



KONGSBERG

HUGIN Superior AUV Product Description

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Disclaimer

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Definitions / Abbreviations

ALL	Kongsberg datagram format
BMU	Battery Management Unit
BMC	Battery Management Computer
DPCA	Displaced Phase Centre Antenna
DVL	Doppler Velocity Log
GPS	Global Positioning System
FLS	Forward Looking Sonar
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
JSF	Edgetech side scan and SBP file format
LF	Low Frequency
MBES	Multi-Beam Echo Sounder
MF	Medium Frequency
NAS	Network Attached Storage
ppm	parts per million
PU	Processing Unit
QC	Quality Control
SBP	Sub-Bottom Profiler
SOLAS	Safety Of Life At Sea (international convention)
UHD	Ultra-high definition
UHF	Ultra-high frequency
UN	United Nations
USBL	Ultra-short baseline
UTP	Underwater Transponder Positioning
XTF	eXtended Triton Format

1 PRODUCT DESCRIPTION

The HUGIN Superior AUV is the most sophisticated HUGIN AUV offered by Kongsberg Discovery, equipped with the most advanced sensors and systems available for AUV integration. The main mechanical characteristics of the vehicle are:

Depth rating	External diameter	Length (m)	Weight (kg)	Speed range (knots)
6000 m	Ø875 mm	6.6	2200	2-5

Note: Dimensions and weight are approximate for a standard configuration and may vary.

Note: The typical survey speed of HUGIN Superior is 3-4 knots.

The HUGIN Superior builds on the success of the HUGIN AUV family and continues the same design principles. In particular, the vehicle hull consists of a carbon-fiber reinforced syntactic foam hull, the vehicle is energized using a pressure tolerant Lithium battery and the electronics and onboard equipment are housed in separate pressure vessels interconnected by underwater cables. The main differences between HUGIN Superior and the normal HUGIN are the ability to carry even more advanced sensors, such as the HISAS1032 Dual Receiver, and a more advanced autonomous navigation aiding toolbox. The HUGIN Superior also comes equipped with a new generation pressure tolerant battery providing greater endurance than before.

1.1 Configuration

The HUGIN Superior AUV System comes in a fixed configuration with the following equipment and capabilities:

- **HUGIN Superior AUV rated to 6000 m water depth, including:**
 - 6 battery modules providing 67 kWh of energy
 - A second full set of batteries for fast battery swap between missions
 - HISAS 1032 Dual Rx synthetic aperture sonar (SAS).
 - SAS imagery (real-time and post-processed).
 - SAS bathymetry.
 - Real-aperture imagery and bathymetry.
 - EM2040 Mk II multi-beam echo sounder.
 - EM2040 water column data.
 - EM2040 extra detections.
 - Dual swath (double along-track density)
 - EdgeTech Sub-Bottom Profiler.
 - 1-6 kHz, 2-16 kHz or 4-24 kHz.
 - CathX Ocean digital still image colour camera and laser profiler.
 - 48.5 field of view.
 - OFG self-compensating magnetometer.
 - Nortek DVL with bottom track and water track.
 - Sunstone 400 INS System
 - AML 3RT, CT, P, and SV
 - Environmental sensors:
 - Turbidity sensor.
 - Methane (CH₄).
 - Carbon dioxide (CO₂).
 - Dissolved oxygen (O₂).
 - Removable Network Attached Storage (NAS)
- **Topside Equipment:**
 - Operator and post-mission analysis computers.
 - Battery charging and monitoring system.
 - 40 ft. DNV 2.7-3 certified AUV offshore container with hydraulically operated aft doors and traversing crane. PAM certification option.
 - 20 ft. DNV 2.7-1 certified Operations offshore container. PAM certification option.
 - Hydraulically powered launch and recovery stinger.
 - Pneumatic grapnel launcher, service cart and lifting bar.
- **Software Capabilities:**
 - Sunstone aided inertial navigation system, including
 - USBL aiding.
 - HISAS Micronavigation.
 - UTP single transponder navigation.
 - Terrain-referenced navigation.
 - Sunstone Postea navigation post-processing tool suite.
 - Pipeline tracking.
 - Reflection post-mission analysis software, 1 licence.

- HISAP post mission reprocessing of HISAS, 1 licence.

1.2 Environmental specification

The table below list the main environmental specifications for the HUGIN Superior vehicle and battery:

Storage temperature	Minimum operating temperatures	Maximum operating temperatures
-20° to +40° C	Turn on: 0°C Powered up: -20°C Short time (< 20 min): -35°C Battery charging: 0°C	30°C

For operation in temperatures lower than the specified minimum temperatures, the vehicle should be protected with a cover and heated with external warm air. The battery control system will refuse charging if the internal battery temperature is too low. In warmer climates, the electronic containers should be flushed externally with cold sea water to avoid over-heating the internal electronics. Also, exposure to direct sunlight should be avoided in this case.

1.3 Battery system

HUGIN Superior is delivered with the latest generation pressure-tolerant Lithium Polymer battery, offering up to 30% more energy within the same volume compared to the previous generation. Each individual battery has its own battery management unit (BMU) with built-in hardware and software safety and monitoring functions. Several safety barriers are in place to avoid thermal runaway in the unlikely event of a cell short circuit.

The vehicle is delivered with 6 batteries, configured as two 3-packs, with a total battery capacity of approximately 67.2 kWh. The standard charge time after a complete discharge is about 9.5 hours but using a high current mode it is possible to reduce this to about 6 hours. When using the high current mode, some reduction in expected battery life must be expected.

To facilitate quick turn-around times, the HUGIN Superior is delivered with a second set of batteries that can be charged on-board the vessel while the vehicle is in operation. The battery packs are hot-swappable when the vehicle is connected to external power and a full 3-pack can be lifted from the vehicle in one operation. The charger system contains a dedicated Battery Management Computer (BMC) that controls charging and has functions for monitoring and maintenance.

