l Aeronautics and Space Administration

FY24 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.
- 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 with integrated models is critical to successful design, testing, and deployment of solutions, and ensure full system autonomy by minimizing system risk in these highly uncertain environments.

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 and 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. The results will be relayed to the New Frontiers-5 and Discovery Venus proposal teams to help define requirements and system design and support Step-1 and Step-2 proposals.

Results:

In Year 2 we continued the modeling and experimental effort by developing and testing a unified flexible multibody aerobot flight dynamics tools to analyze multiple designs in support of NF-5 and Discovery proposals in Year 3, which included:

- A System-level Time-domain Multibody Dynamics Model (Fig. 2) to analyze multiple scenarios with representative towed body and drone-gondola connection architectures including towed and attaching/re-attaching atmospheric probes with long tethers; enabling lateral trajectory control; multiple flight architectures for instrument placements (Fig 3);
- System-level Frequency-domain Finite Element Models (Fig. 1, Left) for continued data-analysis of the experimental data already taken in Mojave and Blackrock and testing finite element models of flight chain with coupling structural effects;
- The Development and Analyses of Stochastic Wind Effects (Fig. 4) to evaluate the effect of wind gusts and determined that balloon dynamics drives the system dynamic response. Currently we are working to include fluid-structure interaction effects which will enable infrasound detection in Year 3
- Development of Fluid-Structure Interaction Models (Fig. 5): Since the experimental data and simulation results showed that the balloon envelope triggers gondola oscillations, we started the development of fluid-structure models of wind- balloon interaction.

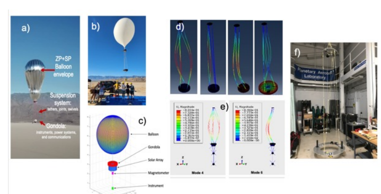

Figure 1. (Left) a) current configuration of Venus Aerobot; b) configuration being modeled in Mojave flight test. c) geometry of aerobot being modeled; (Center) d) and e) Results of finite element analyses; f) modal analysis test set-up in building 82 at JPL.

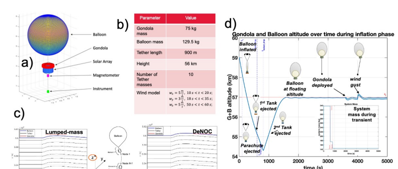

Figure 2. (Left) Results of aerobot system flight simulator: a) flight chain system geometry; b) system parameters; and c) representative system response under wind loading. (Right, d) Results of preliminary simulator of transient deployment and inflation dynamics from Year 1.

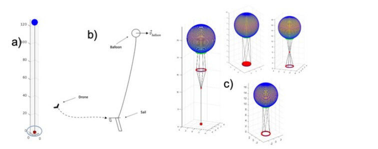

Figure 3. Available Aerobot configurations that are being analyzed with our simulator: a) towed and attaching/re-attaching atmospheric probes with long tethers; b) mechanisms for lateral trajectory control; c) multiple flight architectures for instrument placements.

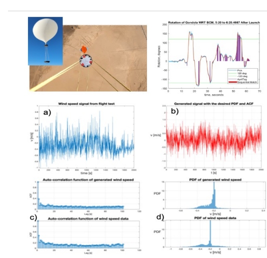

Figure 4. (Top): Extracted torsional stiffness of BCM-tether-Gondola subsystem and determined that balloon drives the system dynamic response. (Bottom) Wind gust model based on real data: a) measured wind speed magnitude; b) synthetic wind speed; c) comparison of autocorrelation functions; and d) comparison of probability distribution.

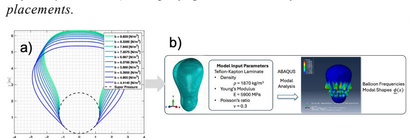

Figure 5. a) Models of inflation of balloon envelope are generated and given to the Abaqus finite element modeler (b) to generate spectrum of balloon envelope for fluid structure interaction analyses.

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Publications:

- Poster on Year 1 accomplishments presented at IPPW2023 in Marseille, France
- Lesieutre, G, Quadrelli, M: Dynamics of Viscoelastic Tethers for Planetary Aerobots using a Fractional Derivative Model, presented at AIAA SCITECH 2024, submitted to AIAA journal
- Poster on first 6 months of Year 2 accomplishments presented at IPPW2024 in Williamsburg, VA, June 8-14
- Bandinelli, C., Capello, E., Goel, A., Rossi, F., Quadrelli. M.: Real time data-based wind model for a Venus Aerobot: development and testing, to be presented at the International Astronautical Congress, Milano, Italy, in October 2024
- Vergari, P., Dr Matteis, M., Quadrelli. M., Blomqiust, R., Rossi, F., Apa, R., Aliberti, S., Romano, M.: Modeling and Analysis of Tethered System Dynamics and Towed Body Problem for Venus Aerobots and Towed Probes, to be presented at the International Astronautical Congress, Milano, Italy, in October 2024
- Montesano, L., Rossi, F., Quadrelli, M., Braghin, F.: Finite element modeling and parametric frequency domain analysis of Venus Aerobot flight train, to be submitted to Acta Astronautica.

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