First Principle Applications in RoRo-Ship Design

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1 Abstract

Despite the fierce competition within the shipbuilding market, European Shipyards still maintain market shares in the segment of complex ship types. The reason is that ship operators are in some cases willing to accept slightly higher newbuilding prices if the ship is more competitive during its life cycle compared to of the shelf ship designs. To remain in the market, a shipyard has to focus on two main aspects: Offering a more efficient ship at the same price level (Design Competence) and offering the ship at a more competitive price level (Production Competence). To increase the Design Competence, one efficient approach is to establish First Principle Design Methods instead of designing Cook- Book Ships. These kind of methods are typically developed at research institutes and universities to solve scientific problems on a more generic level. On the other hand, a ship designer needs methods to evaluate his specific design at any time in the design process and to identify optimization potential. Therefore, these first principle based methods need to be customized to work efficiently during the design process, which means automatic data processing and appropriate presentation of the results. This paper demonstrates the results that can be achieved if the design process is rearranged accordingly.

2 Increasing the Efficiency of RoRo- Ships

2.1 General

If RoRo- Ships are benchmarked with Container Ships, it is to be noticed that the efficiency of Container vessels has boosted during the last ten years duet to market demands. This is due to the fact that Container Ship development was in the focus of most operators and shipyards, whereas RoRo- Designs seemed to change gradually only. This may be illustrated by the following example: A typical RoRo- Ship could be characterized by roughly 3200 lane meters, which is equivalent to the carriage of approximately 440 Containers (2 carried by one Truck) or roughly 850 Containers carried on double- stackers. A comparable Container vessel (same \( L \cdot B \cdot D \)) can carry approximately 2800 Containers. When the Container Ship entered the market, such kind of ship could carry approximately 1000-1200 Containers. Today, Vessels carrying 8500 Containers are designed and built, and designs of ships for 12000 Containers are in discussion.

This simplified comparison shows that there must be potential in increasing the efficiency of RoRo Ships, too, which has not been addressed due to the fact that there was no sufficient push from the market. Now, the situation has changed drastically: The Container Ships have more or less become the dominating segment of Far East Shipyards, because they can offer ships at competitive prices (regardless weather this is due to price dumping or not) at a technical level which meets customer’s requirements. Consequently, European Shipyards now focus on market segments where they can see a chance to survive. Especially the RoRo- segment offers good opportunities, for the following reasons:

- As there is still a lot of technical potential to gain, the balance between higher newbuilding prices in Europe can still be compensated by the technological level of the ships, provided the design is significantly more competitive in operation and that the difference in newbuilding price can be compensated in reasonable time span by operational earnings.
- RoRo customers typically operate their ships themselves instead of putting them in the charter market, which means that they have a natural interest in improved products. A RoRo- operator is more willing to accept a price increase for a technological improvement of his ships if the pay back rate is sufficient.

As mentioned above, there is much potential to increase the efficiency of RoRo- Ships, which holds for
pure freight RoRos as well as for RoPax ships. Designwise (this paper will not treat developments in produccion technology that lead to price reductions) two simple measures have to be taken:

- Increasing **cargo input** of the ships
- Increasing the **speed** of the ships

Consequently, these two items are discussed in the following sections.

### 2.2 Increasing Cargo Input of the Ships

#### 2.2.1 Freight RoRo

Cargowise, there are the following restrictions to RoRo- Ships which have to be regarded when increasing cargo- intake:

- **Length:** Due to harbour or operational restrictions, LoA is typically 200 m or slightly below. At the moment, it seems hard to increase the length.

- **Breadth:** Due to harbour and/or lock restrictions, typical beams are between 26-27 m, which are also more or less fixed values.

- **Draught:** For the same reasons, typical drafts are about or below 7.40 m.

For these reasons, it is obvious that the trend will go into the same direction as for the Container Ships, which has lead to a drastic increase of the cargo carried on deck. For RoRo ships, we can define deck cargo as cargo that is carried above the freeboard deck, which brings the necessity to increase the number of decks above the freeboard deck.