Each battery is built up of battery blocks that are UN 38.3 certified and transportable by air, sea, and land. A training course for battery disassembly and assembly is provided by Kongsberg. Battery life is hard to predict and depends on use, number of charge cycles, storage temperature, storage charge state etc. Our batteries are delivered with the following lifetime specification:

- Full charge capacity better than 80% of initial capacity after 7 years of storage,

OR

- Full charge capacity better than 80% of initial capacity after 1000 charge cycles, whichever comes first. Storage and charging must be done in accordance with the procedures described in provided battery system documentation.

1.4 Endurance

The endurance of a HUGIN Superior AUV depends strongly on the chosen speed of the vehicle and the payload sensors in use. Below we state the estimated endurance for a HUGIN Superior vehicle running at 3 and 4 knots with payloads operating 90% of the time:

Payload sensors operating	Estimated endurance @ 3 knots	Estimated endurance @ 4 knots
All payload sensors operating.	62 hours	47 hours
HISAS, EM and SBP operating.	76 hours	55 hours

Endurance is stated with batteries fully charged. The vehicle will abort the mission on a critical capacity level to make sure it has some emergency reserve.

Remarks:

- Speed is specified as speed through water.
- Total available travel distance along the planned trajectory will be affected by currents. Anything other than positive along-track currents will need to be offset by an AUV velocity component in the opposite direction.
- Endurance can be affected by very cold ($< 4^{\circ}\text{C}$) water temperatures.
- Endurance will be affected by poor ballasting.
- Endurance is reduced with battery age.

1.5 Modes of operation

HUGIN Superior can be operated in either autonomous or semi-autonomous mode, depending on the goal of the operation. HUGIN Superior is a fully autonomous system and does not require any inputs from the operator once underway. The mission plan is loaded into the vehicle and the mission execution system executes the mission without human intervention. The collision avoidance system is there to deal with unexpected terrain or obstacles, and a rigorous error handling system takes online decisions in case of failures or unexpected situations 

The need for semi-autonomous mode, where one follows the AUV with a surface vessel, comes from stringent position requirements in commercial offshore work. The majority of commercial operators supervise their missions using a HiPAP positioning and communications system. During supervised work, the AUV is running autonomously, but we simply augment its performance by sending a position update every 30 seconds. We also collect the HiPAP position data topside at its full rate (rate depends on range to vehicle) for use in post-processing. This effectively binds the position error of the navigation system, making the data position as accurate as possible. The operator is also able to see quality control data from the payload sensors and make changes to the setup as he sees fit.

To facilitate unsupervised and autonomous surveys, the HUGIN Superior is delivered with an extensive toolbox of autonomous positing aiding techniques, including single-transponder navigation, terrain-referenced navigation and SAS micro-navigation. These aiding techniques are discussed further in Section 2.

1.6 Data storage and offloading

HUGIN Superior is delivered with a swappable Network Attached Storage (NAS) solution consisting of two NAS data bottles and a topside docking station. During the mission, data is logged to the swappable NAS and once the vehicle is back on deck, the used data bottle can be swapped with a blank one. The used data bottle can then be connected to the NAS docking station for data download and data processing. The disk capacity of the NAS bottle is 13 TB or higher.

The NAS comes with a 10G Ethernet interface (10GbE). This is a relatively new Ethernet standard and offers 10 times the theoretical bandwidth of the more common gigabit Ethernet found in most computer systems. While the theoretical bandwidth is increased by a factor ten, the practical bandwidth is usually increased by a factor 5. Regardless, this translates into substantial transfer speeds of ~500 MB/s, greatly reducing the time-to-data. 10GbE transfer is currently available through the topside docking station and not for direct offload from the vehicle. A solution for 10GbE vehicle offload is being worked on and will be available via future upgrade options.

1.7 Buoyancy adjustment

The HUGIN Superior vehicle is designed to be neutrally buoyant in water. A set of trim weights can be used to change the buoyancy and trim (pitch and roll) for varying density conditions ranging from 1.000 to 1.034.

1.8 Safety systems

1.8.1 Nose release

The nose is released at the surface with recovery line attached. The nose can be released automatically at the end of the mission or commanded manually when initiating the recovery process.

1.8.2 Air bladder

The air bladder is filled with CO₂ at end of mission to keep vehicle buoyant.

1.8.3 Drop weight

The drop weights are released in some emergency situations when the vehicle experiences a critical error or cannot drive to the surface. The HUGIN Superior vehicle includes both a rear and a forward drop weight 

The drop weight can be released autonomously by the mission control system or by the stand-alone emergency system following a watchdog timeout or power loss. A drop weight release can also be commanded manually by the operator through the acoustic link.

The drop weights can be locked before the mission to prevent the vehicle from dropping weights (e.g. under ice or in covert operations).

1.8.4 Iridium emergency GPS beacon

The vehicle includes an independently powered Iridium and GPS system. In case of vehicle failure (power loss or watchdog timeout), the system transmits its GPS position using the Iridium Short Burst Data (SBD) message service. The battery is dimensioned for 72 hours of operation, sending one position message every 45 minutes . The Iridium GPS system will utilize the main vehicle batteries as long as possible and only switch to the internal backup battery when necessary.

1.8.5 cNODE MiniS emergency transponder

The vehicle includes a galvanically isolated and independently powered cNODE transponder for acoustic emergency localization. The MiniS has a quiescent battery lifetime of approximately 30 days and several days of operational battery life. The MiniS must be re-charged using a supplied battery charger at regular intervals.

For long range emergency localization an LF beacon option is available. This option requires an extra LF cPAP or HiPAP.

1.8.6 Visual localization

The vehicles are equipped with battery operated Xenon flasher beacons on the vehicle body and the drop nose.

1.9 Documentation

The standard set of documents delivered includes these user manuals:

- Operator Manual
- Operational Procedures
- Topside Instruction Manual
- Maintenance Manual
- Battery System Instruction Manual
- Launch and Recovery Instruction Manual

The language of the manuals is English. The manuals describe installation, maintenance and operational procedures for all line replaceable units (LRUs) defined for the system.

