Volcano Plume Monitoring with UAS

a Ruggedized UAS for Scientific Data Gathering in Harsh Environments

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Figure 1: Aerial view of the Eruption of Eyjafjallajökull volcano.

Introduction

In April 2010, Icelandic volcano Eyjafjallajökull erupted. The resulting ash plume caused over 95,000 flights to be canceled. The economic impact attributed to the volcano was estimated at $1.7 billion in losses. All due to the microscopic particulates that make up the ash cloud; the fine, abrasive particles erode metal, clog fuel systems, and pose a danger to all leading edges of an aircraft.

As a result of this natural disaster, aircraft manufacturers were forced to define specific limits on how much ash is considered acceptable for a jet engine to ingest without damage. The National Aviation Authority (NAA) in conjunction with engine manufacturers, set new guidelines which allowed aircraft to fly where levels of volcanic ash are between .2 and 4 milligrams per cubic meter of air space. These levels were declared by governments, aircraft manufacturers, and airlines not to have safety implications if appropriate maintenance and ash inspection procedures were followed. Airspace in which the ash density exceeds this limit is categorized as a no fly zone.

How then are airlines, traffic controllers, and aviation authorities to accurately establish ashfall advisories for future scenarios without compromising passenger safety?

1 A Collaborative Effort

NASA, in collaboration with Boulder-based Black Swift Technologies (BST), is creating a small unmanned aircraft system (sUAS) to explore volcanoes in order to improve air traffic management systems and the accuracy of ashfall measurements.

The success of this ambitious initiative calls for the development of a sUAS platform by the engineers at BST that meets the sensing needs required for routinely sampling volcanic ash clouds. This tightly integrated system will consist of an airframe, avionics, and sensors specifically designed to measure gas and atmospheric parameters (e.g., temperature, pressure, humidity, and 3D winds).

This novel platform will be based on BST's commercially-available SuperSwift™ airframe, whose capabilities will be expanded to achieve high altitude flights through strong winds and damaging particulates. Additionally, the SuperSwift's well-documented power and data interfaces will be employed to integrate the sensors required for the measurement of atmospheric chemical phenomenon for targeted application areas.

The aircraft engineered to address the challenging requirements of this mission will be called the SuperSwift™ XT. (Figure 2).

2 Signficance of this Initiative

Accurate predictive modeling of certain atmospheric chemical phenomena (e.g., volcano plumes, smog, gas clouds, wildfire smoke, etc.) suffers from a dearth of information, largely due to the fact that the dynamic qualities of the phenomenon evade accurate data collection. In situ measurements are currently made through the use of ground sensors and dropsondes. Ground sensors, "such as seismometers, tiltmeters, in-ground gas monitors and near-field remote sensing instruments" have limited measurement density and provide only information about atmospheric boundary conditions. Dropsondes can provide measurements over the entire vertical profile, but are limited to sampling over a small time period. In situ measurements

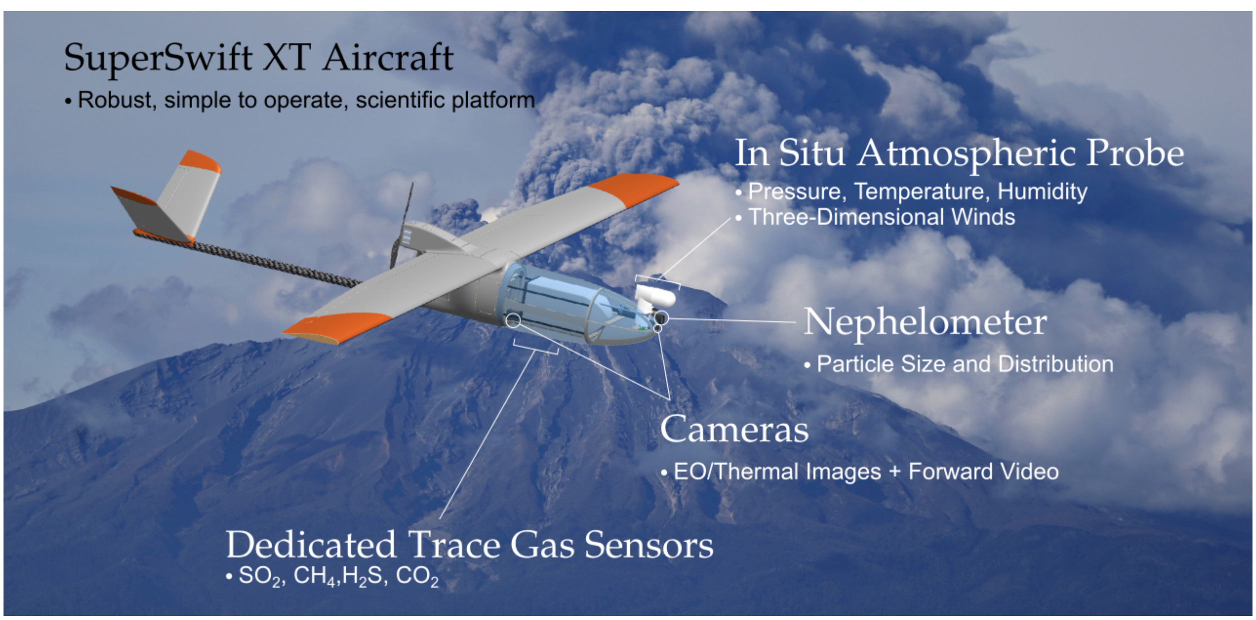

Figure 2: The SuperSwift™XT and its specialized payload.