Damage stability requirements for RoRo- Ships (as they have no transversal subdivision) have been by far the governing criterion for the limitation of deck cargo, although it will be demonstrated later that special measures have to be taken to guarantee good intact stability characteristics in heavy weather especially for these kinds of ship. Some time ago, it was clear to everybody that a 3200 lane meter ship, one deck above the freeboard deck, required initial GM values of 2.20m or more.

When the first RoRo- Design for the Turkish Customer UND was developed (left section in figure [1]), it had three decks and was operating at a GM- value lower than 2m, allowing for good cargo intake, high flexibility and good seakeeping performance. Initially, these ships had been designed also for the transportation of containers (on mafi double stackers) leading to increased deadweight (and draught, too) on one hand and large deck heights on the other. Now it is a general philosphy whether a RoRo- Ship should also be enabled to carry Container Cargo which obviously leads to the conclusion that it is under these circumstances less efficient as it would be if optimized for pure trailer cargo.

Consequently, the next ships of the building programme for UND were optimized for road trailer intake, which meant the application of a partly fourth trailer deck to increase road trailer input, offering some extra 500 lane metres. As the high draft now was no more required, the aftbody could be adapted for the road trailer design loadcase, resulting in an increase of 0.5 knots service speed.

The next consequent step was the development of the 4000 lm RoRo ships for Danish customer DFDS: The deck heights were squeezed (also due to intensive steel structure optimizations carried out by detailed FEM investigations), damage stability was optimized and a complete fourth trailer deck could be fitted, refer to fig. [1] middle. The next step forward is the introduction of another trailer deck on top, the RoRo 5- Decker, which is under development (fig. [1] right). As damage stability is optimized, this solution becomes possible, allowing for another boost in RoRo- cargo input.

![Figure 1: Three different main sections of pure freight RoRo- ships, showing an increase in deck cargo.](image)
The same basic principles which have been found for RoRo- Ships are also valid for RopPax vessels: The key goal is to manage higher cargo input by vertical extension of the ship. But for RopPax vessels, the damage stability requirements are more complex due to the fulfillment of SOLAS requirements combined with Stockholm agreement. Based on detailed cost/benefit investigations carried out at Flensburger Schiffbau- Gesellschaft, it was found out that for optimum cargo input, it is better to get rid of the lower hold and to introduce a complete additional vehicle deck on top. Although at the first moment it does not sound efficient to carry void spaces below the vehicle deck instead of cargo, there are the following striking arguments:

- The lane meters gained by the lower hold are inferior to those on the vehicle deck, because due to the B/5 longitudinal bulkhead, the lower hold becomes narrow, making handling of the trailers inefficient.
- The fabrication costs per lane meter are significantly higher for the lower hold, because much cost intensive sub supplier parts have to be used (RoRo- equipment, HVAC, etc). If the shipyard is efficient in steel production, an additional vehicle deck on top is much more cost efficient.
- Due to the damage stability requirements, high initial stability is required for the lower hold solution, which leads to low ZCG- demands. This not always cost effective. In some cases, this can result in unfavourable operational behaviour (seakeeping). The pure transversal subdivision allows for achieving low GM- values on one hand, which compensate the higher ZCG- values due to the additional cargo deck. From the viewpoint of steel weight, both solutions are equivalent.
- From safety point of view, the pure transversal subdivision is definitively superior, because damages exceeding B/5 are survived, too. The same holds for bottom damages penetrating the double bottom.

The development of a fast 26 kn, 140 m RopPax ferry, which follows the same basic principle, goes one step further in this direction.

### 2.3 Increasing the speed of the ships

Here, the key goal is to design hulls that have a minimum resistance. Today, numerical tools are available to predict the flow around ships. If the peripheral processes such as grid generation, post processing, hullform changes etc. are automated according to the design process demands, a complete calculation cycle takes not more than a few minutes. The CFD-results allow to do optimizations that can not be performed with model tests alone. Using these tools in a consequent way, remarkable improvements are achieved.

