# Working on Technological Development of Special Vessels -Special Vessel Building Achievements and Construction of Research Vessel Kaimei-

Research vessel Kaimei

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*In Japan, which is surrounded by the sea in all directions, the continuous execution of comprehensive oceanographic investigation and research of coastal and inshore water areas and also utilization of marine resources reserved in the ocean, such as minerals and energy sources, are considered important issues. In addition, it is important for Japan to maintain international contributions to research and studies for unraveling the mechanisms of the global ocean environment and climatic change and for exploring the origins of the earth and organisms. With such a background, Mitsubishi Heavy Industries, Ltd. (MHI) has been continuously building many special vessels including training ships and cable laying ships in addition to research vessels and investigation ships, and have advanced technical capabilities with regard to special vessels. This paper summarizes the technical requirements for special vessels, our achievements, and the outline of the research vessel Kaimei, which was completed in March 2016.*

## 1. Introduction

MHI has built many special vessels including research vessels, investigation ships, training ships, cable laying ships for government agencies, universities, marine research institutes, marine resource development agencies, and ocean development companies.

Collectively known as "special vessels", these include various ships having different specifications such as size, structure and equipment depending on the required function and are operated in a different manner from normal ships. Therefore, experience and know-how accumulated over a long period of time are very important for design and building technologies for special vessels.

In addition, it is necessary to determine the overall location of research facilities and various investigative observation devices while optimizing and making the most of available space because the internal space of a ship is characteristically limited.

## 2. Technological requirements for special vessels

### 2.1 Functions of special vessels

This section describes functions of investigative observation ships among special vessels. Investigative observation is classified into general ocean observation, ocean environment investigation, marine ecology investigation, marine resource investigation, etc. Generally, these investigative observations use the following methods.

- The general ocean observation uses devices called CTD (Conductivity Temperature Depth profiler) and ADCP (Acoustic Doppler Current Profiler) to investigate the seawater

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temperature, salt content, tidal current, etc.

- Ocean environment observation uses metrological observation devices, doppler radar equipment, etc., to investigate wind direction and speed, temperature, atmospheric pressure, rainfall amount, solar radiation amount, wave height, etc.
- Marine ecology investigation uses various nets for collection of organisms and metering fish finders or scanning sonars for generation of soundwaves to investigate the distribution of marine organisms.
- Acoustic investigation uses a multi-beam acoustic sounding system or sub-bottom profiler for generation of soundwaves to investigate the geographical features of the seafloor and the sedimentary layer under the seabed.
- Underwater/seafloor investigation uses an unmanned underwater survey vessel represented by ROV and AUV to perform activities on the seafloor such as underwater and seafloor photographing, sampling, and installation of observation devices.
- Geophysical exploration uses a seismic reflection survey system that performs soundwave analysis with the use of an air gun (audio source device) and streamer cables (wave receiving device) and maeasurement system for the gravitational force and magnetic force of the earth to investigate the geographical features of the seafloor, the structure under the seabed, etc.
- Sampling investigation uses a bottom sampler such as a piston corer, a water sampler, excavating equipment, etc., to perform underwater and under-the-seabed sampling.

## 2.2 Technological requirement for special vessels

To perform these investigative observation activities accurately and efficiently, investigative observation ships are required to satisfy the following elements different to general ships.

- Auxiliary facilities for observation such as a winch and a crane for lifting from and putting into the sea of various observation devices and a sufficiently wide work deck shall be provided.
- The work deck height above the sea level shall be lower in consideration of lifting from and putting into the sea of various observation devices.
- In order to prevent the vessel from swinging as little as possible, the observation winch and system shall have a heave compensation capability against motion generated by lifting from and putting into the sea observation devices.
- A laboratory for analysis and storage of samples and data obtained by investigative observation work shall be provided.
- A system for efficiently processing the obtained large amounts of data shall be provided.
- Noise generated by the propeller and the vessel during sailing shall be reduced and bubbles shall not enter into the position of the transmitter/receiver mounted on the bottom of the ship in order to maintain the performance of acoustic equipment mounted there.
- Excellent damping performance for suppression of vessel swing shall be provided so as not to disturb activities on the work deck and in the laboratory during sailing.
- Excellent vessel controllability and dynamic positioning performance that enables the ship to stay within a certain area even in stormy weather shall be provided in order to operate sampling equipment, etc.
- Improved fuel efficiency in travelling to the test sea area shall be attained and continuous efficient low-speed sailing for observation work shall be possible.

