Development of the High-Speed Mono-Hull Type Passenger and Car Ferry "Unicorn"

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The fastest passenger and car ferry in Japan, which can carry 423 passengers and 106 cars, has been completed. The Ship can be operated at a speed of more than 42 knots which is about twice that of a conventional car ferry and now in commercial service on the Tsugaru Channel between the Honshu Island and Hokkaido Islands. The technical features are as follows. (1) Newly developed slender deep-V form mono-hull. (2) A tough light weight construction using high tensile steel in the main hull and aluminium alloy in the superstructure. (3) A reliable high-power propulsion system consisting of 4 high-speed diesel engines and 4 individually steerable water jet pumps.

1. Introduction

Recently, ship speeds have been increasing, and in particular, there is strong demand for higher speed passenger and car ferries. "Unicorn" is the first high-speed mono-hull type passenger and car ferry in Japan. Developed to accommodate a loading capacity of more than 100 cars, the ship is capable of speeds of about twice that of conventional passenger and car ferries, and is designed to be competitive with other means of transport such as railways and tunnels.

Construction of the ship, "Unicorn" was started in May 1996, and business operation was started in June 1997 by East Nihon Ferry Co. The ship entered service on the route between Aomori and Hakodate winning a good reputation all around. **(Fig. 1)**

2. Present Status of High-speed Passenger and Car Ferries

Domestic passenger and car ferries engaged on long range routes in Japan shoulder the domestic physical distribution of trucks and trailers as the main means of transport. They operate at speeds as high as 20—27 knots, which falls into the high-speed range for general merchant ships. Such speeds are located at the upper limit of the speed range for conventional displacement type ships.

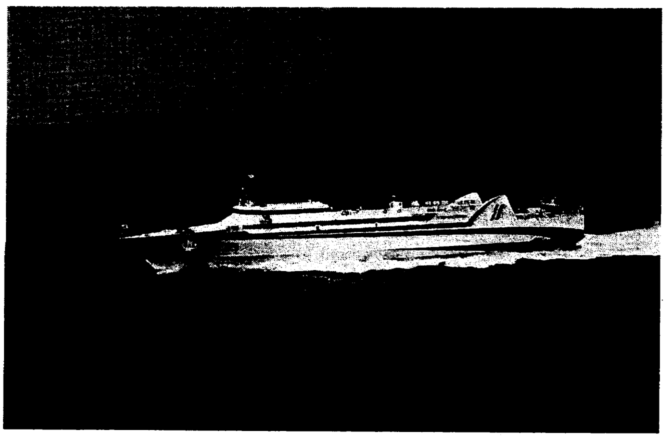

Fig. 1 Photograph of Unicorn

Still, there is ever greater demand for fast passenger transportation on the sea. Recently, many small fast boats for commuters have appeared mainly ply the routes to and from isolated islands[(1)].

Fig. 2 shows the relationship between the speed of existing ships and deadweight. High-speed passenger and car ferries are increasingly expected to have operating speeds of 30—40 knots in the high-speed range and a deadweight ranging from several hundred to one thousand tons. These factors are in the extrapolation range for conventional displacement type ships and fast passenger ferries, indicating that the undeveloped performance as the ship is required[(2)].

Though high-speed passenger and car ferries have already appeared mainly in Europe 4—5 years ago, it will be necessary for fast ferry service in Japan to meet the present conditions of passenger and car ferry operations.

In particular, the following two matters are most important.

