Venus Atmosphere Penetrating Explorer (VAPE)

Final Presentation

Group members

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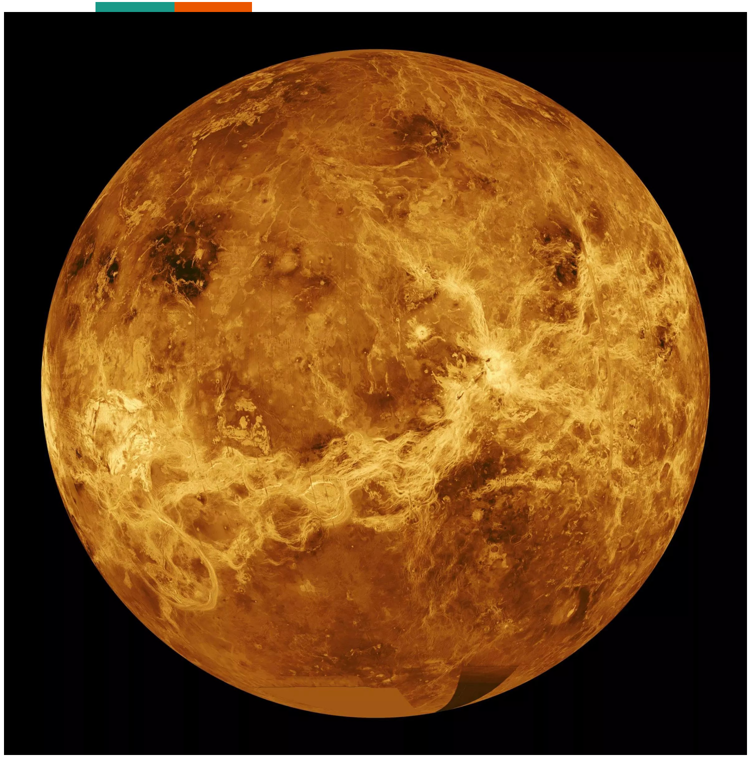
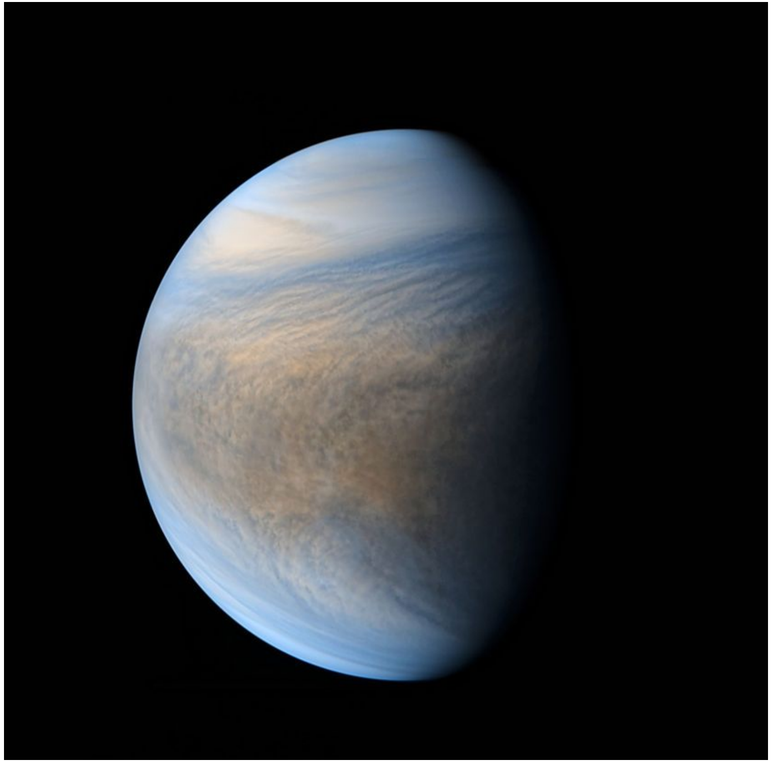
Mission objective



- To provide in situ measurements and gather scientific data on Venus by penetrating the atmosphere of the planet in order to investigate its greenhouse event and atmospheric composition

Mission overview



http://www.planetary.org/blogs/guest-blogs/2018/0116-a-new-look-at-venus-with-akatsuki.html

- Detect presence microbial life in potential algae plumes in the clouds at 40km
- Seasonal variability of atmospheric behaviour
- Detect presence of different greenhouse gases at different altitudes
- Detect presence of noble gases in atmosphere
- Analyse chemical composition at different altitudes
- Orbital trajectory from Earth parking orbit to chosen Venusian orbit
- Measurement of downwelling longwave radiation

Constraints to mission objectives

- Finding life on another planet would broaden our search on exoplanets they are theorized to form at 40 km above the surface
- Detection for seasonal variability would mean our mission will need to last several years to determine a conclusion as well as negate outliers in data
- Measure carbon dioxide, nitrogen, carbon monoxide and all other minor elements concentrations to an accuracy of 10 ppm
- Detect (Carbon Dioxide and Sulfuric Acid) wavelength at different altitudes between (30 km to 50 km)
- Mass spectrometers have extensive flight heritage (sounding rockets, Apollo programme, Huygens, Viking, Phoenix, Venus Express)[1]. One of the few techniques to detect noble gases.
- Direct Hohmann transfer widely used by recent Venus missions. Length of trajectory is highly variable.
- DLR measurement : from 0 W m^{-2} to $20\,000 \text{ W m}^{-2}$ to accuracy ± 1.0 (from EPCC science paper)

Key mission requirements - Functional

VAPE-REQ-FUNC-0060	Description	The probe shall survive in the Venusian atmosphere for at least 3 months.			Time/Level of Verification	Payload system assembly	
	Comment	Base duration on technology level and scientific needs.			Nature of Verification	Environmental simulations	
	Rationale	Allow for measurements and observations to be made during the decommissioning phase of the mission.			Version	V-1.0	
	Written on	05 FEB 2019	Initial Author	Matthieu Durand	Last modified	13 FEB 2019	

VAPE-REQ-FUNC-0011	Description	The payload MDS shall gather atmospheric samples at a height where pressure is like Earth's.			Time/Level of Verification	Full spacecraft integration	
	Comment	Pressure should be about one (1) bar			Nature of Verification	Perform spacecraft testing in own atmosphere for verification	
	Rationale	We will need data collected from regions where microbial life has been theorized.			Version	V-1.0	
	Written on	05 FEB 2019	Initial Author	Jacob Samson	Last modified	13 FEB 2019	

Key mission requirements - Performance

VAPE-REQ-PERF-0020				
Description	The thermal on-board instruments shall collect atmospheric temperature levels to ± 0.5 K accuracy.	Time/Level of Verification	Component
Comment	Based on ISO 11225:2012 (space environment-- guide to reference and standard atmosphere models).	Nature of Verification	Ensure sensors that are used can provide required accuracy through testing and verification
Rationale	To differentiate between normal and extreme temperature levels. Provides accuracy baseline for requirement VAPE-REQ-FUNC-0070.	Version	V-1.0

Written on	05 FEB 2019	Initial Author	Yaseen Al-Taie	Last modified	13 FEB 2019

VAPE-REQ-PERF-0070			
Description	The spacecraft MDS shall be able to communication back to Earth with a bit rate of at least 60 Kb/s	Time/Level of Verification	Flat-sat
Comment		Nature of Verification	Test communication bands to ensure fast enough data rate
Rationale	The space craft must be able to receive and send telemetry and science data at a reasonable rate.	Version	V-1.0

Written on	05 FEB 2019	Initial Author	Jacob Samson	Last modified	13 FEB 2019

Key mission requirements - Interface

VAPE-REQ-INTE-0020	Description	The MDS shall receive data from the instruments on a daily basis.		Time/Level of Verification	Full spacecraft integration
	Comment	Sampling of the atmosphere will need to be determined. Increasing our sample rate allows for more confidence in the data that is being received.		Nature of Verification	Testing of interfacing between the instruments and MDS bus.
	Rationale	Sampling of the instrument readings determine data volume and required telemetry rate.		Version	V-1.0
	Written on	05 FEB 2019	Initial Author	Michael Tabascio	Last modified	13 FEB 2019

VAPE-REQ-INTE-0040	Description	The payload MDS shall be deployed into the atmosphere by the spacecraft MDS.		Time/Level of Verification	Full spacecraft assembly
	Comment			Nature of Verification	Test of separation processes and validation of simulated atmospheric insertion
	Rationale	The payload shall not be fitted with orbital manoeuvre capabilities; thus, it must be deposited into the atmosphere by the parent spacecraft.		Version	V-1.0
	Written on	05 FEB 2019	Initial Author	Matthieu Durand	Last modified	13 FEB 2019

Key mission requirements - Regulatory

VAPE-REQ-REGU-0010						
Description	The MDS shall adhere to all regulation set by Defence Production Act and Controlled Goods Regulations.			Time/Level of Verification	All phases	
Comment				Nature of Verification	Will cross-reference system with regulations.	
Rationale	Needed for system to be legal in Canadian domain.					
				Version	V-1.0	
Written on	05 FEB 2019	Initial Author	Jessie Atamanchuck	Last modified	13 FEB 2019	

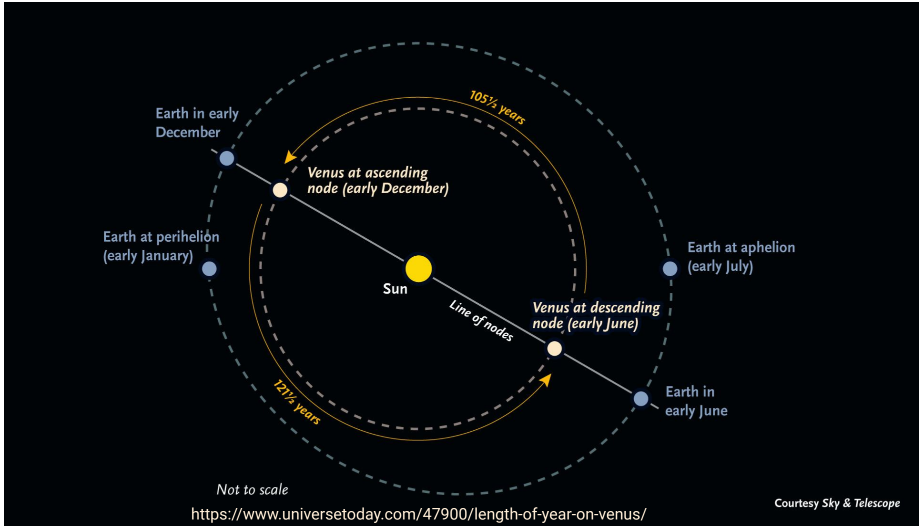
VAPE-REQ-REGU-0050						
Description	Cleaning and decontamination activities of hardware and components shall be performed according to standard ECSS-Q-ST-70-01C.			Time/Level of Verification	Full spacecraft integration	
Comment	Specifically, section 5.4 on activity applies.			Nature of Verification	Examination of cleaning procedures by inspector(s)	
Rationale	To remove contamination of the MDS assembly by biological, chemical, and other contaminants.					
				Version	V-1.0	
Written on	05 FEB 2019	Initial Author	Matthieu Durand	Last modified	13 FEB 2019	

Key mission requirements - Programmatic

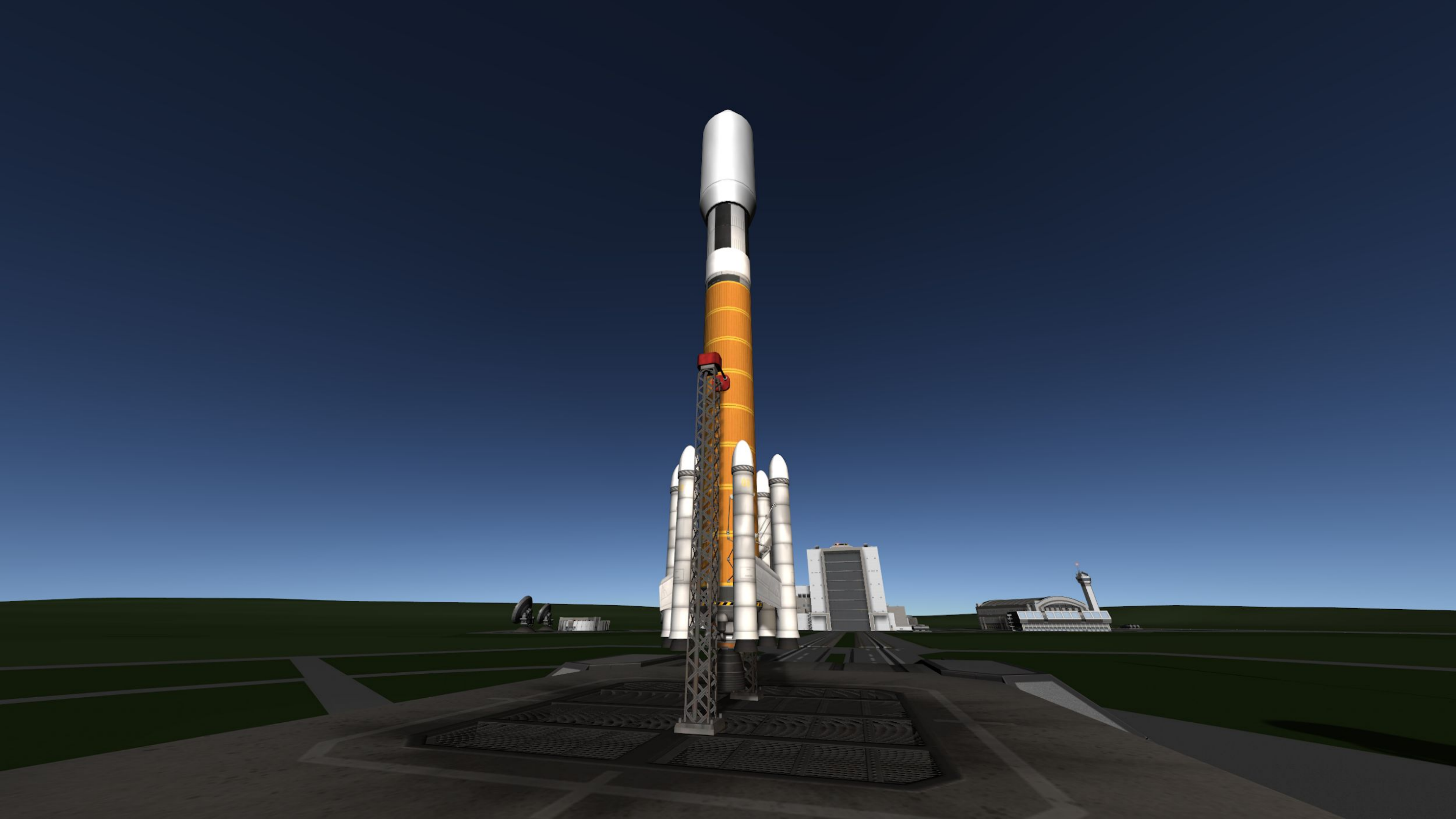
VAPE-REQ-PROG-0020	Description	The mission cost shall be no more than 600M CAD.		Time/Level of Verification	End of build		
	Comment	Looking at similar missions will allow to come up with a cost that will be comparable to the cost of our mission.		Nature of Verification	Stakeholders will restrict the cost of the mission		
	Rationale	Need to set and meet budget constraints. Important for getting the project approved.		Version	V-1.0		
	Written on	05 FEB 2019	Initial Author	Michael Tabascio	Last modified	Written on	