## 2.3 MHI technology for special vessels

In response to the above required functions and technological requirements for special vessels, MHI has the following specialized elemental technologies for special vessels.

(1) Realization of various observation activities

The capability to examine and evaluate technological elements regarding the vessel, engine, electricity, and observation in reference to technological requirements that vary according to observation activities, and the capability to determine the whole layout to which these technological elements are integrated and to examine and adjust optimum observation devices and auxiliary observation devices that provide functions according to the purpose.

(2) Optimization of on-vessel layout

The capability to arrange a research area, living quarters, engine section, etc., within the limited space on the vessel in a high-density and highly functional manner.

(3) Optimum vessel shape and propulsion system taking into consideration the propulsive, acoustic, seaworthiness, and dynamic positioning performances

The capability to select a vessel shape and propulsion system enabling both high propulsion efficiency and quietness that are trade-off to each other and to select a vessel shape and a swing reduction device that suppress vessel swing so as not to disturb observation activities on and off the vessel during sailing, and the capability to examine and evaluate the dynamic positioning performance that enables the ship to stay within a certain area with use of actuators such as the propulsion units and the thrusters.

(4) Realization of high levels of quietness and power manageability due to adoption of electric propulsion system

The capability to examine and adjust the adoption of an electric propulsion system and the achievement of such adoption. The capability to examine and evaluate the quietness, taking advantage of the electric propulsion system to the maximum extent. The capability to examine and set the power management that contributes to energy saving effects due to selection of a generator usage pattern according to the on-vessel electric power load.

## 3. MHI achievements of special vessel building in recent years

MHI has built many special vessels utilizing technological elements required for special vessels. **Table 1** shows MHI's records of special vessel building since 2013 including those under construction and the main specifications of such special vessels.

**Table 1 MHI's records of special vessel building results since 2013**

| Ship name | Ship owner (name upon ship completion) | Ship type | Completion (year) | Major dimensions Length (m) | | Width (m) | | Depth (m) | International gross tonnage |
|---|---|---|---|---|---|---|---|---|---|
| Muroto | Japanese Ministry of Defense | Cable laying ship | 2013 | Appx. 131.2 | x | 19.00 | x | 11.00 | Appx. 4,900*1 |
| Shinsei maru | Japan Agency for Marine-Earth Science and Technology | Research vessel | 2013 | Appx 66.0 | x | 13.00 | x | 6.20 | 1629 |
| Ramform Titan | PGS TITANS AS | Geophysical research vessel | 2013 | Appx 104.2 | x | 70.00 | x | 14.20 | 20637 |
| Ramform Atlas | PGS TITANS AS | Geophysical research vessel | 2014 | Appx 104.2 | x | 70.00 | x | 14.20 | 20637 |
| Ramform Tethys | PGS TITANS AS | Geophysical research vessel | 2016 | Appx 104.2 | x | 70.00 | x | 14.20 | 20637 |
| Ramform Hyperion | PGS TITANS AS | Geophysical research vessel | Scheduled in 2017 | Appx 104.2 | x | 70.00 | x | 14.20 | Appx. 20,640 |
| Kaimei | Japan Agency for Marine-Earth Science and Technology | Research vessel | 2016 | Appx 100.5 | x | 20.50 | x | 9.00 | 5747 |
| Shinyomaru | Tokyo University of Marine Science and Technology | Training ship | 2016 | Appx 64.6 | x | 12.10 | x | 4.55 | 1343 |
| Substituting Tenyomaru | National Fisheries University | Training ship | Scheduled in 2018 | Appx 64.7 | x | 11.90 | x | 4.50 | Appx. 1,340 |

*1: Reference displacement weight (tons)

(1) Muroto (completed in 2013)

A cable laying ship that has a set of cable laying devices and ocean observation devices. This special vessel is used to lay and maintain sonars and cables fixed under water.

