Bluefin Spray Glider

Technical Information Document

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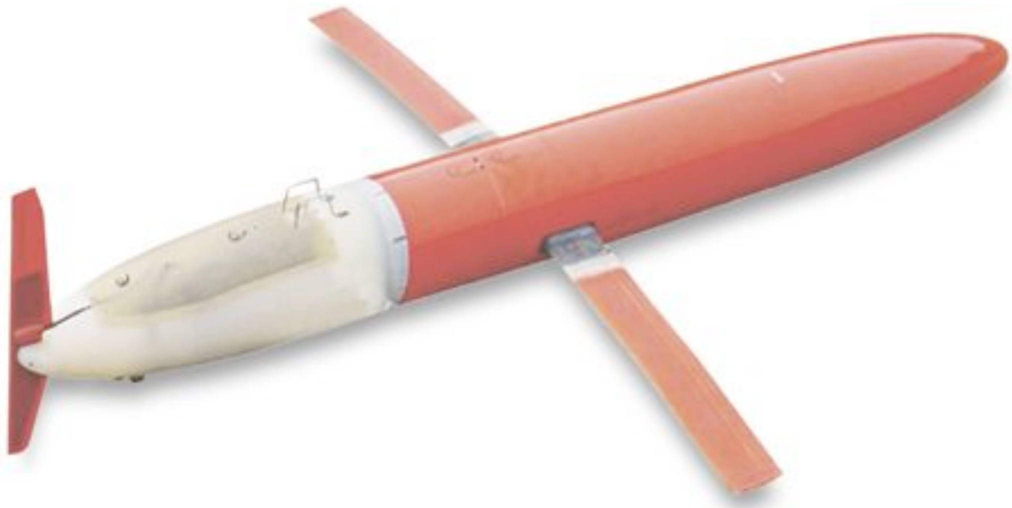

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1. Introduction

The Bluefin Spray Glider is a small autonomous underwater vehicle (AUV) designed to enable extended-endurance missions. The lightweight Spray Glider operates unlike traditional AUVs. Instead of using its power supply to drive propellers, the Spray uses its power to change its buoyancy, using a hydraulic pump, enabling it to glide forward in an up-and-down sawtooth pattern. One or more Spray vehicles can autonomously profile a specified region of the ocean over individual deployment periods of as long as six months.

The Spray Glider technology was developed at Scripps Institution of Oceanography under Dr. Russ Davis, with funding provided by the Office of Naval Research. In 2004, Bluefin licensed the design and production rights for the Spray Glider from Scripps and established the first commercial glider production line. Since licensing the technology, Bluefin has continued to leverage its experience in underwater vehicle design and manufacturing to achieve improvements and efficiencies in the Spray design and its production.

2. Vehicle Architecture

In its standard configuration, the Bluefin Spray Glider (Figure 1) includes a pumped oceanographic-grade conductivity-temperature-depth (CTD) sensor, and it can accommodate a variety of other optional oceanographic sensors for water profiling. The Spray uses the principles of buoyancy to drive its motion. The glider autonomously manipulates its buoyancy characteristics by transferring hydraulic fluid between its pressure hull and the free-flooded sensor bay. The variable ballast system was designed to provide up to 400g of positive or negative buoyancy submerged. The vertical buoyancy is transferred into horizontal motion using a pair of wings. Pitch and roll packs adjust glider pitch when submerged and, when at the surface, elevate one of the wings with embedded GPS and Iridium antennas out of the water to enable the vehicle to establish a link. The vehicle's high-energy-density lithium batteries (13MJ) are integrated with the pitch and roll packs to provide additional mass for responsive maneuvering.

