

MARINE TECHNOLOGY

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Thrusters

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ON THE COVER

The General Dynamics Mission Systems Bluefin™-9 autonomous unmanned underwater vehicle provides unmatched high-resolution data, leading navigation, data processing and mission turnaround time in a two-man portable UUV. Deployable from a RHIB, the Bluefin-9 can be launched, recovered, and re-launched within 30 minutes.

Photo credit: General Dynamics Mission Systems



Know What's Below: General Dynamics Mission Systems Bluefin Robotics®

Unveils the Bluefin™ - 9 UUV

General Dynamics Mission Systems has a history of success in the development and delivery of mission-critical solutions for the undersea domain. With Bluefin Robotics' legacy of design and developmental know-how and General Dynamics' extensive engineering reach and customer intimacy, a new generation of autonomous unmanned underwater vehicles (UUVs) was created to meet dynamic operational needs in challenging underwater environments. Most notably, General Dynamics is the systems integrator for the U.S. Navy's Knifefish Surface Mine Counter Measure program of record. A highly advanced derivative of our commercial Bluefin-21 medium-class UUV, Knifefish autonomously searches, detects, classifies, and identifies buried, bottom, and volume mines in high-clutter environments in a single pass.

General Dynamics believes in the quality of their products, which is why the company investment in the completely redesigned Bluefin-9 has yielded significant improvements to the design, production quality, modularity and reliability. The entire Bluefin Robotics product family upgrades results in UUVs with more mission capability and lower total cost of ownership. Using our expert engineering and manufacturing tradecraft, the Bluefin-9 has been purpose-built to provide capability that only larger UUVs could previously offer. Combining high navigational accuracy, outstanding sonar resolution, and a host of new on-board processing capabilities, the Bluefin-9 delivers operators highly detailed subsurface information in minutes rather than hours. The Bluefin-9 is the tool for defense, industrial, and academic applications that value data quality, reliability, and ease-of-use.

Systems Integration

General Dynamics Mission Systems specializes in systems integration. With data quality being of the utmost importance to UUV operators, it's necessary to evaluate the three main components that directly impact the ability to collect and process data. First are the sensors themselves. The Bluefin-9's sensors provide optimal data quality for the application. Then, to accurately place data in four dimensions, a highly accurate navigation and timing solution

is engineered. Finally, understanding that the observing platform must not move erratically or inconsistently, the Bluefin-9 employs dynamic control tuning that nullifies as much of that variation as possible. When these criteria are carefully followed, the Bluefin-9 delivers operators timely, relevant, and accurate data across a variety of mission domains.

Introducing the Bluefin-9

The Bluefin-9 is a two-man portable littoral survey vehicle weighing in at 155 pounds (70 kg) and measuring 95 inches (241 cm) long and operates at depths up to 200 meters. General Dynamics has built upon previous free-flooded designs by outfitting the Bluefin-9 with a full carbon fiber body, providing additional strength improvements and weight savings. The redesigned gimbaled thruster is able to drive the vehicle at maintained survey speeds of three knots and comfortably propel the vehicle at sustained speeds of six knots. The new 1.9 kWh field-replaceable Li-Ion rechargeable battery delivers up to eight hours of operation (two hours transit, six hours survey at three knots) and provides 33 percent more energy density for the same weight as its predecessor 1.5kWh battery. The oblong, small-class Bluefin-9 is 9.375" (23.8 cm) W x 10.375" (26.4 cm) H and offers increased stability in water over previous designs thanks to improved weight separation and innovative packaging. The coupling between the integrated Inertial Navigation System and the Doppler Velocity Log delivers navigation accuracy that easily meets 0.3% D.T. CEP 50 requirements.

The Bluefin-9 UUV can be rapidly deployed and recovered by two men at dockside, over the side of a rigid hull inflatable boat (RHIB), or from other vessels of opportunity.

After a mission, UUVs are full of data and out of energy. Before a UUV can be redeployed, its batteries must be changed or recharged and data offloaded. The new Removable Data Storage Module (RDSM) coupled with the removable battery means that the Bluefin-9 can be recovered and redeployed in 30 minutes or less to start another 8 hour mission. Using this approach, the Bluefin-9 achieves sustained area coverage rates that previously required op-

erators to endure timely recharging cycles or use costly multiple-vehicle solutions.

Highlighted Bluefin-9 Capabilities and Sensors:

- o Sonardyne Solstice Multi-Aperture Sonar (MAS): This high-resolution, interferometric side scan sonar was built for UUV integration and provides class-leading data in a low-power (18 Watts) solution. The Sonardyne Solstice outpaces current side scan sonars available for small-class UUV integration and delivers near-Synthetic Aperture Sonar (SAS) quality imagery and bathymetry across a 200 meter swath range. An impressive along-track resolution of 0.15 degrees Solstice integrated on the Bluefin-9 maximizes effective resolution, decreases false-positives, and improves operational efficiencies.

