VECTOR

VENUS. EXPLORATORY. CUBESAT. TRANSFER. ORBIT. RESEARCHER

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AEE 445 Team 7

Overview

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Mission & Background

Mission Statement

- Relatively little is known about Venus's atmosphere, weather patterns, and toxicity.
- There is a need for high-value, low-cost interplanetary science.
- This mission will be to reach Venus orbit through the means of a cubesat built from COTS.
- Primary need:
    - Build a **CubeSat** with **COTS components** and get it into **Venus** orbit
- Secondary need:
    - Perform useful science with a small and inexpensive instrument
        - Verify existence of lightning

Mission Requirements - Level 1

ID	Requirement	Verification	Parent
MR1.1	System shall execute a Venus orbit insertion burn	Demonstration	Mission Statement
MR1.2	System shall perform a science objective based on the Decadal survey	Demonstration	Mission Statement
MR1.3	System shall increase TRL of cubesat COTS components	Demonstration	Mission Statement

Venus Background

- Venus is the second planet from the sun
- Hottest planet in solar system with average temperature of 462°C
- Venus may have once been Earth-like, but due to the runaway greenhouse effect, its atmosphere is filled with carbon dioxide and is covered in clouds of sulfuric acid that trap heat
- These clouds of sulfuric acid may be responsible for lightning strikes on Venus
- 40 previous missions to Venus (23 successful)
    - 1 in operation (JAXA's Akatsuki - launched 2010, ~520 kg's, ~$300 Million)
- 2 future missions planned to Venus
    - DAVINCI (NASA - scheduled 2029, ~$500 Million)
    - VERITAS (NASA - delayed to 2031, ~$500 Million)

Societal Impacts

- Societal Impacts
  - Inspires young generation of STEM
  - High-value, low-cost science
  - Increases excitement towards smallsat
- Scientific Advancements
  - Venus lightning verification
  - Venus weather patterns
- Technological Advancements
  - Increase TRL of COTS components
  - First cubesat to insert into non-Earth planetary orbit

Constraints

Monetary:

- Estimating budget of **$25 M**
  - Funding sources include government and private sector

Launch:

- **Size**: 12U Cubesat Standard
- **Mass**: 24 Kg
- **Vehicle**: Rocketlab Photon Spacecraft, Electron launch vehicle
- **Timing**: Launch Windows (4/2023, 12/2024, 7/2026, 3/2028, 10/2029)

Assumptions

- VECTOR can rideshare on Rocketlab’s Photon Venus mission, for a trans-Venusian injection burn
- Use of the Deep Space Network (DSN)

Stakeholders

Primary Customer	● National Aeronautics and Space Administration (NASA)
Secondary Customer	● Arizona State University (ASU)
Providers	● Rocketlab ● Jet Propulsion Lab (JPL) ● Smallsat Companies (BCT, Ibeos, etc)
End Users	● Planetary Research Scientists ● Future University/Industry Cubesats

Mission Selection & Overview

Mission Concept Trade Matrix

Arizona State University

Team Totals	For definitions, please see Report 1. Weights are 10%, 10%, 30%, 30%, 20% respectively.											
	Commercial value:		Scientific value:		Delivery difficulty:		Payload difficulty:		Path forward:		Total points:	
Project:	**Average**	**Std**	**Average**	**Std**	**Average**	**Std**	**Average**	**Std**	**Average**	**Std**	**Sum**	**Std**
Venus Cubesat	1.83	0.41	4.17	0.75	3.67	0.82	4.00	1.10	4.17	0.98	3.73	0.99
Cislunar Cubesat	2.00	0.63	4.33	1.03	4.67	0.52	3.00	0.63	4.33	0.82	3.80	1.13
Titan Lander	2.67	1.86	4.50	0.84	1.33	0.52	2.33	0.82	3.33	0.82	2.48	1.18
Enceladus Lander	2.17	1.17	4.17	1.17	1.33	0.52	1.67	0.52	3.00	0.63	2.13	1.14
Europa orbiter	2.00	0.89	3.83	1.33	1.67	0.82	2.67	0.82	2.83	0.41	2.45	0.84
Asteroid mission	3.33	1.37	3.83	0.75	2.00	0.00	2.33	0.52	3.17	0.75	2.65	0.75
Kuiper belt objects	2.00	0.89	4.33	0.52	1.67	0.52	2.67	0.82	3.33	0.82	2.60	1.07
Remote mining	4.83	0.41	3.33	1.37	1.83	0.41	2.33	0.52	4.17	1.17	2.90	1.24
Propellant depot	4.50	0.55	2.00	1.55	2.50	0.84	1.83	0.75	3.83	0.75	2.72	1.18
Observatory for moon	2.83	1.33	3.67	1.21	2.33	0.82	2.50	1.38	3.00	0.63	2.70	0.52
Modular propulsion asteroids	2.83	1.33	2.33	0.52	2.17	0.41	3.33	0.82	3.33	1.03	2.83	0.55

V.E.C.T.O.R TEAM 7

Mission Alternatives - 1.1

Selection Element:	Weights	Custom Components		COTS	
		Motivation	**Score**	**Motivation**	**Score**
Cost	**0.5**	New parts incur high R&D costs + procurement	4	Only procurement cost	2
Payload Capacity	**0.25**	No significant advantage	2.5	No significant advantage	2.5
Lifetime	**0.15**	No significant advantage	2.5	No significant advantage	2.5
Reliability	**0.1**	Slight significant advantage	2	Increasing the TRL	3
Decision Scores:	**1.0**		3.2		2.3

Note:
5 = worst
1 = best

Mission Alternatives - 1.2

Selection Element:	Weights	Fly by		Insertion	
		Motivation	Score	Motivation	Score
Cost	**0.5**	Lower cost per mission, higher overall cost	3	Higher cost per mission, lower overall cost	2
Payload Capacity	**0.25**	Increased payload capacity by 10-15%	2	Decreased payload capacity by 10-15%	3
Lifetime	**0.15**	Limited to time of fly-by	4	Much longer time in service	2
Reliability	**.1**	Less reliable data Less time in proving tech	4	More data available Longer tech life-time	2
Decision Scores:	**1.0**		3		2.25

Note:
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1 = best

Mission Alternatives - 1.3

Selection Element:	Weights	Fully self-propelled		Assisted propulsion	
		Motivation	Score	Motivation	Score
Cost	**0.5**	More fuel & power costs	4	Less power and fuel required	2
Payload Capacity	**0.25**	Smaller area due to increased battery capacity and propulsion fuel reserves	4	Larger area for science mission due to less power or fuel requirements	2
Lifetime	**0.15**	Travel alone + science mission = Build for a Longer mission	2	Science mission will last less time due to no travel	4
Reliability	**.1**	More design/development risk	3	Less design/development risk	2
Decision Scores:	**1.0**		3.6		2.3

Note:
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1 = best

Mission Alternatives - 1.4

Selection Element	Weight	Radio		Magnetometer and Electrostatic Analyzer (ESA)		Neuromorphic Camera	
		Motivation	Score	Motivation	Score	Motivation	Score
Cost	**0.5**	Cost effective	3	Cost effective	3	New and not as cheap	4
Size	**0.1**	No significant advantage	2	No significant advantage	2	No significant advantage	2
Future Missions	**0.2**	Ability to understand the chemical composition of the planet	2	Predict the space weather around Venus, and how Solar Winds interact with the planet	2	Catalog the weather and environment of Venus	1
Societal Impacts	**0.2**	Interesting, but not wholly eye-catching	4	There may not be much interest about what occurs around Venus	3	Lightning and meteor strikes hold potential to excite	1
Scores	**1**		2.9		2.7		2.6

Note:
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1 = best

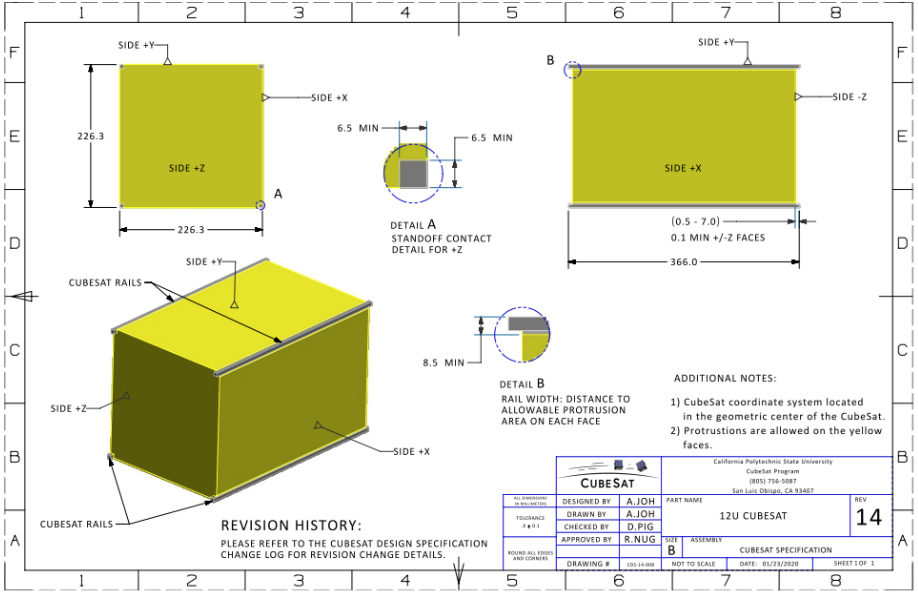
Mission Selection

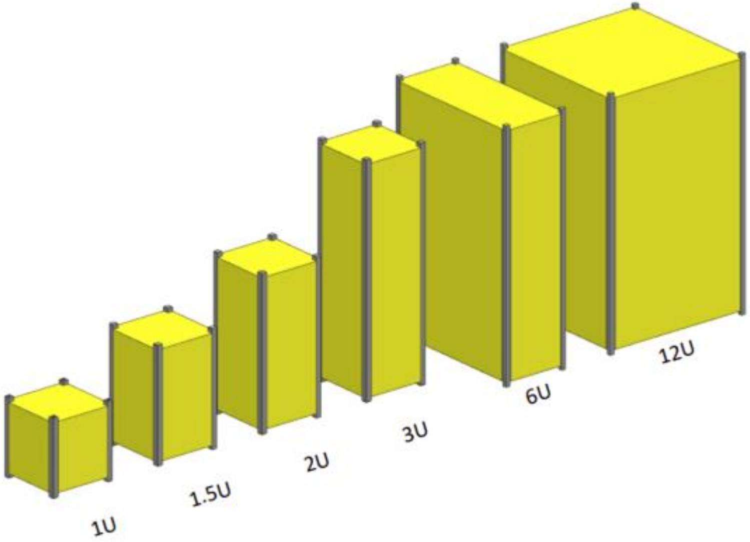
Trade Study:	Selection:	Motivation:
1.1 - Component design	COTS Components	Reduced R&D costs, higher compatibility
1.2 - Orbit	Insertion into Venus Orbit	Longer mission lifetime, more science capability
1.3 - Propulsion to Venus	Assisted propulsion	Higher payload capacity, reduced fuel requirement
1.4 - Payload	Neuromorphic Camera	Slightly more costly, but would engage public interest and fulfill secondary mission statement

Summary: VECTOR is a venusian ride sharing mission built from COTS components to perform an insertion burn with a neuromorphic cammer

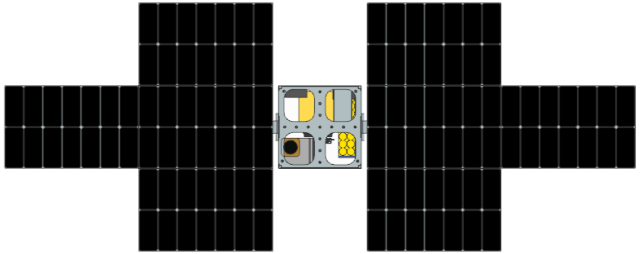
Cubesat

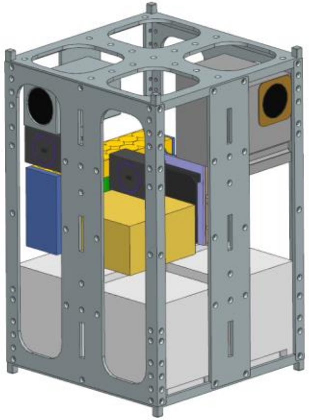
- Cal Poly Standard
- 12U Selected

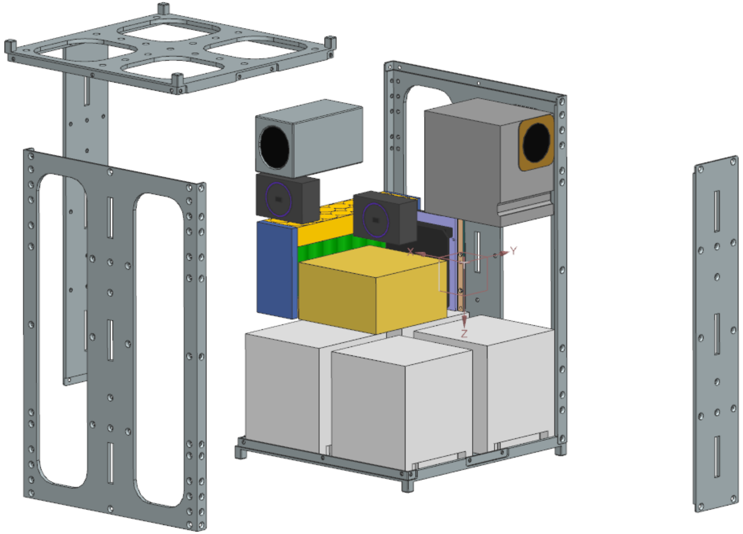


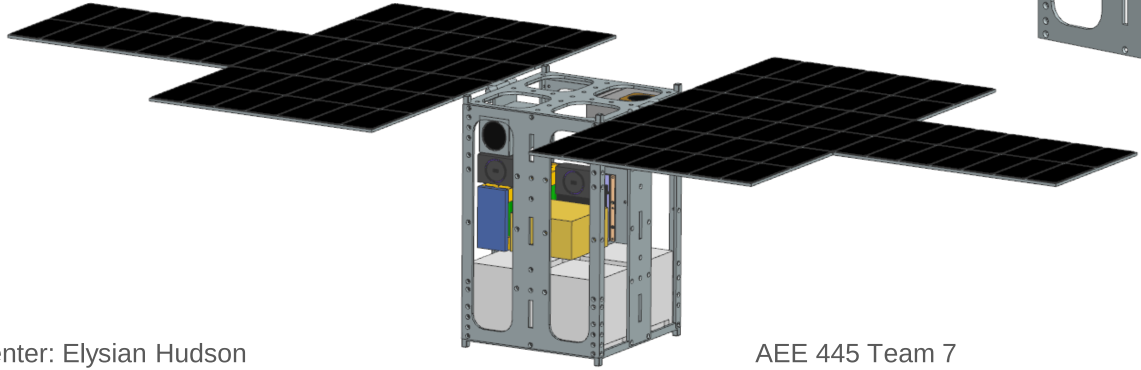


VECTOR CAD Model:

