NASA SBIR/STTR
Small Business Innovation Research / Small Business Technology Transfer

NASA SBIR 2021 Phase I Solicitation

S3.05 Terrestrial Balloons and Planetary Aerial Vehicles

Lead Center: GSFC

Participating Center(s): AFRC, JPL

Scope Title:

Planetary Aerial Vehicles for Venus

Scope Description:

NASA is interested in scientific exploration of VenusÂ using aerial vehicles toÂ perform in situ investigations of its atmosphere, surface, and interior structure. The 2019Â Venus ExplorationÂ Analysis Group (VEXAG)Â Strategic PlanÂ identified several key science objectives that are ideally suited to aerial platforms. The areas of scientific interest include:
Atmospheric Gas Composition, Cloud and Haze Particle Characterization, Atmospheric Structure, Surface Imaging, and Geophysical Investigations.

Venus features a challenging atmospheric environment that significantly impacts the design and operation of aerial vehicles. NASA is currently developing concepts for controlled-variable-altitude balloons with payloads of up to 200 kg operating at an altitude range between 52 and 62 km over a latitude range of 0Â° to +/-60Â°. Proposals forÂ the followingÂ Venus aerial vehicle components areÂ encouraged: (1)Â Entry, deployment, inflation technologies for a Venus balloon, (2)Â Instrument sondes, and (3)Â Helium transfer pump.

1. The most critical phase of a Venus balloon mission is the transition from atmospheric entry to a free-flying configuration. Concepts for any or all of the critical phases of the transition are desired: deployment of the balloon from the atmospheric entry vehicle, inflation of the balloon, and separation of the balloon from the inflation system and parachute system.
2. Deployment of instrument sondesÂ from the payload could enhance and lengthen the balloon mission operating lifetime by reducing payload mass as lift capability is lost over time. Sondes with a mass up to 5 or 10 kg should be capable of operating

for several hours, carry a small science instrument payload, and be able to communicate with the primary balloon mission. The sondes envisioned for this solicitation are categorized into ascending and descending investigations. Ascending science investigationsÂ carry small science payloads up to 70 km altitude, andÂ descending science investigations carryÂ a small science payload down to near the surface (i.e., <10 km altitude). Proposals offering both heavier-than-air and lighter-than-air (relative to the Venus atmosphere) solutionsÂ are solicited. Furthermore, the sonde concepts may have powered propulsion or unpowered flight. Suggested vehicle types include, but are not limited to:

   - Solar-heated balloonsÂ thatÂ would operate on the sunlit side. This kind of sonde would be deployed from the payload gondola,Â auto-inflate in a free fall through the atmosphere, and attain float as the solar balloon heats from the Sun. This could possibly operate either above or below the primary balloon mission altitude range.
   - Probes deployed from the payload gondola that perform stabilizedÂ vertical descents, gliding descents,Â powered ascents, or aÂ combination of both ascents and descents.

3. A controlled-variable-altitude balloon may use a pump to transfer helium from a zero-pressure balloon into a superpressure balloon. Pumping technologies capable of pumping helium with a pressure rise of 50 kPa at 100 liters per minute are desired. Multistage or parallel flow pump solutions are acceptable for consideration. Light weight and high efficiency are important factors in the pump since itÂ must fly with the balloon payload.