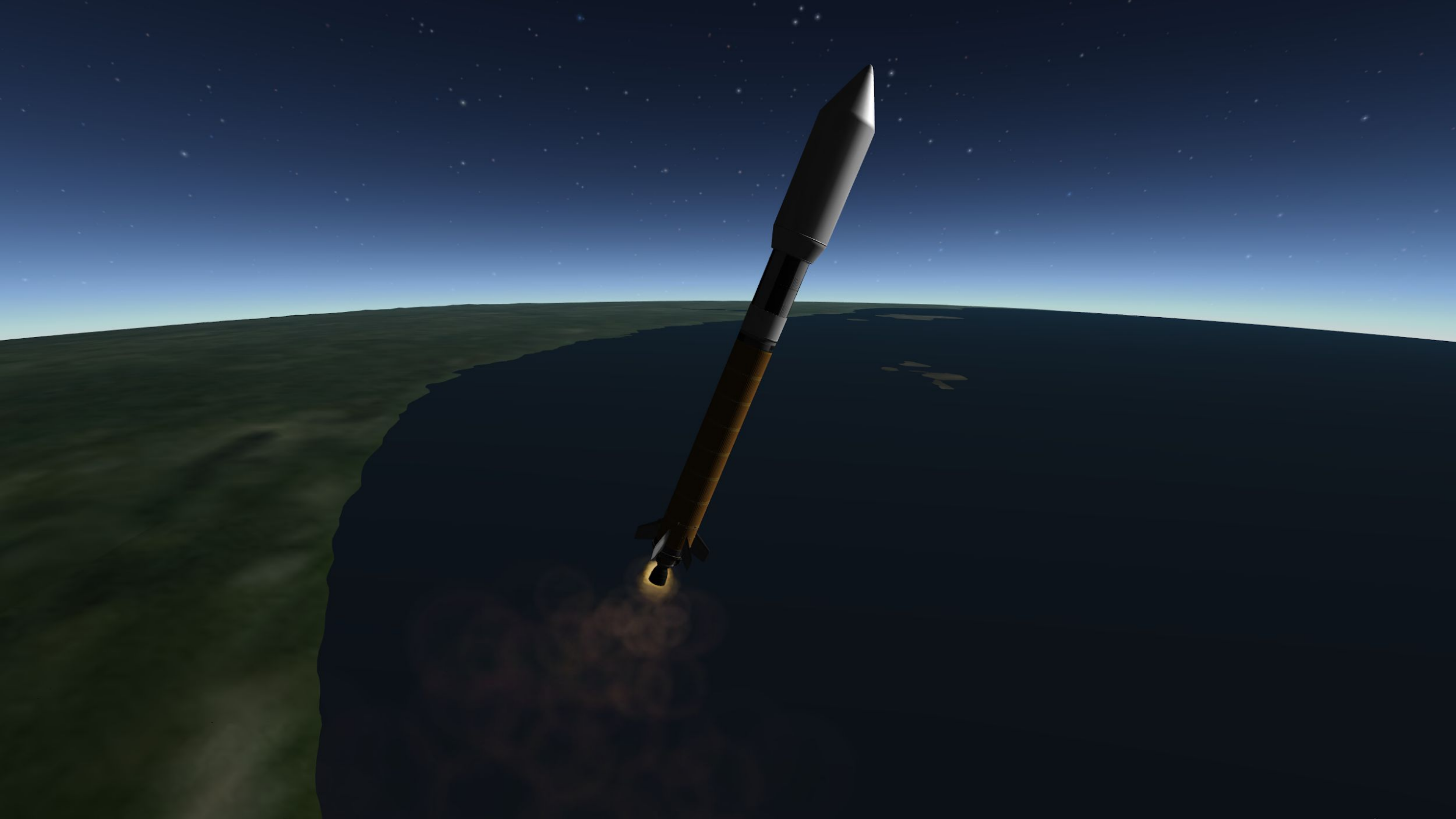
VAPE-REQ-PROG-050	Description	The payload MDS shall operate using the local Venus solar time of the location in enters the atmosphere.		Time/Level of Verification	Flat-sat		
	Comment	This means a time conversion algorithm is needed.		Nature of Verification	Run test(s) of automated processes using VST.		
	Rationale	Allows for the synchronisation of science activities with the local position of the Sun on Venus.		Version	V-1.0		
	Written on	05 FEB 2019	Initial Author	Matthieu Durand	Last modified	Written on	

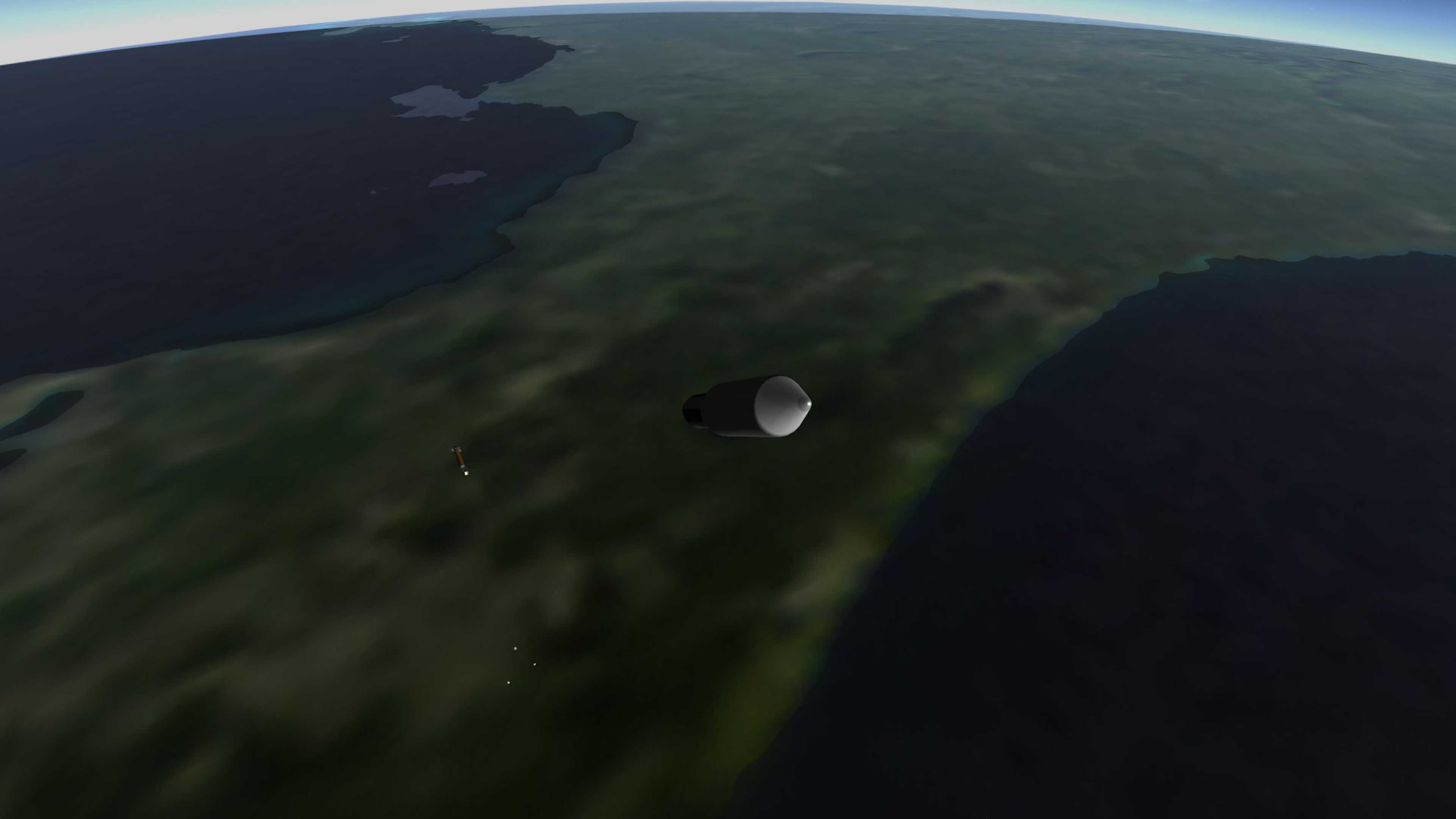
Mission phases

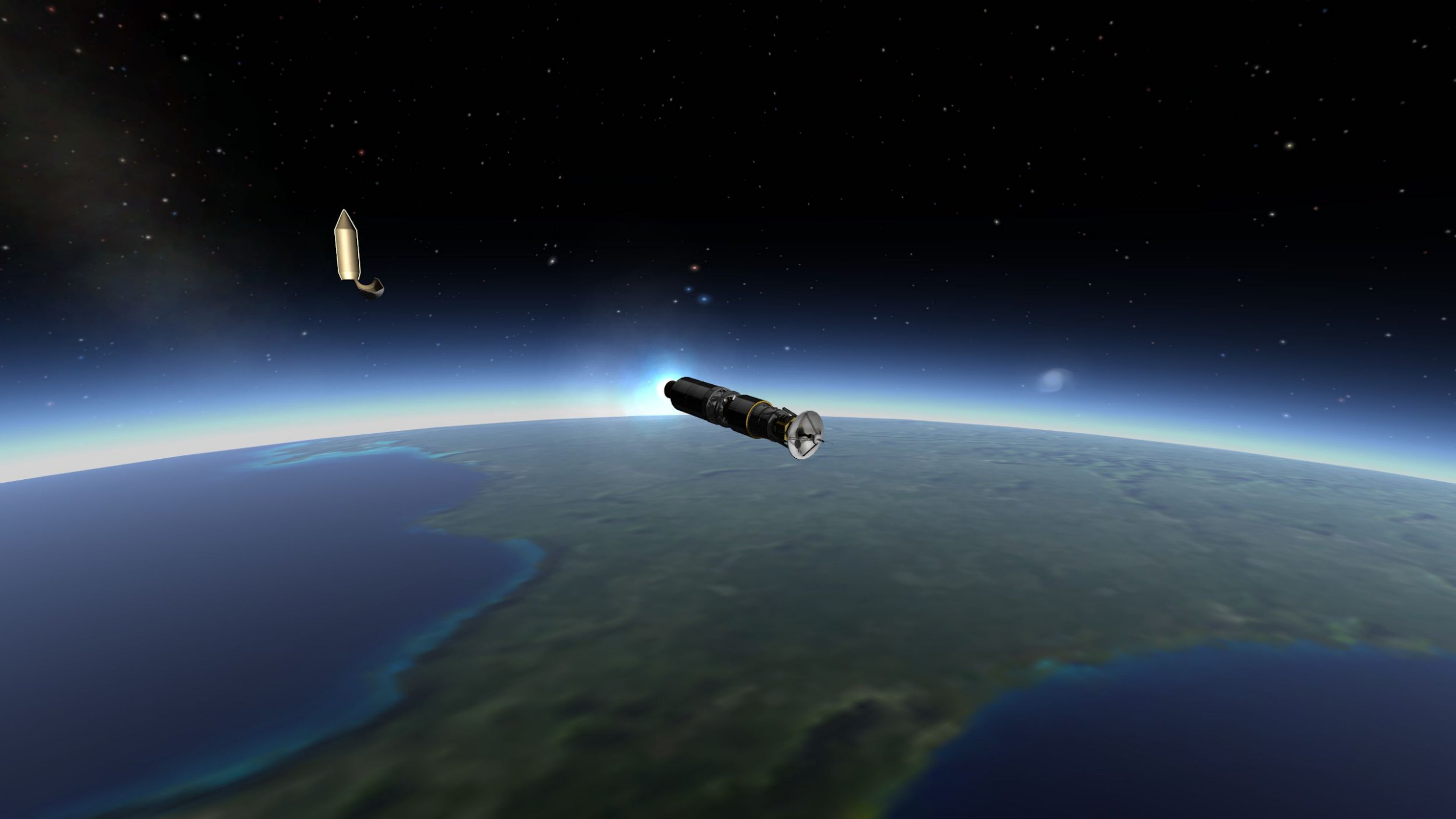


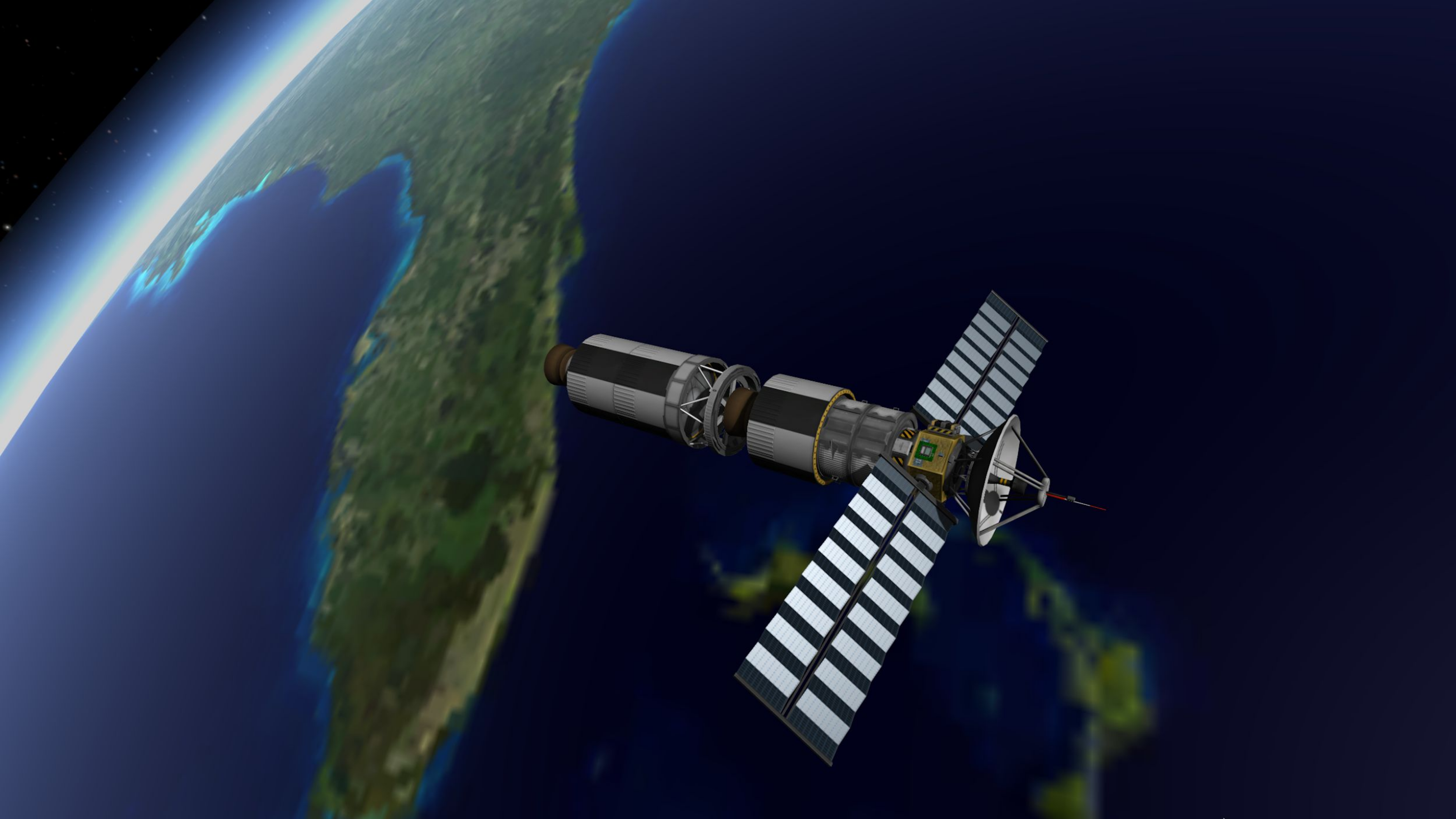
- **Travel phase:** The spacecraft will be launched and follow a hohmann transfer orbit to arrive at venus
- **Deployment Phase:** It will then enter a polar orbit around venus and deploy a probe equipped with a balloon to descend into the atmosphere
- **Science phase:** The probe will take a variety of measurements in the atmosphere over a period of a year
- **Communications phase:** The probe will transmit all of the science data to the orbiter which will then relay it to earth

