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Long-duration balloon for in-situ exploration of the Venus atmosphere

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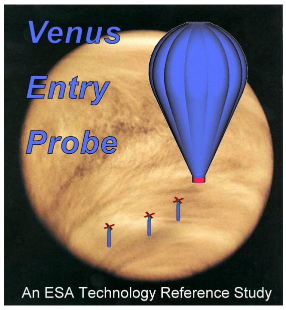
Introduction

The European Space Agency together with industrial partners has studied a concept for low-cost in-situ exploration of the atmosphere of Venus: the Venus Entry Probe. The Venus Entry Probe is one of ESA's Technology Reference Studies (TRS). TRSs are model science-driven missions that are, although not part of the ESA science programme, able to provide focus to future technology requirements. This is accomplished through the study of several technologically demanding and scientifically meaningful mission concepts, which are strategically chosen to address diverse technological issues. The TRSs complement ESA's current mission specific development programme and allow the ESA Science Directorate to strategically plan the development of technologies that will enable potential future scientific missions.

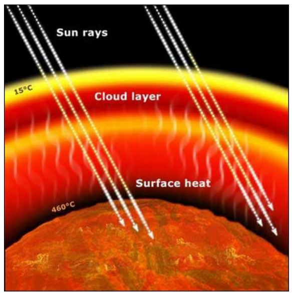
Venus has been targeted because in-situ exploration of the atmosphere of Venus is both scientifically interesting and technologically challenging.



Mission objectives

The key scientific objectives for a Venus atmospheric mission have been derived from a literature survey:

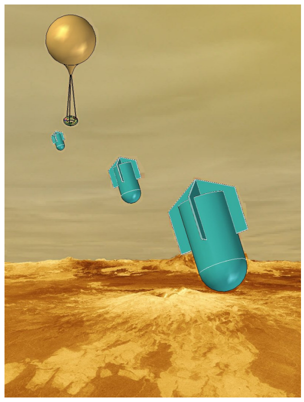
- ***Origin and evolution of Venus atmosphere***
  - ✓ Comparative planetology (Venus vs Earth)
- ***Composition of lower atmosphere***
  - ✓ Atmospheric chemistry
  - ✓ Runaway greenhouse effect
  - ✓ Tracking active volcanism
- ***Aerosol analysis/exobiology***
  - ✓ Analysis of large (ø ~ 7 μm) cloud particles
- ***Atmospheric dynamics/thermal balance***
  - ✓ Super-rotation
  - ✓ Hadley cell circulation?
  - ✓ Weather patterns in main cloud deck
  - ✓ Polar vortices



Mission requirements

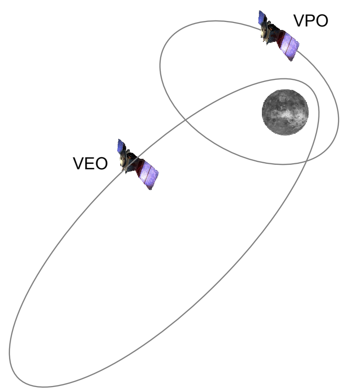
In order to address the key scientific questions, the mission should comply with the following:

- ***In-situ exploration between 40-57 km at all longitudes***
  - ✓ Long-duration aerobot
- ***Vertical profiles of atmospheric properties at multiple locations***
  - ✓ Atmospheric microprobes
- ***Global remote sensing of the Venus atmosphere***
  - ✓ All longitudes and latitudes, including polar vortices every 5 hours
    - ➢ Venus Polar Orbiter (VPO)
  - ✓Also concurrently with aerobot measurements to provide:
    - ➢ global and regional context of in-situ measurements
    - ➢ ground truth for remote sensing experiments