It is expected that a Phase I effort will consist of a system-level design and a proof-of-concept experiment on one or more key components. Proposers should be familiar with the atmospheric pressure, temperature, solar,Â infraredÂ (IR) heating, and corrosion aspects of the Venus atmosphere as described in this call.Â The atmospheric temperature ranges from -30Â°C at 62Â km to 62Â°C at 52Â km, the pressure ranges from about 18 kPa at 62Â km to 80Â kPa at 52Â kmÂ (Venus International Reference Atmosphere, VIRAÂ [see Kliore, 1985]), the solar flux can be as high as 2,300 W/m^2Â at 62Â km, and the IRÂ heat flux coming up from the lower atmosphere can be as high as 830 W/m^2Â at 52Â km [Crisp, 1986].Â The sulfuric acidÂ *vapor*Â abundance is less than less than 1 ppmv at 52 km and above [Oschlisniok, 2012]. The sulfuric acidÂ *liquid*Â aerosols have a concentration between 75% (pH -1.5) and 90% (pH -2.0) [Titov, 2018]. Although the cloud droplets are highly acidic, they are very small, typically in the range of 1 toÂ 10 Âµm in diameter, and fairly diffuse, with cloud droplet abundance only on the order of 100 droplets/cm^3Â for the 1-Âµm-sized particles; and on the order of 10 droplets/cm^3Â for the larger (r > 3Âµm) particles. The maximum observed aqueous H_2SO_4Â content in the balloon operating environment is on the order of only 30 mg/m^3Â [Knollenberg, 1980].Â AdditionalÂ information on the Venus atmospheric environment can be found in the References section.

Expected TRL or TRL Range at completion of the Project:Â 2 to 3Â
Primary Technology Taxonomy:Â
Â Â Â Â Â Level 1: TX 04 Robotics SystemsÂ
Â Â Â Â Level 2: TX 04.2 Mobility**Â**
Desired Deliverables of Phase I and Phase II:

- Research

- Analysis
- Prototype

Desired Deliverables Description:

It is expected that a Phase I effort will consist of a system-level design and a proof-of-concept experiment on oneÂ or more key components. Deliverable items for Phase I shall be a final report describing the results of the concept analysis and demonstration of any key component technology developed.

The Phase II effort will focus on the development of a concept prototype and feasibility testing.Â Phase II deliverable should includeÂ a final report on design concept documentation, test reports, and photos of any prototypes that were built and tested.

State of the Art and Critical Gaps:

Terrestrial-based aerial vehicles, including lighter-than-air and heavier-than-air vehicles, are mature technologies and continue advancingÂ in capability, reliability, and autonomy. However,Â these need adaptation for operation in the Venus environment.
Several gaps exist in aerial vehicle technology for Venus atmospheric flight:

1. There is a strong need for aerial deployment systems forÂ balloons and their payloadsÂ since most balloons are launched from the ground and from the upper atmosphere. Methods for deployment may leverage techniques for Mars entry vehicle systems that deploy from an aeroshell and eventually separate from a parachute. However, a balloon inflation inserted into the middle of this sequence is a complicating element and preventing damage to the balloon is paramount.
2. Small instrument sondes or vehicles for expanding the exploration range and mission duration have not been sufficiently developed for a Venus mission to be included as part of future mission proposals. Novel vehicles for conducting science that can be deployed from the balloon payload could play an important role in meeting these objectives. The guidance, stabilization, and control of sondes has been identified as a need for collecting images of the surface during a deep atmospheric descent.
3. Altitude variation of a balloon requires changing the density of the lifting gas. There are no commercially available pumps in the market today that have the pressure rise and flow rate capabilities needed for a Venus balloon. Most pumps or compressors are not built to be lightweight, which is of critical importance on a balloon mission.

Relevance / Science Traceability:

Relevance: The Mars Helicopter, Ingenuity, and the Titan Dragonfly mission showÂ there is significant interest in planetary aerial vehicles for science investigations. It is in NASA's interestÂ through the SBIR program to continue fostering innovative ideas to extend our exploration capabilities by developing technologies forÂ Venus aerial mission concepts.

JPL's Solar System Mission Formulation Office and the NASA Science Mission Directorate's Planetary Science Division advocate Venus aerial vehicle platform development. NASA recently completed the Venus Flagship Mission concept study, which included a balloon system for the Planetary Decadal Survey [Gilmore, 2020].

Science Traceability: The 2019Â VEXAG Venus Strategic Plan identified several key science investigations that are ideally suited to aerial platforms. The areas of scientific interest include: Atmospheric Gas Composition, Cloud and Haze Particle Characterization, Atmospheric Structure, Surface Imaging and Geophysical Investigations. The variable-altitude aerial vehicle platform is ideal for investigating these science goals and objectives. Building the variable-altitude balloon requires the development of several key components as identified in this call.

