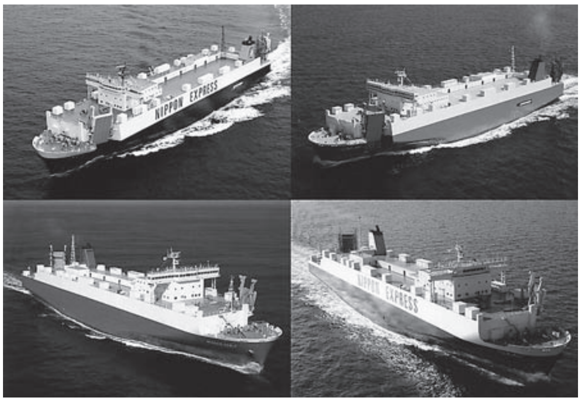

High-Efficiency Roll-on/Roll-off Cargo Ship Adapted to MODAL SHIFT Policy

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A focal point in logistic industries nowadays is the Modal Shift Policy, a major shift from the current main lines of transport predominantly by truck to efficient, low-emission mass transit systems such as domestic shipping and rail transport. To promote this shift, Mitsubishi Heavy Industries, Ltd. (MHI) has developed a large, high-speed, roll-on/roll-off cargo ship capable of ensuring compatibility between the conflicting targets of speedup and fuel economy for domestic shipping (the "RORO ship"). The salient features of the RORO ship include high-speed navigation with a sustained service speed of up to 23 knots, enhanced economic efficiency (powered by a low-speed diesel engine with excellent fuel efficiency as the main engine), reduced environmental load, higher transport efficiency, and an outstanding design enabling the simultaneous mounting of 160 trailers (12m-chassis) and 251 passenger cars.

1. Introduction

Increased transport efficiency, reduced transport costs, and high-quality services are indispensable to promote the modal shift in the domestic shipping industry while coping with diversifying needs of cargo owners. Responding to these needs of the times, Nippon Express Co., Ltd. and MOL Ferry Co., Ltd. plan to commence a joint service on a space-charter base on the Tokyo-Hakata shipping route.

Nippon Express and MOL Ferry have each put RORO vessels into service. The former has independently assigned two RORO-container ships every other day on the Tokyo-Hakata shipping route. The latter has assigned four RORO ships every day on the same route. In the near future, these companies plan to jointly assign four large, high-speed, identical RORO ships for the expansion of their physical distribution services.

To develop the RORO vessels, our company has taken up various technical challenges using the elemental technologies we have accumulated in the construction of high-speed ships.

2. Development objectives

The top concerns in developing this ship are reduced navigation time through speedup and an augmented loading capacity. The following specifications have been presented to us as development objectives by the chartering company and the Ship's owner.

2.1 Reduced navigation time through speedup

The clients requested a reduction in the navigation time from Tokyo to Hakata from 37 hours to 33, based on deliberations of the operational diagram. Accordingly, a service speed of 23.0 knots, with a speed increment of about 3 knots compared with that of existing ships, has been presented as the required specification. Concurrently with this request for speedup, the clients also requested that the overall fuel oil consumption of the four new ships be reduced by more than 20% compared with the fuel consumption of the six existing ships.

Figure 1 shows the energy-saving specification for the new ship in comparison with that for the existing ships, where the fuel oil consumption per day required for transporting 1-ton deadweight is set on the vertical axis.

