National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

Modeling, Analysis and Design of Dynamic Couplings in Planetary Tethered Aerobot Systems

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Strategic Focus Area: Descent, Ascent

Background and Significance:

Planetary aerobots are expected to play a key role in future missions to Venus and Titan, with tethers between many elements – balloons, instruments, solar arrays, etc. With the focus of aerobot applications delayed and now moving to Discovery and NF-6, there is now an extraordinary opportunity to inject new technologies that can enhance the capabilities of a future aerobot mission. Tethers will play a critical role in both the initial deployment and inflation of the variable altitude balloon. They will then play a role after inflation has been completed in the deployment of the communications systems and science instruments as well as in the subsequent ~100-day operational phase of the mission as the aerobot responds to altitude changes and to the effects of atmospheric turbulence. Understanding the stability, dynamics, and control of these kinds of tethered systems is critical to successful design, testing, and deployment of solutions, and ensure full system autonomy by minimizing system risk in these highly uncertain environments. Figure 1 shows a) current configuration of Venus Aerobot; b) elements of Venus balloon flight systems prior to deployment/inflation; c) different types of tethered connection between balloon and gondola being investigated.

Goals: to identify, analyze, test, and mitigate (or take advantage of) critical dynamic couplings for novel tethered aerobot designs that lead to significantly increased system autonomy in the Venus dynamic atmospheric environment.

Objectives:

- Develop analytical models for two and three body tethered systems in a turbulent atmosphere.
- Verification of system models updates with subscale two and three body tethered laboratory experiments.
- Evaluate transient dynamic mitigation approaches with analyses and lab/field experiments.
- Apply the model & mitigation approaches to the Venus aerial platform design under consideration for mission infusion.

Benefits:

Outcome will lead to mitigating risks due to dynamic transients during deployment, inflation, and station-keeping of suspended payloads for planetary atmospheric missions with aerobots

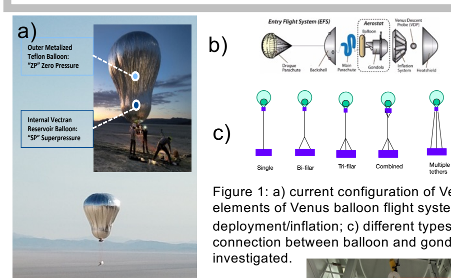

Figure 1: a) current configuration of Venus Aerobot; b) elements of Venus balloon flight systems prior to deployment/inflation; c) different types of tethered connection between balloon and gondola being investigated.

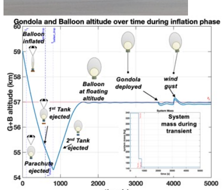

Figure 2. Results of a simulation of system deployment, inflation and altitude stabilization of Venus aerobot with gondola deployed at floating altitude of 57 km. System trajectory is shown

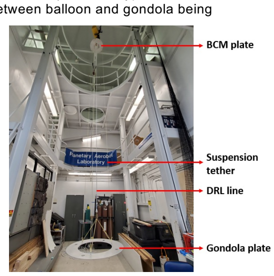

Figure 4: experimental set-up in 82-116. Drop tests will be conducted in year 2.

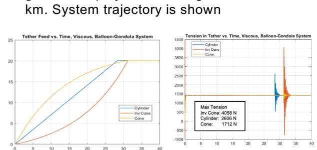

Figure 3: the tether velocity and tension vs. time for three different DRL types (cylinder, cone, inverted cone).

Results:

- **Multibody Deployment Inflation Model**: (Fig. 2) This unique tool will help us understand inflation and deployment transients. The assumptions in current models are that: the parachute is fully opened and steady; the system is descending at terminal velocity; there are multiple viscoelastic tethers between the balloon and the gondola; the balloon is modeled as rigid body with variable mass; the gondola is modeled as rigid body; the balloon inflation is modeled with a variable mass flow rate vs. time; we include both steady and unsteady aerodynamics, and zonal wind and stochastic wind gusts.
- **Descent Rate Limiter (DRL) Model**: (Fig. 3) DRLs are used to mitigate and modulate the deployment loads on the gondola. We found that the effects of transient dynamics on the Balloon-Tether-Gondola system during gondola deployment can be sufficiently mitigated through proper DRL design. The DRL can be tailored to feed out the tether faster at the beginning and slower at the end to sufficiently limit shock loads as the tether feed hits the end stop, and to fit within the deployment timeframe.
- **Experimental Validation of Models**: The experimental setup involves two annular plates, as shown in Fig. 4. The upper plate represents the BCM (Buoyancy Control Module) attached rigidly to the bottom end-fitting of the balloon and the lower plate represents the gondola. This 1:4 scale setup is used to vary: a) Tether configuration: bifilar, tri-filar etc.; b) Tether material; c) mass distribution on the gondola. A high frame rate camera and IMUs mounted along with a battery and data acquisition system on both the plates are used to characterize the behavior of the system. A commercially available rescue device (3M DBI Sala Rolgliss 550) is used to mimic the behavior of a DRL Based on the results of these lab experiments and simulations, two of the most successful configurations were field tested in the summer of 2023, and a large volume of data collected (will be processed and validated with models in year 2 of this task).

References:

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3. Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032. https://doi.org/10.17226/26522
4. Aerial Platforms for the Scientific Exploration of Venus. https://solarsystem.nasa.gov/resources/2197/aerial-platforms-for-the-scientific-exploration-of-venus
5. Cutts, J., et al: https://doi.org/10.1109/AERO53065.2022.9843740

Publications

- A poster on our Year 1 work was presented at the International Planetary Probe Workshop 2023, in Marseille, France. Journal paper is in progress.

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