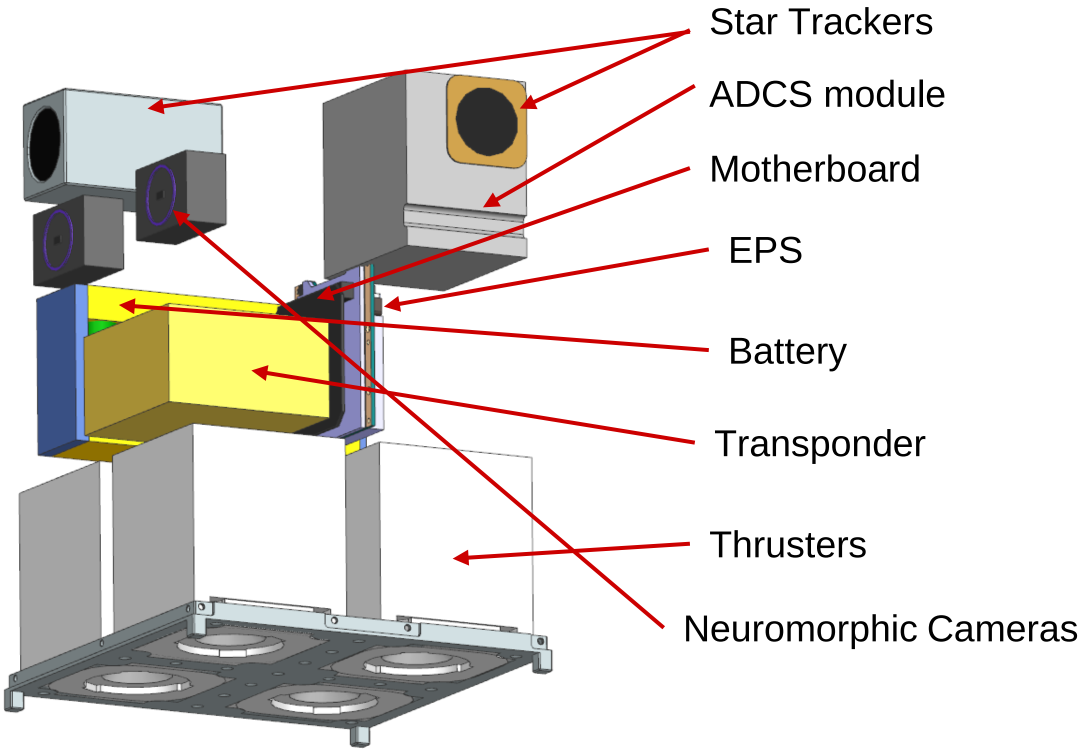


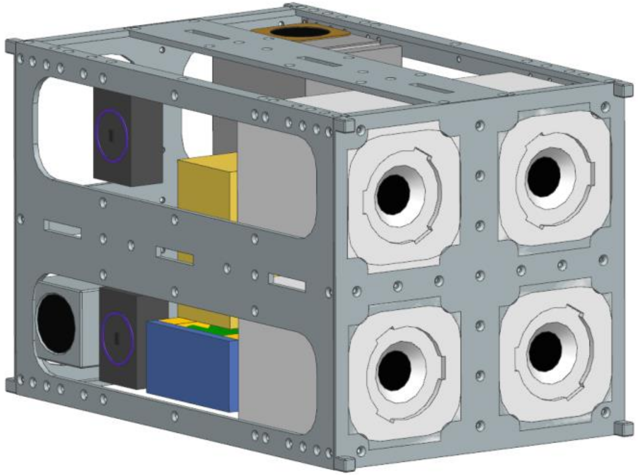






VECTOR CAD Model: Stowed Position

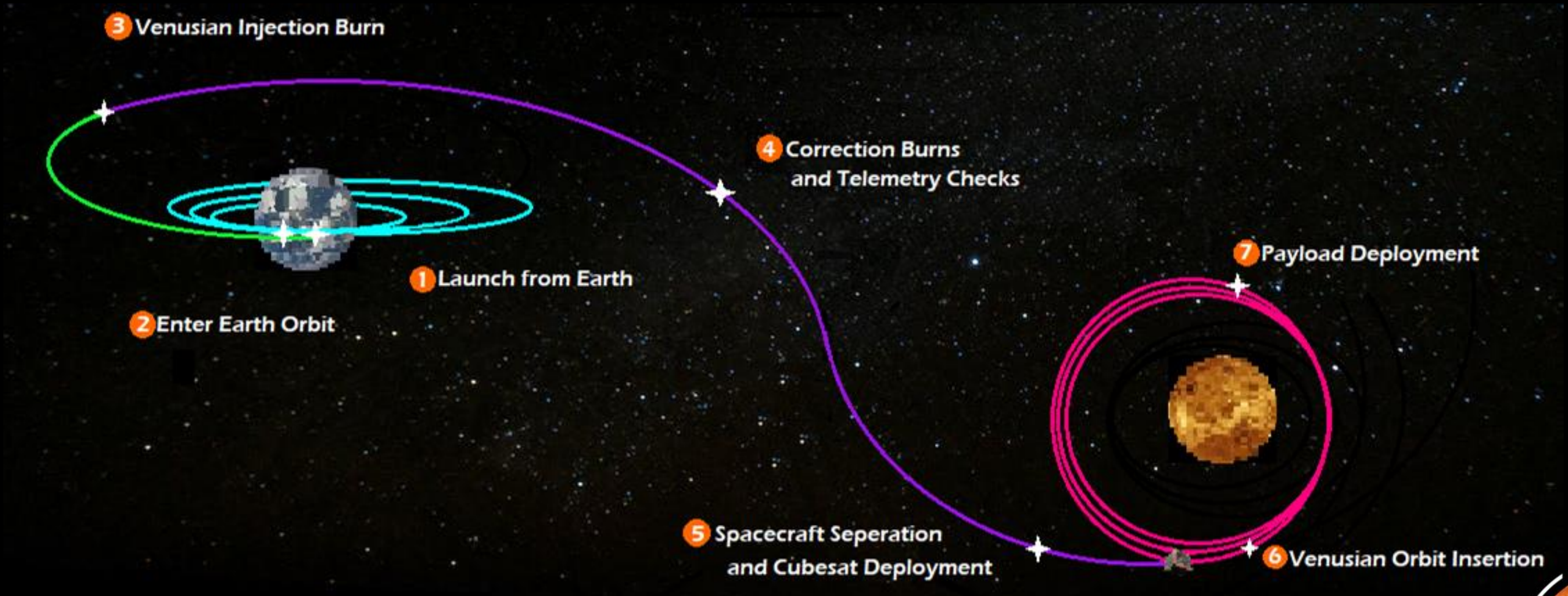




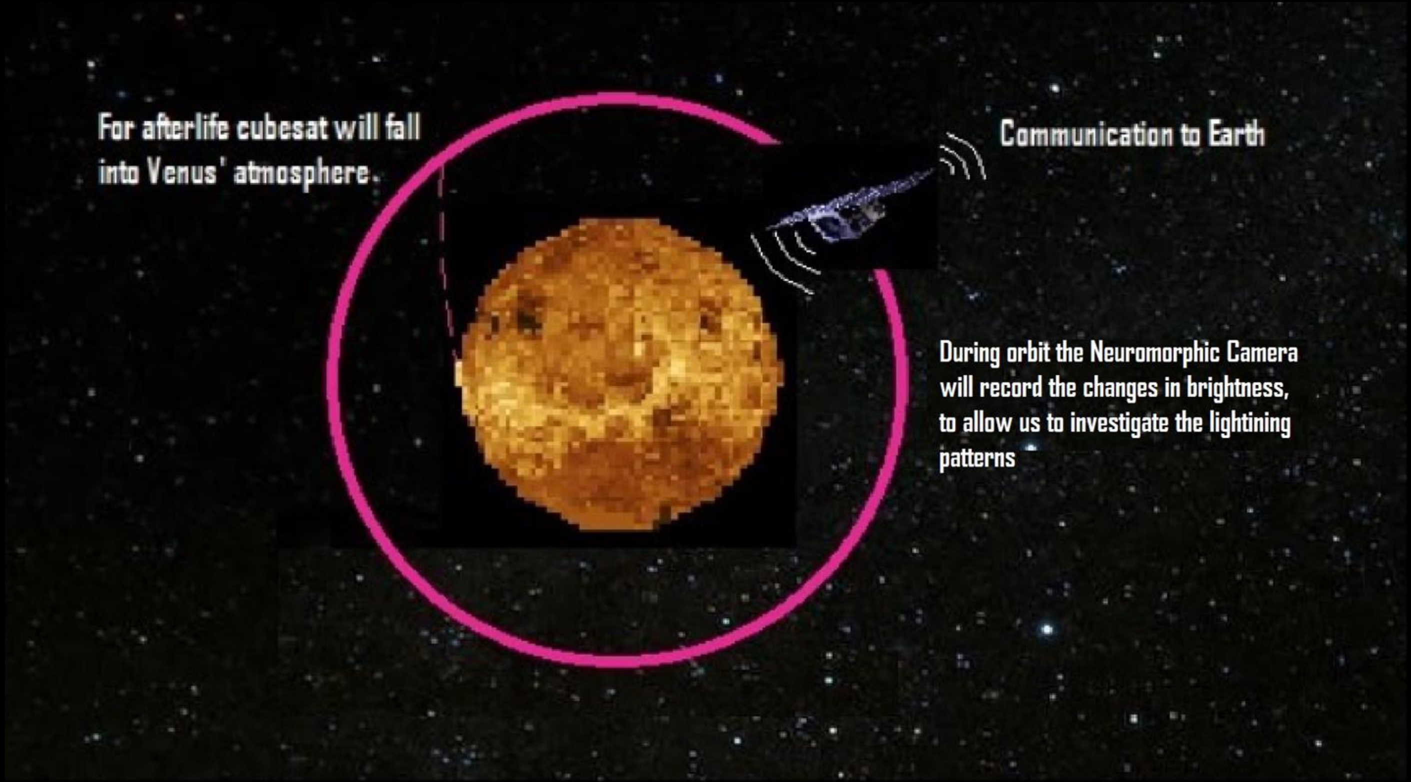
12U Cubesat Deployer

- Deployer Specifications:
  - Max Mass: 24kg
  - Rail Width (X): 340.5mm
  - Rail Height (Y): 226.3mm
  - Rail Length (Z): 226.3mm
- Deployment Mechanism:
  - 4 x Helical Springs

