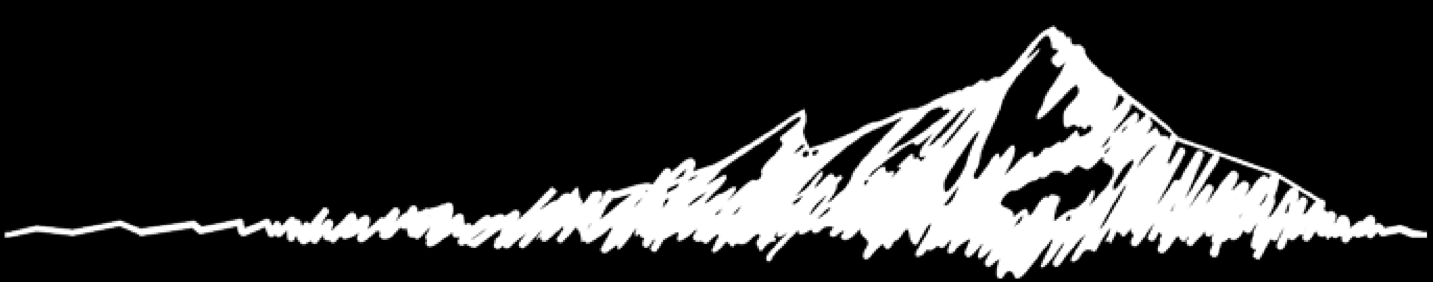
BlackSwift TECHNOLOGIES

WHITE PAPER

SOIL MOISTURE MAPPING WITH UNMANNED AIRCRAFT SYSTEMS (UAS)

Designing an Advanced UAS for Environmental Monitoring



THE ISSUE AT HAND

Water is a critical resource, especially when it comes to the world's food supply. The ability to accurately and quickly map soil moisture on the scale of individual farms will go a long way to conserving this precious resource. NASA's Soil Moisture Active Passive (SMAP) mission uses satellite technology to monitor drought, predict flooding, and assist in crop productivity. However, the nuances of the Earth's surface can easily be missed by satellite. Obtaining high resolution data in addition to the satellite images would greatly improve NASA's ability to track soil moisture along with providing valuable data to tomorrow's growers.

Beyond satellite calibration, several disciplines including agriculture, land management, emergency management, and military planning can benefit from the ability to determine the soil moisture content at high resolution. When provided with timely and accurate information, water is conserved and crop health is improved, land is more effectively used, and crises such as flash floods can be more accurately predicted and their effects mitigated. Current remote sensing methods for sampling soil moisture often fail to provide measurements with adequate spatial and temporal resolution, or any indication of moisture content at typical root depths.

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INTRODUCTION

Black Swift Technologies (BST), a specialized engineering firm located in Boulder, Colorado, and the Center for Environmental Technology (CET) have developed an unmanned aircraft system (UAS) with a unique sensor payload designed to provide both spatial and temporal resolution to diagnose problems and get a better understanding of the dynamics of soil drainage and moisture retention at typical root depths. Key to the demonstrated effectiveness of this technology is a unique L-band radiometer developed and tested under NASA's Small Business Innovation Research (SBIR) program. Using the soil moisture mapping UAS, scientists, agronomists, crop consultants, and farmers alike can gather low altitude measurements from the on-board passive microwave radiometer with a higher revisit frequency. This can greatly improve satellite calibration by providing localized, high resolution data of areas of interest, even under dense canopy crops.

BST has been working with several agriculture research groups at the University level along with commercial entities to look into utilizing this unique data to reduce water usage on farms. Two years of flight campaigns have been conducted at a precision agriculture research site with flights of the instrument over various crop types throughout the growing season. This technology is a key attribute for complete systems that take advantage of variable rate irrigation to reduce water usage.