This is demonstrated by fig. 3. There, four Ro/Ro- Designs are presented in a chronological way, from left to right. Far left, the design of a typical RoRo-Ship is presented which is udes as benchmark case. The wave elevation shows good interference along the hull, but a remarkable amount of stern generated waves is left in the wake, which are hard to evaluate by model tests. These transversal transom waves were the dominating part of the wave resistance, and consequently, this design has high power demand at service speed of approx. 21.1 knots.
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The avoidance the transom generated waves was a main task of the design for Turkish owner UND using a thoroughly optimized aftbody including a trim wedge. The application of Bernoulli’s Basic Law to a RoRo-aftbody results in the fact that if the aftbody is designed for a minimum of transom generated waves, more longitudinal waves will occur. So an overall optimum has to be found.

It can clearly be seen that the wave pattern is more favourable overall and consequently, the power was significantly reduced. The next generation of RoRo-Vessels, the single screw driven top-deck vessels built for Danish owner DFDS show that a clever hull concept can also be developed for single screw solutions. The wave elevations show that also this vessel has a low resistance and the service speed could be increased further. The vessel far right demonstrates that CFD is most beneficial the higher the power demand: The innovative hull concept of a 140m, 26 knot RoPax ferry requires 26100 kW main engine power at 26 knots service speed. To achieve this, more than 250 hull form versions have been tested in the numerical towing tank and even the smallest details have been thoroughly optimized. Compared to the benchmark hull, the gain is evident.

3 Increasing the operational performance of the ships

3.1 General

The detailed specification of the ship clearly describes the ship as such as well as the functionality of all systems. So when the ship is finally delivered and all topics of the contract are checked and fulfilled, the operator expects that his newbuilding will perform well under his specific conditions. However, reality shows that there are in some cases problems with ships, such as

- Excessive vibrations and/or noise
• Poor seakeeping behaviour (speed losses, excessive accelerations, discomfort)
• Poor Manoeuvering (yaw checking, turning, crabbing)

Whenever one of these topics occurs, the situation becomes difficult for both the shipowner and the shipyard (and in some cases also for the sub supplier), because the operational target is not clearly stated in the spec and therefore subject to different interpretations. And in most cases, if one of the above mentioned problems occurs, major, cost intensive modifications are the result. These can be avoided if the behaviour of the ship (or a system) is investigated beforehand by numerical simulations.

3.2 Reducing Propeller induced vibrations

Before a propeller design is analyzed in the towing tank and the HYKAT, numerical pre-optimizations should be performed. A given propeller design can be analyzed by numerical methods with respect to efficiency, cavitation and pressure pulses. Besides excellent efficiency figures, much care has to be taken to minimize the pressure pulses, because they affect comfort of crew and passengers and are therefore also important safety issues.

![Figure 5: Panel Grid and calculated pressure pulses at different time steps, DFDS-vessels, 15700 kW at propeller, propeller Design No. 7. The code was developed by HSVA.](image)

Figure 5 shows the results of pressure pulse calculation for the DFDS-ships at Trial Design condition. The pictures show the pressure pulse that is induced at the hull when a blade is passing, including cavitating and non cavitating part. To go the limit of what is technically possible, seven propeller designs have been analyzed in detail in HSVA’s large cavitation tunnel and for each design, 2-3 pre-designs have been analyzed in the computer. The benefit is shown in the following diagram (ref. Fig. 6): Here, the pressure pulses at blade rate and 2nd order are plotted for each individual propeller design chronologically. Starting with some 4 kPa at first order and 2.7 kPa second order, the final values at design no. 7 have decreased to 2 kPa and 1.1 kPa, respectively.

Further improvements are possible, so the final values will be about 1.3 / 0.3 kPa, respectively. For the customer, these excellent values are of high economical interest: As the vessels have to operate under shallow water conditions, the speed can be kept at high values without having comfort problems.