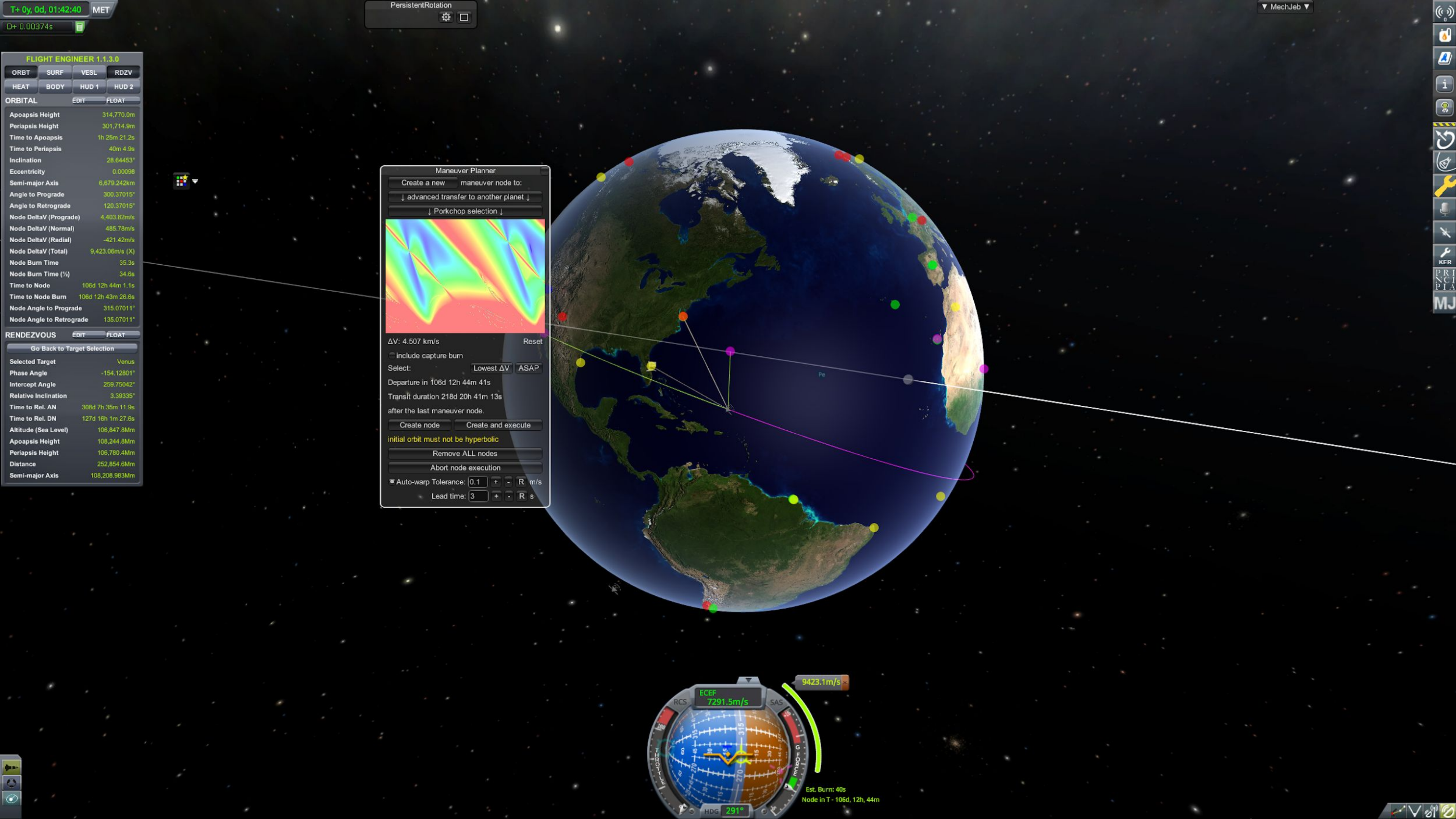


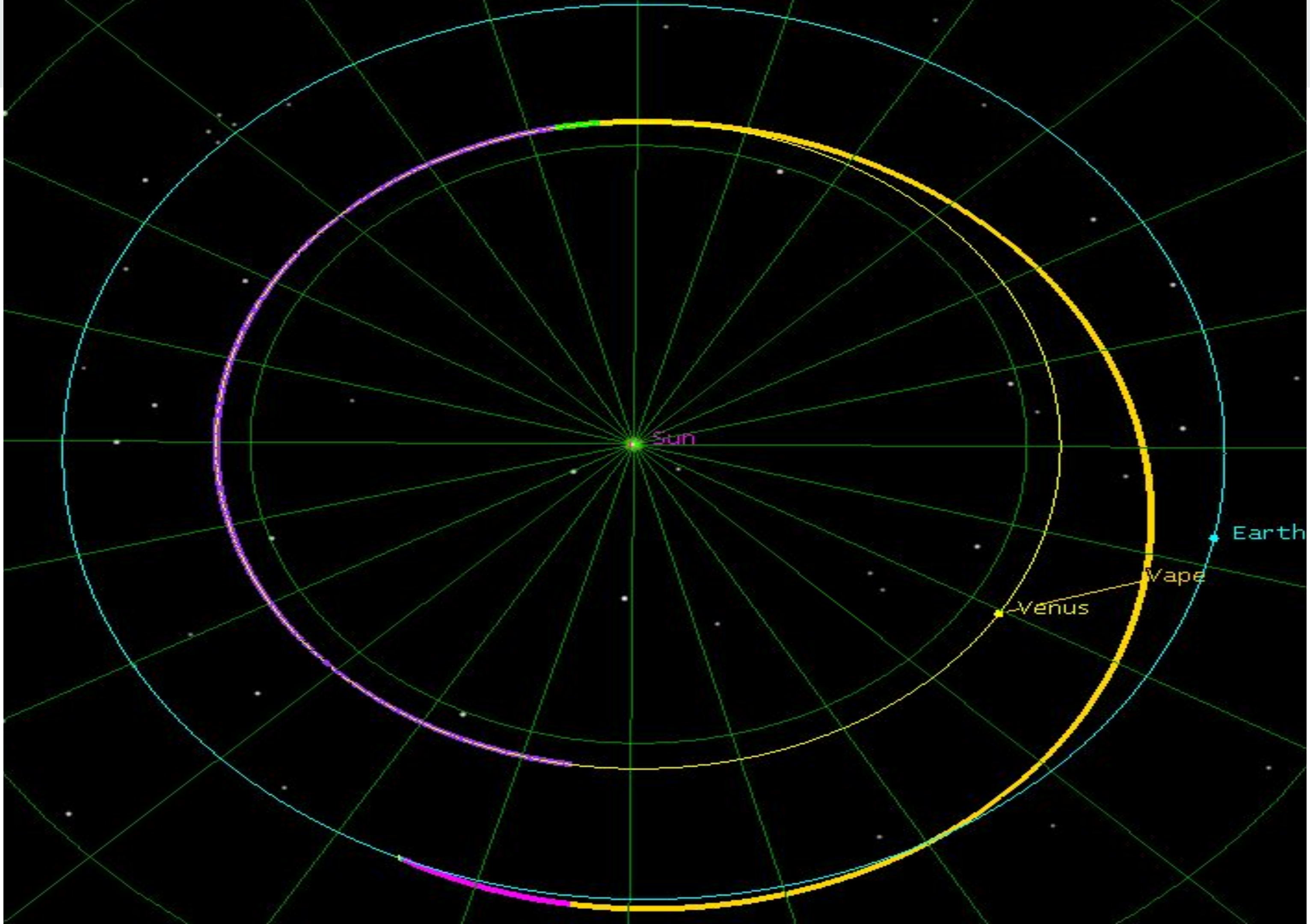




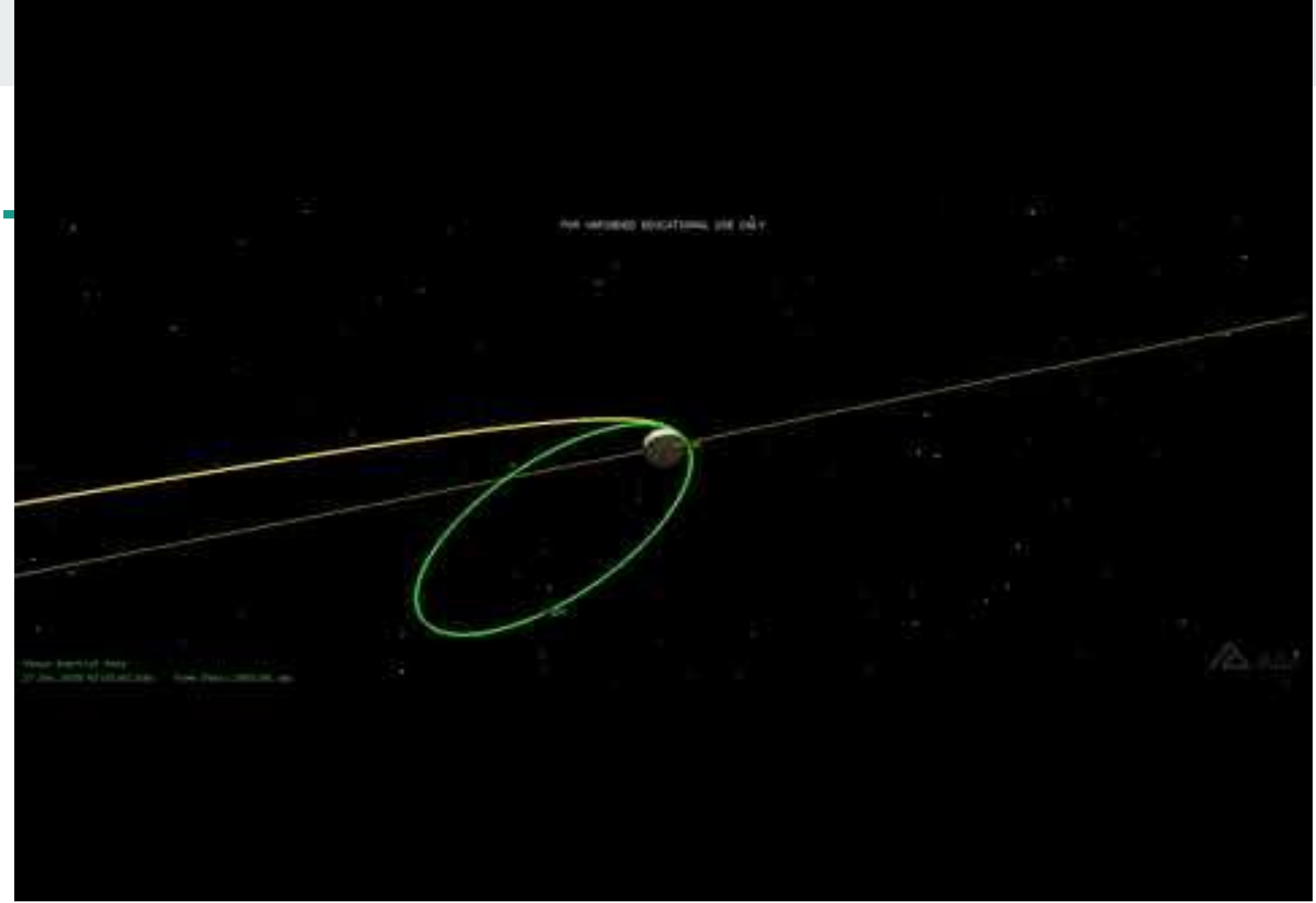


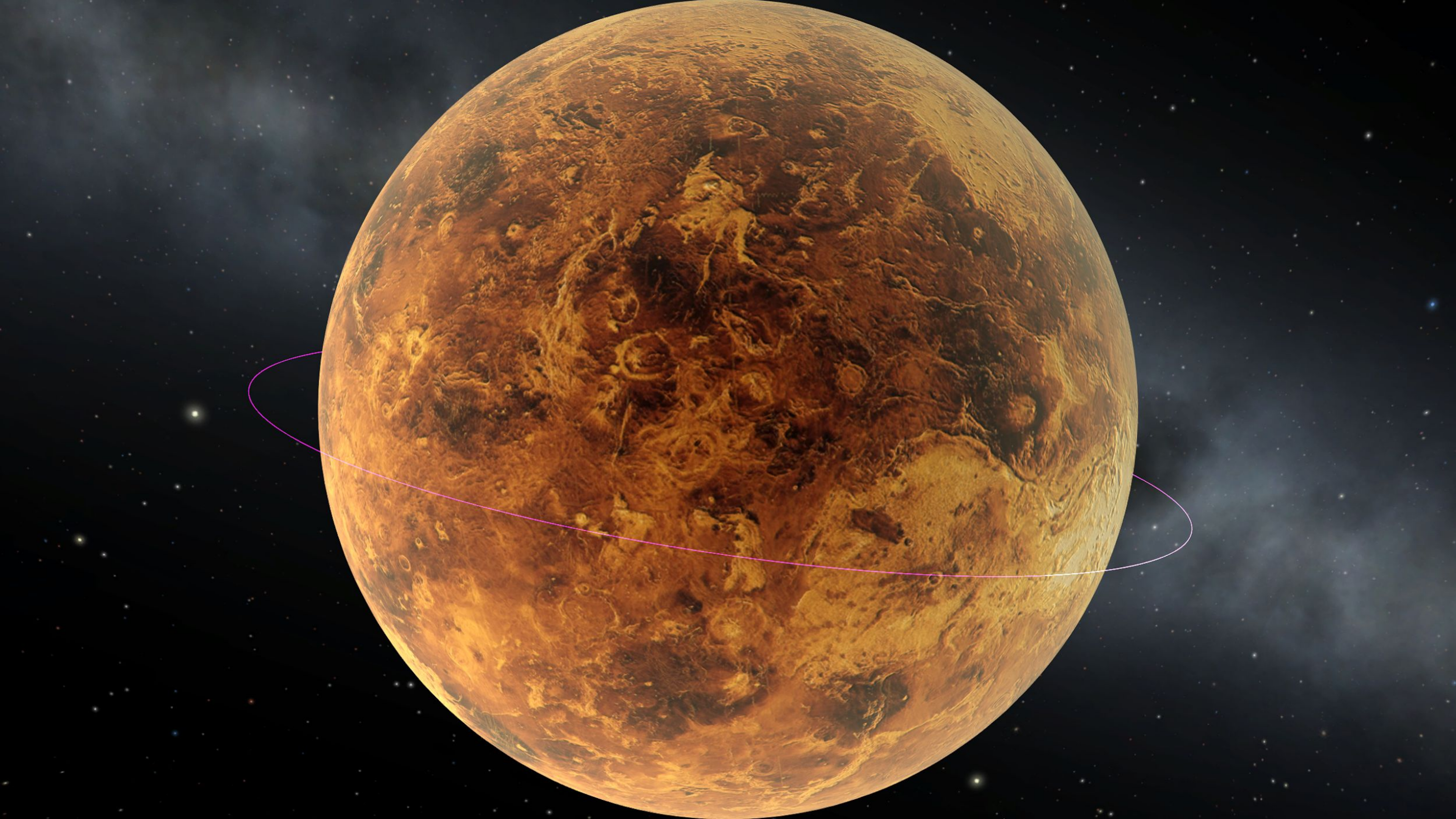


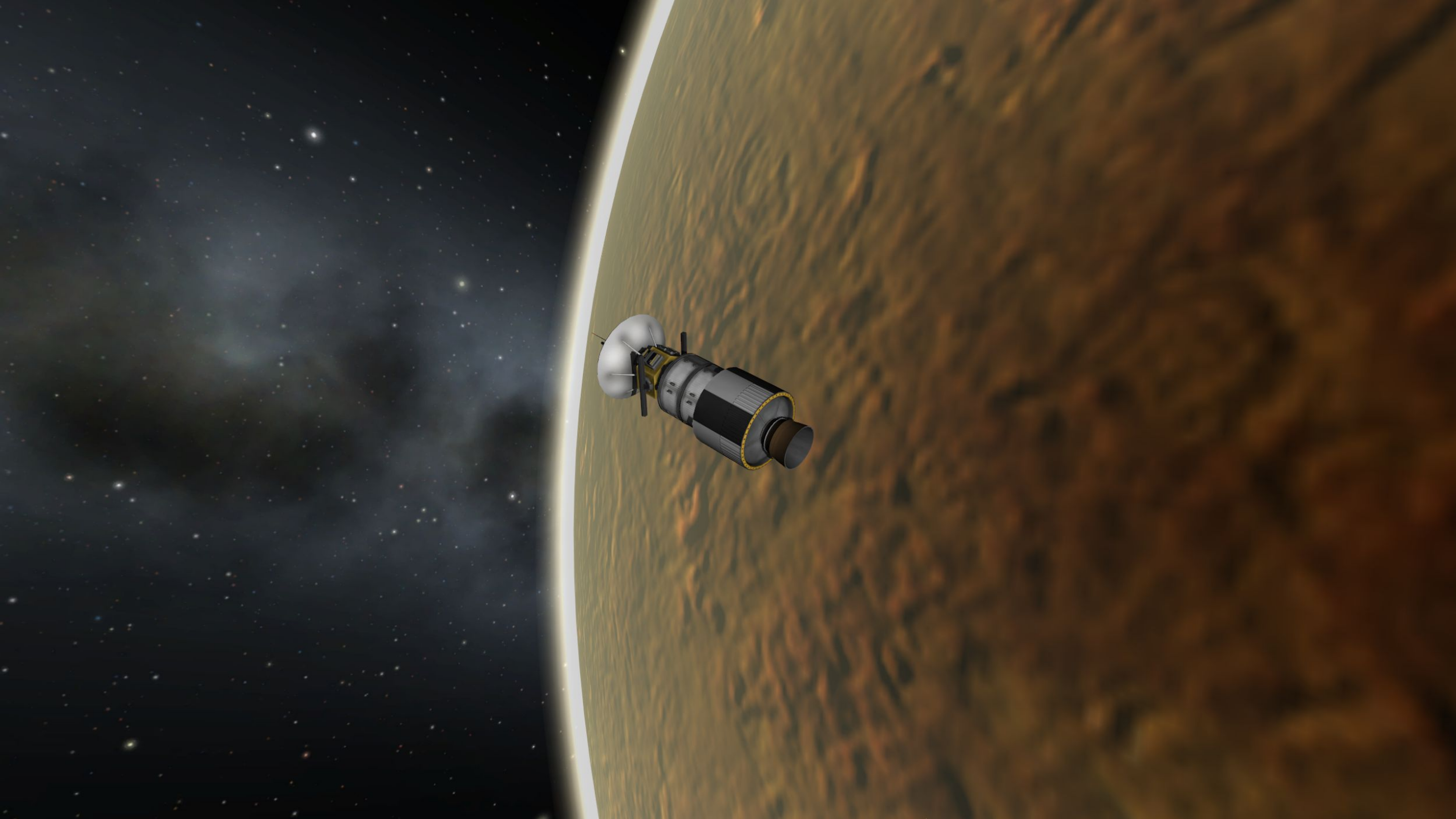

T+ 0y, 0d, 01:42:40
MET
D+ 0.00374s
PersistentRotation
▼ MechJeb ▼
FLIGHT ENGINEER 1.1.3.0
ORBT SURF VESL RDZV
HEAT BODY HUD 1 HUD 2
ORBITAL EDIT FLOAT
Apoapsis Height 314,770.0m
Periapsis Height 301,714.9m
Time to Apoapsis 1h 25m 21.2s
Time to Periapsis 40m 4.9s
Inclination 28.64453°
Eccentricity 0.00098
Semi-major Axis 6,679.242km
Angle to Prograde 300.37015°
Angle to Retrograde 120.37015°
Node DeltaV (Prograde) 4,403.82m/s
Node DeltaV (Normal) 485.78m/s
Node DeltaV (Radial) -421.42m/s
Node DeltaV (Total) 9,423.06m/s (X)
Node Burn Time 35.3s
Node Burn Time (½) 34.6s
Time to Node 106d 12h 44m 1.1s
Time to Node Burn 106d 12h 43m 26.6s
Node Angle to Prograde 315.07011°
Node Angle to Retrograde 135.07011°
RENDEZVOUS EDIT FLOAT
Go Back to Target Selection
Selected Target Venus
Phase Angle -154.12801°
Intercept Angle 259.75042°
Relative Inclination 3.39335°
Time to Rel. AN 308d 7h 35m 11.9s
Time to Rel. DN 127d 16h 1m 27.6s
Altitude (Sea Level) 106,847.8Mm
Apoapsis Height 108,244.8Mm
Periapsis Height 106,780.4Mm
Distance 252,854.6Mm
Semi-major Axis 108,208.983Mm
Maneuver Planner
Create a new maneuver node to:
↓ advanced transfer to another planet ↓
↓ Porkchop selection ↓
ΔV: 4.507 km/s Reset
include capture burn
Select: Lowest ΔV ASAP
Departure in 106d 12h 44m 41s
Transit duration 218d 20h 41m 13s
after the last maneuver node.
Create node Create and execute
initial orbit must not be hyperbolic
Remove ALL nodes