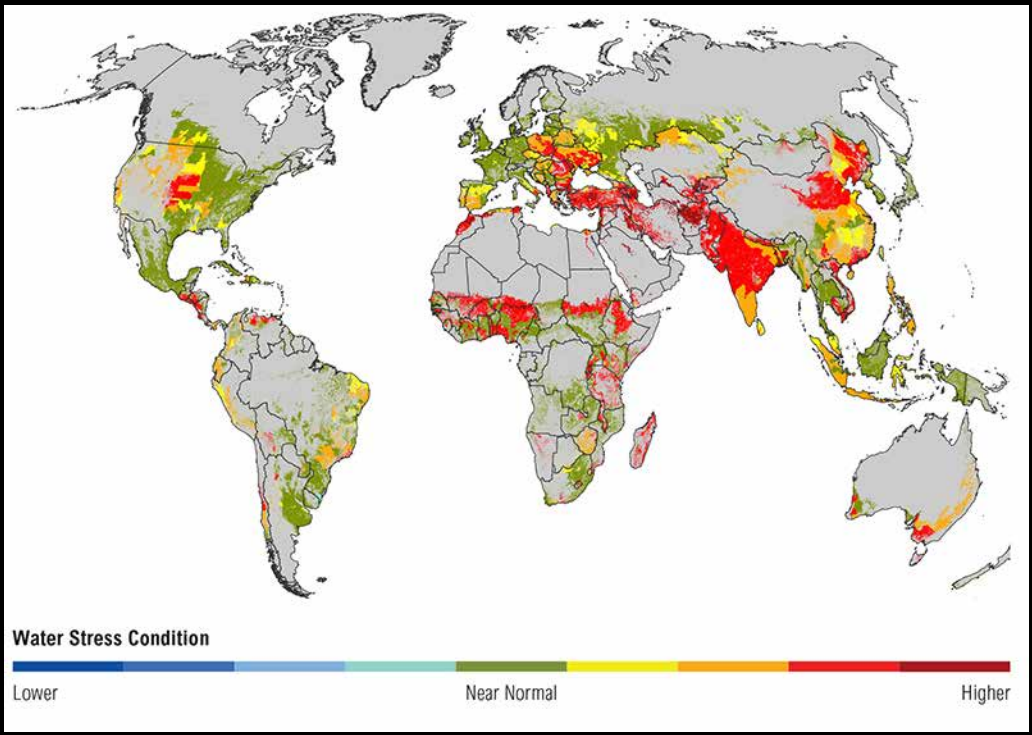
The soil moisture mapping UAS provides a novel platform for conducting Earth science research. This purpose-built system is capable of mapping soil moisture content at critical depths in a low cost, easy to operate package.

BACKGROUND

MAPPING OUR RESOURCES

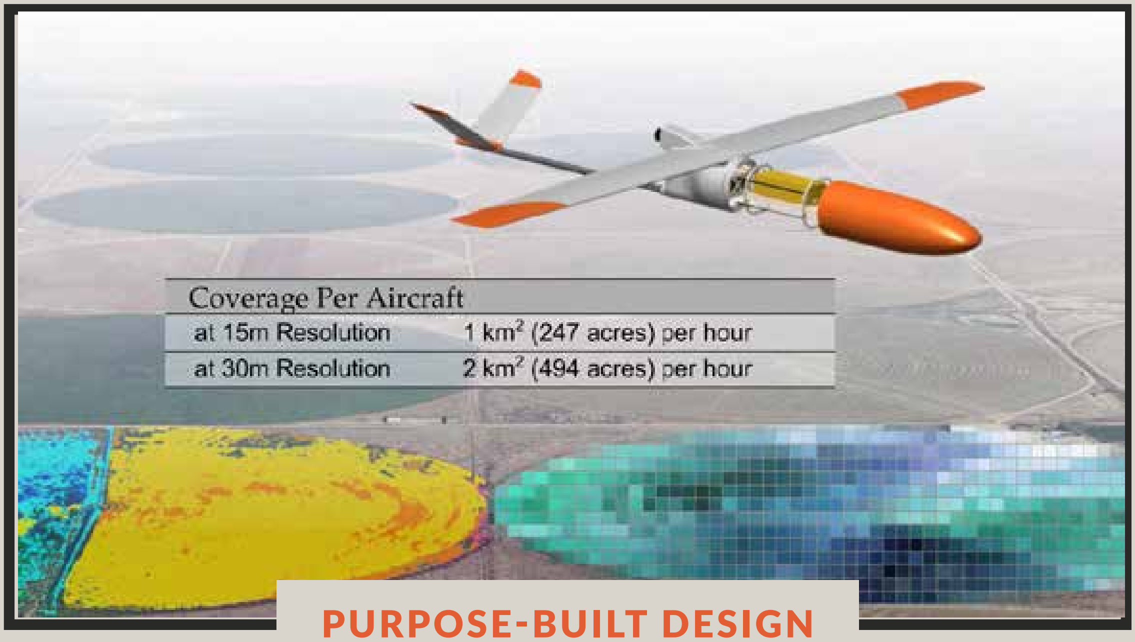
WATER IS A CRITICAL RESOURCE, ESPECIALLY WHEN IT COMES TO THE WORLD'S FOOD SUPPLY.

