Venera-D Modeling Workshop, IKI, Moscow Meeting Report

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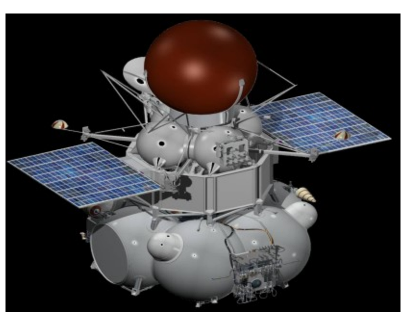

List of Meeting Attendees

Participant Name (Last, First)	Affiliation as of October 2017
Belyaev, Denis	IKI
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Collinson, Glyn	Goddard Space Flight Center
Cutts, James	JPL
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Gerasimov, Mikhail	IKI
Glaze, Lori	Goddard Space Flight Center
Gorinov, Dmitry	IKI
Grandidier, Jonathan	JPL
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Gromov, Vladimir	IKI
Gubenko, Vladimir	Kotelnikov Institute of Radioengineering and Electronics (IRE)
Gudkova, Tamara	Schmidt Institute of Physics of the Earth (IPE)
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Kosov, Alexandr	IKI
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Navarro, Thomas	University of California
Nikolaev, Eugene	Skolkovo Institute of Science and Technology
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Parkinson, Christopher	University of Michigan
Patsaeva, Marina	IKI
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Ustinov, Eugene	JPL
Vaisberg, Oleg	IKI
Vorontsov, Viktor	Lavochkin Association
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Zeleny, Lev	**IKI, Director**

Indicates Venera-D Joint Science Definition Team Members

Modelling Workshop Meeting Scribes: Glyn Collinson (Scribe Content Editor), Amanda Brecht, Kevin McGouldrick, Sara Port, Thomas Navarro, Dimitry Gorinov, Mikhail Luginin, Evgenia Guseva

Preface

Venus is considered as the Earth's twin sister: both planets were formed in the inner solar system out of the same protoplanetary material. Although these 'sisters' have nearly the same size, mass, and density, unlike Earth, Venus' climate is fueled by a massive CO_2 atmosphere producing an enormous greenhouse effect (surface pressure of 90 bar and temperature of 470°C) The atmosphere undergoes superrotation, with the upper clouds rotating at a rate 60 times faster than the surface. Shrouded in clouds of sulfuric acid, Venus' surface lacks water and has been sculpted by volcanism and deformed by faulting and folding forming belts of rifts and mountains. The lack of an intrinsic magnetic field suggests the planet's interior structure may also be different than that of the Earth. These differences indicate that the Earth and Venus had substantially different evolutionary paths. What remains unanswered is when, why and how the paths diverged. Additionally, it remains that the Earth stands as our only known and verified example of a planet with an active biosphere.

NASA and IKI/Roscosmos established in 2015 a Joint Science Definition Team (JSDT), to document the scientific goals of the Venera-D Mission and the synergy between the goals of Venera-D with those of NASA. The baseline Venera-D mission concept would consist of an orbiter and lander (Roscosmos) with advanced, modern, instrumentation. A key task of the JSDT is the identification of science gaps and the study of possible mission augmentations (experiments /elements) that could fill these gaps. A list of possible "contributed mission elements" includes aerial platform and long-lived surface stations (NASA) and a subsatellite (Roscosmos). The science objectives of the Venera-D mission should address key questions about the dynamics of the atmosphere with an emphasis on atmospheric superrotation, origin and evolution, the geological processes that have formed and modified the surface, with emphasis on the mineralogical and elemental composition of surface materials, and the chemical processes related to the interaction of the surface and the atmosphere.

As a resource to the JSDT a Venus modeling workshop took place at the NASA Glenn Research Center located in Cleveland, Ohio, USA in the month of May 2017, with the participation of the wide community of Venus scientists. It focused on understanding the limitation and needs of current models (e.g., General Circulation Models (GCMs) and interior structure models), landing site selection, and the types of measurements needed to more adequately constrain parameters in the models and experiments. This would in-turn form a basis for identifying the priorities of a new Venus mission and the types of instruments needed to achieve the goals of the mission. In October 2017 the "Venera-D Venus modelling workshop" was held at IKI (Moscow, Russia); this second workshop was devoted to informing the Venera-D mission conceptualization. Because of the strong coupling between interior, surface, atmosphere and plasmas, Venus should be considered as a system and studied simultaneously from different apparatus, such as: remote measurements from orbit and in situ measurements in the atmosphere and on the surface. The Venera-D mission concept focuses on providing a major step in understanding our sister planet through detailed study of Venus' complex atmosphere, surface, and plasma environment. In its ongoing work, the JSDT will incorporate into its deliberations information derived from each modeling workshop. This information will be used to identify the needed high-value data/measurements that could be obtained by Venera-D that would advance the science goals defined for the Venera-D mission and those defined for future modeling work, specifically the development of new GCMs. This in turn will help the JSDT to determine the functionality and characteristics of the instruments (and mission elements) that should be included in the notional Venera-D mission concept.

Explanation of Meeting Objectives

On October 5-7, 2017 the Space Research Institute (IKI), Moscow, Russia, hosted a Venera-D Venus modelling workshop convened by Dr. Ludmila Zasova, (atmosphere) Co-Chair of the Joint Science Definition Team, and Dr David Senske (surfaces) Co-Chair. The workshop focused on the Venera-D mission in light of the current knowledge base of the Venusian models (e.g. General Circulation Models of the atmosphere, or GCMs, as well as models of the surface and interior structure and plasma environment). The workshop discussion topics included the priorities and motivations for the landing site selection, as well as the types of measurements needed to parameterize and more adequately constrain theoretical geophysical models and the experiments needed to validate or refute results derived from these models. The intent was to form a basis for identifying the mission architecture elements required to achieve the key Venera-D science goals defined in the Roscosmos/IKI – NASA Joint Science Definition Team Phase I report such as atmosphere probes, aerial platforms or aerobots, long lived surface stations, and a lander. (See the JSDT Phase I report at https://www.lpi.usra.edu/vexag/reports/Venera-D-STDT013117.pdf). Likewise, the workshop findings provide a basis for identifying the suite of instrumentation that would provide the highest science return from each mission element.

The workshop consisted of oral and poster presentations; the findings derived from these presentations and the ensuing presentation discussions were collated by mid-career scientists who acted as scribes for the meeting. These findings are summarized and presented in this report; while access to the individual presentations given at the workshop can be found at: http://workshop.venera-d.cosmos.ru.

