COSMIC

THE POWER OF COLLABORATION

PennState
College of Engineering

COSMIC Capstone Challenge: Final Briefing

NEBULOR Debris Removal Mission

Venus Visionaries, Penn State

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Mentor: Gregory Richardson, Aerospace Corporation

April 16, 2025

Image references provided in slides notes section.

Team

NEBULOR Debris Removal Mission

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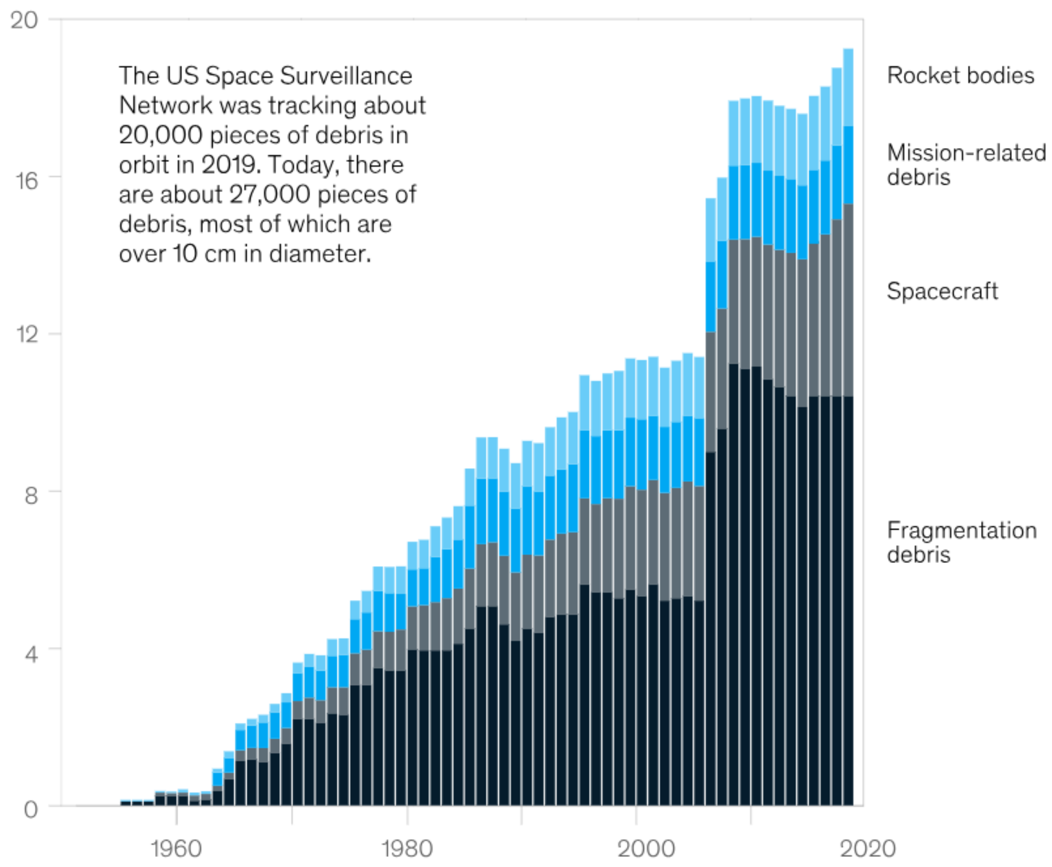
Executive Summary

NEBULOR Debris Removal Mission



NEEDS

- Debris will make LEO unusable [1]
- Kessler's Syndrome [2]

GOALS

- Demonstrate rendezvous and orbit change
- Autonomous from commands

Operations

1. Perform proximity operations in day or night
2. Deorbit Aerocube 6B (0.5U CubeSat)
3. Recover & Reset

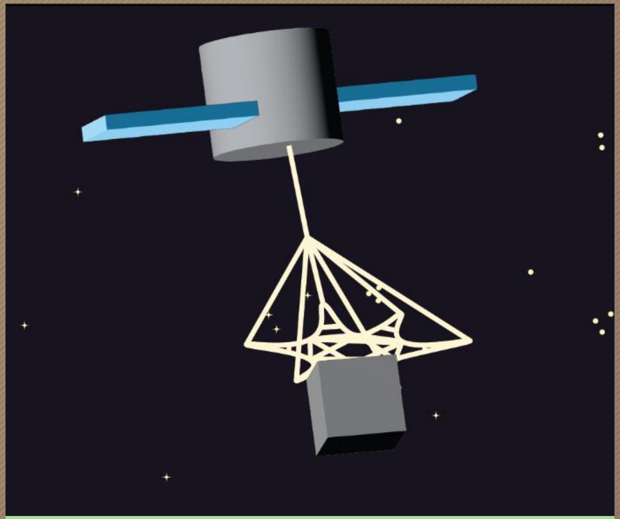
2.4 Systems Engineering Milestones

Engineering Timeline

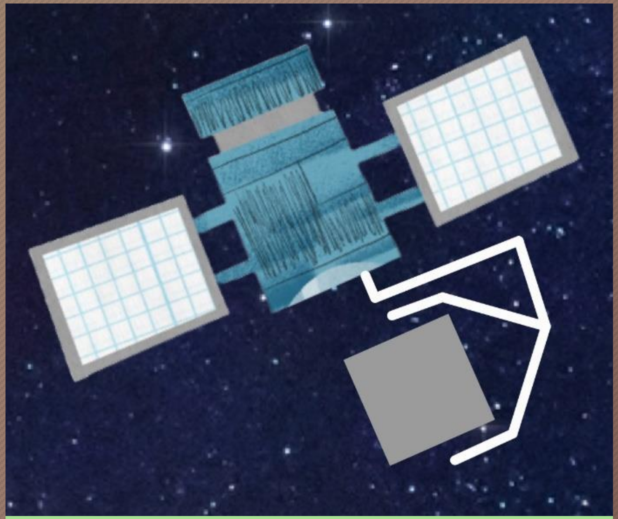
Milestone	Date or Timespan	
Program Manager Selected	September 12, 2024	
Debris Removal Capability Defined	September 29, 2024	Project Scoping
System Requirements Defined	October 16, 2024	
System Requirements Review	December 15, 2024	
System Trade Studies	November-December 2024	Trade Studies
Subsystem Trade Studies	January-February 2025	
Conceptual Design Finalized	March 7, 2025	
Concept Design Review	March 19, 2025	
Path to PDR Developed	March-April 2025	

Initial Concepts

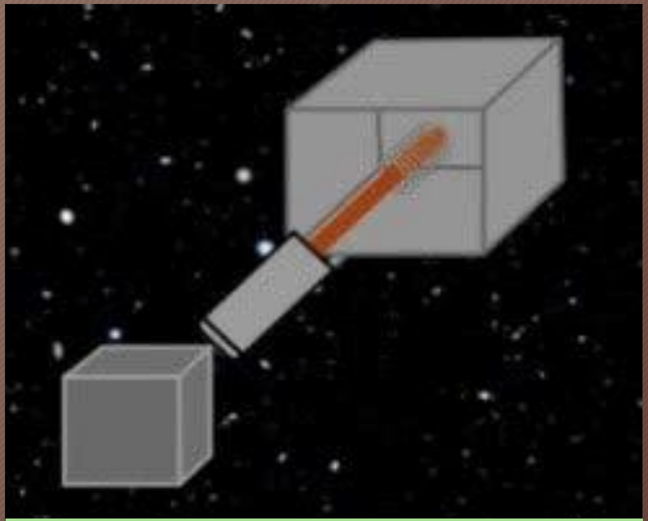
3.1 Innovative Concepts



Net Capture



Claw Capture



Junk Annihilation Vehicle

Concept Trade Study

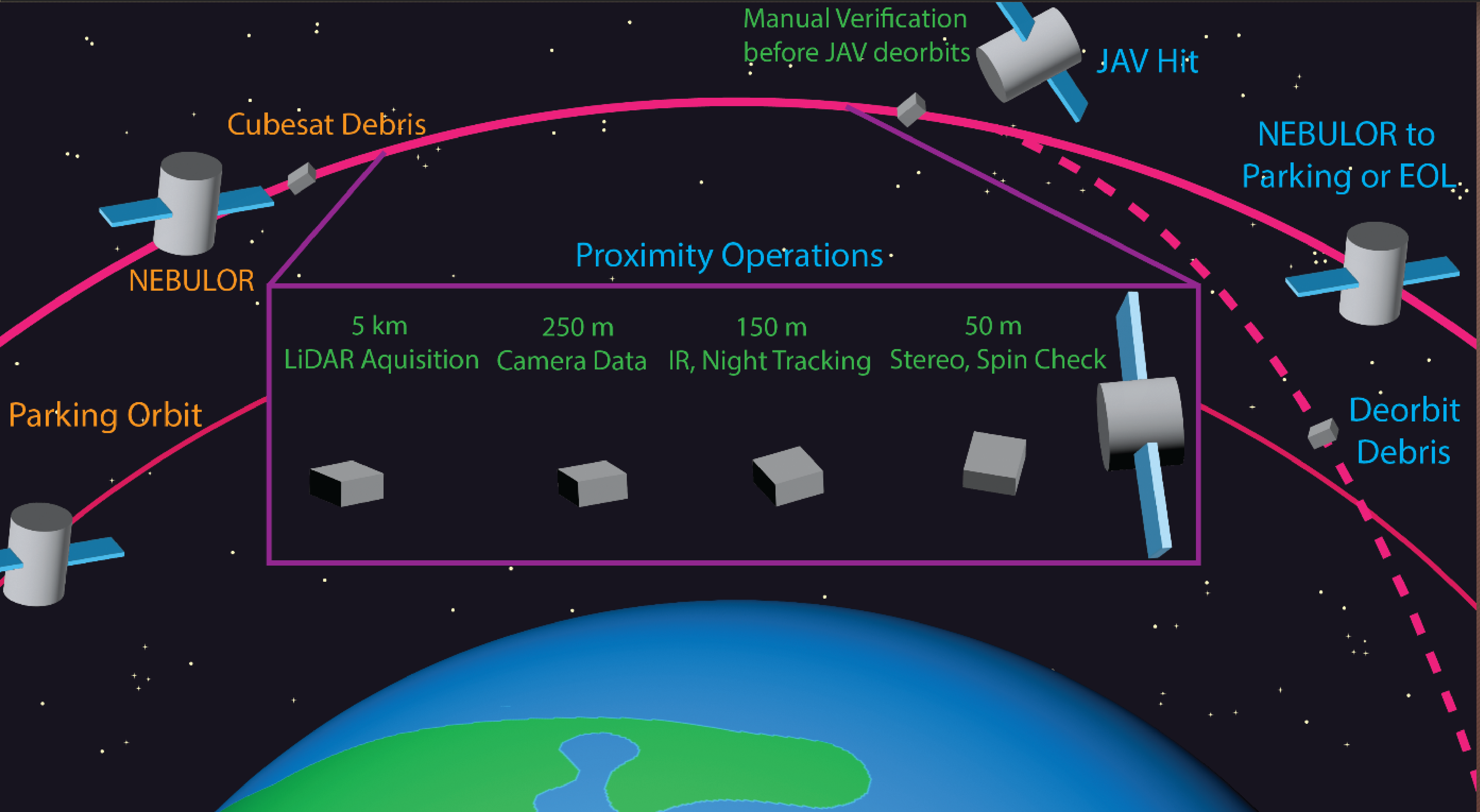
3.1 Innovative Concepts

Criteria	Weighting	Net	Claw	Jav
Payload Cost	10%	3	2	1
Reusability	25%	1	2	3
Complexity	15%	3	1	2
Reliability	10%	2	1	3
Adaptability	10%	3	1	2
Proximity Risk	15%	2	1	3
Breakage Risk	15%	2	3	1
	100%	2.1	1.65	2.25