(2) Shinsei maru (completed in 2013) (**Figure 1**)

A research vessel built for research of the marine ecosystem in the Tohoku region to promote research needed for "Tohoku Ecosystem-Associated Marine Sciences" established to help the recovery of the fishery industry, a major recovery issue, from the Great East Japan Earthquake that occurred on March 11, 2011. This special vessel enables comprehensive research and observation in adjacent and coastal water areas in the Tohoku region such as ocean environment observation, investigation of geographical features of the seafloor, and marine meteorological observation, in an effective and efficient manner.

The design of Shinsei maru takes into consideration the operation of transportable observation devices in addition to various fixed observation equipment, and is used for a wide range of investigations and observations such as hydrographic and meteorological observation, acoustic investigation, geophysical exploration, sampling investigation, and seabed surface observation with the use of ROV and Deep Tow.

The propulsion system adopts an electric azimuth thruster to reduce underwater radiated noise, and constructs a dynamic positioning system in combination with a large tunnel-type bow thruster.

**Figure 1 Shinsei maru**

(3) Ramform Titan/Atlas/Tethys (completed in 2013/2014/2016) and Ramform Hyperion (to be completed in 2017)

Uniquely shaped geophysical research vessels, called the Ramform type, developed by Petroleum Goe-Services ASA (hereinafter referred to as PGS), the Norway-based major resource exploration company. These special vessels are used for a three-dimensional seismic reflection survey.

A seismic reflection survey is an observation method to study geological properties under the seabed by obtaining positioning data in addition to reflected waves towing an air gun that transmits seismic waves (acoustic wave) to the seabed and streamer cables that incorporates a hydrophone for observation of reflected waves from the seabed .

The three-dimensional seismic survey is defined as a method to explore a situation of the seabed in a three-dimensional manner ty towing pararell multiple streamer cables.

When the number of towed streamer cables is large, three-dimensional seismic reflection survey can explore wider areas during one sailing and therefore the exploration efficiency increases. For this reason, these special vessels have a width of 70 meters that enables towing of up to 24 streamer cables, thus attaining high-level exploration.

(4) Kaimei (completed in 2016)

A research vessel built for efficient wide-area seabed investigation such as investigation of marine resource distribution and for comprehensive scientific research including the study of the generating environment of minerals and mineral deposits. This special vessel is the world's first research vessel that can perform full-scale three-dimensional seismic survey and ocean observation on the same vessel. Details of Kaimei are presented in the next section.

(5) Shinyomaru (completed in 2016) (**Figure 2**)

A training ship built for marine science education from Tokyo Bay to the tropical regions of the Pacific Ocean. This special vessel has many research and observation devices in addition to the training equipment. Therefore, this small vessel is equipped with large amount of equipment includingmany investigative observation apparatuses in addition to fishery equipment and a transportable container laboratory mounted and utilized on the deck.

Shinyomaru can perform organism investigation with the use of surface middle /bottom layers trawling equipment mounted on the stern, exploration of seafloor geographical feature exploration and seafloor organism investigation with the use of acoustic equipment mounted in the ship’s bottom dome, and observation of the seawater temperature, salt content, tidal current, etc., with the use of CTD and ADCP. Also, operation of a seismic survey device (transportable) or AUV can be handled. The propulsion system adopts an electric controllable-pitch propeller (CPP) to take care of underwater radiated noise and low-speed sailing ability.

This special vessel was launched in November 2015 and delivered in March 2016.

**Figure 2 Shinyomaru**

(6) Tenyomaru (to be completed in 2017)

A multipurpose ship having functions of a fishery training ship to perform practical training, investigation, and research with regard to the marine products industry (fishery), marine resources, and marine organisms, and functions of a fishery investigation ship to perform various investigative tasks such as ocean environment investigation, resources investigation, and biological organism investigation.

Tenyomaru can perform organism investigation with the use of surface layer/middle layer/bottom trawling equipment mounted on the stern, seafloor geographical feature exploration and seafloor organism investigation with the use of acoustic equipment mounted in the ship's bottom dome, and observation of the seawater temperature, salt content, tidal current, etc., with the use of CTD and ADCP.

