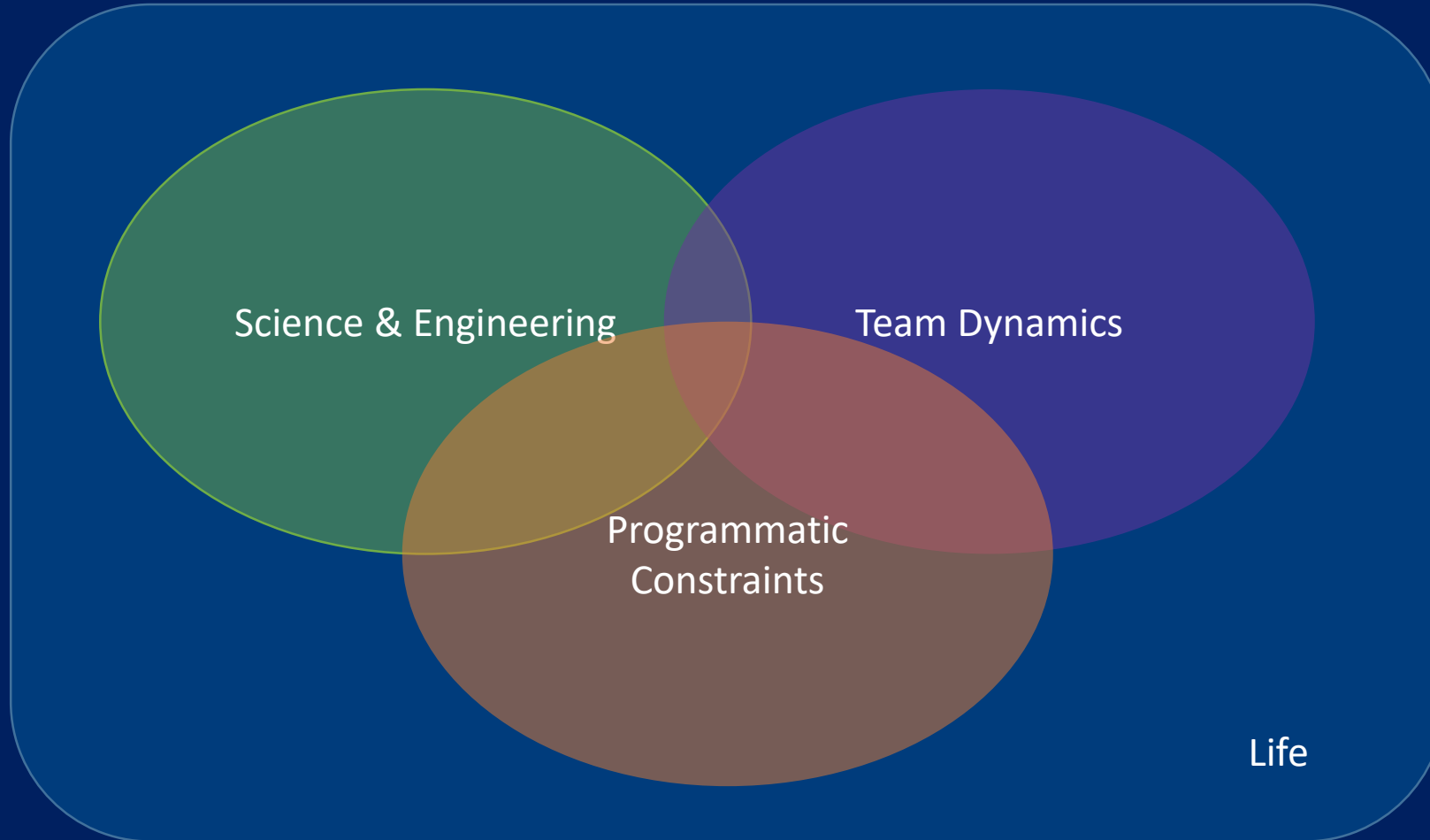
Lessons learned



Lessons learned



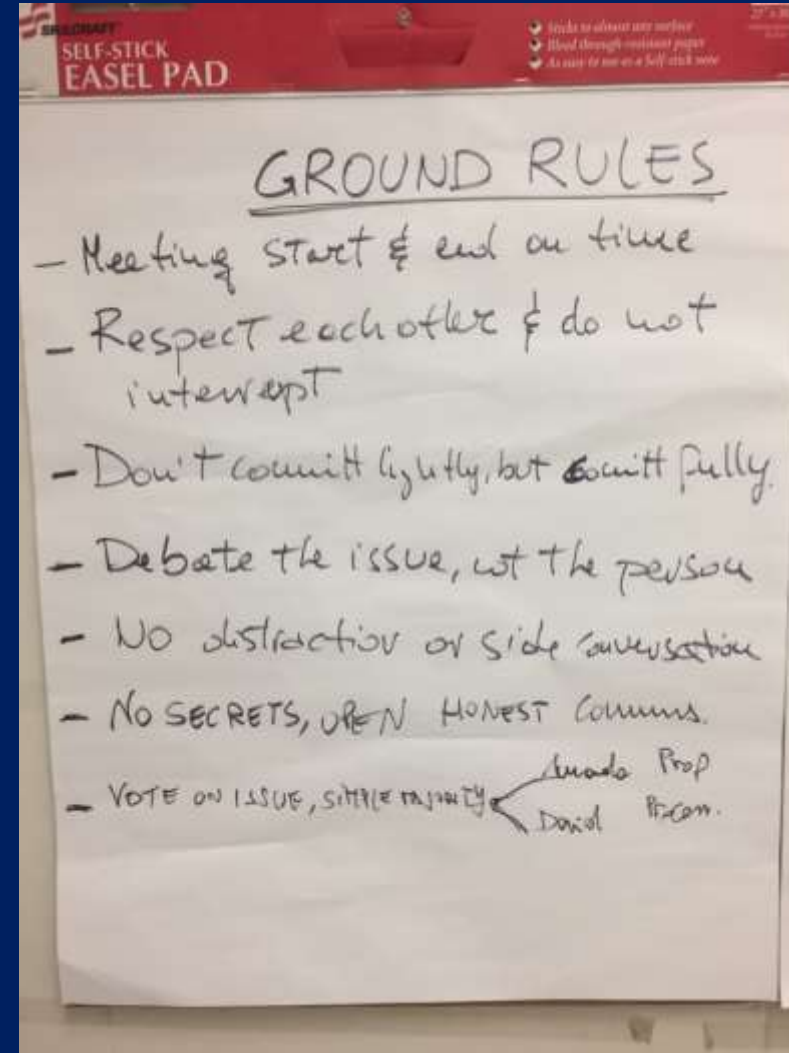
Lessons learned



Practical tips and best practices



➡ • Meeting Ground Rules



Practical tips and best practices

- Meeting Ground Rules
- ➡ • Check out smartphone/tablet/pc at the door unless working session

Practical tips and best practices

- Meeting Ground Rules
- Check out smartphone/tablet/pc at the door unless working session
- ➔ • Prepare meeting in advance:
 - Agenda & expected outcome
 - Assign preliminary work

Practical tips and best practices

- Meeting Ground Rules
- Check out smartphone/tablet/pc at the door unless working session
- Prepare meeting in advance:
 - Agenda & expected outcome
