BlackSwift
TECHNOLOGIES

WHITE PAPER

AI AND MACHINE LEARNING'S ROLE IN ENABLING AUTOMATED EMERGENCY SAFE LANDINGS OF UAS

A Key Enabler for Safe Beyond Visible Line of Sight (BVLOS) Flights.

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At a 2019 FAA UAS Symposium, Jeremy Grogan of FAA Flight Standards Service, noted that a critical concern raised by FAA when considering BVLOS Waivers is, "If the primary method of tracking/locating the sUAS fails, how will the operation ensure safety of the NAS and non-participants is not compromised?"

INTRODUCTION

"Our emphasis is to make UAS operations safer for both operators and the public," emphasizes Jack Elston, Ph.D., CEO of Black Swift Technologies. "The goal of SwiftSTL™ is to be able to take a snapshot and within 60 seconds of something like a catastrophic engine failure, be able to identify a landing zone, calculate a landing trajectory, and safely land a UAS away from people and obstacles. We remain convinced that a thorough understanding and integration of artificial intelligence and machine learning can help serve as a catalyst for accelerating UAS growth and adoption industry-wide."

PROJECT OVERVIEW

LEVERAGING TECHNOLOGY

SwiftSTL™

SWIFTSTL (SWIFT SAFE-TO-LAND) TECHNOLOGY INTEGRATES STATE OF THE ART MACHINE LEARNING ALGORITHMS, ARTIFICIAL INTELLIGENCE (AI), AND CUTTING EDGE ONBOARD PROCESSORS TO CAPTURE AND SEGMENT IMAGES, AT ALTITUDE, ENABLING A UAS TO AUTONOMOUSLY IDENTIFY A SAFE LANDING AREA IN THE EVENT OF A CATASTROPHE.

Technology that can capture, identify, and label images—at altitude—enabling a UAS to autonomously land without harm to people or property in the event of a catastrophe, is a key enabler for safe beyond visible line of sight (BVLOS) flights.

To this end, Black Swift Technologies (BST) has developed a small form factor, low power consumption, integrated hardware and software solution, Swift Safe-To-Land (SwiftSTL), that uses semantic segmentation machine vision to enable a UAS that has undergone a catastrophic in-flight failure to automatically land in a safe area. BST's solution processes high resolution images quickly and efficiently onboard the UAS to enable the identification of objects and terrain to be avoided to safely land the aircraft.

SwiftSTL technology was developed under a NASA SBIR grant awarded to BST and is currently being tested for commercial release. Fundamental to this advanced functionality is the development of onboard machine semantic segmentation on an integrated, small form factor hardware platform to identify obstacles (people, buildings, vehicles, structures, etc.) that could impede finding a viable, safe landing area. Semantic segmentation is a branch of machine vision that allows objects to be classified at the pixel level by assigning each pixel to a class label. This is a more complex solution than merely assigning an object to a class. A key differentiator to BST's solution is its ability to collect and process massive amounts of data that a human alone could not, to quickly make an emergency landing location decision.

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HOW IT WORKS

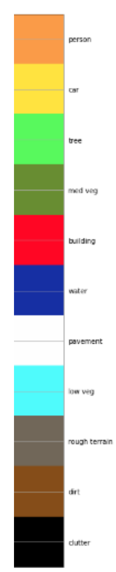
MACHINE VISION, IMPLEMENTED WITH SEMANTIC SEGMENTATION ON A SMALL FORM FACTOR HARDWARE PLATFORM, ALLOWS COMPUTER SYSTEMS TO PERCEIVE AND UNDERSTAND THE WORLD AROUND THEM TO MAKE REAL-TIME OPERATIONAL DECISIONS.

Ensuring safety to non-participants is not a subject the FAA or the UAS industry takes lightly. As a result, a number of advances have come to the forefront to help ensure that the public's safety is not compromised in the event of a catastrophic system event, such as engine failure, when UAS are flying over people. Current solutions include autonomous drone parachute systems, and, more recently, the automated emergency safe landing technology (SwiftSTL - Swift Safe-To-Land) designed by BST.

SwiftSTL works by segmenting video or still images of the ground and identifies them as humans, animals, vehicles or structures—objects to be avoided at all costs, even at the expense of the aircraft—to identify a safe landing area for the distressed UAS (Figure 1).

