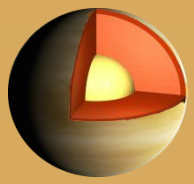


Venus Aerial Platforms Study

James Cutts[1], Larry Matthies[1] & Thomas W. Thompson [1]
and members of the Venus Aerial Platform Study Team

November 14, 2017

1. Jet Propulsion Laboratory, California Institute of Technology

Topics

- VEXAG - Strategy for Venus Exploration
- VEXAG - Aerial Platforms Preliminary Roadmap
- Venus Aerial Platforms Study
- VEXAG Goals and Objectives for Venus Exploration
- Assessment Approach
- Cost-Benefit Trends
- Venus Environmental Modeling Needs
- Summary

VEXAG - Strategy for Venus Exploration *

- Provides a vision for Venus exploration for the next 30+ years;
  - Science objectives
  - Flyby and orbiter missions
  - Aerial exploration
  - Surface exploration and sample return

- Identifies the unique challenges and opportunities for exploring Venus resulting from the dense atmosphere and high surface temperatures

- Defines the set of high priority technologies for achieving the exploration goals including
  - New thermal protection systems (TPS).
  - High-temperature subsystems and components for long-duration (months) surface operations.
  - **Aerial platforms for long-duration operations in the atmosphere**
  - Deep-space optical communications

* VEXAG presentation at Planetary Science Visions 2050 meeting February 2017

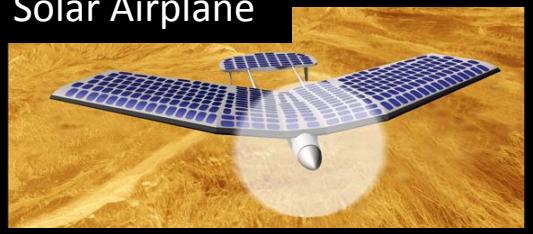
VEXAG - Aerial Mobility Preliminary Roadmap

Superpressure Balloon

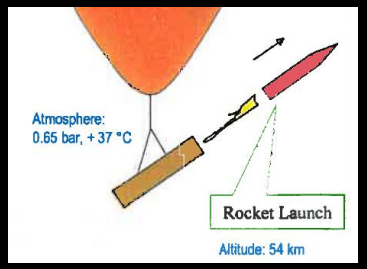
Lateral mobility

Hybrid Airship (VAMP)

Solar Airplane

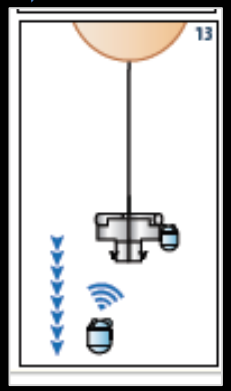


Surface and Cloud Particle Sample Return



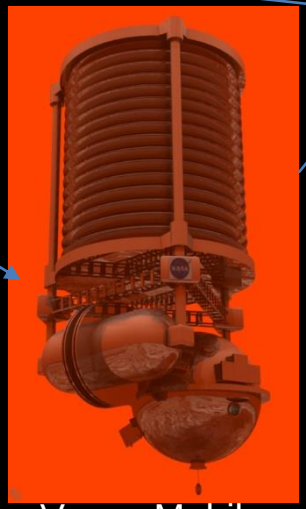
In Situ Sample Analysis @ 54km)

DEPLOY PROBES AND SONDES



Altitude Control

AM-SAC Aerostat



Venus Mobile Explorer

Dual Balloon concept for raising Venus Surface Samples to 55 km altitude

Near Term

Mid Term

Far Term

Pre-Decisional Information -- For Planning and Discussion Purposes Only

Venus Aerial Platforms Study

- NASA Planetary Science Division has formed a study team to refine the preliminary roadmap for aerial platforms and develop a technology plan

- First study team meeting – May 30 to June 2 2017
  - Scientific opportunities offered by aerial platforms at Venus,
  - Environments that aerial platforms must content with
  - Capabilities of alternative aerial platform technologies

- Second Study Team Meeting Dec 5 to Dec 8, 2017
  - Feasibility of options identified in the first meeting
  - Maturity of extreme environment technologies
  - Mission design and architecture

- Reporting Phase – target completion Feb 2018

VEXAG Goals and Objectives for Venus Exploration

Atmosphere

- How did the atmosphere form and evolve?
- What controls the atmospheric super-rotation and greenhouse?
- What is the impact of clouds on climate and habitability?