Criteria	Scale Ratings		
	1	2	3
Payload Cost	High	Medium	Low
Reusability	Low	Intermediate	High
Complexity	Complex	Nominal	Simple
Reliability	>5	3 to 5	<3
Adaptability	Low	Intermediate	High
Proximity Risk	<2 meters	2-5 meters	>5 meters
Breakage Risk	Low Force, Safe	Inconsistent	High Force, Unsafe

Full Mission Architecture

2.2 Storyboard of Complete Operations



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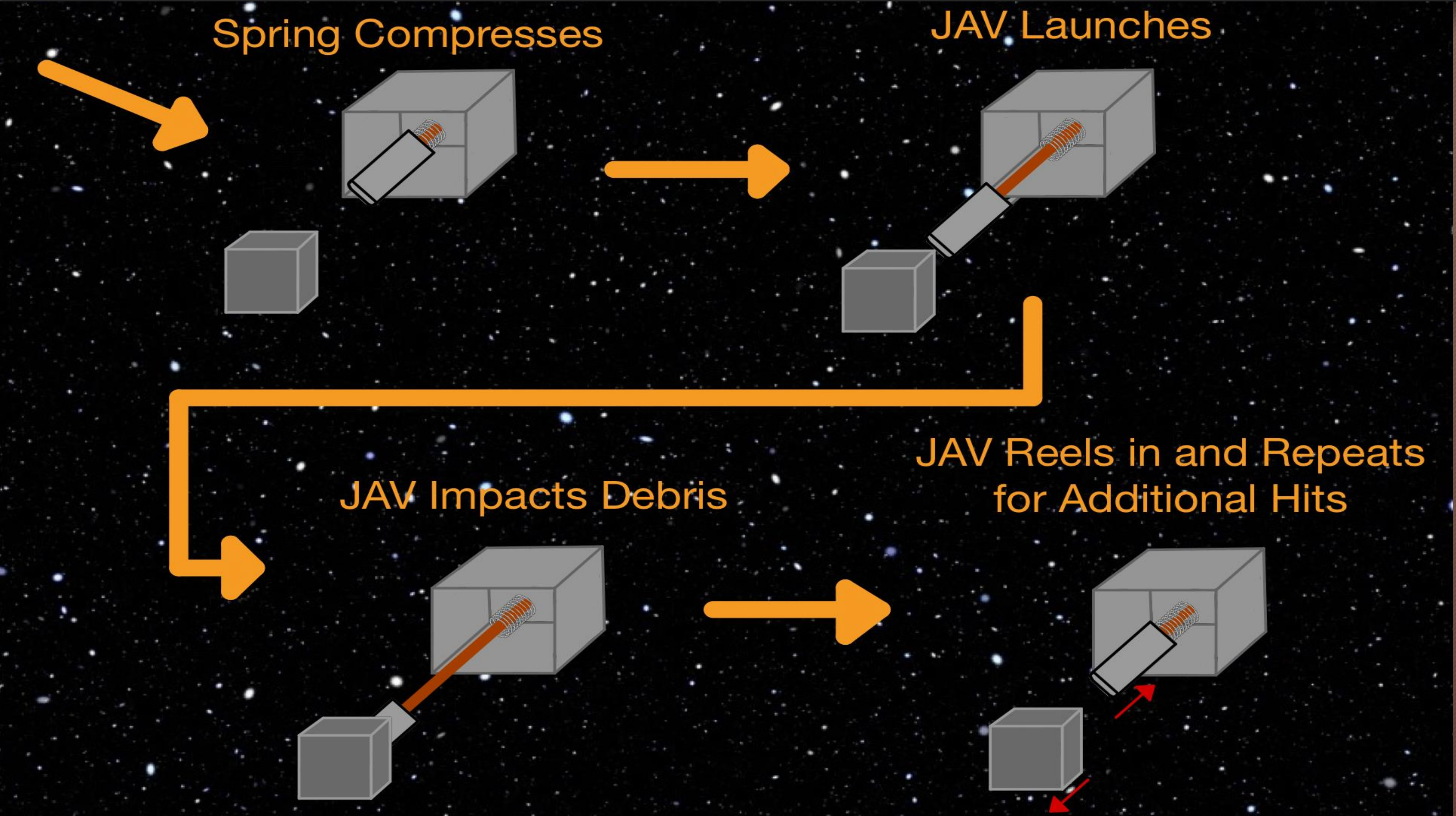
NEBULOR

JAV Payload Mission Architecture

2.2 Storyboard of Complete Operations



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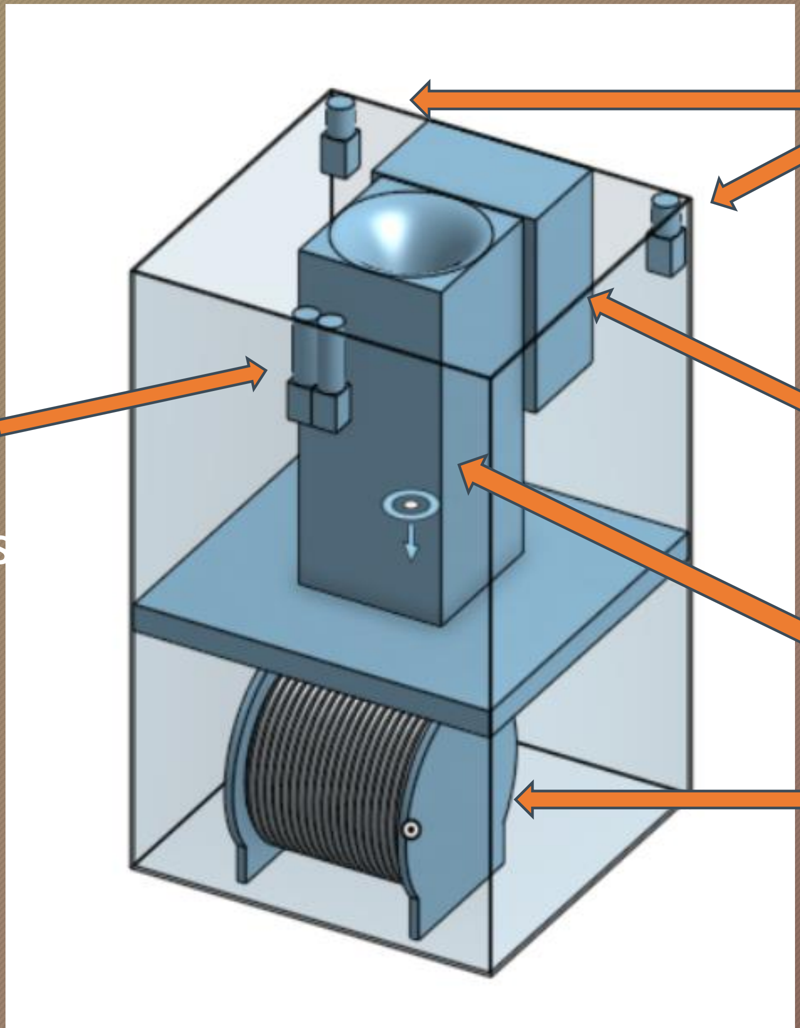
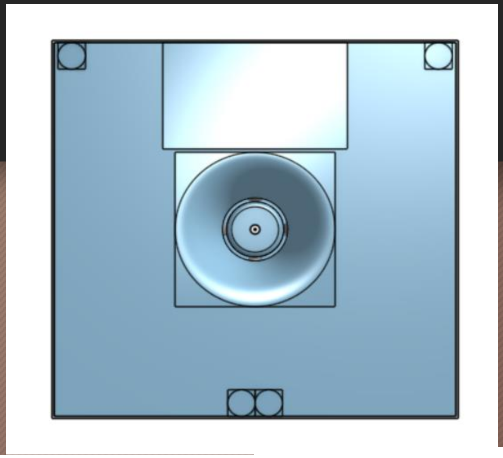
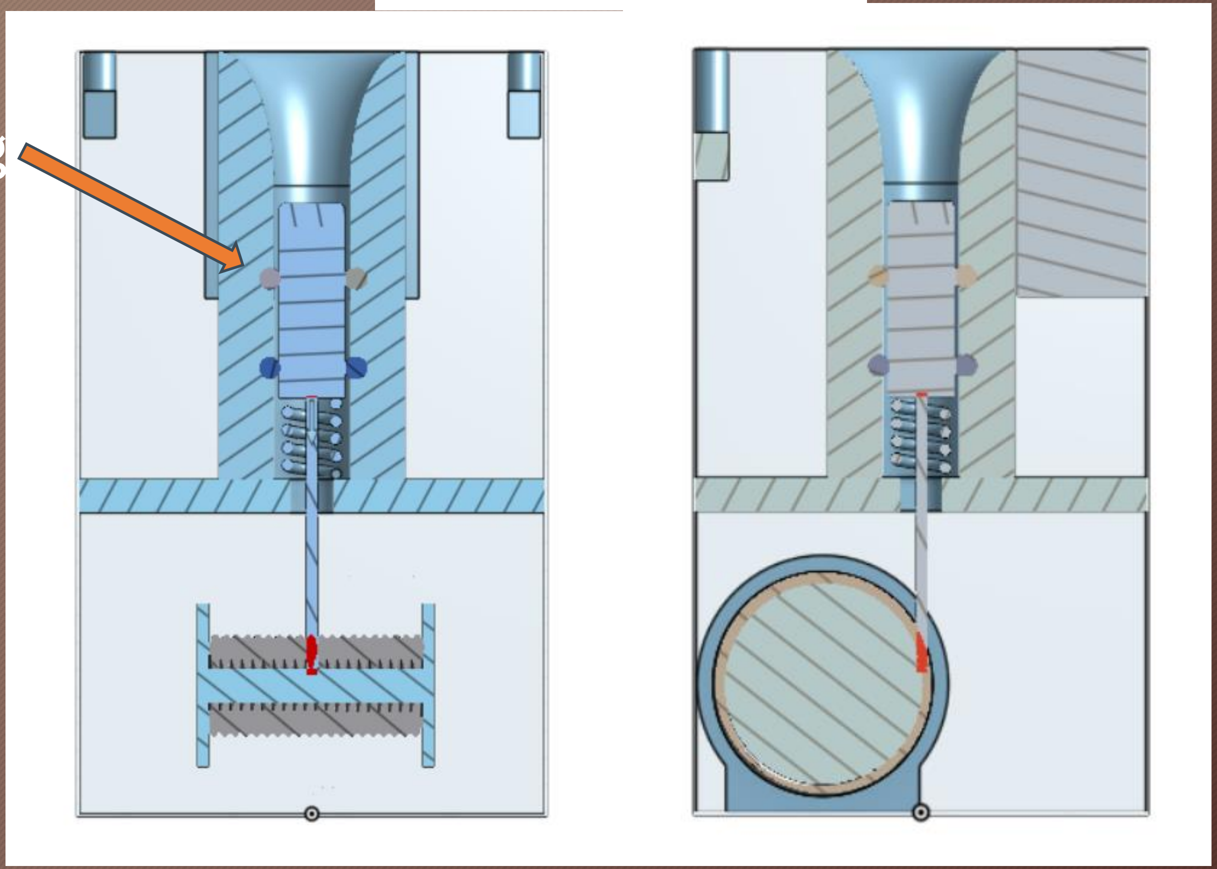
NEBULOR