2 NAVIGATION SYSTEM

HUGIN Superior is delivered with a state-of-the-art aided inertial navigation system called Sunstone. The navigation system centers around the IMU and can be aided by various sources. In the most basic mode, Sunstone receives aiding from DVL bottom and water track along with GPS surface fixes and possibly HiPAP USBL. A more sophisticated aiding toolbox is also available with UTP single transponder navigation, terrain-referenced navigation and synthetic aperture sonar velocity aiding. Additional techniques and interfaces may be available upon request.

2.1 Navigation and Guidance sensors

2.1.1 *Altimeter*

The HUGIN Superior is delivered with two independent Kongsberg Mesotech digital altimeters: one downward looking and one forward looking. The altimeters are used as input for vehicle altitude control. The acoustic frequency of the altimeters is 675 kHz and the range of the altimeters is about 75 meters. For operations requiring greater range, the 675 kHz versions can be replaced by 120 kHz versions. The range of the 120 kHz altimeters is about 200 meters. Note however that while the 120 kHz altimeters provide greater range, the price paid is reduced accuracy in rough terrain. This is due to these altimeters having greater acoustic beam widths and hence larger footprints

2.1.2 *Doppler Velocity Log (DVL)*

The HUGIN Superior is delivered with a Nortek 500 kHz DVL with bottom track and water track. The maximum range of the DVL is about 180 meters, depending on seabed conditions.

The vehicles can furthermore be delivered with an optional upward-facing DVL. In the default configuration, the upward-facing DVL is supplied with water and bottom track (i.e. surface/ice) functionality. The data from the upward DVL can also be used as input to the navigation system if running under ice and the bottom is out of range. However, tracking an ice surface will typically not give the same accuracy as tracking the bottom. The downward-looking DVL can be calibrated to a higher accuracy than the upward-looking DVL because it can be calibrated against a stationary sea floor. In addition to this, movement of the surface ice will tend to introduce errors in the navigation solution. Tracking the water surface without ice has not shown to give consistent results.

2.1.3 Depth sensor

The standard depth sensor of the HUGIN is the Paroscientific Digiquartz 8000 series. Typical accuracy of this sensor is 0.01% of full-scale reading (manufacturer specification). The sensor's full-scale reading is chosen to give the best accuracy in accordance with the depth rating of the vehicle. Customers may choose to buy spare sensors with other depth ranges for the best performance in other depth regions. 

2.1.4 Sound speed and CTD

HUGIN does not have a traditional CTD sensor. Instead it has a CT sensor, a sound speed probe that measures the sound speed directly (not derived from CTD), and pressure sensor (D). Additional environmental probes may also be fitted. The AUV may also have redundant readings of pressure and temperature. The CT sensor and sound speed probe is delivered by AML. The range of the sound velocity calculations is 1375-1625 m/s with an accuracy of ± 0.025 m/s (manufacturer specification). Alternate sound speed may be derived based on temperature, conductivity and pressure.

2.1.5 GPS Receiver

The HUGIN Superior includes a dual-frequency Novatel L1/L2 GPS receiver with GLONASS tracking. The expected position accuracy of the GPS receiver is 1.2 m RMS (manufacturer specification, single-point L1/L2). The receiver is capable of receiving SBAS (WAAS/EGNOS) corrections, with a manufacturer accuracy specification of 0.6 m, but in practice this has not shown to give any significant improvement in performance. 

2.1.6 Forward Looking Sonar (FLS)

The HUGIN Superior vehicles include a 260 kHz Imagenex DeltaT FLS for obstacle avoidance and terrain following. The FLS has a maximum range of about 100 meters and transmits 120 acoustic beams ahead of the vehicle to map out upcoming terrain, mid-water objects, ice, and surface objects. The data from the FLS is used both for terrain altitude control and collision avoidance. The anti-collision system has modes for bottom avoidance, mid-water object avoidance and surface/ice avoidance. The FLS-aided altitude control system ensures a smooth ride over rough terrain and enhances the quality of the recorded payload data. 

2.1.7 HiPAP USBL aiding

The vehicle includes a cNODE transponder for positioning by HiPAP. The global position of the vehicle is calculated by the HiPAP system on the vessel by merging USBL measurements with vessel GNSS measurements. The rate of these measurements is dependent on the range to the vehicle but is typically in the range 0.25-1 Hz. All the calculated global positions are stored to file and can later be used in navigation post-processing.

The vehicle is positioned by HiPAP using the almost continuous acoustic uplink from the vehicle. Every 30 seconds, the vehicle keeps quiet for a short period to allow for a downlink from the vessel. Position updates can then be sent to the vehicle to allow the vehicle to update its internal position estimate. The transmission of position updates is controlled by the operator.

2.1.8 Underwater Transponder Positioning

Underwater Transponder Positioning (UTP) is an optional software feature in NavP. The concept involves placing one or more transponders on the seabed and determining their global position (using e.g. HiPAP). By knowing the transponder's global position and measuring the range from the AUV, HUGIN can update its position when moving past a transponder. Provided that a suitable geometry is obtained, the accuracy is comparable to that of USBL aiding and only a single seabed transponder is needed. If more than one transponder is within range, NavP can utilize them all independently. The range of UTP transponder interrogation is typically around 1 km.

Note: UTP positioning will reduce the throughput on the vehicle data uplink during transponder interrogation. However, UTP is primarily intended for autonomous operations, and one would typically not use UTP positioning if already there with a surface vessel.

Note: Vehicles with UTP functionality will have an additional cNODE transponder with horizontal beam pattern mounted.

2.1.9 Terrain navigation

The principle of terrain navigation is to match current bathymetry measurements to a stored bathymetric map. The bathymetric map is uploaded to the AUV prior to the mission. The EM2040 or the DVL can be used as real-time bathymetry sources. The navigation accuracy obtained with terrain-aided navigation is typically comparable to the resolution of the stored map, as long as the terrain is sufficiently "non-flat". Practical map resolutions are 3-10 meters. Maps for terrain navigation can be generated by Reflection.