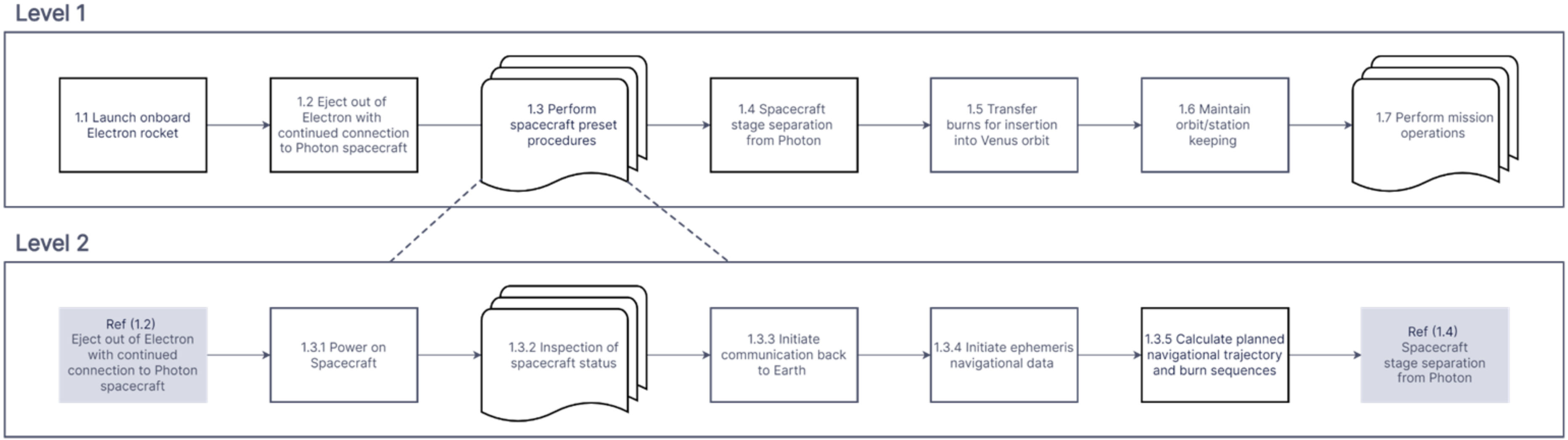
Concept of Operations



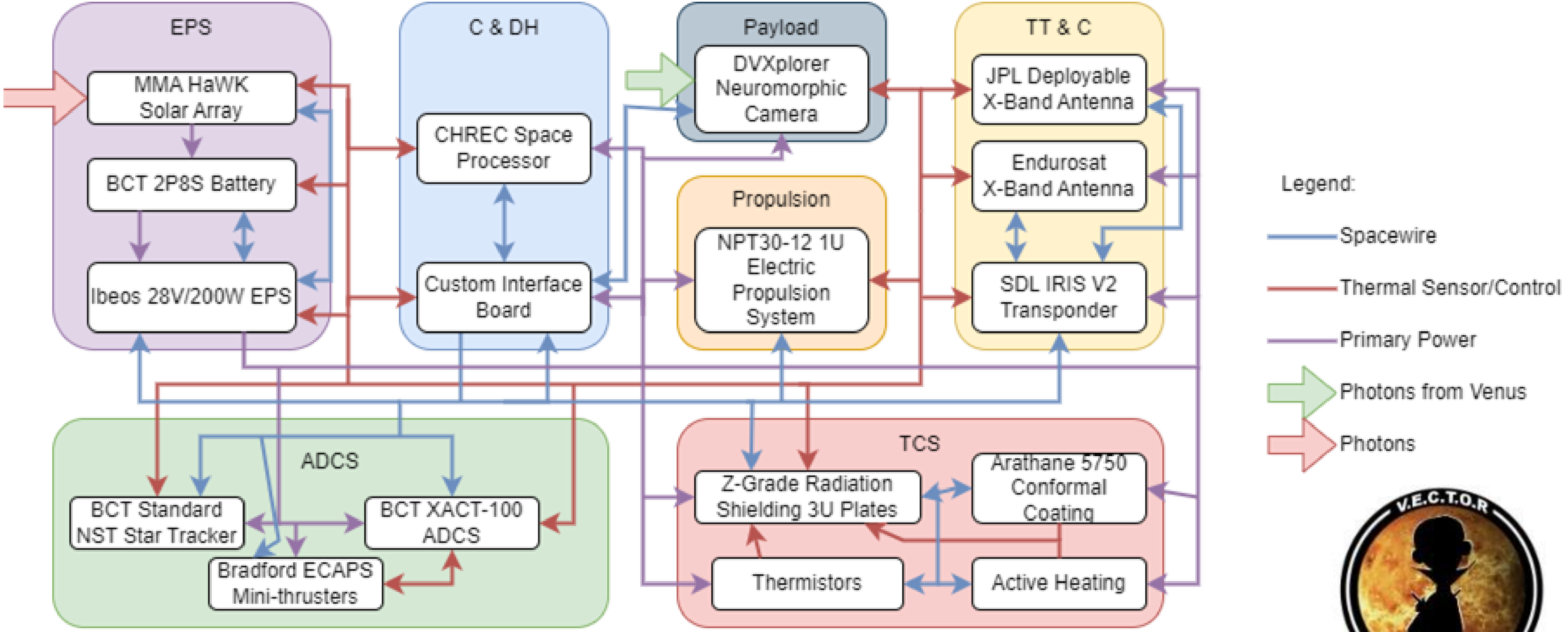
Concept of Operations



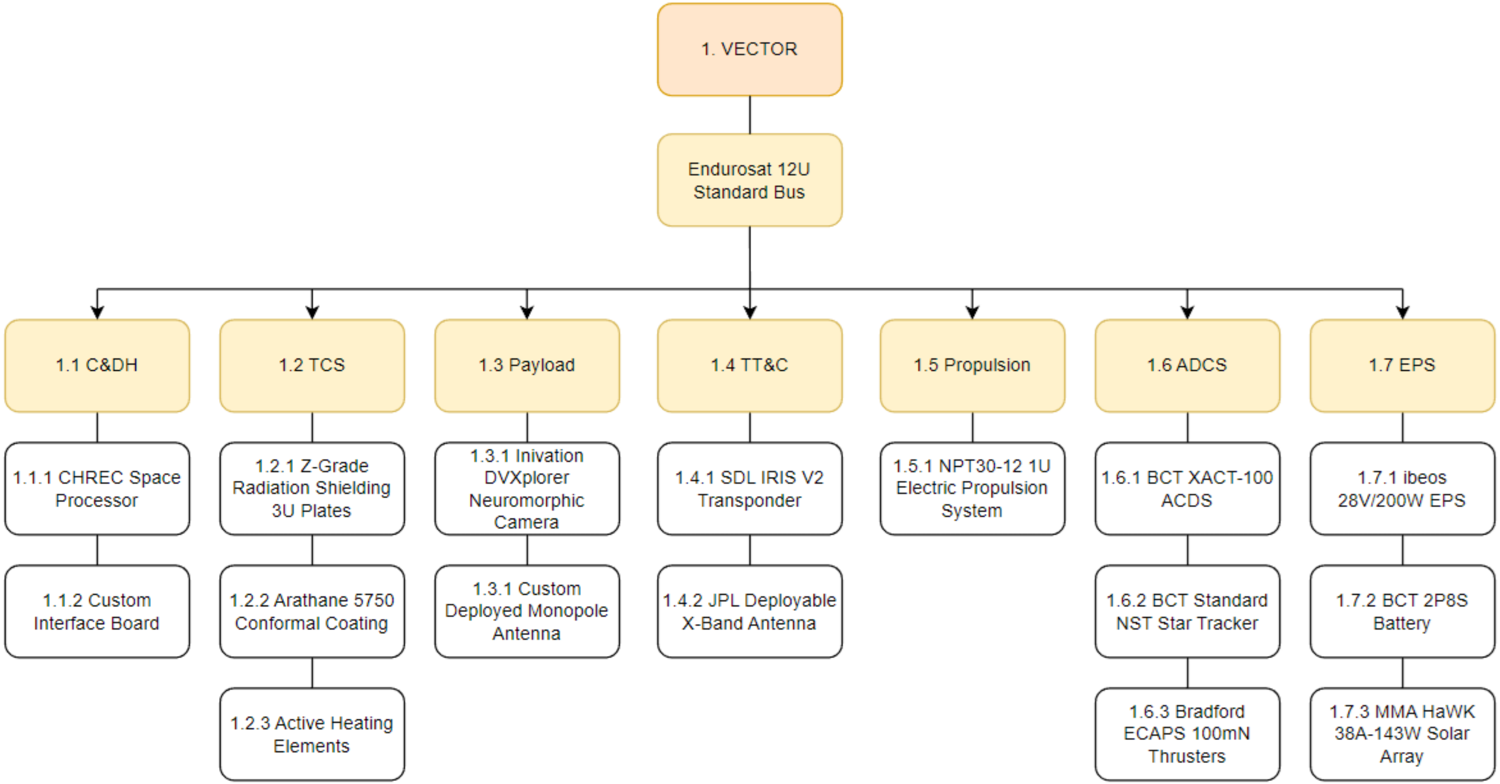
Functional Block Diagram



Physical Architecture



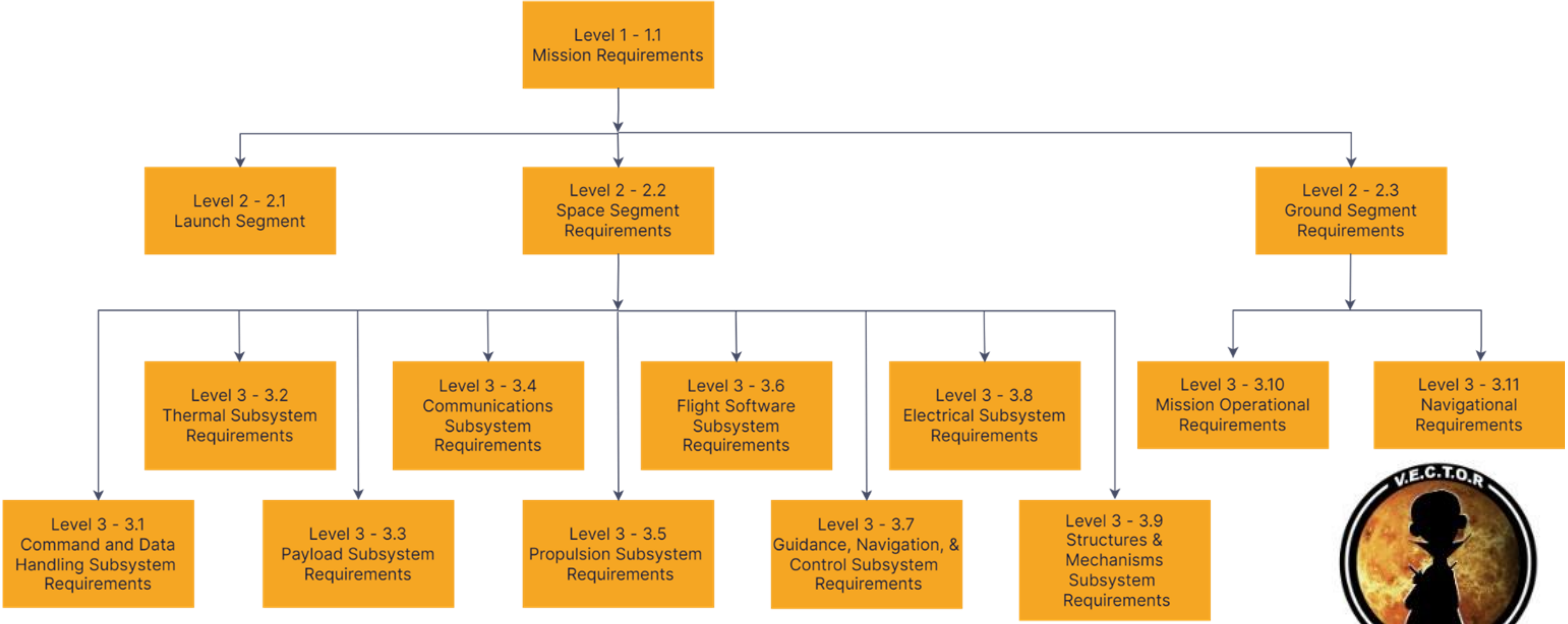
Product Work Breakdown Structure



N2 (Interfaced Diagram)

TT & C	Nav, command, TT & C status data					
Overall system data, payload data	C & DH	Required attitude adjustments	Required thermal countermeasures	Required magnitude thrust	Command data, required attitude data (TBD)	Power required by each system
	ACS status data	ADCS				
Active cooling countermeasures (TBD W)	TCS status data, Active cooling countermeasures (TBD W)	Active cooling countermeasures (TBD W)	TCS	Active cooling countermeasures (TBD W)	Active cooling countermeasures (TBD W)	Active cooling countermeasures (TBD W)
	Propulsion system status data			Propulsion		
	Payload system data, payload result data				Payload	
Electric power (TBD W)	Electric power (TBD W), EPS status data	Electric power (TBD W)	Electric power (TBD W)	Electric power (TBD W)	Electric power (TBD W)	EPS

Requirements Flowdown



Launch Requirements - Level 2

ID	Requirement	Verification	Parent	Child
LS-2.1	System shall be designed for launch onboard Rocket Lab Electron Rocket, as stated in “Payload User’s Guide V6.6”	Inspection	MR1.2	TBD
LS-2.2	Launch system shall have ability to insert spacecraft into Venus transfer orbit	Demonstration	MR1.1	TBD
LS-2.3	System shall have primary vibrational and acoustical modes that do not correspond to launch vehicles primary modes	Testing	MR1.2	TBD
LS-2.4	Launch shall occur only when Venus is nearing closest approach to Earth	Inspection	MR1.1	TBD

Spacecraft Requirements - Level 2

ID	Requirement	Verification	Parent	Child
SC-2.1	System shall have a minimum 2U payload capacity	Inspection	MR1.2	TBD
SC-2.2	System shall have a minimum operational life of 510 days	Analysis	MR1.3	TBD
SC-2.3	System shall generate sufficient power for each subsystem	Testing	MR1.2	TBD
SC-2.4	System shall have a controlled deorbit plan	Analysis	MR1.3	TBD
SC-2.5	System shall have ability to power on and off	Demonstration	MR1.1	TBD

Spacecraft Requirements - Level 2

ID	Requirement	Verification	Parent	Child
SC-2.6	System shall be able to stay within allowable temperature range for each subsystem	Testing	MR1.2	TBD
SC-2.7	System shall be powered off from time of delivery through orbit delivery	Testing	MR1.1	TBD
SC-2.8	System shall wait a minimum of 30 minutes after deployment switches triggered before releasing deployables	Testing	MR1.2	TBD
SC-2.9	System shall have attitude control accuracy to meet pointing constraints	Testing	MR1.2	TBD

Spacecraft Requirements - Level 2

ID	Requirement	Verification	Parent	Child
SC-2.10	System shall retain operational integrity throughout the mission duration	Testing	MR1.2	TBD
SC-2.11	System shall be protected against radiation during entire duration of mission	Testing	MR1.3	TBD
SC-2.12	System shall have at minimum one deployment switch	Inspection	MR1.2	TBD
SC-2.13	System shall be capable of communication back to Earth on average once every Earth day	Test	MR1.2	TBD

Spacecraft Requirements - Level 2

ID	Requirement	Verification	Parent	Child
SC-2.14	System shall have redundant downlink methods	Inspection	MR1.2	TBD
SC-2.15	System shall incorporate mechanism(s) to prevent premature subsystem operations	Inspection	MR1.2	TBD
SC-2.16	System shall provide flight system telemetry	Demonstration	MR1.2	TBD
SC-2.17	System shall have enough fuel to remain in desired orbit for 510 days	Analysis	MR1.1	TBD

Ground Requirements - Level 2

ID	Requirement	Verification	Parent	Child
GS-3.1	System shall be operational during the entirety of the mission	Inspection	MR1.3	TBD
GS-3.2	System shall interface with the flight system to upload commands	Inspection	MR1.2	TBD
GS-3.3	System shall interface with the flight system to receive and process telemetry and payload science data	Inspection	MR1.2	TBD
GS-3.4	System shall be available for communication with the flight system at any point during a 24-hour period	Inspection	MR1.2	TBD