Surface & Interior

- How is heat released from the interior and has the global geodynamic style changed with time?
- What are the contemporary rates of volcanism and tectonism?
- How did Venus differentiate and evolve over time?

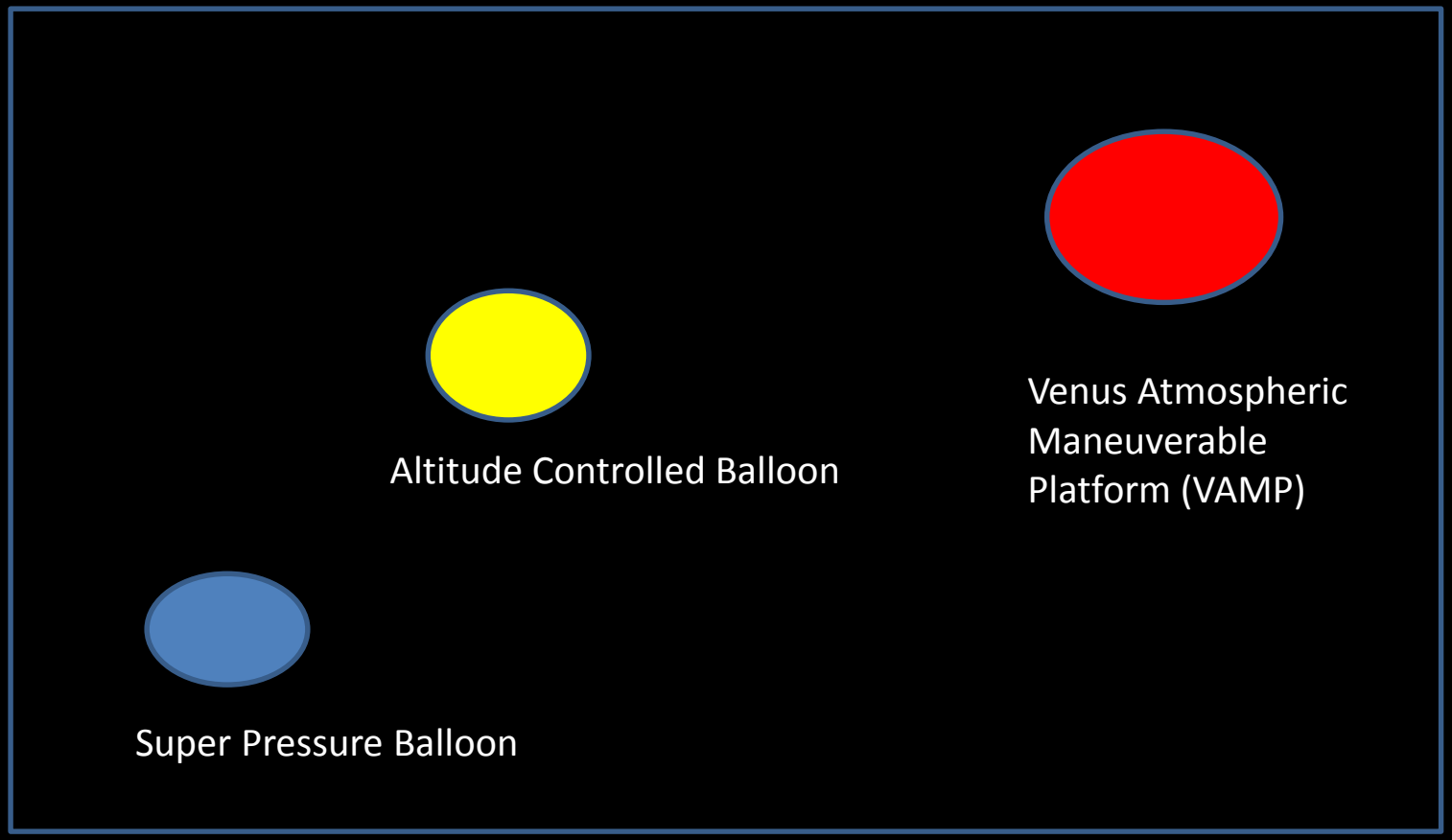
System Interactions & Water

- Was surface water ever present?
- What role has the greenhouse had on climate history?
- How have the interior, surface, and atmosphere interacted as a coupled system over time?