References:

- Crisp, D. (1986):Â â€œRadiative forcing of the Venus mesosphere I: Solar fluxes and heating rates,â€Â *Icarus*, 67, 484-514.
- Gilmore, M., et al. (2020):Â â€œVenus Flagship Mission Planetary Decadal Study,â€Â Planetary Mission Concept Studies Virtual Workshop.
- Knollenberg and Hunten (1980):Â "The microphysics of the clouds of Venus: Results of the Pioneer Venus Particle Size Spectrometer Experiment,"Â *JGR*, 85:8039-8058, doi:10.1029/JA085iA13p08039.
- Oschlisniok, J. et al. (2012): "Microwave absorptivity by sulfuric acid in the Venus atmosphere: First results from the Venus Express Radio Science experiment VeRa,"Â *Icarus*Â 221, 940.
- Titov, D., Ignatiev, N. I., K. McGouldrick, Wilquet, V., andÂ Â Wilson, C. F. (2018): â€œVenus III: Clouds and hazes of Venus,â€Â *Space Sci. Rev.*Â 214, 126.
- The VEXAG Strategic Plan 2019 is found at:Â https://www.lpi.usra.edu/vexag/reports/Combined_VEXAG_Strategic_Documents_Current.pdf
- The Venus Atmospheric Properties are available inÂ Kliore, A. J., Moroz, V. I., Keating G. M., Eds.Â (1985):Â â€œThe Venus International Reference Atmosphere,â€Â *Adv. Space Res.*, Vol. 5, No. 11, pp 8+305, ISBN 0-08-034631-6.

Scope Title:

Improved Downlink Satellite Communications for Balloons

Scope Description:

Improved downlink bit rates and innovative solutions using satellite relay communications from balloon payloads are needed. Long-duration balloon flights currently utilize satellite communications systems to relay science and operations data from the balloon to ground-based control centers. The current maximum downlink bit rate is 150 kbps,Â operating continuously during the balloon flight. Future requirements are for bit rates of 1 MbpsÂ or more. Improvements in bit rate performance, reduction in size and mass of existing systems, or reductions in cost of high-bit-rate systems are needed. Tracking and Data Relay Satellite SystemÂ (TDRSS) and Iridium satellite communications are currently used for balloon payload applications. A commercial S-band TDRSS transceiver and a mechanically steered 18 dBi gain antenna provide 150 kbps continuous downlink. TDRSS K-band transceivers are available but are currently cost prohibitive. Open port Iridium service is also in use, but the operational cost is high per byte transferred.

Expected TRL or TRL Range at completion of the Project:Â 1 to 6Â
Primary Technology Taxonomy:Â
Â Â Â Â Level 1: TX 05 Communications, Navigation, and Orbital Debris Tracking and Characterization SystemsÂ
Â Â Â Â Level 2: TX 05.5 Revolutionary Communications Technologies**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I: Desired deliverables include: (1) results of analysis or simulationÂ or (2) test results of actual prototype hardware and/or software.

Phase II: Deliverables could include a prototype that could be test flown on a balloon mission.

State of the Art and Critical Gaps:

Current commercially available satellite relays systems that could be used for balloon flightÂ are either too costlyÂ orÂ do not provide the needed downlink data rates.Â Tracking and Data Relay Satellite SystemÂ (TDRSS) and Iridium satellite communications are currently used for balloon payload applications. A commercial S-band TDRSS transceiver and a mechanically steered 18-dBi-gain antenna provide 150 kbps continuous downlink. TDRSS K-band transceivers are available but are currently cost prohibitive. Open port Iridium service is also in use, but the operational cost is high per byte transferred.