System Performance Requirements

ID	Requirement	Verification	Parent	Child	status
LS-2.3	System shall have primary vibrational and acoustical modes that do not correspond to launch vehicles primary modes	Testing	MR1.2	TBD	TBD
SC-2.2	System shall have a minimum operational life of 510 days	Analysis	MR1.2	TBD	TBD
SC-2.3	System shall generate sufficient power for each subsystem	Testing	MR1.2	TBD	meeting
SC-2.5	System shall be able to stay within allowable temperature range for each subsystem	Testing	MR1.2	TBD	TBD
SC-2.13	System shall be capable of communication back to Earth on average once every Earth day	Test	MR1.2	TBD	meeting
SC-2.22	System shall contain enough propellant to satisfy on-orbit stationkeeping requirements	Testing	MR1.1	TBD	meeting

Critical Design Requirements

ID	Requirement	Verification	Parent	Child	Status
SC-2.1	System shall have a minimum 2U payload capacity	Inspection	MR1.2	TBD	meeting
SC-2.8	System shall have attitude control accuracy to meet pointing constraints	Testing	MR1.2	TBD	meeting
SC-2.11	System shall be protected against radiation during entire duration of mission	Testing	MR1.3	TBD	TBD
PRO-3.5.1	System shall produce a velocity increment of at least 1 km/s	Testing	MR1.1	TBD	meeting

Sub-System Level

Computing & Data Handling (CDH)

CDH Requirements - Level 3

ID	Requirement	Verification	Parent	Status
CDH-3.1.1	System shall resist at least 40 krad.	Testing	SC-2.12	TBD
CDH-3.1.2	System shall collect telemetry data for communication at minimum every 12 hours.	Inspection	SC-2.12	TBD
CDH-3.1.3	System shall operate neuromorphic camera during orbit.	Inspection	MR-1.2	TBD
CDH-3.1.4	System shall have at minimum 1GB of local storage.	Inspection	SC-2.12	TBD
CDH-3.1.5	System shall have at minimum 200 MHz of processing power.	Inspection	SC-2.12	TBD

Analysis of Alternatives - Processor

Selection Element	Weight	Alen Space TRISKEL		EnduroSat OBC		CHREC Space Processor	
		Motivation	Score	Motivation	Score	Motivation	Score
Cost	0.2	Unknown	3	$4,300-$10,400	2	Unknown	3
Weight	0.1	200 g	5	130 g	3	74 g	1
Radiation Resistance	0.5	No data, TRL 4	5	40 krad	3	100 krad	1
Storage	0.1	1 GB, room for more	4	8 GB	1	4 GB	2
Processing	0.1	280 MHz/32b	4	216 MHz	5	766 MHz	2
Scores			**4.4**		**2.8**		**1.6**

Note:
5 = worst
1 = best

Technical Details

CHREC Space Processor

- Xilinx Zynq 7020 System on Chip
- Reconfigurable FPGA
- CPU: 766 MHz
- Memory: 32 Gbit FM, 2 Gbit NAND, 8 Gbit SDRAM
- Linux OS
- Radiation tolerant, up to 100 krads
- Vibration: NASA GEVS Acceptance Levels
- Temperature: 0°C to +70°C

Thermal Control System (TCS)

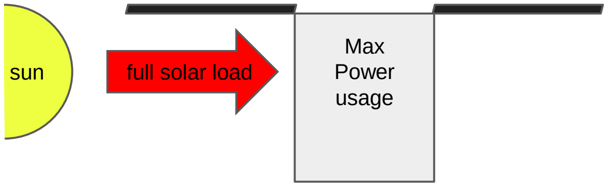
TCS Requirements - Level 3

ID	Requirement	Verification	Parent	Status
TCS-3.2.1	System shall maintain internal operating temperature between 0℃ and 50℃.	Testing	SC-2.6	TBD
TCS-3.2.2	System shall have a nominal operating temperature of 20℃.	Analysis	SC-2.6	TBD
TCS-3.2.3	System shall be have the ability to modulate the internal temperature of the spacecraft by ± 25 ℃	Testing	SC-2.6	TBD
TCS-3.2.4	System shall have a peak power usage of 154.7 W.	Testing	SC-2.6	TBD

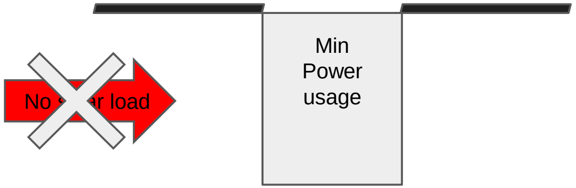
1st Order Thermal Analysis

Assumptions:

1. If the system can achieve a **net zero load in both the hot case and the cold case**, then the system can **survive any temperature within that range**.
   a. **Hot Case:** during insertion burn while in sun

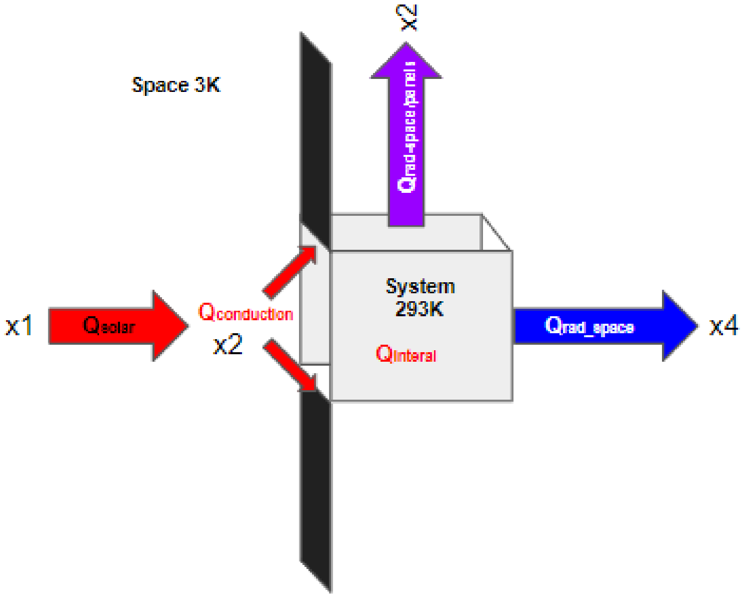


   b. **Cold Case:** in orbit & venus in between SC & sun



1. If the steady state NASTRAN simulation attains similar results as the hand calculations, then the model can be considered **validated** and the transient simulation can be trusted.
2. For internal loads; **1-Watt of power consumption is equal to 1-Watt of heat generation** because of the inefficiencies of microprocessors.
3. Average distance between spacecraft and sun is 0.7 AU. (~ avg sun-venus radius)
4. Only radiating to space (venus/sun are sufficiently far enough away)

Thermal Calculations



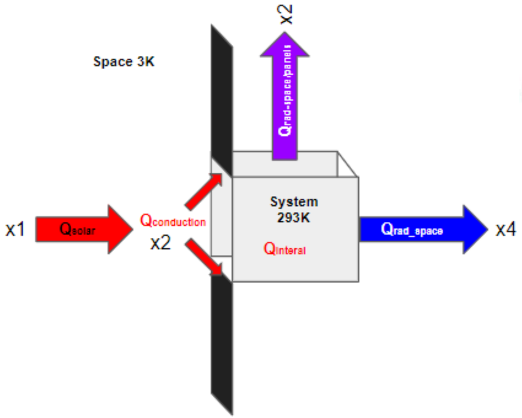
Governing Equations

- Radiation $Q = \varepsilon\sigma FA(T_1^4 - T_2^4)$
- Conduction $Q = kA(T_1 - T_2)/L$

Thermal Controls:

- Adjust emissivity
- Adjust absorptivity
- Material Selection for thermal conductances
- Use of MLI
- Radiators

Thermal Calculations

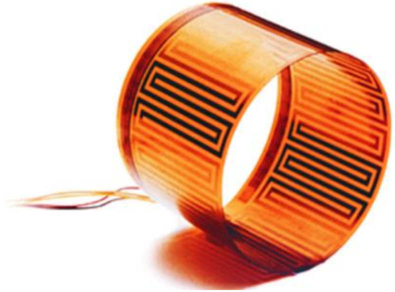


Hot Case, initial NO TCS implimented	
Q_solar, W	42.851328
Q_internal, W	154.7
Q_rad-space, W	-36.31
Q through Solar Panel	
Temp of SP faceing SC	
Q_cond_engine	57041.23
Q_rad-space/panels, W	72.59
Total Conductance	2.198494193
Q_cond-panels, W	314.7144437
Q_in, W	57589.78
Q_out, W	-36.31
Q_net, W	**57553.46**
if positive system is heating, if negative system is cooling. If 0 assume ss stable	

Hot Case, with TCS		TCS Method
Q_solar, W	27.1391744	Paint sun-side white
Q_internal, W	38.9	
Q_rad-space, W	-0.45	Painted Black
Q_rad-space/panels, W	-63.02	wrap in MLI & paint black
Q_cond-panels, W	0.000	aerogell insulation
Q_cond_engine	0	aerogell insulation
Q_in, W	66.04	
Q_out, W	-63.47	
Q_net, W	**2.56**	
if positive system is heating, if negative system is cooling. If 0 assume ss stable		

Cold Case	
Q_solar, W	0
Q_internal, W	55.91
Q_rad-space, W	-0.45
Q_rad-space/panels, W	-63.02
Q_cond-panels, W	0.000
Q_in, W	55.91
Q_out, W	-252.54
Q_net, W	**-7.56**
if positive system is heating, if negative system is cooling. If 0 assume ss stable	

Active/Passive Thermal Controls



Mounting	Acrylic Adhesive (PSA)
Thickness (in)	0.060
Min Temp (°F)	-26
Max Temp (°F)	212
Weight (oz)	0.080
Style	Etched Kapton/WA
X dim (in)	1.00
Y dim (in)	4.00
R (Ω)	23.59
AWG	26
Area (in^2)	3.3232
Volt	28.00
Watt	33.2
Watt Density (w/in^2)	10.00

Payload (PAY)

Payload Requirements - Level 3

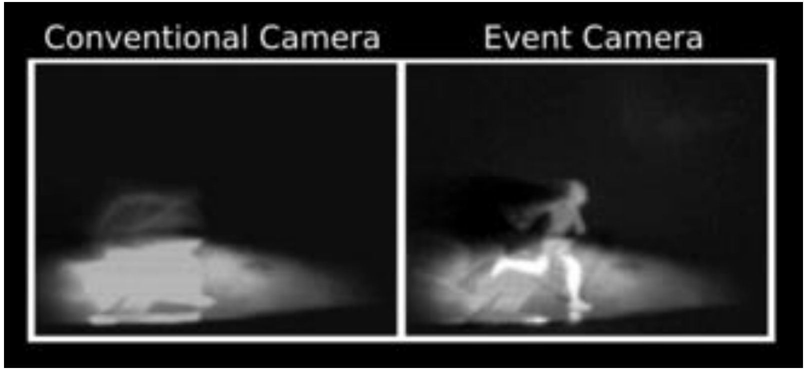
ID	Requirement	Verification	Parent	Status
PAY-3.3.1	System shall be an instrument sensitive to lightning	Test	MR1.2	Meeting
PAY-3.3.2	System shall consist of shielding to moderate radiation damage and background signals	Analysis	SC-2.11	TBD
PAY-3.3.3	System shall reside inside the spacecraft volume	Inspection	SC-2.1	Meeting
PAY-3.3.4	System shall have a method for confirmation of event detection	Demonstration	MR1.2	Meeting

Science Traceability Matrix (STM)

Science Goals	Science Objectives	Science Measurement Requirements: Physical Parameters	Science Measurement Requirements: Observables	Instrument Performance Requirements	
There is strong evidence to suggest that lightning forms on the planet Venus	Determine if lightning forms from the sulfuric acid clouds within the Venusian atmosphere	Identify the images of lightning strikes in the Venusian atmosphere	Collect low-latency, high-speed, light-changing events with no motion blur over a large area	Latency Range:	<150ms
				Framerate:	>7,000 fps
				Dynamic Range	>70 dB
				Power Consumption:	30 mW
	Confirmation of the existence of lightning	Identify the radio signals emitted from lightning strikes on Venus	Collect radio waves in the very low frequency (VLF) range of 10-80 kHZ	Frequency Range:	1kHz-300MHz
				Dynamic Range	>/=50 dB
				Power Consumption:	3-26W

Neuromorphic Camera

- Neuromorphic camera is inspired by the biology of the human retina
- Captures the motion of an object, also called events
- An array of pixels react to fluctuations in brightness within a given scene
- When an event is captured, motion blur is significantly reduced allowing for a clearer image
- Contains high dynamic range, allowing for a greater detection between light and dark patches
- Typically does not incorporate color or texture



Technical Details

Instrument	Instrument Performance Requirements	Predicted Instrument Performance
Neuromorphic Camera: Inivation DVXplorer	Latency Range:	20ms
	Framerate:	10^6 fps
	Dynamic Range	120dB
	Power Consumption:	~ .7W
Radio: Red Pitaya STEMlab 125-14	Frequency Range:	DC - 50MHz
	Dynamic Range	~50dB
	Power Consumption:	~10W

Telemetry Tracking & Control (TT&C)

TT&C Requirements - Level 3

ID	Requirement	Verification	Parent	Status
TTC-3.4.1	System shall communicate through DSN	Inspection	SC-2.16	meeting
TTC-3.4.2	System shall withstand radiation up to particles with 20GeV	Testing	SC-2.10	TBD
TTC-3.4.3	System shall communicate back to Earth on average once per day	Analysis	SC-2.12	meeting
TTC-3.4.4	System shall compile telemetry check data every 12 hours	Testing	SC-2.16	TBD
TTC-3.4.5	System shall include redundant communication systems	Inspection	SC-2.14	meeting

