Overview of Past Venus Missions and Potential Architectures for Future Missions
– architectures – issues – failures –

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Overview

- **Introduction**
  - Extreme environments & Science drivers

- **Typical Mission Architectures to Explore Venus**
  - Role of mission architectures
  - Mission elements & Architectures

- **Brief Overview of Venus Missions**
  - Past missions
  - Present missions & Missions under development
  - Future mission concepts

- **The Good, the Bad, & the Future**
  - Lessons learned from past missions
  - Challenges for future missions

- **Conclusions**
Introduction

A First Look at Venus
• Why is Venus so different from Earth?
  – What does the Venus greenhouse tell us about climate change?
    • Could be addressed with probes & balloons at various altitudes
  – How active is Venus?
    • Could be addressed with orbiters & in-situ elements
  – When and where did the water go?
    • Could be addressed with landers

Ref: M. Bullock, D. Senske, J. Kwok, Venus Flagship Study: Exploring a World of Contrasts (Interim Briefing), NASA HQ, May 9, 2008

Ref: Image by E. Stofan & T. Balint
Science Drivers for Venus Exploration

Introduction

Venus Exploration Goals and Objectives

Goal 1: Origin and Early Evolution of Venus: How did Venus originate and evolve?
- Determine isotopic composition of atmosphere
- Map the mineralogy and composition of the surface on a planetary scale
- Characterize the history of volatiles in the interior, surface and atmosphere
- Characterize the surface stratigraphy of lowland regions and the evidence for climate change
- Determine the ages of various rock units on Venus

Goal 2: Venus as a terrestrial planet: What are the processes that have and still shape the planet?
- Characterize and understand the radiative balance of the Venus atmosphere
- Investigate the resurface history and the role of tectonism, volcanism, impact, erosion and weathering.
- Determine the chronology of volcanic activity and outgassing
- Determine the chronology of tectonic activity
- Investigate meteorological phenomena including waves, tides, clouds, lightning and precipitation.

Goal 3: What does Venus tell us about the fate of Earth’s environment?
- Search for fossil evidence of past climate change in the surface and atmospheric composition.
- Search for evidence of changes in interior dynamics and its impact on climate
- Characterize the Venus Greenhouse effect and its similarities to those on Earth and other planets

The Past

The Present

The Future

Ref: VEXAG White Paper, 2007-2008
Introduction

The Extreme Environment of Venus

- Greenhouse effect results in **VERY HIGH SURFACE TEMPERATURES**
  - Average surface temperature: ~ 460°C to 480°C
  - Average pressure on the surface: ~ 92 bars

- Cloud layer composed of **aqueous sulfuric acid droplets** at ~45 to ~70 km attitude
- Venus atmosphere is **mainly CO₂ (96.5%)** and N₂ (3.5%) with:
  - small amounts of noble gases (He, Ne, Ar, Kr, Xe)
  - small amount of reactive trace gases (SO₂, H₂O, CO, OCS, H₂S, HCl, SO, HF …)

- **Zonal winds**: at 4 km altitude ~1 m/s; at 55 km ~60 m/s; at 65 km ~95 m/s
- **Superrotating prograde** jets in the upper atmosphere


Ref: C. Wilson, U of Oxford, Personal communications
Ref: V. Kerzhanovich et al., "Circulation of the atmosphere from the surface to 100 km"
Typical Mission Architectures to Explore Venus

– mission elements – architectures – trajectories –
The Role of Mission Architectures

Mission Architectures

Science

Programmatics

Technologies

e.g., - mission class (flagship, NF, Discovery)
  - mission cost cap
  - SSE Roadmap; mission lineup
  - international collaboration

Mission Architectures

e.g., - NRC Decadal Survey;
  - VEXAG goals & objectives
  - Project science team
    measurements & investigations

Science

e.g., - mission class (flagship, NF, Discovery)
  - mission cost cap
  - SSE Roadmap; mission lineup
  - international collaboration

Programmatics

e.g., - extreme environments technologies
  - systems approaches:
    tolerance, protection & hybrid systems
  - atmospheric entry, descent, landing,
    balloon inflation
  - instrument technologies