(1) Such vessels must be highly reliable in keeping low rates of voyage cancellations close to those of conventional

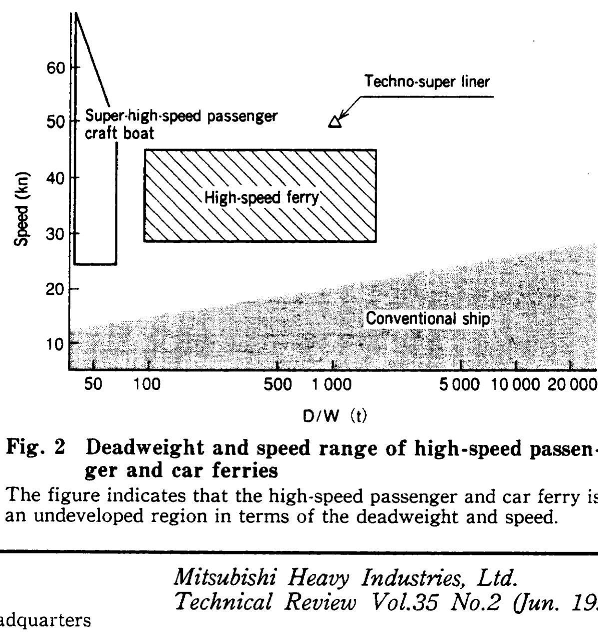

Fig. 2 Deadweight and speed range of high-speed passenger and car ferries
The figure indicates that the high-speed passenger and car ferry is an undeveloped region in terms of the deadweight and speed.

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passenger and car ferries all year round even under the severe sea conditions common around Japan.

(2) Such vessels must also be capable of loading cargo trucks in such fashion as not to ruin high-speed operations because the existing routes are commonly used for cargo transport.

Taking these two requirements into consideration, Mitsubishi Heavy Industries, Ltd. (MHI) developed a novel passenger and car ferry utilizing the specific technology the company evolved and applied taking advantage of its experiences with numerous high-speed boats, and the basic technology fostered in the development of the Techno-Super Liner.

3. Outline of Design

The hull form is a newly developed slender deep-V form mono-hull, which is excellent in sea kindliness.

Principal particulars of the ship are shown in **Table 1**, and its general arrangements are shown in **Fig. 3**, respectively.

Cars are loaded on the car deck which is the first deck. The mezzanine deck is made of aluminium alloy provided at the height of 2.65 m above the car deck, and two central lanes are used for large cars. A maximum of five large buses and trucks up to twenty tons can be loaded. Smaller size trucks can be loaded on the rear part of the car deck. One set of 5.2 m wide ramps is equipped at the stern in an arrangement where the direction of the cars can be reversed in the turning space located at the bow part. The movable ramp intended for the mezzanine deck is also made of aluminium alloy.

The most important matter to achieve the target speed in the case of high-speed ships is to reduce the light weight which comprises 70—80% of the total ship weight. For this purpose, the main hull below the upper deck is made of steel with extensive application of high-tensile steel, while the upper structures, including the passenger rooms, are made of aluminium alloy, taking into consideration the safety in collision,

Table 1 Principal particulars

Overall length	100.56 m	Maximum number of passengers	423 persons
Breadth	14.90 m	Number of cars	106 passenger cars
Depth	10.30 m		78 passenger cars, 5 large cars
Draught	2.70 m	Main engine	MTU 20 V 1163 TB 73 L × 4 sets
Gross tonnage	1 498 t	Maximum continuous output	8 840 PS × 1 275 rpm
Maximum speed at sea trial	42.39 kn	Propeller	KaMeWa W/J 112 SII × 4 sets