Analysis of Alternatives - Antenna

Selection Element	Weight	MarCO-type Custom HGA/MGA/LGA (X-Band)		Syrlinks SPAN-X-T3		Endurosat Module (X-Band)	
		Motivation	Score	Motivation	Score	Motivation	Score
Weight	0.2	1.25 kg	4	65 g	2	53 g	1
Cost	0.1	~ $760k	4	Unknown	3	$8,400	1
Data rate	0.3	Max 1kbps up, 8kbps down	2	Unknown	3	Unknown	3
Radiation resistance	0.3	Unknown [DS Exp.]	2	Unknown [FH Unk.]	5	Unknown [FH Unk.]	5
Data loss	0.1	X-Band	1	X-Band	1	X-Band	1
Scores			**2.5**		**3.2**		**2.8**

Note:
5 = worst
1 = best

Analysis of Alternatives - Radio

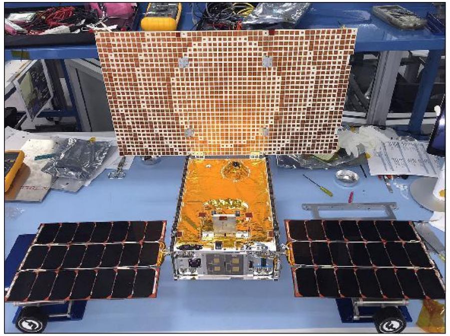
Selection Element	Weight	JPL IRIS v.2		GD Small Deep Space Transponder	
		Motivation	Score	Motivation	Score
Weight	0.2	1.2 kg	2	3.2 kg	4
Cost	0.2	$500k	2	~ $5 mil	4
Data rate [BPSK]	0.3	Max 8kbps up, 6.25 Mbps down	3	Max 4kbps up, 15 Mbps down	2
Radiation resistance	0.2	> 23.0 krad	4	50 krads	2
Data loss	0.1	X-Band	3	X-Band and Ka-Band	2
Scores			**2.8**		**3.0**

Note:
5 = worst
1 = best

Technical Details

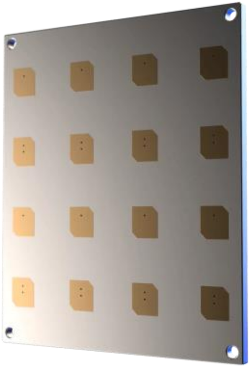
Mar-CO Custom Antenna Arrays:

- Frequency Range = 8-12 GHz
- Low Gain = 6dBi
- Medium Gain = 9dBi
- High Gain = 29.2 dBi
- Mass = ~1 kg
- Power = 4W



Endurosat X-band 4x4 Patch:

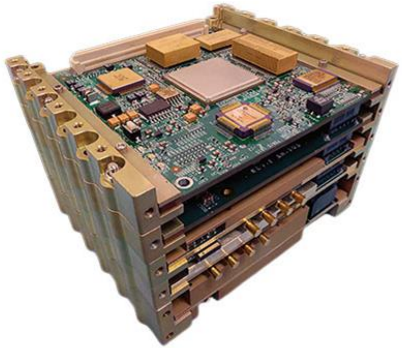
- Frequency Range = 8.25 - 8.4 GHz
- Gain = 6+ dBi
- Mass = ~3g
- Power = 4W

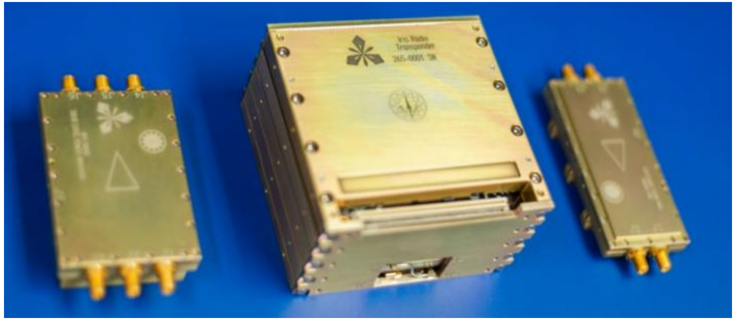


Technical Details

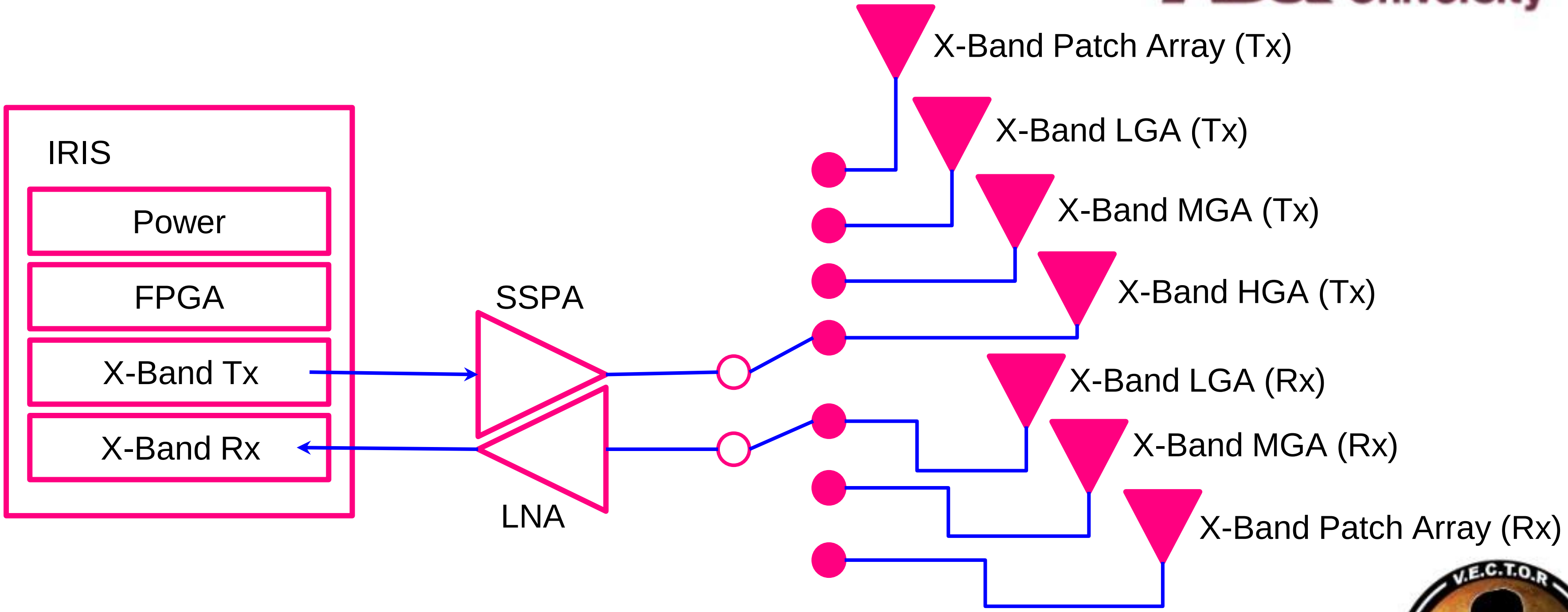
JPL IRIS v.2 Radio

- Dry Mass = 1.1 kg
- Average Power = 35.0 W DC power consumption at 3.8 W RF
- Transponder Volume = ~0.5U
- X-Band: 7.2 GHz uplink, 8.4 GHz downlink
- Design Lifetime = ~3yr
- Noise Figure: 2.2 dB X-Band
- Carrier Tracking Signal Range: -70 to -130 dBm
- Operating Temperature: 253 K to 323 K





Block Diagram



Propulsion (PRO)

Propulsion Requirements - Level 3

ID	Requirement	Verification	Parent	Status
PRO-3.5.1	VECTOR shall produce a velocity increment of at least 1 km/s	Test	MR-1.1	TBD
PRO-3.5.2	System shall retain at least TBD kg of propellant for deorbit burn	Demonstration	SC-2.4	TBD
PRO-3.5.3	System shall contain a propellant depletion gauge	Inspection	SC-2.17	Meeting
PRO-3.5.4	System shall contain at least one redundant thruster	Inspection	MR-1.1	Meeting
PRO-3.5.5	Propulsion system shall monitor and control the S/C thrust	Test	SC-2.16	Meeting

Analysis of Alternatives - Propulsion

Selection Element	Weight	Electric Ion Propulsion		Bi-Propellant		Mono-Propellant	
		Motivation	Score	Motivation	Score	Motivation	Score
Mass	**0.4**	Does not require much propellant mass to achieve needed Isp	1	Will consume large amounts of propellant	3	Will consume large amounts of propellant	3
Complexity	**0.10**	Ionization process less complex as compared to liquid feed systems	2	Feed Systems more complex compared to mono-propellant	4	Feed System slightly less complex than bi-propellant	3
Cost	**0.25**	Cost effective compared to liquid propellant	2	Separate fuel and oxidizer increases costs	5	Less costly than Bi-Propellant	4
Efficiency	**0.25**	Produces small thrust but high Isp	1	Works best for medium to heavy satellites and spacecrafts	5	Good in-space propulsion for smaller maneuvers (end-of-life)	3
Scores	**1.0**	**Best Choice**	**1.35**		**4.1**		**3.25**

Note:
5 = worst
1 = best

Note: 5 = worst ; 1 = best

Trajectory Details

ΔV Requirements	
Photon	3.42 km/s
VECTOR	0.4 km/s (minimum) - 0.97 km/s (nominal)

Target Orbit Parameters			
Apoapsis	Periapsis	Orbit Period	Eccentricity
40,000 km	1,000 km	13.25 hours	0.734

- Transfer period of 144 days from LEO to Venus capture
- VECTOR delta V can be minimized to around 0.4 km/s, the minimum needed to enter Venus orbit (e = ~0.98). This will be the contingency plan in case of propulsion system anomalies.
- Contingency orbit will reduce effectiveness of payload, but still satisfy MR-1.1

ΔV Calculations

ΔV_1 to achieve transfer orbit (Photon):

Transfer orbit parameters

$$V_{a,t} = \sqrt{2\mu_{sun}\frac{r_V}{r_E(r_E + r_E)}} = 27.72\frac{km}{s}$$

$$V_{p,t} = \sqrt{2\mu_{sun}\frac{r_E}{r_V(r_E + r_V)}} = 37.45\frac{km}{s}$$

Desired excess velocity after exiting Earth's SOI

$$V_{\infty,e} = V_E - V_{a,t} = 2.058\frac{km}{s}\,relative\ to\ Earth$$

ΔV_1 to initiate transfer is given by

$$\Delta V_1 = V_{after\ burn} - V_{park}$$

Velocity in LEO parking orbit

$$V_{park} = \sqrt{\frac{\mu_{Earth}}{r_{park}}} = 7.78\frac{km}{s}$$

Required velocity after burn to achieve desired excess velocity

$$V_{after\ burn} = \sqrt{V_{\infty,e}^2 + 2\frac{\mu_{Earth}}{r_{park}}} = 11.2\frac{km}{s}\,relative\ to\ Earth$$

Thus, required ΔV_1 for Photon to initiate transfer orbit is

$$\Delta V_1 = V_{after\ burn} - V_{park} = \mathbf{3.42\frac{km}{s}}$$

Necessary Constants:

$r_E = 1.469 \times 10^8$ km (mean Sun-Earth distance)

$r_V = 1.0874 \times 10^8$ km (mean Sun-Venus distance)

R_V = 6,051 km (mean Venus radius)

$\mu_{sun} = 1.327 \times 10^{11}\ km^3/s^2$

$\mu_{Venus} = 324{,}860\ km^3/s^2$

$\mu_{Earth} = 398{,}600\ km^3/s^2$

V_E = 29.78 km/s (mean orbital speed)

V_V = 35.02 km/s (mean orbital speed)

ΔV Calculations

ΔV_2 to capture into elliptical 1000km x 40,000km Venus orbit (VECTOR)

Excess velocity upon arrival into Venus SOI, relative to Venus

$$V_{\infty,V} = V_{p,t} - V_V = 2.43\,\frac{km}{s}\,relative\ to\ Venus$$

Semi-major axis of hyperbolic arrival trajectory

$$a = -\frac{\mu_{Venus}}{V_{\infty,V}^2} = -55{,}015.3\ km$$

Velocity at closest approach (1000km above surface)

$$V_{p,approach} = \sqrt{\frac{2\mu_{Venus}}{r} + \frac{\mu_{Venus}}{a}} = 9.9\,\frac{km}{s}\,relative\ to\ Venus$$

Desired orbit parameters:

$$r_a = 46{,}051\ km, r_p = 7{,}051\ km$$

$$a = \frac{r_a + r_p}{2} = 26{,}551\ km$$

$$e = 1 - \frac{r_p}{a} = 0.734$$

Velocity at periapsis of desired orbit

$$V_{p,desired} = \sqrt{\frac{\mu_{Venus}}{a}\left(\frac{1+e}{1-e}\right)} = 8.93\,\frac{km}{s}$$

Thus, ΔV_2 required to capture into elliptical Venus orbit is the velocity at periapsis of desired orbit minus our velocity at closest point of our hyperbolic approach:

$$\Delta V_2 = V_{p,desired} - V_{p,approach} = \mathbf{-0.97\ km/s}$$

Note that the negative velocity indicates that we will be slowing down to capture. Delta V can be further reduced by increasing eccentricity however this will decrease the usefulness of our payload. Camera will be most effective at close proximity to the surface.