Original Input Image

Semantic Segmentation Map



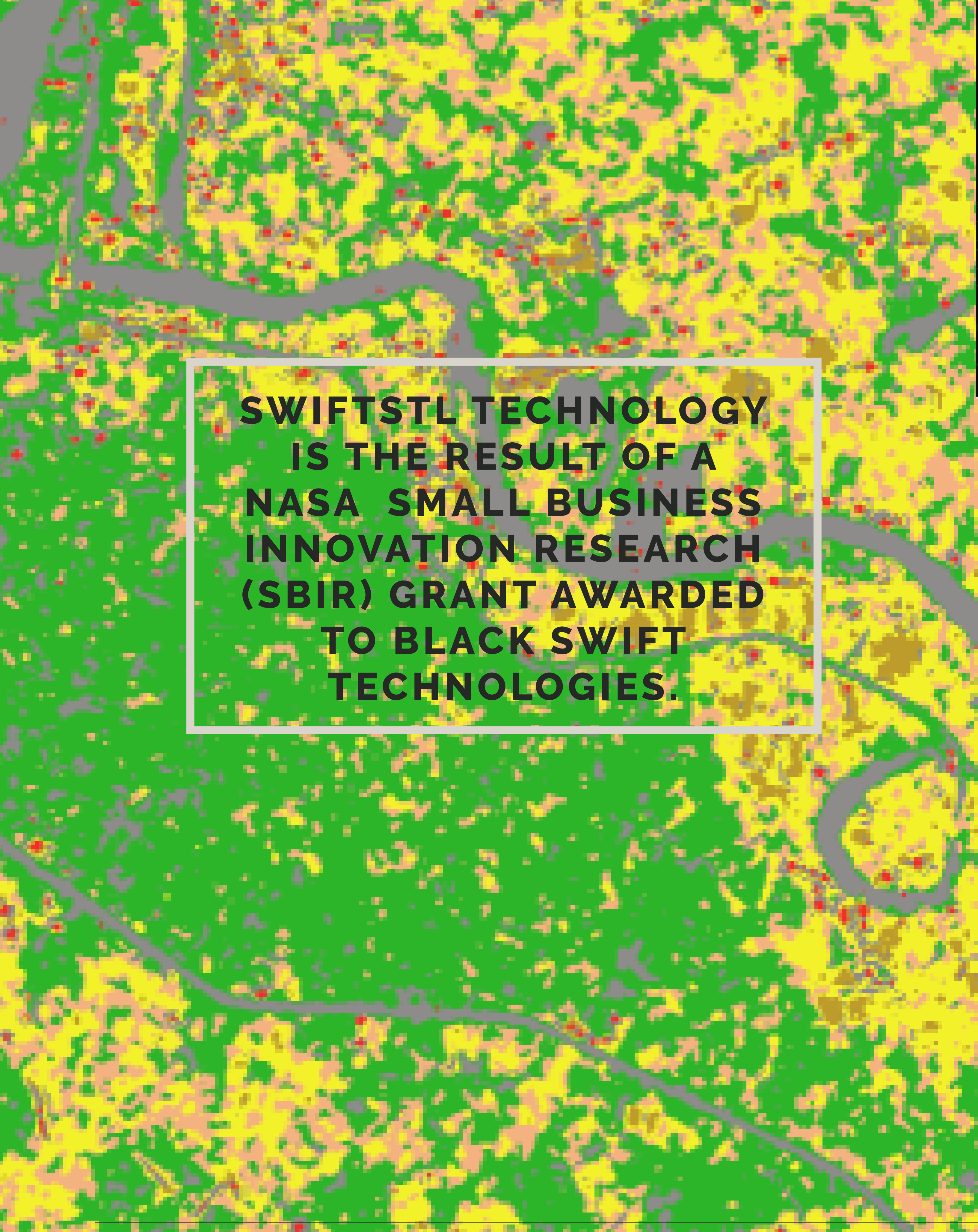
SEMANTIC SEGMENTATION

SwiftSTL gives the UAS a perception of the world around it in order to make critical decisions in real-time.

SwiftSTL gives the UAS a perception of the world around it in order to make critical decisions in real-time. This solution processes large amounts of data quickly and efficiently to enable the identification of objects and terrain to be avoided in order to land the aircraft without causing detrimental impact to people or property.

Figure 1: Processed hazards and safe landing areas identified with landing site selection

> *"SwiftSTL builds upon algorithms that are used widely for self-driving cars, which encounter a similar type of problem."*
>
> Austin Anderson, Machine Learning Lead Engineer, BST



SWIFTSTL TECHNOLOGY IS THE RESULT OF A NASA SMALL BUSINESS INNOVATION RESEARCH (SBIR) GRANT AWARDED TO BLACK SWIFT TECHNOLOGIES.