This special vessel is scheduled to be launched in March 2017 and delivered in October 2017.

## 4. Construction of the research vessel Kaimei

In March 2013, Japan Agency for Marine-Earth Science and Technology, hereinafter referred to as JAMSTEC, held a proposal-based public offering for building a research vessel having the capability to perform not only wide seabed investigation such as investigation of marine resource distribution but also comprehensive scientific research including the study of the generating environment of minerals and mineral deposits.

In response to this public offering, in September 2013, MHI was selected as the prospective contractor, and held meetings many times with JAMSTEC. In accordance with the requirements of JAMSTEC, the research vessel Kaimei was designed to have various functions of a crustal structure exploration, an under-seabed sample collection, a multiple-AUV simultaneous operation, and a general ocean observation as main investigative observation functions. This special vessel is the world's first research vessel that can perform full-scale seismic reflection survey and ocean observation on the same vessel. **Table 2** shows the specifications of Kaimei, and **Figure 3** shows the photograph.

**Table 2 Main specifications of the research vessel Kaimei**

| | |
|---|---|
| Overall length | 100.5 m |
| Width (at vessel center) | 19.0 m |
| Width (at expanded part of stern) | 20.5 m |
| Depth | 9.0 m |
| Gross tonnage | 5,747 tons |
| Sailing speed | 12.0kn |
| Cruising range | Approximately 9,000 miles |
| Maximum capacity | 65 persons (27 crew members and 38 researchers) |

**Figure 3 Research vessel Kaimei**

(1) The research vessel Kaimei can carry out the following three types of survey to image the internal structure of oceanic crust according to the purpose: two-dimensional (2D) seismic survey with the use of one streamer cable of 12,000 meters in length, three-dimensional (3D) seismic survey with the use of four streamer cables of 3,000 meters in length, and high-accuracy shallow-layer three-dimensional (HR3D) seismic survey with the use of twenty streamer cables of 300 meters in length. A sub-bottom profiler, a gravimeter, and a magnetometer provided on this vessel enables multilateral crustal structure surveys in conjunction with operation of the sea bottom seismometer, (**Figure 4**).

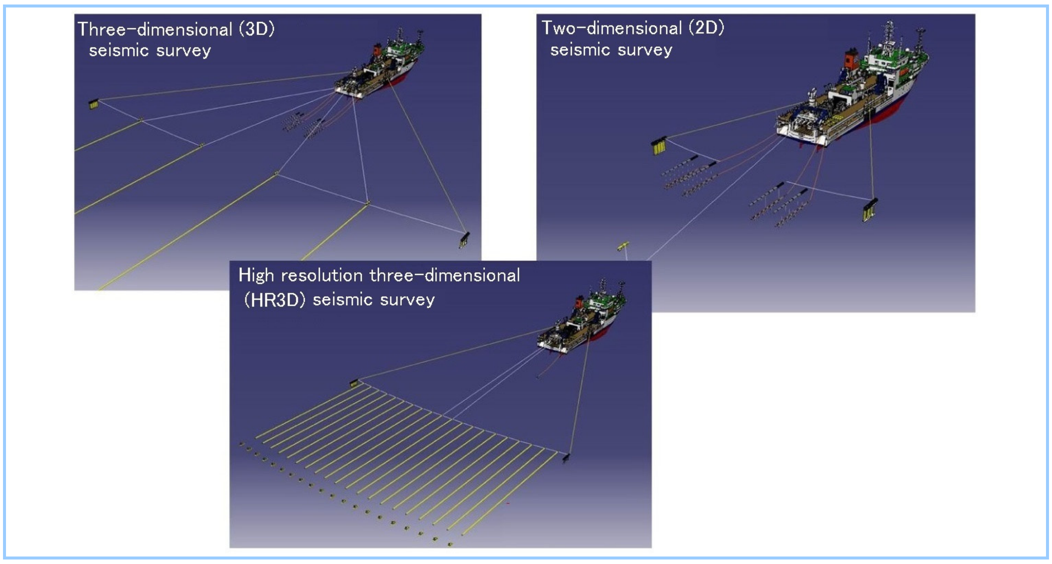


**Figure 4 Three-mode multi-channel seismic survey system of the research vessel Kaimei**

(2) Samples under the seabed can be collected by using on-vessel auxiliary observation devices to handle a giant piston corer (the maximum length of 40 m and the maximum operating depth of 11,000 m), a boring machine system (the maximum operating depth of 3,000 m), power glove samplers (clamshell type and six-finger type, the maximum operating depth of 6,000 m for the both), etc., as fixed and replaceable observation devices. In addition, the winch that handles these observation devices has an AHC (Active Heave Compensation) function to reduce the effect of swinging of the vessel on observation devices and cables.