2.1.10 Sunstone Postea navigation post-processing

Sunstone Postea is an optional navigation post-processing software suite. Postea reads the full set of navigation sensor data recorded by the vehicle during the mission, including DGPS/HiPAP data recorded by HuginOS, and re-computes the AUV trajectory with higher accuracy than is possible in real time. In particular, Postea uses the DGPS/HiPAP data recorded topside at full rate, as well as utilizing smoothing techniques to generate navigation data with both higher accuracy and consistency. The use of the Sunstone Postea solution in payload data post-processing will typically increase the quality and consistency of the payload data, can remove swell effects, and increase HISAS image sharpness. The exported Sunstone Postea solution is supported by many 3rd party post-processing applications.

2.1.11 Navigation accuracy

The obtained navigation accuracy of Sunstone depends on many factors. The table below shows the expected in-situ straight-line navigation accuracy of HUGIN with the different Sunstone variants, assuming no position updates.

INS	Error of distance travelled (DT), CEP50
Sunstone 400	0.04 % ¹

0.04% means that after traveling autonomously in a straight line for 1 hour at 4 knots, the circular position error is expected to be less than 3 meters (50% of the time).

The table below shows the expected accuracy with various types of position aiding:

¹ 0.04% with all velocity navigation aids (DVL bottom track and HISAS Micronavigation) functioning

Position aiding scenario	Expected accuracy (CEP50): in-situ	Expected accuracy (CEP50): post-processed
GPS fix every 1-2 hrs ^{1), 5)}	2-10 m	2-6 m
UTP aiding ^{2), 5)}	1-7 m	1-5 m
HiPAP USBL aiding ^{3), 5)}	0.5-7 m	0.5-5 m
Terrain navigation aiding ^{4), 5)}	3-10 m	2-8 m

1) Relying on GPS fix for position aiding is not well suited when operating in deep waters due to the loss of DVL bottom track during the time it takes to ascend to and descend from the surface. The stated navigation accuracy assumes a water depth of approximately 200 m or less.

2) The accuracy of UTP ranging also depends on the sound speed profile between the vehicle and the seabed transponders as well as the accuracy of the box-in position of the seabed transponders (which often relies on using HiPAP USBL).

3) The accuracy with HiPAP USBL aiding depends on the depth of the vehicle, sound speed profile, vessel to AUV geometry, and the accuracy of the vessel GNSS system.

4) The accuracy with terrain navigation aiding depends on the resolution and accuracy of the pre-loaded map and that the terrain is "sufficiently non-flat" to match bathymetry features.

5) The obtained improvement in post-processing depends on the frequency of the position fixes. The highest uncertainty tends to be at the mid-point between fixes, typically increasing the further apart the fixes are.

3 COMMUNICATION SYSTEMS

The HUGIN Superior AUV system includes several redundant forms of communication both when submerged and at the surface. For surface communication, the vehicles are equipped with UHF radio modem, two-way Iridium modem and an individually powered Iridium emergency GPS beacon. The UHF modem provide line-of-sight communication capability, while the two-way Iridium modem provides an over-the-horizon surface communication capability. Wi-Fi is an available option on vehicles for civilian usage scenarios.

For communication below the surface, the vehicle includes a Kongsberg cNODE acoustic transponder system together with an individually powered cNODE MiniS emergency transponder. The main cNODE transponder provides both positioning and two-way communication through Kongsberg's cPAP, μ PAP and HiPAP systems. The cNODE MiniS provides additional redundancy by providing an isolated and individually battery powered transponder for emergency localization. The transponders can be chosen with different beam patterns to suit different modes of operation: vertical beam patterns for deep water operation, hemispherical beam patterns for mixed or general purpose use and horizontal beam patterns for shallow water or mainly horizontal communication.

The standard cNODE system delivered is based on the cNODE medium frequency (MF) family. This system is compatible with the Kongsberg cPAP, μ PAP and HiPAP. The typical maximum range of these systems are 4500-5000 meters. For ultra-deep operations or long stand-off distances, the vehicle can be delivered with cNODE low frequency (LF) versions which are compatible with LF HiPAP systems. The range of this system can be up to 10000 meters, depending on conditions.

Communication using cNODE is not synchronized to the acoustic transmission of other onboard acoustic sensors. This is usually not a problem, as the frequencies are for the most part well separated. Interference can however still occur at very long range and it may sometimes be necessary to reduce the acoustic communication to get the maximum performance out of the onboard sensors in these scenarios.

Note that the required ship-borne acoustic positioning and communication equipment (i.e., the HiPAP system) is not part of the standard offering.

The different communication systems available on a HUGIN Superior are summarized in the table below:

Communication system	Functionality	Typical range
cNODE acoustic comm.	Positioning, commands and status. Up to 2 kbps uplink.	Up to 5000 m (MF) and up to 10000 m (LF).
UHF radio modem	Commands and status. Up to 9600 bps.	Up to 2-4 km line of sight.
Wi-Fi (option)	Commands, status, data download. Up to 54 Mbps.	250-600 m line of sight.
Iridium emergency GPS beacon	GPS position and minimal status information	Global coverage.
Iridium two-way modem	Commands and status. Up to 2400 bps.	Global coverage.
Cabled Ethernet	Vehicle configuration and data download. 1 Gbps Ethernet.	For use on deck.

Note: UHF and Wi-Fi range depends strongly on the ship-borne antenna placement. cNODE range is affected by ship-generated acoustic noise and sound speed profile.

Note: Customers have reported successfully using cNODE MF with HiPAP 502 to almost 6000 meters depth, but this is actually outside the specification and hence cannot be guaranteed.

4 SOFTWARE SYSTEMS

4.1 Control and payload processor

HUGIN Superior is delivered with two main on-board software systems called CP (Control Processor) and PP (Payload Processor). The CP handles vehicles control, communication and navigation, while the PP handles the payload sensors.

4.2 Operator system

HUGIN Superior is delivered with the operator system HuginOS, which is used for mission planning, replay of previous missions and real-time monitoring and control. HuginOS also has dedicated payload commanders for most of the on-board payload systems, where one can monitor the status and manipulate payload-specific settings (e.g., sonar range, coverage sector, operation mode etc.). HuginOS also provides interfaces to HiPAP and other ship-borne systems such as the ship navigation system. HuginOS also comes in a remote version intended to be run on the bridge. This is a no-control version showing the map with vehicle position and other relevant status information.