OTHER APPLICATIONS

While the goal behind SwiftSTL is to make it safe to autonomously land a UAS in distress, the technology is certainly not limited to only that functionality. Object recognition technology can also be used for real-time asset tracking and counting. Equipment managers can now more easily identify and track equipment stored or deployed on diverse sites accurately and effectively. SwiftSTL technology can also help firefighters quickly and efficiently identify and categorize wildfires, feeding information directly to ground crews. Semantic segmentation can also enhance navigation in GPS-denied or -limited environments. Being able to automatically identify roads and use that information as a reduced data product for more reliable navigation without GPS is another avenue being explored.

The technology behind SwiftSTL functionality also extends beyond aerial applications. Firms conducting underwater infrastructure inspections could send a submersible or remotely operated vehicle (ROV) down to inspect pipelines on the seafloor and assess the condition or deterioration of those assets in real-time. This technology could also automatically detect cracks or leaks in a pipe,and not only confirm the existence of the crack or leak, but identify and record its exact location on the pipe and the seafloor.

While many find value in the real-time aspect of SwiftSTL's autonomous system, there is also tremendous potential to use post-processing software to gain valuable insights from the data collected. One example might be a marine biologist tasked with counting seals as part of a population study. They don't need to count the number of seals present as their images are captured, but they need to accurately identify and assess the number of seals present in a specific location after the fact. An asset manager could use a similar approach to quantify the number of tractor trailers or pipe sections in their yard. Post-capture processing software can be used to accurately make these counts after the data is collected.

SwiftSTL technology could enhance all of these different scenarios with a unified system that can positively impact multiple industries and consumers based on how it is deployed.

SUMMARY

Machine vision, implemented with semantic segmentation on a small form factor hardware platform, allows computer systems to perceive and understand the world around them to make real-time operational decisions.

By leveraging machine learning, SwiftSTL technology can process large amounts of data quickly and efficiently to enable the identification of objects and terrain to be avoided in order to safely land a UAS in the event of engine failure or similar onboard catastrophe. It can also serve as a catalyst for accelerating UAS growth and adoption industry-wide.

"Our technology is intended to help enable a safer flight experience both for UAS operators and the general public," states Jack Elston, Ph.D., CEO, Black Swift Technologies. "All the data products that we'd be accessing are going to be common across any autopilot. We don't want to give too much decision making data to the autopilot— just enough to know what to avoid and where to safely land."

BLACK SWIFT S2 UAS

PAYLOAD-CENTRIC

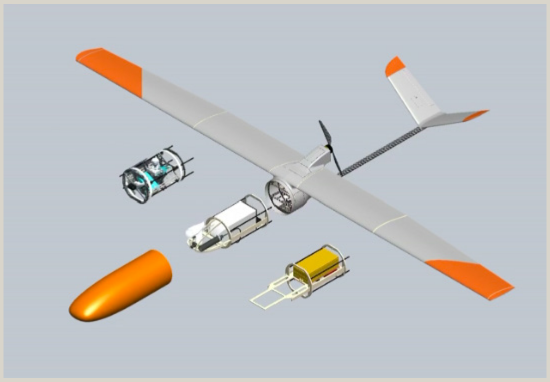
THE S2 WAS DESIGNED AROUND THE PAYLOAD. THE NOSE CONE CONTAINS A LARGE VOLUME TO EASILY INTEGRATE NEW SYSTEMS AND ALLOW EASY ACCESS IN THE FIELD.

The S2 is capable of conducting fully autonomous flights in unimproved areas. Take-off is fully autonomous and the advanced landing algorithm provides for robust and precise autonomous belly landings utilizing the laser landing system. The S2 has a high operational ceiling, and has been designed for altitudes up to 20,000 ft for NASA science missions. It has primarily been employed for complex science missions, but the overall system will perform well in surveying work, land management, crop damage assessment, and large area ecological studies. The specifications of the S2 are listed in the table below.