Propulsion System

4 x NPT30-I2 1U Electric Propulsion System

Wet Mass	1.2 kg
Size	96mm x 96mm x 113mm
Propellant	Solid Iodine
Total Power	35-65 W
Specific Impulse	<2400s
Input Voltage	12-28 V
Operating Temperature	-40 - 50 C
Radiation Tolerance	>20 krad

Attitude Determination & Control System (ADCS)

ADCS Requirements - Level 3

ID	Requirement	Verification	Parent	Status
ADCS-3.7.1	System shall control the spacecraft attitude to reference frames to support default, propulsion, and science pointing modes	Analysis	SC-2.9	Meeting
ADCS-3.7.2	System shall autonomously control pointing of the solar array to within 2 degrees of the angle that provides optimal Sun illumination of the solar array in any attitude	Analysis	SC-2.9	TBD
ADCS-3.7.3	System shall provide attitude control of < 1 degree in all axes	Analysis	SC-2.9	Meeting
ADCS-3.7.4	System shall maintain and propagate on-board estimates of the spacecraft attitude and state vector	Analysis	SC-2.9	TBD

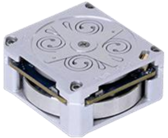
Analysis of Alternatives - ADCS

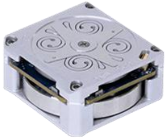
Selection Element	Weight	BCT XACT-100		AAC Clyde Space IADCS400		CubeSpace CubeADCS Gen 2	
		Motivation	Score	Motivation	Score	Motivation	Score
Mass	**.1**	1.52kg	2	1.3kg	1	1.25kg	1
Flight Heritage	**.2**	Multiple successful LEO and beyond flights	1	Multiple successful LEO missions	2	Just launched in LEO missions	4
Cost	**.2**	~$500k	4	Unknown	3	~$65k	1
Accuracy	**.2**	+/- .003 degrees (1-sigma)	1	< 1 degree (3-sigma)	4	< .1 degrees	2
Size	**.1**	.5U	1	.7U	2	1U	4
Peak Power	**.2**	6.7W	2	5W	1	6.5W	2
Scores	**1.0**		**1.9**		**2.3**		**2.3**

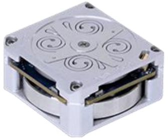
Note:
5 = worst
1 = best

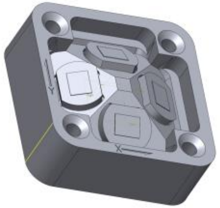
Technical Details

- ADCS System Specifications
  - BCT XACT-100
    - Star tracker
    - 50 mNms reaction wheels
    - MEMS IMU
    - 2 x Pyramid Sun Sensors
    - TRL 8
  - BCT NST
    - TRL 8



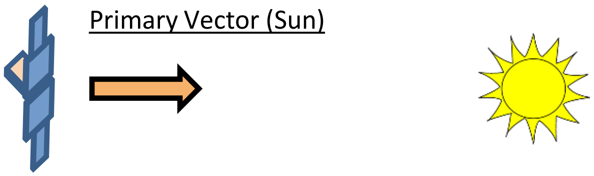






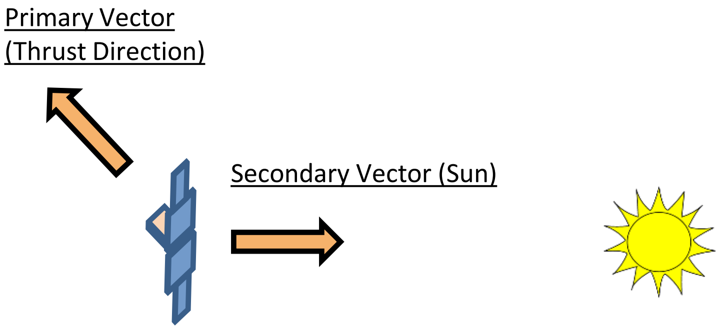
Safe Mode

- Defined by one vector
  - Point +X axis at sun
- Primary object is met by control system
  - Sun acquired using 2 x pyramid sun sensors
  - If no sun in sight, rotisseries until sun is discovered
- Once Sun acquired, rotisserie at table defined rate about sun line



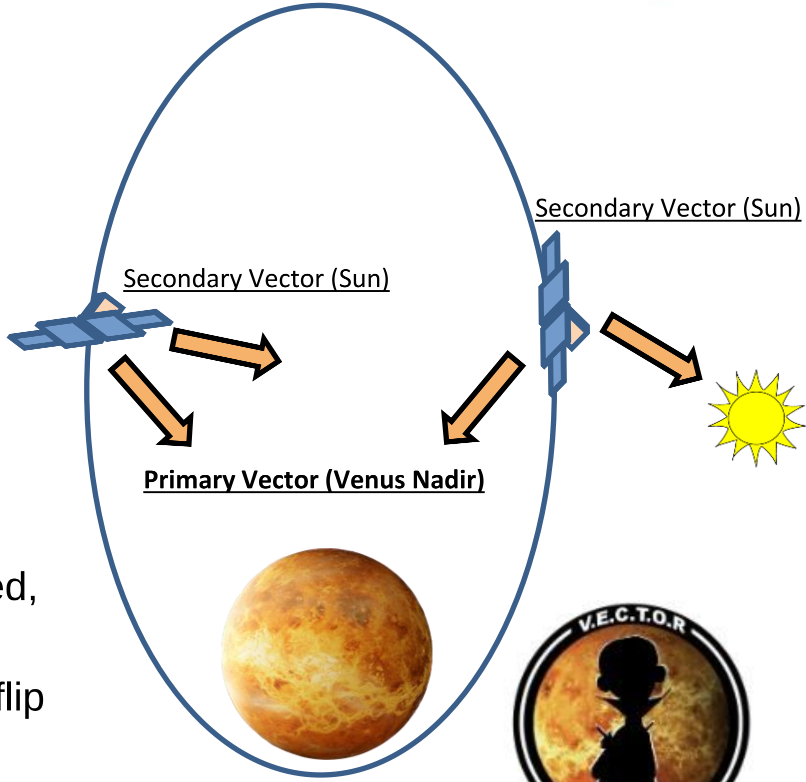
Fine Reference Point: Thrusting

- Defined by two vectors
  - Primary: point thrust vector in velocity or anti-velocity direction
  - Secondary: point solar array articulation axis perpendicular to Sun line
- Primary objective is met by control system
  - Defines 2-axis of attitude
- Secondary objective is met as closely as possible
  - Defines the rotation about the primary axis
- When thrust and Sun vector become co-aligned, a yaw flip automatically occurs
  - Spacecraft physics limit the peak speed of this flip



Fine Reference Point: Venus Science

- Defined by two vectors
  - Primary: Point radio and neuromorphic camera (+Z) to Venus nadir
  - Secondary: point solar array articulation axis perpendicular to Sun line
- Primary objective is met by control system
  - Defines 2-axis of attitude
- Secondary objective is met as closely as possible
  - Defines the rotation about the primary axis
- When Venus nadir and Sun vector become co-aligned, a yaw flip automatically occurs
  - Spacecraft physics limit the peak speed of this flip



Angular Momentum Unloading

Bradford ECAPS 100 mN HPGP Thrusters

- 8 thrusters for full 3-axis control
- 0.04 Kg per thruster
- 0.5 Kg propellant for momentum management
- LMP-103S monopropellant

Thrusters pairs will be fired as needed to help unload angular momentum

- When slowing RW speed, angular momentum is transferred to S/C (momentum is conserved)
- Thrusters provide external torque to counter this
- Maintain S/C attitude during unload

Electrical Power System (EPS)

Electrical Requirements - Level 3

ID	Requirement	Verification	Parent	Status
EPS-3.8.1	System shall generate, regulate, store, and distribute power to each subsystem	Test	SC-2.3	Meeting
EPS-3.8.2	System shall be powered off prior to separation and, upon detecting separation, power on C&DH and TT&C	Test	SC-2.7	TBD
EPS-3.8.3	System shall use approved batteries based on NASA/TM-2009-215751	Inspection	SC-2.3	Meeting
EPS-3.8.4	System shall provide 8 solar array inputs	Test	SC-2.3	Meeting

Analysis of Alternatives - Solar Panels

Selection Element	Weight	MMA HaWK 38A-191		AAC Clyde Space PHOTON		BCT 12U-H Triple Wing	
		Motivation	**Score**	**Motivation**	**Score**	**Motivation**	**Score**
Mass	**0.1**	No significant advantage	2	No significant advantage	2	No significant advantage	2
Flight Heritage	**0.2**	Multiple successful LEO and beyond flights	1	Flown mostly with 3U configuration	2	Flown mostly with 6U configuration	2
Cost	**0.2**	Aerospace Industry Standard	3	Aerospace Industry Standard	3	Aerospace Industry Standard	3
Peak Power	**0.5**	191W, 29.5% Efficiency	1	85W, Unknown Efficiency	4	118W, 30% Efficiency	2
Scores	**1.0**		**1.5**		**3.2**		**2.2**

Note:
5 = worst
1 = best

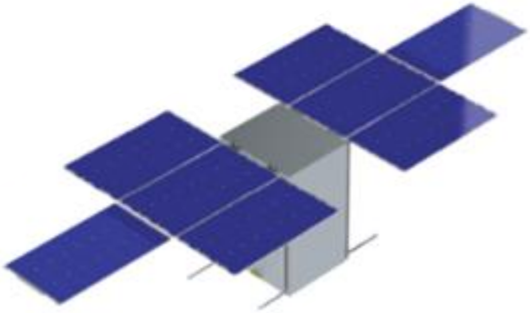
Analysis of Alternatives - Batteries

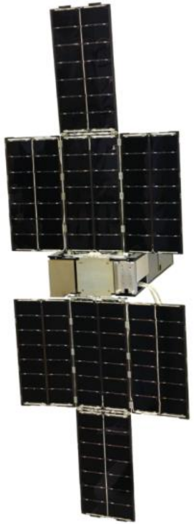
Selection Element	Weight	GOM NanoPower BPX		Ibeos B28-135		BCT 2P8S	
		Motivation	Score	Motivation	Score	Motivation	Score
Mass	**0.2**	2 x .5kg = 1kg	2	.8kg	1	1.2kg	3
Flight Heritage	**0.3**	Mostly LEO missions	3	In development, never flown in space	5	Multiple successful LEO and beyond flights	1
Cost	**0.2**	Aerospace Industry Standard	3	Aerospace Industry Standard	3	Aerospace Industry Standard	3
Energy	**0.3**	2 x 86Wh = 172Wh	4	135Wh	3	198Wh	1
Scores	**1.0**		**3.1**		**3.2**		**1.8**

Note:
5 = worst
1 = best

Technical Details

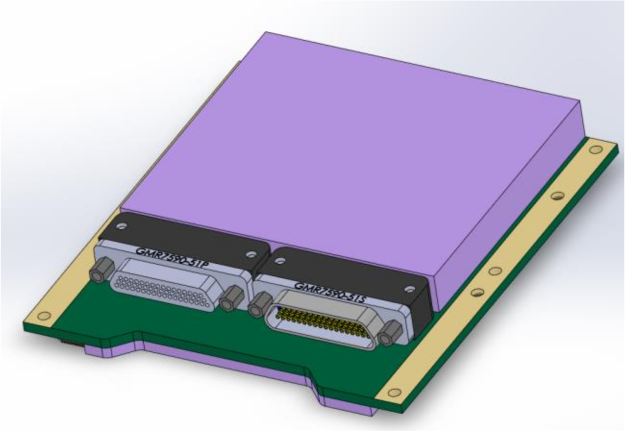
- Battery Cell Specifications:
  - BCT 2P8S
  - 18650B Lithium Ion
  - Nominal Energy: 198Wh
  - TRL 8
- Solar Panel Specifications:
  - MMA HaWK 38A-191
  - 4 x Deployed Panels (2U x 3U)
  - Peak Power: 191W
  - SADA
  - TRL 9



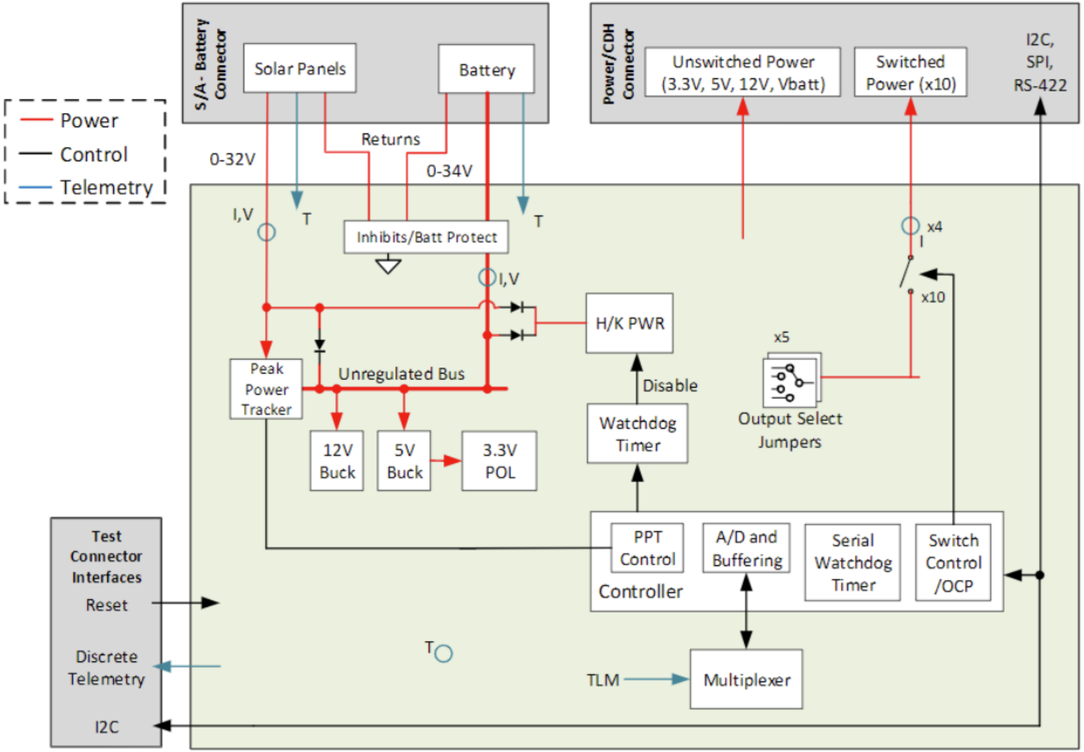


Technical Details

- Power System Specifications:
  - Ibeos 28-200 EPS
  - Max Power: 250W
  - Battery Power: 28V
  - 3.3V, 5V, 12V
  - I2C, SPI
  - Watchdog
  - TRL 8



EPS Block Diagram



Structure and Mechanisms (STR)

