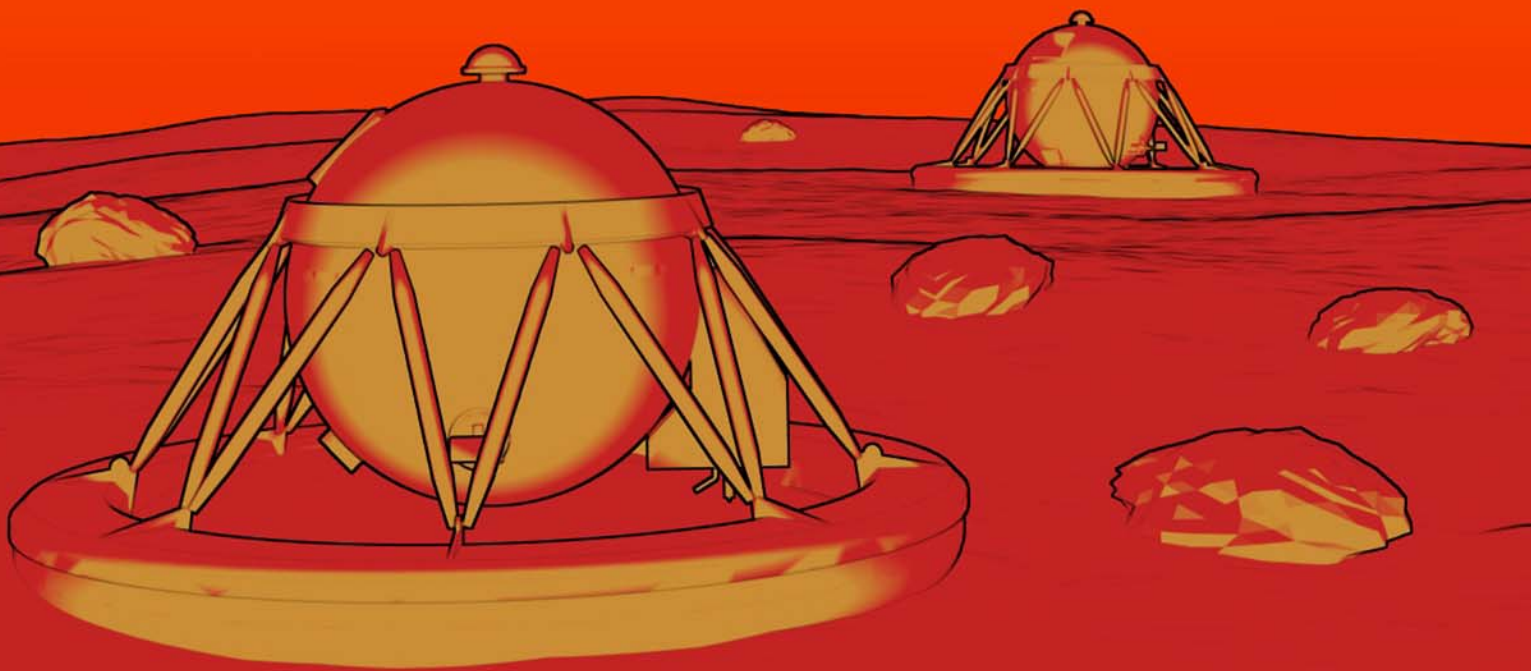


NASA'S FLAGSHIP MISSION to VENUS

FINAL REPORT
OF THE VSTDT - VENUS
SCIENCE & TECHNOLOGY
DEFINITION TEAM



VENUS STDT FINAL REPORT TABLE OF CONTENTS 11/26/08

FACT SHEET

1.0 EXECUTIVE SUMMARY

- 1.1 Introduction: Science Drivers
- 1.2 Study Approach
- 1.3 Science Definition
- 1.4 Architectural Elements
- 1.5 Mission Architecture
- 1.6 Payload
- 1.7 Mission Design
- 1.8 Mission Costs
- 1.9 Technology Development Needs
- 1.10 Conclusion

2.0 VENUS SCIENCE GOALS AND OBJECTIVES

- 2.1 Introduction: Mysteries of Venus
- 2.2 Venus Science for the Benefit of Earth
- 2.3 Venus STDT Structure and Approach
- 2.4 Science Background, Goals, and Objectives
 - 2.4.1 The Venus Atmosphere
 - 2.4.2 Venus Surface & Interior
 - 2.4.3 Venus Geochemistry
- 2.5 Venus and Planets Around Other Stars
- 2.6 Scientific Advancement to be Achieved by a Venus Flagship Mission