Purpose and Scope

The objectives of this three-day workshop were to discuss (1) the modeling of Venus' exosphere, atmosphere, surface, and interior as they relate to the Venera-D mission; including a review of the findings from the May 2017 Venus modelling workshop and (2) the science factors that would help guide the Venera-D mission architecture. The workshop participants included, the JSDT, a delegation of NASA Venus scientists as well as researchers from Russia and other countries, who employ numerical, computational, or analytical methods to study Venus.

Workshop Structure and Organization

The workshop was designed to be interactive and consisted of a combination of cross-disciplinary plenary sessions. Invited talks were given for the purpose of providing a focus for discussion on the Venera-D science optimization. The plenary briefings provided short overviews and summary information and lay a foundation for attendees to have an open dialogue on focus topics. Plenary topics included summaries of recent modeling efforts, the state of understanding regarding Venus' evolution, Venus interior and landing sites and Venera-D mission architecture elements (orbiter, lander, payload, aerial platform, etc.) in relation to its science priorities. A portion of the time was allocated to review the scribe record of the plenary discussions on Venus' exosphere and orbital environment, atmosphere, surface, and interior. Venera-D orbit recommendations were also discussed and identified.

The scientific workshop content was developed by the JSDT program committee taking into account the findings from the Venus Exploration and Analysis Group (VEXAG) modelling workshop held in May 2017.

This workshop report will be archived on the VEXAG and IKI website to enable open and future access.

The findings from this Modeling Workshop will serve as a reference to the Venera-D JSDT as they further refine the mission architecture concept and identify the trade space for possible contributed elements. The Venera-D JSDT Phase 2 report is due January 31, 2019.

Summary of Answers provided as aids to the Venera-D Concept Development

Orbital Science:

- **For atmospheric observations, what is the desired orbit of the orbiting spacecraft, (note that this might be constrained due to the need of the orbiter to perform relay for the lander(s))?**

- **Orbit preference: equatorial vs polar orbit. Elliptical vs circular?**

  Multiple participants from multiple disciplines advocated for an elliptical, polar (or non-equatorial) orbit, offering access to a wide range of phases (latitude, longitude, and altitude) at multiple local times.

However, the high science return possible from an equatorial orbit as it relates to the study of super-rotation (which is ranked as a high mission priority) based on zonal cloud motions and low-latitude emissions within the atmosphere was openly discussed.

Additionally, a specific concern was raised concerning communications links to, and delivery of, VAMP possibly requiring an equatorial orbit.

A common need was for long time-baseline remote-sensing observations of key atmospheric parameters, at multiple latitudes.

The lowest ultimate periapsis requested (for in-situ measurements of the atmosphere and ionosphere) was 200-300 km.

The highest apoapsis requested was >30,000km.

A study of the long-term evolution of the orbit was suggested as an action item.

Landed Science:

- **What is the prioritized terrain types for a lander and are there constraints on the latitude of the landing site?—bearing in mind landing must be in the daylight.**

  Under an initial assumption of a 7° maximum slope, regional plains were chosen as a priority target. However, a later discussion by specialists from Lavochkin Association (NPOL) suggest 15° is attainable which allows additional access to landing sites and is thus worthy of future discussion.

  A landing site free of impact ejecta would be preferred.

  The landing site should be on regions that are representative of the most common rock on Venus, e.g., the regional volcanic plains that contain large areas of lava flooding.

  Smooth plains of impact origin were suggested as the safest to land on, but the distribution of impact ejecta at these sites needs to be accurately accounted for (see notes section for details).

  NPOL specialists reported that there are minimal trajectory constraints on the latitude of the landing site.

- **List of prioritized targets vs science return**

1. Regional plains (Compromise between excellent science and minimal slopes)
2. Smooth plans (Safest landing option, but likely to include impact ejecta that complicates interpretation)

3. Tesserae (Highest possible science, but very risky landing without high-resolution surface information and precision landing)

- **How many long-lived stations are optimal? What is the best distribution?**

  A single long-lived element on the main lander was discussed as the simplest and lowest risk.

  The value of using two to three long-lived stations (or dropsondes) at regions of varying elevation to establish the gradient of temperature as a function of altitude was discussed.

Delivery of Long-Lived Stations in conjunction with the larger descent lander pre-determines the relative range between landing sites for a collection of long-lived stations.

Aerial Platforms:

- **For observations in the atmosphere (aerial vehicles—balloon or airship) what key measurements need to be made and what instrumentation is needed? What are the limitations?**

  Numerous possible types of measurements were discussed (see executive summary below).

  The two types of measurements most frequently raised at the meeting were for basic atmospheric properties (temperature, winds, etc.), and measurements of aerosols (composition, size, vertical and spatial distributions and variations in these distributions).

  However, prioritization of science and instruments is currently underway

Payload:

- **Prioritized payload in the orbiter, the lander and aerial platform.**

  A broad range of potential instruments was discussed relative to the Workshop Splinter topics which were: General Circulation Models; Atmospheric Chemistry and Clouds; Aerial Platforms; Plasmas; Interior, Surface, Landing site. A summary of the potential candidates is provided in the following pages per topic; specific prioritization of the payload items was not discussed/assigned.

  It is vital that sponsoring agencies (NASA/Roscosmos) make early investments in instrument development and technology for in-situ investigations, including sampling systems.

Potential Additional Elements:

- **What is the best science to be performed by a sub-satellite**

1. Simultaneous measurements of upstream conditions (Sub-satellite) and ionosphere (Main Orbiter) to study the influence and impact of external driving factors on Venus.
2. Observations of airglow by both sub-satellite and main orbiter to expand both temporal coverage and vertical coverage

Executive Summaries by topic

General Circulation Models

Science Needs:

- Understand "transition region" (~90 – 110km; region where the zonal super rotation and the subsolar-antisolar flow merge), and the driver of zonal super rotation.
- Understand the Planetary Boundary Layer
- Understand how the Ionosphere and Thermosphere couple: the role the ionosphere plays in super-rotation

Measurement Requirements:

- Remote Spectroscopy
- High precision measurement of bulk atmosphere (CO_2 and N_2) through the atmosphere
- Accurate measurements of radiant flux through the atmosphere from ionosphere to surface
- Near surface atmospheric properties: wind velocity, temperature, lapse rate, including CO_2 and N_2 at high precision, radiative fluxes
- Neutral atmosphere ~60 km and up: temperature, winds, composition, wave parameters (e.g. planetary waves, gravity waves), nightglow (NO UV, O_2 IR, OH IR), dayglow, minor species (CO, O, SOx)
- In-situ particles: thermal electron/ion temperature, ion/neutral winds
- Observing NO UV and O_2 IR nightglow simultaneously provides 3rd dimension
- Longer observing times (nightglow, surface wind speeds)

Possible Instruments:

- LIDAR
- RADAR
- One or more short to long term surface weather stations/dropsodnes; multiple long-lived stations that are co-located in latitude and longitude but residing at different near surface elevations were strongly desired.