Abort node execution
Auto-warp Tolerance: 0.1 + - R m/s
Lead time: 3 + - R s
Pe
9423.1m/s
ECEF
7291.5m/s
RCS SAS
THROTTLE
G FORCE
HDG 291°
Est. Burn: 40s
Node in T - 106d, 12h, 44m
KER
PRINCIPIA
MJ



Sun
Earth
Vape
Venus

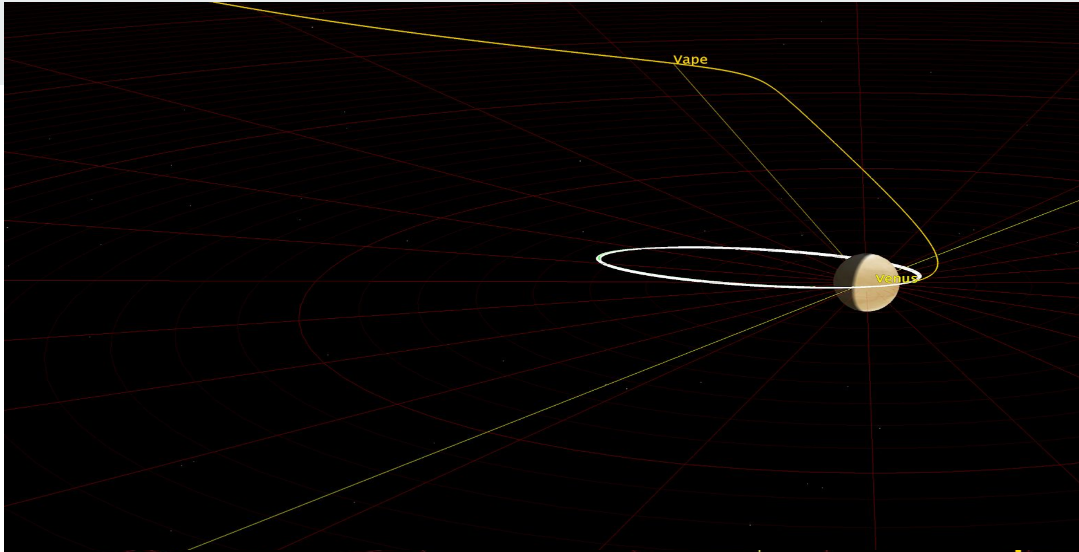


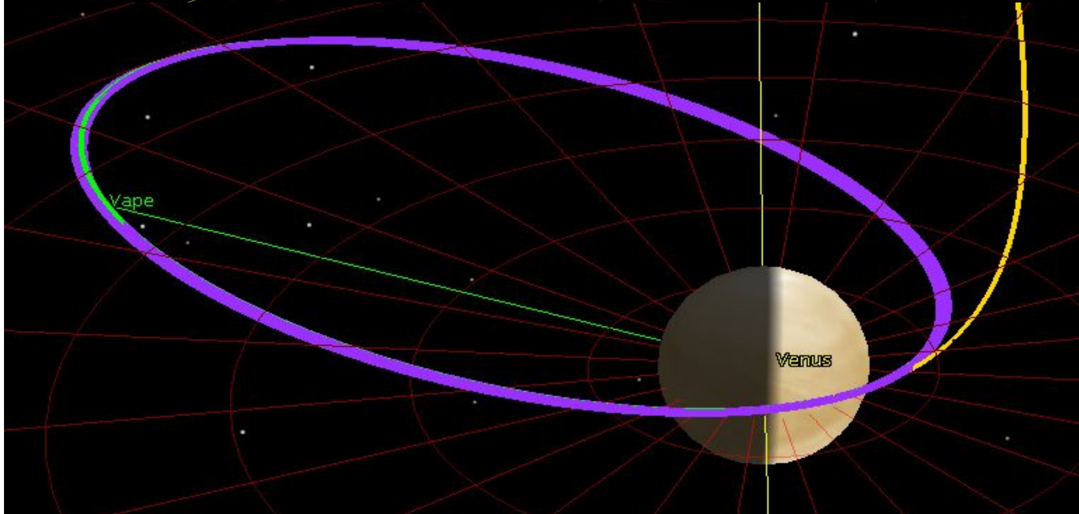




Venus Orbit parameters

- Orbit Period: 3.20 hours
- Orbit Inclination: 89 degrees
- Semi major axis: 10,290.67km
- Planetary Coverage: 90%





Trade study results (Venus orbit)

1) Ground stations access times (between Vape and the ground stations)

- The access full time duration for DSA-1 station is 8.8 Hour
- The access full time duration for DSA-2 station is 6.65 Hour
- The access full time duration for DSA-3 station is 6.1 Hour

2) Perturbations

- Polar orbit is the most suitable orbit, which needs a little of corrections for deltaV. That means more observation ➔ less fuel ➔ and spend more time to focus on the main objective of the mission.

3) Radiation environment

- Accurate measurement of accumulated dose during the life of a satellite is essential for optimizing radiation shielding design for electronic components. As satellite require reduced parameters such as power, weight, volume, and cost, while increasing performance requirements, enabling technologies to have come to the forefront. We present data for these enabling technologies in spacecraft.

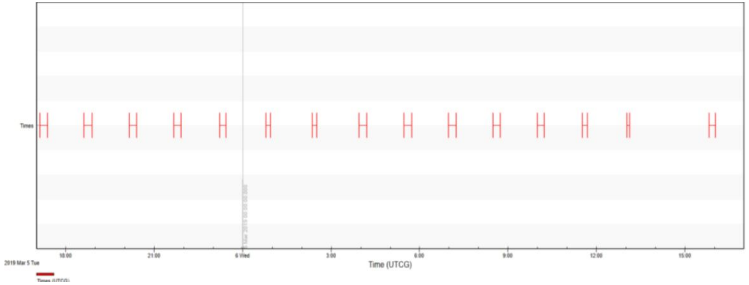
Trade study results (polar orbit)

4) Power generation

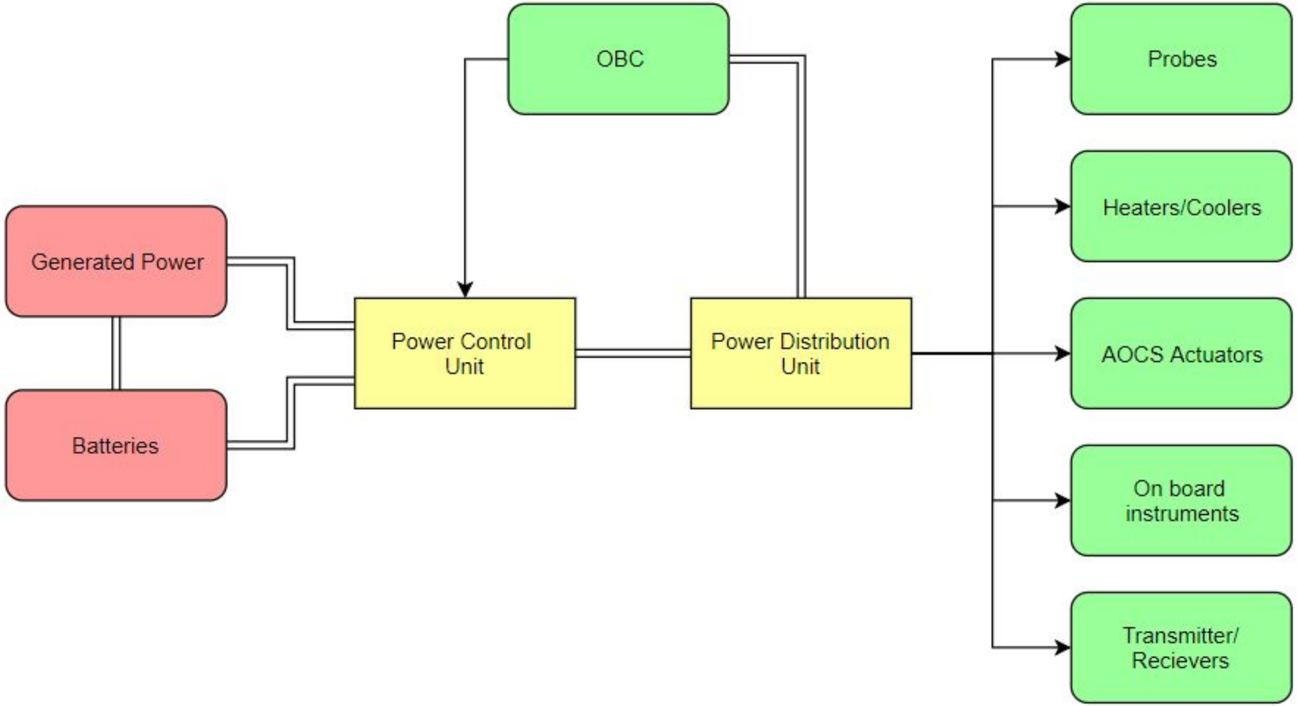
- Sun-synchronous orbit is more suitable for power generation as it generates more free power than low inclination orbit.