Structure Requirements - Level 3

ID	Requirement	Verification	Parent	Status
STR-3.9.1	System shall accommodate a 12U internal volume	Inspection	LS-2.1	Meeting
STR-3.9.2	System shall interface with 12U deployer	Inspection	LS-2.1	Meeting
STR-3.9.3	System shall provide mounting interface and clearance accommodations for solar panels and SADA	Inspection	LS-2.1	Meeting
STR-3.9.4	System shall remain fully operational following a random vibrations test	Testing	LS-2.3	TBD

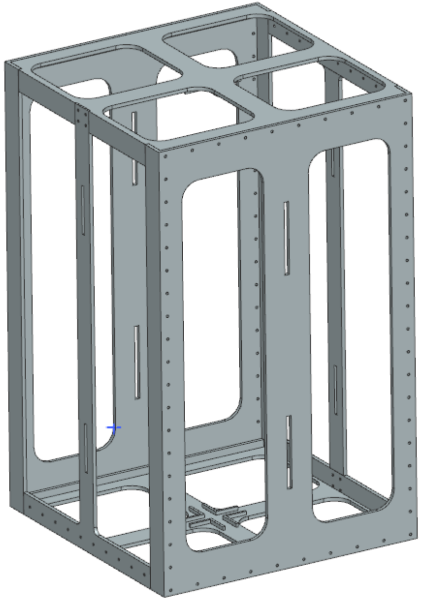
Analysis of Alternatives - Structure

Note:
5 = worst
1 = best

Selection Element	Weight	Enduro Sat		Custom Built	
		Motivation	Score	Motivation	Score
Cost	**0.4**	$12,500	**1**	~$6,000 machining + money spent designing/review	**3**
Schedule Risk	**0.3**	Immediately available	**1**	Needs to be designed	**4**
V&V	**0.3**	COTS tested	**2**	Needs to be internally vibed, temperature cycled, etc	**4**
Scores			**1.3**		**3.6**

Technical Details

- Endurosat 12U CubeSat Structure
- 226.3 x 226.3 x 366 mm
- 2.44 Kg
- Hard Anodized Aluminum-6082
- Room for 1-4 Switches
- PC104 compliant



Risk & VV

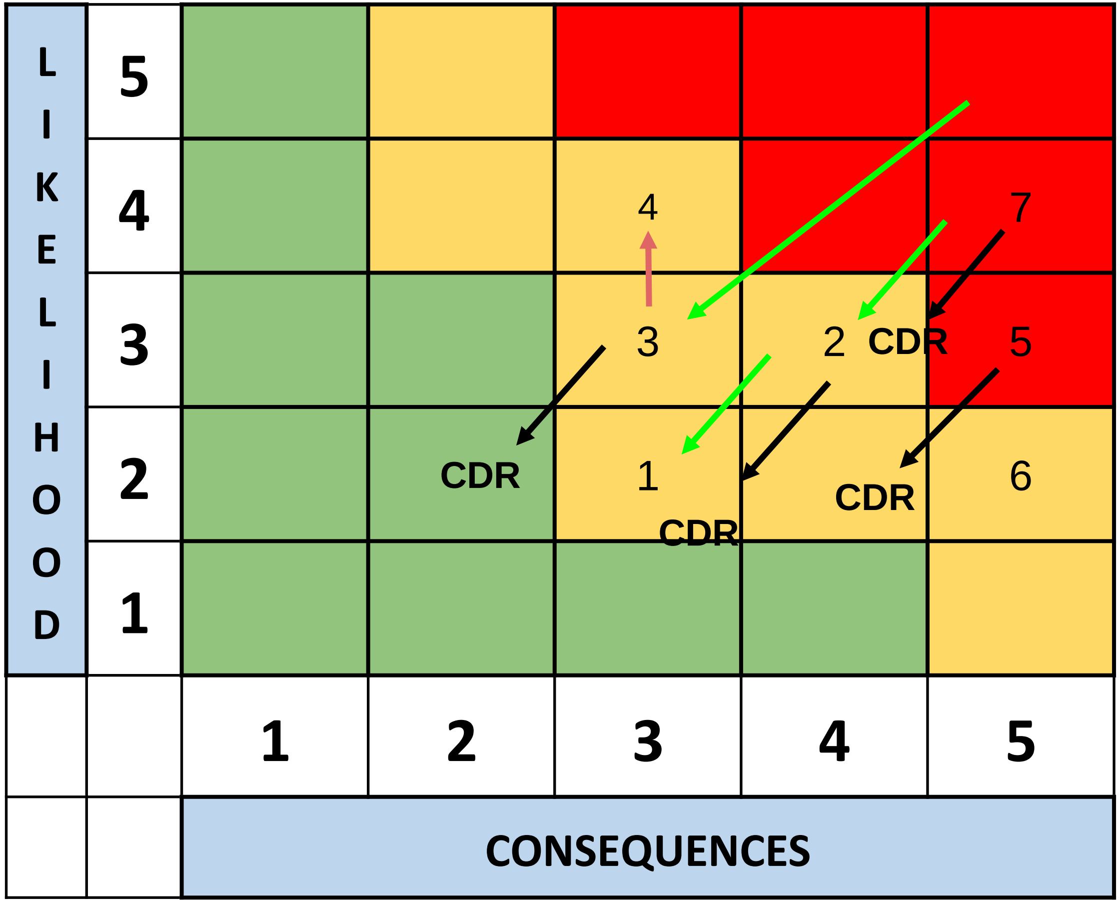
Risk Management Matrix

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Environment	2	3	→	R	Charged particles and magnetic interference in Venusian orbit causing failure of subsystems	Active
2	Propulsion	2	4	↓	W	CubeSat fails to enter desired orbit around Venus	Active
3	Communication	2	2	↓	M	Unable to establish/maintain two-way communication due to receiver/transceiver failure or inconsistent pointing	Active
4	Budget	4	3	→	A	Missions exceeds $25 million cost cap	Active
5	Power	2	4	↓	M	System fails to generate TBD Watts or battery performance experiences premature degradation	Active
6	Schedule	1	4	→	M	On-orbit failure due to schedule slippage	Active
7	COTS Components	3	4	↓	A	COTS components failure	Active

L = Likelihood (1-5)	LxC Trend
1 = not likely	**↓ - Decreasing (improving)**
5 = extremely likely	**↑ - increasing (worsening)**
C = Consequence (1-5)	**→ - unchanged**
1 = low consequence	**NEW - added this month**
5 = high consequence	

Approach	
A - accept	W - watch
M- mitigate	R - research

PDR Risk Mitigation Matrix



Criticality
HIGH
MED
LOW

CDR Risk Mitigation Matrix

LIKELIHOOD						
	5					
	4			4		
	3				7	
	2		3	1	5,2	
	1				6	
		1	2	3	4	5
		CONSEQUENCES				

Criticality
HIGH
MED
LOW

Risk Mitigation Plan

<table>
<tr><th>ID: Summary</th><th>1: Environment</th><th>2: Propulsion</th><th>3: Communication</th><th>4: Budget</th><th>5: Power</th><th>6: Schedule</th><th>7: COTS Components</th></tr>
<tr><td rowspan="3">Mitigation Plan</td><td>Centralize mission-critical components with mass and shielding material coverage</td><td>Propulsion module will be purchased from a reputable supplier</td><td>Ensure quality of communications components</td><td>Acquire standardized materials (COTS)</td><td rowspan="3">Power system charge and discharge testing</td><td>Set the purpose and vision of the mission early-on to ensure success</td><td rowspan="3">Subject COTS components to rigorous testing</td></tr>
<tr><td>Optimize central “critical” flight stack with research, analysis, and testing; power cycle “non-critical” components</td><td rowspan="2">Unit will be subjected to V&V tests</td><td>Perform a communication link testing with the ground station</td><td>Simplify CubeSat and payload</td><td rowspan="2">Stock spare components</td></tr>
<tr><td>Unit will be subjected to V&V tests</td><td>Redundant downlink capabilities</td><td>Follow NASA Project Life-Cycle to mitigate schedule slip</td></tr>
</table>

Verification & Validation:
Critical Design Requirements

Req ID #	Verification Method	Test
SC-2.8 ADCS-3.7.1 ADCS-3.7.2 ADCS-3.7.3 ADCS-3.7.4	Testing	Momentum Control System Testbed (Facility TBD)
SC-2.12 SC-2.17	Testing	Simulate a 5-year mission worst case scenario by exposing the satellites’ subsystems to a Cobalt-60 radiation source (Facility TBD)
PRO-3.5.1 PRO-3.5.1 PRO-3.5.2 PRO-3.5.3 PRO-3.5.4 PRO-3.5.5	Testing	Thrust Test Bench (Facility TBD)

Verification & Validation:
System Performance Requirements

Req ID #	Verification Method	Test
LS-2.3 STR-3.9.4	Testing	Analysis of the CAD model using **NASTRAN** will be performed to verify the preliminary design. A **viderations test(s)** will be performed to validate the system after the CDR. (facility TBD)
SC-2.2 SC-2.5 TCS-3.2.1 TCS-3.2.2 TCS-3.2.3	Analysis	Analysis of the CAD model using **NASTRAN** will be performed to verify the preliminary design.**Thermal-Vac lifecycle test** will be performed to validate the completed system. Unit thermal-vac tests will be performed on critical subsystems throughout the build process. (facility TBD)
SC-2.3 EPS-3.8.1	Testing	**Natural sunlight or a solar simulator tests** will be performed. The set of measurements is performed from the solar panel open-circuit point, where the output current will be at its minimum and the output voltage reaches its maximum value, i.e. Voc. From this testing condition, the output current is increased until its maximum value is reached, i.e. Isc, when the solar panel is short-circuited and the output voltage is at its minimum value, i.e. zero.
SC-2.12	Analysis	Computational Electromagnetics (CEM) Laboratory and Computational Electromagnetics (CEM) Laboratory facilities at NASA Johnson Space Center. (ideal)

Summary & Future

Power Budget: Insertion Burn

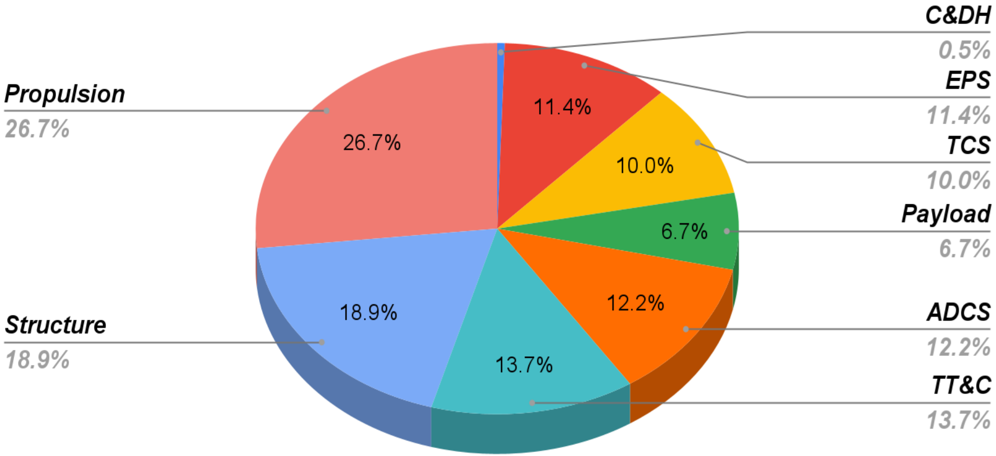
Subsystem	Generic Component Name	Specific Component Name	Qty	Instantaneous Power	Total Instantaneous Power	Duty Cycle	Orbital Average Power (w/ Inefficiency)
GENERATED							
EPS	Solar Array	MMA HaWK 38A-191	1	191.00W	191.00W	0.9	154.71W
	Battery	BCT 2P8S	1	0.00W	0.00W	1	0.00W
						TOTAL GENERATED POWER	***154.71W***
CONSUMED							
C&DH	Mother board	CHREC Space Processor	1	2.85W	2.85W	1	2.85W
	Interface Board	Custom	1	1.00W	1.00W	1	1.00W
EPS	Power System	Ibeos 28-200	1	1.50W	1.50W	1	1.50W
TCS	Shielding	Z-Grade Radiation Shielding 3U Plates	8	0.00W	0.00W	0	0.00W
	Confirmal Coating	Arathane	2	0.00W	0.00W	0	0.00W
Payload	Camera	Inivation DVXplorer	2	0.70W	1.40W	0.5	0.70W
	Antenna	Custom Deployed Monopole	1	0.00W	0.00W	1	0.00W
	Radio	Red Pitaya STEMlab 125-14	1	10.00W	10.00W	0.5	5.00W
ADCS	ADCS	BCT XACT-100	1	5.00W	5.00W	1	5.00W
	Star Tracker	BCT Standard NST	1	1.66W	1.66W	1	1.66W
	Propellent	LMP-103S	1	0.00W	0.00W	1	0.00W
	Momentum Mangement Thursters	100 mN HPGP Thruster	8	7.00W	56.00W	0.015	0.84W
TT&C	Transponder	SDL IRIS V2	1	35.00W	35.00W	0.077	2.69W
	Antenna	JPL Deployable X-Band	1	0.00W	0.00W	1.000	0.00W
	Antenna	Endurosat X-Band Patch	1	0.00W	0.00W	1.000	0.00W
Structure	Bus Structure	Endurosat 12U Standard Bus	1	0.00W	0.00W	0	0.00W
	Cabling & Harnessing	Custom	1	0.00W	0.00W	0	0.00W
Propulsion	Thruster	NPT30-12 1U Electric Propulsion System	4	65.00W	260.00W	0.5	130.00W
						TOTAL CONSUMED POWER	***151.24W***
						POWER MARGIN	***3.47W***