3.0 CHOOSING THE MISSION ARCHITECTURE

- 3.1 Science Traceability Matrix
- 3.2 Study Objectives
- 3.3 Study Assumptions
- 3.4 Science Traceability Matrix
- 3.5 Methodology
 - 3.5.1 Science Figures of Merit
 - 3.5.2 Technological Difficulty
 - 3.5.3 Mission Architecture Elements
 - 3.5.4 Rapid Cost Estimates
- 3.6 Mission Architecture Components
- 3.7 Mission Point Design
- 3.8 Science Figures of Merit
- 3.9 Technological Difficulty
- 3.10 Rapid Cost Estimates
- 3.11 Mission Architecture Components
 - 3.5.1 Orbiter
 - 3.5.2 Balloons
 - 3.5.3 Lander/Probes
- 3.12 Mission Point Design

4.0 DESIGN REFERENCE MISSION

- 4.1 Introduction
- 4.2 Payload description (mass, power, data)
 - 4.2.1 Orbiter instruments
 - 4.2.2 Balloon instruments
 - 4.2.3 Lander instruments
 - 4.2.4 Data taking scenario and data volumes
- 4.3 Mission Design and Trajectories
 - 4.3.1 Overview
 - 4.3.2 Trajectories and Launch Vehicle
 - 4.3.3 Mission Design and Related Requirements
 - 4.3.4. Orbiter Science Mission Design
 - 4.3.5 Trajectory, timeline, operations scenarios, telecom scenario
 - 4.3.6 Overall mission
 - 4.3.7 Orbiter details
 - 4.3.8 Carrier / balloon / lander storyboards
- 4.4 Vehicle descriptions for Mission Elements (baseline configuration- DRM: structure, payload, sub-system, mass/power)
 - 4.4.1 Orbiter
 - 4.4.2 Carrier
 - 4.4.3 Entry vehicle
 - 4.4.4 Balloons
 - 4.4.5 Lander
 - 4.4.6 Mission ops
 - 4.4.7 Ground segment
 - 4.4.8 Programmatics – mission phases including schedule
 - 4.4.9 Team X Risk assessment & Team X costing
 - 4.4.10 Technology development/testing summary
- 4.5 Open Issues, Trades and Options (extended configuration: long lived element,
 - 4.5.1 Introduction
 - 4.5.2 Open issues and trades
 - 4.5.3 Options
- 5.0 MISSION AND PAYLOAD ENHANCEMENTS FOR EXTRAORDINARY SCIENCE RETURN
 - 5.1 Seismometer and Meteorological Planetary Network
 - 5.2 Long Lived Landers
 - 5.3 Mobility
 - 5.4 Optical Telecommunications
- 6.0 TECHNOLOGY CHALLENGES TO EXPLORING VENUS
 - 6.1 The extreme environment of Venus
 - 6.2 Infrastructure for technology development and testing
 - 6.2.1 Venus environmental chamber
 - 6.3 Technologies for reference mission architectural elements
 - 6.3.1 Sample acquisition, processing, and distribution
 - 6.3.2. Pressure vessel technologies
 - 6.3.3 Ruggedized landing configuration due to unknown rough terrain

- 6.4 Technologies for reference mission science instruments
- 6.5 Technologies for augmented reference mission and/or long-lived Venus exploration systems (including instruments)
 - 6.5.1 Venus specific surface Radioisotope Power System
 - 6.5.2 Refrigeration systems for active thermal control
 - 6.5.3 High temperature/high pressure components
 - 6.5.4 Mobility (including balloons at different altitudes, such as super-pressure, metallic bellows)
- 6.6 Venus Exploration Technology Roadmap (integration of development schedules and cost)
- 7.0 PATHWAYS TO VENUS SURFACE SAMPLE RETURN
 - 7.1 Venus Surface Sample Return
 - 7.2 Enabling Technologies
 - 7.3 Balloons
 - 7.4 Mass Requirements for VSSR
- 8.0 SUMMARY
- 9.0 TEAM MEMBERS AND ROLES
- 10.0 ACKNOWLEDGEMENTS
- 11.0 REFERENCES