5) Converge access time of the satellite above Venus

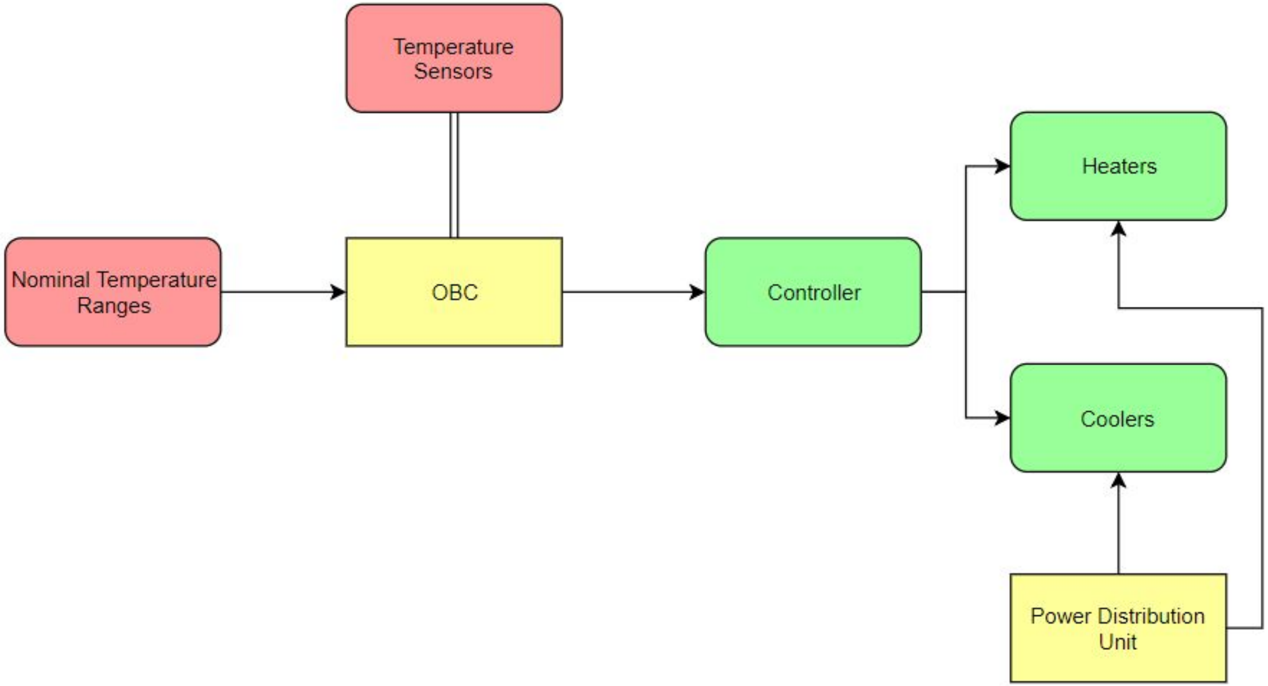
- Depends on our simulations on STK, for this orbit, we can see from the figure that coverage time covers almost the whole points. Which consider the best orbit to cover more points, and that means more accurate date.



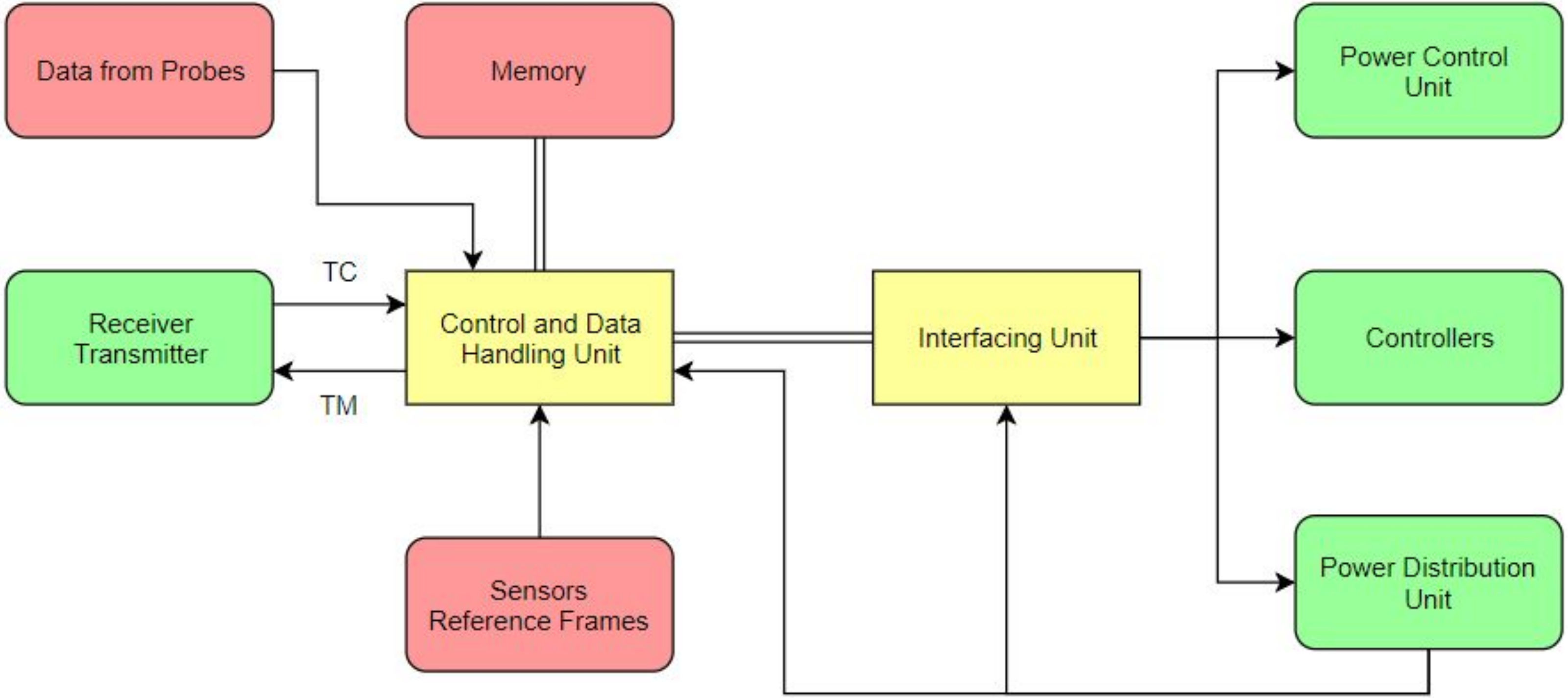
System Block: Power



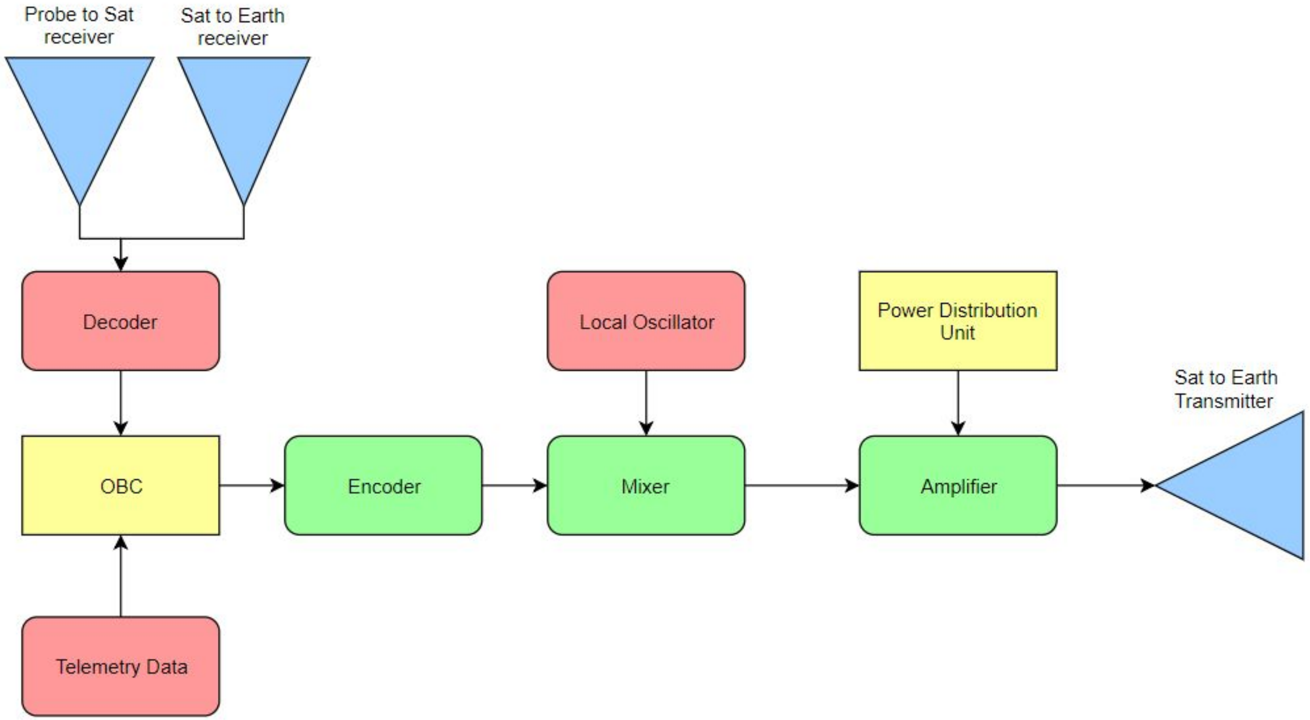
System Block: Thermal



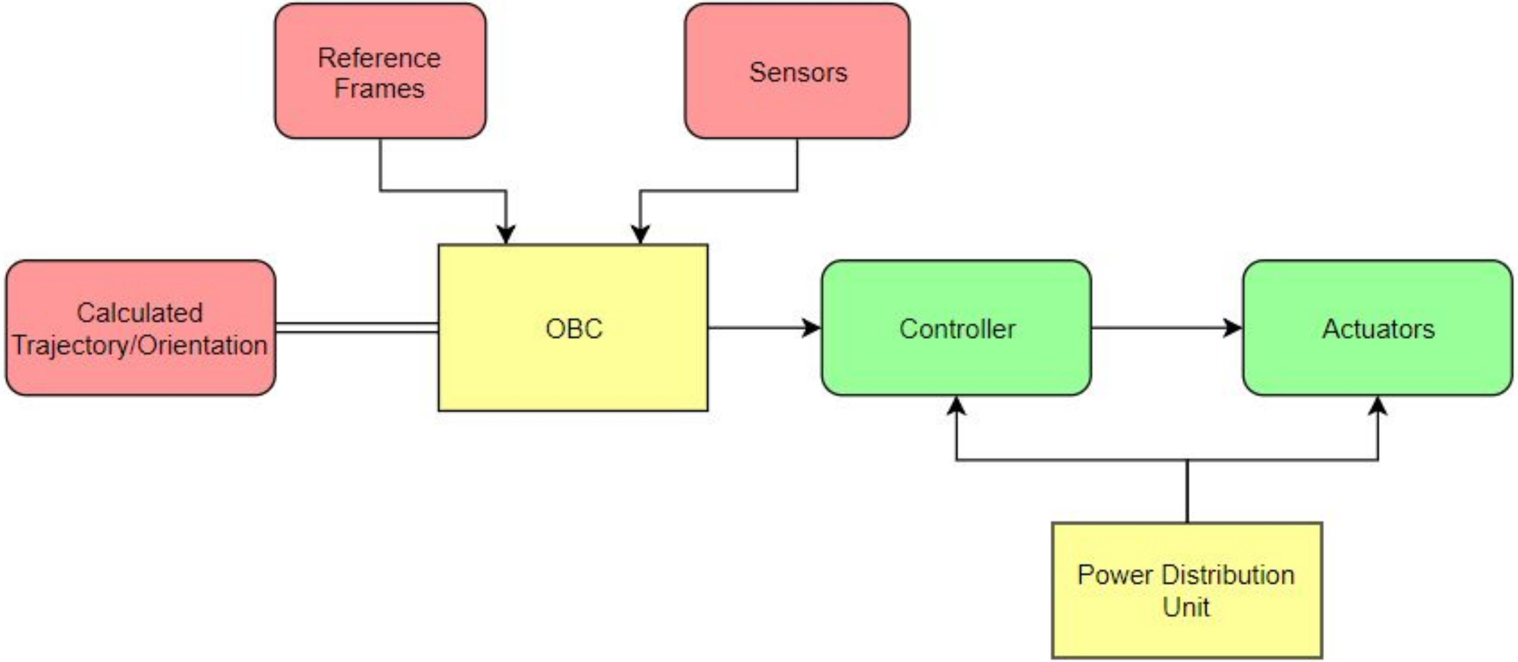
System Block: OBC



System Block: Communications



System Block: AOCS



Engineering Budgets:

- Delta-V Budget
- Mass Budget
- Power Budget
- Link Budget
- Data Budget

DeltaV budget for the operations

Operations:

- Change plane
- Adjust the inclination from Earth to Venus
- Change maneuvers (velocity)
- Adjust the eccentricity
- Adjust the right ascension at venus and earth to be in the right path

$$\Delta v_{\text{Periapsis}} = \sqrt{\frac{\mu}{r_1}}\left(\sqrt{\frac{2r_2}{r_1 + r_2}} - 1\right)$$

$$\Delta v_{\text{Apoapsis}} = \sqrt{\frac{\mu}{r_2}}\left(1 - \sqrt{\frac{2r_1}{r_1 + r_2}}\right)$$

DeltaV budget for the operations

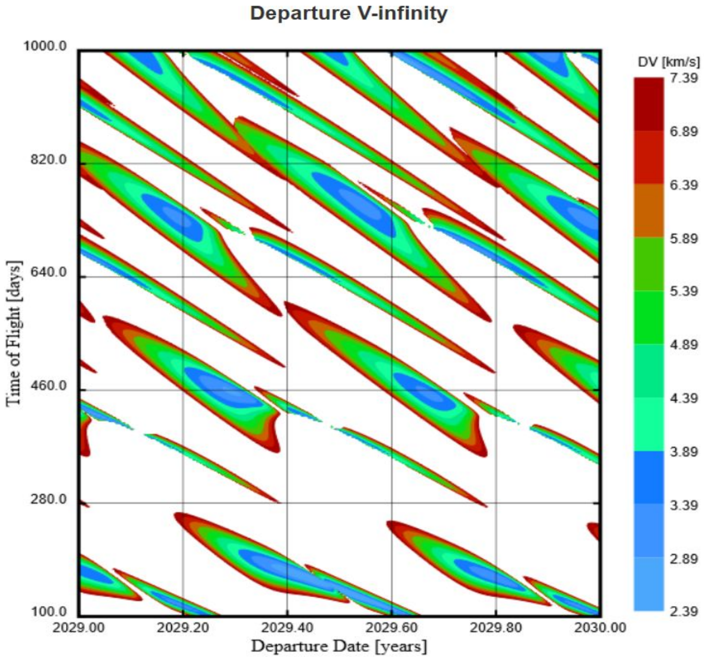
Plane change maneuvers⇒

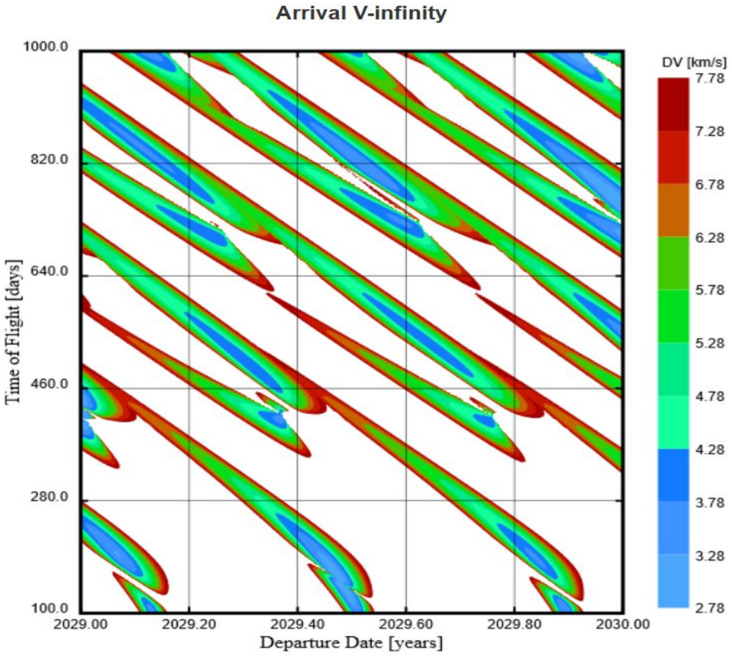
- The satellite is required to change orbital planes to reach venus and that is done by adjusting the Inclination and right ascension.
- DeltaV at first maneuver = 3.2 km/s (STK)