(3) This special vessel can accommodate three autonomous underwater vehicles (AUV) and operate them simultaneously using underwater communication devices and acoustic positioning apparatuses equipped on the vessel’s bottom to enable various underwater and seabed observation activities.

(4) This special vessel can perform underwater/seafloor/under-seafloor investigation in an accurate and real-time manner due to satisfactory acoustic apparatuses including deep and shallow sea multi-beam acoustic sounding devices, sub-bottom profilers, and deep and shallow sea multi-layer flow direction and flow velocity meters. In addition, atmospheric and ocean observation can be performed using meteorological and hydrographic observation

devices, GPS, an automatic ejector of the meteorological sonde, and surface seawater analysis devices. Furthermore, this special vessel can place and withdraw TRITON buoys.

(5) This special vessel has a laboratory equipped with various analysis equipment and a sample storage that allow collected samples to be analyzed in a fresh state. In addition, an on-board LAN system that enables efficient processing of a large amount of information such as sailing information and observation device data everywhere on the vessel is established in order to enhance the accuracy and efficiency of research activities.

(6) The propulsion system adopts two electric azimuth thrusters. This enhances controllability in combination with a tunnel-type bow thruster and an elevating and rotating bow thruster mounted on the bow. These actuators are controlled integratedly by the dynamic positioning system (DPS), allowing accurate vessel control and dynamic positioning that keeps the ship within a certain area with easy operation. As a result, observation activities can be performed in an efficient manner.

The dynamic positioning performance of this vessel allows the vessel to stay within an area having a radius of 50 m under conditions where the wind speed is 15 m/s (from any direction), the significant wave height is 3 m (from any direction), and the tidal current speed is 5 knots (from +/-30 degrees from head-on). This performance is determined through simulative examination and confirmed by testing using a model.

(7) For maintaining the performance of underwater acoustic devices equipped on the vessel's bottom and enhancing the accuracy of seismic survey, measures to reduce underwater radiated noise and bubble generation are taken such as optimization of the propeller shape, adoption of an electric propulsion system, two-stage reduction in vibration of the main power generating engine, application of a vibration control material onto the external panel of the vessel bottom, and optimization of the bow shape.

(8) For improvement in observation efficiency in bad weather, this special vessel is equipped with a variable cycle anti-rolling tank (ART) as a vessel rolling reduction device using the movement of liquid in the tank in addition to DPS described above. Adoption of the variable cycle type enables generation of a rolling reduction effect according to a change of the vessel rolling cycle.

(9) This special vessel is a next-generation research vessel that realizes a high-density and high-functionality layout of the research area, living quarters, engine section, etc., within a limited space on the vessel having an international gross tonnage of 6,000 tons or below, and is equipped with facilities that realize energy-saving, observation workability, controllability, and environmental friendliness. In addition, an appearance suitable for a next-generation research vessel is realized by adopting a round shape for the upper front center part of the upper structure to bring about a design accent in consideration of the functionality in the pilothouse. Not only is a cowling from the bow to the vessel side provided in order to create a beautiful side view, but also the whale watch room, which is integrated with the mast on the top story of the upper structure, is elaborately designed.

## 5. Conclusion

The research vessel Kaimei was launched in June 2015 and was delivered in March 2016 after a wide range of trial operations at sea for the mounted observation devices. This special vessel is expected to enable efficient wide seabed investigation such as that of marine resource distribution and comprehensive scientific research including the study of the generating environment of minerals and mineral deposits. We will continue to contribute not only to investigation, research, and development of marine resources, but also to the ways to expand Japanese ocean development, utilizing many special vessel designing and building technologies cultivated in the past.