- Imaging Spectrometers
- Neutral/Ion mass spectrometer with winds
- Langmuir Probe
- Cold Ionospheric Ion Spectrometer (with density and winds)

Orbital requirements:

- High Circular/Elliptical Polar orbit/ or High Circular/Elliptical Equatorial Orbit
- High circular polar/precession orbits required to view both poles with same resolutions and to get a more global view—this is the preferred orbit
- Long term observations of both day and nightside atmosphere at multiple latitudes from equator to pole and multiple altitudes extending from 10 to 100 km; and ability to communicate with long term observations from aerial platform in the deep atmosphere; and from long-lived surface stations.

Lander requirements:

- Long term (~ 3 months or longer) meteo (wind, T, P) observations in surface boundary layer
- High precision measurements of bulk atmosphere (CO_2 and N_2) and radiant flux during descent from highest altitude possible to surface

Aerial Platform requirements:

- Long term (~ 3 months or longer) observations (w, T, P, radiant flux) at, below and above cloud top level

Atmospheric Chemistry and Clouds

Science Needs:

- Measurements of different types of emission (airglow [O, O_2], nightglow [O_2, NO, OH]), which emerge from different altitudes; airglow measurements trace zonal transport of minor species
- Remote sensing (orbital) determination of minor species abundances: H_2O, HDO, CO, HCl, HF, OCS, SO_2, SO, HBr, SO_2Cl_2; and if possible: O_3, SO_3, ClO and S_x to understand sulfur and oxygen budgets, and the role of chlorine in mesospheric chemistry.
- D/H isotopic ratio might answer the question: what happened to water on Venus?
- Pressure and temperature profiles are needed for a correct retrieval of minor species. (Solar/Radio occultation and in-situ)

- Aerosol properties can be determined with glory phenomena analysis (phase function) and aerosol extinction analysis recorded in visible and IR spectral regions. (remotely or in-situ)

Measurements:
- Nadir spectroscopic observations can give information on minor species abundances, different kinds of emission, distribution of an unknown UV absorber, upper clouds, scale height, deep atmosphere on the night side.
- Solar occultation observations will provide vertical profiles of pressure, temperature, abundances of minor species, aerosol extinction coefficients.
- Spectroscopic and LIDAR measurements may be used to determine abundances of minor species and aerosols inside the cloud layer.
- In situ observations will give information on aerosol properties (size, phase, distribution) inside the clouds that is impossible to do with the remote sounding (this is a very high priority)

Possible Instruments:
- Orbital: High spectral resolution spectrometers
- Orbital: Imaging spectrometers and cameras
- Aerial: instruments to determine composition, distribution and particle properties of aerosol species: infrared spectroscopy, lidar, nephelometer, polarimeter, other particle detecting (imaging) instrumentation
- Aerial: instruments to determine composition and distribution of UV absorber: UV, visible and infrared spectroscopy, life detection microscope

Mission Functional Requirements:
- All of the described measurements should be made at different local times, latitudes, throughout whole mission lifetime to present diurnal, latitudinal, inter-annual variabilities.
- Orbit: Polar orbit allows access to large phase space (latitude, longitude and local time). Although it is harder to get detailed equatorial measurements of emissions and to trace local-time-driven chemistry from polar orbit; it is impossible to get continuous polar observations from an equatorial orbit.

Aerial platforms

Science needs:
- Understand the atmospheric circulation and super-rotation

- What is the radiative budget in the atmosphere, in particular as a function of the altitude?
- What are the physical properties of the clouds?
- What is the atmospheric composition and chemistry in the deep atmosphere?
- Can we detect and characterize seismic activity?
- Can volcanic activity be detected?
- Detect signature of surface processes (seismic activity, volcanoes) in the atmosphere
- Measure heating and cooling rates, in the visible and infrared bands
- Measure cloud particulates
- *Extended goal: Imaging of Tesserae*

Possible Instruments:

- Nephelometer
- Gas Chromatograph Mass Spectrometer (For isotopic ratios, Halogens, D/H, and SO_X)
- Particulate microscope (potentially with life detection capabilities)
- Accelerometer /Thermometer / Barometer
- Solar and Thermal Flux Radiometers
- Active UV and IR spectrometers
- Cloud Internal Field Radiometer (CIFR)
- Magnetometer for planetary magnetic field detection
- *Extended goal: Surface imager [Visible imaging challenging due to visibility of the surface and temperature >100^{o}C, therefore other techniques should be studied]*

Options for aerial platform:

- Fixed altitude VEGA-style balloon (55 km), 120kg payload with 7m JPL balloon *[Easiest engineering, highest technology readiness level, but stuck near one altitude]*
- Controlled altitude with deep dives *[advocated as the best scientific return over cost ratio, but does not exist yet and would require much development due to thermal challenges]*
- VAMP aircraft *[Most science return, but has the largest impact on mission architecture, still has long lead time for development which may impact launch timeline and/or overall mission cost—proper assessment should be derived from NASA sponsored aerial platform study report, available April 2018]*

Plasmas

Science needs:

- How are ionospheric dynamics driven by the solar wind? How are they coupled?
- What are the absolute planetary ion escape fluxes/compositions?
- What is the escape rate of Hydrogen versus Deuterium?
- Detangle the complex web of competing escape channels and processes (Upper atmosphere and ionosphere pickup, ionosphere scavenging, ionospheric clouds and streamers, Ambipolar fields, current sheets). Which ones dominate? How do they interact?
- How do solar wind ions precipitate and accumulate in the atmosphere?
- What is the influence of solar wind and radiation on cosmogenic time scales?
- What role does friction between the ionosphere and thermosphere play in driving super-rotation?

Mission requirements:

Simultaneous measurements of upstream conditions (Sub-satellite) and ionosphere (Main Orbiter) strongly desired to directly study the influence and impact of external driving factors on Venus. Oleg Vaisberg gave a comprehensive review of the best package on behalf of Lev Zelenyi advocating:

- Orbit: Elliptical, polar, inclined
  - Periapsis ~200/300km
  - Apoapsis: 10,000-15,000km preferred
- Comprehensive modern particles and fields package on orbiter, reduced payload on sub-satellite

Payload/instrument requirements (using modern package, reduced sub-satellite option, see O. Vaisberg presentation for additional details:

Main orbiter instruments:

- Ion spectrometer
- Electron spectrometer
- Langmuir probe
- Magnetometer
- Plasma waves
- Energetic electrons detector
- Energetic ions detector
- UV photometer

Sub-satellite instruments:

- Ion spectrometer
- Electron spectrometer
- Magnetometer
- Energetic ions detector

Interior, surface, landing sites

Science needs:

- Study seismic waves on Venus
- What is the bulk composition and mineralogy for a representative surface rock?
- Are the tesserae made of different material than the plains? Are they all composed of the same material?
- Do the surface rocks retain evidence of the past?
- Are there any remnant continents? I.e. Ishtar Terra, potential candidate for low-density (continental?) crust. Implications for water and plate tectonics.
- Is there current volcanic activity on Venus? (Spikes in SO_2 seen by both PVO and VEX)
- What chemical/physical reactions are responsible for the abrupt changes in reflectivity seen at high altitudes in radar observations?