 - Assign preliminary work
- ➡ • Brainstorming: use diverse options

Practical tips and best practices

- Meeting Ground Rules
- Check out smartphone/tablet/pc at the door unless working session
- Prepare meeting in advance:
 - Agenda & expected outcome
 - Assign preliminary work
- Brainstorming: use diverse options
- ➡ • Action Items: assign & review

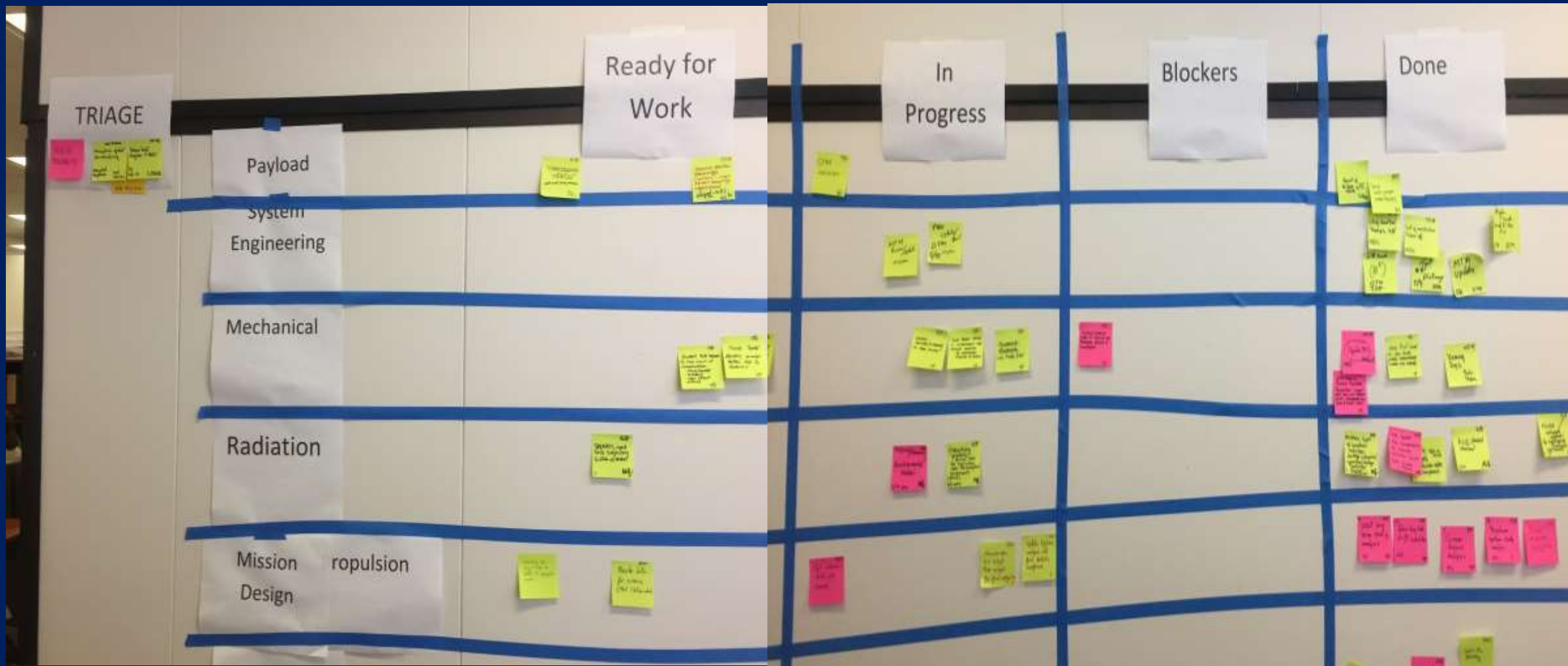
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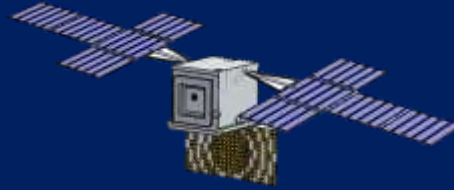
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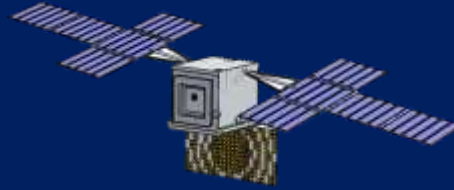
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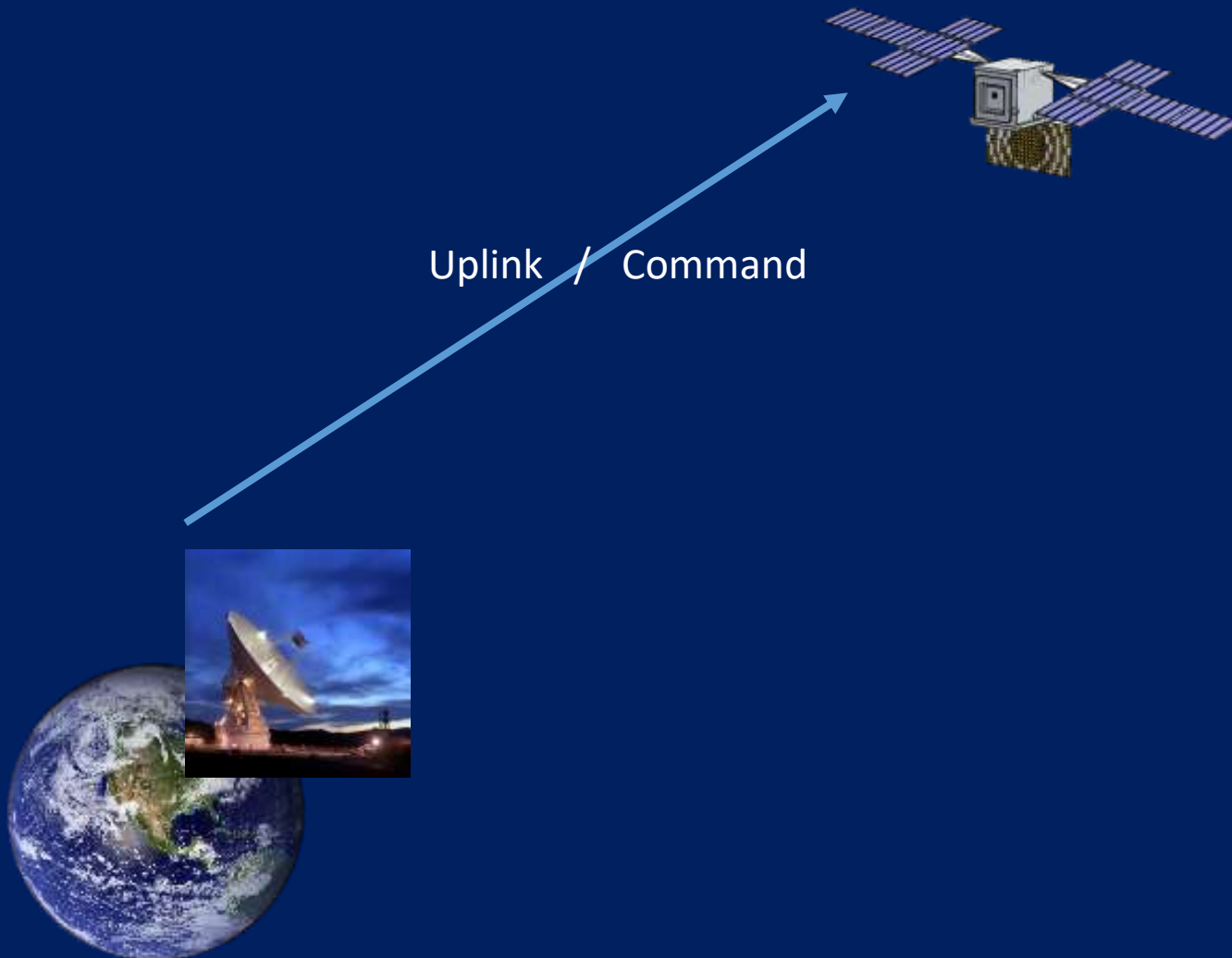
Spacecraft Telecomm Sub-System