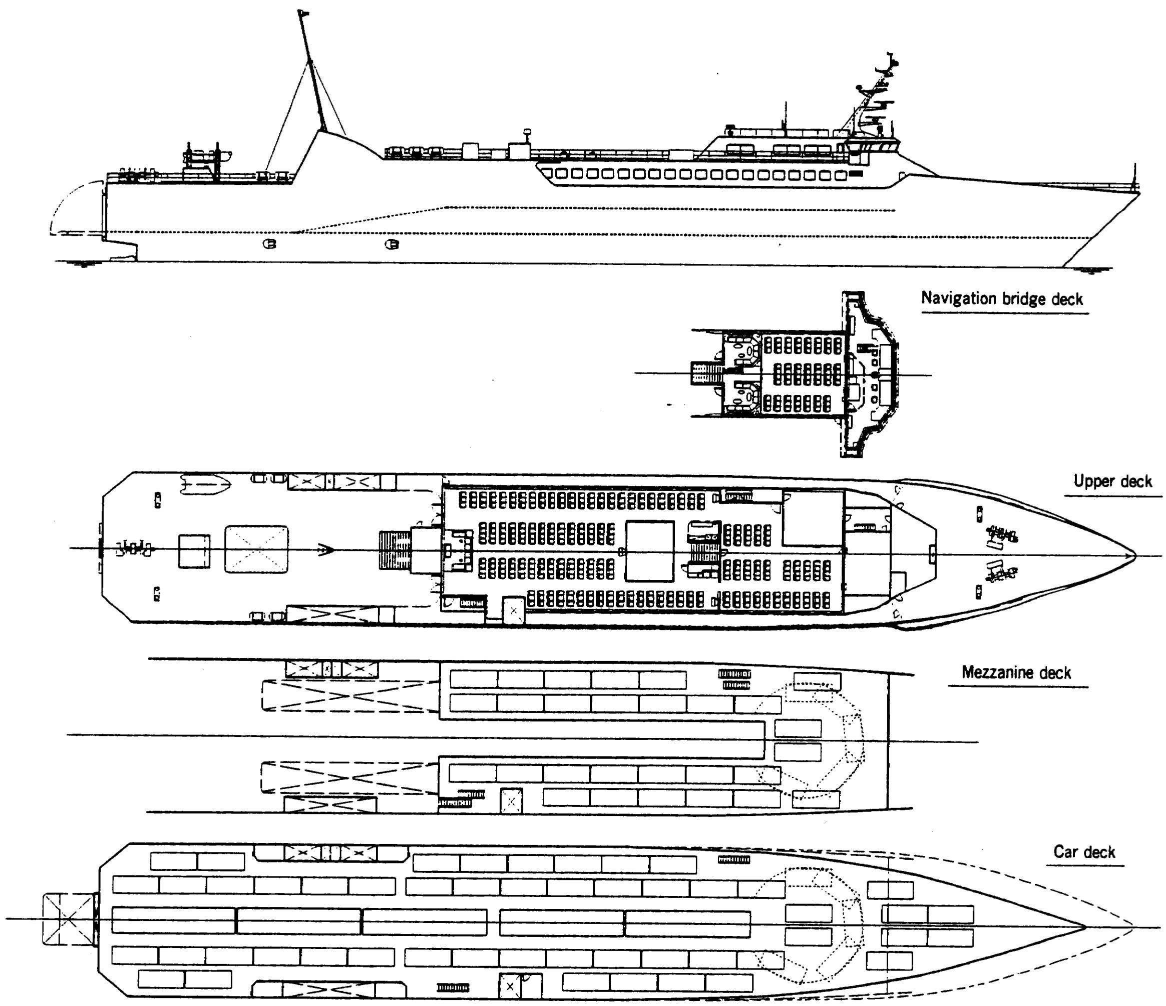

Fig. 3 General arrangements

measures for fire protection of the car deck space, repair work in dock, and the construction cost, etc. A system was adopted in which the aluminium upper structures are welded to the main hull through aluminium clad steel plate.

Complicated structure and design are eliminated in the propulsion plant as much as possible from the viewpoint of reliability. In order to realize uniformity of the parts, four independent engine-shaft systems were adopted in which the main engines, gears, and water jets of the same type are combined. The water jets for four shafts are independently steerable, operated by joystick controllers which are arranged on both bridge wings, enabling versatile maneuvering motion through interlocking operation with the bow thruster.

3. 1 Propulsive performance

(1) Resistance by appendages

It is necessary to gain a quantitative grasp of the resistance caused by appendages such as fin-stabilizers and bow thruster which is small in ratio to the whole hull resistance from the viewpoint of improving propulsive performance through the minimization of hull resistance.