Technologies

e.g., - single or multi-element architecture
  - single or dual launch
  - mission elements (orbiter, flyby,
    balloon, lander, probe, plane)
  - lifetime (hours, weeks, years)
  - telecom link (relay, Direct-to-Earth)
Grouping of Typical Venus Mission Architectures

Mission Architectures

Earth-to-Venus Cruise (~180 days)

Remote Sensing

- Short Observation
  - Flyby S/C
- Long Observation
  - Orbiter

Multi-Element Architectures

- High Altitude Balloon + Micro-probes
  - Balloon Network
- Orbiter + Multi-probes
  - Seismic Network

Sample Return

- Sample Return
  - Venus Atmospheric Sample Return
    - Free Return Trajectory
  - Venus Surface Sample Return

In-Situ

- Short Lived
  - Pioneer-Venus type Descent Probe
  - Venera type Lander
  - Venus In-Situ Explorer (VISE)
- Long Lived
  - High altitude balloon (~60-65 km)
    - Balloon to Lower Clouds (~30–40 km)
  - Long Lived Lander
  - Venus Mobile Explorer (VME)
    - Air mobility, or
    - Surface rover

Mission Class Floor:

- Small mission
- Medium mission
- Large mission

Ref: Cutts, Balint, “Overview of typical mission architectures”, 3rd VEXAG meeting, Crystal City, VA, Jan.11-12, 2007
Brief Overview of Venus Missions

– past – present – future –
Past Missions

Past: Russian Missions to Venus

• Between 1961 & 1984/(1985) **Russia** carried out the most successful Venus exploration **program** among nations

• **Launched 29** missions to Venus:
  – Failed: 12
  – **Succeeded (fully or partially): 17 !!**

• The program included
  – **Venera-1** and **Sputnik-7** probes (failed)
  – **Venera** orbiters, landers
  – **Cosmos** landers and flybys (failed, see **note on page 20 about Cosmos designation**)
  – **Zond-1** lander (failed)
  – **Vega** landers and balloons

• Achieved multiple firsts, e.g.,
  – First to reach Venus; entry; landing; longest surface operation (127 minutes); surface pictures (also in color); international Venus mission

Ref: http://www.russianspaceweb.com/spacecraft_planetary_venus.html
Ref: Balint, "Summary of Russian Planetary Lander Missions", JPL, 2002
Ref: images – various from the web
Past Missions

Past: US Missions to Venus

• 1962 - Mariner 2
  – flew by Venus (12/14/62);
  – Verified high temperatures.

• 1974 - Mariner 10 to Mercury,
  – flew by Venus (2/5/74);
  – Tracked global atmospheric circulation
    with visible and violet imagery

• 1978 – Pioneer-Venus Orbiter
  – radar mapped Venus (12/78)

• Pioneer-Venus Multiprobe
  – dropped four probes through
    Venusian clouds
  – Orbiter & probes launched separately

• 1989 - Magellan
  – launched to Venus (5/4/89)
  – arrived at Venus in 1990
  – mapped 98% of the planet
  – mission ended in 1994

Ref: Images – various from the web
Present Missions & Missions Under Development

Present/Ongoing: VEX, VCO, Other Flybys

- ESA’s Venus Express (VEX) orbiter
  - Launched: November 9, 2005
  - Mission ends: May 2009 (extended lifetime)

- JAXA’s Venus Climate Orbiter (VCO)
  - Planned launch: June 2010
  - Mission lifetime: 2 years

- APL’s MESSENGER (with Venus flybys)
  - Launched: August 3, 2004
  - Mission to Mercury

- APL’s Solar Probe (with Venus flybys)
  - Planned Launch: 2015
  - 9 Venus Flybys

Ref: Images – various from the web
Future Mission Concepts

Future: The Road Ahead for US Venus Missions

• Future Venus missions are expected to be **science driven**
  – with input from programmatic (e.g., cost cap)
  – and support through enabling or enhancing technologies

• NASA’s 2008 **Venus Flagship study** (ongoing):
  – NASA appointed a Science & Technology Definition Team
  – **STDT** assessed science figure of merit
  – **Recommended** a science driven mission architecture
    • **Orbiter + 2 mid-cloud balloons + 2 short lived landers**
      including an extended life element
    – Assumed launch period: between 2020 and 2025