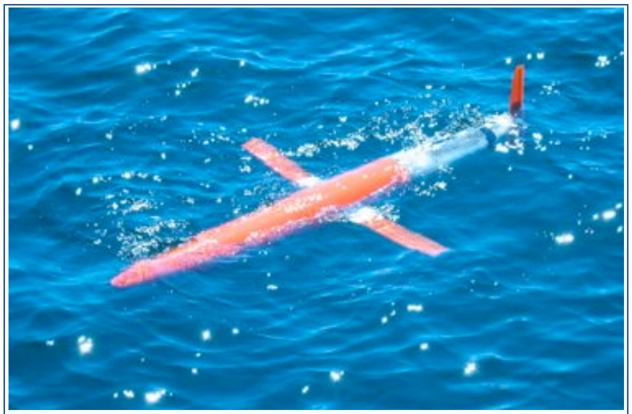

Figure 1. Bluefin's Spray Glider engaged in at-sea operations.

The Spray Glider is designed to support both deep and shallow water operations. It can operate in depths of up to 1000 meters, with a maximum survivable depth of 1500 meters. The Spray can achieve greater than 35 cm/sec of horizontal velocity over a range of buoyancies and glide angles (e.g., 35 cm/sec with a 19-degree glide angle and 300g buoyancy, or with a 25-degree dive angle and 235g buoyancy). It can reach full speed within 9 meters of leaving the surface or commencing an ascent. The operational endurance of the vehicle is highly dependent on the configuration and mission profile, but the vehicle enables durations exceeding six months in its standard configuration.

A simple, menu-driven software tool enables the creation of Spray mission plans. This tool allows the user to input select parameters to build a mission profile, including geographic waypoints that the Spray autonomously navigates by using GPS fixes. As it travels between the designated waypoints, the Spray automatically takes measurements from each sensor and records them to a data logger for later data analysis, or for transmission following each dive.

2.1 Structure

The Spray's pressure housing is an aluminum cylinder, which houses the internal chassis and all of the vehicle's internal sensors, batteries, electronics and hydraulics (Figure 2). The vehicle was designed with a free-flooded sensor bay and adjustable ballast to accommodate payload modifications without impacting the physical glider or the overall fore-and-aft ballasting. Connections to external devices – such as the CTD, external bladders, and burn wire – are made through a bulkhead penetrator connection.

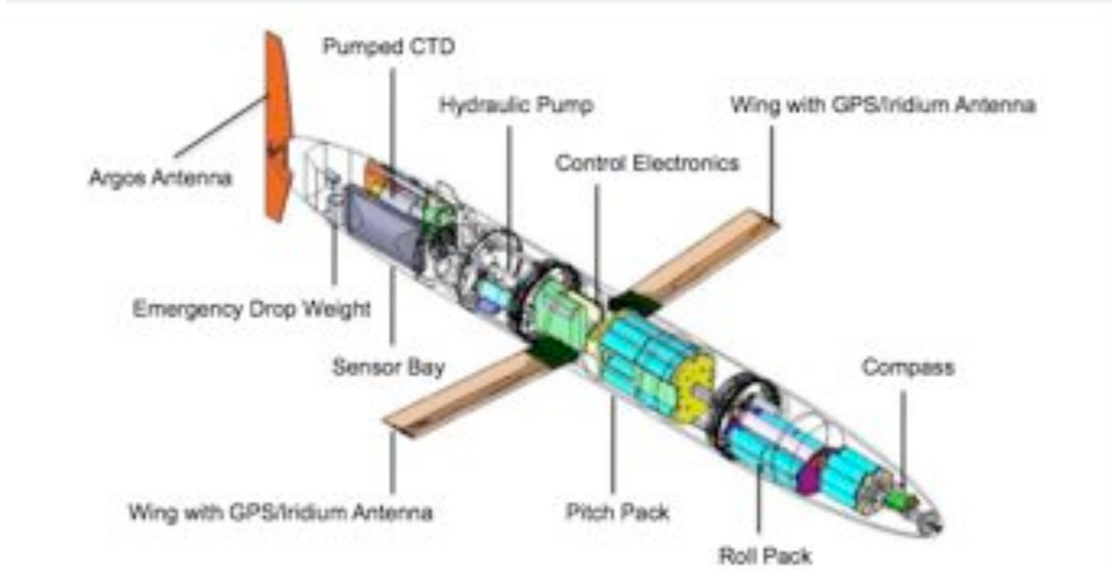

Figure 2. Bluefin Spray Glider vehicle anatomy.

