Unmanned Aerial Vehicle (UAV) Based Measurements of Ice Clouds and Environment Related to Rocket Launch Exhaust Plume (UAV-REP)

1. Summary

Autonomous systems have progressed to the point of being able to conduct atmospheric sampling up to 30 km where most piloted aircraft cannot fly. Such systems are uniquely capable of, not only testing instruments prior to permanent deployment, but also for in-situ sampling in support of NASA's climate change mitigation goals. The new space economy brings with it the growing concern about the impact of rocket exhaust gases, particulates, and flow dynamics on the environment. New observation methods are needed to constrain models on environmental impacts, 'else regulatory agencies will rely on outdated models, negatively impacting space commerce. **The objective of UAV-REP project is to employ a new instrumentation suite onboard a hybrid, balloon launched, stratospheric glider unmanned aircraft system (UAS) to measure meteorological conditions and evaluate pre- and post-rocket launch environments to obtain a dataset useful to regulatory agencies and climatic researchers.**

Flight tests will advance the TRL by gathering critical observations of ice and aerosol parameters up to an altitude of 30 km. In-situ measurements will be collected above thunderstorms and within rocket launch exhaust plumes, which will allow improved evaluation of rocket launch environmental impacts. Flights will be conducted over three-weeks in 2023 near Cape Canaveral, Florida where regular rocket launches occur. The first flights are planned for cloud free environments to ensure all system components are working properly, followed by pre- and post-rocket launch event flights sampling within and downwind of a launch corridor.

The UAV-REP opens a pathway to low-cost, targeted, in-situ sampling enabling new scientific insights to the effects of rocket exhaust plume in the upper troposphere and lower stratosphere. Such monitoring is critical to avoid unforeseen reductions (over corrections) to launch frequency imposed for environmental protection and will, in general, give rise to best practices going forward. The NASA Flight Opportunities Program is a critical step in demonstrating the system's capabilities in a high-altitude, operational environment and advancing the TRL.

2. Introduction

Given the steadily rising frequency of worldwide commercial rocket deployments, there are new concerns about impacts to the environment (Kokkinakis and Drikakis 2022). Additionally, there is new interest in how thunderstorms effect the transport of pollutants and ice crystals to the stratosphere (Smith 2021). Addressing these issues requires time sensitive observations in the upper troposphere and lower stratosphere to advance our scientific understanding. Such observations have been limited due to the expense of specialized aircraft needed to deploy the large payloads available. Over the last decade, instrumentation size and weight have been reduced to enable quick, remote location deployment on smaller platforms. Furthermore, there are now research tools, such as the flight providers' balloon launched stratospheric glider, that can deploy and return miniaturized instrumentation to a desired sampling location up to 30 km altitude (Schuyler, T. J., et al 2019). The proposed platform has been proven effective at low (-60 °C) temperatures, in challenging (180 km/hr) wind conditions, and during high (9 G) maneuvering. Funds will support the integration, bench testing and full campaign deployment of the sensor suite onboard the proposed stratospheric glider and prove the resilience of the payload in a stratospheric flight regime. This offers new, essential possibilities to the earth observation community as we move expeditiously into this new era of space travel.

3. Relevance

The use of UAV-REP project for in-situ sampling of ice clouds and exhaust plumes is directly relevant to NASA's missions to understanding the Earth's environment as well as contributing to the advancement of commercial spaceflight. With the possibility of more frequent and intense storms in a changing climate, the NASA Earth-observing community needs to conduct more routine upper troposphere and lower stratosphere observations than currently possible with available platforms. The NASA WB-57 and ER-2 aircraft for example provide high-altitude, stratospheric in-situ sampling; however, their expense limits deployment to large field projects and they require large airport facilities. Additionally, their high velocity negatively affects in-situ sampling. Conversely, high altitude balloons provide the ability to obtain ozone, hydrometer, and aerosol profiles; however, balloons cannot be directed to conduct specific horizontal flight profiles. Therefore, these existing platforms do not support routine, in-situ measurements of ice and aerosol particles in the lower stratosphere. Specifically, measurements on ice and aerosol particles resulting from rocket flights have been very limited. The outcomes of the proposed UAV-REP field campaign would allow us to accurately assess the consequences of rocket launches and therefore contribute to a more concise formulation of future launch regulatory initiatives. Such an assessment would support proper development of space commerce as an environmentally aware industry.

4. Technical Approach

The proposed **Autonomous System for In-situ Stratospheric Sampling (ASISS)** falls under the solicitation's flight vehicle category of high-altitude balloons, being a balloon launched, fixed-wing hybrid system. ASISS is a new, all-in-one platform that includes atmospheric state parameter instruments, a state-of-the-art, light-weight Cloud Droplet Probe (CDP), an optical aerosol particle counter (OPC) and an extinction probe (EP). If platform constraints allow, a chemical cell ozone instrument and small dropsonde system will also be incorporated. Temperature, humidity, pressure, and GPS location is measured using an InterMet IMET-XQ2 instrument. Atmospheric 3D wind is measured using a Raindynamics 5 port gust probe system designed for small Unmanned Aircraft Systems (UASs). The aerosol particle spectrum is measured using a Brechtel mini-OPC (model 9405). The ice particle spectrum is measured using a Droplet Measurements Technologies (DMT) UAV CDP with particle sizing adjusted for ice instead of the standard water droplet configuration. A Raspberry Pi acquires digital data streams from all instruments. The platform and all instruments have been previously deployed. The project's objective is testing <u>**a fully integrated system**</u> capable of obtaining scientifically useful measurements at high and cold altitudes to evaluate overshooting thunderstorm tops and rocket exhaust plumes.

The project scope includes bench testing and preliminary flight tests leading up to a three-week intensive operational period (IOP) where ASISS is tested at Cape Canaveral during the summer-time peak in thunderstorm activity. Exact deployment dates will be adjusted to accommodate/include pre-scheduled rocket launches. Ideally, a liquid and a solid fueled rocket exhaust plume would be sampled during the IOP. Flights will be initially planned based on the NOAA weather forecast. Radiosonde measurements will be used to adjust initial flight profiles and real-time flight adjustments will be arranged using the National Weather Service Melbourne radar. The project objective is to bring the proposed system from a TRL 5 to TRL 8 following the campaign. The project science team will analyze all measurements obtained and publish the results in peer reviewed journals. The successful demonstration of the system is a critical step towards commercializing this unique, high-altitude monitoring sensor suite as a compliment to the new space economy and an application to Earth system research.