According to the World Resources Institute, water stress will increase in many agricultural areas by 2025 due to growing water use and higher temperatures.



Source: World Resources Institute (http://ow.ly/rpfMN

Beyond satellite calibration, several disciplines including agriculture, land management, emergency management, and military planning can benefit from the ability to determine the soil moisture content at high resolution. When provided with timely and accurate information, water is conserved and crop health is improved, land is more effectively used, and crises such as flash floods can be more accurately predicted and their effects mitigated. Current remote sensing methods for sampling soil moisture often fail to provide measurements with adequate spatial and temporal resolution, or any indication of moisture content at typical root depths.



PURPOSE-BUILT DESIGN

BST's soil moisture UAS solution consists of the Black Swift S2™ airframe, avionics, radiometer, and supporting sensors specifically designed for the task of accurately measuring soil moisture content, even under dense canopy crops. The primary instrument is a passive microwave radiometer that provides full coverage soil moisture measurements over an area of up to 600 acres per flight. Tight integration of the sensor with the avionics and airframe will enable precise flight control for low altitude missions in the range of 15m-30m above ground level (AGL) required for the sensor to accurately map soil moisture down to 5cm in depth at up to a 15m resolution.

At the core of the system is the S2 airframe and SwiftCore flight management system. The pair provides a highly capable UAS platform specifically designed to accommodate the next generation of scientific payloads. It has passed NASA's rigorous flight safety review, and contains a level of autonomy and redundancy to ensure data collection can be done routinely and safely. The aircraft limits electromagnetic interference from sub-systems and is capable of low altitude, terrain following flight. In addition, the S2 is designed around a modular architecture, allowing rapid development to accommodate new instruments with the aircraft. Through this innovation, BST is able to rapidly develop solutions to meet the needs of the data gathering mission and each customer's unique requirements.

BST HAS BEEN WORKING WITH SEVERAL AGRICULTURE RESEARCH GROUPS AT THE UNIVERSITY LEVEL ALONG WITH COMMERCIAL ENTITIES TO LOOK INTO UTILIZING THIS UNIQUE DATA TO REDUCE WATER USAGE ON FARMS.

THE SOIL MOISTURE MAPPING UAS PROVIDES A NOVEL PLATFORM FOR CONDUCTING EARTH SCIENCE RESEARCH. This system is capable of mapping soil moisture content at critical depths in a low cost, easy to operate package.

01

BST has been working with several agriculture research groups at the University level along with commercial entities to look into utilizing this unique data to reduce water usage on farms. Two years of flight campaigns have been conducted at a precision agriculture research site with flights of the instrument over various crop types throughout the growing season. This technology is a key attribute for complete systems that take advantage of variable rate irrigation to reduce water usage. It can be further expanded to the application of nutrients and result in lowering the amount of fertilizer used based on the exact water content of the soil which will reduce the ecological effects of fertilizer runoff.

02

The soil moisture mapping UAS provides a novel platform for conducting Earth science research. This system is capable of mapping soil moisture content at critical depths in a low cost, easy to operate package. It can be employed by current NASA projects to provide valuable localized high resolution data to compare with satellites such as the AMSR-E radiometers mounted on the EOS Aqua satellite and the radiometers specified for the HYDROS mission. Beyond NASA projects, its unique capabilities can also potentially benefit other federal agencies such as agricultural extension service offices, who can deploy the system to provide farmers with data that can improve the productivity of their crops.

