COSMIC

THE POWER OF COLLABORATION

COSMIC Capstone Challenge: Final Briefing

Orbital Catch & Release

Tri-State Horizon, The Pennsylvania State University

Students: Ashley Loftis, Wesly Green, Rachael Krugh, Brandon Gero, Lyze Glenister, Braden Johnson
Advisor: Professor Sara Lego
Mentor: Brian Holt

April 14th, 2025

Executive Summary

Orbital Catch & Release

- Problem Identified: space debris collisions with spacecrafts
  - Previous attempts have shown it is difficult to not damage the debris
- Proposed Capability: 3 Catch & Release operations
  - 1. soft capture
  - 2. hard capture
  - 3. release
- How it solve the problem: removes debris to prevent future damage to spacecraft
- Current Status: proof of concept

Team

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CONSORTIUM FOR SPACE MOBILITY AND ISAM CAPABILITIES

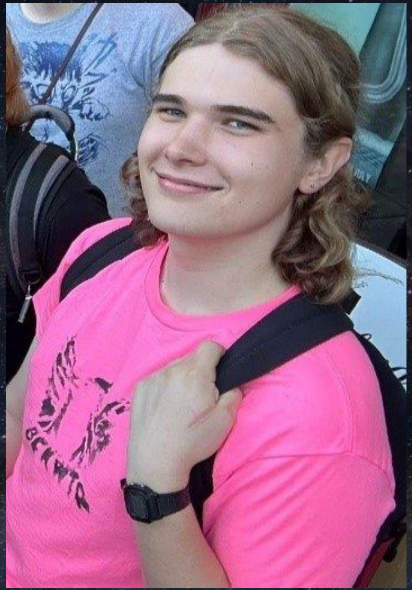
Orbital Catch & Release

Ashley Loftis
Team Lead

Wesley Green

Rachael Krugh

Brandon Gero



Lyze Glenister

Braden Johnson

2.4 Systems Engineering Milestones

Orbital Catch & Release

- September 13, 2024 — Program Manager Selection
- October 7, 2024 — Mission Operations Selection
- October 16, 2024 — System Requirements Definition
- February 10, 2025 — Trade Studies Completion
- March 19, 2025 — Conceptual Design Completion
- April 1, 2025 — Preliminary Design Review

3.1 Innovative Concepts

Concepts 1 and 2

- Future release to a third-party in-space recycler
- The three initial concepts had the same base design each with a hard-capture system, robotic arm(s), and an end-effector

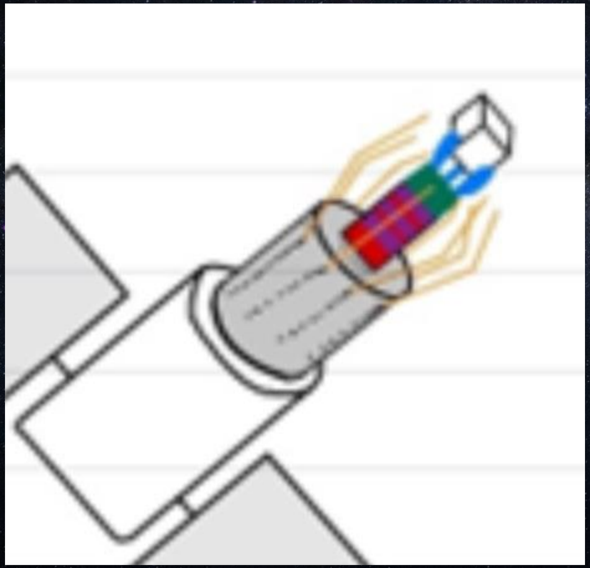
Concept 1

- End-Effector - Inflatable pneumatic fingers
- Soft Capture - Inflatable pneumatic arms
- Hard Capture - Cage arms

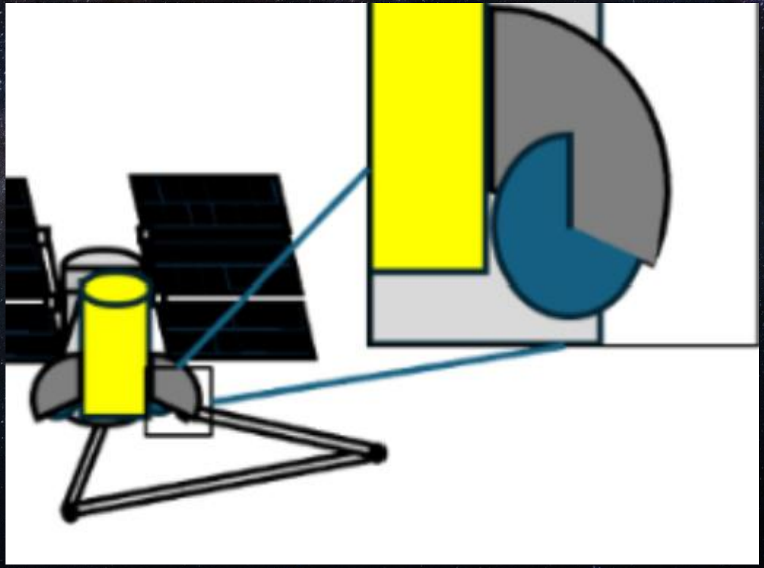
Concept 2

- End-Effector – Magnet
- Soft Capture - Canadarm
- Hard Capture - Crab Claw

Concept 1

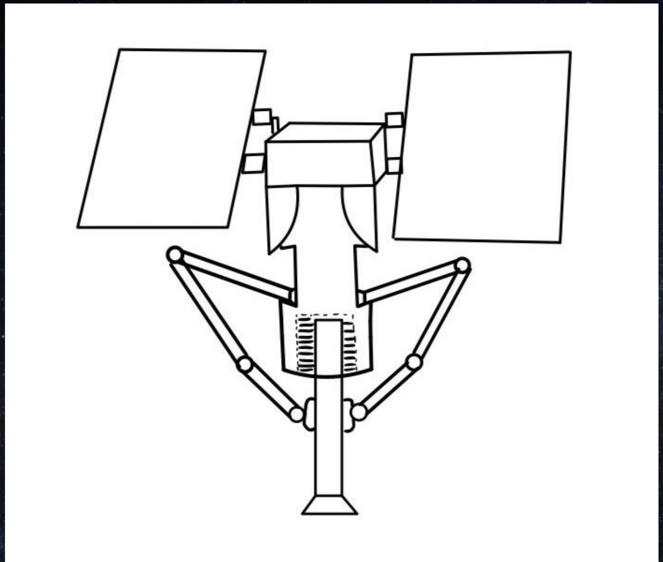


Concept 2



3.1 Innovative Concepts

Concept 3 and Trade Study



Concept 3

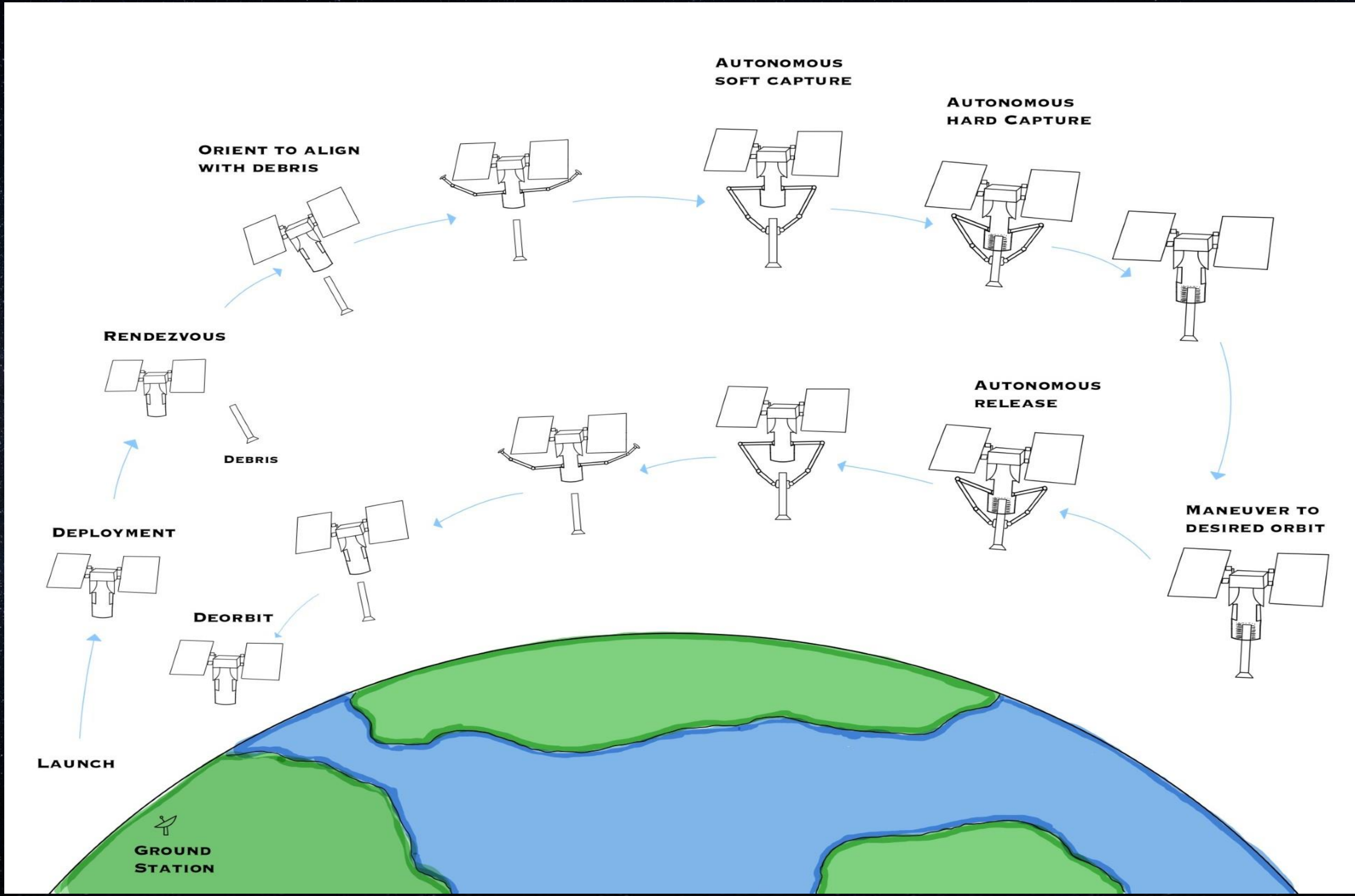
- End-Effector - Gecko Grippers
- Soft Capture – Robotic Arms
- Hard Capture - Multi-pin Pressure Sensor Chamber

