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Ro-Ro Passenger Ship for Adriatic Outer Isles and the Croatian National Waters

Professional paper

In order to enlarge and improve the domestic passenger fleet by using their own shipbuiding capacities, the shipyard Viktor Lenac, the passenger ferry operator *Jadrolinija* and *Brodarski institut* (*Marine Research & Special Technologies*) made joint efforts and investments during the years 2002 and 2003 to develop some new designs. Among the projects developed on that occasion, a preliminary design of a "daily" Ro-Ro passenger ship for the Croatian national waters, for the outer isles of the Adriatic, has been created. A short technical description of the above mentioned design is presented in this article. In addition, the main particulars of the specific equipment for this ship type and its purpose in the light of the actual infrastructure of the harbour are given. The survey of model testing is based on the CFD computational fluid dynamics analysis (made by *MARIN*-Wageningen) and on towing tests performed by *Brodarski institut.*

Key words: *preliminary design, RO-RO passenger ships, model tests*

Ro-Ro **putnički brod za jadranske vanjske otoke i nacionalnu plovidbu**

Stručni rad

U cilju obnove domaće putničke flote uz pomoć vlastitih brodograđevnih kapaciteta, tijekom 2002. i 2003. godine došlo je do suradnje i zajedničkog ulaganja *Jadrolinije*, brodogradilišta *Viktor Lenac* i *Brodarskog instituta* na razvoju nekoliko perspektivnih projekata putničkih brodova. Između ostalih izrađen je idejni projekt "dnevnog" *Ro-Ro* putničkog broda za područje obalnog mora Republike Hrvatske, odnosno za povezivanje jadranskih vanjskih otoka s kopnom. U članku slijedi kratki opis spomenutog projekta, čija je dokumentacija izrađena do faze ugovora u tadašnjem *Odjelu projekta i konstrukcije* brodogradilišta *Viktor Lenac* u Rijeci. Navode se glavne značajke specifične opreme za brod ovoga tipa i namjene, podešene donekle postojećoj infrastrukturi u otočnim lukama. Pregled modelskih ispitivanja odnosi se na CFD-numeričke analize strujanja (*MARIN* - Wageningen) i tegljenje modela u bazenu *Brodarskog instituta.*

Ključne riječi: *idejni projekt, Ro-Ro putnički brodovi, modelska ispitivanja*

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1 Introduction

A design of a Ro-Ro passenger ship was made within a joint program on the ship design development of the passenger ferry operator *Jadrolinija*, *Brodarski institut* and the shipyard *Viktor Lenac*, in accordance with the *Plan for the Jadrolinija Passenger Fleet Development* (*Plan obnove putničke flote Jadrolinije*), made effective as of September, 2001. The work on the preliminary design started at the beginning of the year 2002, and the preliminary ship design, including model testing, was completed in the first half of the year 2003.

The Ro-Ro passenger ship with the intended use to connect the eastern coast of the Adriatic Sea and the outer populated islands has been designed as a "daily" ship, i.e. without cabins for passengers, and primarily as a regular liner on the route Split-Vela Luka-Lastovo, with an alternative putting in at the port of Hvar. It does not mean that this ship cannot be used on some other, similar "isle" route or, during the tourist season, for isolated cruises along the coast.

One should bear in mind that the island of Korčula ranks highly among Dalmatian islands as far as its economic development goes, and at the same time, along with the island of Hvar, it is a famous tourist destination. Hence the need for a safe and relatively fast daily service all the year round to connect the island with the coast, i.e. with Split, a powerful economic and transport centre which can expect a considerable rise in the flow of cargo and vehicles, and consequently of passengers, i.e. tourists, to and from the islands, due to the fact that it has recently been connected with Zagreb and Rijeka, and thus with Europe, by means of a modern motorway.

2 Trends in the design requirements

The majority of ship lines, ferry lines in particular, are subjected to seasonal oscillations (summer-winter) in the degree of vehicle and passenger loading. The same is true about this line. In the full tourist season, a twice-daily service to and from the islands is required due to the great increase in the number of vehicles and passengers and, in that period, the service speed of the ferry is of major importance. As for the rest of the year, it can be noted that the needs are significantly reduced. In the autumn and winter, when weather conditions are worse, with more frequent periods of bad weather and rough sea, the safety and sustainability of regular sailing in such conditions are very important.

The loading capacity of vehicles and passengers, which determines the main dimensions of the ship, has to satisfy, to a reasonable degree, the peak transport demands, especially during the summer period.

A good manoeuvrability is also a requirement to be met as the ship on this line has to manoeuvre and put in the limited waters of island ports of Vela Luka (Korčula) and Ubli (Lastovo).