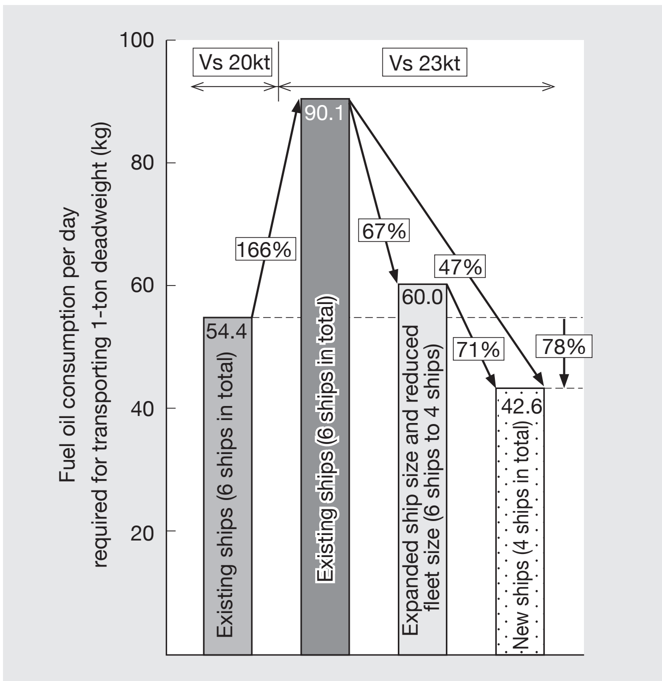

Fig. 1 Required specifications for energy saving

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The total fuel oil consumption of the six existing ships per day required for transporting 1-ton deadweight is about 54 kg and rises by 66% to about 90 kg if the navigation speed is augmented by 3 knots. Even if these six ships are reduced to four ships, the fuel oil consumption is about 60 kg, slightly higher than that of the six existing ships. The targeted reduction of fuel oil consumption by about 30%, to about 43 kg, is the required specification for the new ship. More specifically, the total fuel oil consumption per day for transporting 1-ton deadweight of the six RORO ships, with propulsive performance equivalent to the existing ships, is about 90 kg, while that of the new ship is reduced by about half, to 43 kg.

2.2 Enhanced cargo loading capacity via an expanded vessel size

It is of considerable importance, from the standpoint of improved transport efficiency and reduced transport cost, to expand the cargo transport capacity while reducing the number of ships in the fleet.

Given this factor, it has been determined that the existing fleet of six ships comprising two RORO-container ships and four RORO ships with respective lengths of 110-130m is reduced to four RORO ships. Each of the four RORO ships, however, is enlarged to a 170m-long RORO ship, thereby increasing the fleet cargo capacity by about 30% on a weight basis for the fleet.

3. General description of development

Our company has developed a high-speed, energy-saving hull form with reduced wave-making resistance, in order to attain the development targets described in the previous section. In doing so, we also made serious efforts to improve the propeller capability by closely considering balancing with the cavitation and propeller vibratory force. To fulfill

Table 1 Principal particulars

Length overall	(m)	166.90
Breadth	(m)	27.00
Depth	(m)	23.27
Deadweight	(t)	abt. 6200
Gross tonnage		abt. 10500
Complement		Crew 15 Passenger 12
Vehicle capacity		12-m chassis 160 Car 251
Service speed	(kt)	23.0
Main engine		9UEC52LSE × 1
Max. output		15345 kW × 127 min^{-1}

