sion design and operational planning to manage radiation risks in future space missions. The ARRBOD GUI can identify the proper shielding solutions using the gender-specific organ dose assessments in order to avoid ARR symptoms, and to stay within the current NASA short-term dose limits. The quantified evaluation of ARR severities based on any given shielding configuration and a specified EVA or other mission scenario can be made to guide alternative solutions for attaining determined objectives set by mission planners.

The ARRBOD GUI estimates the whole-body effective dose, organ doses, and acute radiation sickness symptoms for astronauts, by which operational strategies and capabilities can be made for the protection of astronauts from SPEs in the planning of future lunar surface scenarios, exploration of near-Earth objects, and missions to Mars.

❯ Probabilistic Path Planning of Montgolfier Balloons in Strong, Uncertain Wind Fields

This algorithm can be used for underwater unmanned vehicles for automated scientific data collection and for military uses.

NASA's Jet Propulsion Laboratory, Pasadena, California

Lighter-than-air vehicles such as hot-air balloons have been proposed for exploring Saturn's moon Titan, as well as other bodies with significant atmospheres. For these vehicles to navigate effectively, it is critical to incorporate the effects of surrounding wind fields, especially as these winds will likely be strong relative to the control authority of the vehicle. Predictive models of these wind fields are available, and previous research has considered problems of planning paths subject to these predicted forces. However, such previous work has considered the wind fields as known *a priori*, whereas in practical applications, the actual wind vector field is not known exactly and may deviate significantly from the wind velocities estimated by the model.

A probabilistic 3D path-planning algorithm was developed for balloons to use uncertain wind models to generate time-efficient paths. The nominal goal of the algorithm is to determine what altitude and what horizontal actuation, if any is available on the vehicle, to use to reach a particular goal location in the least expected time, utilizing advantageous winds. The solution also enables one to quickly evaluate the expected time-to-goal from any other location and to avoid regions of large uncertainty. This method is designed for balloons in wind fields but may be generalized for any buoyant vehicle operating in a vector field.

To prepare the planning problem, the uncertainty in the wind field is modeled. Then, the problem of reaching a particular goal location is formulated as a Markov decision process (MDP) using a discretized space approach. Solving the MDP provides a policy of what actuation option (how much buoyancy change and, if applicable, horizontal actuation) should be selected at any given location to minimize the expected time-to-goal. The results provide expected time-to-goal values from any given location on the globe in addition to the action policy.

This stochastic approach can also provide insights not accessible by deterministic methods; for example, one can evaluate variability and risk associated with different scenarios, rather than only viewing the expected outcome.

The resulting path-planning tool is a general-purpose guidance algorithm that can be applied to exploration balloons on any moon/planet with atmosphere, including Titan, Mars, Venus, and gas giants, provided the wind field models are available. The algorithm is particularly useful for mission planning and trade studies because it not only delivers the optimal expected path, but also provides insights into the variability and risk associated with different mission scenarios (e.g., under different wind variability or vehicle capabilities). Finally, these techniques may be useful for other variably buoyant vehicles operating in strong vector fields, such as underwater vehicles in ocean currents, which may have additional scientific or military significance.