Trade Study

- Assessed Each Component by: Functionality, Reliability, Cost, Complexity, Manufacturing Difficultly, Power consumption, Technology Readiness, Mass
- Down-selected and Combined Based on Results
- Final Design: Concept 3

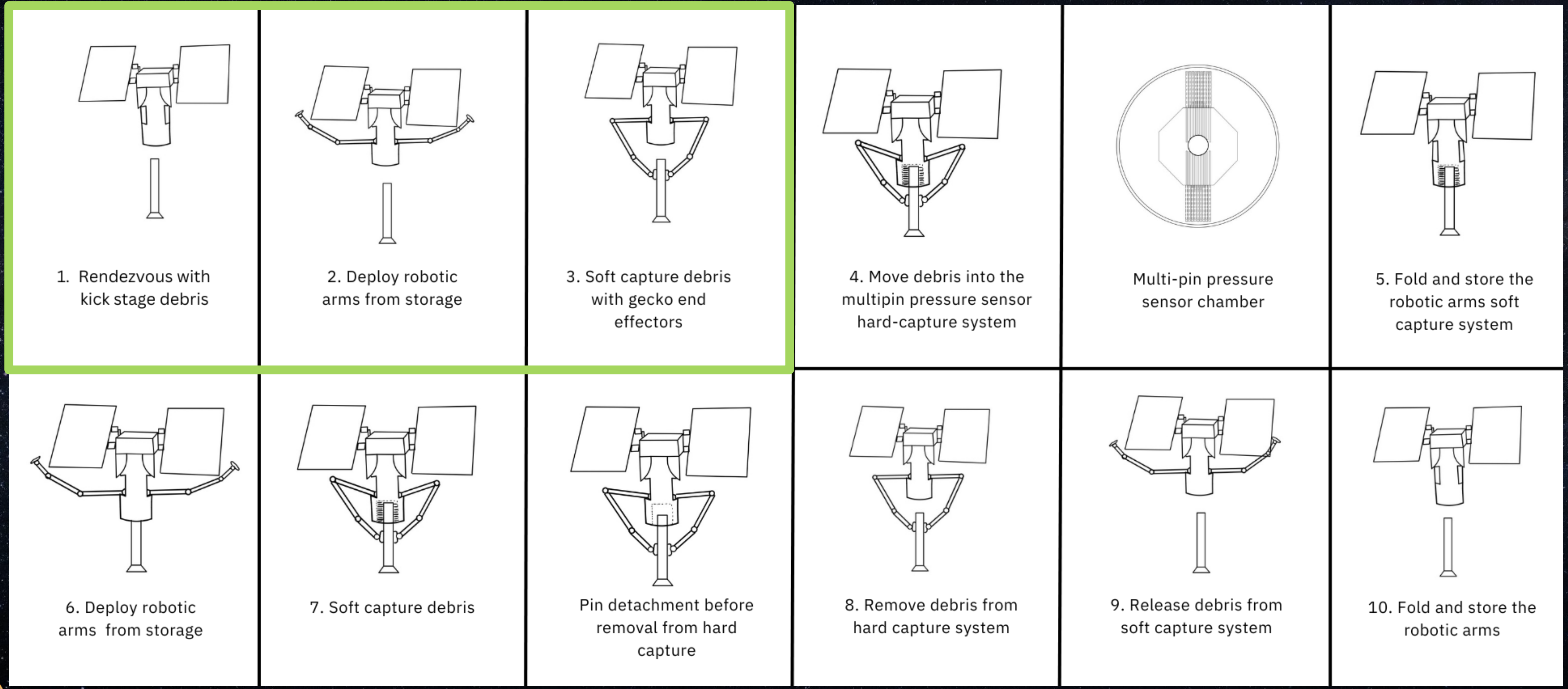
2.2 Storyboard of Complete Operation

Macro-Level Mission Architecture



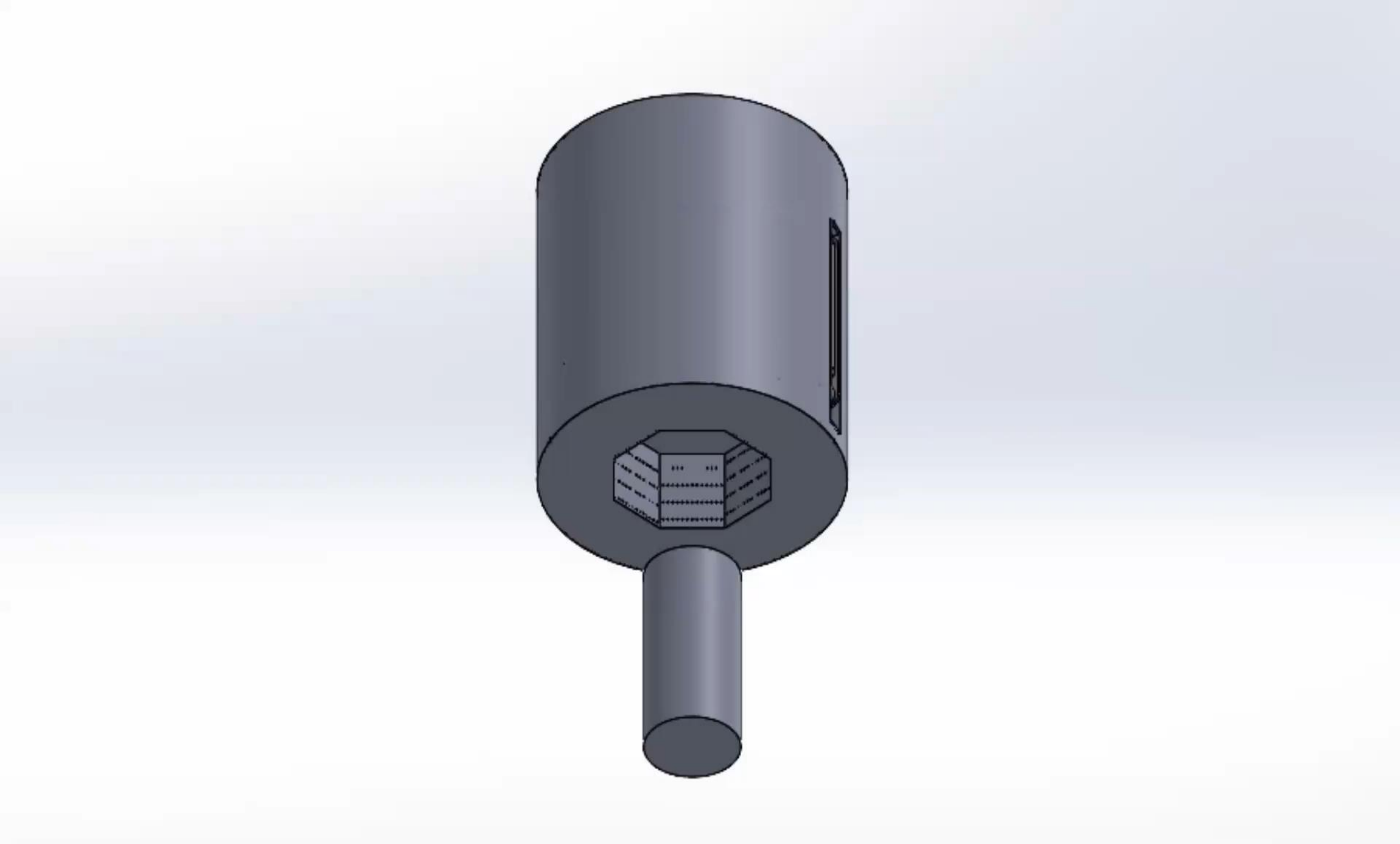
2.1 Animation of Key Operating Sequence

Micro-Level Mission Architecture



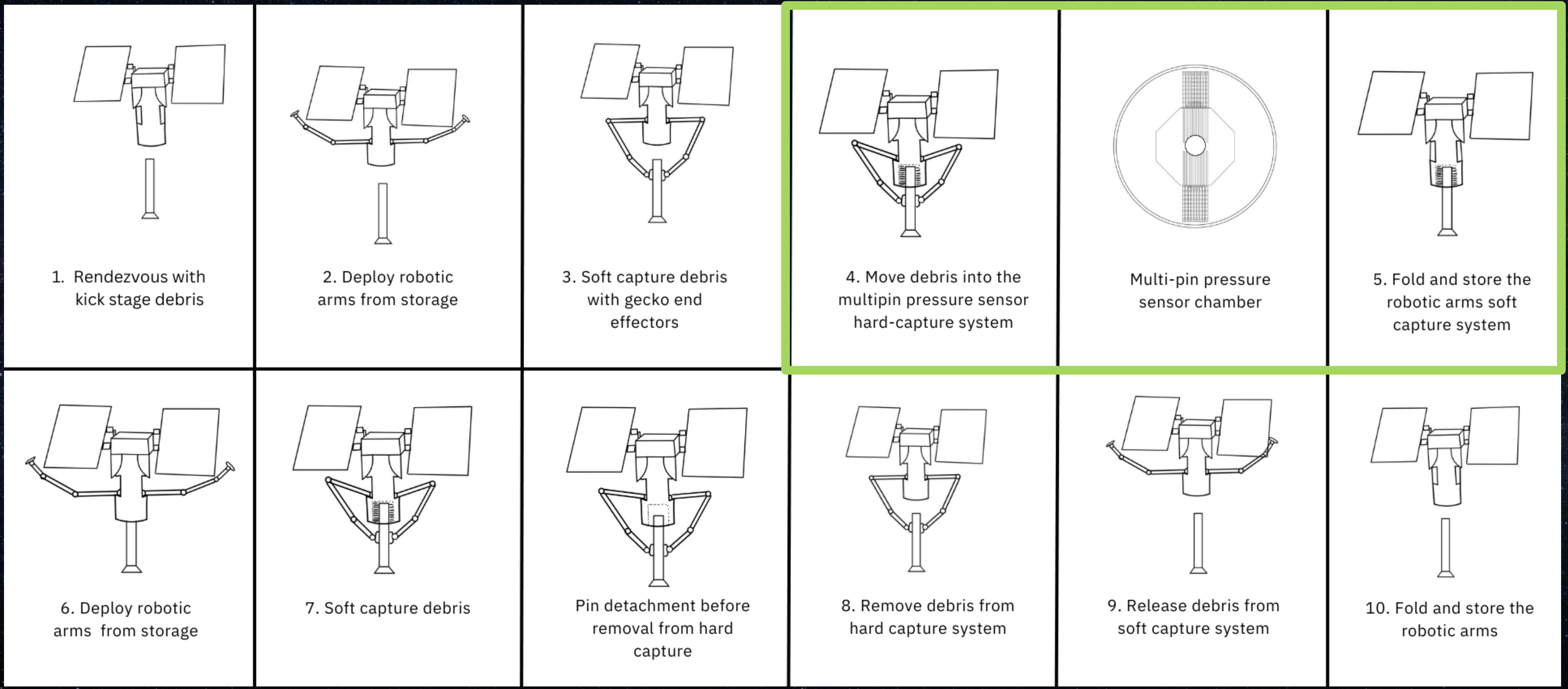