Measurements:

- Analyze the mineralogy and chemical composition of surface and the composition beneath the surface. Go for the lava, take one drilling, take multiple samples down through it to understand weathering, and the dust on top.
- Study atmospheric composition near the surface and surface/atmospheric interactions
- Better D/H constraints for water inventory
- Need in-situ measurements of Xe, Kr, Ar, and isotopes to constrain geochemistry and mantle redox states
- Improved resolution of the surface to better understand the geomorphology
- Use acoustic waves to search for Venus quakes/seismic activity (red airglow)—these measurements may be accessed from aerial platform, orbiter or sub-satellite observations (additional study required to determine most effective/cost efficient platform).

Possible Lander Instruments:

- Elemental chemistry and minerology:

- XRD: Used to determine mineralogy. Spaceflight heritage. However challenging because sample will need to be ingested.
- XRF/APXS: Currently the choice instrument for elemental chemical composition. Detects all elements above sodium (Na). Lots of spaceflight heritage. Could possibly use on aerosols on descent, measuring sulphur, etc. 0.5kg, 0.5W
- CAP/LIMS—under development by IKI for chemical/isotopic analysis of gases, aerosols on descent and surface rocks on landing
- Raman/LIBS [Remote Sensing]: Preferred instrument for mineralogical composition in laboratory, not flown in space yet, will fly on ExoMars rover and Mars 2020. Can be inside the lander and remotely sample through a window. 8-10kg, power 20-80W—concerns were raised by Russian colleagues about temperature control; a review of recent work/tech development was suggested by Lori Glaze.
- Neutron/Gamma spectrometer: passive observations will provide gamma and neutron spectra from the subsurface under the lander via passive and active observations in cycle, providing measurements of decay of short and long living isotopes. Passive observations (prior to operations with Pulse Neutron Generator unit) will characterize abundance of natural radioactivity elements. Active observations (during operations with PNG unit) will characterize subsurface elemental composition. Passive observations (after end of operations with PNG unit) will characterize subsurface elemental composition. 7kg, power 5 W (passive mode) / 19 W (active mode).
- Mossbauer Spectrometer: works only on iron bearing minerals, 0.5kg, 0.6W, several hours accumulation time required. *[Discussion: Would only be useful on the plains, would need to be sure there would be enough time for a measurement]*
- Mechanism to remove outer rock surface, if possible

- Surface/Atmosphere interaction:
  - Gas Chromatograph Mass Spectrometer (tunable laser spectrometer). Technically very challenging but would be desirable for isotopic composition of rock forming elements and near surface atmospheric composition. 10.5kg, 12W
- Morphology
  - Imaging: Descent, Panoramic, and Sample
  - Higher resolution SAR (~100m) to better constrain surface properties for science and future landings

Funding for instrument development for Venera-D is critical, as in-situ Venus missions are very challenging. Requests were made for support from NASA in influencing the release of funds to our Russian counterparts in a timely manner so that sufficient resources are available for instrument development and the refurbishing of the required testing facilities. Near-term funding from both NASA and the Russian space agencies is essential, especially since engineers with expertise regarding in-situ Venus missions are rapidly retiring.

<u>Landing Sites/Orbit:</u>

- Orbiter:
  - Measurement of Acoustic Waves:
    - Requirement: Image Venus with a slow orbital drift, implying high apoapsis (>30,000km)
    - 6U-12U satellite option could be piggyback on a Venus orbiter mission, left behind at high altitudes.
    - Needs long time series images
- Lander:
  - VEXAG Priority Sites:
    - Tesserae
    - Volcanic plains
    - Young volcanic terrain
  - Slopes are a major threat to lander mission. 7° degree slope limit for Venera-D *[Discussion: Venera-9 landed at a 30 degree slope, but probably came close to failure, so wouldn't risk this today*. Lavochkin suggested that 15° is attainable, which allows additional access to landing sites*]*
  - Land away from impact ejecta to go for pristine basalt
  - Plausible Sites:

    1. Regional Plains: Given the 7° slope limit, pristine lava in the region plains were advocated as a primary landing site

    2. Smooth plains (Impact related): As a backup, being easier to land, but being more contaminated by impact ejecta
- Long-lived lander
  - Measurements: Temperature and Wind
  - Instruments: Simple Meteorological station
- Additional Comments:
  - Divide Venus into three latitude ranges; specify best landing sites, and science that can be done from that orbit. IKI to work with orbital engineer.

- A Venus program with additional or multiple landers which go to other landing sites?
- Drop a sonde from aerial platform for optical images of Tessera surface? Data can then be used for future missions.
- Does life exist, or could it have possibly existed on Venus? How could we determine this?

Notes from talks in aid of Venera-D Concept Development

Documentation Advisory: These notes focus on meeting presentation high-lights and comments made that addressed the overarching questions set for the meeting, and not a detailed (blow by blow) account of each science discussion.

General Circulation Models

Alexander Rodin: ***Gas dynamics general circulation model***

- Key measurements needed are remote spectroscopy at the transition from zonal flow to sub-solar anti-solar
- In-situ accurate measurements of local dynamics, including the various transitions for solar atmosphere interactions. Airglow/nightglow/aurora, for photochemistry
- Instruments: LIDAR and RADAR. High resolution spectrometer at wavelengths appropriate for atmospheric molecules, his main focus is to look at emissions at different altitudes

Orbit: Circular Polar Orbit, sufficiently high to observe global view. Circular, so spatial resolution the same at both hemispheres. *[Post presentation discussion indicates this would rule out in-situ measurements in the thermosphere and ionosphere]*

Sebastian Lebonnois: ***Behavior of Venus planetary boundary layer as predicted by the GCM***

- Interested in Atmospheric structure parameters (wind velocity, and temperature), lapse rate (change in temperature with altitude) at the surface.
- Characterize relative mixing ratios of CO_2 and N_2 at the surface to high precision.
- If we drop multiple long-lived landers, wants to see them at different surface elevation (one at surface and one on mountain). Two probes would do, but co-located, e.g. at Aphrodite terra, one high and one low. *[Discussions at the meeting suggest this is impracticable, since precision landing is not possible, and flat surfaces are required]*
- Interested in surface wind speeds over a diurnal cycle *[JSDT clarification: current anticipated long lived lander lifetime is 3 months]*