4.3 Sunstone Postea

Sunstone Postea is a software package for navigation post-processing as described in Section 2.1.10.

4.4 Reflection

Reflection is an optional software package for post-mission analysis. It is designed to do post-mission analysis of the recorded payload data. Reflection supports the native data formats of almost all HUGIN payload sensors, hence avoiding time consuming conversion of data. All recorded data can be visualized in the same mission view so that points of interest can be inspected using multiple data sources (e.g. using multi-beam, HISAS imagery, camera etc.). If a Postea (or NavLab) post-processed navigation solution is available, Reflection can be configured to georeference data from any payload sensor using the Postea solution through the click of a button. Reflection can also be used to generate maps for use in terrain navigation. Reflection also contains a 'target viewer' for closer inspection, including a 3D view of bathymetric data. Reflection is useful for visualization, analysis and quality assessment of the recorded payload data.

Reflection has a plug-in interface for adding functionality. Available plug-ins include a module to find "similar" contacts from a target database. The SITAR automated target recognition (ATR) system for mine detection and classification (only available to military customers) also works as a Reflection plug-in for maximum ease of use.

4.5 HISAP

HISAP is the post-processing software for generating SAS data products from the HISAS1032 Dual Rx system. It runs on a dedicated computer and reads the raw HISAS data from the NAS bottle and process them into high resolution acoustic images and bathymetry. SAS imagery is exported in XTC format while SAS bathymetry is exported in Kongsberg ALL format. Real-aperture imagery and bathymetry data products are also available. HISAP is controlled through a Reflection plug-in (see Ch. 4.4).

4.6 Maintenance agreement

We encourage our customers to sign software maintenance agreements. With a maintenance agreement, you will receive software updates including both bug-fixes and improvements. The HUGIN software system is constantly evolving, and our customers are benefiting from the continuing developments. We also value input from our customers on how to improve our systems.

5 PAYLOAD SENSORS

5.1 EM 2040 MKII

HUGIN Superior is delivered with the second-generation Kongsberg EM 2040 multi-beam echo sounder known as EM 2040 MKII. This is a 0.7x0.7-degree system providing 400 beams and a user configurable operating frequency of 200, 300, 400, 600 or 700 kHz. The system can be configured to alternate between two of these frequencies from ping to ping. In the MKII version of the sensor, the maximum coverage sector is increased by 10 degrees and now provides up to 150 degrees (~7.5x altitude) coverage on flat bottom in the 200 and 300 kHz modes. The coverage sector in 400 kHz mode is up to 120 degrees. The system can be operated in both external and internal trigger mode with internal trigger rates exceeding 40 Hz at low altitudes.

The EM2040 also comes pre-configured with the additional options for extra detections, water column logging and dual ping. The dual ping option includes an additional processing card in the EM processing unit and doubles the along track ping density at any ping rate.

The data storage rate of the standard EM2040 is typically 0.5-2 GB/h, depending on ping rate. Water column data logging adds an approximate 12 GB/h.

5.2 HISAS 1032 Dual Receiver

HISAS 1032 Dual Receiver (Rx) is the latest addition to Kongsberg Discovery's HISAS synthetic aperture sonar (SAS) family. This sonar doubles the receiver array length compared to the standard HISAS 1032 system employed in other HUGIN vehicles, and greatly improves the maximum range for a given speed.

A new post-processing toolchain named HISAP now also provides full swath SAS bathymetry in addition to full swath SAS imagery, making the HUGIN Superior a very capable bathymetric mapping platform. The basic specifications of the HISAS1032 Dual Rx system are given in the table below:

HISAS 1032 Dual Rx Specification	
SAS imagery resolution	< 5 x 5cm @ 200m range < 7.5 x 5cm @ 300m range <12.5 x 5 cm @ 500 m range (along-track x across-track)
SAS imagery data output	Geo-referenced XTF (X21)
SAS bathymetry resolution	20x20x20 cm @ 200m
SAS bathymetry data output	Kongsberg .all (RA123/XYZ88) Point cloud .xyz
SAS max slant range (per side)	500m @ 2.5 knots, 300m @ 4 knots.
Area coverage rate	~4.0 km ² /h SAS imagery coverage ~4.5 km ² /h bathymetry coverage (with gap fill)

The HISAS sonar works by collecting raw sonar data during the mission and then post-processing the sonar data into high resolution acoustic images, or SAS images. The sonar range is speed dependent, while the area coverage rate remains approximately constant. Range is also dependent on altitude and a general rule of thumb is that the range is limited to ten times the vehicle altitude. The sonar is designed to work both in deep and shallow waters and has proven performance also in difficult terrain and high-crab situations. The area coverage rate of the HISAS 1032 Dual Rx is 4.0-4.5 km²/h, depending on topography and sound speed profile.

The HISAS system collects raw data for post-processing during the mission. Side-scan data (i.e. real aperture data) is however generated in real-time, and stored in XTF format, and is available immediately after download. The data storage rate of the HISAS 1032 Dual Rx is approximately 180 GB/h.

5.3 HISAS In-Mission Processing (IMP)

The HISAS system includes in-mission processing, which gives near real time HISAS imagery. Imagery is full resolution and full coverage of the sonar, providing data interpretation capability as soon as the vehicle is recovered. Note that usage of HISAS IMP has an implication on vehicle endurance due to the added power consumption.

5.4 Sub-Bottom Profiler (SBP)

HUGIN Superior is delivered with an Edgetech sub-bottom profiler. The customer can choose between a 1-6 kHz, a 2-16 kHz and a 4-24 kHz system. Data is stored in JSF and XTF data formats. The data storage rate of the SBP system is approximately 500 MB/h, depending on ping rate.

Note: Some pulse types and frequency bands of the SBPs has reduced interoperability with cNODE due to overlapping acoustic frequencies. Specifically, the center frequency of cNODE LF is 12.8 kHz and cNODE MF is 25.6 kHz. SBP pulse types must be chosen to avoid interference or the cNODE data uplink must be disabled.