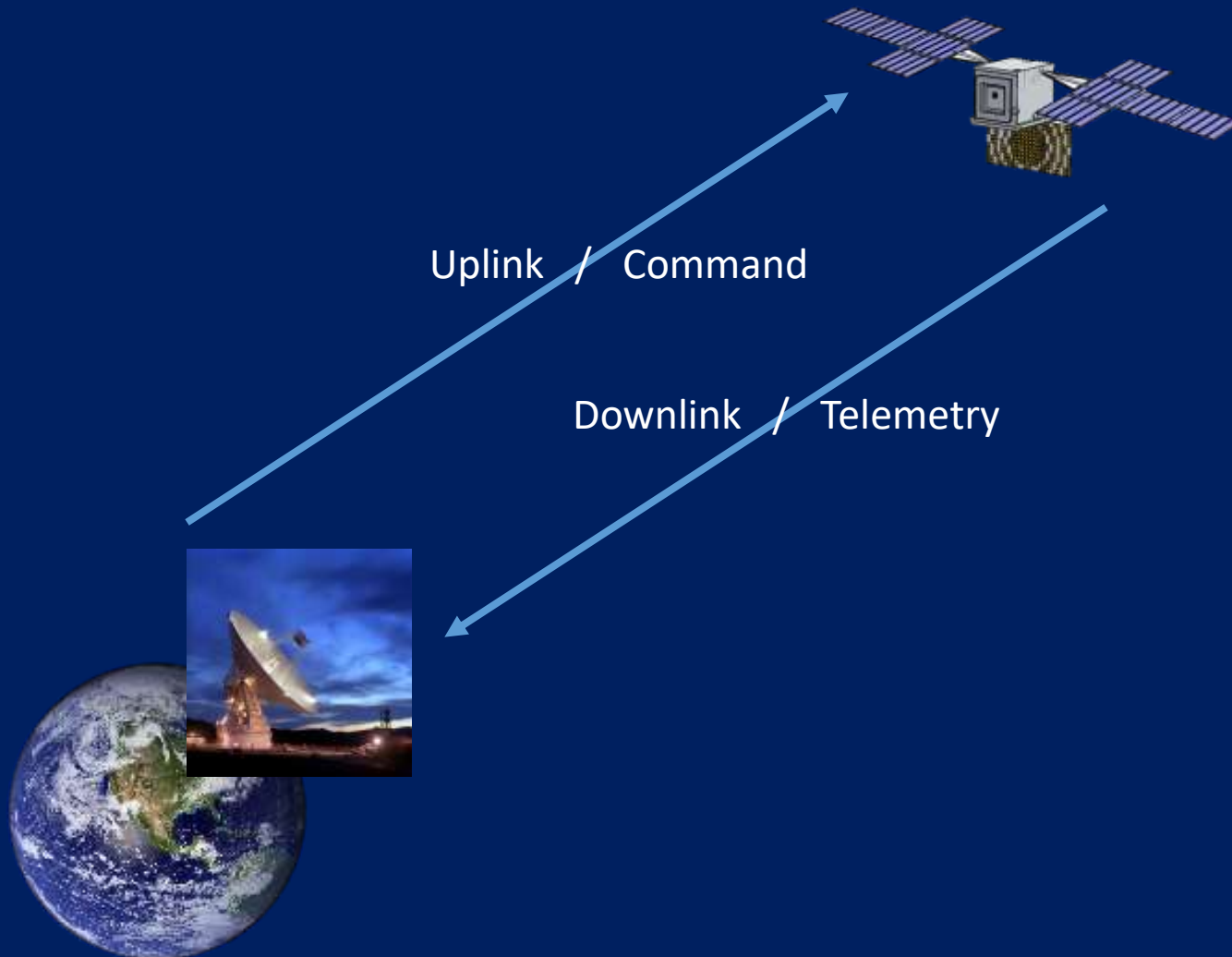
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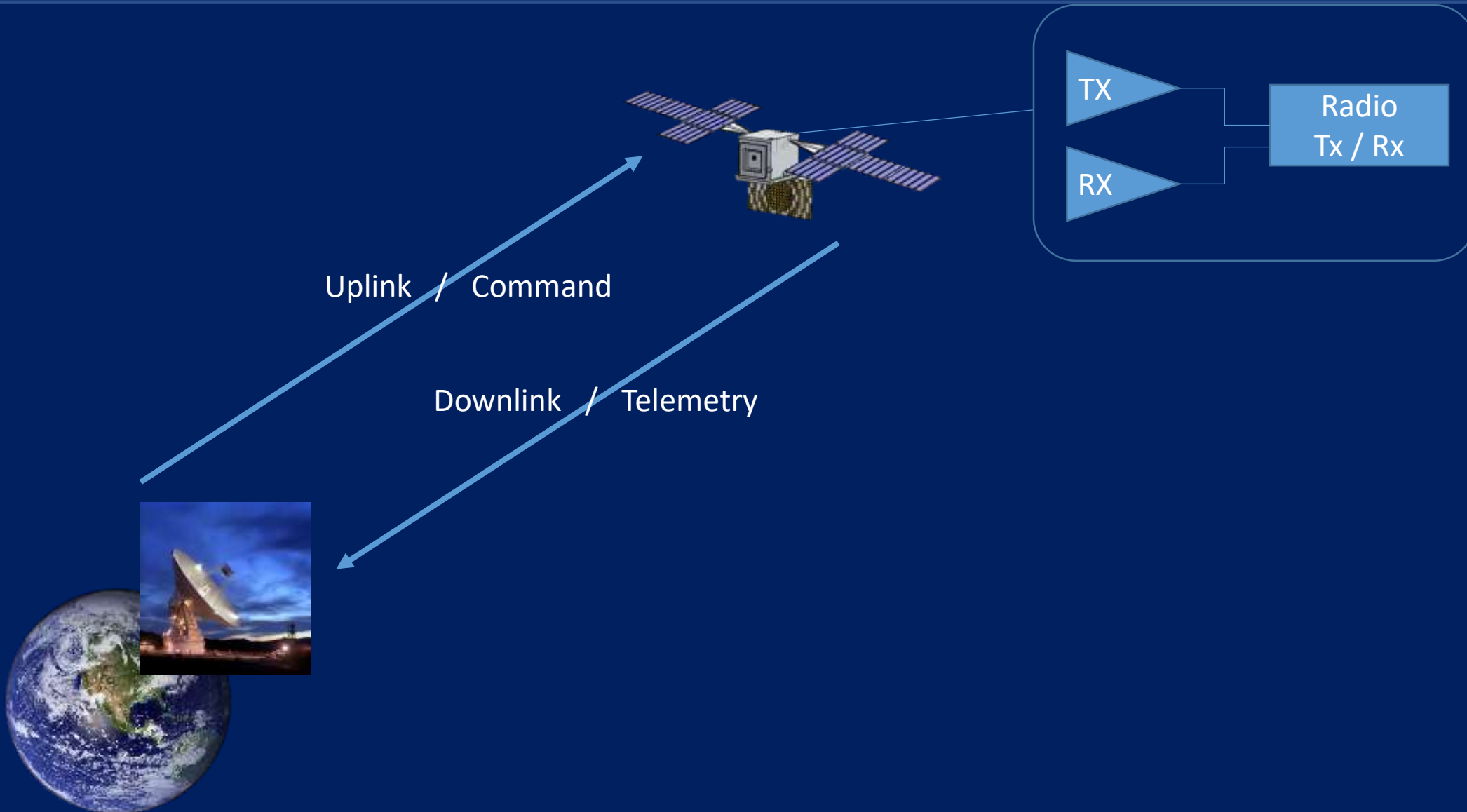