Relevance / Science Traceability:

Science Mission Directorate (SMD) - NASA HQ (Astrophysics Division)Â enables multiple Research OpportunitiesÂ in Space and Earth Science (ROSES) opportunities, Small Explorer (SMEX) Announcement of Opportunity (AO)Â (Astrophysics), Astrophysics Mission of Opportunity, and Hands-On Project Experience (HOPE) (annually).

Improvements to satellite communications for research balloons would enable greater and better data collection,Â possibly extended flight duration, and other such potential benefits.

References:

- NASA's SuperTIGER Balloon Flies Again to Study Heavy Cosmic Particles:Â https://sites.wff.nasa.gov/code820/
- GUSTOÂ (Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory) missionÂ is a planned high-altitudeÂ balloon missionÂ that will carry an infrared telescope to measure emissions from the interstellar medium. The missionÂ is being developed by NASA's Explorers Program - GUSTO, University of Arizona (Prof. Chris Walker).
- Scientific balloon information:Â https://sites.wff.nasa.gov/code820/technology_capabilities.html
- 2020 NASA Technology Taxonomy:Â https://www.nasa.gov/offices/oct/taxonomy/index.html

Scope Title:

Steerable Recovery/Parachute System

Scope Description:

NASA is looking for an innovative way to reduce the termination dispersions from a few miles to within 1/2 to 1/4 mileÂ of the predicted termination point by the use of a steerable parachute recovery system (SPRS).Â The SPRS will need to be able to maneuver around infrastructure (e.g., oil wells, power lines, wind mills), protected areas (e.g., national parks, special habitats), natural resources (e.g., rivers, mountains, lakes), and other areas of interest (e.g., farm land).Â The SPRS will need to be provide real-time maneuverability for a science gondola from a remote operations control room using the communications and telemetry systems provided by the Columbia Scientific Balloon Facility (CSBF).Â The system should be lightweight, no more than 75 lbÂ including power.

Expected TRL or TRL Range at completion of the Project:Â 1 to 6Â
Primary Technology Taxonomy:Â
Â Â Â Â Â Level 1: TX 17 Guidance, Navigation, and Control (GN&C)Â
Â Â Â Â Level 2: TX 17.X Other Guidance, Navigation, and Control**Â**
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype

Desired Deliverables Description:

The deliverables for Phase IÂ includeÂ a trade study of the potential systems, a simulation of how each system should work, and a report on the recommendation of oneÂ to twoÂ systems to be further developed in Phase II.Â It is anticipated that these products are achievable given the SBIR time and funding constraints.Â

The deliverables for Phase IIÂ includes an engineering development unit and testing with a report of the results.

State of the Art and Critical Gaps:

A scientific balloon floats at an average altitude of 110,000 ft or more and carries science payloads up to 8,000 lb.Â At the end of a scientific balloon mission, the science payload on the gondola (from this point on â€œscience gondolaâ€) is separated from the balloon and falls to Earth on a parachute following the wind currents at the time of release and lands on cardboard crush pads.Â In most cases this allows recovery of the science gondola, though the payload and gondola may be in areas that are hard to reach using conventional recovery trucks.Â However, there are rare cases where the science gondola falls either in water or in areas that require special equipment or are difficult for recovery (e.g., inaccessible area).

Currently, trajectory predictions for termination are within a few miles and are dependent on models, map overlays (showing restricted air space, national/state parks), and observations from a plane on areas along the trajectory to determine the best area to terminate the balloon and bring the science gondola safely to the ground. Â Some items that are considered during the termination discussions are science mission minimums, trajectory predications (e.g., national or state parks, lakes, mountains, rivers, infrastructure, crop lands), weather conditions, and risk to the public.Â Current state of the art does not include steerable systems in balloon parachutes.Â Success in this endeavor will entail primarily steerability, but this also results frequently in a safety analysis, which will allow more â€œgreen lightsâ€ for launch than would otherwise be the case.

Relevance / Science Traceability:

This subtopic will beÂ relevant to any mission directorate, commercial entity, or other government agency that drops payloads from an altitude, including the Balloon Program.Â Other potentially interested projects include NASA sounding rockets, UAV, and aircraft programs.