can be augmented with satellite-based remote sensing systems, such as ASTER, MODIS, AIRS and OMI. However, satellite-based data suffers from its relatively low spatial density and limited frequency of measurement. A need exists for additional targeted in situ data from volcanic ash clouds, particularly to assess "...particle size distribution, ash cloud height, and ash cloud thickness including spatial (horizontal and vertical) and temporal variability of ash concentration."

Unmanned Aircraft Systems (UAS) provide instrument platforms that are able to operate in airspaces that are otherwise too difficult or hazardous for manned aircraft. In addition, small UAS (sUAS) are typically more economical to construct, operate, and maintain than manned systems or larger UAS. This makes the loss of aircraft more acceptable in some high-risk applications. Furthermore, the simultaneous deployment of multiple aircraft for improved temporal (flight scheduling) or spatial (formation flying) measurements can be more feasible with relatively low-cost sUAS. Therefore, the use of UAS is well-suited to making targeted, in situ measurements of atmospheric chemical phenomenon to span the gaps in current data collection methods. These platforms have been shown to be capable of carrying a variety of sensors, including mass spectrometers, gas sensors and basic atmospheric sensors. The wider use of these sensing capabilities is limited only by the current availability of airframes and avionics, which are not intended for use in carrying scientific instruments in harsh environments (high altitude, high winds, damaging particulates, etc.) involved in observing atmospheric chemical phenomena, such as volcanic plumes.

The proposed innovation, the SuperSwift™ XT, will meet NASA's need to "enhance the performance and utility of NASA's airborne science fleet" by providing a durable, terrain-following UAS vehicle that can be used in harsh environments containing environmental phenomena that impacts societal activity (i.e. volcanic emissions impacting the safety of passenger aviation). The sUAS will provide targeted, in situ observations from previously inaccessible regions that can significantly advance NASA's goal of safe, efficient growth in global aviation by aiding in the collection of scientific data from which predictive Volcanic Ash Transport and Dispersion models (VATD) can be used to inform air traffic management systems.

Figure 3: Flight cancellations across Europe were widespread.

The existence of a sUAS capable of carrying the necessary instruments routinely through harsh environments adds an invaluable contribution to the calibration and validation of data collected from ground- and satellite-based methods. The flight envelope, concept of operations (CONOPS), and rugged nature of the SuperSwift™ XT will permit researchers to collect data previously unobtainable through traditional data collection methods or existing sUAS. This includes gathering difficult to obtain data sets such as from volcanic plumes shortly after eruption (i.e., particle size-frequency distribution, vertical ash concentration distribution, SO_2 flux, etc.). The targeted, in situ data collected from a sUAS can better inform comprehensive 3D models as compared to traditional sensing methods. Additionally, the reliable nature of the platform will allow for the mission be extended to support use of multiple coordinated UAS. Such a configuration would greatly enhance the sensing capability of the platform, such as through the ability to obtain instantaneous spatial derivatives, or the ability to reduce the time required to sample an entire plume, providing a better understanding of the plume structure as it continually evolves.

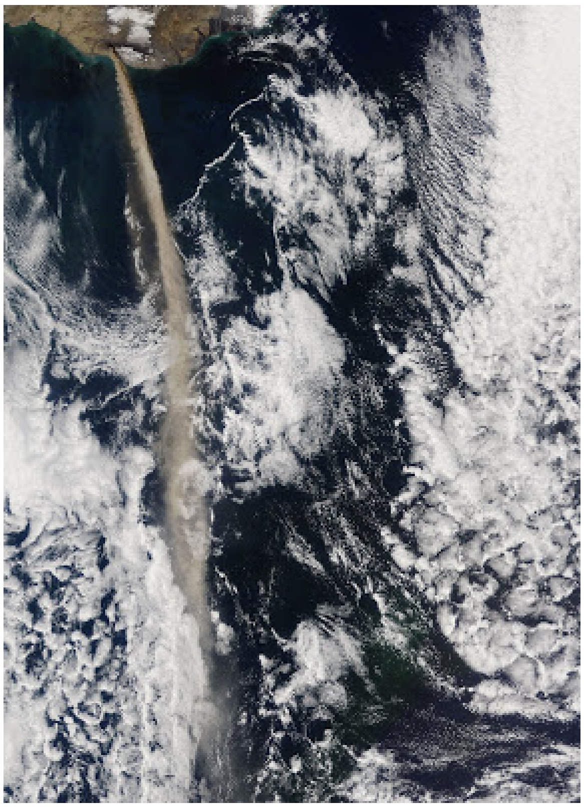

Figure 4: NASA's view of the plume from space.