Orbit: Highly elliptical for long term observations, Polar PVO-like

Amanda Brecht: ***The latest on the VTGCM***

- Measure temperature, winds, and composition at the cloud-tops and up
- Measure atmospheric wave parameters (planetary Gravity Waves)
- Nightglow via remote sensing (NO UV, O_2 IR, OH IR)

- Minor species (CO, O, SO_X)
- Electron/Ion temperatures, Ion and Neutral Winds, for Ionosphere/Thermosphere coupling to investigate the role that the ionosphere plays in super-rotation
- *[Participant Comments: Observing NO and O_2 nightglow simultaneously permits for simultaneous measurements at two altitudes.]*
- *[Participant Comments: Time series of evolution of nightglow desirous to study mesospheric circulation]*

Orbit: Highly elliptical for long term observations, equatorial preferred, could live with polar

Thomas Navarro: ***Large Stationary Gravity Waves***

- Measure length of day passively by landing radar retro-reflector on the surface, and then with an orbiter measure Doppler shift. *[Ed: later discussions suggested that the reflector would have to be very large, and you may not do any better than the natural surface features, since lava flows already give very sharp edges. The other problem is that, unlike the Lunakohd or Apollo reflectors, nobody knows for sure where the Venera probes are exactly. One estimate from experiments at Earth suggested you might need a surface reflector of area $100m^2$]*
- Wants to monitor stationary features (Akatsuki discovered), especially the smaller scale features, to better understand the dependence on topographical features on the surface.
- Long-lived In situ measurements of winds, density, over a day, to understand the stability conditions in the boundary layer. Should ideally happen on the flank of an equatorial mountain. *[Participant discussion: This last requirement is extremely challenging due to slope constraints]*

Orbit: Design elliptical orbit and field of view to monitor stationary atmospheric features, equatorial

Dmitry Gorinov: ***Circulation of Venusian atmosphere at 95-100km from apparent motions of 1.27 micrometer O_2 nightglow***

- We need to observe nightglow at equatorial latitudes. Reasoning for the observation: they are located altitude wise in a transition region between two main atmospheric circulation modes - the region is currently not well understood
- We need a longer time-series of observations, for a spacecraft to look at the same location from to get a) orbit-to-orbit variations and b) more consecutive images within one orbit
- We need equal coverage of all geographic longitudes to fill in VIRTIS data gaps.

Orbit: 24 Hour Elliptical; line of apsides – 0 - 45°

Akatsuki

Takehiko Satoh: ***Venus from Akatsuki***

- Large (up to of order 1000 km long) bow shaped waves seen in the Venusian afternoon by LIR camera (~10 micron) at cloud top altitudes as atmosphere moves over topographic rises exceeding 3km above mean Venus surface elevation.
- Correlation between cloud height seen by IR2 camera (~2 micron) and the wave brightness temperature revealed at the 10 micron (higher cloud height corresponds to cooler brightness temperatures; and vice versa).
- UVI camera shows evidence of 0.28 micron contrasts (diagnostic of SO_2 abundance) correlated in space and time with observed 10 micron bow shaped wave
- Multi-wavelength observations of Venus are important to understand atmospheric dynamics

Orbit: Equatorial for detailed study of the super-rotation mechanism

Yeon Joo Lee: ***Venus seen from UV Imager Onboard Akatsuki***

- Long term monitoring the ultraviolet albedo of Venus, to characterize the unknown absorber cloud top distribution, relationship to sulfur species and impact on cloud top radiant energy. Investigations of unknown absorber distribution relies on observations made from the UV into the mid-visible wavelengths
- Remote Sensing of the aerosols at low phase angle to obtain more "glory" phenomenon observations (to characterize its behavior with wavelength and hence confirm the particle size distributions in the upper clouds).

Orbit: Equatorial/Polar; equatorial provides more detail for study of hemispheric asymmetry and long-term monitoring of low-latitude region where UV absorber is most prominent

Sanjay Limaye: ***Multispectral Day and Night Cloud Morphology of Venus from Akatsuki Cameras***

- Discussed how the cloud cover appears different at different wavelengths and on the day and night sides due to different cloud forming processes

- Wants cloud particle physical shapes and size distribution
- Chemical composition of cloud particles – organic, inorganic
- Ambient environmental conditions (bulk composition and abundances of trace species, T, P, wind, up/down radiative fluxes)
- Really wants VAMP and upper cloud and balloons in lower cloud region and lower and instruments to make sustained measurements.

Orbit: Elliptical, permitting communications with VAMP

Atmospheric Chemistry and Clouds

<u>Vladimir Krasnopolsky:</u> ***Modeling of Chemical Composition in the Lower and Middle Atmospheres of Venus***

- Wants to measure HBr, SO_2Cl_2, ~1ppb. *[Participant Comment: This is probably unmeasurable with existing technologies]*
- Like to have active infrared spectroscopy in the clouds [McGouldrick: This can provide aerosol and atmospheric composition]
- *[McGouldrick: He would desire Iron Chloride measurements, which he has put forward as a possibility for the unknown UV absorber]*
- Requires In-situ measurements

<u>Franklin Mills:</u> ***Simulations of Vertical Profiles of SO and SO_2 in Venus' Mesosphere***

- Addressed diurnal variations of SO_X. Needs detailed geographical, vertical, and temporal resolution observations of sulfur-oxide species and atmospheric species that control the sulfur oxide chemistry.
- Needs better understanding of sulfur distribution within cloud layers with local time
- Needs more complete lab data on reaction rates for chemical pathways expected to influence sulfur-oxide chemistry cycle.

Orbit: Equatorial is best / Polar is tolerable

<u>Kevin McGouldrick:</u> ***Microphysical Modeling of the Sulphuric Acid Venus Cloud System***

- Seconded Sanjay: Camera to look at particle shapes (habit – crystal shape), sizes

- Composition of aerosols and resolve what they are. Direct compositional measurements of aerosols below cloud decks. Existing measurements have been inconsistent. Advocates for long-lived platform. (In-situ measurements)

Christopher Parkinson: ***Understanding the nature and variation of the Venusian middle atmosphere via Observations and Numerical modeling of the Key Tracer Species***

- Amount of H_2O strongly regulates the amount of SO_2 that you have (and vice versa), because the SO_x and H_2O rapidly become H_2SO_4, which thus controls cloud formation.
- Wants descent profiles of SO_x, H_2O, H_2SO_4, in the clouds from a descent probe.
- Wants to understand the spatial variations of these aforementioned species.