An adequate flow of vehicles and passengers in order to reduce the loading/unloading time to minimum, i.e. the required time spent in ports, is also an important feature of the ferry on this line, as well as on other ferry lines, for that matter.

Taking into account all the above mentioned requirements and the *Plan for the Jadrolinija Passenger Fleet Development* (*Plan obnove putničke flote Jadrolinije*), a preliminary design of a new Ro-Ro passenger ship has been made:

- A drive-through (garage) with access ramps at bow and stern
- Vehicle capacity: 100 passenger cars (on the main deck and on 2 side platforms)
- Passenger capacity: 600 in enclosed saloons and 200 on the open deck
- Propulsion: 2 controllable pitch propellers (CPP); 1 bow thruster in the tunnel
- Speed: minimal service speed of 18 knots

Ever since the work on the preliminary design started, attention has been focused on the optimisation of the ship form in order to achieve the required speed by the economical use of power provided by the main propulsion machinery.

3 A review of main ship particulars

Ship type, intended use and material of construction:

Ship type: twin screw passenger Ro-Ro ferry with a drive-through (garage)

Intended use: transport of passengers and road vehicles (passenger cars, campers, trucks, trailers and buses) on a daily route between the mainland and the outer islands of the Adriatic or major ports.

Material of construction: standard steel used in shipbuilding, grade A

Main dimensions:

Length overall (without the “ducktail”)	96.50 m (approximately)
Length between perpendiculars	88.00 m
Beam	16.00 m
Depth	5.60 m
Draught (maximum)	3.80 m
Deadweight (draught of 3.70 m)	800 t (approximately)

Clear height of decks/platforms:

• Above the main deck (amidships)	4.70 m
• Below the side car platforms	2.30 m
• Above the side car platforms	2.10 m

Speed and power:

Service speed (at 85% of maximum power of main engines and 15% margin for service conditions)	18 knots
Maximum power of main Diesel engines (medium-speed)	2 x 2700 kW, approximately
Diameter of the controllable pitch propellers (2)	2800 mm, approximately
Diesel electric generating unit	3 x 470 kVA, approximately

Basic loading conditions:

100 passenger cars (4.4 m x 1.8 m) and 790 passengers; **or**
48 passenger cars, 8 trailers (of 40 t each) and 790 passengers; **or**
10 passenger cars, 10 trailers (of 40 t each) and 790 passengers

Capacity:

Number of passengers in enclosed saloons	610
Number of passengers on the open deck	180
Total number of passengers	790
Number of European standard passenger cars (4.4 m x 1.8 m) – basic layout	
• on the main deck	78
• hoistable side ramps	22
Total number of passenger cars	100
Number of crew members	20

Class and stability of the ship:

The ship is intended to meet the requirements of the *Croatian Register of Shipping* (*Hrvatski registar brodova*) for the restricted navigation area number 5 in the national service (class C according to the regulation EU 98/18).

The proposed notation of the class is CRS *50A1 5 AM1 AUT1

The stability of the ship is in accordance with the requirements stated in the *Register*, IMO and the EU regulation 98/18 for the two compartment standard.

4 Purpose-related equipment

Vehicle loading/unloading equipment:

Hydraulically effected access ramps at bow and stern have to be large enough to enable a quick and efficient flow of vehicles onto and from the ship.

The bow access ramp at the main deck level shown in Figure 2 is a watertight, two-part folding ramp with:

• driving width of	4.0 m, approximately
• length (excluding flaps)	11.0 m, approximately
• height of clear opening	5.1 m

The design solution of the bow structure system comprises complex conditions such as: the required ramp width, the highest possible pivot point of the ramp on the deck, sufficiently high clear opening in the hull for a safe loading of the highest and longest road vehicles on the ship (trailers, refrigerator lorries and Euroliner coaches), and relatively fine entrance angle of ship lines into the bow bulb. These conditions have been analysed in detail by computer simulations of loading at the ramp slope of +5 to -8 degrees, depending on the available average height of the coast and the ship’s draught.