An integrated GPS and Iridium antenna is installed in each of the vehicle's wings. The wings are bolted onto the pressure housing at mounting holes in the side of the housing and use a bore seal O-ring to provide a sealed volume inside the pressure housing. Antenna cables are passed through the mounting holes within the circumference of the bore seal. The vehicle's wings provide stability during the glide, and work to change heading during a roll.

2.2 Energy

The Spray Glider is fitted with three internal battery packs, composed of lithium sulfuryl chloride cells. One of the battery packs is mounted at the forward end of the internal chassis in a fixed position in order to contribute to trim and ballast in the vehicle's final ballast configuration. A second battery pack, the roll pack, is fixed to the central tube of the chassis just behind the forward pack. This pack is rotated around the central tube in order to roll the vehicle while it is in the water. At the level-roll position, the roll battery packs hang below the central tube to provide stable and level flight, as well as proper vehicle orientation. A third battery pack, the pitch pack, is fixed to the central tube of the chassis behind the roll pack. This pack is transitioned along the central tube by a motor (separate from the roll motor) in order to change the vehicle's pitch while it is in the water.

2.3 Propulsion

The Spray Glider relies on buoyancy for propulsion through the water. Its buoyancy engine is composed of the hydraulic system and the internal and external oil bladders. These components control the propulsion of the vehicle through changes in the vehicle's buoyancy, while the pitch and roll battery packs control the vehicle's forward motion, depth, heading and glide angle. At the start of a dive cycle, when the Spray is at the surface, the external bladders are full. When the vehicle is ready to dive, a valve is opened, resulting in the Spray's internal vacuum drawing in all of the oil from the external bladders. The empty bladders cause the vehicle to attain negative buoyancy. This, coupled with a forward position of the pitch battery pack, causes the vehicle to sink and pitch down, resulting in a forward diving motion. When the vehicle reaches the desired depth, the pump turns on and reverses the process, which causes the vehicle to pitch up and ascend. The pump runs until the vehicle obtains the correct vertical velocity for its ascent, as measured by changes in depth (pressure).

2.4 Communications

Satellite communications are used to provide data connectivity between the operator's computer and the glider – both for download of commands to the glider from the operator's computer and to upload glider data at the end of each dive. Integrated into each Spray is an Iridium Subscriber Unit (ISU) and SIM card that is unique to each customer and vehicle. The SIM card includes both a physical entity and a license; customers are responsible for purchasing their own SIM card. If Bluefin receives the SIM card two months before vehicle at-sea testing, Bluefin will install the card prior to shipment. The Spray is currently configured for Iridium Short Burst Data (SBD), a service that provides two-way transmission of small quantities of data in a message format.

Figure 3. The Spray Glider inducing a roll to lift its wing out of the water to obtain a GPS fix.

During operations, Iridium messages are sent and received following the reception of a GPS fix, both at the beginning of the mission and during each surfacing. This is accomplished by inducing a roll, which lifts the wing with the embedded antenna out of the water (Figure 3). Messages that are sent during the Iridium uplink time contain averaged points of data from the sensors to provide the vehicle's status, progress, and a condensed version of the acquired data. The SBD services transmit data at rates of 1960 bytes/message inbound and 1850 bytes/message outbound, which results in a data transfer rate of approximately 300 bytes/second.

If greater data throughput is desired, the existing hardware can be reconfigured to use the Iridium Router-based Unrestricted Digital Inter-working Connectivity Solution (RUDICS) data transfer capability. While similar to SBD in data transfer rate, RUDICS provides for lower-cost data transmission in larger quantities.

2.5 Navigation and Control

The Spray Glider has an integrated navigation system consisting of a GPS receiver, digital compass and an optional altimeter for those vehicles requiring seafloor avoidance in near-bottom operations. The standard Spray Glider uses a three-dimensional compass to provide heading, pitch, and roll data for navigation. Heading data is used to determine the direction to steer toward the next waypoint, and pitch and roll data are used for measuring pitch angles during descent and ascent, and for control of the steerage (roll) onto a heading.