2.1 Animation of Key Operating Sequence

CAD Animation of soft capture



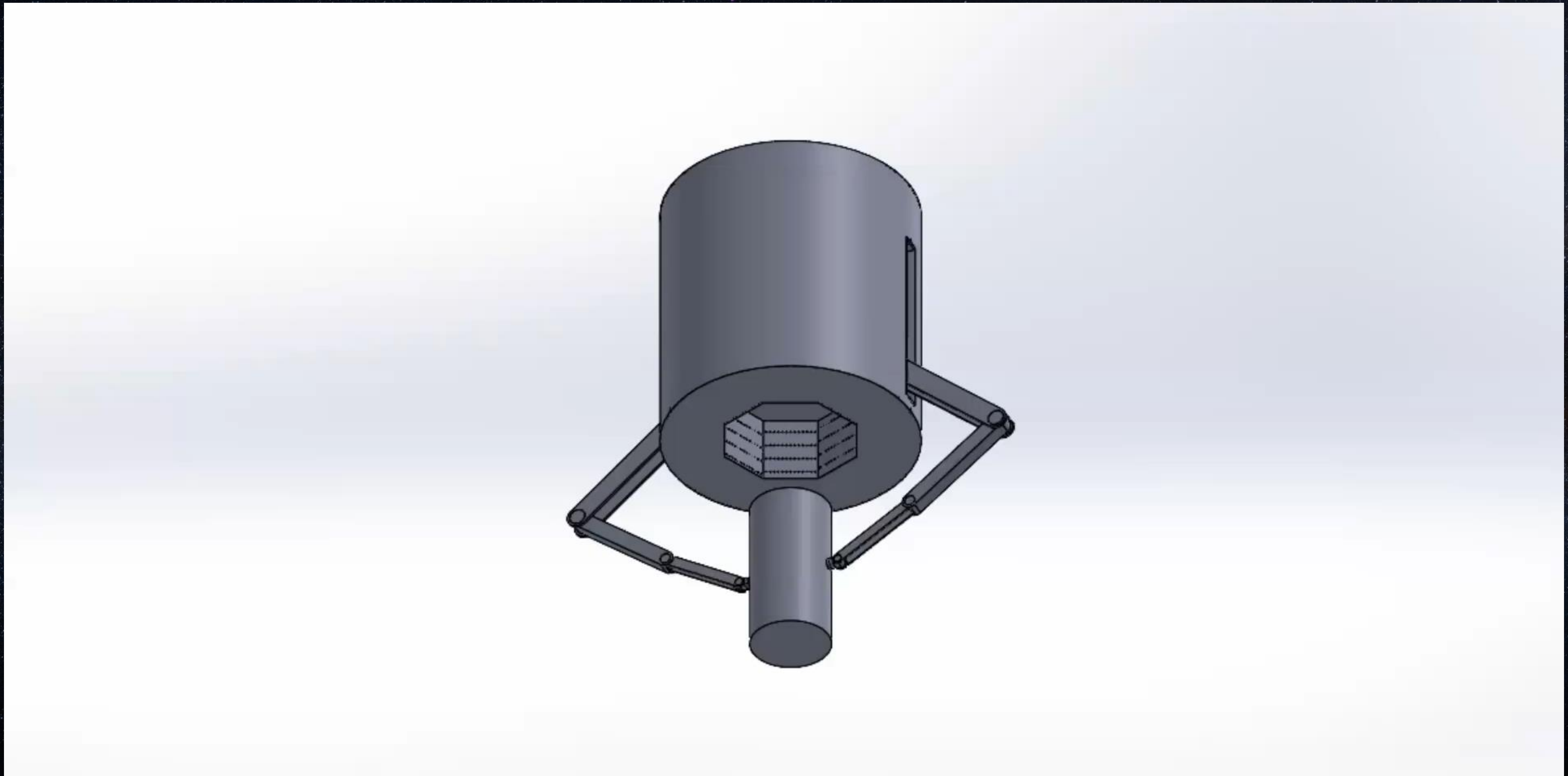
2.1 Animation of Key Operating Sequence

Micro-Level Mission Architecture



2.1 Animation of Key Operating Sequence

CAD Animation of Hard Capture



2.1 Animation of Key Operating Sequence

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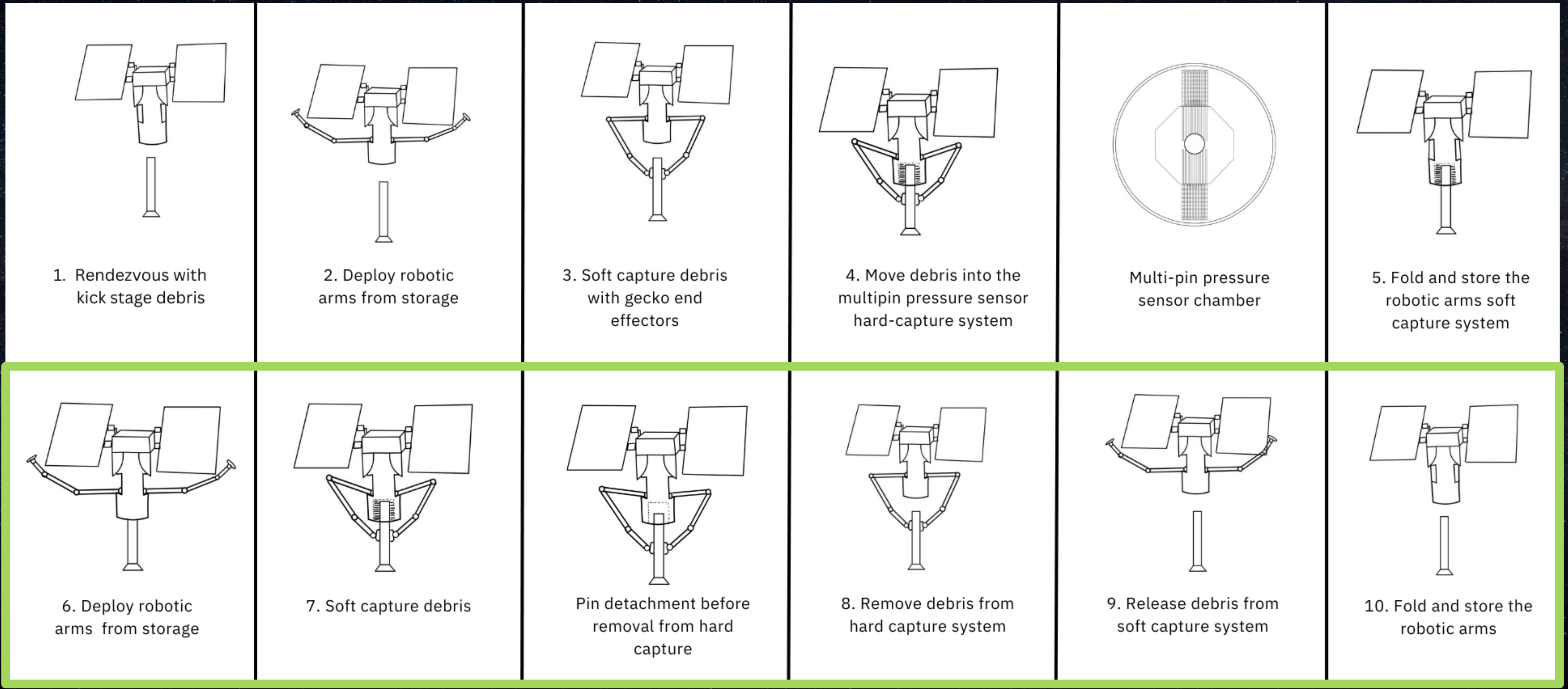
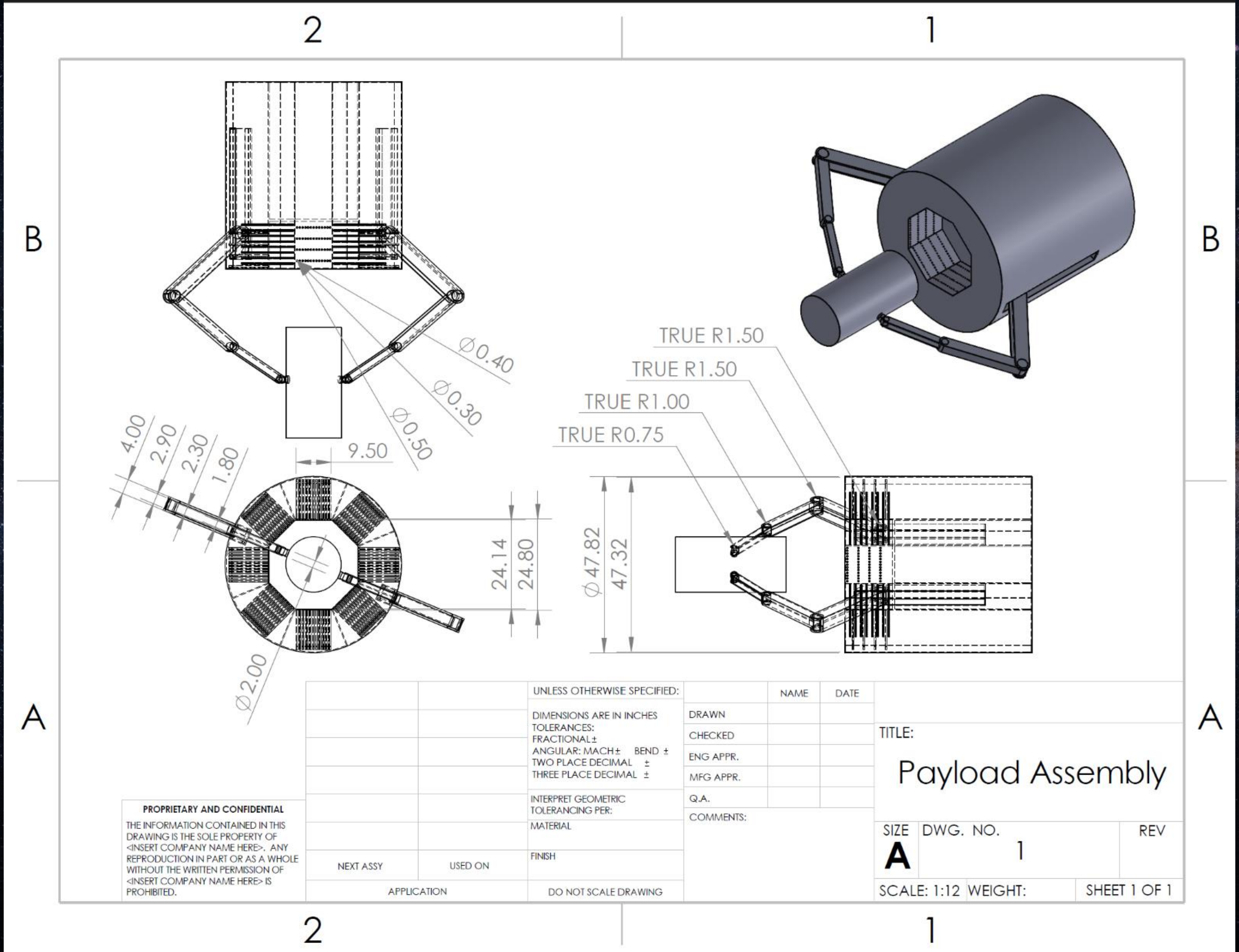
Micro-Level Mission Architecture