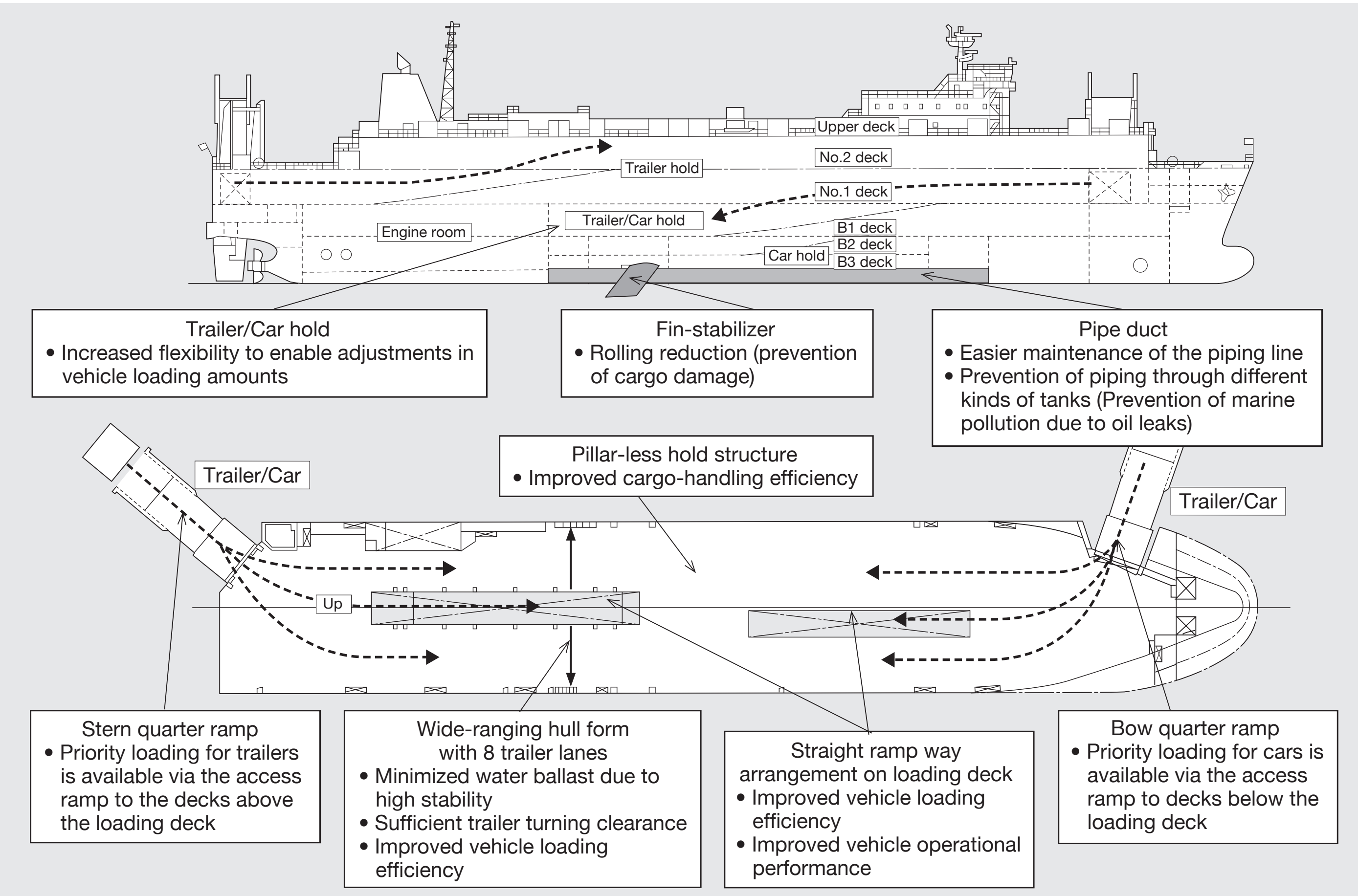

Fig. 2 Outline of the arrangement

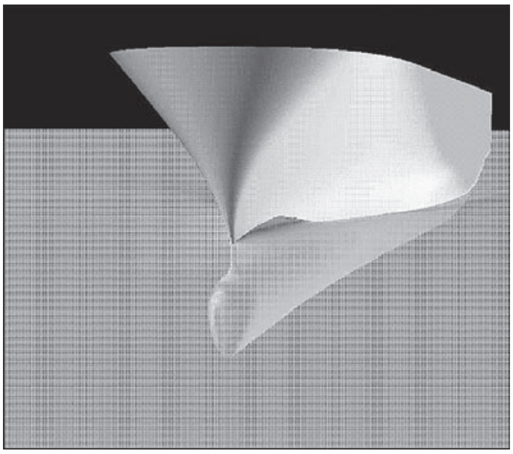

Fig. 3 Example of computation with CFD

the target fuel consumption, on the top of the improvements of the hull form and propeller, the engine department shares the less-than-10% reduction of fuel consumption. And to reinforce the cargo loading capacity, the vehicle loading space has been expanded by applying a wide-ranging hull form and five-layer vehicle holds.

The main particulars of the ship are shown in **Table 1** and an outline of the arrangement is shown in **Fig. 2**

3.1 Hull form plan

The magnitude of hull resistance, especially the wave-making resistance element, influences the performance of the high-speed hull form. In developing the hull form, we therefore worked to minimize the hull resistance using the rapidly evolving techniques of computational fluid dynamics (CFD). **Figure 3** shows the estimated results of wave-making resistance as an example of computation by CFD.

First of all, a series of CFD computations were carried out for the hull form plan. Through this approach, the hull form with minimal hull resistance was identified by computing the effects of many adjustments to the main particulars, such as the ship length, breadth, depth, and center of buoyancy. Next, the bow and stern forms for the hull form thus identified were optimized for selection of candidate hull forms. Finally, a single hull form was selected based on the results of the performance evaluations carried out through model tests with the candidate hull forms selected in the earlier stages.

3.2 Measures for reducing the fuel oil consumption of main engine

High-speed ships of this design are generally mounted with a medium-speed diesel engine of the type mounted on car ferries. As an alternative, we mounted this ship with a low-speed diesel engine with excellent specific fuel-consumption, by rationalizing the arrangement of the engine room periphery. The low-speed diesel engine allows an increase in the power per cylinder versus that of the medium-speed diesel engine, and a reduction of the number of cylinders in the main engine. This reduces maintenance works, saves labor, and improves operational economy.