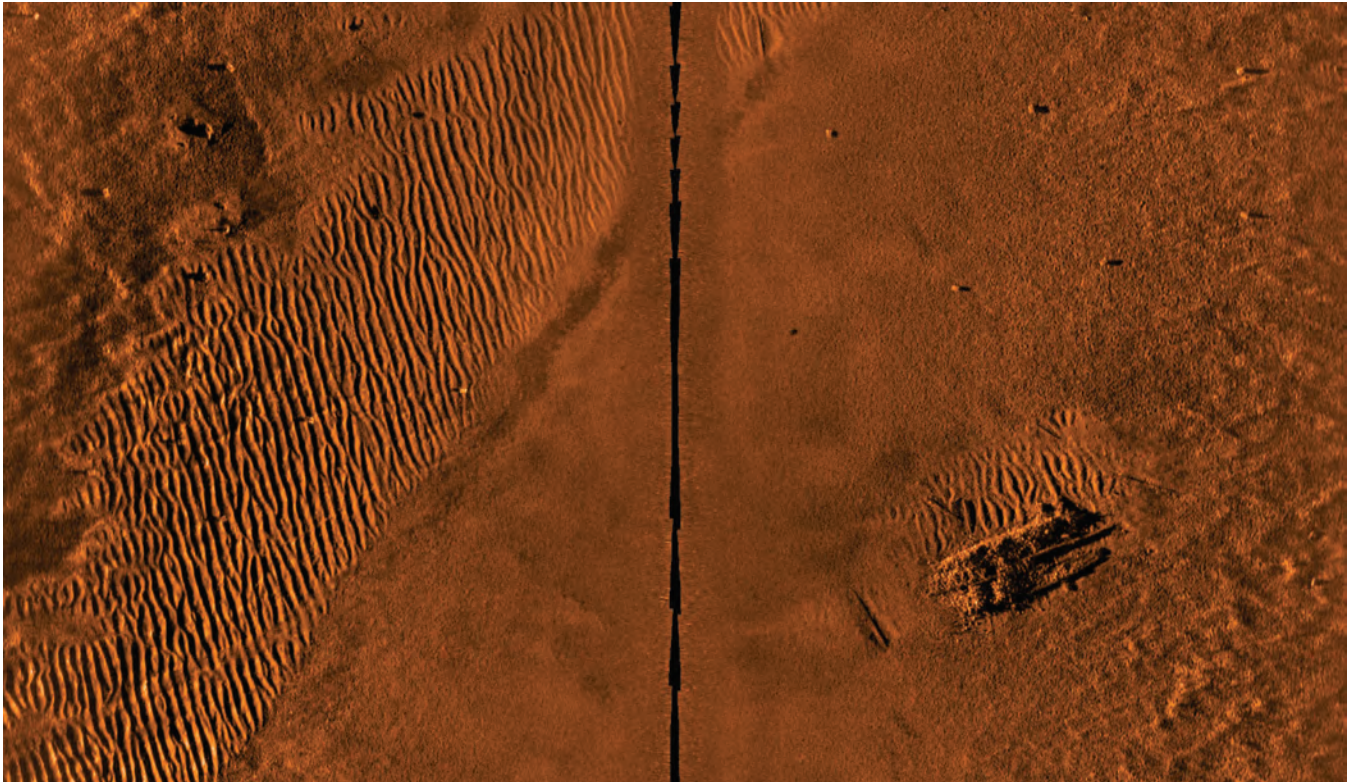
The image below shows recent data collected in Boston Harbor with the Bluefin-9. Degradation in image quality towards the edge of the swath is minimal and there is an incredibly high signal-to-noise ratio. These small artifacts are conventional lobster pots. Note the distinction between their shape and the surrounding environment. The ability to clearly discern one of the lobster pots at an across-track range of 92 meters is a compelling example of the effective scanning range of this system. This contrast leads to better estimates of highlight and shadow pairs, which lead to better operator decisions and improved performance of any third-party image recognition that an operator may use.

- o Removable Data Storage Module (RDSM) with Camera: The new RDSM acts as an independent data processor, generating and storing post-processed data with a simple interface to an operator's workstation. The RDSM contains a high-definition, machine vision-grade monochrome camera that captures still images and video. The use of a monochrome camera, instead of a color one, leads to lower noise and higher overall image quality in a low-light, subsea environment. Imagery is geotagged for easy review during post mission analysis. Researchers can use the RDSM processor to run front-seat autonomy solutions via the Bluefin Robotics Standard Payload Interface (SPI).