5.5 Still image camera

HUGIN Superior is delivered with a CathX Ocean color still image camera. The camera system delivers still images in UHD resolution (4096 x 2304 pixels) in 16:9 format up to 7 Hz framerate. The field of view of the camera is 48.5 degrees giving a swath width of approximately 0.9 times the altitude. Still images are stored in the JPEG format. Typical useful framerate is about 3 Hz, giving a data storage rate of approximately 22 GB/h. The range of the still image camera system depends strongly on visibility conditions, but a general rule of thumb is 4-5 meters under normal conditions. The installed turbidity sensor can give an indication of the visibility and guide the user in determining a suitable altitude.



5.6 Laser profiler

HUGIN Superior is delivered with a CathX Ocean laser profiling system. The laser profiler is an extension to the still image camera system and the laser and still image camera operation is synchronized to avoid interference between the two systems. The frame rate for the laser system is typically 30 Hz, with 2048 data points per laser line. Data is stored using a CathX proprietary format at a rate of approximately 1 GB/h. The range of the laser system is approximately 4-5 meters, depending on visibility.

5.7 Magnetometer

HUGIN Superior is delivered with a self-compensating magnetometer from Ocean Floor Geophysics. Both the raw data and converted data is stored together with corresponding time stamps. The sensor is calibrated on board the vehicle to remove the effects of static magnetic fields. Real-time measurements of motor current consumption are also used to compensate for the induced magnetic field from the propulsion motor.

5.8 Environmental sensors

HUGIN Superior is configured with environmental sensors for measuring turbidity, methane (CH₄), carbon dioxide (CO₂) and dissolved oxygen (O₂). Specifically, these are 

- WetLabs turbidity sensor (FLNTU)
- CONTROS CO₂ sensor
- CONTROS CH₄ sensor
- Aanderaa optode 4831F O₂ sensor

Other sensors can potentially be integrated upon request. Below we list some sensors that have already been integrated in HUGIN AUVs:

- SeaBird Deep SUNA nitrate sensor
- SeaBird OCR 500 Series Multispectral Radiometer
- SeaBird SBE43 Dissolved Oxygen sensor
- SeaBird SBE49 CTD sensor
- Various WetLabs ECO sensors

The level of integration of these sensors must be discussed and agreed with the customer. In the simplest form, we can only log the raw sensor data with corresponding time stamp. It is also possible to convert the data into usable values, provide real-time quality control data to the operator, add support for real-time operator control of the sensor and integrate support to visualize the data products in Reflection.

6 TOPSIDE SYSTEMS

HUGIN Superior is delivered with a topside system including a HUGIN operator station (HOS) computer and a post mission analysis (PMA) computer. These computers are integrated into a computer cabinet along with other equipment such as an uninterruptible power supply (UPS), NAS docking station and APOS Survey computer (if applicable). Topside communication equipment such as Iridium modem, Wi-Fi access point (option) and UHF modem are also provided. The system is delivered with four monitors.

For vehicles supposed to operate using HiPAP, we strongly recommend to include the APOS Survey computer. APOS Survey interfaces the vessel's HiPAP system through a high-speed serial line and makes it possible to use the cNODE transparent modem and control functions without making changes to the vessel's APOS software or installation parameters. This also holds true when the vessel APOS does not have the transparent modem function enabled. The use of APOS Survey also allows for faster mobilization, as the interface between HOS and APOS Survey remains constant (i.e. IP addresses and port settings remain unchanged).

Charger cabinets with battery monitoring computer and chargers are also part of the topside installation. The charger cabinets are usually integrated into a launch and recovery container or provided for fixed installation on board a vessel. A portable version in Peli-type cases are also available upon request. To support the nominal charge times (8 hours), a 6 kW charger is required per 3-pack of batteries. An additional 6 kW charger is required for high-current charging. The power input requirement is 400 VAC 3-phase and 6, 12 or 18 kW for one, two and three chargers, respectively. Note that it is also possible to use fewer or smaller chargers if the electrical infrastructure cannot support this power requirement. The charge time will be longer in these cases. This is however usually not a problem when using two sets of batteries for continuous operation. A charger cabinet solution running off 230V are available upon request.

6.1 Time Synchronization

Prior to launching the vehicle, both the AUV and the topside systems are synchronized to GPS time. To keep track of time while submerged, a low-drift oscillator with less than 0.1ppm drift specification is used. The oscillator is further calibrated to remove static bias effects usually giving less than 0.05 ppm actual drift. We also make sure all payload systems are synchronized to this common time source according to the manufacturers specification. This ensures that all data logged, both topside and subsea, are referenced to synchronized GPS time.



6.2 Acoustic Trigger Synchronization

To minimize acoustic interference between payload sensors, HUGIN Superior provides synchronized transmit trigger signals to most acoustic sensors, including the DVL, altimeters and acoustic payload sensors such as the multi-beam echo sounder and synthetic aperture sonar. This makes it possible to operate most acoustic sensors simultaneously. In situations where there is no risk of acoustic interference, internal sensor triggering can be used if desirable.

6.3 Containers

The HUGIN Superior AUV system is delivered with a launch and recovery (LARS) container and an operations (Ops) container. The containers are certified according to DNV 2.7-3/2.7-1 respectively.

6.3.1 Ops container

The operations (Ops) container is an insulated, air-conditioned container equipped with an office desk, two operator chairs and four wall-mounted computer monitors and two sets of keyboards and mice. The operations container also contains a computer cabinet (mounted on shock absorbers) with HUGIN operator station computers, APOS survey computer (if applicable) and necessary communication equipment such as UHF and Iridium modems. A docking station for swappable NAS storage devices and a HISAS post-processing computer are also integrated into the computer cabinet. Power to the computer cabinet and monitors is provided through an uninterruptible power supply (UPS) that can sustain operation during short power outages.

The electrical system consists of a 230V (230VAC, 1-phase, 50/60 Hz, 32A) electric circuit breaker panel with European Type F (Schuko) wall sockets, interior lighting, local fire alarm and an electric oven for heating. A wall mounted air condition unit is supplied for cooling. The electrical installation delivered is in accordance with Norwegian standards for electrical ships installations, defined in NEK400. The electrical installation is primarily grade IP44, but some outlets are IP20. The external electrical connections are IP66.