Mission concept

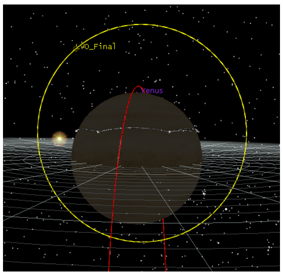
S/C Module	Measurements	Strawman payload	Requirements
Venus Polar Orbiter (VPO)	- Atmospheric composition - Atmospheric dynamics - Atmospheric structure	- Microwave sounder - Visible-NIR imaging spectrometer - UV spectrometer - IR radiometer	- Large FOV - Resolution ~ 5 km - Operational before aerobot deployment - Polar orbit - Orbital period < 5 hr - Aerobot communications
Venus Elliptical Orbiter (VEO)			- Entry probe deployment after VPO has reached operational orbit - Data relay station
Aerobot	- Isotopic ratios noble gases - Minor gas constituents - Aerosol analysis - Pressure, temperature etc. - Tracking and localization of microprobes	- Gas chromatograph/ Mass spectrometer with aerosol inlet - Nephelometer - IR radiometer - Meteorological package - Radar altimeter	- Long duration (different longitudes) - Microprobe deployment - Altitude 40 - 57 km (aerosols)
Atmospheric microprobes	- Pressure, temperature - Light level (up and down) - Wind velocity	- P/L fully integrated with probe	- Operational down to 10 km or less

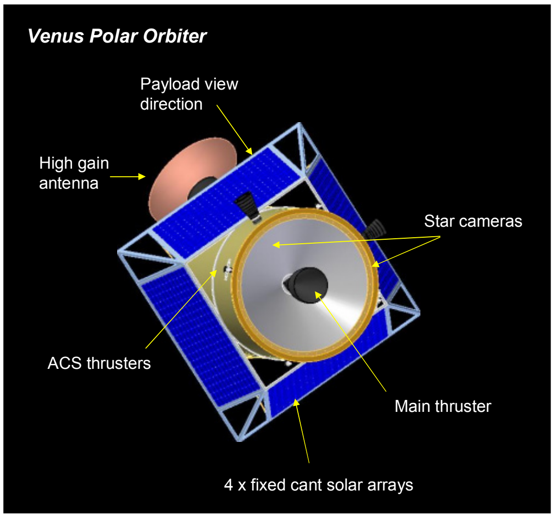


Mission analysis

- Launch with Soyuz-Fregat 2 (1b) from Kourou
  - ✓ Cost-efficient
  - ✓ Highly reliable
  - ✓ Mass capability:
    - ~ 1400 kg direct Venus escape
    - ~ 2400 kg into Highly-Elliptical Earth Orbit (200 km x 70,000 km)
- Standard high thrust heliocentric interplanetary transfer
  - ✓Duration 120 – 160 days
  - ✓Flexible (1.6 years synodic period)
- Insertion into 250 km x 215,000 km (ΔV = 1.45 km/s)
  - ✓Conservative launch date (2-11-2013)
- Operational orbits:

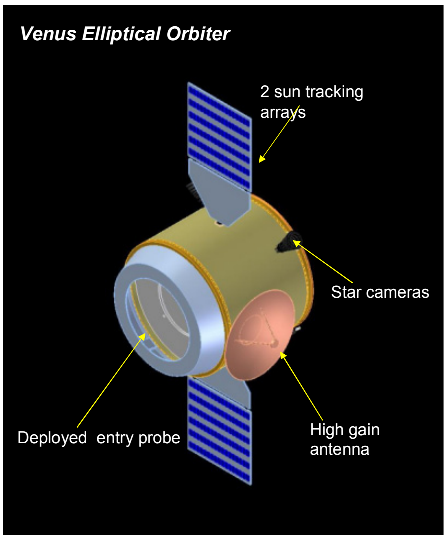
	VPO	VEO
Periapse (km)	2000	250
Apoapse (km)	6000	215,000
Period (hr)	3.1	117 (4.9d)
Inclination	90º	90º
Total ΔV (km/s)	3.5	1.7