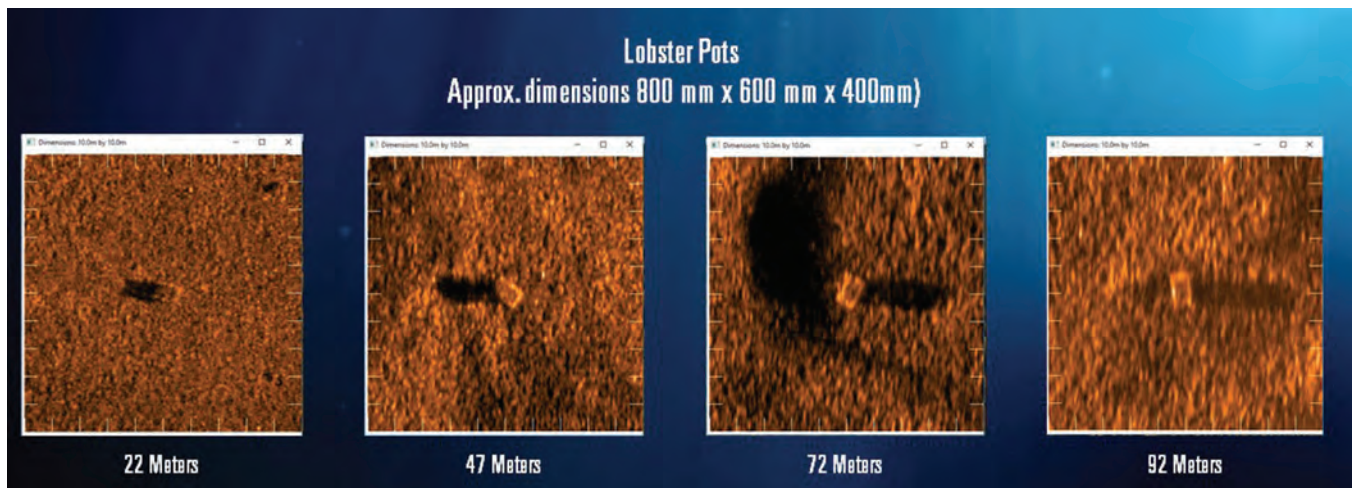
- o Improved Navigation and Timing: The Bluefin-9 incorporates a 1MHz Doppler Velocity Log (DVL), Inertial Navigation System (INS), and high-precision GPS that feed the system's dynamic control architecture. New on-board clock management and synchronization features further add to the confidence of this data and support the superior data quality provided by the platform as a whole.



Credit: General Dynamics Mission Systems



Credit: General Dynamics Mission Systems



o Emergency Operations System: An innovative emergency operations system that provides redundancy to the Bluefin-9's core functions in the event of a failure. An independently powered, low-power microcontroller ensures key communications systems are able to provide vehicle position and telemetry to an operator to facilitate prompt and safe recovery of the vehicle.

Bluefin-9 Packages

Bluefin-9 packages are available to meet varying operational needs. Our basic configuration includes:

- Bluefin-9 UUV
- Rugged Operator Laptop: Pre-loaded laptop with all necessary software to interface with the Bluefin-9 UUV, including Bluefin Planner and Bluefin Dashboard applications.
- Topside Radio Direction Finder (RDF): Radio directional finder tracker and antenna allows for measuring the direction of the vehicle when surfaced. This is an independently powered system separate from the main electronics and is generally used in non-standard recovery operations.



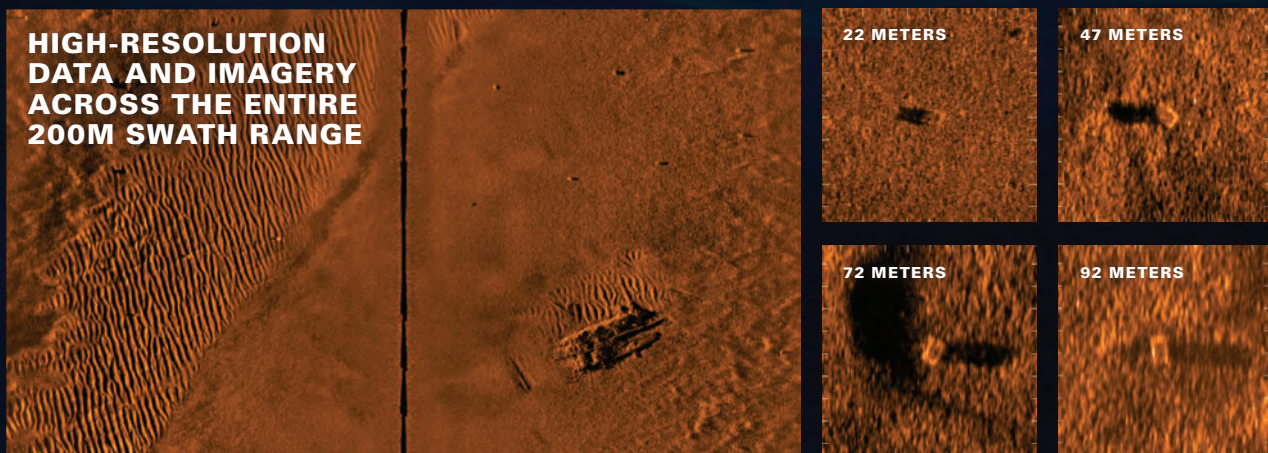
KNOW WHAT'S BELOW

BLUEFIN™-9 UNMANNED UNDERWATER VEHICLE (UUV)