Phasing maneuvers⇒

- The VAPE satellite required to enter venus trajectory
- To capture the maneuver of venus we need a DeltaV = 0.795259 km/s (STK)
- DeltaV at Venus orbit = 1.5 km/s (STK)
- Total DeltaV = 5.2 km/s (Hand Calculations)
- Total DeltaV = 5.5 km/s (STK)

DeltaV


Departure V-infinity
1000.0
820.0
640.0
460.0
280.0
100.0
Time of Flight [days]
2029.00
2029.20
2029.40
2029.60
2029.80
2030.00
Departure Date [years]
DV [km/s]
7.39
6.89
6.39
5.89
5.39
4.89
4.39
3.89
3.39
2.89
2.39


Arrival V-infinity
1000.0
820.0
640.0
460.0
280.0
100.0
Time of Flight [days]
2029.00
2029.20
2029.40
2029.60
2029.80
2030.00
Departure Date [years]
DV [km/s]
7.78
7.28
6.78
6.28
5.78
5.28
4.78
4.28
3.78
3.28
2.78

DeltaV Breakdown

Maneuvre	ΔV [km/s]
Launch to LEO	9.300 [1]
Plane Change Maneuver	0.457
Earth Escape Burn	3.195
First Hohmann Transfer Burn [retrograde]	2.495
Second Hohmann Transfer Burn [Prograde]	2.701
Margin (25%)	4.530
Total: LV (S/C) [Combined]	16.190 (6.495) [22.648]

NOTE: Assumed LEO parking orbit of 322km

Mass budget

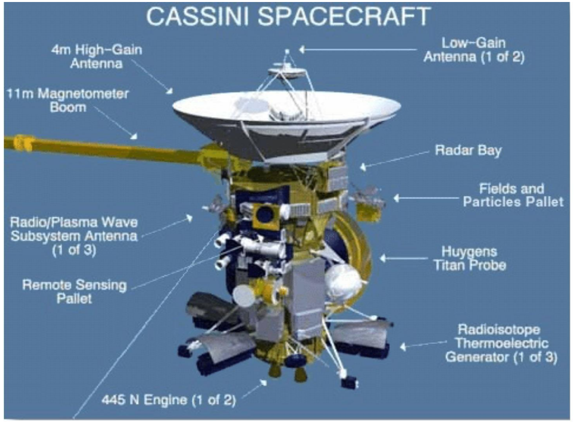


Table 2.4.4. Mass breakdown of the Cassini/Huygens spacecraft.

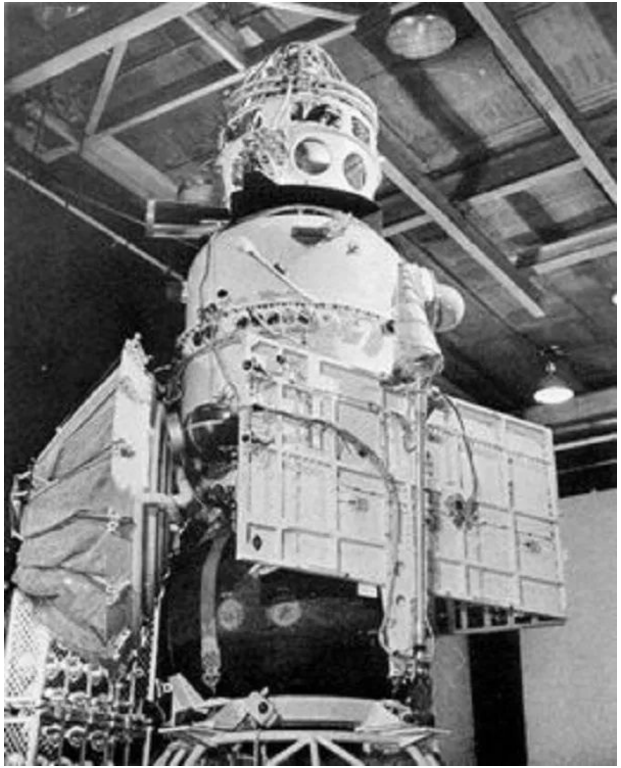
Orbiter (dry, inc. payload)	2068 kg
Probe (inc. 44 kg payload)	318 kg
Probe Support Equipment	30 kg
Launch adaptor	135 kg
Bipropellant	3000 kg
Monopropellant	132 kg
Launch mass	5683 kg

Figure 2.4.4. The Cassini/Huygens spacecraft and its principal features.

http://sci.esa.int/science-e/www/object/doc.cfm?fobjectid=35787

- Our mission is highly based around the probes and the main structure will mostly serve as a communications link back to earth.
- We investigated 3 other probe-based space missions Cassini, Venera 5, and Vega 2.
- With the Huygens probe and adapter weighing in at 348 kg and the dry spacecraft weighing in at 2068kg the Huygens consisted of 17% of the mass of the spacecraft.
- The total wet mass of cassini was 5683kg so with the with propellant included the probe only represented 6% of the mass.

Mass budget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- The Venera 5 and Venera 6 spacecraft were of identical design and launched 5 days apart in January 1969.
- The spacecraft were designed to make in-situ measurements as it descended through the Venusian atmosphere.
- The total dry mass of Venera 5 was 1130kg. The probe was spherical with a mass of 405 kg which represented 40% of the total mass of the mission.

Mass budget

https://upload.wikimedia.org/wikipedia/commons/5/52/Vega_model_-_Udvar-Hazy_Center.JPG

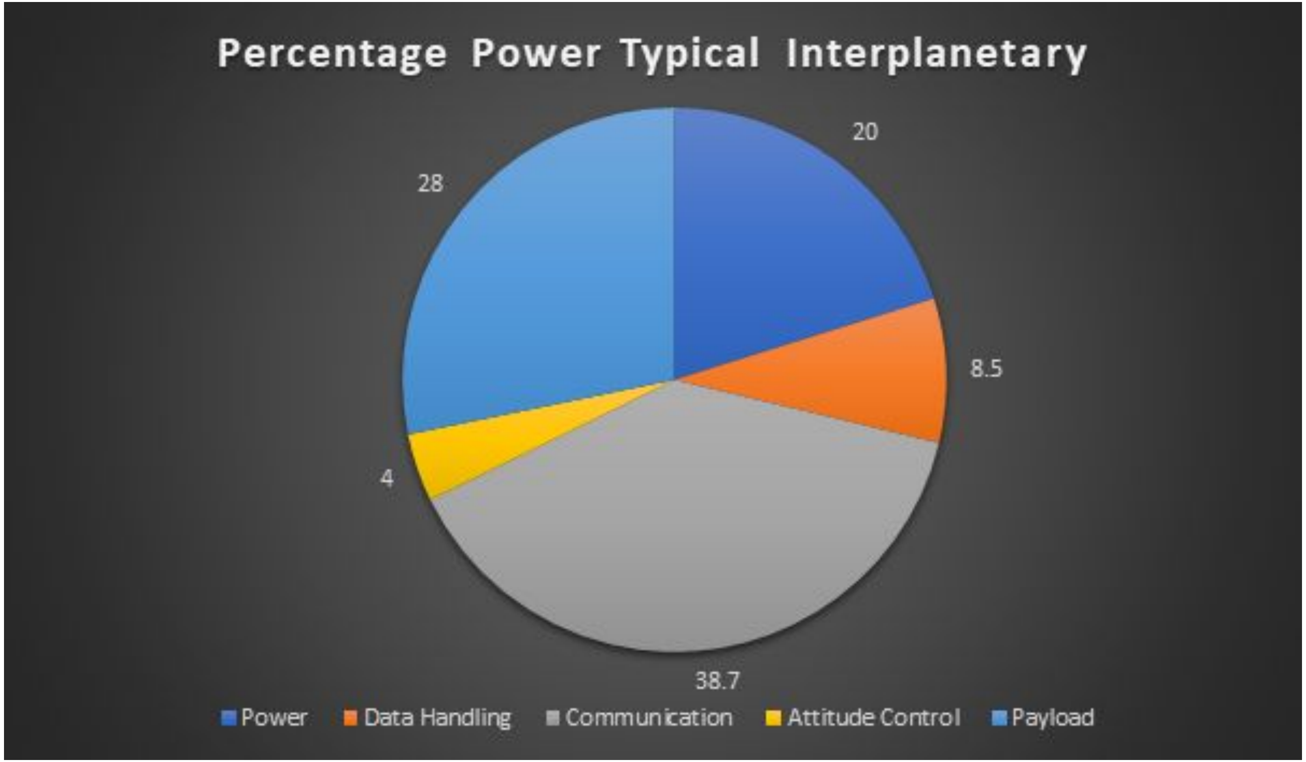
- Vega 2 was a multi goal mission as the Venus lander was just stage 1 of the full mission to intercept Halley's comet
- The total spacecraft had a mass of 4920kg with the probe/lander weighing 1500kg with a balloon suspended probe assembly with a mass of 21kg.
- In total the probe only accounted for .5% of the mass but the lander consisted of 30% of the total mass.

VAPE mission Mass budget

- With the scope of our mission and the capability of our launch vehicle our total mass budget will be no greater than 3500kg
- We are still pre phase A on our mission design so we have left large margins surrounded the subsystems

Subsystem	Mass (Kg)	Margin (%)	Total mass (Kg)
Power	150kg	20	180
Payload	500	15	575
Communications	100	10	110
Attitude control/ thrusters	300	10	330
Thermal control	50	10	55
Shielding	100	5	105
Harness (5%)	70	0	70
Structure (20%)	300	0	300
Total dry mass			**1725 Kg**
Additional System margin (25%)			430
propellant			1300
Total wet mass			**3456 Kg**

Power Budget

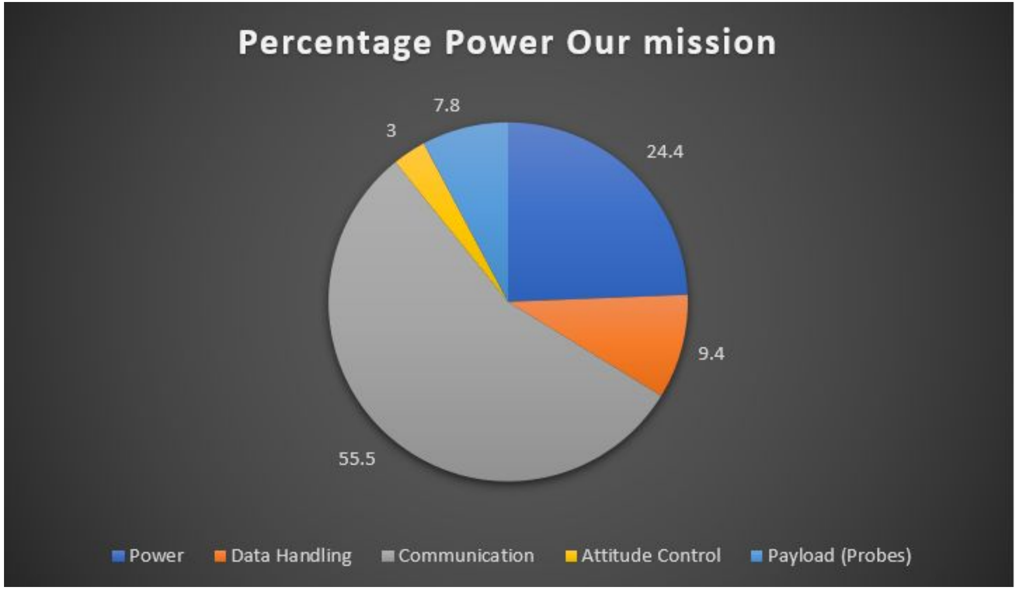


Venus Express

- ESA mission to Venus from 2006 to the conclusion of its primary science phase in 2014
- Travel and orbits types can be compared to our mission
- Development, integration and test time of only 3 years
    - Design was updated from Mars Express and changed design to adhere to Venus environment

Power Budget

- More emphasis on keeping devices at nominal temperature due to environment
- Communication between Earth and Satellite and Satellite and probe needed
- Payloads are not directly on Satellite and therefore do not require much power



Budget Estimate

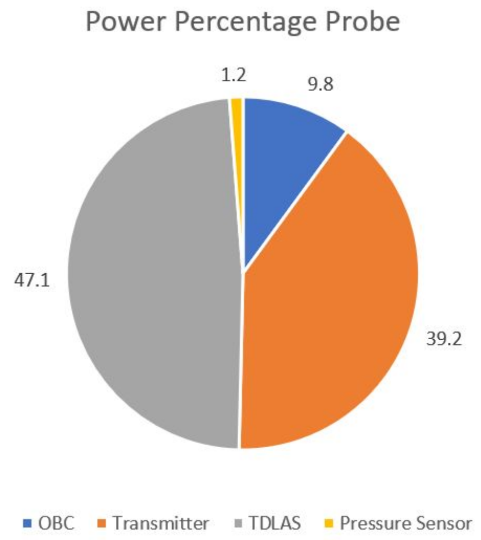
Power Subsystem	Power (W)
Hot Case Coolers	30 W
Cold Case Heater	30 W
Power Total	**60 W**
Data Handling Subsystem	**Power (W)**
OBC	18 W
Control Electronics	5 W
Data Handling Total	**23 W**
Communication Subsystem	**Power (W)**
Receiver from Earth	4 W
Receiver from Probe	4 W
Transmitter X - band	8 W
Transmitting Amplifier	120 W
Communication Total	**136 W**

Budget Estimate (cont.)