Along with depth, glide angle, and timing considerations, a Spray Glider mission is composed of a route defined by a number of waypoints, as well as instructions on what to do when the route has been completed. The user specifies the number of waypoints in the route, as well as the latitude and longitude for each waypoint. The route is then created by defining the order in which the waypoints are to be visited. During the mission, the vehicle proceeds through the route by transiting to the next waypoint on the route, assessing whether or not it has reached the waypoint by obtaining a GPS fix when it surfaces.

If, during the course of the mission, it is determined that the vehicle mission needs to be changed, the waypoints can be updated from shore via Iridium SBD messages. At the end of the mission, the glider can be located by its GPS position, or a radio direction finder (RDF) signal (detailed further below) can be set off to pinpoint the exact location for recovery via a small boat or shipboard launch and recovery system.

2.6 Vehicle Safety Systems

Bluefin's Spray Glider has an integrated emergency system in the event of a malfunction, including a drop weight that can be released, allowing the vehicle to resurface for recovery. Additionally, an Argos transmitter is integrated into the vehicle. The Argos system is intended for emergency vehicle location if the GPS and/or Iridium systems fail. Each time the vehicle surfaces from a dive, the Argos transmitter is turned on for a brief time, during which an Argos message containing rough position information is transmitted. In the event of a loss of GPS and/or Iridium, the Argos message provides an approximate position, at which point the signal can be used as a beacon to locate the exact position of the vehicle using RDF topside equipment on a nearby support vessel.

2.7 Software

The Spray Glider user interface and mission planning software is a simple, menu-driven tool. This Terminal Emulator Program, run from an operator's laptop computer, allows the user to input select parameters to build a mission profile and drive the Spray operations. Updates to the Spray software are provided as available for the complete warranty period.

The interface between the computer and the vehicle is established through an RS-232 serial connection over a shore communications cable. The Spray Glider interface is designed so that any terminal program can be used to access the serial port for communication. If a customer prefers to use their own mission planning tools, this approach enables an easy integration between the Spray and the customer's customized software.

The Terminal Emulator Program allows the operator to plan missions, check and set calibration constants, and control parameters. The program displays several types of data, such as:

- Mission profile data
- Sensor profile data
- Navigation data: waypoints, dives, heading, distance, etc.
- Engineering time-series data: descent speed, pressure, heading, pitch/roll angles, health of pitch/roll sensors
- Communication data
- Energy levels
- Vehicle state-of-health data

2.8 Payload Interface

The Spray Glider has been designed with a free-flooded sensor bay (Figure 4), which is reconfigurable to easily accommodate new sensors. The design allows the user to quickly swap different types of sensors between missions or replace individual sensors, if a sensor malfunctions, with no modification to the glider hardware or software.

Figure 4. The Spray Glider's free-flooded sensor bay.

The vehicle has two communications lines available for payload sensors, above and beyond the lines already being used for the core system components and the standard CTD sensor. If a dissolved oxygen sensor is desired, this does not require the use of one of the available lines – it can be linked directly into the line being used by the CTD. The remaining communications lines can be used for a variety of sensor combinations, depending on mission requirements. For missions requiring use of an altimeter, this hardware will use one of the available lines, still leaving room for another additional sensor.

Throughout the mission, all sensor data is stored on a 256MB compact flash drive onboard the vehicle. Averaged sensor data is transmitted when the vehicle surfaces at the end of each dive, and the complete data set can be downloaded directly from the vehicle upon recovery.

3. Performance

Shown in the table below are the specifications for a standard Bluefin Spray Glider. Parameters such as endurance and range are highly dependent on the configuration of the vehicle and mission profile, so average values for a vehicle in its standard configuration are shown.

Table 1. Bluefin Spray Glider Specifications.

Parameter	Specification
Diameter	20 cm (8 in.)
Length	200 cm (80 in.)
Wing Span	110 cm (44 in.)
In-Air Weight	52 kg (115 lbs)
Depth Range	0-1500m survivable, up to 1000m operating
Gliding Speed	Variable, 19-35 cm/sec typical
Endurance	> 6 months, payload and profile dependent
Range	> 4,800km, payload and profile dependent
GPS Accuracy	Better than 15m, 95% typical
Data Storage	256 MB

4. Payloads and Applications

The Spray Glider is designed for applications where longer endurance and/or range are crucial. The Spray can profile large regions of the ocean over a duration of approximately six months. Multiple Spray Gliders can be used in a coordinated fashion to provide ocean surveys that are wider ranging or of higher spatial resolution.