MOST POWERFUL SENSOR PACKAGE IN A TWO-MAN PORTABLE UUV

SIDE SCAN SONAR WITH FULL SWATH BATHYMETRY
HD MACHINE VISION CAMERA • FLUOROMETRY • TURBIDITY
SOUND VELOCITY SENSOR + TEMPERATURE + PRESSURE

HIGH-RESOLUTION
DATA AND IMAGERY
ACROSS THE ENTIRE
200M SWATH RANGE

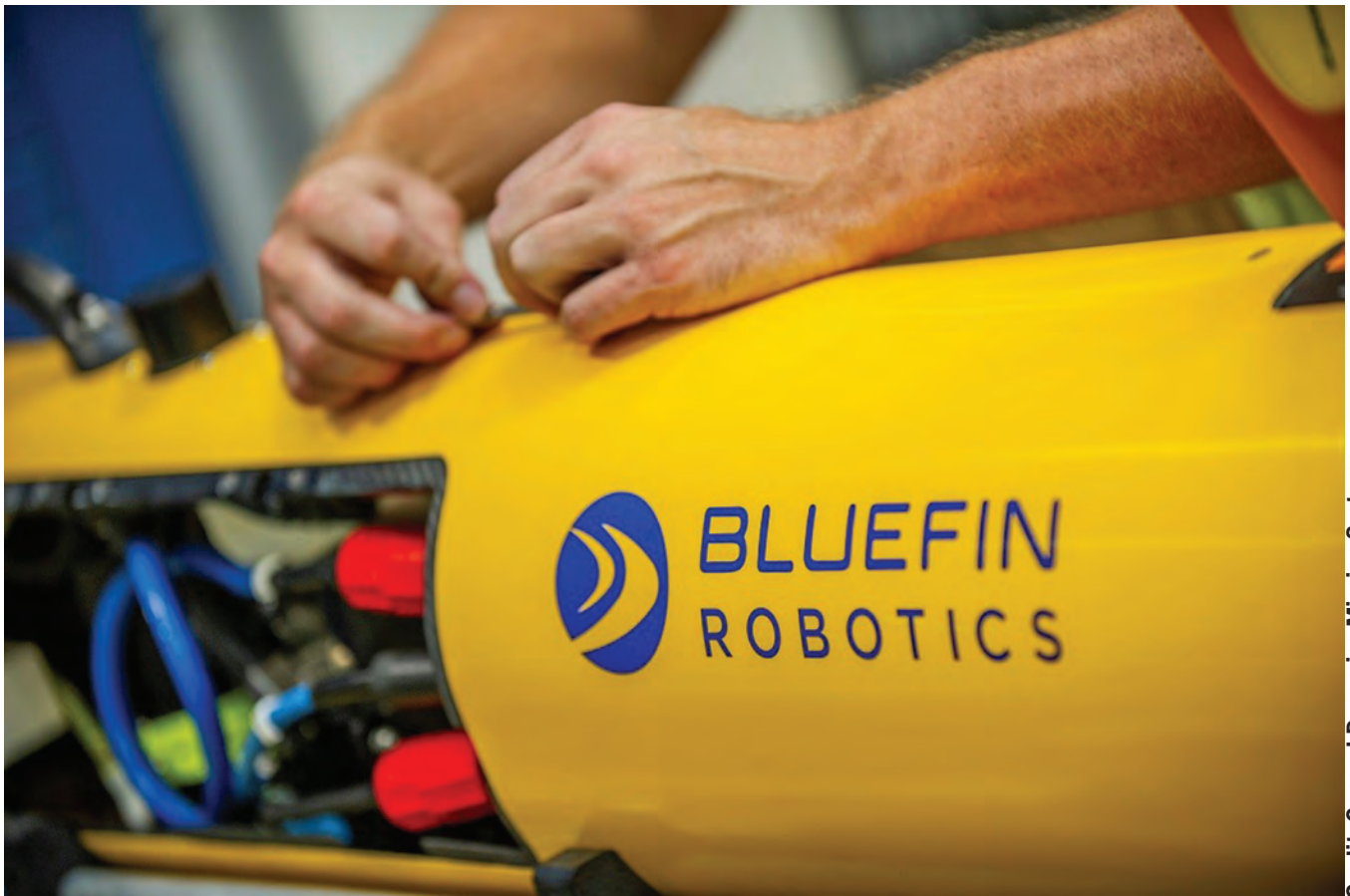


LEARN MORE AT WWW.GDMISSIONSYSTEMS.COM/BLUEFIN-9

GENERAL DYNAMICS
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 **BLUEFIN**
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Credit: General Dynamics Mission Systems

- 1.9kWh Battery Charger: The battery charger unit is a self-contained charging unit that can charge two UUV batteries simultaneously. Two batteries can be recharged from fully depleted in six hours.
- Toolkit: A multi-purpose tool kit containing common hand tools that are needed for line-replaceable units (LRUs) and perform regular service of the vehicle.
- Shipping Case: A hardened shipping case with inserts to safely pack and stow the Bluefin-9 vehicle.
- User Manual
- Standard 18 Month Product Warranty