In one example, flow simulations by using CFD (Computational Fluid Dynamics) were performed on the bow thruster opening. The shape of the opening for the bow thruster was changed so as not to disturb the streamline near the opening, and the angle of the grid was examined by observing the flow using tafts. These results were incorporated in the basic hull form, and the optimum hull form was selected so that total hull resistance is minimized.

(2) Mutual interference of water jet intakes

Four sets of large output water jets are brought very close to each other due to restriction of the arrangement. It was feared that such an arrangement might result in deterioration of the thrust due to mutual interference of the fluid between water jet intakes.

To cope with this phenomenon, observations were made of the flow using a self-propulsion model having a small water jet. Measurements of the flow velocity distribution in the boundary layer were performed, after which the flow with the actual ship scale was estimated by CFD. In so doing the technology to estimate the self-propulsion factors and the quantity of mutual interference at the flush type intake was established.

(3) Propulsive performance in waves

When air suction is generated from the water jet intake while the ship is in waves, the load on the impeller instantaneously becomes close to zero, and the fuel injection is automatically cut off so that the main engine does not enter an over-speed condition. When this phenomenon is frequently generated, a drop in speed and adverse effects on the main engine are feared.

It was observed that the air sucked by the fin-stabilizers exposed above the water surface can be led into the outside water jet intakes from the result of the self-propulsion model test in the beam sea. The position of the fin-stabilizers was adjusted to be in a range in which motion damping is not adversely affected.

3. 2 Hull Structure and fittings

In the hull structural design, emphasis was placed on the lively weight reduction design taking into consideration the degree of importance of the various members and the possible effects thereof in a damaged condition.

Since the ship is of a character which falls between the conventional ship and the high-speed small craft, there are as yet no structural design standards that applicable directly to it at the present stage. Consequently, domestic standards for high-speed mono-hull type crafts up to 50 m in length which are recently established were applied with necessary modifications. In determining the final dimensions of each member, the design load was verified using ship motions and wave loads measured in tank tests and estimated by simulation calculations. After the arrangement of the main structures and the scantlings of the members were determined, various FEM (Finite Element Method) analyses were performed to review the detailed design. At the same time, fatigue strength was also evaluated to check the structural reliability of the vessel design.

One example of the FEM analysis model is illustrated in **Fig. 4**.

In the area where the ship is engaged in a certain season, whales are frequently seen, and the damage that would be generated in collision with a whale were estimated. The calculation results, shown in **Fig. 5**, indicate that the hull is strong enough not to be damaged in a collision with a whale. Further, collision acceleration is also very small thus verifying that there are no problems in terms of safety.

The manufacturers' standard of each fitting were reviewed taking into consideration the service conditions in which the ship is expected to operate, thereby greatly reducing the weight of the vessel. In particular, Danfoth type anchors and wire ropes of the anchoring equipment, armorless type electric cables, aluminium honeycomb internal wall materials, and the like made of light materials or weight-saving specifications were adopted.

In the construction stage, every block and piece of equipment was weighed in order to control weight. The difference in the light weight when completed from the weight in the design plans was only 0.5%.