CAD Model

Payload Design

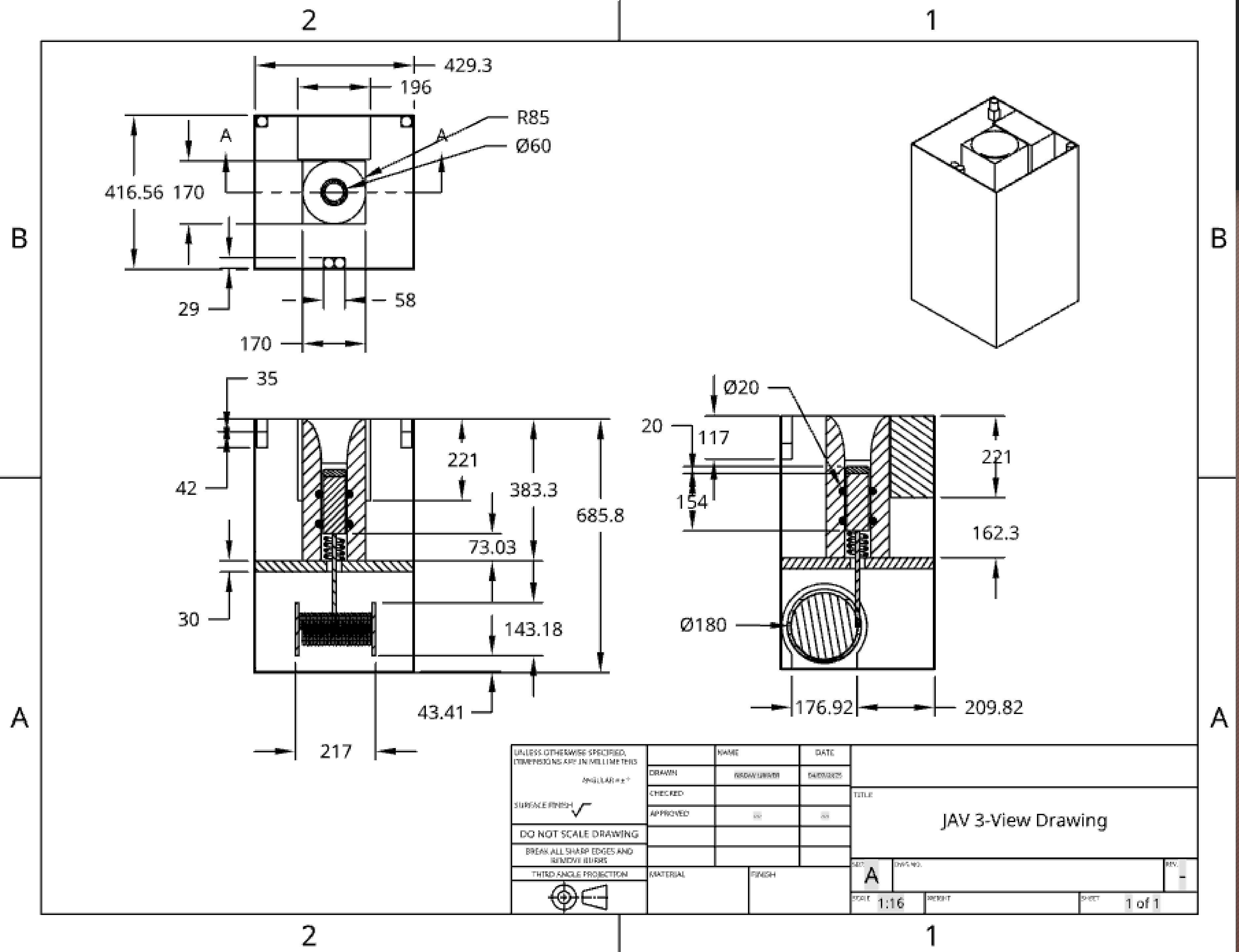






3-View Drawing

Payload Design



Payload arranged in:

17”x16.4”x27”

(Volume for Dual)

NEBULOR

Proximity Operations Design

Sensor Trade Studies

Designs Considered

- Stereoscopic Imaging & LiDAR
- Thermal Imaging & Radar
- Optical & Hyperspectral Imaging

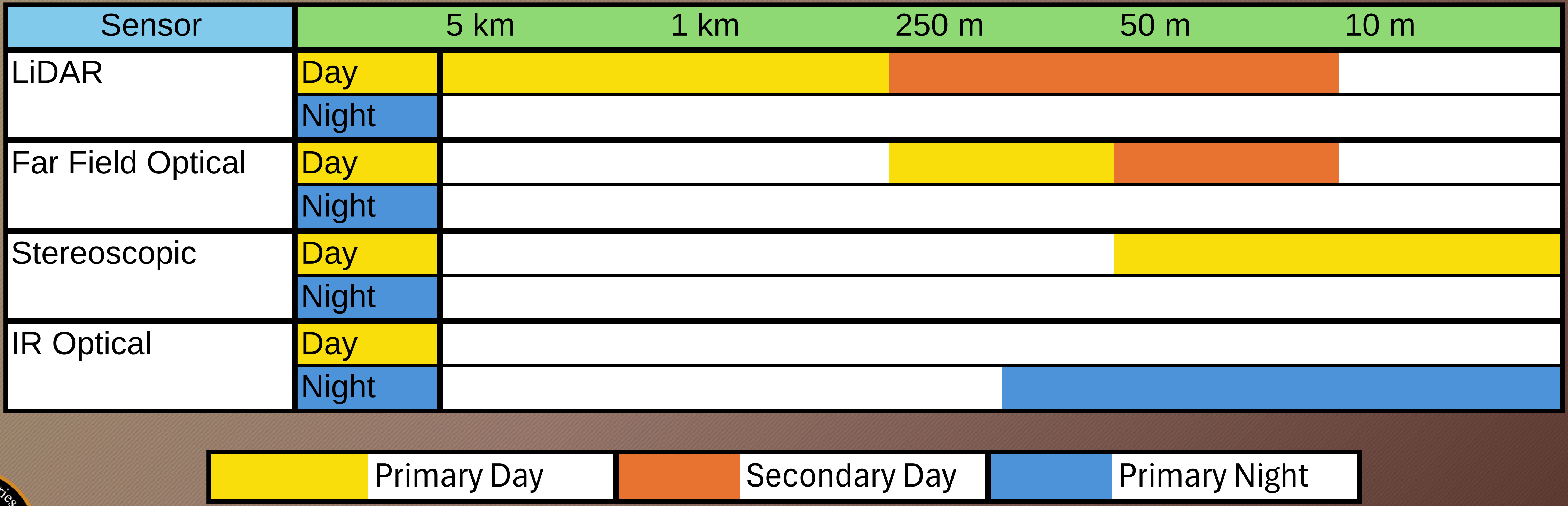
Criteria	Weight	Goal	Stereo-Lidar	Radar-Thermal	Hyperspectral-Optical
Cuboid Volume (cm^3)	25%	MIN	2000	2000	1500
Normalized			0	0	1
Mass (kg)	25%	MIN	6.5	15	15
Normalized			1	0	0
Peak Power (W)	25%	MIN	17	35	30
Normalized			1	0	0.277777778
Range (km)	25%	MAX	50	5	50
Normalized			1	0	1
		Score	0.75	0	0.569444444