An Expanding Line of Products

General Dynamics is constantly innovating. To continue improving operational efficiencies with the growing family of UUVs, the suite of expeditionary support equipment that enhances and simplifies system operation is expanding, to include:

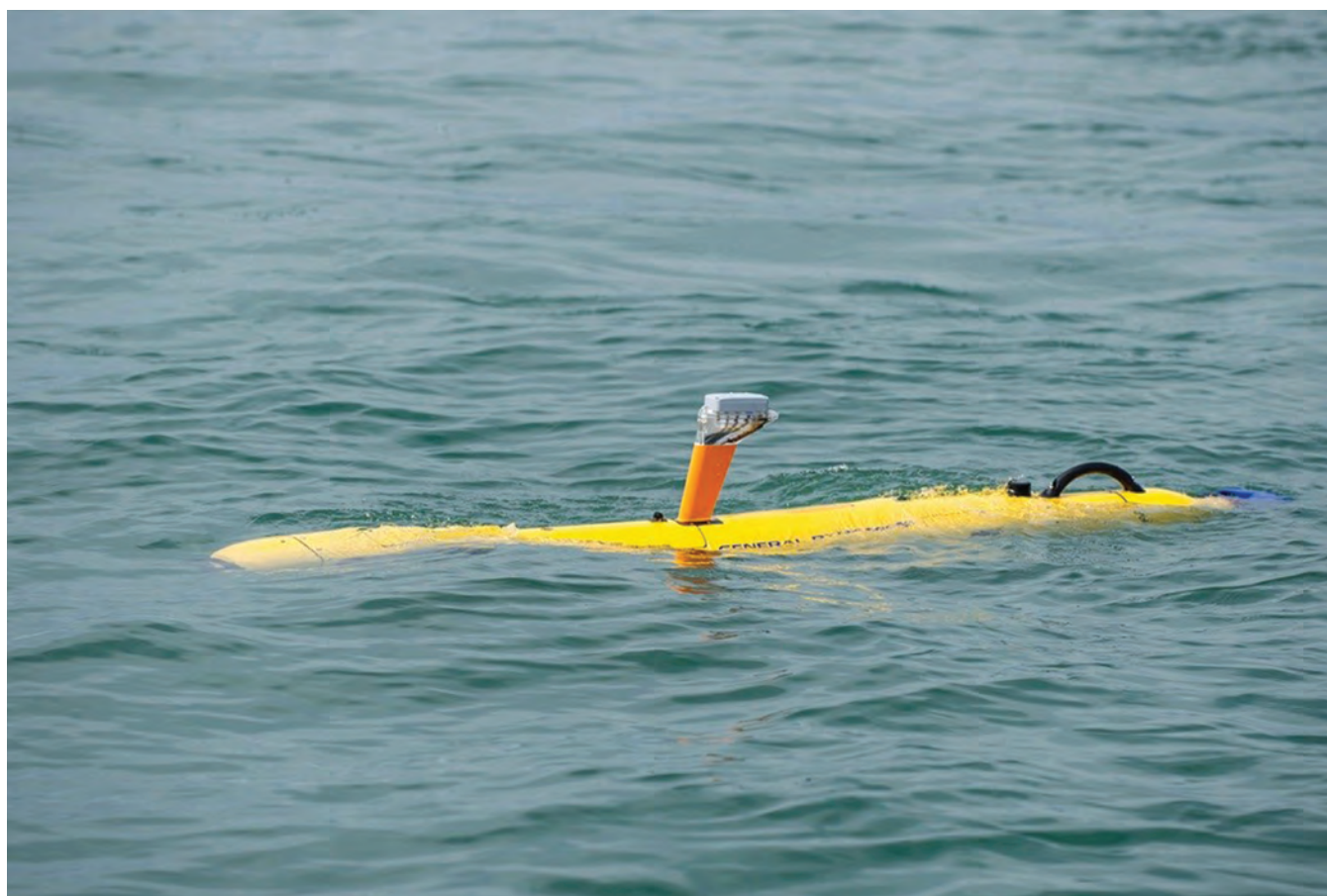
- Topside Communications Hub (TCH): The advanced Topside Communications Hub is a self-contained and self-powered interface that centralizes all topside services to the

Bluefin Robotics UUV and enables multi-vehicle operations. The TCH provides reliable communications with the deployed UUV and displays vehicle position and telemetry information to the operator via a web interface. The TCH also provides a future avenue for dynamic re-tasking by an operator while the UUV is underway.

- Topside Junction Box (TJB): The Topside Junction Box provides gigabit Ethernet communications and power. The box includes connections for an acoustic transducer, RDSM, the operator laptop, and the Topside Communications Hub. It is designed to be used on small vessels with internal battery power or shipboard power.