Power Budget: On Orbit

Subsystem	Generic Component Name	Specific Component Name	Qty	Instantaneous Power	Total Instantaneous Power	Duty Cycle	Orbital Average Power (w/ Inefficiency)
GENERATED							
EPS	Solar Array	MMA HaWK 38A-191	1	191.00W	191.00W	0.9	154.71W
	Battery	BCT 2P8S	1	0.00W	0.00W	1	0.00W
						TOTAL GENERATED POWER	*154.71W*
CONSUMED							
C&DH	Mother board	CHREC Space Processor	1	2.85W	2.85W	1	2.85W
	Interface Board	Custom	1	1.00W	1.00W	1	1.00W
EPS	Power System	Ibeos 28-200	1	1.50W	1.50W	1	1.50W
TCS	Shielding	Z-Grade Radiation Shielding 3U Plates	8	0.00W	0.00W	0	0.00W
	Confirmal Coating	Arathane	2	0.00W	0.00W	0	0.00W
Payload	Camera	Inivation DVXplorer	4	0.70W	2.80W	1	2.80W
	Antenna	Custom Deployed Monopole	2	0.00W	0.00W	1	0.00W
	Radio	Red Pitaya STEMlab 125-14	1	10.00W	10.00W	1	10.00W
ADCS	ADCS	BCT XACT-100	1	5.00W	5.00W	1	5.00W
	Star Tracker	BCT Standard NST	1	1.66W	1.66W	1	1.66W
	Propellent	LMP-103S	1	0.00W	0.00W	1	0.00W
	Momentum Mangement Thursters	100 mN HPGP Thruster	8	7.00W	56.00W	0.025	1.40W
TT&C	Transponder	SDL IRIS V2	1	35.00W	35.00W	0.077	2.69W
	Antenna	JPL Deployable X-Band	1	0.00W	0.00W	1.000	0.00W
	Antenna	Endurosat X-Band Patch	2	0.00W	0.00W	1.000	0.00W
Structure	Bus Structure	Endurosat 12U Standard Bus	1	0.00W	0.00W	0	0.00W
	Cabling & Harnessing	Custom	1	0.00W	0.00W	0	0.00W
Propulsion	Thruster	NPT30-12 1U Electric Propulsion System	4	65.00W	260.00W	0.038	10.00W
						TOTAL CONSUMED POWER	*38.90W*
						POWER MARGIN	*115.81W*

Mass Budget: Overview

VECTOR Mass Analysis	
Total Mass	17.98 kg
Total Mass With 20% Margin	21.58 kg
Maximum Mass (Per 12U Standard)	24 kg



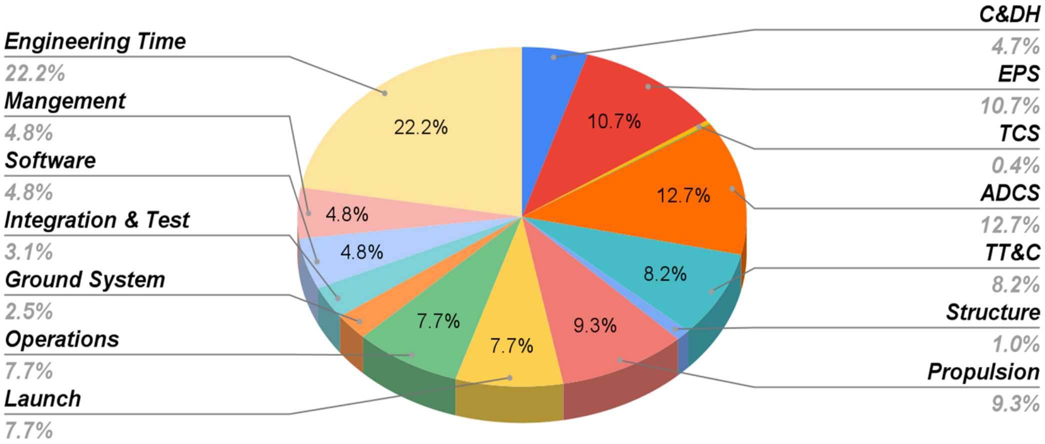
Mass Budget: Detailed

Subsystem	Generic Component Name	Specific Component Name	Qty	Mass	Total Mass
C&DH	Mother board	CHREC Space Processor	1	0.07kg	0.07kg
	Interface Board	Custom	1	0.02kg	0.02kg
EPS	EPS	Ibeos 28-200	1	0.14kg	0.14kg
	Solar Array	MMA HaWK 38A-143	1	0.71kg	0.71kg
	Battery	BCT 2P8S	1	1.20kg	1.20kg
TCS	Shielding	Z-Grade Radiation Shielding 3U Plates	8	0.20kg	1.60kg
	Confirmal Coating	Arathane	2	0.10kg	0.20kg
Payload	Camera	Inivation DVXplorer	2	0.10kg	0.20kg
	Antenna	Custom Deployed Monopole	1	0.50kg	0.50kg
	Radio	Red Pitaya STEMlab 125-14	2	0.25kg	0.50kg
ADCS	ADCS	BCT XACT-100	1	1.52kg	1.52kg
	Star Tracker	BCT Standard NST	1	0.35kg	0.35kg
	Momentum Mangement Thursters	100 mN HPGP Thruster	8	0.04kg	0.32kg
TT&C	Transponder	SDL IRIS V2	1	1.10kg	1.10kg
	Antenna	JPL Deployable X-Band	1	1.25kg	1.25kg
	Antenna	Endurosat X-Band Patch	2	0.05kg	0.11kg
Structure	Bus Structure	Endurosat 12U Standard Bus	1	2.40kg	2.40kg
	Cabling & Harnessing	Custom	1	1.00kg	1.00kg
Propulsion	Thruster	NPT30-12 1U Electric Propulsion System	4	1.20kg	4.80kg
				TOTAL MASS	17.98kg
				TOTAL MASS WITH 20% MARGIN	21.58kg

*See references for component details

Cost Budget: Overview

VECTOR Cost Analysis	
Total Mission Cost	$25.8 Million USD
Spacecraft Components Cost With 20% Margin (W/ EDU units)	$12.18 Million USD
Development Time	3-4 Years
Mission Operational Time	1.5 Years (minimum)
Funding Mechanism	NASA SIMPLEx



Cost Budget: Detailed

Subsystem	Generic Component Name	Specific Component Name	Qty	Price	Total Cost
C&DH	Mother board	CHREC Space Processor	2	$500,000.00	$1,000,000
	Interface Board	Custom	2	$10,000.00	$20,000
EPS	EPS	Ibeos 28-200	2	$500,000.00	$1,000,000
	Solar Array	MMA HaWK 38A-191	1	$1,000,000.00	$1,000,000
	Battery	BCT 2P8S	3	$100,000.00	$300,000
TCS	Shielding	Z-Grade Radiation Shielding 3U Plates	8	$10,000.00	$80,000
	Confirmal Coating	Arathane 5750	2	$500.00	$1,000
Payload	Camera	Inivation DVXplorer	4	$3,900.00	$15,600
	Antenna	Custom Deployed Monopole	2	$1,000.00	$2,000
	Radio	Red Pitaya STEMlab 125-14	2	$377.00	$754
ADCS	ADCS	BCT XACT-100	2	$500,000.00	$1,000,000
	Star Tracker	BCT Standard NST	2	$75,000.00	$150,000
	Momentum Mangement Thrusters	Bradford ECAPS 100 mN HPGP Thruster	8	$200,000.00	$1,600,000
TT&C	Transponder	SDL IRIS V2	2	$500,000.00	$1,000,000
	Antenna	JPL Deployable X-Band	1	$760,000.00	$760,000
Structure	Bus Structure	Endurosat 12U Standard Bus	2	$12,500.00	$25,000
	Cabling & Harnessing	Custom	2	$100,000.00	$200,000
Propulsion	Thruster	NPT30-12 1U Electric Propulsion System	4	$500,000.00	$2,000,000
				TOTAL COST	$10,154,354
				TOTAL COST WITH 20% MARGIN	$12,185,225

C&DH	$1,224,000.00
EPS	$2,760,000.00
TCS	$97,200.00
Payload	$22,024.80
ADCS	$3,300,000.00
TT&C	$2,112,000.00
Structure	$270,000.00
Propulsion	$2,400,000.00
Launch	$2,000,000.00
Operations	$2,000,000.00
Ground System	$650,000.00
Integration & Test	$800,000.00
Software	$1,250,000.00
Mangement	$1,250,000.00
Engineering Time	$5,760,000.00
Total	$25,895,224.80

*See references for component details

Standards Chart

Document ID	Standard	Verification
Cal Poly CubeSat Design Specification Rev. 14.1	System shall be compliant with the 12U size standard	Inspection
Cal Poly CubeSat Design Specification Rev. 14.1	System shall be less than 24 kg as per 12U standard	Inspection
Cal Poly CubeSat Design Specification Rev. 14.1	System shall have a center of gravity which is compliant with 12U standard	Inspection
NASA-RP-1124-Rev-4	System shall satisfy NASA low-outgassing criteria	Testing
NPR 8715.6	System shall limit orbital debris	Demonstration
AFSPCMAN 91-710, Volume 3	System shall have hazardous materials conform	Inspection
AFSPCMAN 91-710 Volume 3	System shall have propulsion be designed, integrated, and tested	Inspection

ABET Requirements

Requirement	Slide Number’s
Problem to be solved (identifying opportunities, defining requirements)	6-7, 28-36, 39, 43, 48, 53, 60, 67, 75, 82
Which concepts were initially considered and how they were evaluated (generating multiple solutions)	12-17
Decision-making process for arriving at the current design (iterative, creative decision-making process)	40, 54-55, 61, 68, 76-77, 83
Evolution of the design (trade-offs and optimization)	40, 54-55, 61, 68, 76-77, 83
How requirements are met (evaluation against requirements)	89-91
Summary of next steps, changes they would make given time and resources, possible improvements, recommendations for future work and upgrades	101-103

Schedule For Capstone

September 27th

SRR Presentation

Present System Requirements Review to Capstone class. Selection of project, mission design, beginning system requirements.

November 13th

SDR Presentation

Present System Design Review to Capstone class. Completed requirements and mission design finalized.

March 1st

PDR Presentation

Present Preliminary Design Review to Capstone class. Elementary CAD, subsystems chosen, thermal calculations & spacecraft budgets

April 7th

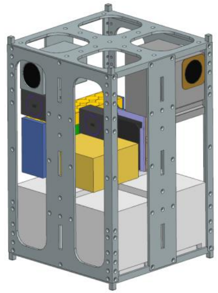
CDR Presentation

Present Critical Design Review to Capstone class. Completed CAD, subsystem models, thermal/orbit simulations & spacecraft budgets

April 21st

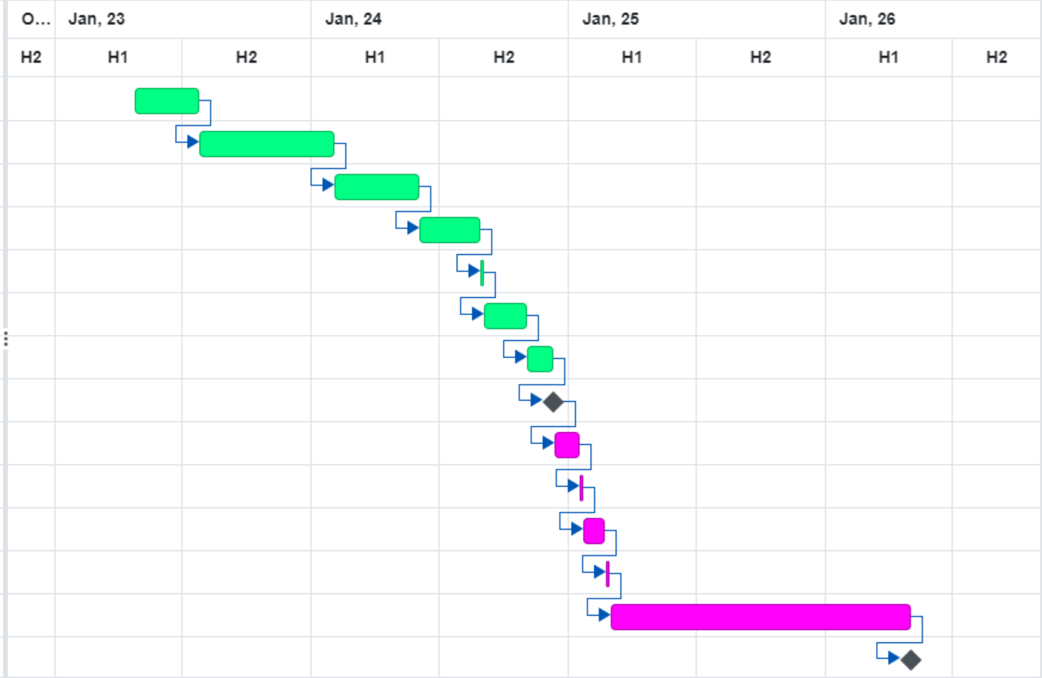
ABET Presentation

Present progress and process throughout capstone and tell a story about VECTOR



VECTOR Schedule Outlook

ID	Name
1	Subsystem CDR's
2	SIR (System Integration Review)
3	System V & V
4	FRR (Flight Readiness Review)
5	Delivery (Deliver to Provider)
6	ORR (Operational Readiness Review)
8	Launch Preparation
7	Launch
9	PSR (Program Status Review)
10	VECTOR Insertion Burn Initiation
11	VECTOR Orbit Stablization
12	Payload Initiation and Calibration
13	Science Operations
14	End of Mission



Summary

The Why

- VECTOR's goal is to prove that high-scientific-value missions are executable at low cost

The How

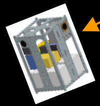
- VECTOR will use COTS CubeSat components for an interplanetary mission

The What

- VECTOR is a venusian ride sharing mission built from COTS components to perform an insertion burn into a circular Venus orbit with a neuromorphic camera

What's Next

- VECTOR will push towards flight!



Thank you!
Questions?

Backup Slides

References

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EPS

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TCS

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https://www.jarocorp.com/wp-content/uploads/2016/12/Arathane-5750.pdf

Payload

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TT&C

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12U Bus

https://www.endurosat.com/cubesat-store/cubesat-structures/12u-cubesat-structure/

Propulsion

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