Additional Sensors for extreme cases

- Long range optical camera
- Infrared optical camera for night

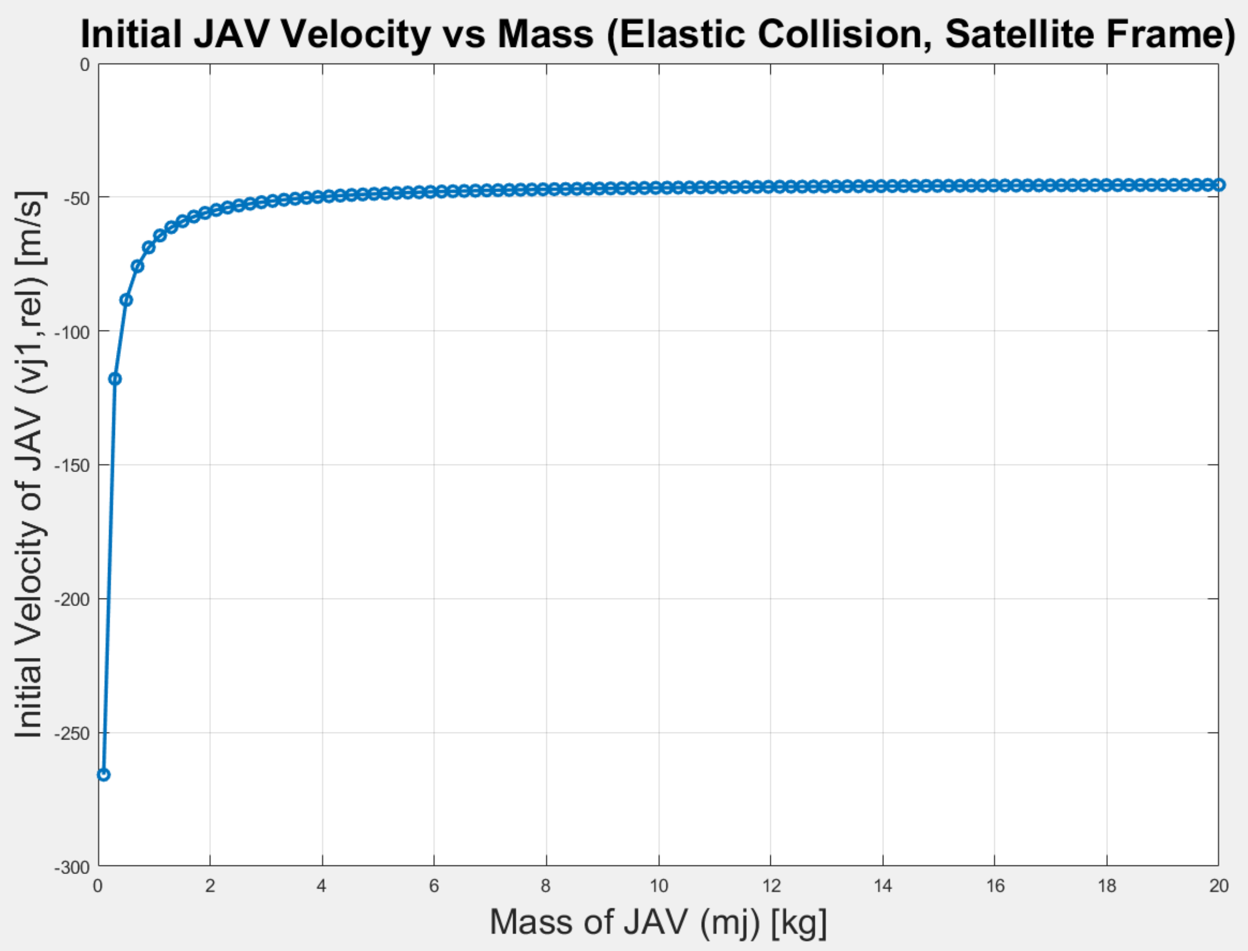
Sensor Ranges

Operational Usage



JAV Design

Sizing of the JAV for Aerocube 6B



- Orbital analysis of Aerocube 6B for necessary ΔV
- 300 km altitude for deorbit
- JAV mass determined by launch velocity
- Multiple launches with spring to achieve total debris ΔV
- Launch velocity of 29.7 m/s

JAV Design

Material Trade Studies

- Trade studies for JAV materials
- Puncturing power analysis for cross-sectional area
- Braided Kevlar tether with winch system for reeling JAV back in
- Ceramic ball bearing for alignment

Criteria	Weight	Goal	Ti-6Al-4V	W-Ni-Fe	AISI 316 Stainless Steel
CTE (µm/m-K)	20%	MIN	8.6	6	16.2
Normalized			0.745098039	1	0
Density (g/cm^3)	20%	MIN	4.43	17	8.03
Normalized			1	0	0.713603819
Hardness (HRC)	15%	MAX	36	32	35
Normalized			1	0	0.75
Yield Strength (ksi)	15%	MAX	128	75	30
Normalized			1	0.459183673	0
UTS (ksi)	15%	MAX	138	110	75
Normalized			1	0.555555556	0
Youngs Modulus (ksi)	15%	MAX	16534	29000	27992
Normalized			0	1	0.919140061
		Score	0.799019608	0.502210884	0.393091773

High Density Backing

JAV Design

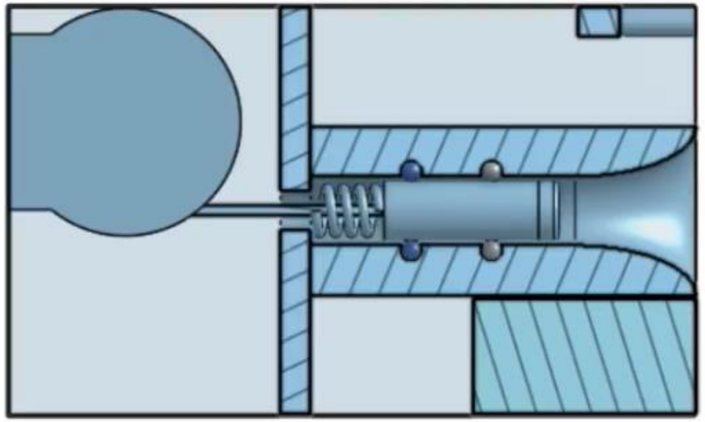
Material Trade Studies

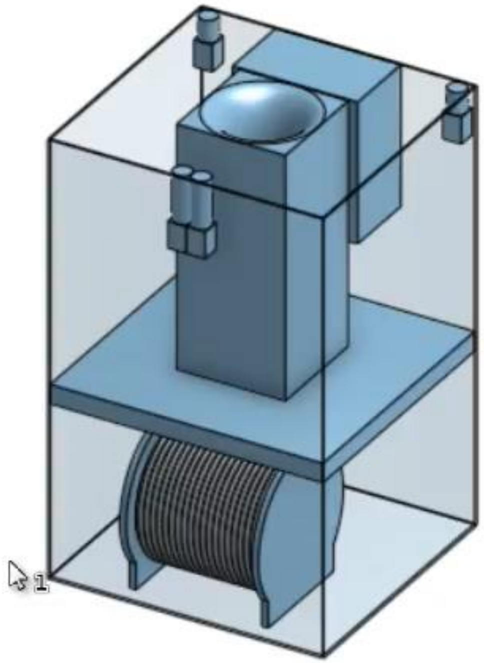
Criteria	Weight	Goal	Polyurethane Rubber	Silicone Rubber	EPDM Rubber
CTE (μm/m-K)	15%	MIN	200	250	275
Normalized			1	0.333333333	0
Coefficient of Restitution	20%	MAX	0.65	0.55	0.8
Normalized			0.4	0	1
Tear Strength (kN/m)	15%	MAX	40	10	30
Normalized			1	0	0.666666667
Ductility	15%	MAX	4.5	5	3
Normalized			0.75	1	0
Glass Transition Temperature (°C)	20%	MIN	-50	-110	-50
Normalized			0	1	0
UV Degradation (%)	15%	MIN	4	1	1
Normalized			0	1	1
		Score	0.4925	0.55	0.45

Impact Surface

2.1 Animation of Key Operating Sequence

Launching the JAV





Mass Budget

1.4 Required Elements

System	Mass	Units	System	Mass	Units
Communications	20	kg	Structure	5	kg
Propulsion	45	kg	JAV	8	kg
GNC	5.3	kg	Prox Ops Suite	7.5	kg
C&DH	1	kg	Margin	20%	%
Structure	10	kg	Payload Margin	4.1	kg
Thermal	1.5	kg	Payload Total	24.6	kg
Power	20	kg	Spacecraft Total	147.96	kg
Margin	20%	%			
Bus Margin	20.56	kg			
Bus Total	123.36	kg			

Payload Mass:

24.6 kg out of 70 kg

Power Budget

1.4 Required Elements

System	Day Min	Day Peak	Night Min	Night Peak	Units
Communications	0	26	0	26	W
Propulsion	0	5	0	5	W
GNC	7.4	37.6	7.4	7.4	W
C&DH	10	10	10	10	W
Structure	1	1	1	1	W
Thermal	25	75	25	75	W
Power	1	1	1	1	W
Bus Total	44.4	155.6	44.4	125.4	W
JAV	0	30	0	10	W
Prox Ops Suite	0	50	0	3	W
Payload Total	0	80	0	13	W
Margin	20%	20%	20%	20%	%
Margin	8.88	47.12	8.88	27.68	W
Spacecraft Total	53.28	282.72	53.28	166.08	W

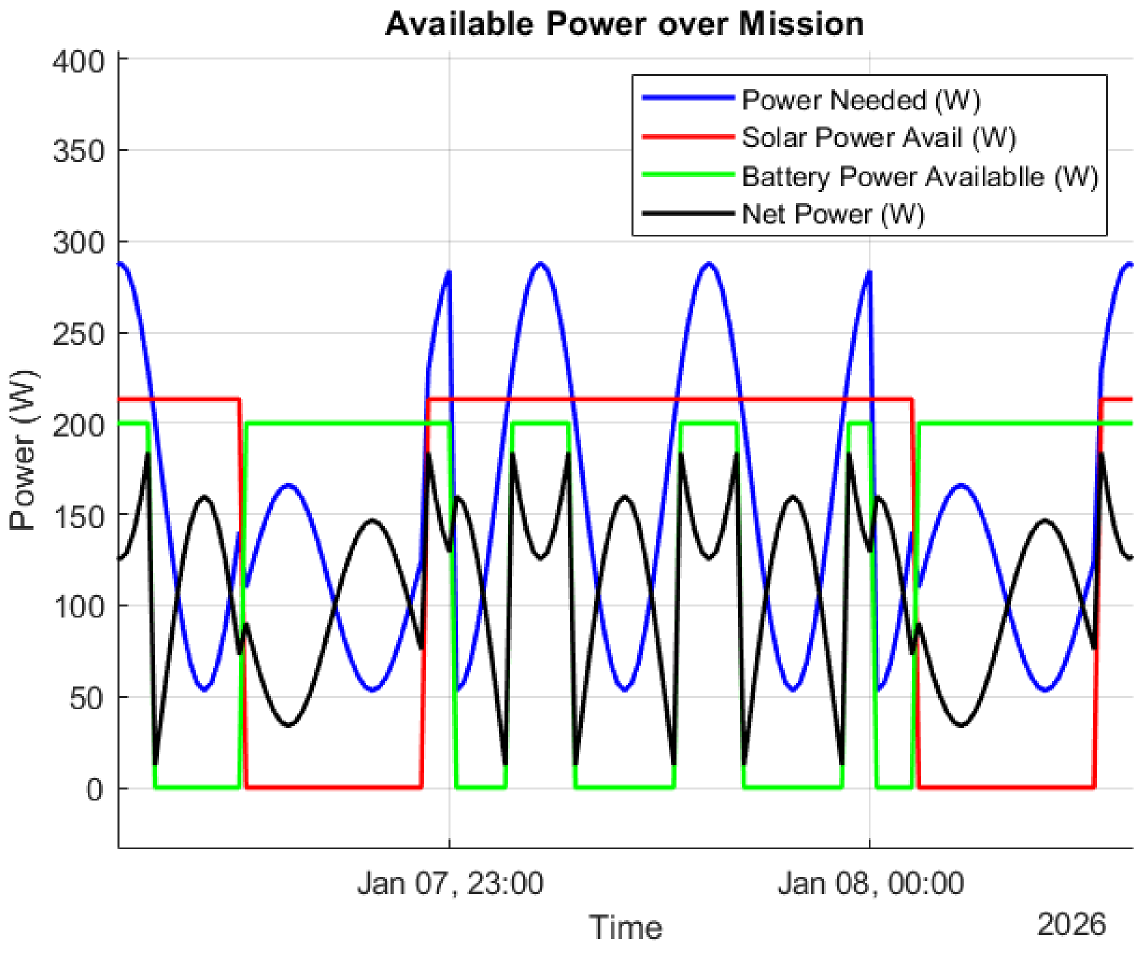
Peak Power:

282.7 W in day

444 W (Dual Array)

Power Profile

Power Analysis Through Multiple Eclipses



Assuming:

- 200 W battery i/o
- Adaptive battery use
- Sinusoidal need variance

Require 213 W in day for sustained operation

Ground System

2.3 Data Handling and Comms

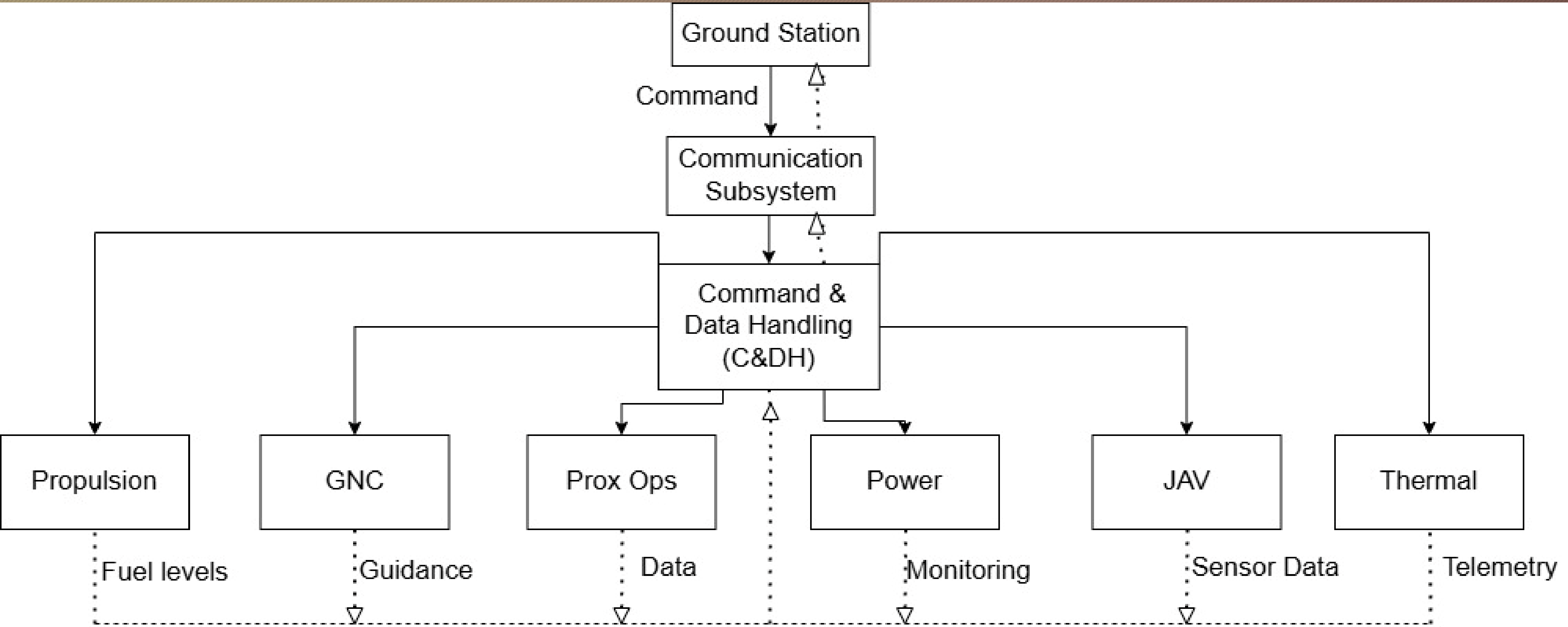
Swedish SSC Ground System

- 15m Antenna: High-gain
- Cost-Effective: Lower operational costs vs. larger networks
- Operates semi-autonomously (in case user deems necessary to abort)

Ground stations of the Swedish Power Stations

Data Flow Chart

2.3 Data Handling and Comms



Comms System Requirements

2.3 Data Handling and Comms

- Data Rates:
    - Uplink (Commands): 1 kbps .
    - Downlink (Telemetry/Sensor Data): 100 kbps.

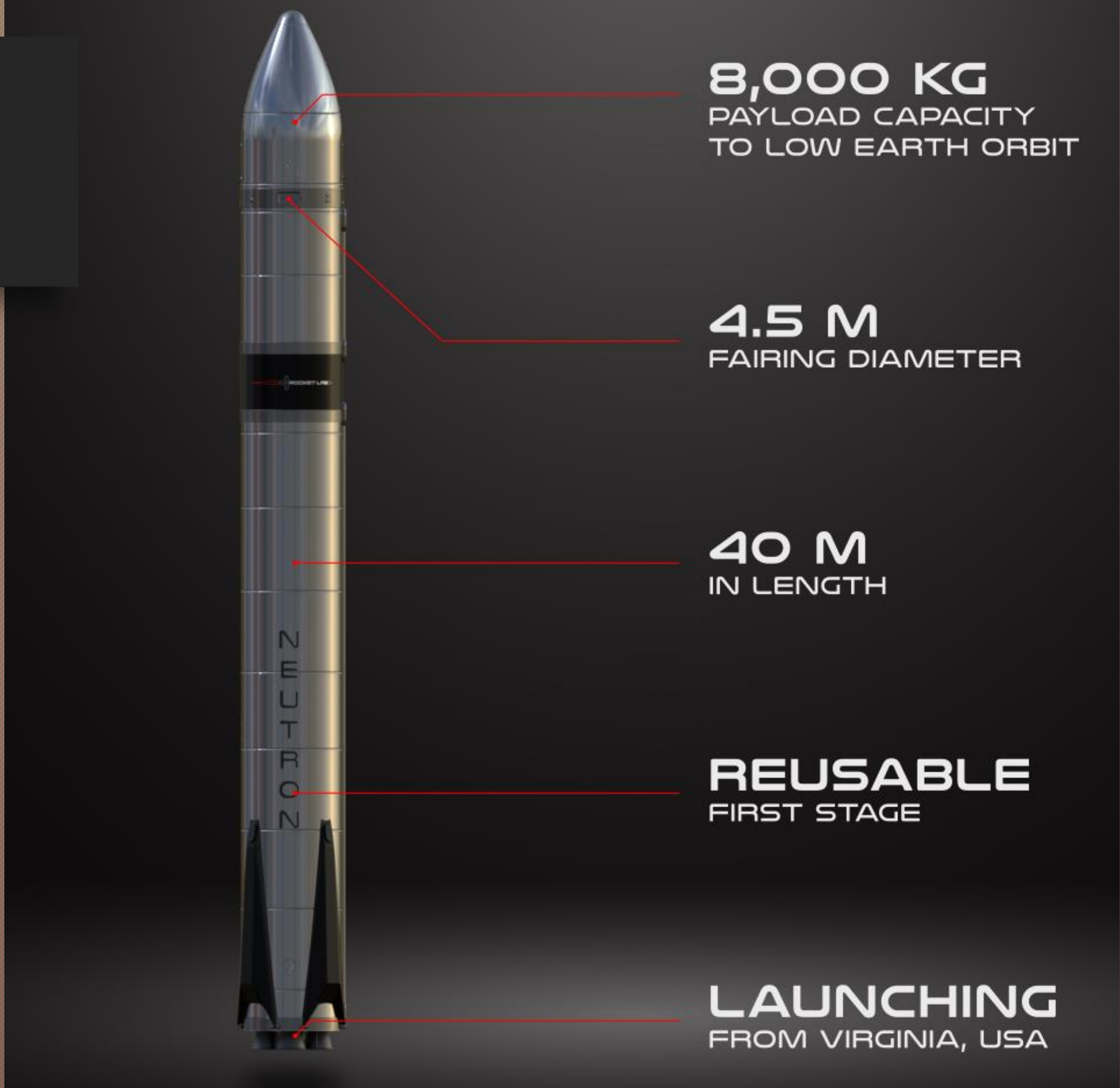
Parameter	Uplink	Downlink
Frequency	2.2 GHz (S-band)	8.4 GHz (X-band)
Transmitter Power	250 W each (500 W total)	5 W (6.99 dBW)
Antenna Gain	24.18 dB	28.66 dB
Space Loss	-160.87 dB	-172.51 dB
Margin	1.91 dB	3.85 dB

Launch Vehicle: Rocket Lab Neutron

- Reusable medium-lift rocket with carbon composite structure
- Balances performance, cost-efficiency, and sustainability

- ESPA ring integration
- Operational Flexibility:
  - Dedicated launch scheduling
  - Customizable launch profiles for NEBULOR mission needs
  - Retrograde orbit insertion capability