A VENUS FLAGSHIP MISSION: REPORT OF THE VENUS SCIENCE AND TECHNOLOGY DEFINITION TEAM. M. A. Bullock¹, D. A. Senske², T. S. Balint², A. Benz², B. A. Campbell³, E. Chassefiere⁴, A. Colaprete⁵, J. A. Cutts², L. Glaze⁶, S. Gorevan⁷, D. H. Grinspoon⁸, J. Hall², G. L. Hashimoto⁹, J. W. Head¹⁰, G. Hunter¹¹, N. Johnson⁶, V. V. Kerzhanovich², W. S. Kiefer¹², E. A. Kolawa², T. Kremin⁶, J. Kwok², S. S. Limaye¹³, S. J. Mackwell¹², M. Y. Marov¹⁴, A. Ocampo¹⁵, G. Schubert¹⁶, E. R. Stofan¹⁷, H. Svedhem¹⁸, D. V. Titov¹⁹, A. H. Treiman¹², ¹Southwest Research Institute, Boulder, Colorado (bullock@boulder.swri.edu), ²Jet Propulsion Laboratory, ³Smithsonian Institution, ⁴Service d'Aéronomie, France, ⁵NASA Ames Research Center, ⁶NASA Goddard Space Flight Center, ⁷Honeybee Robotics, ⁸Denver Museum of Nature & Science, ⁹Kobe University, Japan, ¹⁰Brown University, ¹¹NASA Glenn Research Center, ¹²Lunar and Planetary Institute, ¹³University of Wisconsin, ¹⁴Keldysh, Russian Federation, ¹⁵NASA Headquarters, ¹⁶University of California, ¹⁷Proxemy Research, ¹⁸European Space Agency, Netherlands, ¹⁹Max Planck Institute, Germany.

Introduction: The Venus Science and Technology Definition Team (STDT) was created by NASA's Science Mission Directorate to formulate the science goals and objectives, and to design the mission architecture, science investigations, and instrument payload for a Flagship-class mission to Venus. It was also tasked to develop a prioritized technology roadmap to bring the necessary technologies and instruments to sufficient technology readiness levels. This \$3-4B mission, to launch in the 2020-2025 timeframe, should revolutionize our understanding of how climate works on terrestrial planets, including the close relationship between volcanism, tectonism, the interior, and the atmosphere [1, 2].

Science Themes: Why is Venus so different from Earth? Previous missions have revealed a planet with curious similarities but vast differences from our world. For the first time, NASA has the opportunity to fly a large mission to another Earth-sized planet with the explicit intention of better understanding our own. The Venus Flagship mission science can be summarized by its three themes, (1) What does the Venus greenhouse tell us about climate change? (2) How active is Venus? (3) When and where did the water go?

Mission Architecture: The Venus STDT evaluated a wide range of mission architectural elements, from orbiters to aerial vehicles at all atmospheric levels, to landers and rovers. Mission science objectives were derived largely from the extensive community effort, through the Venus Exploration and Analysis Group (VEXAG), to prioritize Venus exploration objectives [3]. A detailed study of the investigations that could be done from each of the architectural elements in order to address the mission objectives was performed (Fig 1). The result was a science figure of merit for each investigation, and also an index of its technological difficulty.

We found a scientifically synergistic combination of mission architecture elements had the greatest potential for the detailed exploration of Venus that only a Flagship mission can do. To address a broad range of

science questions this mission will be composed of flight elements that include an orbiter that is highlighted by an interferometric SAR to provide surface topographic and image information at scales one to two orders of magnitude greater than that achieved by any previous spacecraft to Venus (Fig. 2). The remaining payload of the orbiter consists of an ion and neutral mass spectrometer, a UV-VIS-IR imaging spectrometer, a sub-mm sounder, magnetometers, and a Langmuir probe. Two balloons with a projected lifetime of weeks will probe the structure and dynamics of the atmosphere in the region at an altitude of 50 to 70-km (Fig 3). Balloon gondolas will house mass spectrometers, nephelometers for cloud studies, net flux radiometers, atmospheric structure investigations, magnetometers, and optical lightning detectors. In addition, two descent probes will collect data synergistic with those from the balloon and analyze the geochemistry of surface rocks over a period of hours (Fig 4). The descent instruments are identical to those carried by the balloons. In addition, descent cameras will enable the acquisition of landing site images. At the surface, the landers will perform meteorology experiments, geochemistry with an X-ray diffraction/X-ray fluorescence spectrometer and a γ -ray spectrometer. The landers also each carry a radar reflector for accurate determination of planetary angular momentum, a heat flux plate for the geothermal heat flux measurements, and cameras.

Technology Roadmap: The Venus STDT developed a prioritized set of technological challenges that must be solved to bring all instruments and spacecraft systems to a Technological Readiness Level (TRL) of 6 by 2016. In addition, it studied more advanced technologies that could enable greatly enhanced science, and pave the way for an eventual Venus sample return mission. Key to enabling a Venus Flagship mission is the ability to conduct investigations and tests in Venus simulation chambers. Pressure and temperature mitigation technologies, whether high temperature elec-

tronics or efficient cooling mechanisms, must also be developed to a high level of readiness. Sensors and transducers that operate for long periods under ambient Venus conditions will also be required. Sample handling and acquisition over periods of hours on the surface is a major technological challenge that can be addressed immediately.