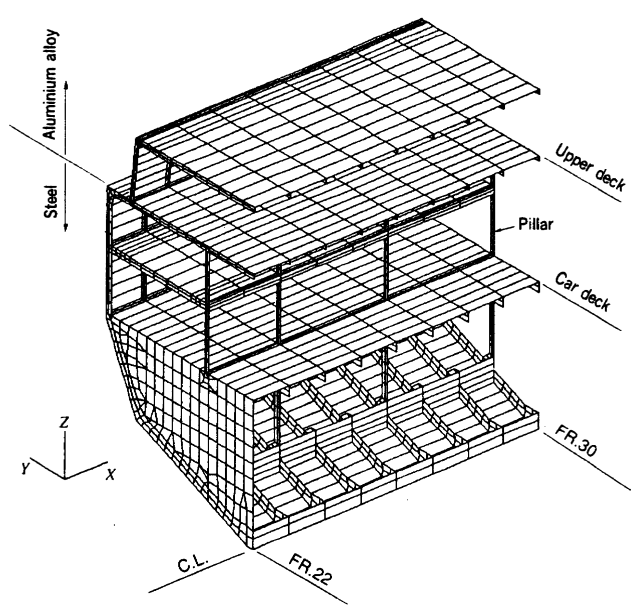

Fig. 4 Example of FEM model

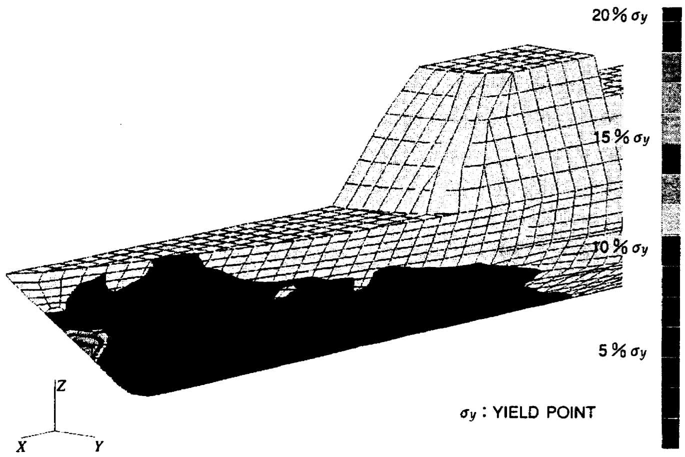

Fig. 5 Stress analysis of collision with whale
The figure indicates the results of the estimated stresses in collision with a whale.

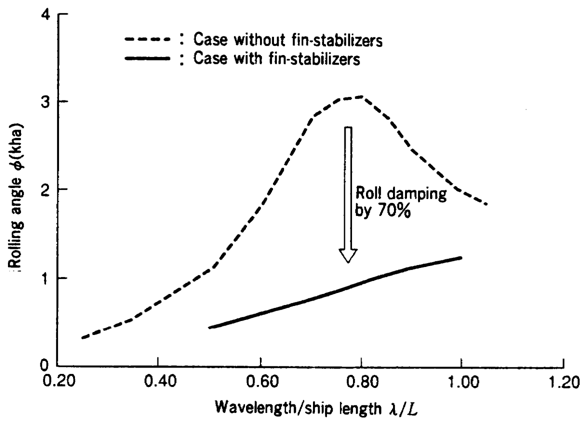

Fig. 6 Roll damping by fin-stabilizer
The graph shows the effect of roll damping by fin-stabilizers estimated from the results of tank tests.

In order to secure comfortable habitability as a passenger ship, a flexible mounting system was adopted for not only the main engine and generator engines which are the main excitation source of vibration, but also the hydraulic equipment. In particular, vibration response analysis by FEM was performed on the complicate structural parts like the water jet ducts. Estimates were also made of noise levels by the SEA (Statistical Energy Analysis) method with respect to the special structure with the upper structures made of aluminium alloy. The results obtained served to help determine where the soundproof material should be placed.

3.3 Roll damping device

The wave conditions in the route between Aomori and Hakodate were examined, where the ship is engaged in order to select the most appropriate motion damping device. It was shown that the beam sea is dominant in the sea state where the wave height exceeds 3 m in the route between Aomori and Hakodate, and roll damping is most effective to improve the comfort of the ride. A non-retractable type fin-stabilizers of roll damping device was equipped near a midship after checking the effect of sufficient damping.

Fig. 6 shows that the roll of the ship is damped by about 70% at the resonance frequency through the installation of the fin-stabilizers.

3.4 Propulsion plant

Fig. 7 shows the arrangement of the propulsion plant of the ship. Four sets of high-speed diesel engines with a continuous maximum output of 6 500 kW are arranged as the main engine. There has been much experience with this type of engine in the high-speed ferries in Europe, demonstrating that they are also very reliable. Each main engine is coupled with a water jet pump through the reduction gears from the aspect of redundancy and weight reduction of the propulsion plant.