- First flight scheduled for 2025, but Electron demonstrated launch reliability



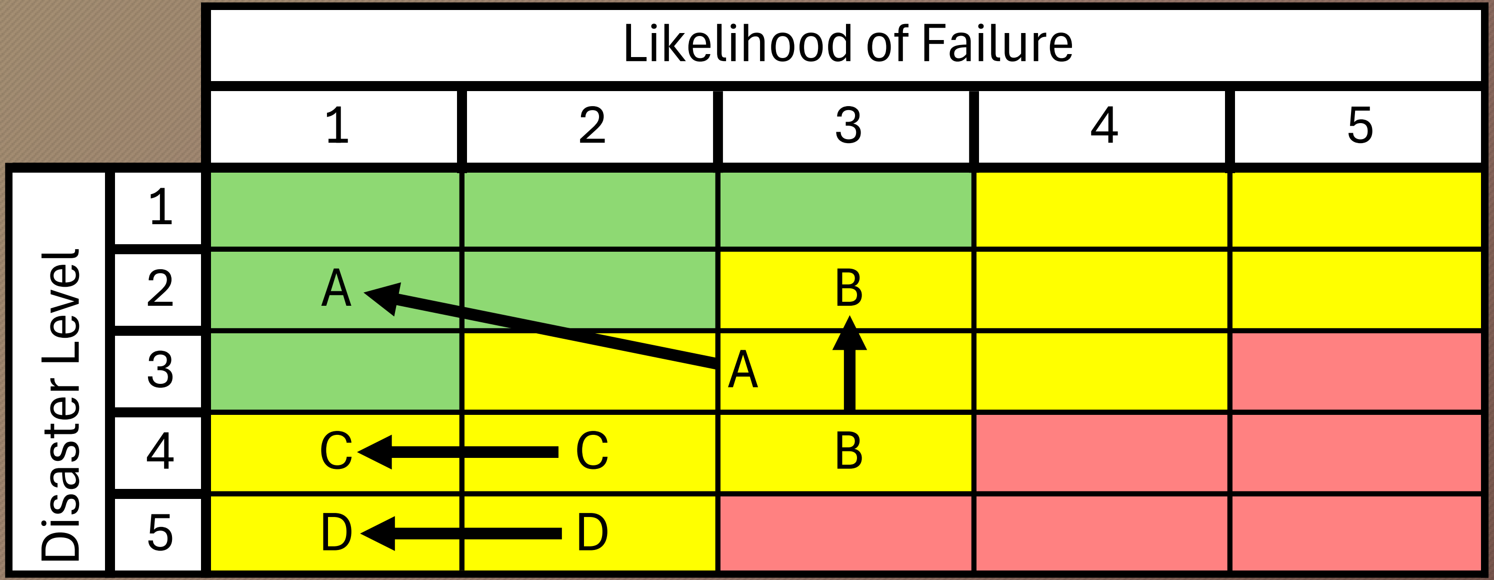
1.5 Risks

Overview and Mitigation

Risk	Mitigation
A. JAV Hit Misaligned	Pointing error budget and correction
B. LiDAR Failure	Inclusion of long-range camera
C. JAV Tether Breaking	Calibrate launch velocity low enough
D. Proximity Collision	Operate sensors below max range

Risk Matrix

1.5 Risks



A. JAV Hit Misaligned
B. LiDAR Failure
C. JAV Tether Breaking
D. Proximity Collision

3.3 Biggest Challenges Encountered

Impacts on Mission

1. Proximity Sensor Ranges
    - Cameras cannot see Aerocube 6B from far
    - Redesign
    - Reliance on LiDAR for range
2. JAV Launch Mechanism
    - Calibrate velocity
    - Unverified alignment
    - Dealing with tether
3. Comms in Polar Orbit
    - Need consistent link
    - One station does not suffice
    - Need global coverage

3.2 Technology Gap Assessment

Limitations on Current Design

Camera Observation

- Impossible to see CubeSats at extreme range
- Rely on LiDAR and ground observation
- Limits autonomy

JAV Alignment

- Launch at perfect speed
- High precision alignment
- Low friction

Thruster Efficiency

- Propellant is main item consumed
- Main limit for number of missions

4.1 Paper

For Journals

Item	Quantity
Abstract	186 words
Length	16 pages (+2 pages references)
References	44

Written to accommodate: AIAA SciTech 2026 Orlando, FL

Recommended Next Steps

1.6 Path to PDR

1. Finalize Component Selection
2. Create simulation programs
3. Develop Prototypes
4. Reverify requirements
5. Bus Integration

Payload Design

1.6 Path to PDR

Proximity Operations

- 3 Basler Ace U
- 1 Basler Ace Classic NIR
- 2 Kowa Lenses 75 mm 1”
- 2 Kowa Lens 35 mm 1”
- 1 ASC GSFL-16KS

JAV

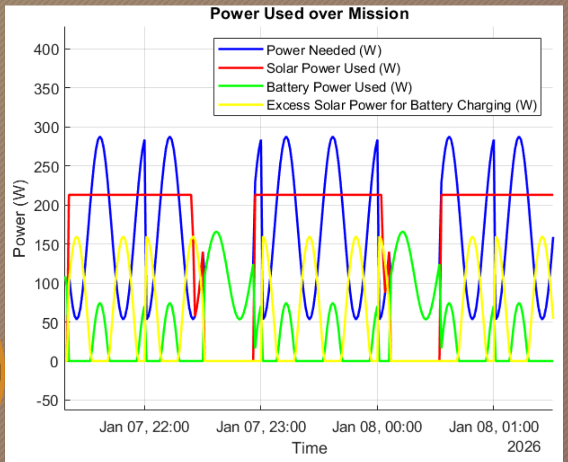
- Ti-6Al-4V
- Silicone Rubber
- Braided Kevlar Tether
- Winch
- Silicon Nitride Ceramic Precision Balls
- LHL 2000D 01 Spring

Subsystem Design

1.6 Path to PDR

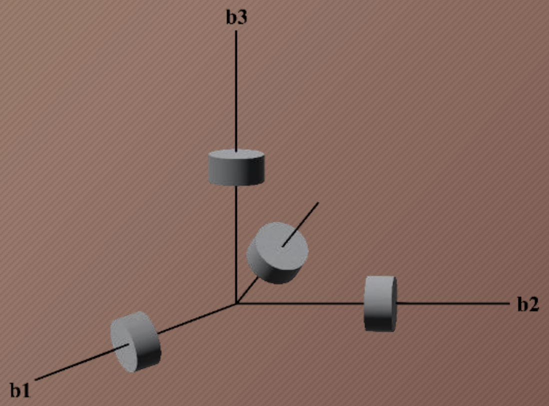
Power

- 444 W Dual Array
- 10.2 Ah Battery
- 28 V DC



GNC

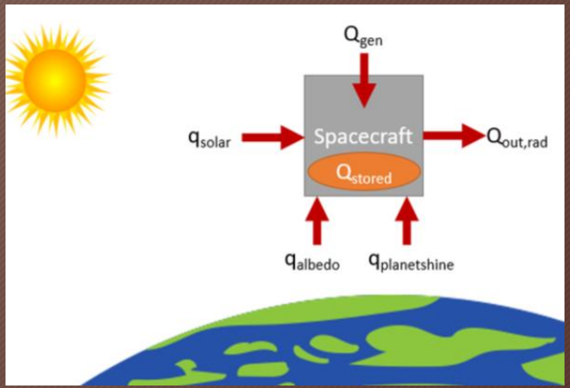
- 2 Standard NST
- 4 RWP 500 Reaction Wheels
- 3 NCTR-M016 Torque Rods
- 1 CODE Computer



Flexcore achieves 0.002° accuracy [18]

Thermal

- MLI Blanket
- 2 Electrical Heaters
- 6 Thermoelectric Coolers
- 2 Radiators
- Variable Conductance Heat Pipe

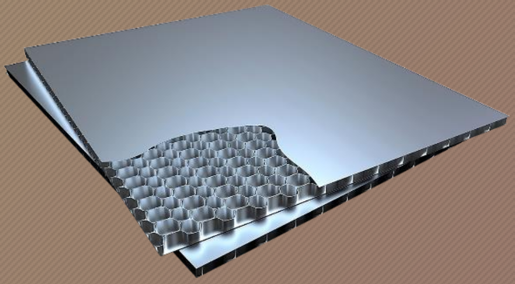


Subsystem Design

1.6 Path to PDR

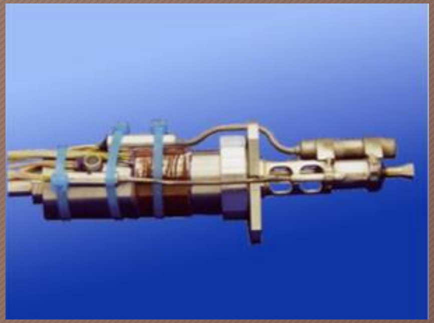
Structure

- Aluminum Alloy 6061 Panels
- 3000 Series Aluminum Honeycomb Cores
- Strain Gauges
- Accelerometers



Propulsion

- 4 Aerojet Rocketdyne MR-103 G Thrusters
- Northrop Grumman 80304-1 PMD
- 40 kg Hydrazine (N_2H_4)



C&DH

- ISIS iOBC
- MRAM + Flash
- I2C + UART + SPI

Design Impact

Use and Uniqueness of NEBULOR and JAV

Technical Impact

- Future satellites may not need on-board deorbit systems
- Assist existing satellites if deorbit systems fail
- Possible with existing technology, but requires scaling

Innovation

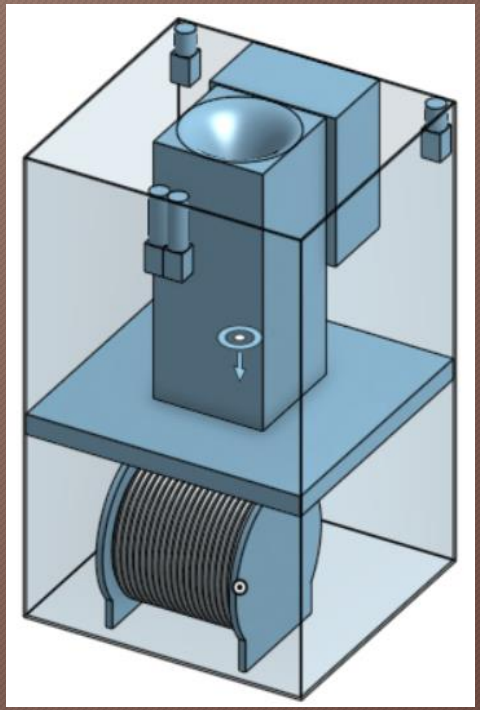
- Based on harpoon
- Novel concept
- Reusable and scalable to different types of satellites