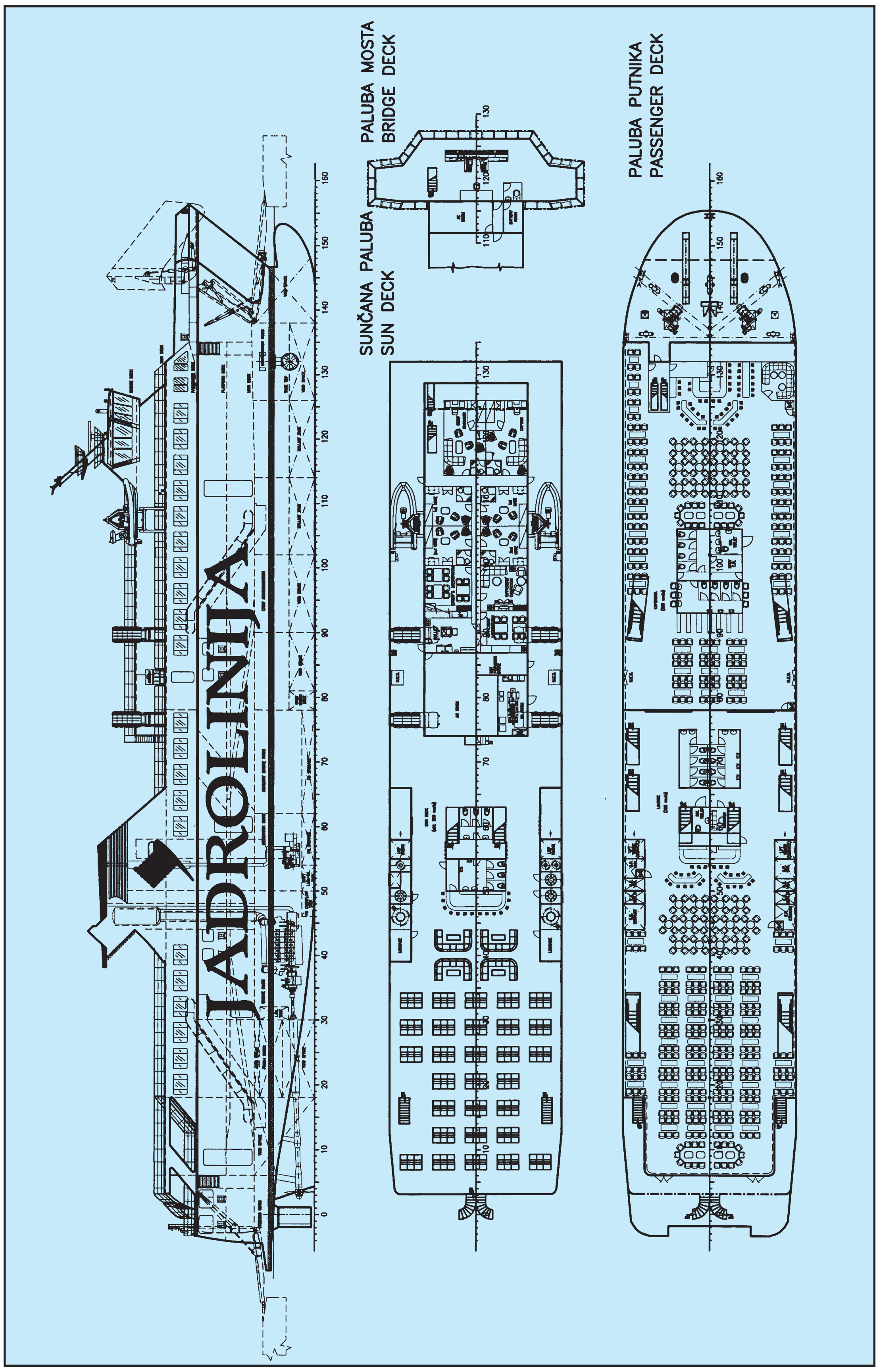


Figure **1 General arrangement - sheet 1**
Slika **1 Opći plan - list 1**

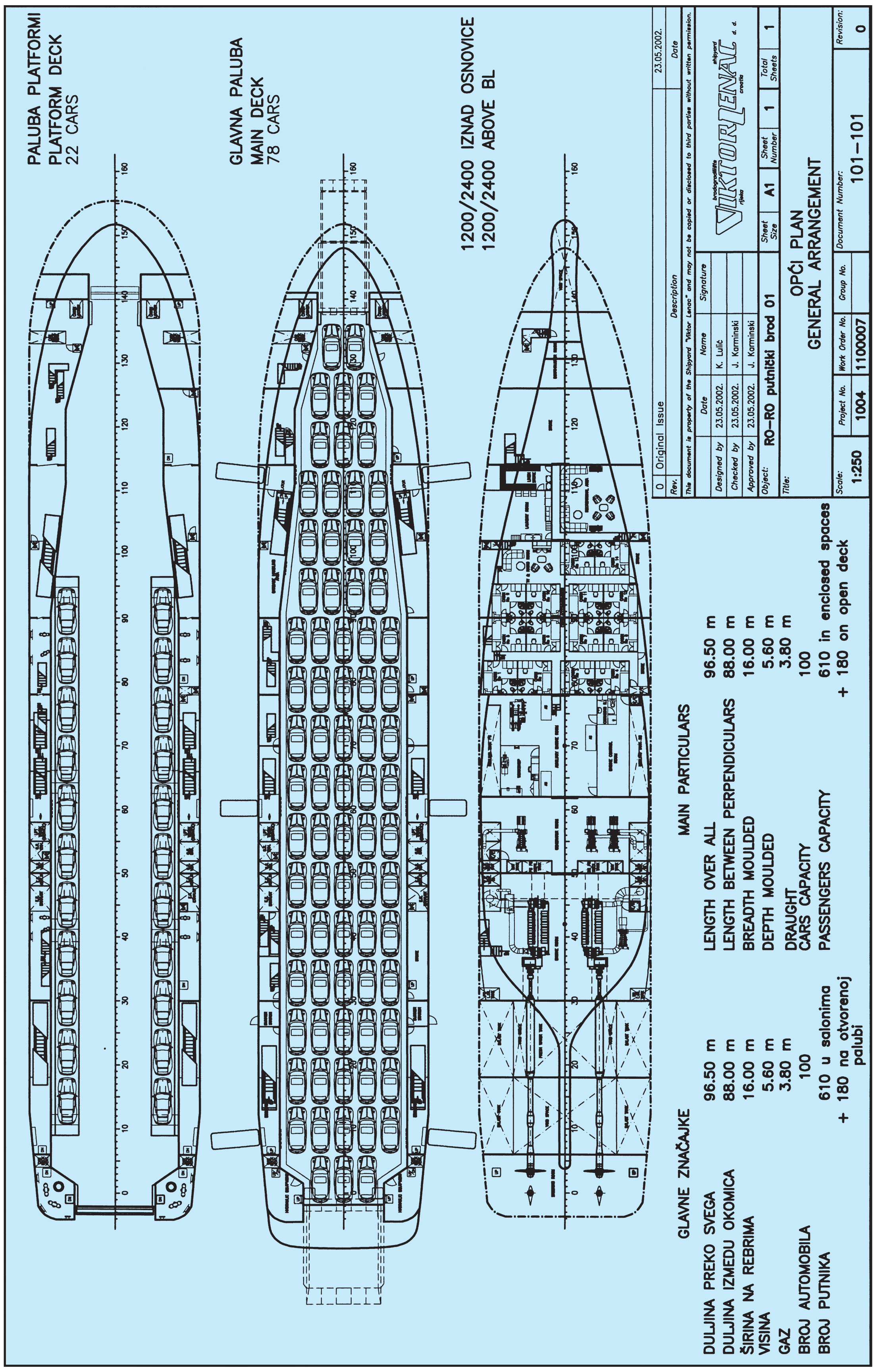


Figure 1 General arrangement - sheet 2
Slika 1 Opći plan - list 2

The different heights of the existing ferry ramps and the coasts in the ports of Split, Vela Luka and Ubli had been photographed and measured before the work on the project started in order to take into consideration this important factor when determining the height of the main deck (vehicle deck) and the adequate dimensions of the ramp.

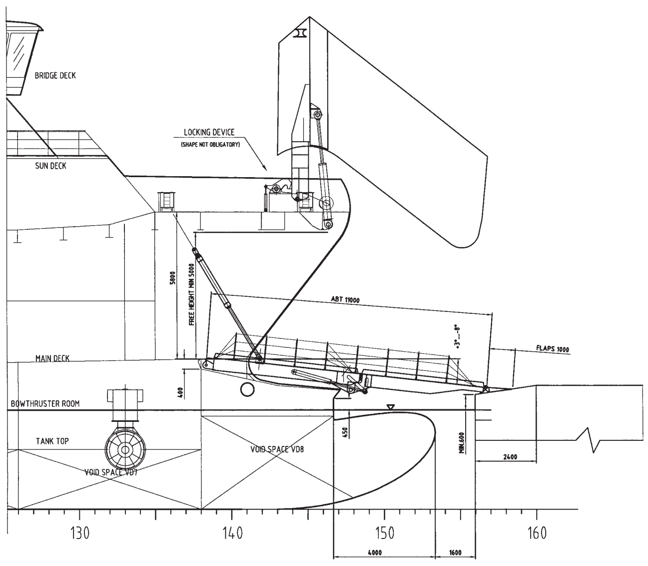


Figure 2 **Bow ramp arrangement**
Slika 2 **Pramčana rampa**

The stern ramp at the level of the main deck is a watertight, one-piece ramp with:

- clear driving width of 6.5 m, approximately
- length (excluding flaps) of 7.0 m, approximately
- height of clear opening (in the hull) 4.8 m
- operational slope of + 5 to -8 degrees

Hoistable side ramps/platforms (2) on the car deck (garage) consist of three hydraulically effected sections (each):

- clear driving width 2.2 m
- maximal operational slope (lowered position) 8 degrees

During sailing, the loaded ramps are lifted into horizontal position at the level of the platform deck.