The Ops container is equipped with a combined optical and thermal sensor mounted in the ceiling and connected to a fire alarm central unit. The fire alarm central unit is further connected to the fire alarm central unit in the LARS container and can be connected to the vessel's fire alarm system through external cabling.

The HUGIN Operator station and APOS Survey computer requires a position input. A Kongsberg SEANAV 300 GNSS compass and position sensor is supplied for this. Other Kongsberg SEPATH systems can also be delivered if higher accuracy is required. It is also possible to communicate navigation information from the vessel navigation system over Ethernet. In this case, a 1PPS signal must also be wired into the container from the vessel navigation system. A ZDA message is also required in this case.

The standard Ops container is 20 ft. long. A 10 ft. version can also be delivered where less deck space is available. The typical interior layout of a 20 ft. Ops container is shown in Figure 1 below.

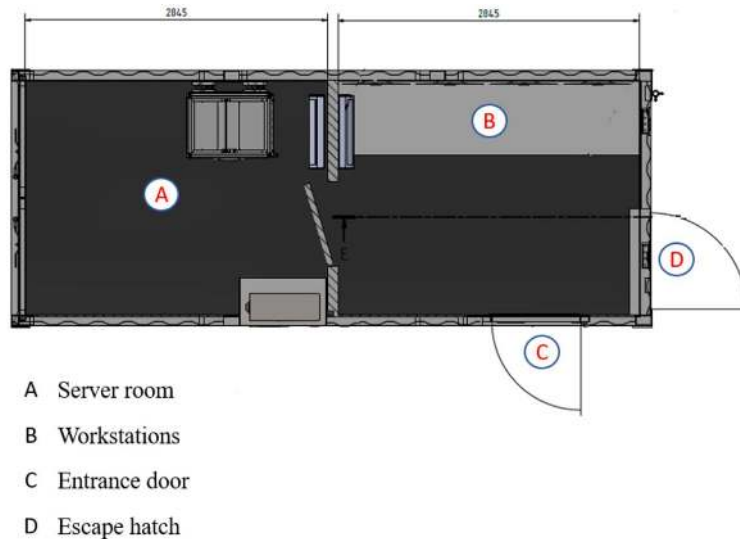


Figure 1 Interior layout of 20 ft. Ops container.

6.3.2 LARS container

The launch and recovery system (LARS) container is an insulated, air-conditioned container holding the vehicle launch and recovery stinger and the battery charger system. The container is also fitted with a service desk, wireless access point, air compressor, CO₂ filling station for the recovery floatation system, GPS repeater, IP camera and ceiling-mounted traverse crane for battery change. Wall-mounted battery storage boxes and water level controllers for use during battery charging are also part of the container functions.

The standard LARS container is 40 ft., but a 40 ft. The container has a hydraulically operated back door.

The electric installation consists of a 400V (400-415V AC, 3-phase, 50/60 Hz, 63A, 4 pol. 6H) electric circuit breaker panel with high-voltage connections to the hydraulic power unit (HPU), aft container door, battery charger and lifting crane. Also part of the electrical installation is a 230V (230VAC, 1-phase, 50/60 Hz, 32A, 3 pol. 6H) electric circuit breaker panel with European Type F (Schuko) wall sockets, interior lighting, local fire alarm and an electric oven for heating. A wall mounted air condition unit is supplied for cooling. The installation is primarily IP54, but some outlets are IP44. The external electrical connections are IP66.

The fire alarm system provided is for local warning and for automatic shutdown of the vehicle battery charger. The detector consists of a combined optical and thermal sensor mounted in the ceiling of the container and connected to a fire alarm central. The fire alarm central is connected to the Ops container fire alarm central through external cabling.

The battery charger system comprises of digital power supplies and a touch screen battery management computer (BMC). These components are mounted inside a computer cabinet mounted on shock absorbers.

A fresh water supply is also needed. Fresh water is used both for general cleaning and filling of battery compartments (vehicle or battery storage boxes) during charging.

The vehicle is launched from and recovered into the container using a stinger system. The stinger is a hydraulically powered mechanical construction for launch, recovery and storage of the AUV. The stinger supports freeboards up to 5 meters and is suitable for use in sea states 0 to 4. The stinger system requires a hydraulic power unit (HPU) in order to operate. An HPU is integrated into the container for this purpose.

The LARS container is connected to the Ops container by Ethernet. Wiring for time reference and fire alarm signaling is also needed.

The typical layout of a 40 ft. LARS container is shown in Figure 2 below. Kongsberg has developed a set of standard Ops and LARS containers. Customizations to these containers are possible, but will result in added cost and potentially extended delivery time.

6.3.3 Other container specifications

External container dimensions: 8 ft. wide, 8.5 ft. high, 10/20/30/40 ft. length.

The container temperature range is -25°C to +72°C, including effects of direct solar radiation.