- Shore Power Box (SPB): The Shore Power Box is a single unit that provides external power to the vehicle and Ethernet communications in a weather resistant case. Shore power is used to power the vehicle on deck without draining the batteries installed in the vehicles. The communications connection provides a gigabit Ethernet line between the vehicle and the operator laptop. This direct Ethernet connection is used during troubleshooting and maintenance.

General Dynamics also provides live and virtual training



Credit: General Dynamics Mission Systems

packages for operators and maintainers as an additional available service. A team of expert marine operators provides expertise to courses hosted at the Bluefin Robotics facility in Quincy, MA, and on-site at customer locations around the world.

Operators and Applications

The Bluefin-9 provides the knowledge and situational awareness that can inform next steps for the U.S. Navy, environmental surveying teams, industrial clients, and researchers at academic institutions worldwide.

Defense Applications

- Mine Counter Measures (MCM)
- Explosive Ordnance Disposal (EOD)
- Search and Recovery (SAR)
- Intelligence, Surveillance and Reconnaissance (ISR)
- Counter UUV/UMS/Vessel Operations
- Force Protection
- Port Security
- Rapid Environmental Assessment (REA)

Industrial Applications

- Baseline Environmental Assessment
- Geophysical Survey
- Water Quality Measurement
- Ecosystem Assessment
- Route Survey

Academic Applications

- Physical Oceanography
- Autonomy Research

The completely redesigned Bluefin-9 is already in demand, with the initial build of vehicles contracted by an international operator and a series of deliveries scheduled throughout early 2019. New orders taken between now and the end of the year will be delivered beginning in the second quarter of 2019.



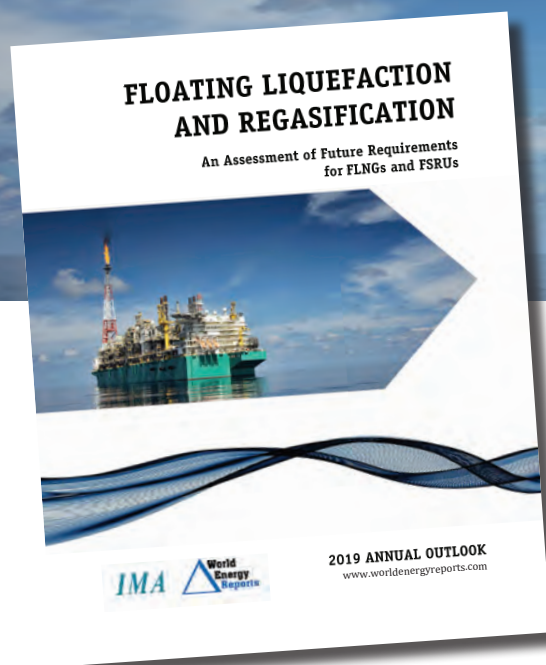
Credit: General Dynamics Mission Systems

DIAMETER | ~9.375" (23.8 cm) W x 10.375" (26.4 cm) H
 LENGTH | 95.2" (241.8 cm)
 WEIGHT (DRY) | 155 lb. (70 kg)
 BUOYANCY | Buoyant in fresh and salt water
 LIFT POINTS | Nose and Aft mounted carrying handles for two-man lift
 DEPTH RATING | 656' (200 m)
 ENERGY | 1.9 kWh rechargeable Li-Ion battery
 »»Designed for rapid removal and replacement—recharges in six hours using rugged battery charger
 ENDURANCE | 8hr @ 3kt
 SPEED | Up to 6.0kt sustained transit, survey at up to 5.0kt
 PROPULSION | Gimballed, ducted thruster for propulsion and control
 NAVIGATION | Real-time accuracy $\leq 0.3\%$ D.T. CEP 50
 »»GPS (1.0 m CEP 50 accuracy)
 »»Dedicated Inertial Navigation System
 »»Doppler Velocity Log
 INTEGRATED PAYLOADS & SENSORS
 »»Sonardyne Solstice 3000 Multi-aperture sonar
 »»Removable Data Storage Module (RDSM) w/ Camera
 »»Turbidity and Fluorometer Sensor
 »»Sound Velocity Sensor + Temperature + Pressure
 ANTENNA | Integrated GPS, Wi-Fi, and Iridium w/ visible strobe
 COMMUNICATIONS | Ethernet, Wi-Fi, Iridium, Acoustic
 SAFETY SYSTEMS | Ground Fault Detection, Leak
 Detection, Independently Powered Emergency Operations System
 SOFTWARE | Bluefin Dashboard and Bluefin Planner

REAL TIME ANALYTICS & REPORTS FOR THE FLNG/FSRU MARKETS



The LNG industry is going through a dramatic transformation. Our 2019 Annual Outlook and real-time FLNG/FSRU database is unique. It is not simply a static report, rather a dynamic and ever-changing database with a continuously updated wealth of data, statistics, exclusive insights and analysis and critical project management contacts designed to keep you a step ahead of the competition.