The reduction gears consist of a planetary gear system and are miniaturized in size. The casing is made of aluminium alloy. High strength nickel-chromium molybdenum steel (SNCM 439) was adopted for the material of the intermediate shaft. A two pieced ball bearing was adopted for the intermediate shaft bearing, which has been used extensively in high-speed boats. The casing for the bearing is also made of aluminium alloy in order to reduce weight.

Integrated control is performed from the wheel house by two set of engine monitoring systems and VTR cameras during navigation, and the engine room is operated in the unmanned condition.

4. Sea trials

Sea trials were carried out in order to check various performances of the ship which are as shown in **Table 2**.

The maximum speed during sea trials of the ship was 42.39 knots whose speed is ranked highest for diesel driven steel ships. The crash astern distance is about 580 m, and the turning circle is about 400 m (mean value for right and left turns,

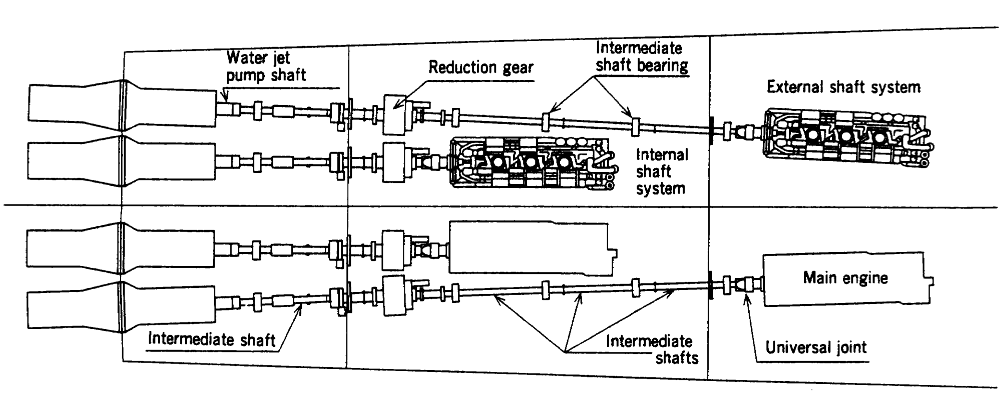

Fig. 7 Arrangement of main engines and water jets

Table 2 Results of sea trial

Items	Results of sea trial		
Speed	Maximum speed at sea trial: 42.39 kn (1/3 DW, 100% output)		
Crash astern distance	About 580 m		
Turning		Maximum longitudinal distance	Maximum transverse distance
	Left turn	About 400 m	About 440 m
	Right turn	About 370 m	About 390 m
Noise	55−67 dB(A) in whole accommodations		
Vibration	1/2 or less of the lower limit of ISO standards in whole accommodations		

equivalent to 4 times the hull length). It was confirmed that the maneuverability is far superior to that of conventional passenger and car ferries.

With regards to the results of the vibration and noise measurements, a noise level of 55 dB(A) to 67 dB(A) was achieved in accommodation areas, while the vibration level was below 1/2 of the lower level specified by ISO standards. Further, it is demonstrated that the ship is sufficiently calm.

5. Conclusion

The passenger and car ferry "Unicorn" is the highest speed ship of its type in Japan. It was built as a first high-speed mono-hull type passenger and car ferry, and entered regular service twice a day since June 5, 1997, playing a new main role in the route between Aomori and Hakodate. In order to ensure high reliability which has been the initial goal, relevant data of hull stress and ship motion in waves has been accumulated in service. The resulting feedback is being applied in the design of the second and subsequent ships.

The authors wish to express their sincere gratitude to the many people of East Nihon Ferry Co. who gave the authors the opportunity of building "Unicorn" with a large number of novel factors.

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