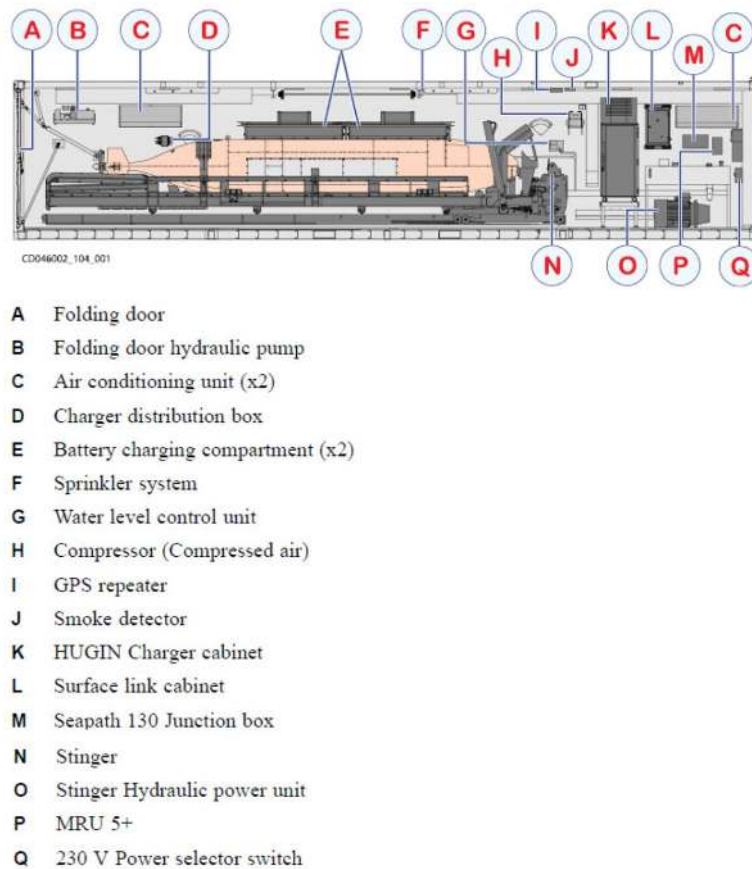


Figure 2 Layout of 40 ft. LARS container.

6.4 Other equipment

The AUV system is delivered with a vehicle ground handling cart and spreader beam for lifting the complete vehicle. Spreader beams for the battery packs are also provided.

A SOLAS compliant grapnel launcher tool powered by compressed air is provided for drop-nose retrieval during the recovery. The grapnel launcher can be recharged using a general diving air supply. The inflatable air bladder in the vehicle uses CO₂ and a CO₂ filling station is located in the LARS container. The filling station uses commercially available 5 kg CO₂ bottles.

7 ACOUSTIC SOURCE LEVELS

The following table contains the acoustic source levels of sensors and communication equipment on the HUGIN Superior.

Unit	Source level (re 1 uPa @ 1m)	Frequency (kHz), documented by manufacturer
HISAS 1032	6 degrees: 210 dB 15 degrees: 204 dB 30 degrees: 200 dB	100 kHz
EM 2040-07	Up to 212 dB	300 kHz
SBP	202 dB	All (1-6, 2-16 and 4-24 kHz)
DVL	210 dB (estimated)	500 kHz
FLS	190 dB (not in documentation, found in article where the unit was used)	260 kHz
Altimeter	217 dB	675 kHz
cNODE	TDR 180V: 184 dB TDR 40V: 197 dB TDR 30V: 200 dB TDR 30H: 184 dB	21-31 kHz (Cymbal at 25,7kHz) Values at High level, two additional 6dB steps below these values.

8 SUMMARY

8.1 Vehicle

Depth rating	6000 m
Operating depth	10 – 6000 m
Length (typical)	6.6 m
Diameter (center section)	875 mm
Weight in air (typical)	2200 kg
Weight in water	Neutrally buoyant (trim weights provided for varying buoyancy)
Speed range	2 – 5 knots
Battery (typical configuration)	6-battery 67.2 kWh Li-Pol
Charge time	6-9.5 hours (with sufficient power input)
Endurance	See Section 1.4
Data storage	Swappable NAS (see Section 1.6)
Communication	cNODE acoustic, UHF radio, Iridium, Wi-Fi (option), cabled Ethernet (see Section 3)
Safety systems	Releaseable nose, inflatable CO2 bladder, drop weight, cNODE MiniS, Xenon flasher on vehicle body and nose (see Section 1.8)
Motion stability (valid at 4 knots)	< 0.5 degrees in roll and pitch < 0.5 degrees in heading over a 10 sec duration
Turning radius	~20 meters
Maximum pitch angle:	± 50 degrees

8.2 Payload sensor options

Multi-beam echo sounder	Kongsberg EM 2040 MKII (see Section 5.1)
Synthetic aperture sonar	Kongsberg HISAS 1032 Dual Rx (see Section 5.2)
Sub-bottom profiler	EdgeTech 2205 sub-bottom profiler (see Section 5.4)
Digital still image camera	CathX Ocean colour still image camera (see Section 5.5)
Laser profiler	CathX Ocean laser profiler (see Section 5.6)
Magnetometer	OFG self-compensating magnetometer (see Section 5.7)
Environmental sensors	Turbidity, methane (CH ₄), dissolved oxygen (O ₂) and carbon dioxide (CO ₂).

8.3 Topside systems

Operator station cabinet	Computer cabinet with: - HUGIN operator station (HOS) - Payload workstation (PWC) - HISAS post-processing server (PMA) - NAS docking station - APOS Survey operator station (optional) Power input: 230VAC, 1-phase, 50/60 Hz, 16 A.
Battery charger cabinet	Computer cabinet with battery chargers and battery management computer. 400-440VAC, 3-phase, 50/60 Hz, 32A.

8.4 Containers

Operations container (see Section 6.3.1)	10 or 20 ft. insulated container with operator stations, communications equipment and post-mission analysis/processing. Electrical connection: 230VAC, 1-phase, 50/60 Hz, 32 A, (3 pol. 32A 6H). Other connections: GNSS navigation system antenna. Connection to LARS container. Ship navigation system and 1PPS (optional). Ship fire alarm signaling (optional).
Launch and recovery container (see Section 6.3.2)	30 or 40 ft. insulated container with launch and recovery stinger, battery charger and HPU. Electrical connections: 400-440VAC, 3-phase, 50/60 Hz, 63A, (4 pol. 63A 6H). 230VAC, 1-phase, 50/60 Hz, 32A, (3 pol. 32A 6H). Other connections: Connection to Ops container. Fresh water supply.

8.5 AUV Navigation Sensors

INS	Sunstone 400
DVL	Nortek DVL500
Forward Looking Sonar/Anti-Collision System	Imagenex sonar and KM algorithms for improved contour following and obstacle avoidance
CT + sound speed	AML 3RT
Depth Sensor	Digiquartz 8000 series
Acoustic Positioning	cNODE transponder for HiPAP (MF)
GPS Receiver	Novatel L1/L2 GPS
Altimeters	Kongsberg Mesotech digital altimeter (down and forward looking)

See further details in Section 2.