THE 2019 ANNUAL OUTLOOK

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FLNG Projects Tracked

There are numerous FLNG and FSRU projects in the planning stage. Not all will move to development. To sort the likely from the unlikely we developed a methodology to rate projects based on specific "success drivers".

130+

Exhibits & Infographics

The 2019 Annual Outlook contains over 55 exhibits and more than 70 infographics, so that you can easily visualize the market data being presented.

150+

Pages of Analysis

There are numerous FLNG and FSRU projects in the planning stage. Not all will move to development. To sort the likely from the unlikely we developed a methodology to rate projects based on specific "success drivers".

THE ONLINE DATABASE



We don't just provide a snapshot of the floating liquefaction and regasification sector. Our online fully searchable LNG database updates all of the project information on a 24/7 basis. As we receive new information about projects from our network of industry contacts, the database is immediately updated to reflect the latest situation.

Database users are able to select any combination of data about projects and export the data to excel for evaluation – or use the sorting and graphics provided with the database for making comparisons and benchmarking.

NO OTHER RESEARCH FIRM PROVIDES MORE INSIGHT INTO THE FLOATING LIQUEFACTION AND REGASIFICATION MARKET. CONTACT US TO LEARN MORE AT:

www.worldenergyreports.com



The FSRU database is a revolution in market insight, it provides real time analytics and information... Everything you need to stay informed of developments in the Floating Liquefaction and Regasification sector.

SUBSEA RELIABILITY IMPROVED: Technological Progress of Subsea Thrusters Saves Both Money and the Environment.

Developing technologies that set new standards within the marine industry takes time. Once in use, however, a robust new technology often proves superior under several parameters. This is the case of the Danish innovative company Copenhagen Subsea A/S.

Founded in 2014, Copenhagen Subsea A/S develops and manufactures four sizes of electrical rim-driven thrusters for the most commonly used subsea vehicles in the marine industry: ROVs, manned submersibles and AUVs. Customers include companies and institutions within both the industrial segment and universities.

The unique thruster technology of Copenhagen Subsea A/S reduces downtime and improves the success rate of subsea operations in several ways.

RELIABILITY FIRST

Ten years ago, the conventional hydraulic thruster was the only option for underwater propulsion. The conventional thruster was also by far the most vulnerable component of the subsea vehicle. Technically, the conventional thruster is

constructed as an atmospheric housing with pressure shaft seals, or as an oil-filled ambient pressure container. With several breakdowns and considerable maintenance costs as the undesirable result, this thruster was the weakest link in the chain of operation.

The market for underwater propulsion was ripe for a substantial re-thinking of technology. In order to meet the industry's new and higher demands for reliable thrusters and decreased operating costs, the solution was to construct a new product-line of electrical rim-driven thrusters. Building on the innovative ring thruster technology, Copenhagen Subsea A/S has been able to develop and manufacture four thruster sizes – from VS as the smallest to VXL as the largest – that show a significant increase in reliability.

The rim-driven thruster is a tight integration of motor parts within a housing. The electrical motor takes the form of a thin ring that has permanent magnets fixed to its rotor. This rotates within the stator arrangement of magnetic flux. The housing remains fixed to its platform on the subsea vehicle. The propeller – the only moving part in the rim-driven thruster



Photo Credit: VXL & VL thrusters from Copenhagen Subsea A/S



Photo Credit: VXL Thruster from Copenhagen Subsea A/S



Photo Credit: VXL Thruster from Copenhagen Subsea A/S

– rotates within the nozzle, eliminating the need for a drive shaft and hub. Speed and direction are managed by a motor controller.

THE 1.000 HOUR TEST

All thruster models from Copenhagen Subsea have been rigorously tested to secure optimal performance. In a 10.000-liter test-tank located on the premises in Hellerup just north in Copenhagen, Copenhagen Subsea A/S performs continuous testing of their thrusters. 1,000 hours of operating time in fact comprise 42 days during which the thruster

operates 24/7 at maximum power. During this period, the thruster is constantly monitored for performance and energy consumption, and any aberration is registered.

When reaching the milestone of 1,000 operating hours, the thruster is carefully examined and, showing no signs of exhaustion or corrosion, allowed to continue operation in the test-tank. The operational limit have yet to be explored, since the thrusters at all times during and after the test have shown that they maintain full functionality and unaffected performance.

DEVELOPMENT SUPPORT FROM THE DANISH MARITIME FUND

The maritime subsea market demands larger thrusters, increased thrust force and less downtime. However, simply upscaling the existing technology would pose a number of challenges. Materials and aspects of the manufacturing process must be considered anew, and the right entrepreneurial solutions applied. With the product line of innovative rim-driven thrusters, Copenhagen Subsea A/S is in a unique position to drive this development.