TRI-STATE HORIZON

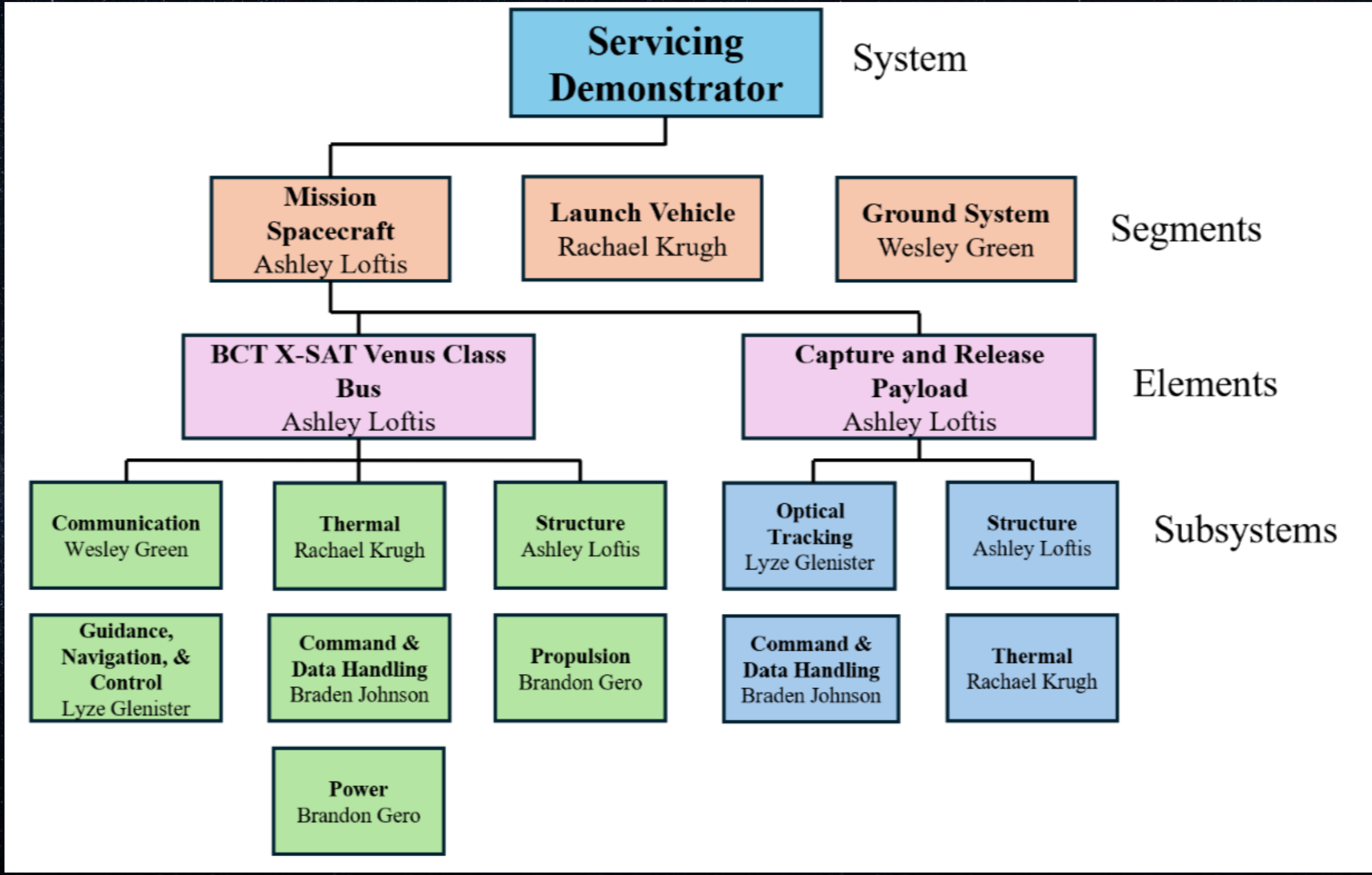
2.1 Animation of Key Operating Sequence

Front, Bottom, Side, and Isometric View of Payload



3 System Decomposition

BCT X-Sat Venus Class Bus and Payload Subsystem breakdown



Launch Vehicle

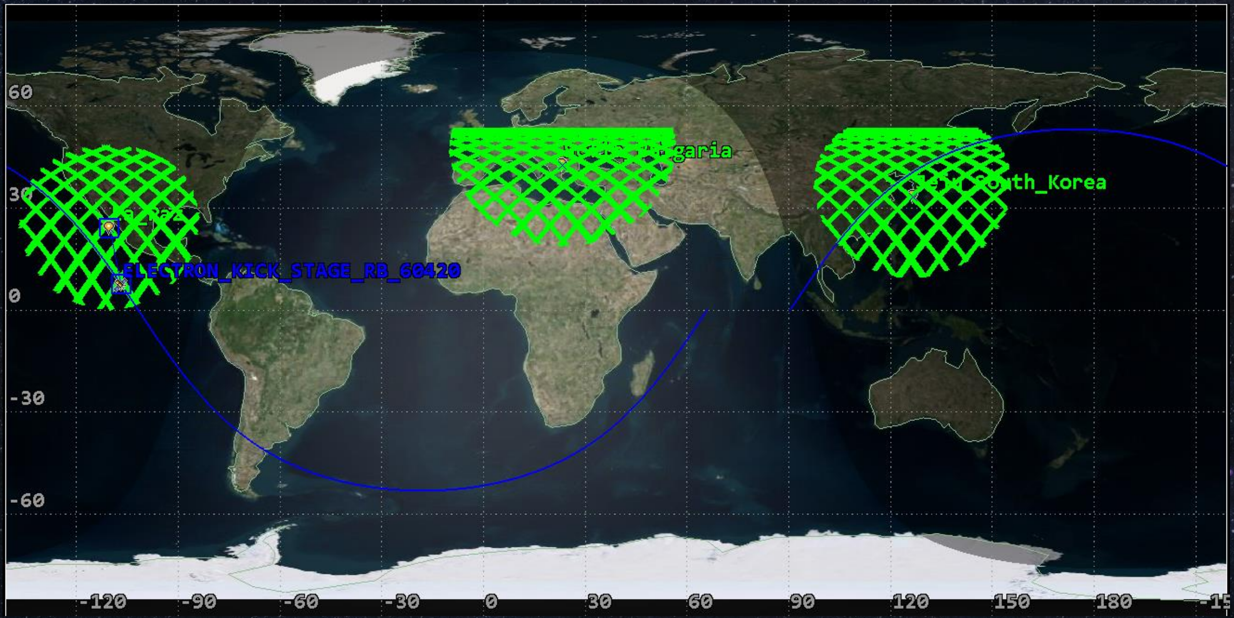
Launch Vehicle Trade Study

Criteria			Launch Vehicle		
Requirement	Weight	Goal	SpaceX Falcon 9	Northrop Grumman Antares Rocket	Northrop Grumman Pegasus
Cost per kg	15%	Min	$2720/kg	$1340/kg	$126410/kg
		Normalized	0.989	1	0
Reliability	15%	Max	99.34%	94.44%	89%
		Normalized	1	0.526	0
Payload Fairing Diameter	35%	Max	3.7 m	3.9 m	1.27 m
		Normalized	0.924	1	0
Vibrational Displacement	35%	Min	4.97 mm	4.97 mm	0.175 mm
		Normalized	0	0	1
Total			2.913	2.526	1

Orbital Analysis

Target, Initial, and Final Orbit

- Target Debris Orbit (used for power, thermal, and communication systems development)
  - Apogee altitude 611.991 km
  - Perigee altitude 592.633 km
  - Semi-major axis 6,980.449 km
  - Eccentricity 0.0013866
  - Inclination 53.0056°
  - RAAN 30.7335°
  - Arg. of periapsis 93.8789°
  - Orbital period 96.74 mins
- Initial Orbit used for Calculations
  - Coplanar with Target Debris Orbit
  - Circular 550km orbit
- Final Orbit
  - Coplanar with Target Debris Orbit
  - Circular 510km orbit
- Orbital Transfer Delta V Requirements
  - Initial Orbit to Target Debris orbit: 77 m/s
  - Target Debris Orbit to Final Orbit: 150 m/s



2.3 Comms and Ground System

Orbital Catch & Release

- Real time downlinks not needed because the mission is autonomous, but are wanted in the event the autonomy fails, and manual override is necessary
- Trade study done to determine ground system based on: G/T, bandwidth, coverage, and # of locations
- Could require an observer, although the ground system chosen features a POCC, SOCC, and MCC with remote access
- Communications system requires S-band characteristics to communicate with the ground system
  - Will receive and transmit data with ground system at a rate between 1-5 Mbps