Spacecraft design

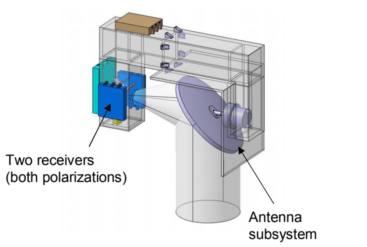
Item	VPO (kg)	VEO (kg)	Remarks
Science payload	25.2		Highly Integrated P/L suite
Entry probe		91.1	
Communications	20.2	20.3	X/Ka band, 1 m antenna, science data > 50 kbps VPO comms duty cycle < 0.5% (VRS 33%)
AOCS	9.5	9.5	CMG, 2 star trackers, 3 sun sensors
ODBH	4.2	4.2	Leon processor
Structure & Harness	82.7	84.1	
Power	18.6	7.1	
Thermal	21.4	16.7	
Propulsion	63.7	42.3	Bipropellant MMH/NTO, Isp = 325 / 285, 500 N
S/C dry mass	***294.5***	***330.3***	Incl. P/L and entry probe
20% system margin	49.1	55.0	
Propellant	594.2	206.2	
S/C wet mass (incl. system margin)	***888.7***	***536.5***	
Launch adapter	45.0		Ref. Venus Express
TOTAL LAUNCH MASS (incl. system margin)	**1470.2**		
Launch vehicle capability	1491		Incl. launch window margin Conservative launch date (ΔV)

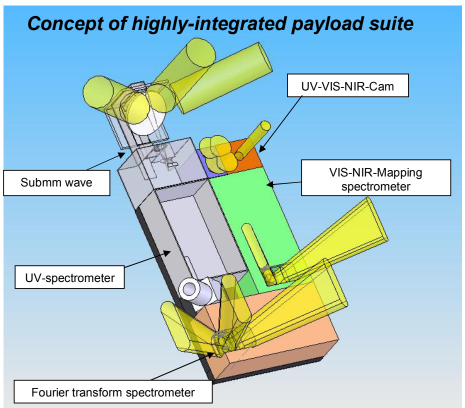


Strawman remote sensing payload suite

Instrument	Mass (kg)	Power (W)	Data rate (kbps)
UV spectrometer	4.5	4	7
UV-VIS-near IR camera	1	2.5	2
VIS-near IR mapping spectrometer	4	16	20
Imaging Fourier transform spectrometer	4	3	30
Submm wave spectrometer	6	31	5
Central power supply	1	8.5	
CPU	0.5	2	
20% margin	4.2	13	
TOTAL	***25.2***	***80 (average 60)***	**64**

Submm-wave spectrometer (ESA CDF study 2004)

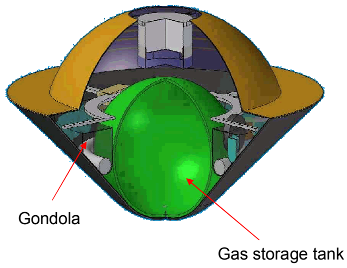




Venus entry vehicle

Atmospheric entry,descent and deployment

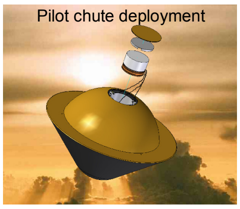
- Release from VEO orbit (250 x 215,000 km)
  - ✓ Balloon deployed after remote sensing investigations have started
  - ✓ Entry velocity ~ 10 km/s
- Spacecraft provides ΔV/orientation
  - ✓ No probe GNC system
- 45º sphere-cone aeroshell
  - ✓ Aerodynamically stable
  - ✓ Low drag (quick entry)
  - ✓ Good packaging shape
- Steep entry angle (40º)
  - ✓ Minimize heat load
  - ✓ High peak heat flux
  - ✓ High peak g-load