Sara Port: ***Metal Sulfides and their Relationship with Gaseous Sulfur on Venus***

- Interested in near surface environment (~15km and below): mineralogy, winds, and gas composition/mixing ratios. Will aid in better understanding the chemical compositions near the surface and weathering.
- XRD/Raman/GCMS on lander element.

Aerial platforms

James Cutts: ***Venus Arial platforms and engineering***

- Discussed possible aerial platforms:
  - Vega style balloons at a constant altitude (55 km). 110 kg payload for 7m balloon tested at JPL. Lifetime is 10+ days (approximately two circumnavigations). 20-30 kg useful science payload
  - Altitude controlled balloon (metal bellows), rising and falling
  - VAMP aircraft
  - Partially buoyant metal "balloon" to sample deep atmosphere (0-30 km)
- Altitude controlled balloon may be the sweet spot in the option space, giving a balance between cost/risk and science value, excepting the 24limited lifetime of the vehicle. *[Discussion: The deeper you go into the atmosphere with your balloon, the more development time and cost required; proper assessment of technology development requirements to come from NASA sponsored aerial platform study, February 2018 publication]*
- Determine atmospheric circulation
- Measurement of heating rates and cooling rates. Radiative transfer fluxes of radiance (short-wave, long-wave)

- Measurement of cloud particles
- We need better measurements of lower atmosphere and how it fits into the whole system, as right now is treated as a boundary layer: Deep atmosphere supercritical fluid questions, such as the kinetics and chemistry of how they interact with the surface. However, this science is limited by visibility of the surface.

Siddharth Krishnamoorthy: ***Infrasound Detection from Balloons***

- Advocates use of two barometers on balloon enables spatial filtering for separating an upward traveling waves associated with earthquakes.
- Other applications include detection of volcanoes. Infrasound community that is active looking at infrasound on Earth.
- There is some concern about background noise from atmospheric turbulence
- Limitation: At 55 km altitude, need to be within a few hundred kilometers from epicenter of volcano or earthquake. *[Post presentation discussion indicated that odds of detecting activity requires the lifetime of platform to be >> 10 days]*
- Could make deep dives with balloons to lower altitudes, but the real challenge in low altitude (< 50 km) balloons is making instruments that will function >100°C.

Eugene Ustinov: ***Cloud Internal Field Radiometer (CIFR)***

- CIFR would conduct in-situ measurements of microphysical characteristics of cloud droplets.
- Multi-spectral, multi-angle measurements of vertical distribution of the field of scattered radiation within the cloud.
- The instrument has a heritage of use, beginning from Venera-9 and 10 landers.

Plasmas

Glyn Collinson: ***Mysteries of Atmospheric Escape and Evolution at Venus***

Science needs:

- Measure 3D cold ionospheric ions (never done before), catch all escaping plasma
- Detangle and understand the competing mechanisms of atmospheric escape and loss (a la MAVEN). Which mechanisms dominate, how do they work, how has loss evolved over time?
- Map and understand Deuterium loss / Water loss

Instrument needs: A comprehensive particles and fields package

- Cold and Hot Ion Spectrometer: Measure all atmospheric loss
- Electron spectrometer + Langmuir Probe: Map and measure ambipolar field, measure ionospheric structure
- Magnetometer: Understand how plasma is being lost
- Neutral and Ion Mass Spectrometer: Measure isotopic fractionation, understand neutral source for plasma

Orbit: Elliptical, polar, inclined, periapsis ~200km, PVO-like would be ideal

Oleg Vaisberg: ***Lessons from MAVEN***

Science needs:

- Simultaneous measurements of upstream conditions and ionosphere to directly study the influence and impact of driving factors on Venus such as the solar wind and solar EUV
- Absolute planetary ion escape composition and flux measurements needed
- What are the escape channels and processes? Upper atmosphere and ionosphere pickup, ionosphere scavenging, ionospheric clouds and streamers [Ambipolar fields, current sheet]
- How do solar wind ions precipitate and accumulate in the atmosphere?
- Understand the influence of solar wind and radiation in cosmogenic time scale

Instrument needs:

- Ionospheric plasma (low energy ions, Langmuir probe for electrons)
- Hot plasma (ions, ion composition, super-thermal electrons)
- Magnetic field
- Plasma waves
- Energetic particles (ions electrons)
- Atmospheric emissions (airglow, aurora)
- Ultraviolet Photometer for solar EUV

Orbit: Elliptical, polar, periapsis 200km to 300km

Interior, surface, landing sites

<u>Philippe Lognonne:</u> ***Venus Seismic Interior-Atmosphere Coupling***

- Wants to use ionospheric acoustic waves to search for Venusquakes and seismic waves. Needs greater than 5.3 magnitude quake to see anything, detected a ~60^{o} distance from epicenter at altitude of 250-300km. Analysis of the frequency of the waves propagating from the epicenter may help to constrain thickness of the Venus crust.
- Payload: Cooled IR imager
- Requirement: Image Venus with a slow orbital drift, implying high apoapsis (>30,000 km)
- 6U-12U satellite option could be piggyback on a Venus orbiter mission, left behind at high altitudes.
- “Needs a movie”, long time series images.

Orbit: Elliptical, high apoapsis (>30,000 km)

<u>Lori Glaze:</u> ***Scientific Rationale for Selecting Landing Sites on Venus:***

- All prior Venus descents (Venera, Vega, PVO have been “Unassisted”. Assuming similar EDL, landing site must be large and uniform for safety.

<u>Science Needs:</u>

- What is the bulk composition and mineralogy for a “typical” surface rock?
- Are the tesserae made of different material than the plains?
- Do all the tesserae share the same composition?
- Do the surface rocks retain evidence for earlier climate conditions?
- Are there any remnant continents? I.e. Ishtar Terra, potential candidate for low-density (continental?) crust.
- Is there current volcanic activity on Venus? (Spikes in SO_2 seen by both PVO and VEX)
- What chemical/physical reactions are responsible for the abrupt changes in reflectivity seen at high altitudes in radar observations?

<u>Instruments:</u>

- Elemental chemistry and mineralogy:
    - XRD [challenging due to sample ingestion]
    - Raman/LIBS [Remote Sensing]
    - Neutron/Gamma spectrometer

- Morphology
    - Descent imaging
    - Panoramic imaging
    - Sample imaging
- Surface/Atmosphere interaction (Mass spectrometer / tunable laser spectrometer)
- Mechanism to remove outer rock surface, if possible

Landing Sites: Top priorities from VEXAG's Venus Exploration Targets Workshop

- Tesserae
- Volcanic plains
- Young volcanic terrain
- No matter where we land, we will learn critical new information about Venus' origin and evolution.