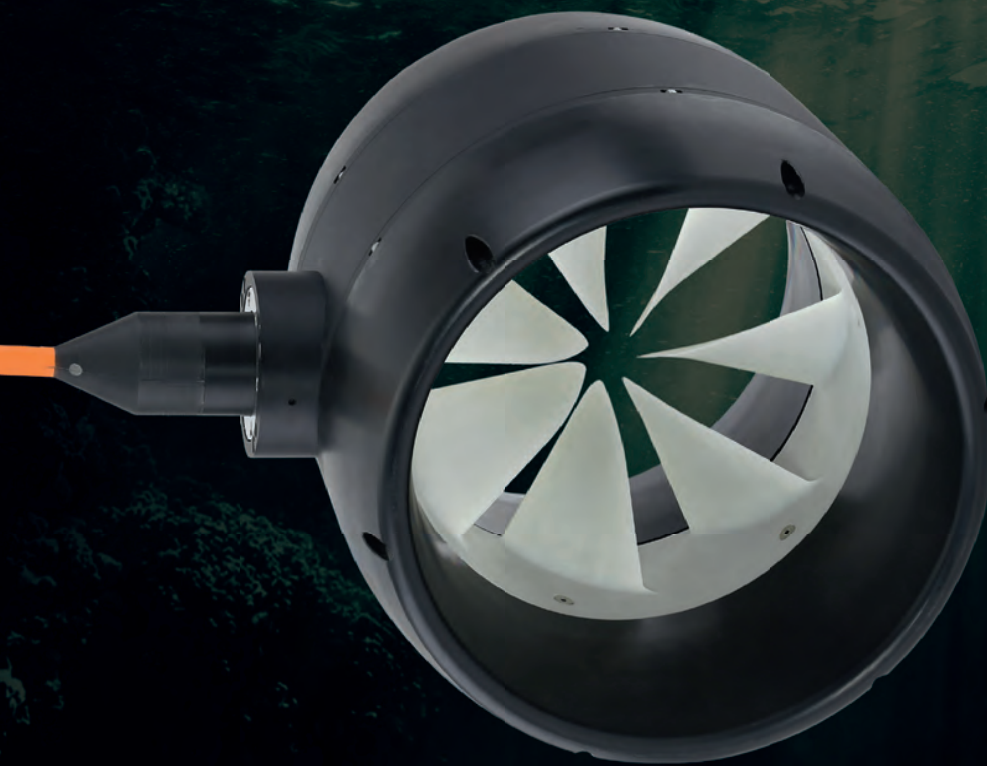
Acknowledging this unique position, The Danish Maritime Fund in 2016 decided to support Copenhagen Subsea A/S in the development of a new and powerful 10-20 kW electrical subsea thruster. Due to the unique design, the surrounding seawater cools the thruster and enables operation at maximum power for extended periods of time. The result is exceptional high thrust force compared to conventional thrusters.

LARGE VXL-VERSION DELIVERS THRUST FORCE OF 3000 NEWTON

Following two years of engineering and testing, the VXL was launched in early 2018. The VXL is the largest thruster in the portfolio of Copenhagen Subsea A/S today. With a propeller diameter of 236 mm, the VXL will deliver a thrust force of up to 2.800 Newton. This output makes the VXL a real alternative to conventional hydraulic thrusters. Low propeller inertia and high motor torque result in fast response when changing thruster RPM. Fast response makes the underwater vehicle highly maneuverable, provide accurate results, and improves working conditions for pilots. High thrust force makes precise navigation possible, even in strong currents.

The advantages of the VXL are many. Like the smaller models in the portfolio of Copenhagen Subsea A/S, it has only one moving part. This means no entanglement and dramatically minimized downtime compared to conventional thrusters. Reliability continues to be of crucial importance in subsea operations. The compact design, with a solid black housing of only 318 mm in diameter, makes the VXL adaptable to most ROV, AUV and Manned Submersible applications. Like the smaller VS, VM and VL models, the VXL comes in three

NEW class of ROV Propulsion



Powerful and silent subsea thrusters from Copenhagen Subsea A/S have been developed with reliability as the highest design priority.

The ROV thrusters are responsive, powerful and easy to integrate – and will provide vehicles with a unique combination of silent power and high maneuverability.

COPENHAGEN SUBSEA A/S

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different configurations: Symmetric, Asymmetric and Compact, according to the specific needs of the client's mission.

ENVIRONMENTAL ADVANTAGES – THE POWER OF SILENCE

Sustainability and environmental issues are important in subsea operations today. There is a heightened awareness of not disturbing marine life. The technology of the electrical rim-driven thruster not only improves reliability, it also makes the rim-driven thruster the right green choice.

The first green advantage is the acoustic profile. The innovative electrical design has no gears, only one moving

part and bearings that make use of the surrounding seawater for lubrication. These unique features lead to significantly reduced sound levels and minimal disturbance of surrounding marine life.

The second green advantage is that the risk of spillage is eliminated completely. Compared to conventional thrusters, which use a fluid for pressure compensation, the thrusters from Copenhagen Subsea A/S use only the surrounding seawater for lubrication. There is no oil or other lubricant inside the thruster. This means absolutely no risk of spillage, and no damage to the surrounding sea life.

Photo credit: VXL Thruster from Copenhagen Subsea A/S



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