• **Smaller missions** could occur before that:
  – **New Frontiers-3** proposals could target a 2015+ launch date
  – **Discovery** missions could target a 2013-15+ launch date
  – There might be 2-3 competed opportunities before Venus Flagship
Future Mission Concepts

Future: Potential Venus Missions

• **Orbiters**
  - Discovery or New Frontiers class
  - Single element architecture
  - Lifetime: years

• **Balloons**
  - Discovery or NF class; NASA/ESA/JAXA
  - 1 or 2 balloons; orbiter or flyby support
  - Lifetime: weeks

• **Landers and probes**
  - NF or Flagship class; NASA/Russia
  - Lifetime: hours for passive cooling; weeks to months for active cooling

• **Multi-element architectures**
  - Likely Flagship class
  - NASA Flagship Study 2008:
    - orbiter + 2 mid-balloons + 2 landers
    - Short lived landers with extended life element
    - Potential for future international collaboration
  - Cosmic Vision EVE
    - orbiter + high-balloon + mid-balloon + lander
    - ESA lead international collaboration proposal
  - Other concepts:
    - Network with 4 landers over a year lifetime
    - Venus Mobile Explorer (SSE Roadmap recommended) with near surface metallic balloon and orbiter

• **Venus Surface Sample Return**
  - Multi-element for delivery; descent; short lived lander; multi-stage ascent balloons; ascent vehicle; Venus orbiter; and Earth return capsule

Ref: Images by T. Balint
The Good, the Bad, & the Future

– lessons learned – future challenges – considerations –
Lessons Learned

Mission Architecture Philosophies

• **Russian (Soviet) approach:**
  – Incremental development & learning,
    • through a full fledged program
    • while flying a large number of missions
    • program continuation was independent of public opinion
  – Launched in pairs, using
    • identically built s/c and lander/probe
    • simple, cost effective, brute force approach

• **US approach:**
  – Missions selected to diverse destinations based on science priorities
    • no dedicated Venus program exists (e.g., compared to Mars exploration)
  – Mitigating risk through
    • ground based development and testing
    • with low risk tolerance
Lessons Learned

Mission Impact of Multiple Elements & Lifetime

- **Multi-element architectures:**
  - Pioneer-Venus & Vega
  - simultaneous in-situ exploration
  - at multiple locations (synergy)
  - relatively simple, short lived elements (balloons, probes, landers, orbiters, flybys)
  - international collaboration (on Vega)

- **Long lived orbiters:**
  - Magellan & Venus Express
  - Long duration exploration of Venus yielded significant amount of scientific data

- Trades between long lived single element vs. short lived multiple elements (science, technology, cost)
## Failures on Past Russian Venus Missions

<table>
<thead>
<tr>
<th>Missions</th>
<th>Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sputnik-7</td>
<td>Stranded in Earth orbit: 4th stage failure (probably due to faulty timer)</td>
</tr>
<tr>
<td>Venera-1</td>
<td>Missed Venus by 100,000 km: probably due to the overheating of a solar-direction sensor</td>
</tr>
<tr>
<td>Sputnik-19</td>
<td>Stranded in Earth orbit: escape stage failure</td>
</tr>
<tr>
<td>Sputnik-20</td>
<td>Stranded in Earth orbit: escape stage failure</td>
</tr>
<tr>
<td>Sputnik-21</td>
<td>Unsuccessful flyby mission: reason unknown</td>
</tr>
<tr>
<td>Cosmos-21</td>
<td>Stranded in Earth orbit (unknown mission, possibly designated as a Venus flyby)</td>
</tr>
<tr>
<td>Cosmos-27</td>
<td>Stranded in Earth orbit: likely due to escape stage failure</td>
</tr>
<tr>
<td>Zond-1</td>
<td>Failed on its way to Venus</td>
</tr>
<tr>
<td>Venera-2</td>
<td>Missed Venus by 24,000 km; s/c systems failed before reaching Venus; no data return</td>
</tr>
<tr>
<td>Venera-3</td>
<td>Communication system failed before any data return (but was the first to land on another planet)</td>
</tr>
<tr>
<td>Cosmos-96</td>
<td>Failed on Earth orbit: reason unknown</td>
</tr>
<tr>
<td>Cosmos-167</td>
<td>Failed on Earth orbit: reason unknown</td>
</tr>
<tr>
<td>Venera-7</td>
<td>Success, but weak signal. Lander may have bounced into its side, impacting antenna pointing</td>
</tr>
<tr>
<td>Cosmos-359</td>
<td>Failed on Earth orbit: reason unknown</td>
</tr>
<tr>
<td>Cosmos-482</td>
<td>Stranded in Earth orbit: escape stage failure (was similar to Venera-8 design)</td>
</tr>
<tr>
<td>Venera-11</td>
<td>Success, but failed to return images. Lens cover didn’t separate after landing due to design fault</td>
</tr>
<tr>
<td>Venera-12</td>
<td>Success, but failed to return images. Lens cover didn’t separate after landing due to design fault</td>
</tr>
</tbody>
</table>