The standard payload on the Bluefin Spray Glider is a CTD sensor that is unique in that it is a pumped sensor. Pumping the seawater through the sensors helps combat biofouling, a problem common to warm water environments, and a crucial issue for long deployments. Bluefin is the only manufacturer who consistently uses a pumped CTD, providing a significant benefit over other glider systems. Additionally, the Spray is capable of being outfitted with a turbidity meter, fluorometer, and dissolved oxygen (DO) sensor, as well as an acoustic Doppler velocimeter.

5. Support Equipment and Services

A Bluefin Spray Glider can be accompanied by a variety of topside equipment and spares. Bluefin recommends a package of topside equipment and spares based on the particular customer's operational plan (e.g., number of vehicles to be operated from a single site) and usage rate. The topside equipment included in a standard Spray Glider package includes:

- Vehicle shipping case – aluminum case with custom-fit foam (Figure 5)
- Terminal Emulator Program for mission planning
- Argos topside shipboard equipment for RDF
- Shore communications cable
- Topside toolkit

Figure 5. The standard, aluminum shipping case.

Each Bluefin Spray Glider is covered by a one-year warranty, commencing at the time of system acceptance by the customer. The warranty guarantees that the product is free of defects in material and workmanship; it does not cover routine maintenance, adjustments or recalibration. During the warranty period, Bluefin provides support on as-needed basis, which includes:

- Free email and telephone technical support services
- Web-based software updates as available to ensure that the system performs as specified
- Web-portal access for status of service requests and feature requests
- A Bluefin support engineer on site (if requested) during operations, provided at the contract day rate plus travel, subsistence and other related expenses

Beyond the warranty period, Bluefin will provide service at the then-current prices for parts, labor and transportation. Detailed warranty terms and conditions will be provided with a formal quotation.

Bluefin typically provides three days of training on the Spray Glider for up to three people at the Bluefin factory and operational facilities. Training consists of classroom training, hands-on vehicle training, and at-sea training. On-site training can be provided at an additional cost.

6. Variations and Options

There are a variety of variations and options to the Bluefin Spray Glider that can be provided to customize the vehicle and tailor the support equipment to the customer's specific requirements. Some examples of the variations and options that are available for the Spray Glider, at additional cost, include:

- Iridium RUDICS communications
- Altimeter for near-bottom operations
- User-customized operator software
- Additional sensors beyond the CTD, either swappable or integrated for simultaneous use
- Customized shipping case
- Vehicle carts
- Launch and recovery equipment customized to the customer's operational plan (Figure 6)
- Spares (e.g., batteries, drop weights, boss plug)
- Training at the customer's facilities

Figure 6. While the Spray requires no specialized launch and recovery equipment, customized equipment can be tailored to customer needs.

In addition to the more straightforward variations, Bluefin has the capabilities and experience to perform more engineering-intensive vehicle modifications. Bluefin has a strong heritage in research and development of sophisticated underwater systems. Bluefin strives to achieve simple and robust solutions using advanced underwater engineering practice combined with off-the-shelf solutions to provide customers with efficient, reliable and rugged vehicles to meet their unique needs.

7. Price and Schedule

The price for a standard Bluefin Spray Glider package is $99,000. This price represents the vehicle in its standard configuration, as described throughout this document. This price includes:

- Bluefin Spray Glider with integrated CTD sensor
- Topside equipment (detailed in Section 5)
- One-year warranty
- 3 days of training for up to 3 people at Bluefin facilities

The cost for any variations or options to this standard package must be quoted on an individual basis.

The typical delivery time for a standard Bluefin Spray Glider is nine months. Bluefin can work with the customer to determine if a more rapid delivery schedule is possible when customer requirements demand it.