Specifications

Mission Capabilities	
Ingress Protection (IP)	IP42
Payload Wieght vs Launch	1.4 kg (3 lbs) hand launch 2.3 kg (5 lb) rail launch
Flight Ceiling	6000 m (20,000 ft)
Max. Winds Endured	15 m/s (30 kts)
Flight Characteristic (6,000 ft density alt)	
Flight Speed	12 m/s (24 kts) stall, 18 m/s (35 kts) cruise
Flight Time	110 min max, 90 min nominal
Range	110 km (60 nm) max, 92 km (50 nm) nominal
Vehicle Characteristic	
Weight	5.2 kg (11.5 lbs) nomoinal, 6.6 kg (14.5 lbs) max
Wingspan	3.0 m (10.0 ft)
Payload Capacities	
Nose Cone Dimensions	20.3 cm (8 in) diameter 63.2 cm (24.9 in) length
Power available for payload	50 W total
Payload weight	2.3 kg (5 lbs) max w/ rail launch
Geotagging Position Accuracy	Typically < 4m in all directions
Telemetry Data Rate	Serial Stream, 9500 bps

The S2 is an aircraft system that was designed around the payload. The nose cone contains a large volume to easily integrate new systems and allow easy access in the field. A standard data and power interface makes the different payloads field-swappable, allowing for spare aircraft without the need for purchasing extra payloads, which can be quite expensive. It is actively being flown for four major scientific field campaigns in both atmospheric science and remote sensing.



S2's Modular Field-Swappable Payload System

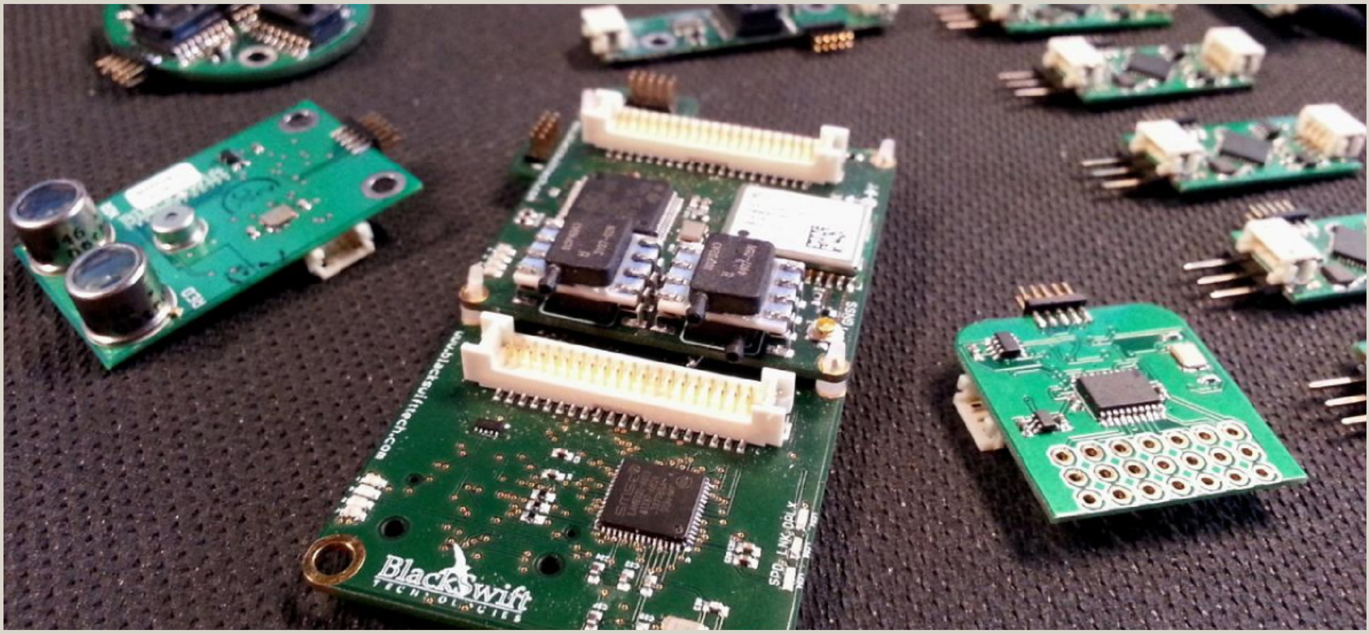
The S2 utilizes the SwiftCore™ Flight Management System, comprised of the SwiftPilot, SwiftStation, and SwiftTab user interface, along with support electronics. The entire system is designed for ease of use along with accurate flight tracking, even in high winds. The SwiftCore is designed by BST and is entirely made in the USA. The SwiftCore has been approved and used for major scientific missions by NASA, deployments by NOAA, and by a growing list of commercial companies.