Passenger loading/unloading equipment:

This equipment plays a vital role in ensuring the required flow of a large number of passengers at loading/unloading in ports. It comprises a hydraulically operated side doors, which, when open, are actually loading ramps for passengers (3 doors on each side), passenger elevators in isolated shafts on both sides, and two passenger escalators on each side (4 escalators all together).

Side passenger ramps (doors) are placed amidships and at both ends and they enable access to the elevators and passenger escalators.

Passenger elevators (lifts) placed amidships are used for vertical communication between the main deck and the sunbathing deck (open deck).

Passenger reversible escalators, 600 mm wide, placed on the fore and aft part of the ship, enable a comfortable and safe communication between the main deck and the passenger deck.

Escalators should enable relatively quick and efficient concurrent loading and unloading of a large number of passengers, primarily in the ports along the route. The operation of passenger loading/unloading is significantly speeded up by escalators and the number of passengers moving across the access ramps is considerably reduced. Consequently, the time spent in ports is reduced.

The arrangement of escalators towards the bow and the stern, as far as it is possible, is expected to provide at least one escalator that would be available to the passengers in the condition of unfavourable port infrastructure (shorter mooring piers).

Bow thrusters and the manoeuvrability of the ship:

Bearing in mind relatively congested water areas of the ports the ship has to put in, a good manoeuvrability is an important feature of her daily exploitation. Two controllable pitch propellers surely contribute to good manoeuvrability, as well as two semi-balanced flap type rudders with the rotation angle of 45^0, but the major contribution comes from a bow thruster placed in the tunnel and propelled by a 400 kW electric motor.

It has been recorded that in the ports of Vela Luka and Ubli (Lastovo) there are strong winds blowing from the south quadrant, mainly during the winter season, reaching 7 to 8 on the Beaufort wind scale, and even exceeding it. As for the port of Hvar, strong gusts of the local north wind "bura" or the western winds accompanied by high tide and confused sea can make the putting in manoeuvring much more difficult and challenging.

Therefore, a more powerful bow thruster would be required (in the opinion of an expert from *MARIN*, Wageningen) or, alternatively, the installation of twin thrusters, one beside the other. Thus, the manoeuvrability of the ship in bad weather conditions (head wind) can be increased, which in turn results with a time-effective and more reliable manoeuvre. This could be the object of further considerations and technical analyses, bearing in mind the predicted electrical energy supply on the ship.

5 A survey of analytical analysis and model tank tests

Analytical analysis of power and speed and optimisation of hull lines carried out by using the CFD computer analysis (*MARIN* – Wageningen, Netherlands):

Analytical analyses for the purpose of hull lines optimisation for a required speed have been carried out in the *Maritime Research Institute* (*MARIN*) in Wageningen, Netherlands. Thus, lengthy model tank tests have been avoided. Mr. Predrag Čudina, BEng, a consultant from Split working on the project throughout its duration, has offered valuable help by sharing his long-time experience.

The power of the main engines for the service speed V = 18 knots was preliminarily confirmed by *MARIN* on the basis of the prediction programme DESP, based on a comparison of statistical data of numerous model tests and trial sailings of built ships. The results obtained by *MARIN* are within the expected values previously obtained by the *Brodarski institut* from Zagreb. The next step was to optimise the hull lines for the Froude number 0.315 and the medium draught of 3.80 m, at the block coefficient of 0.58.

A computer program RAPID, developed in *MARIN* in the period between the years 1990 and 1994 was used in pre-model numerical flow analyses carried out in order to optimise the hull lines with respect to resistance, propulsion and waves.