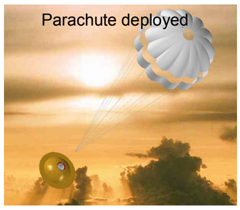


Entry vehicle mass budget

Item	Mass (kg)	Remarks
Gondola	22.7	
Balloon	9.1	Incl. gas replenishment
Gas storage system	16.8	
Parachute	4.3	3.6 m Disk-Gap-Band parachute
Inner structure	4.1	
Back cover	8.0	3 mm Norcoat Liege ablator
Front shield	26.0	7 mm carbon-phenolic ablator
TOTAL MASS	***91***	

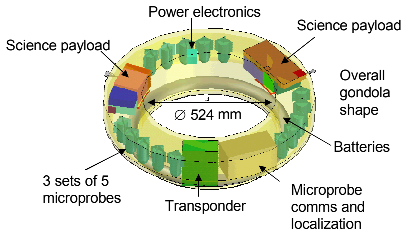
Event	Time (s)	Height (km)	Velocity (m/s)	FPA (deg)	Mach	
Atmosphere interface	0.0	120	9832	-40		
Maximum heat flux	5.0	88.7	9070	-39.8	43	17 MW/m^2
Maximum deceleration	6.7	80.5	5830	-39.8	25.6	216 g
Parachute deployment	15.8	71.0	359	-43.7	1.5	4650 Pa
Aeroshell release	17.8	70.7	113	-48	0.46	
Balloon deployment	716	54.8	13.7	-90	0.05	
Balloon deployed	736	54.5	13.5	-90		
Balloon inflated	756	54.3	7.8	-90		
Gassing system release	761	54.2	7.5	-90		
Minimum altitude	766	54.2	0			
Cruise altitude	1401	55.0	0			





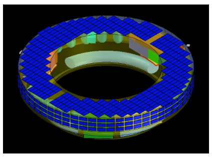
Aerobot

- Baseline: Hydrogen super-pressure balloon
- Altitude: ~55 km (30º C, 0.5 bar)
- Duration: 15 – 22 days (2 – 3 circumnavigations)
  - ➢ Ballast dropping
  - ➢ Ammonia gas replenishment system



Gondola design

Item	Mass (kg)	Remarks
Science instruments	7.92	Highly Integrated P/L suite and microprobe system
Communications	1.64	X-band ranging transponder, patch substrate antenna (science data 2.5kbps)
OBDH	0.84	FPGA sequencer, CPU part of science instruments
Structure & harness	6.86	Ti-SiC
Power	5.40	Primary batteries ($LiSoCl_2$) + Triple-junction α-Si solar cells
TOTAL	***22.7***	



Gondola instruments

Instrument	Mass (kg)	Power (W)	Data rate (kbps)	Duty cycle (%) (day)
Gas chromatograph/Mass spectrometer with aerosol inlet	1.1	6-10	1.6	27
Gas chromatograph/Mass spectrometer (sleep mode)		1		73
Solar and IR flux radiometers	0.3	2.3	0.3	10
Meteorological package	0.07	0.6	0.1	10
Inertial package	0.06	0.6	0.1	23
Radar altimeter	1.0	3.0	0.2	13
Polarization nephelometer	0.2	1.7	0.2	20
15 Microprobes (90 g each)	1.35	(0.25)	-	N/A
Microprobe deployment	0.3	25	-	0.05
Microprobe localization and communication	1.1	25	(0.1)	3
DPU	0.2	0.7		100
Structure	0.3	-	-	-
Margin (20%-30%)	1.9	1.0	-	-
TOTAL	***7.92***	***6.07 (average during day)***	***2.5***	-

Key enabling technologies

Atmospheric entry system

- Test and qualification of carbon-phenolic ablator

Aerobot technology

- Balloon envelope (low-mass, low leakage, acid resistant)

Science instruments

- Low mass GCMS
- Aerosol inlet for GCMS
- Atmospheric microprobes (under development by Qinetiq/Oxford University)
  - o Localization and communication
  - o Full integration

Deep space communications

- Miniaturized deep space (ranging) transponders