Attitude Control Subsystem	Power (W)
Attitude Sensors	1 W
Attitude Processing	2 W
Attitude control electronics	4 W
Attitude Control Total	**7 W**
Payload Subsystem	**Power (W)**
Battery for Probes	1 W
Probe Regulator	3 W
Optical Instruments on Satellite	15 W
Payload Total	**19 W**
Total Power	**245 W**
Margin	**25%**
Total Power	**306 W**

Power Estimate Probe

Probe	Power (W)
OBC	0.5 W
Transmitter	2 W
TDLAS	2.4 W
Pressure Sensor	0.2 W
Probe Total	5.1 W
Margin	30%
Probe Total	6.63 W



Link budget

Uplink:	
Uplink Frequency:	7.9-8.395 GHz
Diameter of Transmitting Antenna:	35 m
Beamwidth:	0.065 deg
Gain:	66.50 dBi
Transmit Power:	20,000 W
Backoff and line loss	-4 dB
EIRP:	135.5 dBW

Propagation Range:	200,000,000 km
Space Loss:	-189.2 dB
Atmospheric Loss:	-10 dB
Net Path Loss:	-199.2 dB
Satellite Noise Temperature:	23.4 dB-K
Satellite Gain:	20.8 dBi
Satellite G/T:	7.11 dB/K
Received Carrier Power:	-34.9 dB-Hz
Carrier to Noise Ratio:	133.9 dB
Available Eb/No Ratio	76.5 dB

Downlink:	
Frequency:	7.250 - 7.745 GHz
Satellite Transmit Power	150 W
Antenna Efficiency:	65%
Backoff and line loss:	-5 dB
Antenna Gain	36.03 dBi
EIRP:	83.26 dBW

Propagation Range:	200,000,000 km
Space Loss:	-188.4 dB
Atmospheric Loss:	-7 dB
Net Path Loss:	-195.4 dB
Satellite Antenna Diameter:	2.2 m
Antenna Beamwidth:	2.84 deg
Antenna Gain:	65.6 dB
Line Loss:	-2 dB
Received Carrier Power:	-36.11 dB-Hz
Carrier to Noise Ratio:	159.3 dB
Available Eb/No Ratio:	101.9 dB

Data Volume Budget

	Data Rate (bits/s)	Time On (s)	Data Volume (bits/orbit)
Balloon	4800	7200	34,560,000
Probe	2700	3600	9,720,000
Housekeeping	70	12000	840,000
		Total	45,120,000

Data Volume Budget

	Data Volume (bits)	Compression Ratios	Data Size (bits/orbit)
Balloon	34,560,000	3.00	11,520,000
Probe	9,720,000	3.00	3240000
Housekeeping	840,000	4.00	210,000
Totals	45,120,000		14,970,000

Available Downlink

- Approximately 15 Mbytes/day
  - Average orbit is 108,000 seconds
  - Communications are available for 54,000 seconds
  - Will transmit for 6 hours once a day = 21,600 seconds

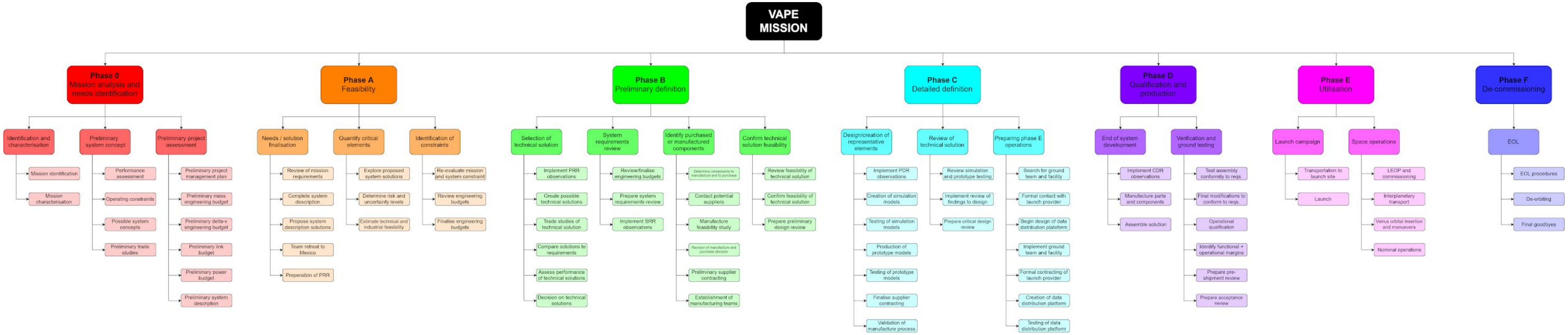
- With a data transfer rate of 720 kb/sec we can transmit 15,552,000
- 15.5 Mbytes/day > 14.9 Mbytes/day
- All data will be transmitted

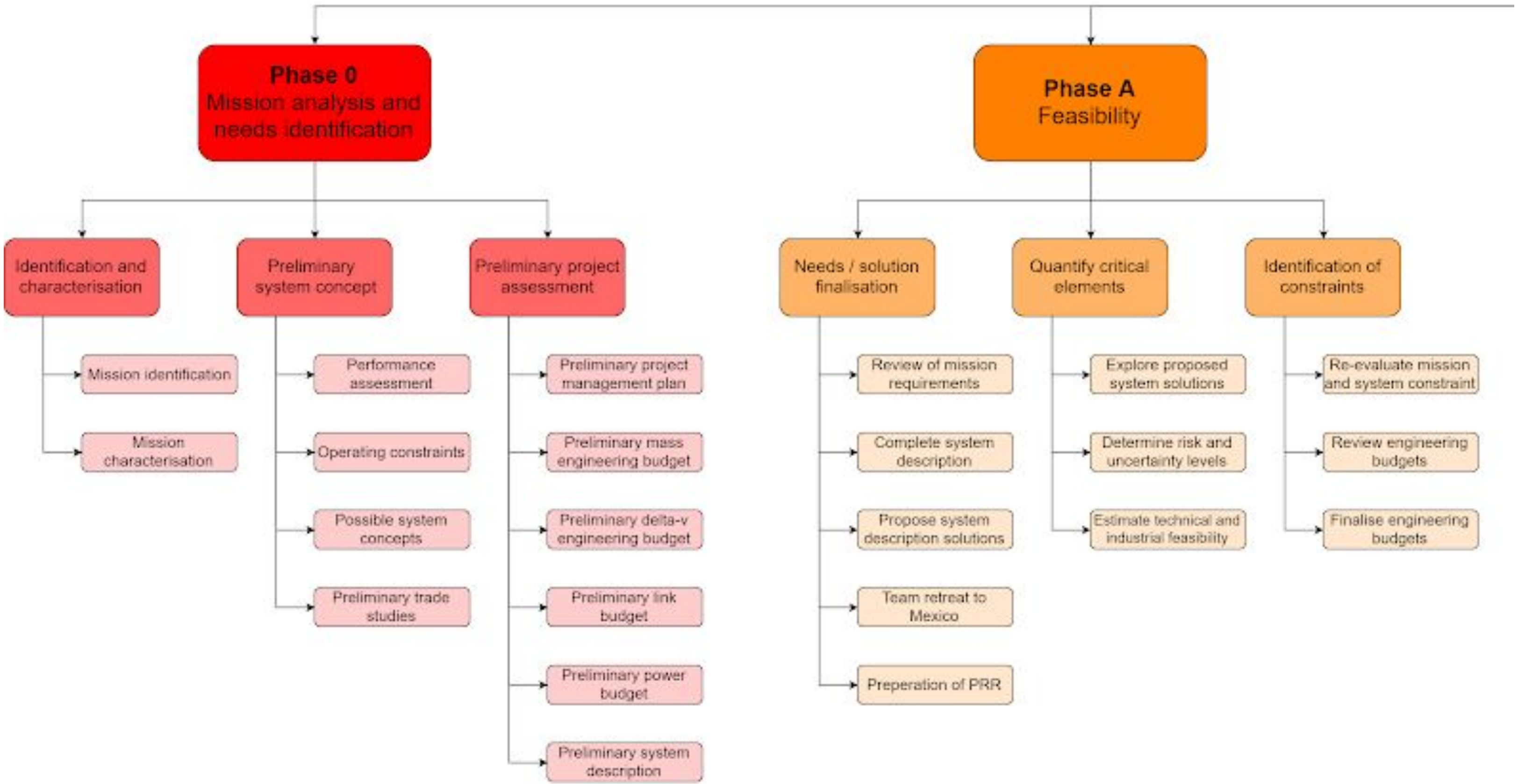
Mission Cost analysis

- Similar missions to venus costed in the range of 200 million to 600 million

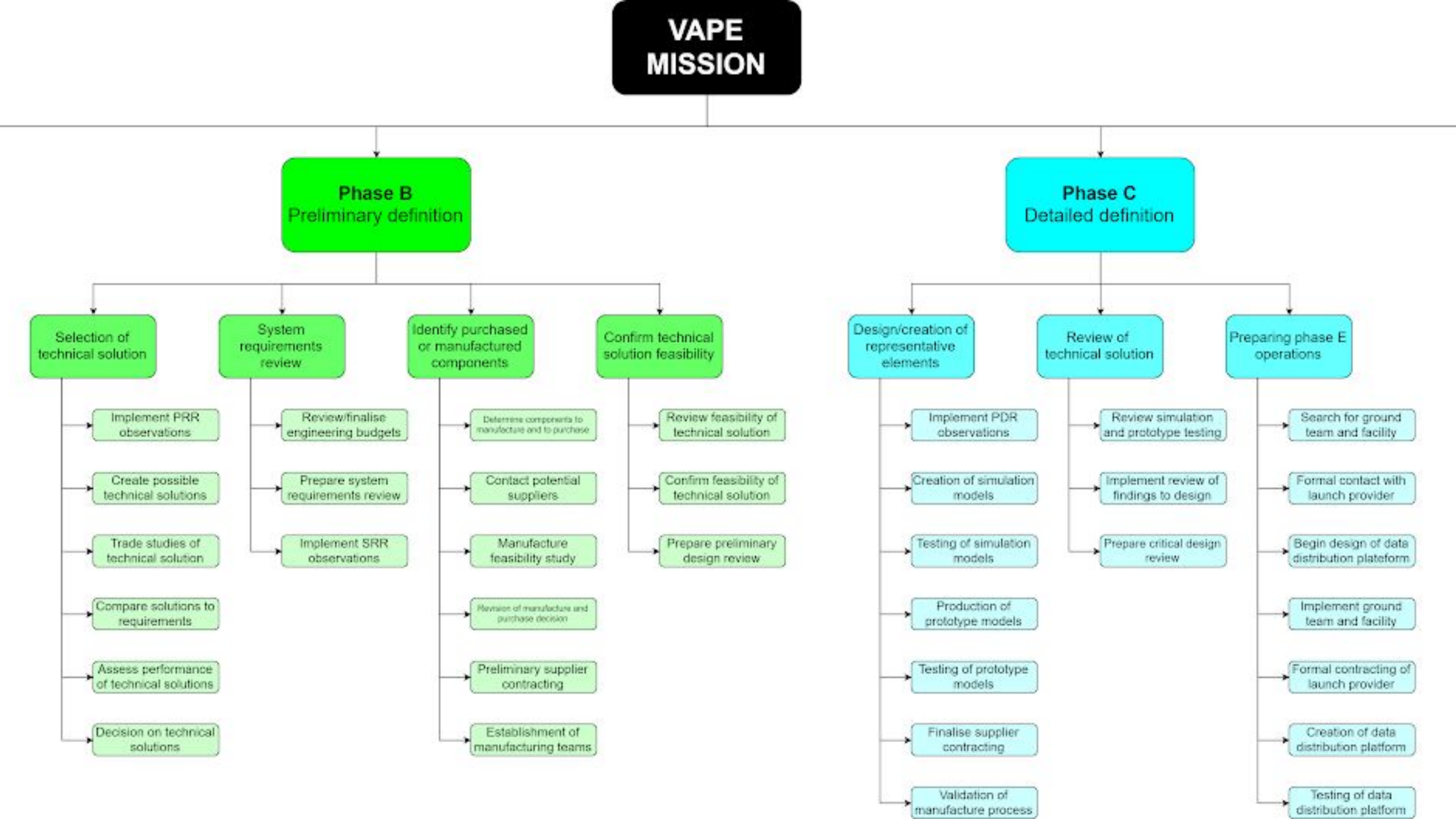
Subsystem	Cost (Millions USD)	Margin (%)	Total Cost (Million USD)
Power	15	10	17.25
Payload	40	20	48
Communications	30	10	33
Thermal control	5	15	5.75
Structure	20	10	22
Assembly	30	15	34.5
Launch Vehicle	158	0	158
Ground Station	4	10	4.4
Testing	20	10	22
Total cost			**345.9**