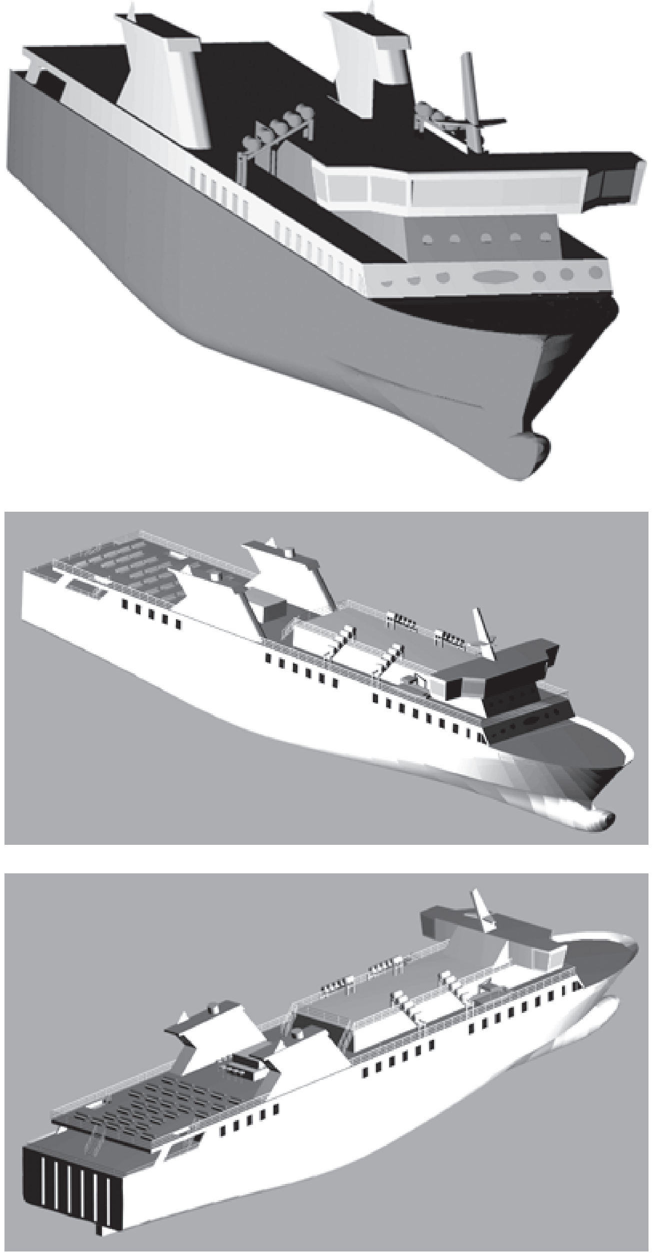


Figure 3 **Numerical simulations in the process of ship form optimisation**
Slika 3 **Numeričke simulacije pri optimizaciji forme broda**

After consultations on the critical points of the bow (bow ramp) and the stern (propeller, steering gears, and main reduction gears), four iterative calculations using the RAPID program were carried out with the following result: the "duck tail" on the stern was lengthened, the large angle of bow flare was reduced, and the length and volume of the bow bulb were increased, thus considerably improving the bow wave system.

As a final result of the calculation and of subsequent modifications of the ship form, the predicted service speed for the same power of engines was increased by 0.4-0.5 knots, depending on the diameter (D = 2.7-2.9 m) and the direction of propeller rotation.

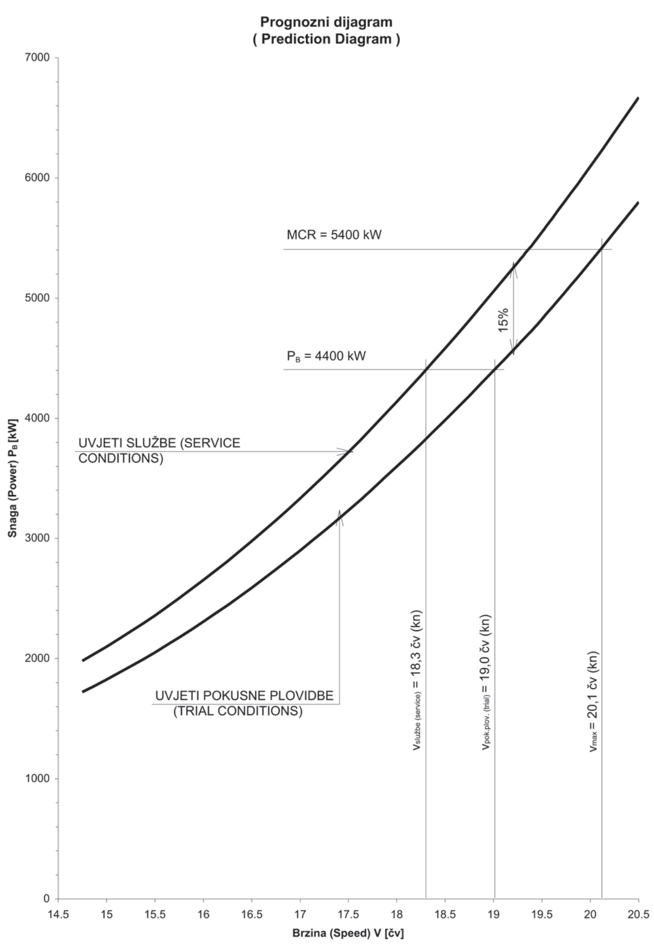
Tank testing of the model to determine hydrodynamic features of the ship (*Brodarski institut, BRODSKA HIDRODINAMIKA* – Zagreb):