De-accelerated navigation is compulsory within the Seto Inland Sea and Tokyo Bay along the Tokyo-Hakata shipping route where the ship enters service. Hence, the main engine should be operated under a low load. Long-duration, low-load operation can lead to several adverse consequences, including impaired fuel oil consumption, performance degradation, and defective engine combustion. This issue has been addressed by setting the low zone within a range of 10-20% of maximum power (equivalent to 10-14kt) and establishing a system allowing 12-hour continuous operation. **Figure 4** shows a conceptual diagram of the system. In normal operation, fuel is jetted with two fuel oil injection valves per cylinder through fuel oil pumps. In low-load operation, one fuel oil injection valve is alternately cut off every 90 seconds automatically. The jet pressure of fuel oil injection valve increases in this state, improving the combustion inside the cylinders. As a result, fuel oil consumption can be improved even in low-load operation.

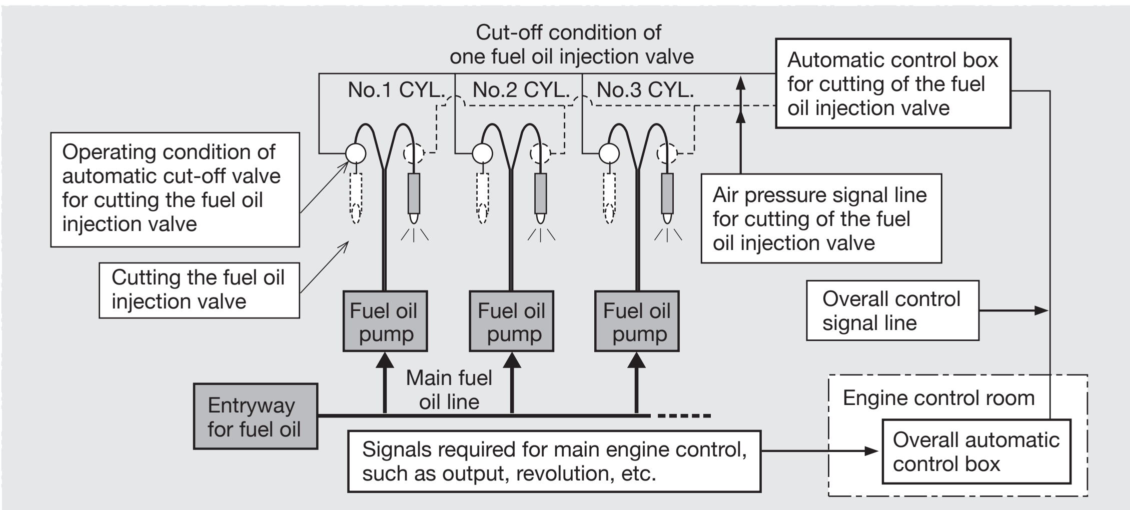

Fig. 4 Conceptual diagram of the automatic control system for cutting the fuel oil injection valve

3.3 Arrangement

As shown in Fig. 2, the ship has five vehicle holds in a five-layer arrangement. These include the No. 1 deck (a loading deck for trailer spaces), the No. 2 deck just above the No. 1 deck (also for trailer spaces), the B1 deck just under the loading deck (a space for both trailers and passenger cars), and the B2 and B3 decks under the B1 deck (spaces exclusively for passenger cars).

The No. 1 deck of the loading deck can be boarded from the bow quarter ramp and stern quarter ramp.

The bow quarter ramp can be used exclusively for the decks below the loading deck, while the stern quarter ramp can be used exclusively for decks above than the loading deck. This arrangement enhances the efficiency of cargo handling, as the priority cargo handling for passenger cars on the bow ramp can be carried separately from the priority cargo handling for trailers on the stern ramp.

Each of the trailer holds is wide, comprising eight lanes for trailer loading. The holds are designed with a pillar-less structure to improve cargo-handling efficiency and vehicle operational performance. To apply the pillar-less structure, special provisions were taken for vibration control, including a main engine bracing and reinforced hull structures just above the propeller (as measures for propeller vibratory force).