References:

https://patents.google.com/patent/EP1463663A4/en

https://www.airforce-technology.com/features/featurejpads-circumventing-gps-for-next-gen-precision-airdrops-4872436/

Scope Title:

Relative Wind Speed Sensor for Scientific Balloons

Scope Description:

A trajectory control system (TCS) for high-altitude scientific ballooning has been a long-term goal of NASAâ€™s Balloon Program Office (BPO). One milestone in the critical path of TCS development is the ability to measure the speed of the winds seen by the gondola during a balloon mission. In addition, NASA has identified wind-speed measurements from a balloon explorer under the TX10.1.2 of the 2020 NASA Technology Taxonomy (see References below). Currently, the BPO has no method of measuring relative winds (wind speed relative to the gondola) in situ above ~15 km in altitude for terrestrial applications. AlthoughÂ several methods of wind speed measurement exist for a variety of applications, there is effort required to port those technologies for the conventional balloon float environment. The goal of this technology development is to develop a sensor to meet the following specifications:

1. Measure relative wind in three axes (u, v, and w).
2. Operate at 4.4 mbar (~36.5 km altitude) or lower pressure.
3. Operate in air temperature from -70 to +65 Â°C.
4. Accuracy of 10 cm/s or better.
5. Resolution of 5 cm/s or better.
6. Sample rate of 1 Hz or faster.
7. Power consumption of 30 W or less at steady state.
8. Mass of 20 kg or less.

9. Withstand shocks of 10g or greater.

Expected TRL or TRL Range at completion of the Project:Â 2 to 6Â
Primary Technology Taxonomy:Â
Â Â Â Â Level 1: TX 08 Sensors and InstrumentsÂ
Â Â Â Â Level 2: TX 08.3 In-Situ Instruments/Sensor**Â**
Desired Deliverables of Phase I and Phase II:

- Prototype
- Hardware
- Software

Desired Deliverables Description:

Phase I: Deliver a conceptual design package for a prototype unit thatÂ meets the design goals and accuracy.

Phase II:Â Deliver a prototype and an accompanying acceptance package that describesÂ the prototype unit in detail andÂ provides experimental validation of the unit having met the design goals and accuracyÂ as well asÂ all accompanying software/firmware required for operation of the sensor.

State of the Art and Critical Gaps:

Wind speed measurements at balloon float altitudes have several benefits:Â First, a relative wind sensor will enable the TCS development by providingÂ a means to measure the speed imparted to the balloon byÂ a future TCS concept. Second, science gondolas with fine pointing requirements must point against the relative wind. Currently, a data set of example relative wind does not exist, which requires science groups to design robust control systems for their telescopes or instruments. Third, relative wind is responsible for any convective cooling seen on large structures, such as baffles on telescopes, which is currently poorly understood. In general, relative wind speed measurements will aide in prolonging flights (both with a TCS and by refining flight prediction capabilities) and enable more informed design of gondola structures and heating systems.
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Commercially available wind speed sensors (anemometers) have been shown to not be capable of accurately measuring the wind speed above ~15 km in altitude. In addition, this technology (if realized) would enable the development of a trajectory control system for balloon missions, which is critical for achieving the goal of 100-day missions at 36 km in the Southern Hemisphere.

Relevance / Science Traceability:

A relative wind sensor for balloon missions would benefit the Science Mission Directorate (SMD)/Astrophysics mission by furthering the state of the art in sensor technology. In addition, the development of a relative wind sensor is a key milestone in the path towards a trajectory control system for high-altitude balloons. Specifically, NASAâ€™s Super Pressure Balloon (SPB) would benefit from trajectory control while pursuing 100-day flights in the Southern Hemisphere.

References:

Scientific balloon information:Â https://sites.wff.nasa.gov/code820/technology_capabilities.html

2020 NASA Technology Taxonomy:Â https://www.nasa.gov/offices/oct/taxonomy/index.html

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