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The system will also have the ability to support FEMA in better understanding flash flood vulnerability. This utility was demonstrated in 2007 where CET led a NASA funded research effort to map soil moisture in a region of North Texas and Oklahoma that suffered from severe flooding. This data was used to provide alerts and warnings to areas susceptible to flash flooding. The S2 UAS could provide this data at a fraction of the cost and thus improve predictions for flooding events in vulnerable watersheds around the country.

Providing information on vegetation density and soil moisture has a potentially powerful application in support of state and federal agencies seeking to understand, monitor, and fight wildfires. As the soil moisture mapping UAS matures this technology will benefit forecasting for wildfires.

UNDERSTANDING SOIL INTEGRITY

THE MEASUREMENT OF SOIL MOISTURE IS A KEY VARIABLE TO UNDERSTANDING AND MAPPING SOIL INTEGRITY. AS SOIL MOISTURE INCREASES, THE SOIL INCREASES IN SLIPPERINESS AND STICKINESS WHILE DECREASING IN STRENGTH.

The ability to asses soil integrity is currently hindered by a dearth of high spatial resolution data, with scales usually on the order of kilometers. The S2 with its soil moisture mapping payload can provide up to 15m resolution data.

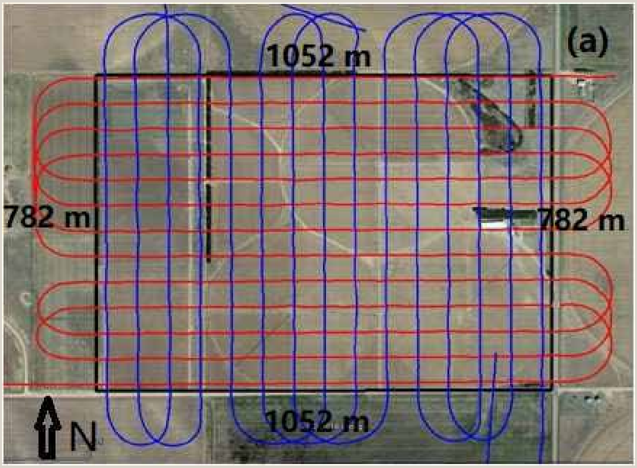
The measurement of soil moisture is also a key variable to understanding and mapping soil integrity. As soil moisture increases, the soil increases in slipperiness and stickiness while decreasing in strength. One particular consumer of this information, the Army Corps of Engineers currently makes use of soil moisture information to assess soil conditions for heavy vehicle tracking and aircraft landing operations. The distribution of moisture within a soil determines the traffic that can be supported on the land surface. For off-road movement there is a specific maximum loading that soil can support. The strength of a soil is determined by soil type and soil moisture and can be used to determine the load.

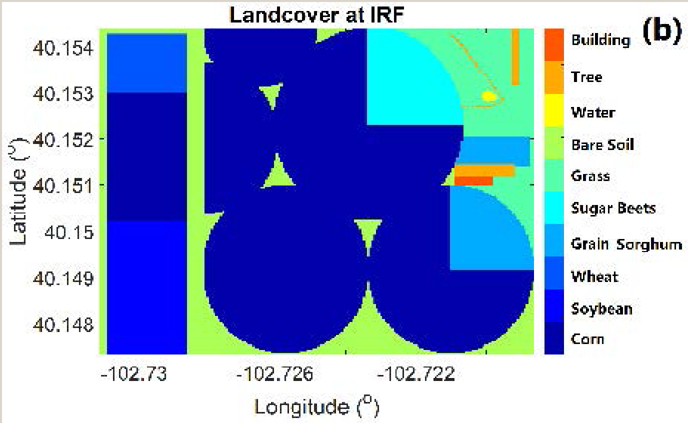
The S2 with its soil moisture mapping payload can provide up to 15m resolution data, allowing for the models to make use of data on a per vehicle scale. Additionally, the low latency determination of the ability of the soil to support the movement of a vehicle directly will greatly enhance the ability of the armed forces to operate in potentially unstable areas such as terrain in and around rivers, wetlands and coastal regions as well as in regions that are susceptible to thunderstorms and heavy precipitation.