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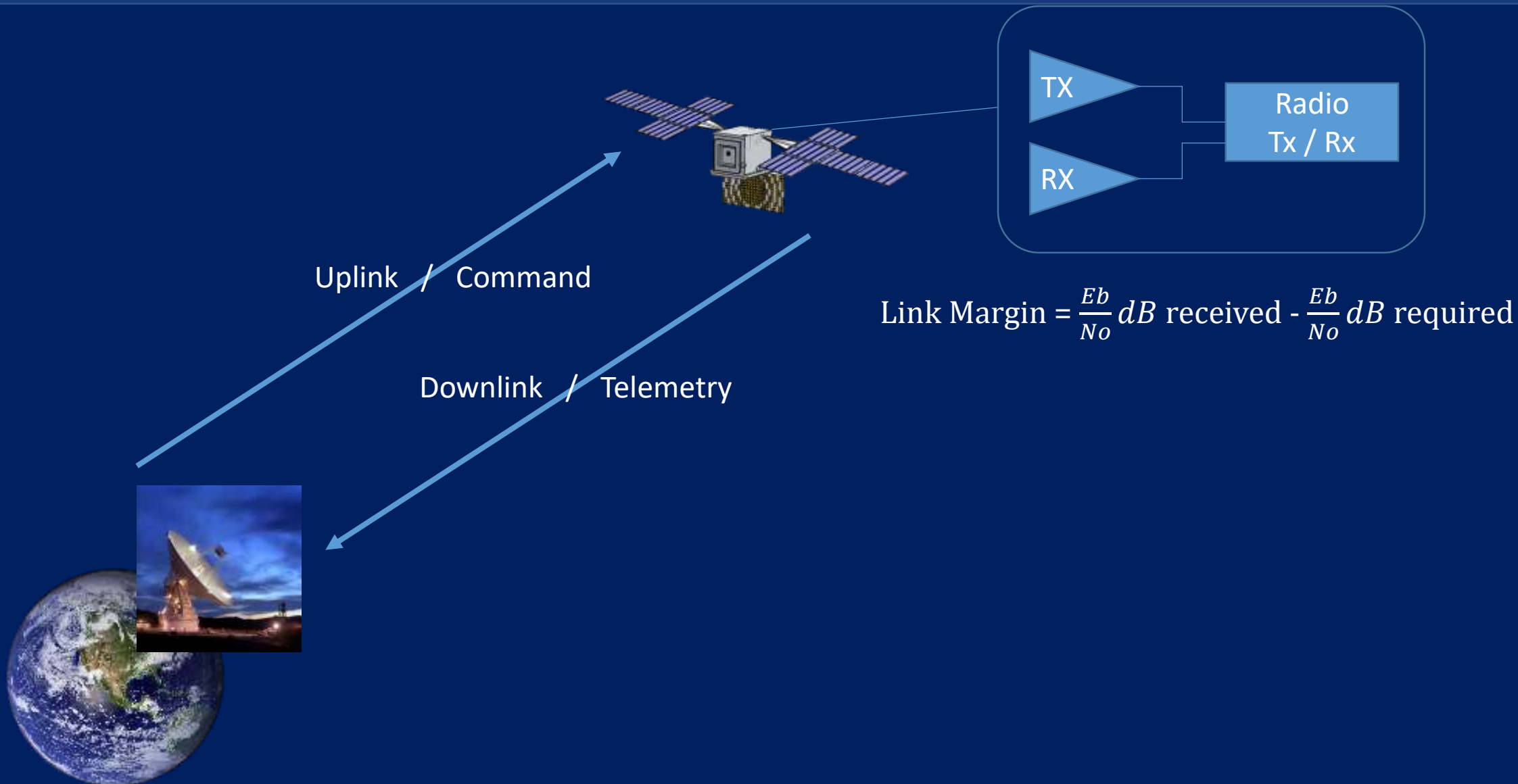
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