Conclusion

NEBULOR Debris Removal Mission

JAV Deorbit of Aerocube 6B

- Simple, novel, and effective
- Reduce debris and assist deorbits



Feasible for implementation by early 2030's

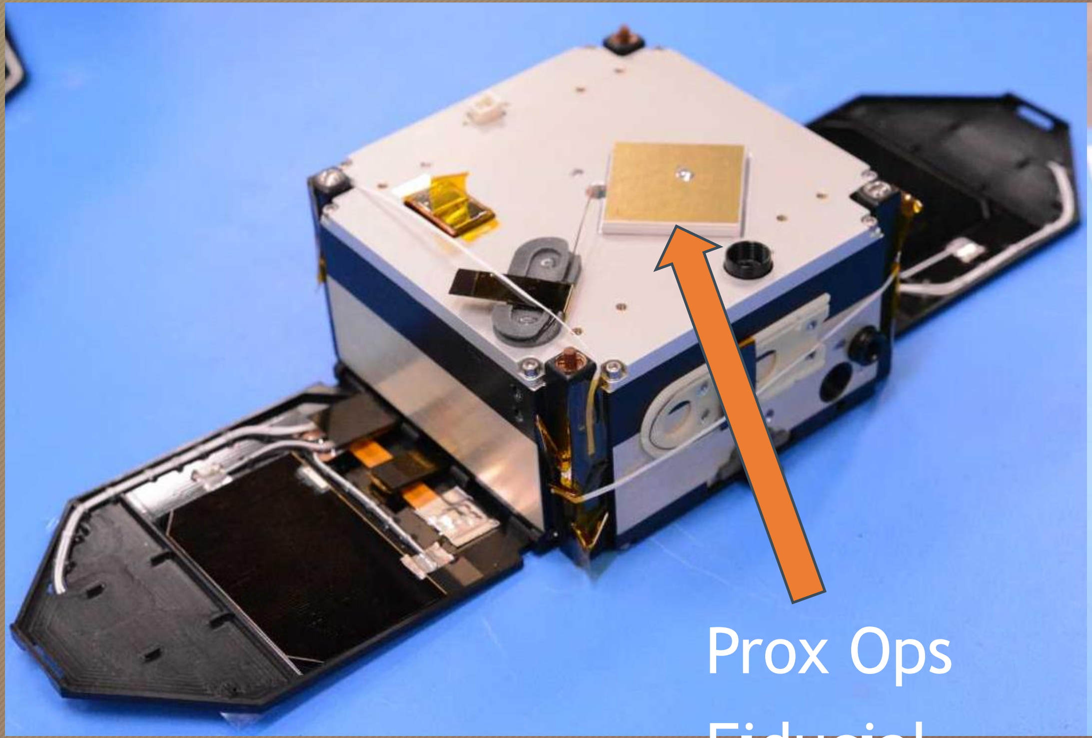
- Mostly off the shelf components
- Main work is with JAV

Space debris is an issue.
NEBULOR can mitigate it currently and prevent it later.

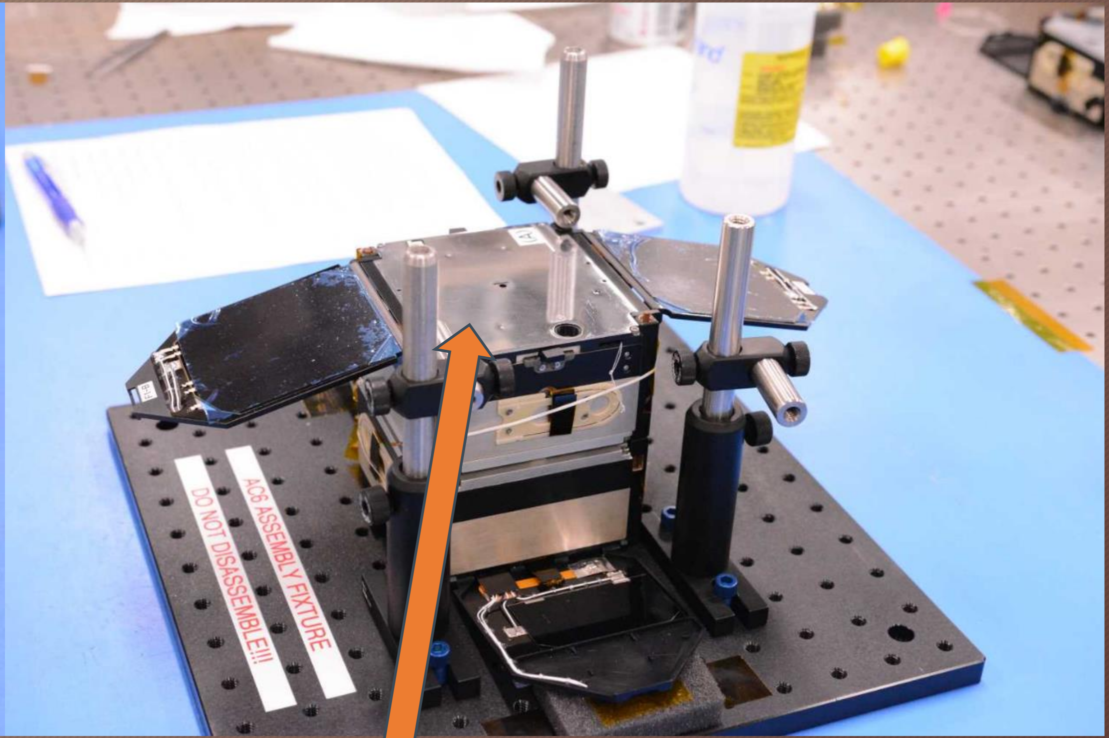
Questions?

Aerocube 6B

Backup Slides



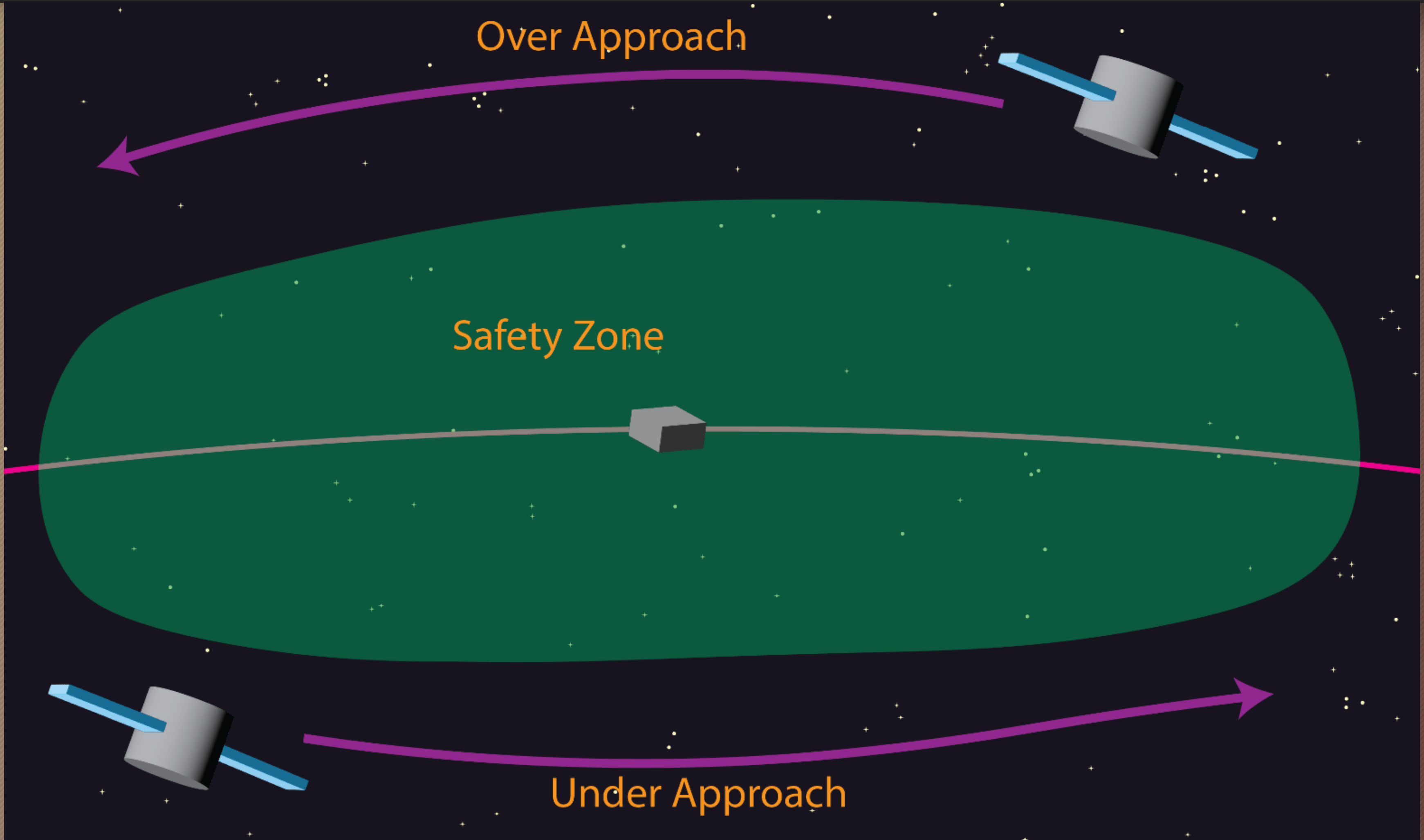
Prox Ops Fiducial



Target Area

Over-Under Approach for LiDAR Failure

Backup Slides



Uplink Budget

Backup Slides

Freq.	f	Ghz	input	**2.20**
Xmtr Pwr	P	W.	input	**5.0000**
Xmtr Pwr	P	dbW	10 log(P)	6.99
Xmtr line loss	L_l	dB	input	**-1.00**
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	9.545
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	24.70
Xmt. Ant. Diam.	D_t	m	input	**1.00**
Xmt. Ant. Pointing Error	e_t	deg	input	**2.00**
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	-0.53
Xmt Ant. Gain	G_t	dB	$G_{pt}+L_{pt}$	24.18
EIRP	EIRP	dB	$P+L_l+G_t$	30.17
Prop. Path Length	S	km	input	**1.200E+03**
Space Loss	L_s	dB	Eq. (13-23a)	-160.87
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**-0.50**
Rcv. Ant. Diam.	D_r	m	input	**15.00**
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	48.18
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	0.64
Rcv. Ant. Pointing Error	e_r	deg	input	**1.63**
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	-78.73
Rcv. Ant. Gain	G_r	dB	$G_{rp}+L_{pr}$	-30.55
System Noise Temp.	T_s	K	input (using Ta	**250.00**
Data Rate	R	bps	input	**1000.00**
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	12.87
Bit Error Rate	BER	--	input	**1.0E-07**
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK	**9.60**
Implementation Loss (3)		dB	input (standard	**0.00**
Margin		***dB***	***(1)-(2)+(3)***	***3.27***