Hydrodynamic features of the ship were dealt with during model testing carried out in *Brodarski institut, BRODSKA HIDRODINAMIKA* in Zagreb. The testing was performed on a fibre-glass model of the ship made to the scale of geometric similitude λ = 14.93 m in a tank 276.3 m long, 12 m wide and 6 m deep. During testing two forms were examined, and the following tests were performed in the condition of design draught:

- modification of the bow
- resistance test – hull with appendages – streamlines test
- measurement of wake field
- open water test of a stock propeller
- self-propulsion using stock propellers turning outwards and inwards

Results of the streamlines test and the hull with appendages test ("I" and "V" struts, shafts, stern tubes, and bow thrusters

Figure 4 **Prediction diagram**
Slika 4 **Prognozni dijagram**



opening) confirmed that the position of the appendage is correct and in accordance with the direction of the flow of water round the hull. Wake distribution over the knuckle on the bow of the basic model was noted at higher sailing speeds. Consequently, the bow form was modified within the limits defined by the ramp width. The modified form showed an improved wave in the resistance test.

According to the results of 3D wake measurement, the flow field on the position of the propeller is suitable for the propeller design. The results of the self-propulsion test using stock propellers were used to predict the power, revolutions and the ship speed that can be reached with the power available for propulsion. The results obtained at the power of P_B = 85% MCR = 2 x 2200 kW, 15% margin for service conditions and 3% of mechanical losses, at the design draught of T = 3.80 m and with the propeller featuring D = 2.8 m, P/D = 0.971, A_E/A_0 = 0.736 and Z = 4 can be seen on the prediction diagram, Figure 4.

The predicted speed that can be reached in service is higher than the given speed of 18 knots. Better results were obtained with the inward rotation of the propeller, and the stock propellers absorb the power of the engine at slightly lower number of revolutions than the given N = 230 min^{-1} (221-223 min^{-1}). It should be mentioned that these results were obtained by fixed pitch propellers, and it is to be expected that the use of controllable pitch propellers, due to their inferior performances (lower propeller efficiency by 1.5%), would reduce the speed that can be reached by 0.1 knot.

The obtained results are comparable with the results of analytical predictions made by *Brodarski institut* as well as with those made by *MARIN*. Hydrodynamic features of the design defined in the first phase of model testing confirm the design requirements set at the start.

6 Designer's reflections (on *Crtice uz Simpozij SORTA 2004* by Igor Belamarić)

It is true that the costs of building a new ship, as well as those of daily service and maintenance can hinder the feasibility of this project.

It should be kept in mind that the service speed of minimum 18 knots was the key element in technical requirements and that it was not an easy task to cope with considering a given ship size and acceptable power of propulsion machinery. This speed, with a theoretical possibility of reaching the maximum of 20 knots in ideal conditions, can be accounted for by a twice daily service on the route Split-Vela Luka-Ubli during the summer season using only one ship.

This route is covered by two older ships with the average speed of 14 to 16 knots during the summer season, and during the winter season there are days when the ships cannot sail due to bad weather conditions.

As for the selection of the main propulsion engines, several practical factors had to be taken into account:

- In spite of the advantages of the mentioned two-stroke engine, i.e. *MAN B&W*S26MC, a solution with a four-stroke engine had to be accepted due to much larger dimensions of the former, primarily when the installation height is concerned (approximately 4 750 mm for the two-stroke *MAN* compared to 2 500 mm for a L27/38 four-stroke of approximately the same power and produced by the same manufacturer). It should be pointed out that with this ship type (engine room below the main deck, or below the vehicle deck), the above mentioned height of the engine directly affects the side depth of the ship, which should have been as low as possible considering the pivot point of access ramps and the height of the existing quays to support them.
- A two-stroke engine requires, as a rule, the use of heavy fuel (HFO), and this in turn requires the installation of a special, in our case additional, system for preparation and transport of this fuel (along with the Diesel-fuel system for other engines). In addition, since numerous manoeuvres are required during the putting in the ports along the route when mainly Diesel-fuel regime is on, the appropriateness of a two-stroke engine becomes questionable.
- Better facilities for heavy fuel supply on the east coast of the Adriatic (bunkers) are still questionable. Therefore, ship operators are reluctant to use heavy fuel.