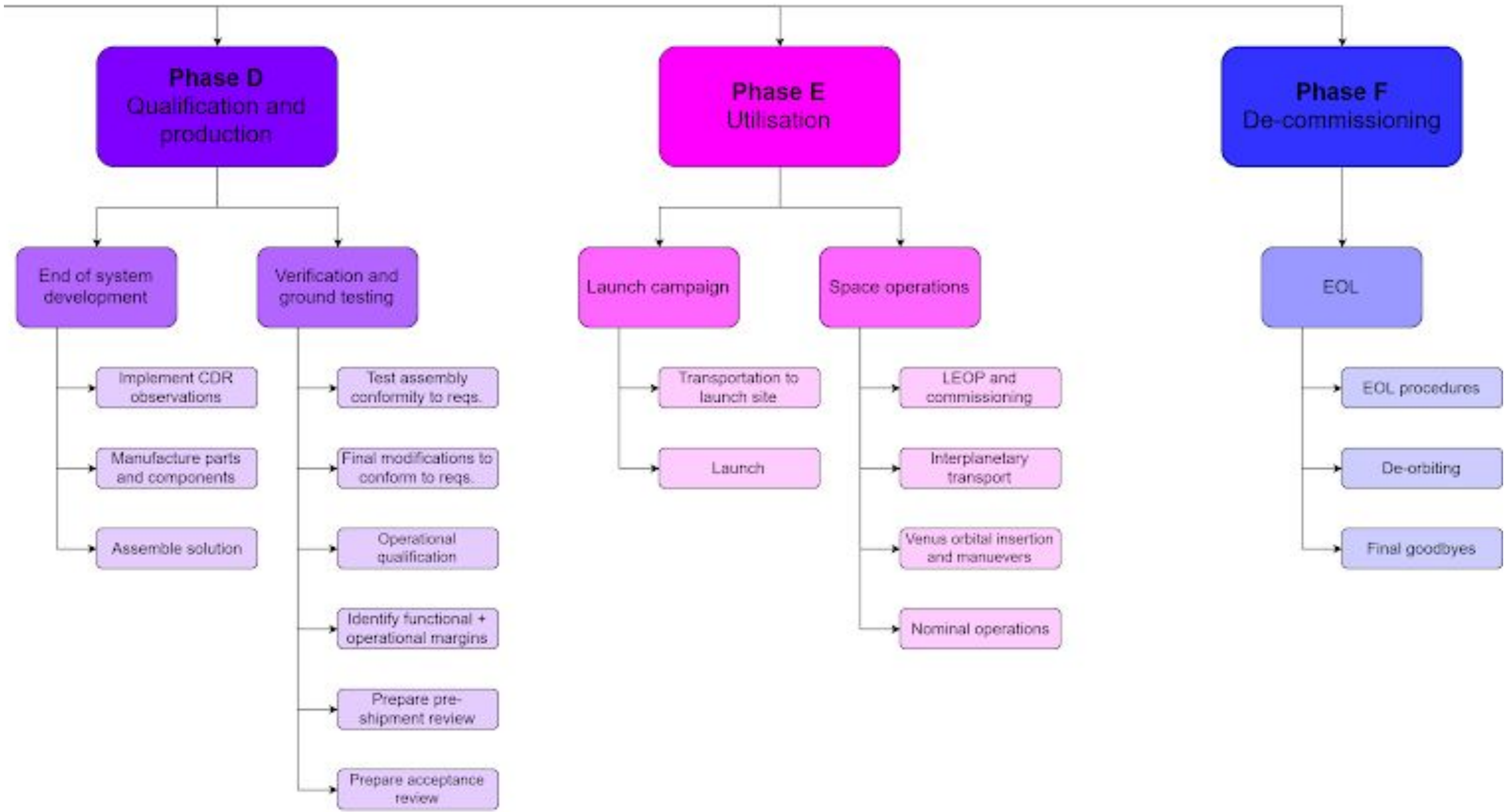
Work breakdown structure



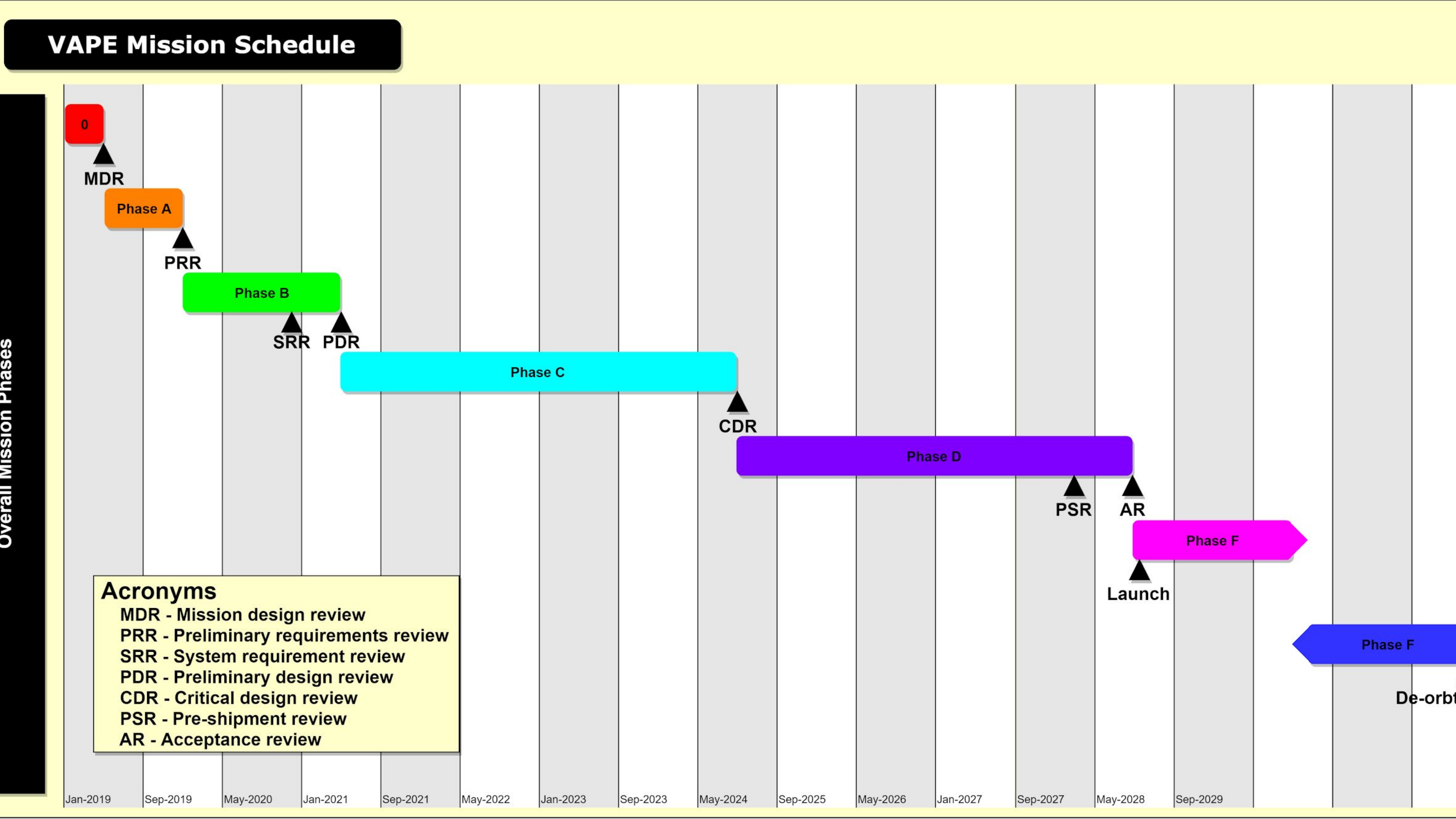


Phase 0
Mission analysis and needs identification
Identification and characterisation
Mission identification
Mission characterisation
Preliminary system concept
Performance assessment
Operating constraints
Possible system concepts
Preliminary trade studies
Preliminary project assessment
Preliminary project management plan
Preliminary mass engineering budget
Preliminary delta-v engineering budget
Preliminary link budget
Preliminary power budget
Preliminary system description
Phase A
Feasibility
Needs / solution finalisation
Review of mission requirements
Complete system description
Propose system description solutions
Team retreat to Mexico
Preperation of PRR
Quantify critical elements
Explore proposed system solutions
Determine risk and uncertainty levels
Estimate technical and industrial feasibility
Identification of constraints
Re-evaluate mission and system constraint
Review engineering budgets
Finalise engineering budgets


VAPE MISSION
Phase B Preliminary definition
Selection of technical solution
Implement PRR observations
Create possible technical solutions
Trade studies of technical solution
Compare solutions to requirements
Assess performance of technical solutions
Decision on technical solutions
System requirements review
Review/finalise engineering budgets
Prepare system requirements review
Implement SRR observations
Identify purchased or manufactured components
Determine components to manufacture and to purchase
Contact potential suppliers
Manufacture feasibility study
Revision of manufacture and purchase decision
Preliminary supplier contracting
Establishment of manufacturing teams
Confirm technical solution feasibility
Review feasibility of technical solution
Confirm feasibility of technical solution
Prepare preliminary design review
Phase C Detailed definition
Design/creation of representative elements
Implement PDR observations
Creation of simulation models
Testing of simulation models
Production of prototype models
Testing of prototype models
Finalise supplier contracting
Validation of manufacture process
Review of technical solution
Review simulation and prototype testing
Implement review of findings to design
Prepare critical design review
Preparing phase E operations
Search for ground team and facility
Formal contact with launch provider
Begin design of data distribution plateform
Implement ground team and facility
Formal contracting of launch provider
Creation of data distribution platform
Testing of data distribution platform

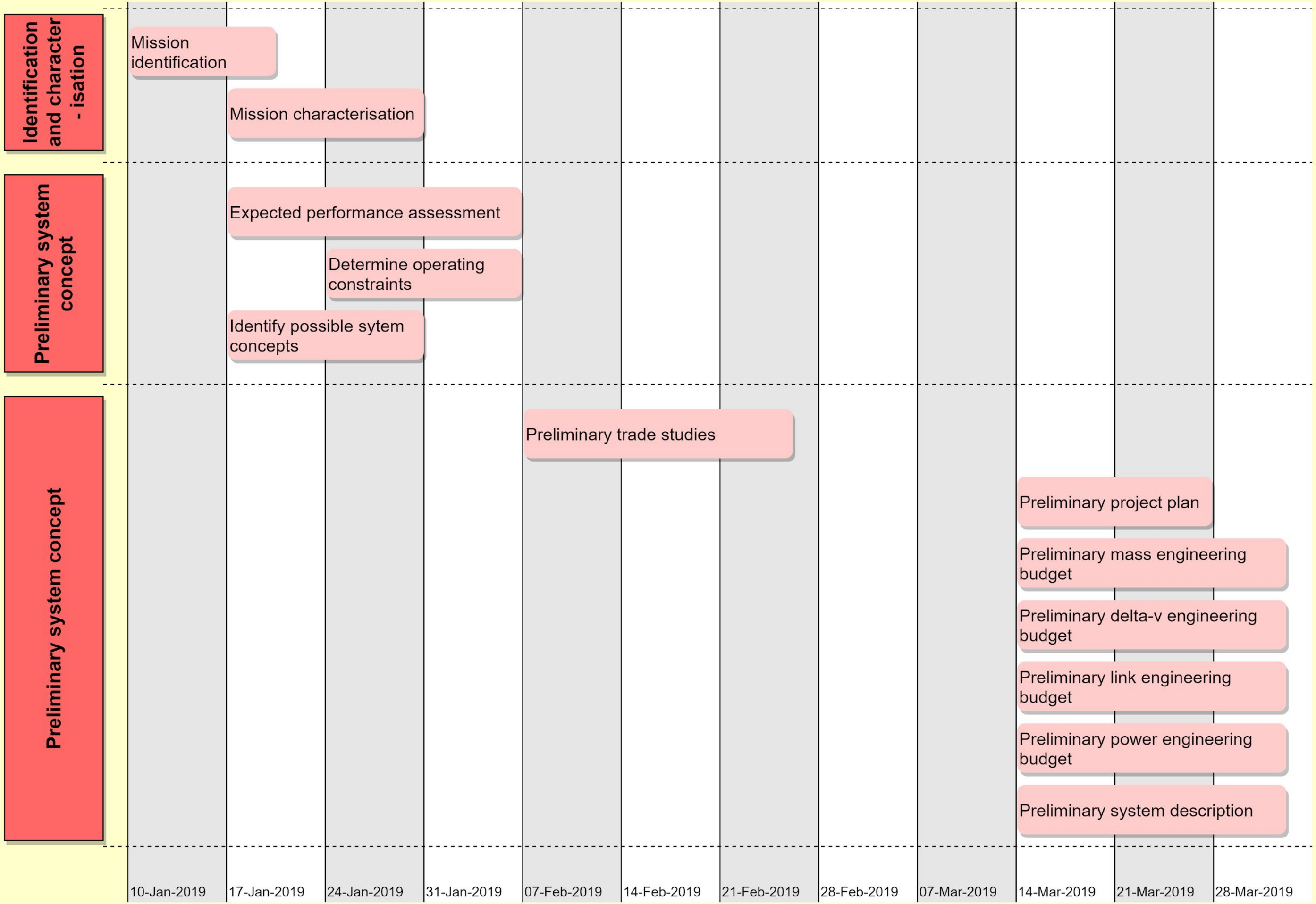


Phase D
Qualification and production
End of system development
Implement CDR observations
Manufacture parts and components
Assemble solution
Verification and ground testing
Test assembly conformity to reqs.
Final modifications to conform to reqs.
Operational qualification
Identify functional + operational margins
Prepare pre-shipment review
Prepare acceptance review
Phase E
Utilisation
Launch campaign
Transportation to launch site
Launch
Space operations
LEOP and commissioning
Interplanetary transport
Venus orbital insertion and manuevers
Nominal operations
Phase F
De-commissioning
EOL
EOL procedures
De-orbiting
Final goodbyes



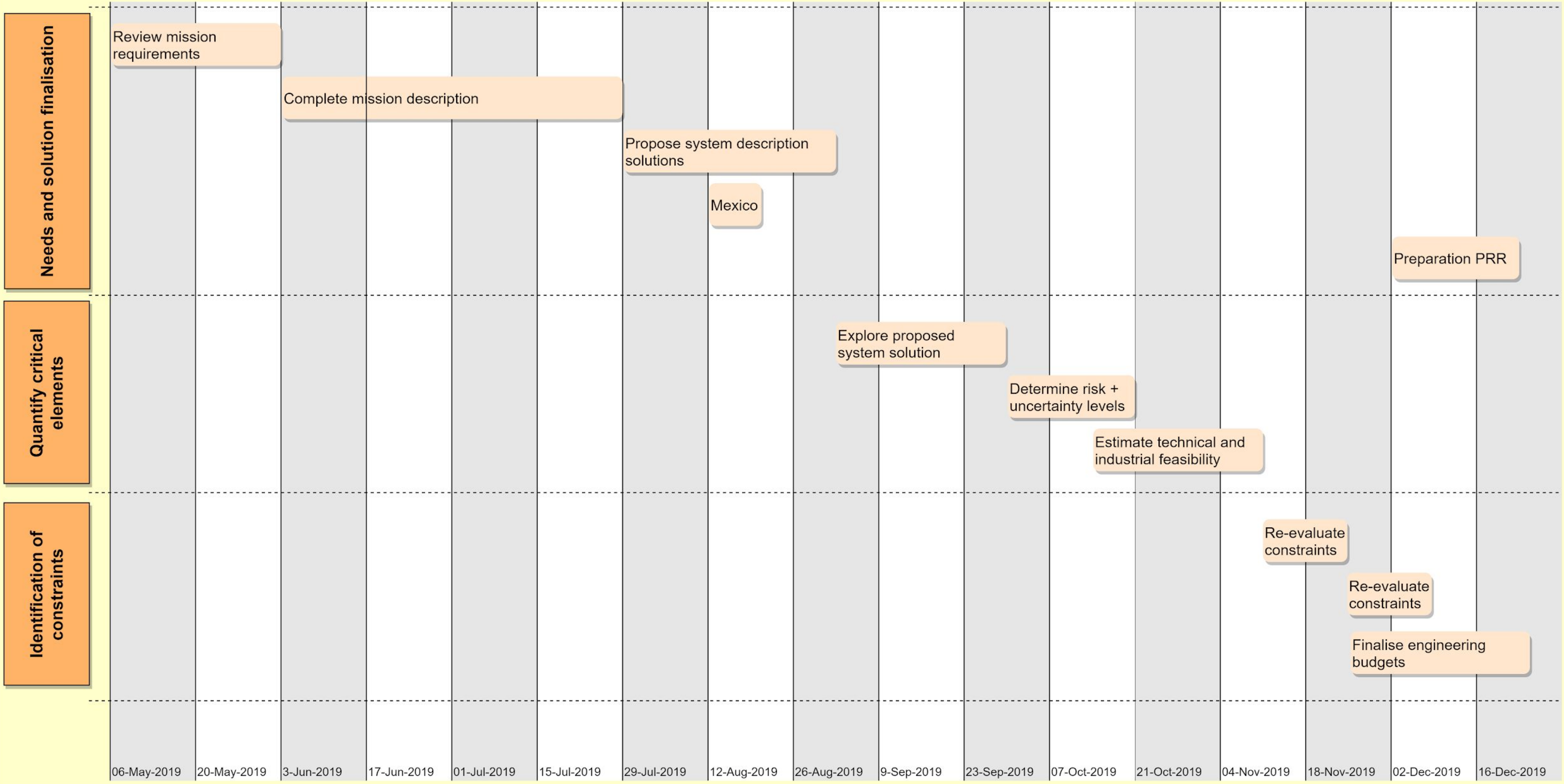
VAPE Mission Schedule
Overall Mission Phases
0
MDR
Phase A
PRR
Phase B
SRR
PDR
Phase C
CDR
Phase D
PSR
AR
Phase F
Launch
Phase F
De-orbt
Acronyms
MDR - Mission design review
PRR - Preliminary requirements review
SRR - System requirement review
PDR - Preliminary design review
CDR - Critical design review
PSR - Pre-shipment review
AR - Acceptance review
Jan-2019
Sep-2019
May-2020
Jan-2021
Sep-2021
May-2022
Jan-2023
Sep-2023
May-2024
Sep-2025
May-2026
Jan-2027
Sep-2027
May-2028
Sep-2029

Phase 0 : Mission analysis and needs identification



Title	Number	Key people/teams	Time	Nominal start	Nominal stop	Category
Review of mission requirements	140	VAPE Concepts Team	4 weeks	06/05/2019	03/06/2019	Needs and solution finalisation
Complete system description	150	VAPE Concepts Team	8 weeks	03/06/2019	29/07/2019	
Propose system description solutions	160	VAPE Concepts Team	5 weeks	29/07/2019	02/09/2019	
Team retreat to Mexico	170	VAPE Concepts Team	1 week	12/08/2019	19/08/2019	
Preparation of PRR	231	VAPE Concepts Team	3 weeks	02/12/2019	23/12/2019	
Explore proposed system description solutions	180	VAPE Concepts Team	4 weeks	02/09/2019	30/09/2019	Quantify critical elements
Determine uncertainty and risk levels for system	190	VAPE Concepts Team	3 weeks	30/09/2019	21/10/2019	
Estimate technical and industrial feasibility	200	VAPE Concepts Team + consulting experts	4 weeks	14/10/2019	11/11/2019	
Re-evaluate missions and system constraints	210	VAPE Concepts Team	2 weeks	11/11/2019	25/11/2019	Identification of constraints
Review of engineering budgets	220	VAPE Concepts Team	2 weeks	18/11/2019	02/12/2019	
Finalise engineering budgets	230	VAPE Concepts Team	4 weeks	18/11/2019	16/12/2019	

Phase A : Feasibility



Team contributions

Name	Contributions
Yaseen Al-Taie	Orbit Simulations STK, Δv budget
Jessie Atamanchuk	Orbit Simulations STK, KSP, Δv budget
Konrad Kaczor	Link Budget, Data Volume budget
Matthieu Durand	Work Breakdown, Schedule
Jacob Samson	Mass Budget, Cost Breakdown
Michael Tabascio	Power Budget, System Block Diagrams