Richard Ernst: ***Venera-D landing site selection based on Magellan radar images***

- Suggested landing site: Alpha Regio
    - Also suggested various other tesserae, rift zones, and coronae
- Tesserae would be the real prize: are they felsic or mafic?
- Otherwise, land in safe plains area with lobate flows that can be integrated into larger geological picture
- Wants to investigate whether Venusian coronae are analogous to circumferential dyke swarms on Earth. Implications for past volcanic activity on Venus.
- Advocated for better Synthetic Aperture Radar data, to better elucidate this relationship, and constrain surface properties for future landings.

Piero D'Incecco: ***Imdr Regio as the landing site of the Venera-D mission: a geologic perspectiv****e (poster)*

- Could provide information about variations in composition and physics of different melts

Thasanis Economou: ***Venus Surface Elemental and Mineralogical Composition***

Instruments: Described the full range of possibilities.

- X-Ray Fluorescence Spectrometer/Alpha Particle X-Ray Spectrometer: *Currently the choice instrument for elemental chemical composition*. Detects all elements above sodium (Na). Lots of spaceflight heritage. Could possibly use on aerosols in descent, measuring sulphur. Etc. 0.500kg, 0.500W
- Chemical Analysis Package: Gas Chromatograph Mass Spec. Challenging for VENERA-D due to the requirement for high vacuum for proper operation, and

this cannot be maintained inside the lander. But would be desirable for isotopic composition of rock forming elements. 10.5kg, 12W

- Active Detection of Radiation of Nuclei: active gamma ray and neutron spectrometer. Provides subsurface elemental composition, radioactivity and decay rates of short and long-lived isotopes. 7 kg, 5W (passive)/19 W (active)
- Mossbauer spectrometer: Works only on iron bearing minerals, 0.5 kg, 0.6 W, several hours accumulation time required. *[Post presentation discussion: Would only be useful on the plains, would need to be sure there would be enough time for a measurement]*
- Raman spectrometer: Preferred instrument for mineralogical composition in laboratory, not flown in space yet, will fly on ExoMars rover and Mars 2020. Can be inside the lander and remotely sample through a window. 8-10kg, power 20-80W.
- None of the old instruments are in existence today, and even if they could exist, we would not want to use them for a new mission due to mass, power, and old technology.
- Requests that NASA fund instrument development for Venera-D. Russia's practice of funding instrument development after selection of a mission is prohibitive to establishing needed infrastructure in a timely manner.

Mikhail Ivanov: ***Estimates of the frequency distribution of short-baseline slopes***

- Slopes are a major threat to lander mission, but the best resolution available (MAGELLAN) is ~5 km/px.
- 7° slope limit for Venera-D. *[Post presentation discussion: Venera-9 landed at a 30° slope, but probably came close to failure, so wouldn't risk this today]*
- To model, used DTMs (digital terrain models) of Earth (Iceland) to mimic relief found on Venus.

Discussion of the possible regions of Venus for landing

- Tessera are a window into the geological past, of great scientific interest. Doesn't look like friendly terrain to land on. Three types of basic topographic features. (1) Open Valley, (2) Cellular relief, (3) Ridge flank

  In most cases, the modeled slopes are very large, 30-40°. Probability of encountering steep slopes is very high in the Tessera. Smooth and flat regions are rare to absent.

  [Lori Glaze: Different interpretation of Tessera. Based on stereo radar of Ovda Tessera, can see that the slopes there are on average less than 5 to10°. Less than 5% of the area is sloped greater than 5°. Mikhail: These results

unfortunately do not have high enough resolution to spot roughness that appeared in our work]

- Several types of plains. In all model cases, the mode of the slope distribution in shield and regional plains is higher than the 7 degrees safety limit. The slope distribution mode for dark flows of lobate plains and smooth plains is well below this limit.
  - **Smooth plains** (Impact related): extensive areas, low radar albedo, smooth deposits of fine-grained ejecta. Dark parabolas around the large impact craters. Parabolas are many hundreds of kilometers wide. Dimensions of the darkest (smoothest) spots are many tens of kilometers. Potentially represent much better areas for safe landing. Form well-mixed and representative samples of the upper crust of Venus.
  - **Regional plains:** likely represent a sample of the upper mantle of Venus, huge areas homogeneous, lava flooding with regular ridges. Relief is complicated by wrinkle ridges. Albedo is lower than in shield plains. Flat areas between the ridges are typically 20-25 km across. May provide better surfaces for safe landing. The plains themselves are thousands of km across, and thus make for a safer landing site. Backscatter radar indicates they are as smooth as parking lots.
  - **Shield plains:** represent a result of crustal melting. Fractional differentiation and crustal contamination are expected. Relief complicated by numerous volcanic constructs. Flat areas between the shields are typically 10-15 km across. May not provide sufficiently large areas for a safe landing. Not as safe as regional plains.
  - **Lobate plains:** Large and numerous lava flows; polyphase eruptions. Likely represent a result of decompressional melting of deep-seated diapirs. Complexes of smooth (dark) and rough (bright) lava flows. Dark flows are typically small and always neighboring with bright flows. Do not provide sufficiently large areas for safe landing

- Landing site: Advocated smooth plains of impact origin

Allan Treiman: ***Venus' Radar-Bright Highlands: Different Causes at low and high latitudes***

- Landing site: Advocates for a landing on high-radar reflectance surface near Cleopatra impact site on Maxwell Montes. Identify what the radar bright surface is. Relatively flat and smooth. Need mineralogical and chemical analyses, surface and shallow depth. Candidate for continental crust, low-density siliceous rock is a possible explanation for high elevations. Major implications for the role of water and possible plate tectonics.

- Tight landing ellipse required. Crater is 105 km in diameter
- Landing ellipse is 300 km
- Likely very steep cliffs and full of boulders

<u>Michael Way:</u> ***Modeling Venus through Time and its Implications for the Habitable Zone***

- Kasting limit. If ~0.1% mixing ratio of H_2O, atmosphere loses an Earth ocean's worth of water in a few Gy. Doesn't think that this is how Venus lost its water, based on how these ancient models evolve.

Scientific Needs:

- Need in-situ measurements of Xe, Kr, Ar, and isotopes to constrain geochemistry and mantle redox states
- Better D/H constraints for water inventory
- Can present day interior and structure and topography tell us about the history of plate tectonics (stagnant lid, subduction, etc.)
- Should we consider looking for signs of life? (very speculative, but we have no idea where life began on Earth) If life did ever exist for any length of time, it could have filled every niche, including the skies and upper cloud decks. Not unreasonable, given there may have been mass exchange between Earth and Venus.
- Exoplanets will inform Venus' climatic history and possibly vice-versa.