The endurance of the ship of 3 000 NM really seems to be too much, but it can be accounted for by practical reasons:

- It enables the ship operator to refuel every 10-12 days (in the case of previously mentioned twice-daily service), which reduces the operating costs of the ship.
- There is enough space below the main deck to put larger fuel tanks, which have a beneficiary effect of ballast; the block coefficient C_B could be slightly smaller, but this does not affect directly the position of fuel tanks.

Since efforts in the early design stages have been focused on maintaining the acceptable ratio between the ship length and beam (L/B = 5.5) with adequately providing place for 100 passenger cars. At the same time the length should be as small as possible (the L_{BP} of approximately 88.0 m is adequate) because of the required manoeuvres/turning of the ship in limited waters of island ports, and also because of a lower price of the ship.

One could say that almost every naval architect has a dream of obtaining the most favourable L/B ratio, i.e. as big as possible, especially if the required ship speed is relatively high. In our case, satisfactory results with respect to the flow round the ship hull, the bow wave system and the obtained speed, having as a consequence the enlarged form of the bow bulb, were achieved owing to large-scale CFD pre-model analyses. In order to protect the enlarged bow bulb, the length of the bow ramp ensures that it is kept at the distance of 1 500-1 800 mm from the quay (see Figure 2).

It is to be expected that CDF analyses will be carried out in our institutions in the near future. Then, it would be desirable to conduct a research on the ship resistance without the bow bulb and with an "attractive" L/B ratio of 6.0, as suggested by Dr. Igor Belamarić in the discussion on this topic held at the SORTA 2004 (Brodogradnja 52(2004)4, p 301-302).

7 Conclusion

Since some twenty documents or plans pertaining to technical documentation (such as: general arrangements and technical description, hull lines, midship section, preliminary trim and stability book in intact and damaged condition, basic shipbuilding calculations and engineering schemes of main ship systems, engine room layout, energy balance of electric power) have been produced since the beginning and the current design stage, the next step would be to start the contract design stage and the work on the classification documentation and on minor modifications of the design on the client's request.

Accommodations on the ship would surely need a more detailed design approach, especially the design of passenger saloons and the passenger arrangement on the open deck.

In the case of further development of the design, additional model testing of self-propulsion and free sailing in the tank, as well as cavitation tests with a complete ship model and propellers on the stern should be carried out in order to verify hydrodynamic features of the hull with controllable pitch propellers.

The properties of manoeuvrability and seakeeping can be determined in more details only by using adequate analytical estimations and tank testing which have not been included in this design stage.

The EU is seriously considering the possibility of extending the Stockholm Agreement on the Ro-Ro ships of the South European countries. For the Adriatic Sea, a significant wave height $H_S = 2.25$ m has been predicted as an input parameter for calculations. Although the *Croatian Register of Shipping* has no regulations pertaining to this aspect of the Stockholm Agreement, a possible impact on this ship design should be considered in the light of the pending admission of the Republic of Croatia into EU.

Jadrolinija insists that its ships, especially on international routes, should meet the regulations of the Stockholm Agreement.

From the presented results of analytical calculations and model predictions about the ship's service speed and the required power it follows that the 85% MCR of the main engines would require the installed power of main engines of MCR = 2 x 2 600–2 x 2 700 kW. Since this is the range covered by four-stroke marine Diesel engines, it is recommended by the designers to go for a higher value in order to ensure minimum power margin for later years of exploitation.

It should be pointed out once more that a sustainable speed of minimum 18 knots in service enables a twice-daily service on the route Lastovo-Vela Luka-Split or three sailings to and from on the route Split-Hvar-Vis, which satisfies the need expressed by the population of outer islands, especially during the summer season.

As for the ship's capacity concerning the transport of passenger vehicles, it could be increased at the request of the client/ship operator by the installation of additional hoistable ramps amidships (in the garage), but in that case, a smaller number of big vehicles – trucks, coaches, refrigerator lorries and trailers - would be loaded.

8 Acknowledgements

The preliminary design of the described Ro-Ro passenger ship has been realised thanks to the joint efforts and investments on the part of the shipyard *Viktor Lenac*, *Jadrolinija* and *Brodarski institut*, Zagreb. This project aims at contributing to the development of the Croatian passenger fleet and to the building of ships on Croatian building berths.

A group of young naval architects, with Krešo Lulić as a leading designer and Lukša Radić as the head of the *Department*, working at the time in the *Design and Construction Department* of *Viktor Lenac*, supported by the leadership of the author, gave a major contribution to the successful development of the project. The author would like to express his warmest thanks to Marin Kustić, BEng, from *Jadrolinija* for his cooperation and valuable help, as well as to Željko Đigaš, BEng, Gordana Semijalac, BEng (who is also a collaborator on this paper) and to Danko Gugić, MSc from *Brodarski institut* who helped in a successful completion of this design stage.

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