  - Operates between a frequency of 2025-2120 MHz uplink and 2200-2290 MHz for downlink
- Links budgets performed from bus to ground stations using 2.5W for uplink, 30W for downlink:
  - La Paz, Mexico (3.7m antenna diameter): uplink — 8.02 dB, downlink — 8.13 dB
  - Plana, Bulgaria (4.5m antenna diameter): uplink — 10.03 dB, downlink — 15.91 dB
  - Jeju, South Korea (3.9m antenna diameter): uplink — 8.98 dB, downlink — 7.96 dB

BCT X-Sat Venus Class Bus and Payload Subsystems

Thermal – Payload and Bus

- Internal Temperature between $-19℃ : 40℃$
- Tempco Silicon Heater attached using pressure sensitive adhesive (PSA)
  - Heritage study from COMPASS-1 Cubesat
  - Area: 128.8 in^2, watt density: 0.5 $\frac{W}{in^2}$, raise temperature max $20\ \frac{℃}{min}$
- Using 4 Gold Chip Thermistors from TE Connectivity
  - Trade study done based on: resistance provided, min temperature, and reliability

BCT X-Sat Venus Class Bus	Payload
- Radiative Heater Transfer Analysis: $3.46℃$	- Radiative Heater Transfer Analysis: 20.68℃ - Louvers: 50% efficiency

BCT X-Sat Venus Class Bus and Payload Subsystems

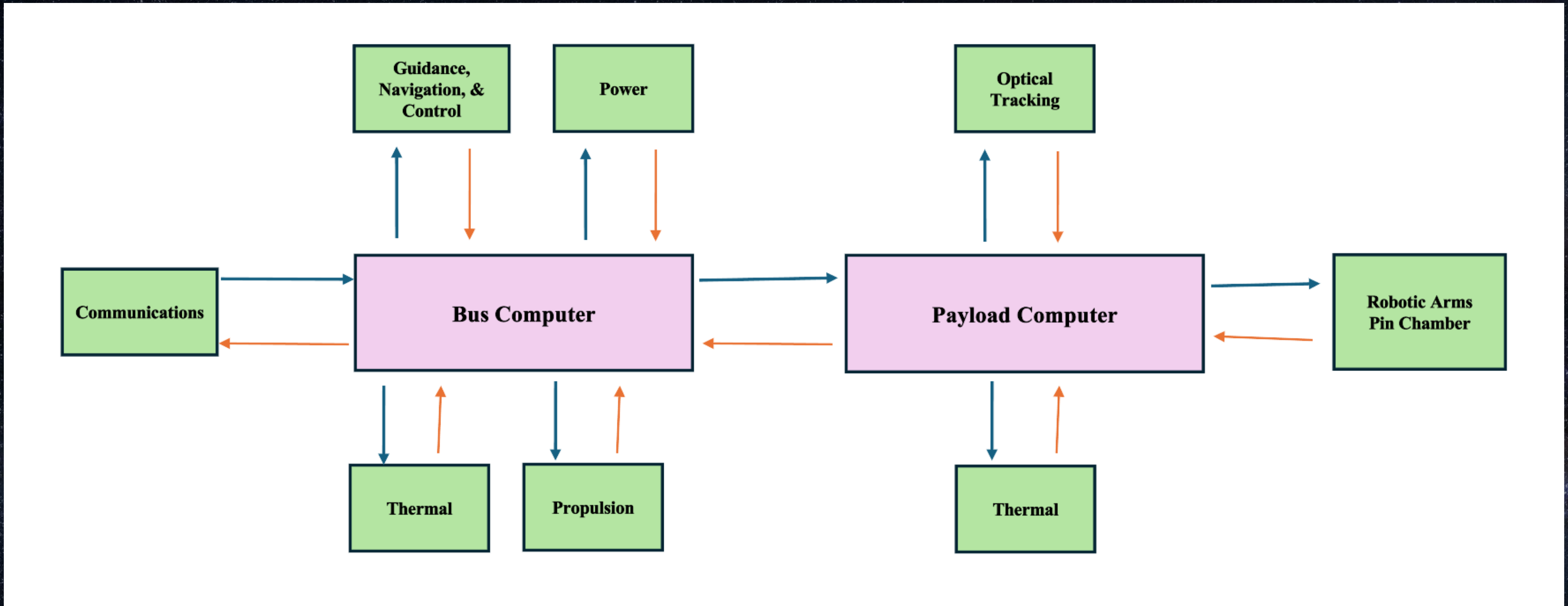
Guidance Navigation and Control - Bus

- BCT FLEXCORE with 4 RW8 Reaction wheels
  - pointing accuracy of ±0.002 deg
  - .6 Nm of torque from each reaction wheel
  - Selected Through Comparison with other BCT solutions
    - XACT-50
    - XACT-100

Criterion	Weight	Goal	XACT-50	XAcT-100	FLEXCORE
Pointing Accuracy	0.6	Min	0.003	0.003	0.002
		Normalized	0.666667	0.666667	1
Momentum	0.4	Max	0.05	0.1	8
		Normalized	0.00625	0.0125	1
total			0.4025	0.405	1

BCT X-Sat Venus Class Bus and Payload Subsystems

Command and Data Handling – Payload and Bus



- Computers with high data storage volume required due to the autonomy of the mission

BCT X-Sat Venus Class Bus and Payload Subsystems

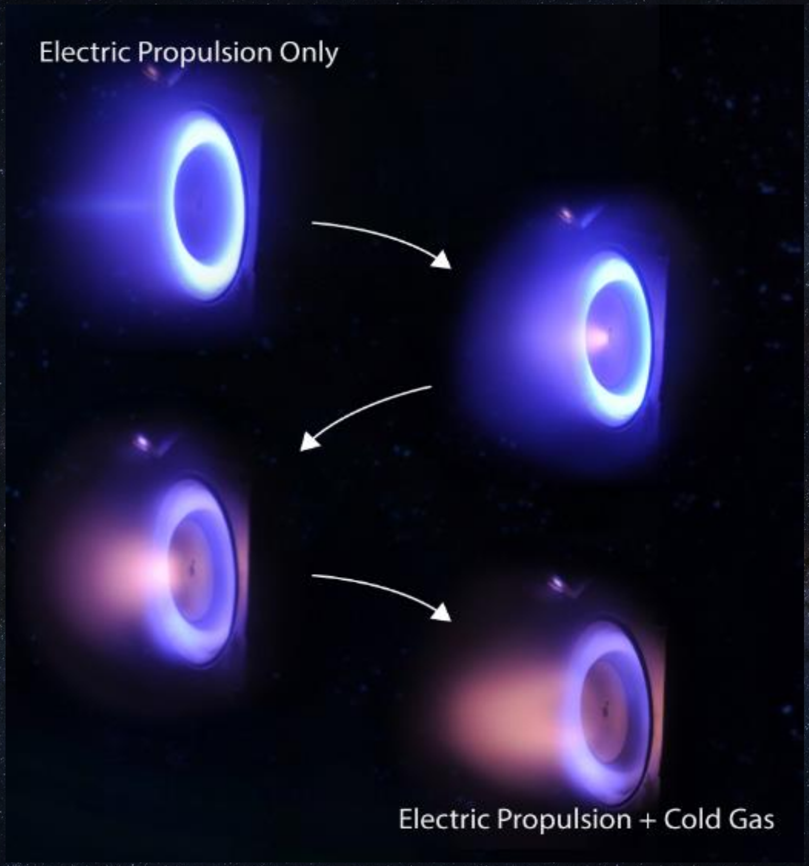
Power – Payload and Bus

- 6 x 2P8S & 3 x 1P8S batteries
- Total battery capacity on board: 1188Wh / 40.8A
  - Enough power for Δv maneuver and attitude control
  - A Δv of ~ 450m/s can be fired for 1 hour