DELIVERING ACTIONABLE DATA

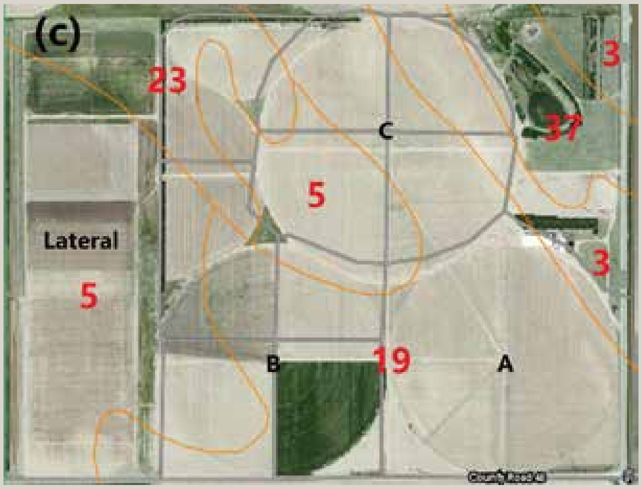
Provides both spatial and temporal resolution to diagnose problems and get a better understanding of the dynamics of soil drainage and moisture retention at typical root depths.

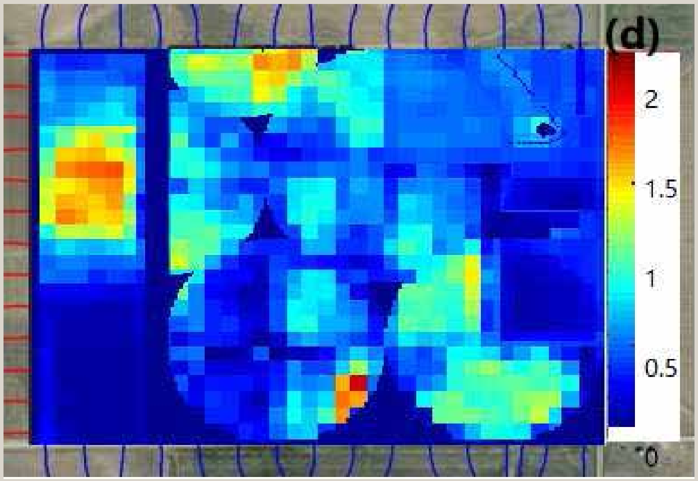
The S2 can map over 600 acres per flight. Flights with this specialized payload have been conducted by Colorado University at Boulder over a number of test sites including the Canton, Oklahoma Soilscape Site, and the Irrigation Research Foundation (IRF) in Yuma, Colorado. Preliminary results of these missions correlate with in situ probes, as well as a strong correlation for different soil types further validating this unique UAS solution.





Maps generated from an actual flight of the S2 equipped with soil moisture mapping sensor suite. (a) Flight trajectories, (b) land convert type, (c) soil type, and (d) volumetric water content (VWC).





BLACK SWIFT S2 UAS

PAYLOAD-CENTRIC

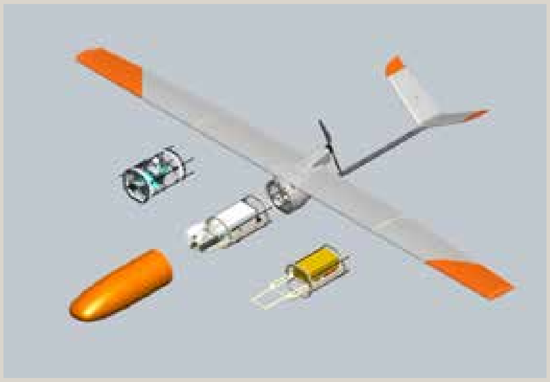
THE S2 WAS DESIGNED AROUND THE PAYLOAD. THE NOSE CONE CONTAINS A LARGE VOLUME TO EASILY INTEGRATE NEW SYSTEMS AND ALLOW EASY ACCESS IN THE FIELD.

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 CO2, 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 CO2 monitoring in volcanic regions to measure CO2 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 (CO2), sulfur dioxide (SO2), methane (CH4), and hydrogen sulfide (H2S), 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

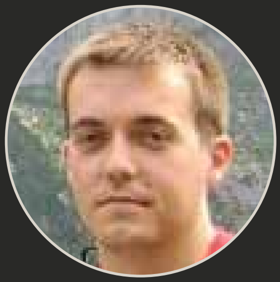
SINCE 2011

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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