Venus Aerial Platforms – Assessment Approach

- The scientific value of different types of aerial platform concept were compared in terms of ability to address VEXAG Goals and Objectives
  - Atmosphere
  - Surface and Interior
  - System Interactions and Water
- Cost complexity and risk of each concept was also assessed at a high level in order to arrive at an assessment of science value
- Explored applicability of these concepts to different mission opportunities
  - Venera D – NASA contribution
  - Venus Bridge – atmospheric element
  - Flagship, New Frontiers and Discovery opportunities
- Modeling needs for aerial platforms were identified in three areas
  - Venus environmental modeling
  - Sensor modeling
  - Engineering modeling

Venus Aerial Platforms - Cost-Benefit Trends



Work to date indicates that altitude controlled balloons represent a "sweet spot" in the option space. Further work is needed to confirm if this is truly the case

Venus Environmental Modeling Needs

- Atmospheric Circulation
  - Zonal Component – determines power an airplane needs to station keep
  - Meridional component – determines lifetime of balloon and control authority requirements for hybrid vehicles
- Solar and thermal fluxes
  - Thermal control – impacts buoyancy control and vehicles strength
  - Solar power – determines availability of solar energy for operations
- Cloud characteristics
  - Vehicle lifetime – impacts lifetime of aerostat envelopes and solar arrays
  - In Situ Resources - affects potential for utilization of hydrogen

Summary

- NASA is conducting a comprehensive study of Venus aerial platforms with the goal of defining a roadmap for aerial platforms at Venus and a plan for the technologies needed to implement it.

- This roadmap will be important in guiding several NASA initiatives involving Venus exploration
  - Venera D – NASA potential contribution
  - Venus Bridge – atmospheric elements
  - Future competitive opportunities – New Frontiers and Discovery

- The second study meeting is scheduled for Dec 5 to 8 2017 & will focus on the technical feasibility of different aerial platform concepts, the maturity of the extreme environment technologies & mission design and architecture.

- The final report is targeted for completion at the end of February 2018

More Information

For more information visit

http://www.lpi.usra.edu/vexag/

Science - Surface and Interior

- Substantial geophysics-related science feasible from aerial platform operating in regions of benign temperatures.
  - Huge improvement in quality of data by being closer to surface (i.e. below orbit);
  - Performance gain achievable with still lower altitude.
  - Magnetic field, Schumann resonance, and gravity are of interest

- Measurements of atmospheric pressure and frictional forces on Venus combined with radar measurements of variations in the length of the day may provide the means of determining the M of I and hence the deep structure of Venus (II.A.2)[1]

- Visible imaging of surface is of interest, but requirements need clarification
  - Need platform within 106 km of the surface
  - IR will be challenging at low altitudes because of the temperatures

- Potential for infrasound-based detection of seismic activity
  - Can detect seismic activity at a low level
  - Need to understand ability to probe interior from aerial platform measurements

Designation refers to VEXAG Goals Objectives and Investigations for Venus

Science - Surface Atmosphere Interaction

- Access to lowest part of the atmosphere with probes, sondes or other very low altitude aerial platforms can enable key GOI objectives
  - Identification and characterization of any areas that reflect formation in a geological or climatological environment significantly different from present day
  - Current rate of sulfur outgassing from the surface

- Objectives in the GOI requiring measurement of noble gases and stable isotope ratios in the atmosphere are feasible
  - Long integration times could permit greater precision
  - Altitude control could enable test of whether ratios are altitude independent

- Geophysical investigations of interior-surface- atmosphere interaction (II.B.5) can help understand the mechanisms controlling the superrotation, Venus rotation and Venus interior structure.
  - Understanding atmospheric torques on the planet pressure and frictional. Including observations of the bow wave in situ and it time of day dependence

First Study Team - Participants

- Kevin Baines, U. Wisconsin,
- Maxim De Jong, TRL Aerospace
- Mona Delitsky, CSE, Pasadena
- Lori Glaze, NASA Goddard SFC
- Bob Grimm, SwRI, Boulder
- Jeffery Hall, JPL
- Attila Komjathy, JPL
- Tibor Kremic, NASA Glenn RC
- Geoffrey Landis, NASA Glenn RC
- Sebastien Lebonnois, LMD, France
- Sanjay Limaye, U. Wisconsin
- Kerry Nock, Global Aerospace
- Peter Ngo, Global Aerospace
- Michael Pauken, JPL
- Danny Sokul, Northrop Grumman
- Gerald Schubert, UCLA
- David Senske, JPL
- Tom Spilker, Consultant
- Paul Steffes, Georgia Tech
- Eugene Ustinov, JPL
- William Warner, JPL
- Steve Warwick, Northrop G

Includes experts in the Venus science (atmosphere, surface and interior) and the capabilities of aerial platforms and mission design and architectures