The Black Swift S2, has been employed in a wide variety of atmospheric research application areas including:

- High-altitude, high-latitude atmospheric research studies in Greenland operating in temperatures near -20°C at altitudes up to 14,000 feet analyzing water vapor above the ice sheet to better understand how climate conditions are impacting Greenland's atmosphere.
- Nighttime in situ measurements of wildfire plumes and remote measurements of wildfire properties utilizing multiple sensors capable of research-quality measurements of CO_2, CO, aerosol, RH, p, and T found in the wildfire plumes, while also providing multispectral high-resolution maps of wildfires, advancing fire weather modeling and forecasting.
- Volcano plume monitoring with sensors specifically designed to measure selected gases and a nephelometer to assess volcanic particle size and distribution, as well as atmospheric probes to analyze pressure, temperature, humidity, and three-dimensional wind patterns, in order to improve air traffic management systems and the accuracy of ashfall measurements.
- Soil moisture mapping (up to 600 acres per flight) using multiple sensors including an L-band radiometer capable of measuring soil moisture content up to 10 cm below the ground, even under dense canopy crops.
- Airborne CO_2 monitoring in volcanic regions to measure CO_2 and plant response around volcanoes in order to understand the ecosystem response in the tropics, the lungs of the planet.
- Using a multispectral camera array for Landsat-8 OLI, and S-NPP VIIRS instrument calibration with NASA's Goddard Space Flight Center.
- Airborne measurements of carbon dioxide (CO_2), sulfur dioxide (SO_2), methane (CH_4), and hydrogen sulfide (H_2S), as well as generation of orthomosaic, thermal and 3D data products.. Resulting data will help NASA/JPL to better understand how volcanoes work, and improve volcano eruption planning and warning capabilities.
- Using P-band reflective signals to measure SWE (Snow Water Equivalent) in mountainous environments from an unmanned aerial platform.
- Integration of a thermal and hyperspectral payload for use in coastline monitoring.

SWIFTCORE AVIONICS

END-TO-END AVIONICS LETTING YOU CONTROL, COMMUNICATE AND COMMAND YOUR UAS FOR FULLY AUTONOMOUS FLIGHT



SwiftPilot™

SwiftPilot is an advanced high-performance autopilot system designed specifically for Unmanned Aerial System (UAS). Enables fully autonomous flight from launch to landing.

- One of the smallest and most powerful autopilots commercially available
- Two dedicated 168 Mhz Cortex-M4 CPUs with FPU for autonomous sUAS functionality (core processors) and one (optional) 1 GHz Cortex-A8 processor (payload processor) for customer use
- Modularized CAN-bus hardware architecture, enabling virtually an unlimited number of connectivity options for peripherals/payloads (UART, I2C, SPI, CAN, Ethernet, USB, GPIO, etc.

SwiftTab™

With its intuitive user-focused interface, SwiftTab enables flight planning that is both simple and easy to accomplish. Operators can program their BST UAS in minutes to calculate the area under review and then begin collecting data for immediate analysis and decision-making.

- Runs on a handheld Android™ Tablet as well as Android-based smart phones
- Flight plans can be modified and uploaded mid-flight
- Easily import maps and other geo-referenced data points
- Gesture-based controls enable users to confidently deploy their UAS with minimal training

SwiftStation™

SwiftStation is a tripod-mounted, intuitive ground station that is both highly portable and customizable to support application-specific sensor integrations.

- Incorporates both a 900MHz and a GPS antenna
- Expandable functionality via custom modules
- Multiple radio options available based on customer's specific requirements
- Seamlessly integrates with X-Plane Pro Flight Simulator

ABOUT BLACK SWIFT TECHNOLOGIES

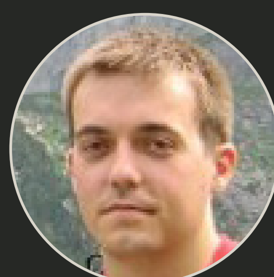
SINCE 2011

Black Swift Technologies (BST) is based in Boulder, CO and has been in operation since 2011. BST is unique is than all UAS sold by BST are built upon it's own SwiftCore^{TM} flight management system (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.

JACK ELSTON

CEO

Dr. Elston received his Ph.D. from the University of Colorado Boulder based on work that developed a complex meshed network, unmanned aircraft system, and control algorithms for in situ sampling of tornadic supercell thunderstorms. Dr. Elston is also the technical lead on all avionics work at BST including the creation of the highly capable autopilot system that anchors the SwiftCore Flight Management System.



MACIEJ STACHURA

CTO

Dr. Stachura received his M.S. and Ph.D., both in aerospace engineering, from the University of Colorado Boulder. During his time at CU, Dr. Stachura was involved in over 300 fight experiments ranging from multi-aircraft cooperative flight experiments to the VORTEX2 field campaign, which involved the first-ever intercept of a tornadic supercell thunderstorm.

Black Swift Technologies

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