BCT X-Sat Venus Class Bus and Payload Subsystems

Propulsion - Bus

- ORBION Aurora Thruster System
  - Dual-Mode Single System Propulsion
    - Cold Gas Attitude Adjustment System
    - Compressed Xenon Gas propellent
    - Hall Effect Propulsion System for Orbit Transfer System
- 6 Thruster design
  - 6 x 2mN – 6 x 2000mN
  - Automatic 3-axis control
    - BCT "FLEXCORE" module
    - 2 sensors



ORBION Space Technologies, "Dual-mode propulsion from a single system" Orbionspace.com

BCT X-Sat Venus Class Bus and Payload Subsystems

Structures – Bus and Payload

- BCT X-Sat Venus Class Bus
  - Estimated dimensions:
    - 50cm x 50cm x 35 cm
    - wall thickness of 0.25 cm
  - Material: Aluminum 6061
  - Fundamental frequency:
    - Lateral: 14.0 Hz
    - Axial: 18.3 Hz
  - Moments of inertia:
    - xy-plane: 4.7E-05 m^4
    - Axial: 8.0E-05 m^4

- Payload
  - Dimensions:
    - H: 50.8cm, Ro: 23.91cm, Ri: 23.66 cm
    - wall thickness of 0.25 cm
  - Material: Aluminum 6061
  - Fundamental frequency:
    - Lateral: 5.19 Hz
    - Axial: 7.35 Hz
  - Moments of inertia:
    - xy-plane: 0.0017 m^4
    - Axial: 0.0034 m^4
  - Critical load: 39.2N

BCT X-Sat Venus Class Bus and Payload Subsystems

Optical Tracking – Payload

- Used to Guide Rendezvous, Capture, and Release Operations
- Obruta Rendezvous, Proximity Operations, and Docking (RPOD) Kit
  - Determines target distance
  - Tracks relative orientation and rotational velocities if loaded with model of target
  - 1% Error

Mass Budget

Payload and Bus with components

System	Subsystem	Component	Mass (kg)	Percentage
BCT X-Sat Venus Class Bus	Communication	Patch Antenna	0.075	0.11%
	Power	6x Batteries	8.15	11.65%
	GNC	FlexCore, 4x RW8, 2 NST	17.0	24.30%
	C&DH	Computer	5.0	7.15%
	Propulsion	Orbion Aurora Thrusters	14.5	20.72%
	Thermal	Thermistors	Negligible	0%
	Reserve	-	3.5	5%
		Total:	48.225	68.92%
Payload	C&DH	Transceiver and Computer	5.19	7.42%
	Structure	Primary Structure, Gecko Grippers, Robotic Arms, Pressure Chamber & Sensors	10.88	15.55%
	Thermal	Heater and Thermistors	0.175	0.25%
	Optical Tracking	Obruta RPOD Kit	2.0	2.86%
	Reserve	-	3.5	5%
		Total:	21.745	31.08%
		Total Mass:	69.97	100%

Power Budget

Payload and Bus

Subsystem	Average Nominal Voltage (V-DC)	Total Peak Wattage (W)
Communication	28	22.75
C&DH	12	12.60
Propulsion + AOCS	28	840.0
Thermal	12	45.08
Optical Tracking	12	20.3
Reserve	-	403.17
Total Peak Power:	1343.9 W	

1.5 Risks

Risk Mitigation Matrix

Risks	Pre-Mitigation	Mitigation Strategy
1. Launch Window Miss	• Launch Window From Cape Canaveral, FL on [TBD] • Next Window on [TBD]	• Wait until next window • Determine new launch site
2. Gecko Gripper Technology Delay	• Current Technology Readiness Level of 6	• Switch to Magnet end-effectors
3. Pin Pressurization Failure	• Each Pin is individually pressurized	• If in Hard-Capture: death code programmed to override pressure sensor failure • If out of Hard-Capture: cancellation of Release Stage
4. Initial Rendezvous with Debris Miss	• Pre-launch calculations to complete initial rendezvous	• Enough fuel on-board to make 1 maneuver to realign
5. Cause Damage to Debris	• Precise attitude adjustment system to avoid damage	• Reevaluate to determine if mission can be continued or if total mission failure
6. Autonomy Failure	• Potential for autonomy to fail during Capture and Release Stages	• Continuous communication with Ground System for Manual Override

1.5 Risks

Risk Mitigation Matrix Cont.

Probability					
Very Likely					
Likely	2.		2. 6.		6.
Possible		1.	1.	4.	4. 5.
Unlikely				3.	3. 5.
Very Unlikely					
	Negligible	Minor	Moderate	Significant	Severe

Likeliness

Risk Level:	Acceptable	Watch	Unacceptable

3.2 Technology Gap Assessment

Orbital Catch & Release

- Gecko Grippers completion
  - Increase mission confidence and allow the mission to proceed as planned
- The development of an in-space Recycling Station
  - Make this mission more impactful and increase the reusability of the debris
- Magnetizing debris
  - Allow for the possibility of utilizing magnets in the capture system

3.3 Biggest Challenges Encountered

Orbital Catch & Release

- Integrating the Payload with the BCT X-Sat Venus Class Bus
  - Needed more information
- Accessing detailed information about each subsystem and system
  - Had to reach out to companies and select new mechanisms when needed information couldn’t be found
- Having limited mass and power for the Payload design
  - Had to reduce FOS and make sacrifices to ensure we had enough power

Lessons Learned

Orbital Catch & Release

- How much space debris there is and how new ISAM capabilities will be able to mitigate it
  - Catch & Release payload for mitigation
- Why finding and planning for risks is important
  - Prevent mission failures and have redundancy measures
- How critical Systems Engineering is to a mission to ensure all parts will work together
  - Ensuring integration and that budgets for mass and power are met for the mission

4.1 Paper

Orbital Catch & Release

- Formatted according to IEEE Aerospace Conference in Big Sky, MT March 1-8th, 2026 for publishing
- Abstract length: 160 words
- Paper length: 20 pages
- Number of references included: 33

1.6 Path to PDR

X-Sat Venus Class Bus Integration Work Completed

- Total Mass and Power Budgets
- Orbital Analysis
  - STK analysis
- Communication Subsystem
  - Link budgets from BCT PCB Patch Antenna to ground station
- Thermal Subsystem
  - Radiative heat transfer analysis and needed thermal control systems
- Guidance, Navigation, & Control (GNC) Subsystem
  - ADCS trade study
- Structure Subsystem
  - Structural load analysis and materials trade study
- Communication & Data Handling (C&DH) Subsystem
  - Need computer size, mass, and power
- Propulsion Subsystem
  - Thruster trade study and needed Isp calculations
- Power Subsystem
  - Needed additional batteries and calculated solar panel area

1.6 Path to PDR

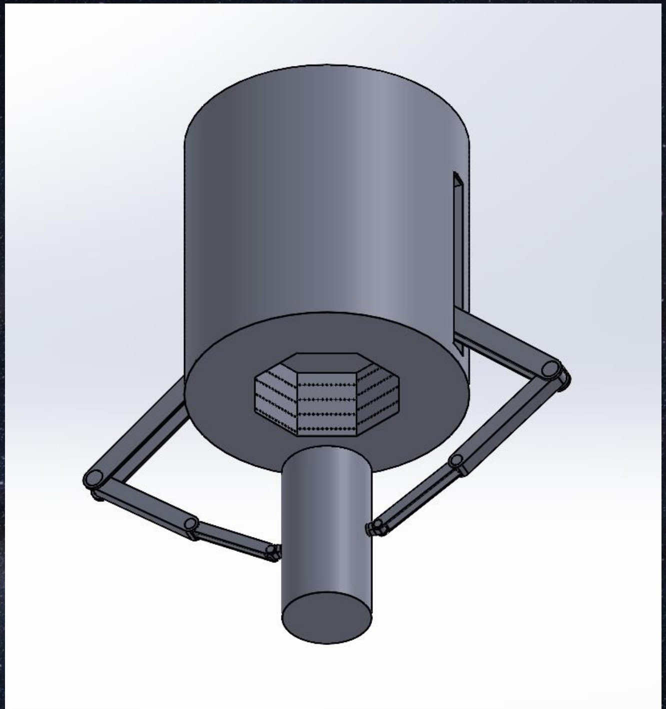
Future Work / Next Steps

- Increase payload/host spacecraft size scale
  - Mission overview could include larger debris and larger FOS with systems
- Payload mission requirements developed with host S/C design
  - Better payload subsystem integration
- Allow for higher power generation
  - Allow longer missions and reduce the amount/size of needed batteries
- Explore combining magnets and gecko grippers as end effectors
- Complete a cost analysis
- Finalize Launch Window

Summary/ Conclusion/ Highlights

Orbital Catch & Release

- Catch and Release: Navigate and rendezvous with selected debris
  - Soft and hard capture features used to catch
  - Releasing debris is the final stage
- Innovative because it tackles the looming debris congestion issue in LEO
  - Soft and hard capture designs can handle irregular shaped debris
  - Release of debris to graveyard orbit or future in-space recycler
- ISAM Impacts:
  - Debris removal
  - Space situational awareness
  - Sustainability



Questions

Orbital Catch & Release

Questions?