A set of fin-stabilizers is installed near the midship to protect cargoes from heavy weather. A bow thruster, two stern thrusters, and a controllable pitch propeller are equipped to improve the ship maneuverability in harbor.

4. Operational status after actual service

The required operational performance of the ship was ascertained by various tests during the sea trial conducted on the stocks. The performance is steadily maintained in commercial operation.

Figure 5 shows the main engine power and fuel oil consumption measured during commercial operation from October 16, 2001 to February 7, 2002. The data have been provided by Aki Kaiun Co., Ltd., the owner of first ship of the series of four ships. As shown in the figure, both the main engine power and fuel oil consumption fall below the levels initially planned. The ship owner praised the vessel for meeting her targets in operational performance in an actual sea area.

5. Benefits to distribution by sea

The original fleet of six ships was restructured to a fleet of four ships by increasing the size and speed of the vessels. As a result, the navigation time was shortened by four hours and cargo transport capacity was increased by 30%, as described in the foregoing.

A ship with the features and performance described above went into service on the Tokyo-Hakata shipping route, and transport service on the route was further improved as a result. To be more precise:

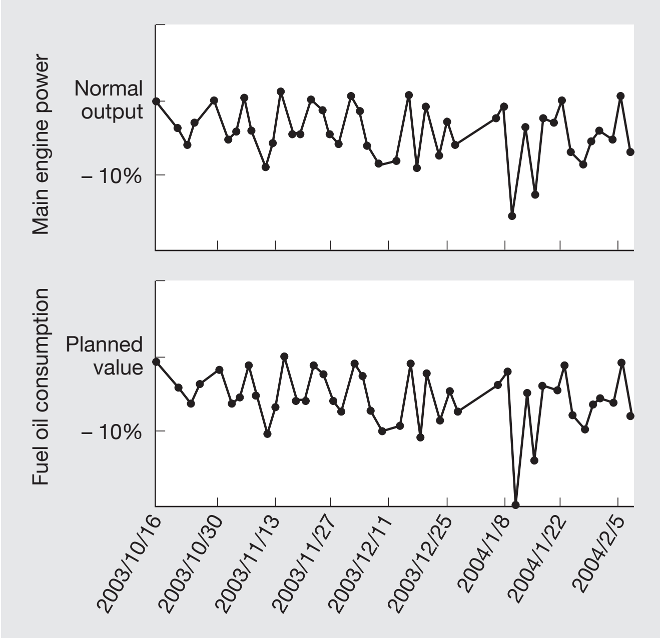

Fig. 5 Main engine power and fuel oil consumption in commercial operation

(1) The improved flexibility of the operation diagram expanded the cargo collection time in large cities: the ship's anchorage time increased by 4.5 hours per day on average in Tokyo and by 1.0 hour per day on average in Hakata, compared with the anchorage times of the previous ships.

(2) The convenience of the daily service between Tokyo and Hakata was enhanced (excluding Sundays).

(3) The service area was expanded by the addition of new mid-calling ports such as Iwakuni, Tokuyama, and Uno. Based on the improvement of the sea transport service between Tokyo and Hakata, a sea distribution system for a Hokkaido-Tokyo-Kyushu route was established through Tokyo as a relay station.

These improvements in capability for sea transport service are expected to activate the international physical distribution through Kyushu as a prospective distribution base and gateway for Asian countries.

6. Conclusion

With the increasing demand for environmental conservation amidst energy shortages, and social problems as reduced urban traffic congestion, the domestic shipping industry is expected to contribute greatly to the development of Japan's society and economy through the deployment of ships with minimal environmental loads and excellent transport efficiency. Under these circumstances, our company takes on the vital roles of launching ships with outstanding operational performance and improving physical distribution systems in communities. Through contributions such as these, we can support the development of the domestic shipping industry and help to promote the Modal Shift.

This ships in this series were awarded the associate "Ship of the Year" prize in 2003 and are expected to play important roles in the future development of sea transport. Several of their features will be instrumental in promoting the Modal Shift Policy, particularly their reduced in navigation time through high-speed performance, their improved economy and reduced environment burden through low-fuel consumption capability, and their improved transport efficiency through expanded ship sizes.

Three new vessels were completed in succession from September 2001 to December 2001. Commercial operation has been steadily advancing and taking on efficient patterns based on the four-ship system since January 6, 2002.

Finally, we would like to express our thanks to the following parties for opening the gates to the production of this series of ships:

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