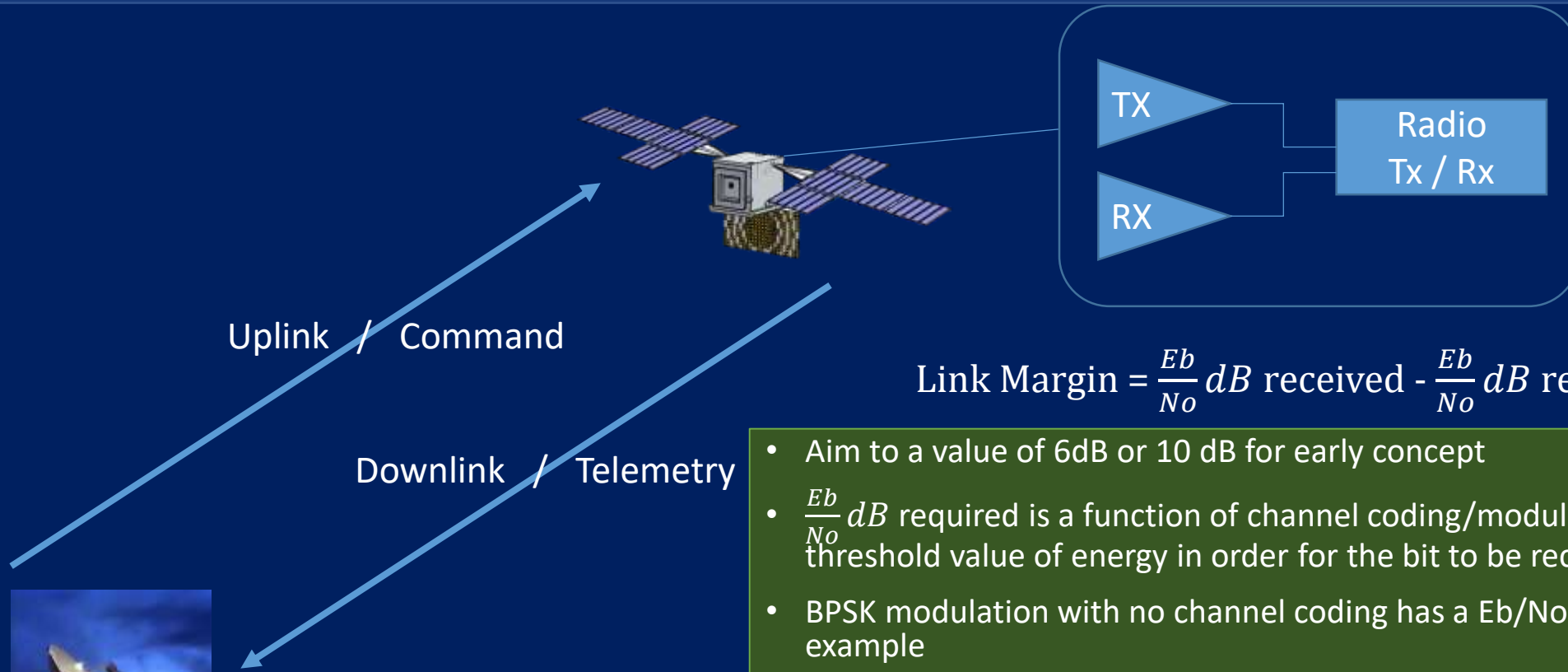
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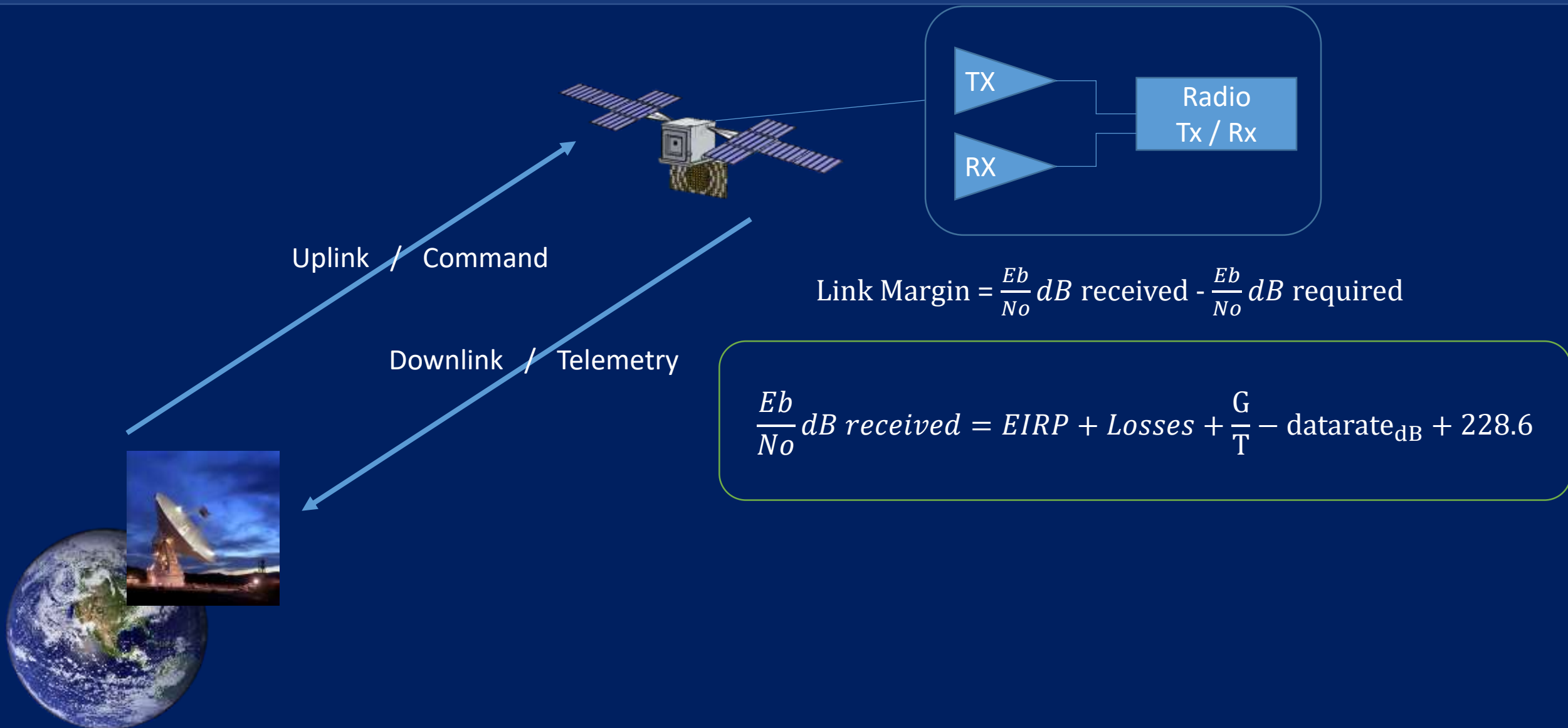