Backup Slides

Backup

Top-Level Requirements

R1	The payload shall demonstrate the capture of space debris.		RFP	
Req Num	Requirement	Rationale	Source	Verification
R1.1	The payload shall demonstrate soft capture and hard capture capabilities	Soft capture allows for an increase of control during hard capture. Hard capture stabilizes the debris.	Mission Object 1	Confirmation checks
R1.2	The payload will not damage debris during capture.	Payload will not damage space debris during capture to prevent further debris.	UNOOSA Space Debris Mitigation Guideline	Sensor Confirmation
R1.3	The payload shall capture space debris within a 300-500lbs. weight range.	Debris within weight range will be manageable to capture	ESA's Annual Space Env. Report - 2023	Testing
R1.4	The Payload shall capture space debris within 0.5-1.5 meters wide.	Debris within width range will be manageable to capture	ESA's Annual Space Env. Report - 2023	Testing

R2	The payload shall integrate with the BCT X-Sat Venus Class bus.		RFP	
Req Num	Requirement	Rationale	Source	Verification
R2.1	The payload shall survive the LEO space environment.	For the mission to be considered successful the payload must be able to operate in LEO.	R2	Testing
R2.2	The payload shall be less than 17" x 16.4" x 27" dimensions.	The bus allocates a specific volume to the payload.	R2	Design Consideration
R2.3	The payload shall weigh less than 70kg.	The bus allocates 70kg of weight to the payload.	R2	Design consideration
R2.4	The payload shall require less than 444W of power.	The bus allocates only 444W of power to the payload.	R2	Design consideration
R2.5	The payload shall be compatible with UART for data transmission	UART allows the payload to communicate with the bus and with ground control.	R2	Design consideration

R3	The payload shall demonstrate the release of space debris.		RFP	
Req Num	Requirement	Rationale	Source	Verification
R3.1	Payload shall not damage space debris during release.	Damage to space debris during release should be avoided to prevent further debris.	UNOOSA Space Debris Mitigation Guidelines	Sensor Confirmation
R3.2	The release procedure shall not add more than TBD m/s to debris velocity.	Extra force added to the debris should be avoided during release, so that it stays on track to its destination.	R3	Analysis

Backup

Completed Trade Studies

- Launch Vehicle
  - SpaceX Falcon 9 Rocket launched out of Cape Canaveral, FL
- Ground Station
  - Leaf Space locations in La Paz, Mexico, Plana, Bulgaria, and Jeju, South Korea
- Structure Subsystem Material
  - Aluminum for the Payload and Bus
- Thermal Subsystem Thermistor
  - TE Connectivity Gold Chip Thermistor
- Guidance, Control, & Navigation (GNC) Subsystem System
  - BCT FLEXCORE ACDS Solution
- Command & Data Handling (CDH) Subsystem Transceiver
  - SRS-3 Transceiver
- Propulsion Subsystem Design
  - Orbion Technologie's Thruster configurator for a Hall effect & cold gas Aurora thruster system

Backup

Ground Station Trade Study

Criteria	Goal	Weight	Leaf Space	AWS	Atlas Space Op
G/T	Max	20%	13.75	16	20.5
	norm		0	0.333333333	1
Bandwidth	Max	25%	50	54	54
	norm		0	1	1
Coverage	Max	30%	0.825252564	0.597493517	0.474919962
	norm		1	0.349877671	0
# of loc	Max	25%	16	12	11
	norm		1	0.2	0
		FOM	0.55	0.471629968	0.45

Backup

Communication system link budgets — La Paz, Mexico

Freq.	f	Ghz	input	**2.15**	
Xmtr Pwr	P	W.	input	**30.0000**	30000
Xmtr Pwr	P	dbW	10 log(P)	14.77	
Xmtr line loss	L_l	dB	input	**0.50**	
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	43.167	
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	11.60	
Xmt. Ant. Diam.	D_t	m	input	**0.23**	
Xmt. Ant. Pointing Error	e_t	deg	input	**0.02**	
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	0.00	
Xmt Ant. Gain	G_t	dB	$G_{pt}+L_{pt}$	11.60	
EIRP	EIRP	dB	$P+L_l+G_t$	26.87	
Prop. Path Length	S	km	input	**3.579E+04**	
Space Loss	L_s	dB	Eq. (13-23a)	-190.16	
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**3.00**	
Rcv. Ant. Diam.	D_r	m	input	**3.70**	
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	35.83	
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	2.64	
Rcv. Ant. Pointing Error	e_r	deg	input	**0.02**	
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	0.00	
Rcv. Ant. Gain	G_r	dB	$G_{rp}+L_{pr}$	35.83	
System Noise Temp.	T_s	K	input (using Tab	**289.56**	
Data Rate	R	bps	input	**5000000.00**	
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	12.52	
Bit Error Rate	BER	--	input	**1.0E-05**	
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK,	**4.50**	
Implementation Loss (3)		dB	input (standard	**0.00**	
Margin		***dB***	***(1)-(2)+(3)***	***8.02***	

Freq.	f	Ghz	input	**2.15**	
Xmtr Pwr	P	W.	input	**26.4200**	26420
Xmtr Pwr	P	dbW	10 log(P)	14.22	
Xmtr line loss	L_l	dB	input	**0.50**	
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	2.640	
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	35.87	
Xmt. Ant. Diam.	D_t	m	input	**3.70**	
Xmt. Ant. Pointing Error	e_t	deg	input	**0.02**	
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	0.00	
Xmt Ant. Gain	G_t	dB	$G_{pt}+L_{pt}$	35.87	
EIRP	EIRP	dB	$P+L_l+G_t$	50.59	
Prop. Path Length	S	km	input	**3.579E+04**	
Space Loss	L_s	dB	Eq. (13-23a)	-190.16	
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**3.00**	
Rcv. Ant. Diam.	D_r	m	input	**0.23**	
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	11.56	
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	43.17	
Rcv. Ant. Pointing Error	e_r	deg	input	**0.02**	
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	0.00	
Rcv. Ant. Gain	G_r	dB	$G_{rp}+L_{pr}$	11.56	
System Noise Temp.	T_s	K	input (using Tab	**289.56**	
Data Rate	R	bps	input	**4300000.00**	
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	12.63	
Bit Error Rate	BER	--	input	**1.0E-05**	
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK,	**4.50**	
Implementation Loss (3)		dB	input (standard	**0.00**	
Margin		***dB***	***(1)-(2)+(3)***	***8.13***	

Backup

Communication system link budgets — Plana, Bulgaria

Freq.	f	Ghz	input	**2.15**
Xmtr Pwr	P	W.	input	**30.0000**
Xmtr Pwr	P	dbW	10 log(P)	14.77
Xmtr line loss	L_l	dB	input	**0.50**
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	43.167
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	11.60
Xmt. Ant. Diam.	D_t	m	input	**0.23**
Xmt. Ant. Pointing Error	e_t	deg	input	**0.02**
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	0.00
Xmt Ant. Gain	G_t	dB	G_{pt}+L_{pt}	11.60
EIRP	EIRP	dB	P+L_l+G_t	26.87
Prop. Path Length	S	km	input	**3.579E+04**
Space Loss	L_s	dB	Eq. (13-23a)	-190.16
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**3.00**
Rcv. Ant. Diam.	D_r	m	input	**4.50**
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	37.53
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	2.17
Rcv. Ant. Pointing Error	e_r	deg	input	**0.02**
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	0.00
Rcv. Ant. Gain	G_r	dB	G_{rp}+L_{pr}	37.53
System Noise Temp.	T_s	K	input (using Tab	**270.00**
Data Rate	R	bps	input	**5000000.00**
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	14.53
Bit Error Rate	BER	--	input	**1.0E-05**
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK,	**4.50**
Implementation Loss (3)		dB	input (standard	**0.00**
Margin		***dB***	***(1)-(2)+(3)***	***10.03***

Freq.	f	Ghz	input	**2.15**
Xmtr Pwr	P	W.	input	**100.0000**
Xmtr Pwr	P	dbW	10 log(P)	20.00
Xmtr line loss	L_l	dB	input	**0.50**
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	2.171
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	37.57
Xmt. Ant. Diam.	D_t	m	input	**4.50**
Xmt. Ant. Pointing Error	e_t	deg	input	**0.02**
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	0.00
Xmt Ant. Gain	G_t	dB	G_{pt}+L_{pt}	37.57
EIRP	EIRP	dB	P+L_l+G_t	58.07
Prop. Path Length	S	km	input	**3.579E+04**
Space Loss	L_s	dB	Eq. (13-23a)	-190.16
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**3.00**
Rcv. Ant. Diam.	D_r	m	input	**0.23**
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	11.56
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	43.17
Rcv. Ant. Pointing Error	e_r	deg	input	**0.02**
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	0.00
Rcv. Ant. Gain	G_r	dB	G_{rp}+L_{pr}	11.56
System Noise Temp.	T_s	K	input (using Tab	**270.00**
Data Rate	R	bps	input	**4300000.00**
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	20.41
Bit Error Rate	BER	--	input	**1.0E-05**
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK,	**4.50**
Implementation Loss (3)		dB	input (standard	**0.00**
Margin		***dB***	***(1)-(2)+(3)***	***15.91***