Additionally, the use of UAS to measure dangerous phenomenon, such as wildfire smoke and volcanic plumes, eliminates the risk of harm to researchers and scientists making observations at close proximity. Utilizing sUAS systems provides researchers with the ability to collect desired data sets while remaining at a safe vantage point from the danger posed by the phenomena. A speedy response time is also critical to determining the effects of volcanic eruptions; an sUAS system can be deployed rapidly and begin transmitting reliable information within minutes of a volcanic eruption.

The innovative SuperSwift™ XT UAS system will enable the collection of in situ data to support three important scientific missions:

1. Supporting new scientific observational capabilities that can improve understanding of the chemical and physical properties of emissions and, thus, improve the ability to respond to aviation ash hazards,
2. Improving the accuracy and precision with which volcanic eruptions can be predicted, and
3. Improving the calibration and validation of traditional volcanic plume sensing methods, especially in the most dangerous circumstances in which ground collection of data is impaired or difficult to collect.

Efforts to date have made use of UAS to demonstrate their enormous potential as a unique method for gathering measurements in volcanic plumes. High-altitude, long-endurance (HALE) and medium-sized UAS have been shown to provide invaluable observations using relatively large instrumentation and powerful sensors. Additionally, sUAS have been used in a complementary nature as they are capable of low-AGL flight that permits the vehicle to directly sample plumes and ash clouds that are low to the ground (but high altitude above sea level) in which the richest chemical and physical samples exist immediately after eruptions.

In considering the next steps to improving upon sUAS that have been used to date for in situ plume measurements, a distinct need becomes apparent from the lack of a platform specifically designed to meet the mission requirements. Although good for observation of small features, such as vents, multi-rotor sUAS do not provide an ideal endurance or operational range to effectively characterize large scale atmospheric structures and compositions. The smaller, fixed-wing UAS flown

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to collect data on coherent atmospheric structures have proven the viability of the platform, but suffer from breakdowns and flight envelope limitations given the airframes and avionics have not been explicitly designed to survive repeated flights through harsh environments.

Thus unlike other systems currently used, the SuperSwift^{TM} XT is a sUAS purpose-built for flying scientific payloads in demanding atmospheric environments (high-altitude, corrosive particulates, and strong turbulence). The SuperSwift^{TM} XT offers the additional benefits of being hand-launchable and having a larger payload capacity than other vehicles while also having longer endurance, higher ceiling, and greater range than vector wing airframes.

This rugged airframe is capable of autonomous launch, flight, and landing from difficult mountainous regions.

Indicative of the science-based missions and flight heritage of the SuperSwift, the XT variant will also feature the field-swappable payload system designed for the original SuperSwift^{TM}.

The field-swappable payload system was designed to:

1. Ensure clean and uncontaminated measurements of the atmosphere by completely enclosing the sensor suite and associated hardware within the nose cone, and
2. Enable rapid changes of the payload in the field using a common power, data, and mechanical interface without any specialized tools. This allows for different sensors suites to be rapidly deployed in successive missions using the same airframe and FMS, extending the utility of the SuperSwift^{TM} XT to numerous applications and missions outside that of volcanic plume detection.

The primary goal of the development effort was the design and development of the SuperSwift^{TM} XT sUAS and integration of trace gas, particulate, pressure, temperature, humidity, and wind sensors. This work will enhance the performance and functionality of NASA's airborne science fleet of UAS by providing a durable class of sUAS that can collect in situ scientific data from an easy-to-operate, highly-capable platform in harsh environments.

2.1 Potential Non-NASA Commercial Applications

A number of post-research and development applications exist, commercial and scientific. The proposed innovation, including the total sensor suite, can be utilized for scientific research by federal and state public agencies and other state-funded laboratories to collect data on coherent atmospheric structures such as smog, volcano plumes, wildfire smoke, chemical fires, forest humidity, etc. Commercial applications for private industry exist as well, such as utilizing the SuperSwift^{TM} XT to assess the composition, and relative danger, of chemical fires at refineries or the chemical composition of smokestack exhaust.

About Black Swift Technologies
Black Swift Technologies (BST) is based in Boulder, CO and has been in operation since 2011. All UAS sold by BST are built upon the SwiftCore^{TM} FMS that includes the autopilot, ground station, user interface, and support electronics. Unlike many competing systems that rely on open-source and low-quality avionics, BST is able to guarantee quality, robustness, and supply of the most critical components of our systems. The SwiftCore FMS was designed by BST from the ground up. This affords control of the critical parts of our products, including the design of all electronics for both the avionics and ground systems, software, mechanical assembly, and the detailed QC process for all outgoing systems. Furthermore, BST uniquely couples avionics expertise with consulting services, and has delivered products and engineering services to many government entities including NASA, NOAA, various universities along with commercial sales to end-users and aircraft integrators.