$$\text{Link Margin} = \frac{E_b}{N_o} \text{ dB received} - \frac{E_b}{N_o} \text{ dB required}$$

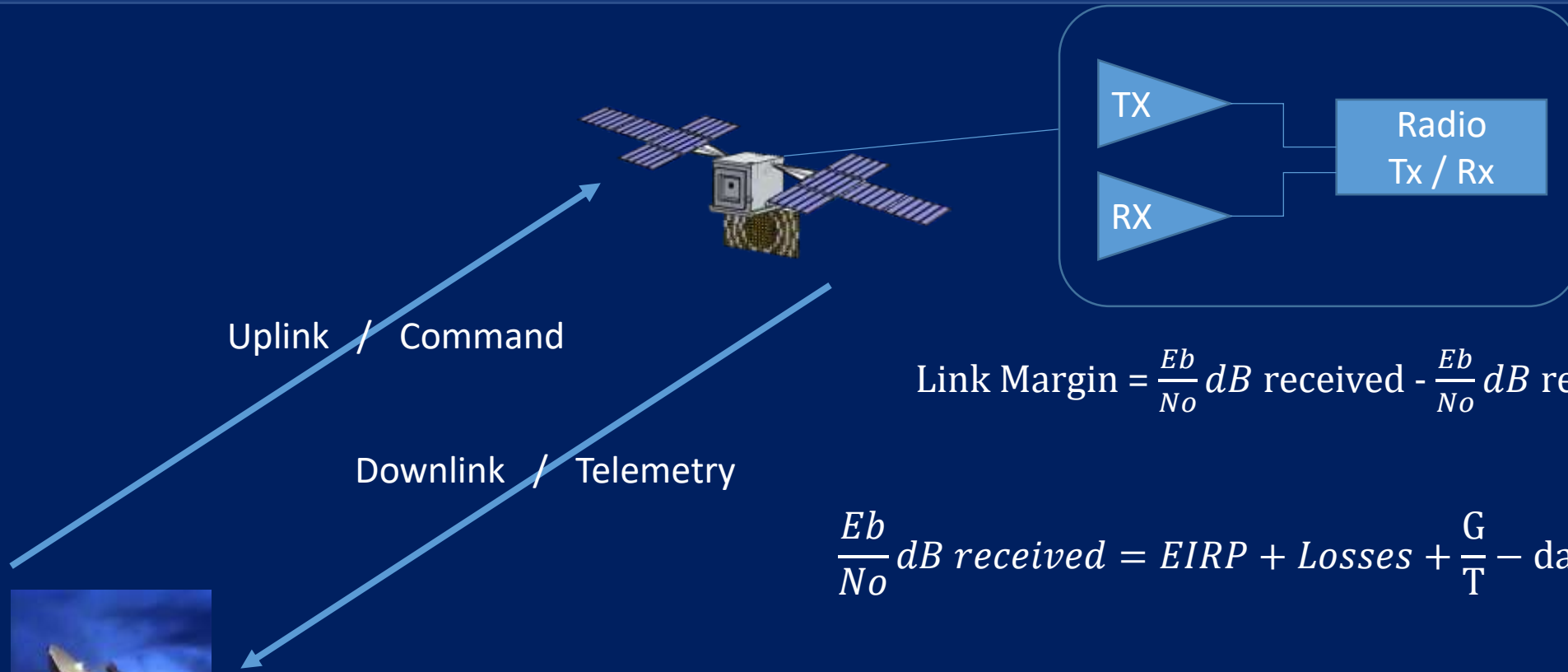
- Aim to a value of 6dB or 10 dB for early concept
- $\frac{E_b}{N_o}$ dB required is a function of channel coding/modulation. It is the threshold value of energy in order for the bit to be received.
- BPSK modulation with no channel coding has a E_b/N_o required ~ 9.6 dB for example