Note: If the engine at Earth parking orbit misfired or the burn was not completed, the probes was left in Earth orbit and given a Cosmos designation.

Most Russian mission failures were due to propulsion system problems.
Lessons Learned

Failures on Past US Venus In-situ Missions

• Pioneer-Venus probes:
  – 12.5 km anomaly resulted in electrical failures
  – Cause investigated (workshop at NASA ARC)
  – Latest views point to supercritical CO₂, which may have dissolved the protective coating on electrical wires
  – Components were tested in high-T/p Nitrogen
    • justified by the assumption that both N & CO₂ are inert gases

• For future in-situ missions, testing in a relevant environment is critical
  – That is: testing in high temperature & pressure CO₂
Future Considerations

Science Synergies for the Proposed Flagship Architecture

• **Deployment** of in-situ elements:
  – 2 landers + 2 balloons deployed at the same time
  – Probe descents to be targeted to go near balloon paths

• **Measurement synergies** for atmospheric science
  – 2 landers give vertical slices of the atmosphere during descent
  – 2 balloons give zonal and meridional slices roughly intersecting balloon paths

• **Science synergies** between **geochemistry and atmosphere**
  – Simultaneous geochemical and mineralogical analysis
  – Spatial and temporal atmospheric gas analysis
    • Two disparate locations at the same time

• **Science synergies** between **geology and geochemistry**
  – Landings on tessera and volcanic plains
    • for comparative geology and geochemistry

Ref: M. Bullock, D. Senske, J. Kwok, Venus Flagship Study: Exploring a World of Contrasts (Interim Briefing), NASA HQ, May 9, 2008
Future Considerations

Technologies

• **Technologies** could play a significant role to
  – enable or enhance future Venus missions

• Mission and **technology impact** would increase
  – for **near surface** descent,
  – combined with **longer lifetime**

• **Technology and science trades** vary and should be assessed between
  – **short lived multi-element** platforms and
  – **long lived single** near surface missions

• E.g., short lived near surface missions
  – may not require active cooling
  – may require technology development for
    • pressure & temperature mitigation;
    • sample acquisition & handling;
    • and others
  • **Instruments technologies**

Ref: Images – various from the web
Future Considerations

International Collaboration

• **Multi-element architectures** lend themselves to international collaboration

• It was recommended in
  – NASA’s 2008 Venus Flagship Study (ongoing)

• Timing for international collaboration:
  – **NASA’s Venus Flagship** targets 2020-2025

  – **ESA's Cosmic Vision EVE** will be re-proposed

  – **JAXA’s mid-cloud balloon** is tentatively proposed for EVE, might be ready in 2016+

  – The **Venera-D lander by Roscosmos** was proposed for EVE, and the work is ongoing
Conclusions
Conclusions

• **Venus exploration** is expected to continue the tradition of highly successful past missions
  – such future missions will be *science driven*,
  – in the framework of programmatics, mission architectures and technologies

• **Mission architecture trades** between short lived multi-element missions and long-lived in-situ missions should be carefully evaluated **against the best science return**

• **Technologies** could significantly enable or enhance potential future missions
  – **Testing in relevant environments** is critical for future technologies

• **International collaboration** will likely play a significant role to maximize science return
The End

The End