Conclusions: A Flagship-class mission to Venus is NASA's first opportunity to fly a large mission to

another Earth-sized planet with the explicit intention of better understanding our own. A deep understanding of how atmospheric greenhouses work, how geological processes in a general sense operate, and the fate of oceans on terrestrial planets is within reach.

References: [1] Bullock, M.A., et al. (2008) B.A.A.S. 40 32.08. [2] Senske, D.A., et al. (2008) Fall AGU, P22A-08. [3] VEXAG (2007) ed. J. Luhmann and S. Atreya.

Science Theme	Science Objective	Instrument type	Observation Platform
What Does the Venus Greenhouse tell us about Climate Change?	Characterize the dynamics, chemical cycles, and radiative balance of the Venus atmosphere	Vis-NIR Imaging Spectrometer	Orbiter
		Sub-millimeter sounder	Orbiter
		Langmuir probe	Orbiter
		Atmospheric Structure (P/T/winds/accel)	Balloon, Lander (on descent)
		Nephelometer	Balloon, Lander (on descent)
		Net Flux Radiometer	Lander (on descent)
Place constraints on the evolution of the Venus atmosphere	Neutral and Ion Mass Spectrometer (INMS)	Radio (with USO)	Balloon
		GC/MS	Balloon, Lander (on descent)
		GC/MS	Balloon, Lander (on descent)
How Active is Venus?	Identify evidence of active tectonism and volcanism and place constraints on evolution of tectonic and volcanic styles	InSAR	Orbiter
		Radio (with USO)	Orbiter
	Characterize the structure and dynamics of the interior and place constraints on resurfacing	Magnetometer	Orbiter, Balloon, Lander
		Heat flux plate	Lander
	Place constraints on stratigraphy, resurfacing and other geologic processes	Seismometer	Lander
When and where did the water go?	Identify evidence of past environmental conditions, including oceans	Vis-NIR camera	Balloon, Lander (on descent)
		GC/MS	Balloon, Lander (on descent)
	Characterize geologic units in terms of chemical and mineralogical composition of the surface rocks in context of past and current environmental conditions	Microscopic Imager	Lander
		XRD/XRF	Lander
		Passive Gamma-ray detector	Lander
Drill and sample acquisition, transfer and preparation	Lander		

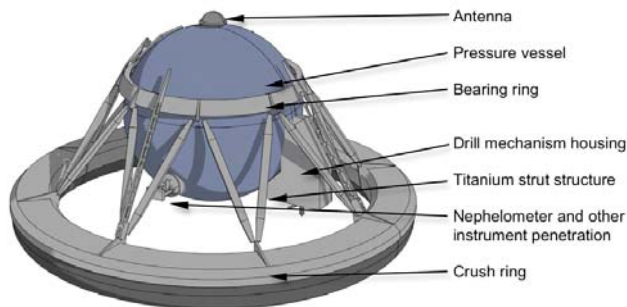
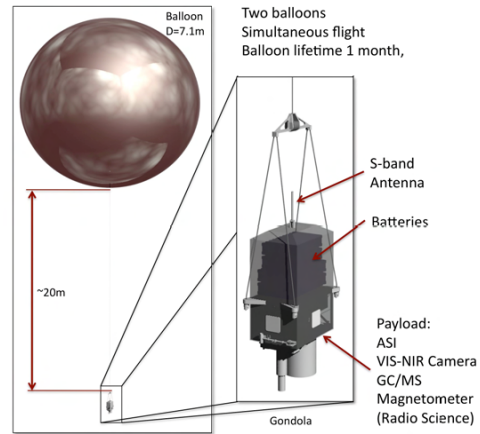
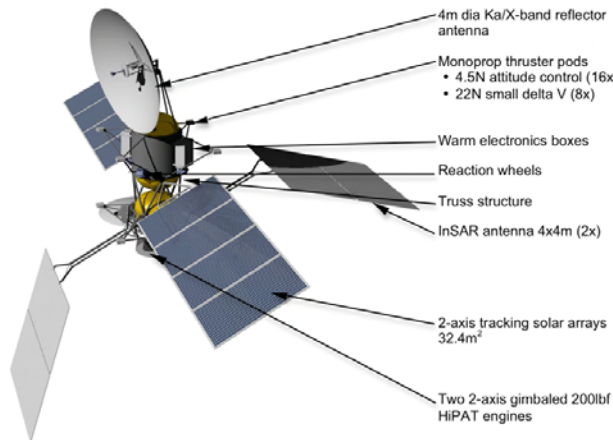


Figure 1. (Top) The instruments and their observation platforms trace to the mission science objectives and overall themes of the Venus Flagship mission.

Figure 2. (Upper Left) Orbiter.

Figure 3. (Upper Right) Balloon and gondola.

Figure 4. (Left) Descent Probe/Lander.