Spacecraft Telecomm Sub-System



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$$\text{Link Margin} = \frac{E_b}{N_o} \text{ dB received} - \frac{E_b}{N_o} \text{ dB required}$$

$$\frac{E_b}{N_o} \text{ dB received} = \text{EIRP} + \text{Losses} + \frac{G}{T} - \text{data rate}_{\text{dB}} + 228.6$$

$$\text{Space Loss dB} = 147.55 - 20\log(\text{Range, m}) - 20\log(\text{Freq, Hz})$$



How to do a Link Budget

$$\text{EIRP} = \text{W RF Out dB} + \text{Antenna Gain dB} - \text{Cable Loss dB}$$

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		Downlink
		DSN 34 meters
Parameter	Units	
Downlink Frequency	MHz	8450.00
Slant Range	km	400000.00
Spacraft Radio		StanfordOne
Transmit Station Parameters		
Antenna Gain	dBi	10.00
Transmitter power	W	5.00
Cable Loss	dB	-1.00
Transmit EIRP	dB	15.99
Propagation Parameters		
Free Space Loss	dB	-223.03
s/c pointing loss	dB	-3.00
Clear Sky Atmospheric Loss	dB	-1.00
Polarization Loss	dB	-1.00
Total Path Losses (dB)	dB	-228.03
Receive Station Parameters		
Rx Losses	dB	-1.00
Receiver G/T	dB/K	54.20
Carrier Parameters		
Required Eb/No for BPSK	dB	9.60
Modulation		BPSK
Data Rate	kbps	100.00
Implementation Loss	dB	1.00
Received Eb/No	dB	20.76
Margin	dB	10.16

Summary & Conclusion



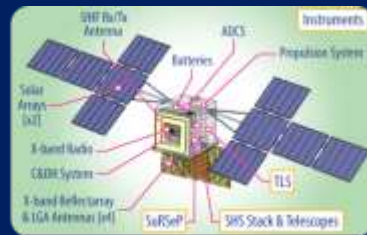
CML 1
"Cocktail Napkin"



CML 2
Feasibility
Does any
solution
exist?



CML 3
Expanded Trade
Space
What other
solutions
exist?



CML 4
Point Design
What is a good
approach, given our
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Summary & Conclusion