Mission Architecture

<u>Mikhail Gerasimov:</u> ***A Prototype of the Soil Sampling System***

- VEGA/VENERA-13 Soil Sampler mass was 26 kg
- Half of mass of instrument is gas tank
- Sample to be ingested is ~5g (assuming density of basaltic rock and stated cylinder with d=16mm, h=36mm)
- Sample acquisition time is 204 seconds
- Sample analysis time was unstated

CONCLUSIONS:

Landing site:

- Guiding science question: “What is a representative rock on the surface of Venus?”
- Go for the lava, take one drilling, take multiple samples down through it to understand weathering, and the dust on top.
- Landing terrain selected: **Target the Regional Plains**
- Land away from impact ejecta to go for pristine basalt.
- Divide into three latitude ranges, specify best landing sites, and science that can be done from that orbit. IKI to work with orbital engineer.

Sample collecting discussion:

M. Gerasimov asks, how many samples will be collected. Also asks, if dust/sand/soil should be collected. Mutual opinion: analyze rock; more important than soil. Gerasimov suggests a combination of a ‘vacuum cleaner’ and driller. Driller withdraws samples from the depth to the surface, ‘vacuum cleaner’ collects it; also at first it could collect and analyze the soil on top, then drill to analyze the rock beneath.

Strawman Instruments:

- XRF
- Fast Mossbauer Spectrometer – Thanasis Economou suggests instrument optimization since Mars instruments require hours for integration!
- Raman/LIBS, vis Mars 2020? There were concerns it may be difficult/complex to put this instrument on the lander because a window which transfers heat inside.
- CAP/LIMS under development by IKI for chemical/isotopic analysis of gases, aerosols on descent and surface rocks on landing
- **Vital that sponsoring agencies (NASA/Roscosmos) make early investments in instrument development and technology for Venus.**

Possible Mission Enhancements:

- Enhanced scenario, a Venus program with additional or multiple landers which go to other landing sites?
- Drop a sonde from aerial platform for optical images of Tessera surface? Information can be used for a future lander on the tesserae

Discussion: Mission Architecture and Orbit

Notes concerning Landers:
The discussion began with a 24 Hours polar orbit, and Viktor was asked about the roadmap for the mission.

Viktor Vorontsov [Paraphrased from notes]: "This was discussed. Today represented the first science input because of new instruments. Let's follow the tasks given to us by the directors, which are to define the architecture of the lander and then the orbiter. This will depend on analysis of launch capabilities. Mass of spacecraft is on the order of a ton. Architecture will depend upon orbital maneuvers."

Discussed specifics on the architecture of the mission with regard to the lander. He mentioned thermal diffusion on the lander as being important, since different instruments will need to be at different operating temperatures. The IKI proposal timescale is required soon and the payload and resource budgets (mass, power, data) are needed soon. Lavochkin Association assumes VAMP as part of the launched payload, but as a black box, which is very challenging.

Venera-9 lander was landed at 15˚ slopes. If NPOL is designing lander for 30˚ slopes, this enables tesserae landing sites, more appealing from the science point of view. [This new possibility requires that M. Ivanov completes new landing analysis simulations, as the one he presented on this meeting was made in assumption of 7˚ slopes to be safe for landing.]

They are considering 4 launch dates: 2026, 2028, 2029, 2031. The first and the last are preferable, as they provide maximal scientific payload. Overall mass of the SC is in range 5800-7000 kg. [Scientific payload mass on the order of ~2000 kg]

NOTE: The outside dimensions, mass, and design of the lander are fixed and will not change

Key unresolved questions:

- The mission architecture and payload are currently vague, and need to be defined, before all other engineering issues can be settled. This needs to be done soon.
- Is the aerial platform optional or to be included in the Lavochkin Association (NPOL) baseline definition? Considering both cases is not easy.

It was discussed that the Aerial platform will be defined at the beginning of 2018. The deployment is dependent on the type of platform; VAMP needs a circular orbit because of its inflation requirement prior to atmospheric entry. Jim Cutts and Jeff Hall pointed out that all the other platforms can enter at the same entry speeds as the lander.

Notes concerning Atmosphere and Aerial Platforms:
Alexander Rodin: Proposed an inter-comparison between Venus Global Circulation Models, with the goal of a standard atmospheric reference model as a baseline for Venera-D. Advocated for orbital science focused on spectroscopy of non-local thermal equilibrium emissions.

Sebastian Lebonnois: Emphasized importance of measuring in-situ heating rates and solar rates on an aerial platform at altitude of 30-40km *[Note: this is technically challenging due to the high temperatures below 50km]*

Lori Glaze: Advocated for a mass spectrometer to measure noble gasses (Kr, Xe, Ne) below the homopause (110 km)

Notes concerning Long Lived Landers:
Chris Parkinson: Advocated for a lander at the equator taking atmospheric composition measurements during descent using LIDAR.

Sebastian Lebonnois: Advocated for wind-measurements on the long-lived lander package, with accuracy of 1cm/s, to be made at least 50cm above the surface. Also advocated weather measurements with 0.1K and sub pascal accuracy. One set of measurements every 24 hours.

Jeff Hall: Strongly advocated the simplicity of mounting a long-lived surface element as part of the main lander, since this will take care of all Entry, Descent, and Landing. [Seconded by Sanjay]

Notes from Orbital Discussion: ***Polar versus Equatorial debate***
Ludmilla Zasova [Polar advocate]: Significant measurements that are able to look at simultaneous day and night style behavior are best obtained from a polar orbit

Takehito Satoh [Equatorial advocate]: Equatorial vantage point is needed to study super-rotation, and Akatsuki did not enter its optimal orbit

Oleg Vaisberg [Polar advocate]: To study atmospheric circulation, a wide geographical phase space (latitude, longitude, altitude) coverage is needed. A [PVO-like] polar orbit gives complete coverage of this phase space, whereas an equatorial orbit is much more limited—in particular the ability to study polar circulation is lost.

***Glyn Collinson [Polar advocate*]:** Advocates an elliptical polar, inclined orbit, with line of apsides (latitude of perigee) near the equator (PVO like) to cover the whole thermosphere and ionosphere over the course of the mission. Asked if the long term evolution of the orbit could be examined. In terms of night-time observations and period of observation of the nightside

Natan Eismont: The long term evolution of the orbit can be studied for altitude and changes in orbit inclination. *[Sanjay Limaye: Due to the lack of a J2 bulge, the inclination evolution is expected to be minimal, and dominated by solar pressure]*

Enhancing Elements/Observations Discussion:

Glyn Collinson: Advocated for a comprehensive particle and fields package to understand the evolution of Venus over time, and the interaction between thermosphere and ionosphere to understand super-rotation.

Missing Orbiter instruments:

Glyn Collinson: Advocated that a EUV solar photometer (as proposed by Oleg Vaisberg) and thermospheric neutral winds instruments be added to the Venera-D orbiter instrument package.