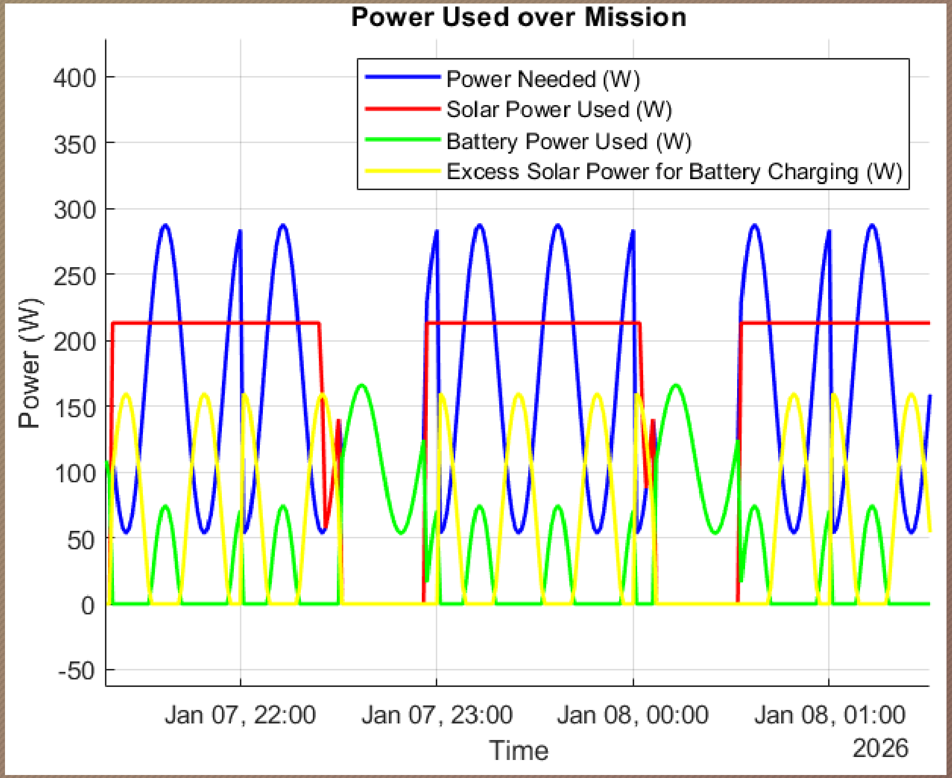
Downlink Budget

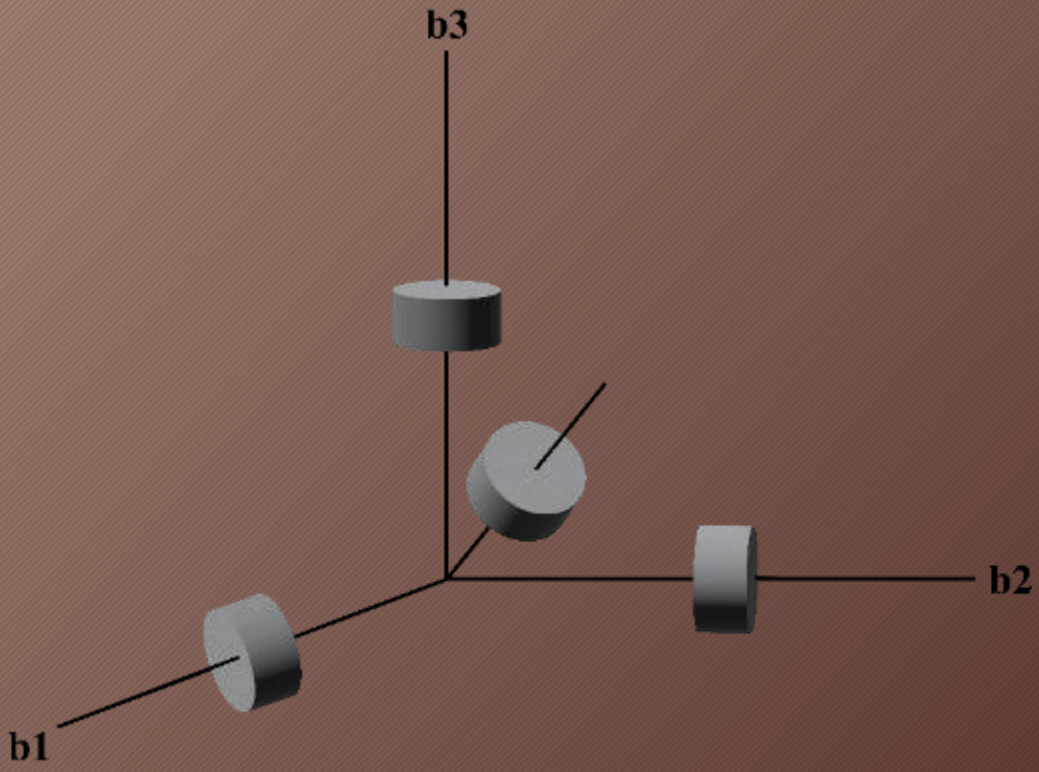
Backup Slides

Freq.	f	Ghz	input	**8.40**
Xmtr Pwr	P	W.	input	**250.0000**
Xmtr Pwr	P	dbW	10 log(P)	23.98
Xmtr line loss	L_l	dB	input	**-1.00**
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	2.500
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	36.34
Xmt. Ant. Diam.	D_t	m	input	**1.00**
Xmt. Ant. Pointing Error	e_t	deg	input	**2.00**
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	-7.68
Xmt Ant. Gain	G_t	dB	$G_{pt}+L_{pt}$	28.66
EIRP	EIRP	dB	$P+L_l+G_t$	51.64
Prop. Path Length	S	km	input	**1.200E+03**
Space Loss	L_s	dB	Eq. (13-23a)	-172.51
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**-0.50**
Rcv. Ant. Diam.	D_r	m	input	**15.00**
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	59.82
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	0.17
Rcv. Ant. Pointing Error	e_r	deg	input	**0.41**
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	-72.62
Rcv. Ant. Gain	G_r	dB	$G_{rp}+L_{pr}$	-12.80
System Noise Temp.	T_s	K	input (using Ta	**1000.00**
Data Rate	R	bps	input	**100000.00**
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	14.43
Bit Error Rate	BER	--	input	**1.0E-07**
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK	**9.60**
Implementation Loss (3)		dB	input (standard	**0.00**
Margin		***dB***	***(1)-(2)+(3)***	***4.83***

Enlarged Subsystem Diagrams

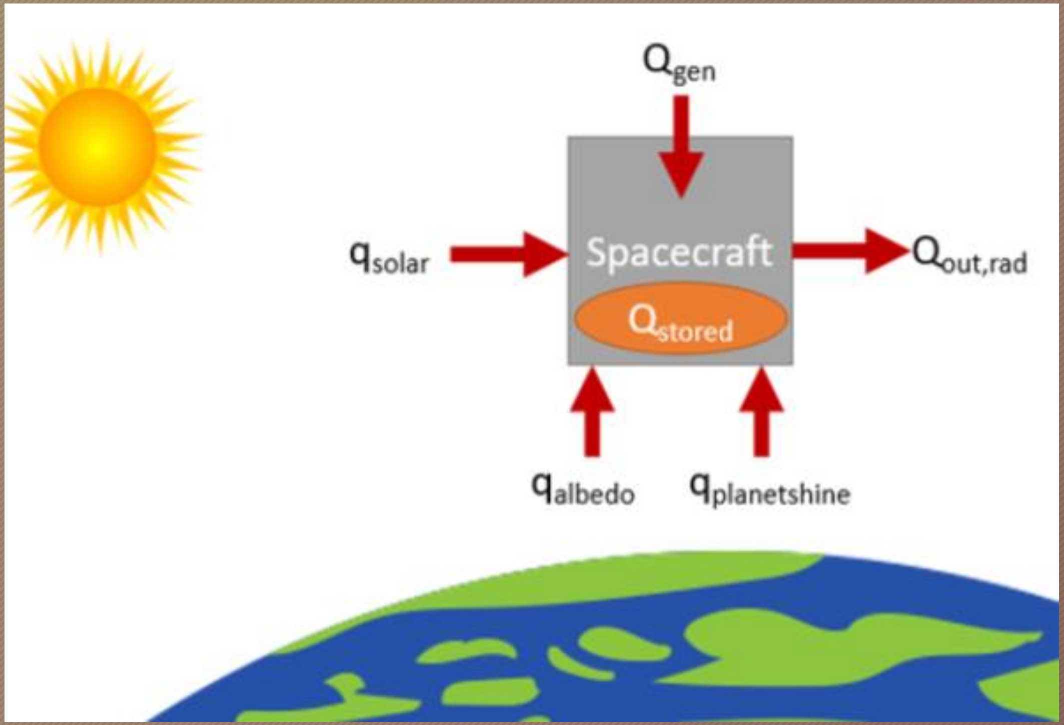
Backup Slides

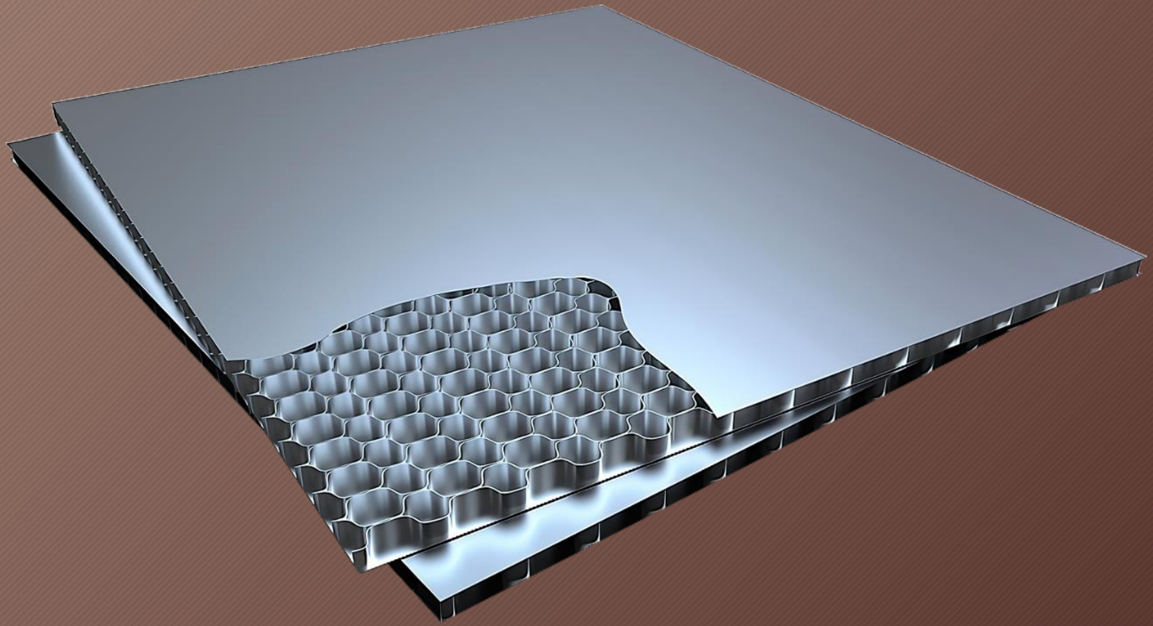




Enlarged Subsystem Diagrams

Backup Slides





Enlarged Subsystem Diagrams

Backup Slides

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