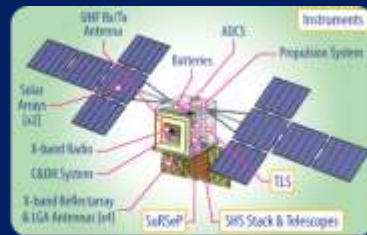
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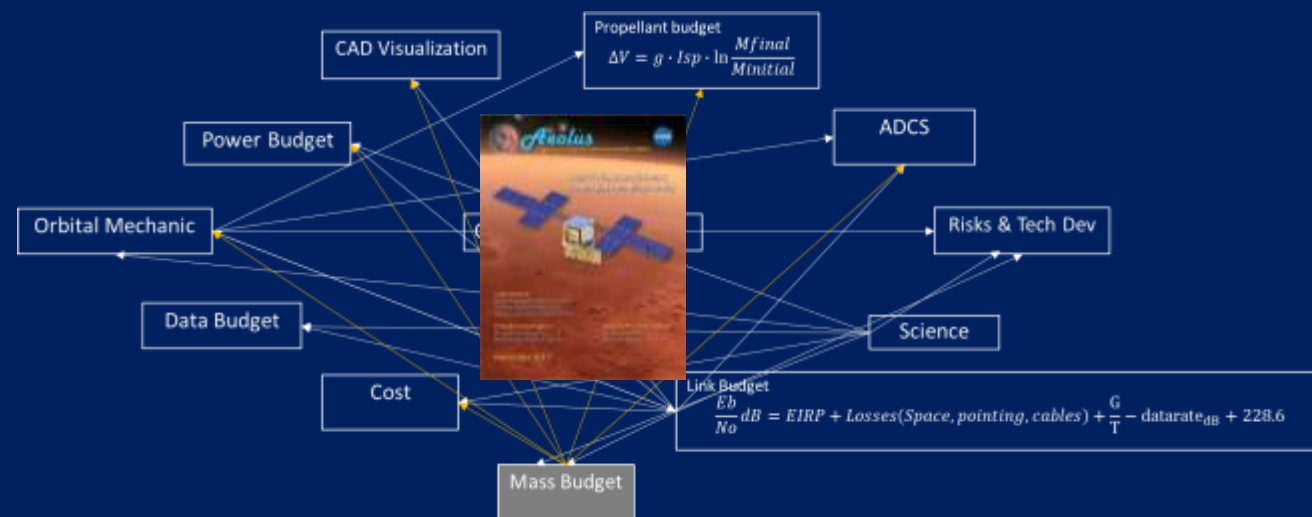
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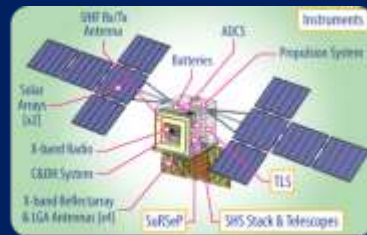
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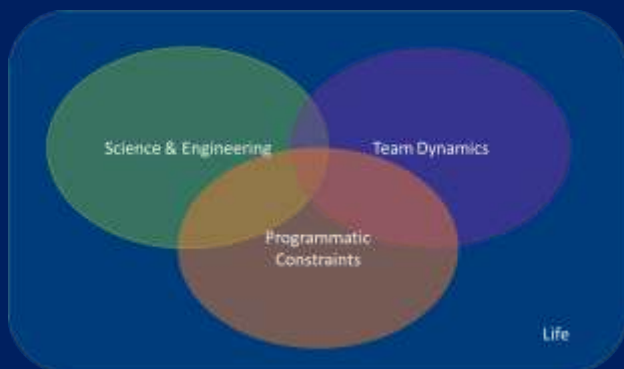
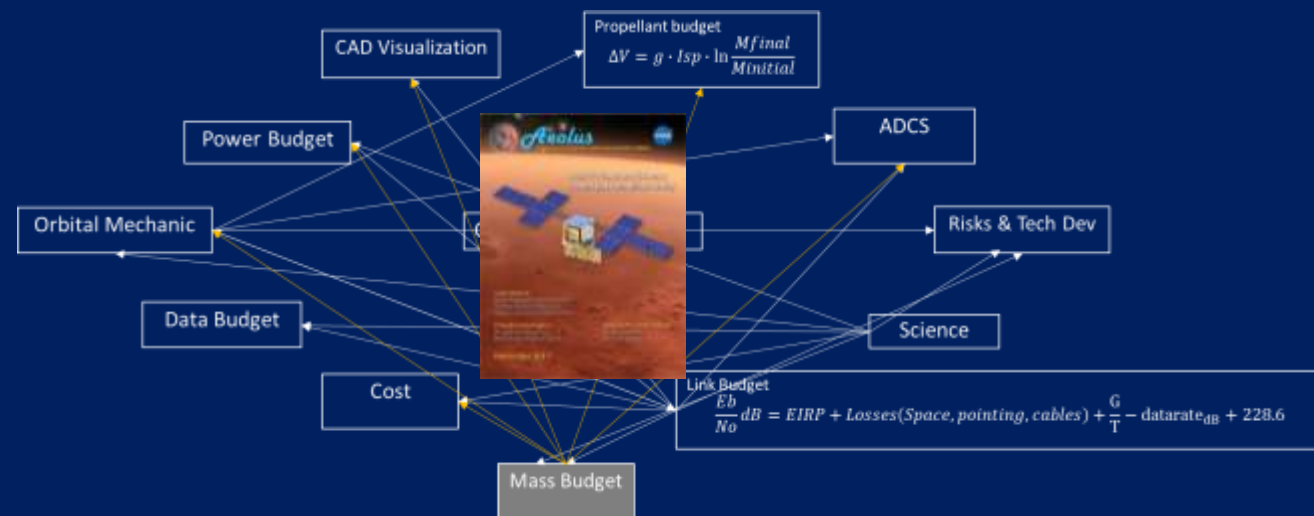
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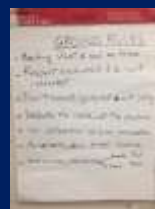
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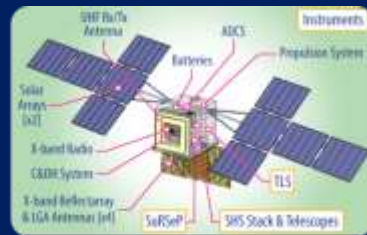
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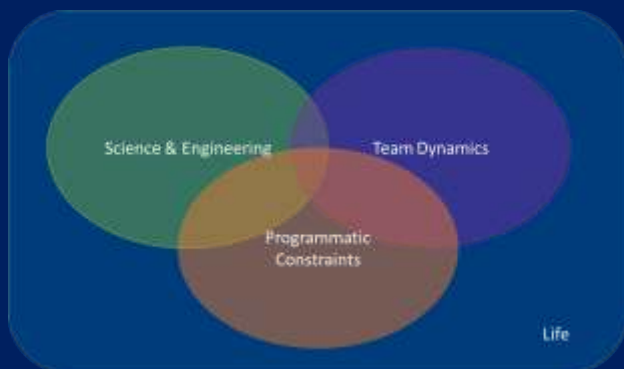
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