Backup

Communication system link budgets — Jeju, South Korea

Freq.	f	Ghz	input	**2.20**
Xmtr Pwr	P	W.	input	**30.0000**
Xmtr Pwr	P	dbW	10 log(P)	14.77
Xmtr line loss	L_l	dB	input	**0.50**
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	42.186
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	11.80
Xmt. Ant. Diam.	D_t	m	input	**0.23**
Xmt. Ant. Pointing Error	e_t	deg	input	**0.02**
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	0.00
Xmt Ant. Gain	G_t	dB	$G_{pt}+L_{pt}$	11.80
EIRP	EIRP	dB	$P+L_l+G_t$	27.07
Prop. Path Length	S	km	input	**3.579E+04**
Space Loss	L_s	dB	Eq. (13-23a)	-190.36
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**3.00**
Rcv. Ant. Diam.	D_r	m	input	**3.90**
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	36.48
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	2.45
Rcv. Ant. Pointing Error	e_r	deg	input	**0.02**
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	0.00
Rcv. Ant. Gain	G_r	dB	$G_{rp}+L_{pr}$	36.48
System Noise Temp.	T_s	K	input (using Tab	**270.00**
Data Rate	R	bps	input	**5000000.00**
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	13.48
Bit Error Rate	BER	--	input	**1.0E-05**
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK,	**4.50**
Implementation Loss (3)		dB	input (standard	**0.00**
Margin		***dB***	***(1)-(2)+(3)***	***8.98***

Freq.	f	Ghz	input	**2.20**
Xmtr Pwr	P	W.	input	**20.0000**
Xmtr Pwr	P	dbW	10 log(P)	13.01
Xmtr line loss	L_l	dB	input	**0.50**
Xmtr Ant. Beamwidth	θ_t	deg	Eq. (13-19)	2.448
Peak Xmt. Ant. Gain	G_{pt}	dB	Eq. (13-20)	36.53
Xmt. Ant. Diam.	D_t	m	input	**3.90**
Xmt. Ant. Pointing Error	e_t	deg	input	**0.02**
Xmt. Ant. Pointing Loss	L_{pt}	dB	Eq. (13-21)	0.00
Xmt Ant. Gain	G_t	dB	$G_{pt}+L_{pt}$	36.52
EIRP	EIRP	dB	$P+L_l+G_t$	50.03
Prop. Path Length	S	km	input	**3.579E+04**
Space Loss	L_s	dB	Eq. (13-23a)	-190.36
Prop. & Polariz. Loss	L_a	dB	Fig. 13-10	**3.00**
Rcv. Ant. Diam.	D_r	m	input	**0.23**
Peak Rcv. Ant. Gain	G_{rp}	dB	Eq. (13-18a)	11.75
Rcv. Ant. Beamwidth	θ_r	deg	Eq. (13-19)	42.19
Rcv. Ant. Pointing Error	e_r	deg	input	**0.02**
Rcv. Ant. Pointing Loss	L_{pr}	dB	Eq. (13-21)	0.00
Rcv. Ant. Gain	G_r	dB	$G_{rp}+L_{pr}$	11.75
System Noise Temp.	T_s	K	input (using Tab	**265.13**
Data Rate	R	bps	input	**4300000.00**
Est. E_b/N_o (1)	E_b/N_o	dB	Eq. (13-13)	12.46
Bit Error Rate	BER	--	input	**1.0E-05**
Rqd. E_b/N_o (2)		dB	Fig. 13-9 (BPSK,	**4.50**
Implementation Loss (3)		dB	input (standard	**0.00**
Margin		***dB***	***(1)-(2)+(3)***	***7.96***

Backup

Concept Trade Studies

Soft Capture

Importance		Concept 1	Concept 2	Concept 3
25%	Functionality	0.79	1.08	1.25
23%	Reliability	0.58	0.97	1.01
17%	Cost	0.22	0.62	0.67
17%	Complexity	0.19	0.61	0.61
5%	Manufacturing Difficulty	0.09	0.19	0.20
5%	Power Consumption	0.13	0.14	0.18
8%	Technology Readiness	0.13	0.36	0.35
1%	Mass	0.05	0.04	0.04
Total Averages:		**2.19**	**4.02**	**4.32**

Hard Capture

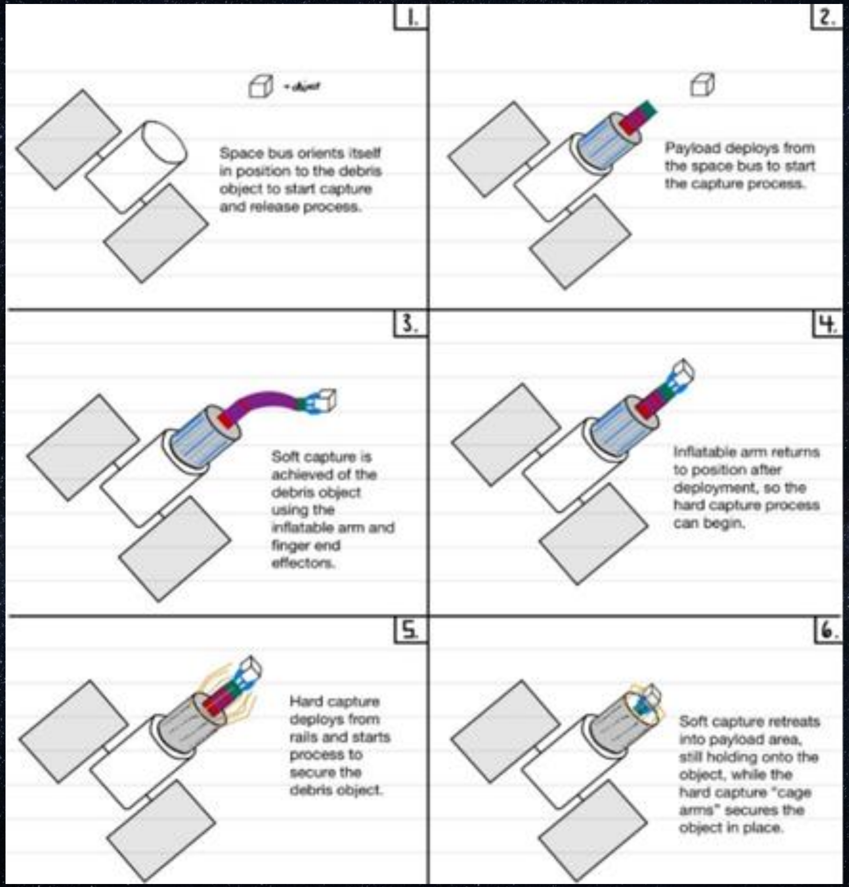
Importance		Concept 1	Concept 2	Concept 3
25%	Functionality	0.75	0.71	1.16
23%	Reliability	0.78	0.66	0.93
17%	Cost	0.53	0.67	0.48
17%	Complexity	0.44	0.69	0.36
5%	Manufacturing Difficulty	0.17	0.21	0.14
5%	Power Consumption	0.15	0.13	0.13
8%	Technology Readiness	0.35	0.31	0.28
1%	Mass	0.03	0.04	0.04
Total Averages:		**3.21**	**3.43**	**3.53**

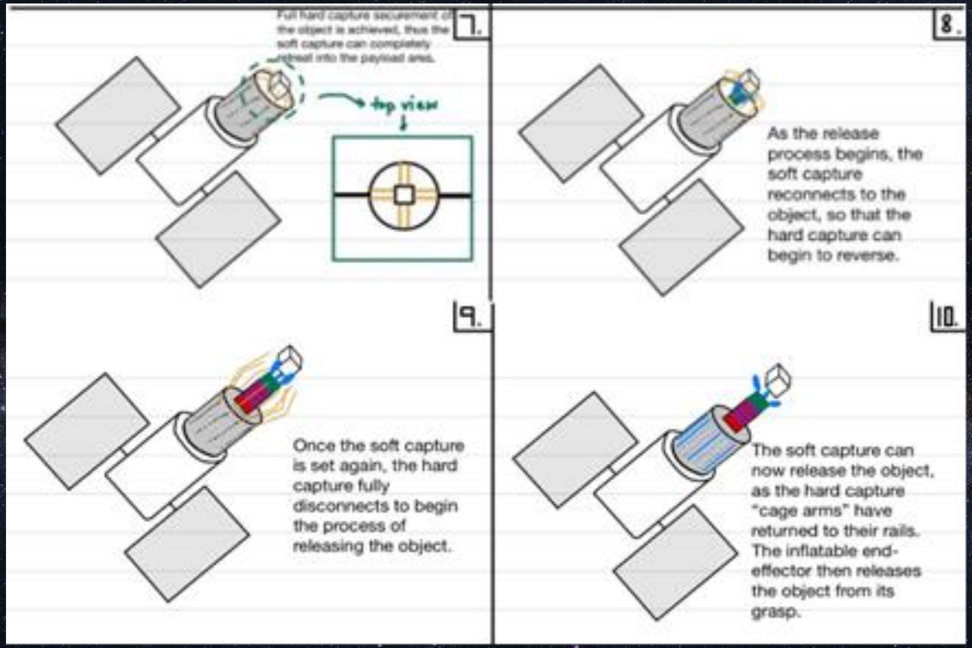
End Effector

Importance		Concept 1	Concept 2	Concept 3
25%	Functionality	0.75	0.79	1.16
23%	Reliability	0.74	0.62	0.93
17%	Cost	0.51	0.62	0.39
17%	Complexity	0.47	0.69	0.61
5%	Manufacturing Difficulty	0.17	0.20	0.17
5%	Power Consumption	0.14	0.13	0.20
8%	Technology Readiness	0.24	0.29	0.24
1%	Mass	0.04	0.03	0.05
Total Averages:		**3.05**	**3.38**	**3.76**

Backup

Concept 1





Backup

Concept 2