![Figure 6: Improvement of pressure pulses during the design process of DFDS-vessels.](image)

3.3 Optimizing Course-Keeping performance

According to author’s opinion, the most important manoeuvering criterion to be achieved is excellent course keeping ability also in coupling with the rolling/yawing motion in a seastate. Course keeping ability is mainly achieved by an efficient hull form, and efficient rudders that have quick turning ability. We design rudders as full spade types with highly efficient profiles, adopted to the slipstream, using a direct panel method for rudders in the propeller slipstream. This method - together with the propeller VLM-codes - is then used to determine all the necessary steering forces. If these are known, direct manoeuvering simulations for all types of manoeuvres are performed to judge upon the manoeuvring capability of the vessel. Together with the customer, it is decided whether the design is further to be improved, because the vessel can be operated easily in the computer.
Figure 7: Zig-Zag tests and course keeping action for UND RoRo-Vessels, Hull No. 713

Fig. 7 shows the results of the numerical optimization: The overshoot-angles calculated by the simulation have been reached during trial trip with an accuracy of approx 0.5 Degree. Compared to the IMO-maneuvering recommendations, the overshoot angles are drastically smaller. The rudder action required for course keeping was found to be approx. 0.5 degree rudder action per minute, as performed by the autopilot during the trial trip. In heavy weather, the course keeping ability can be judged from the resulting drift and rudder angles at yawing and swaying equilibrium (Fig. 7 top right) which can also be derived from numerical simulations. At 40 knots transverse wind speed, ship speed 21.5 knots, the resulting drift angle is less than 2.5 Degree and less than 3.5 degree rudder angle are required for course keeping. These low values, leading to a low additional resistance, have been achieved by systematically optimizing hull form and maneuvering devices for good course keeping ability.

3.4 Seakeeping performance

When designing the hull form, special care must be taken to achieve good seakeeping behaviour. This may be expressed by the achievable speeds against head seas on the one hand and by the judgement of accelerations on the other. To determine additional resistance in seaways, we use a Rankine-source based linear strip theory combined with Faltinsen’s method for additional resistance. The theory includes detailed determination of mass moments of inertia as well as damping (especially for the rolling degree of freedom). Based on these evaluations, the power demand in a seastate and the achievable speeds can be judged upon.

Due to the fact that RoRo- and RoPax-vessels do have a barge type aftbody and a semi-submerged transom, they lose much of their initial stability on the wave crest. Therefore, these vessels are vulnerable to parametric rolling, which should definitively be avoided. Using nonlinear seakeeping simulations, the hullform can be designed for a minimum risk of parametric rolling. The Blume-Criterion is used to judge whether a ship is safe in a certain seastate or not. As results, we get permissible wave heights as function of ship speed and encounter angle.

Fig. 8 gives an overview about the improvements that can be achieved using such design techniques: The left picture shows the results for the initial design of a 200 m, 25 knots RoPax-ferry. It can clearly be seen that in following seas and slow speeds, the vessel suffers from parametric rolling. It capsizes in waves of approx. 4m wave height if wave length equals LbP. With the help of the simulation, the phenomena that lead to capsizing can be accessed by the designer and without impeding speed power performance or other governing criteria, a hull form can be designed that is safe against the risk of capsizing, as fig. 8 right, demonstrates.

Figure 8: Evaluation of parametric rolling. Left: Initial Design of 200 m, 25knot RoPax Ferry, right: Design optimized for safety against capsizing

To fulfill Stockholm agreement for existing ships, the addition of blisters/or sponsons has been suggested as useful and cost efficient measure to ensure formal fulfillment of the prescribed damage stability requirements. As most of the older ships have hidden potential with respect to speed and power, the additional resistance of the sponson can be compensated by fitting duck tails and/or modifying the bulbous bow. Unfortunately, it is sometimes forgotten that ships operate in intact condition typically, and the seakeeping behaviour was in some cases not analyzed in detail. As a consequence, some operators of converted ships blame insufficient seakeeping behaviour, mainly excessive accelerations and/or excessive rolling.
Figure 9: Seakeeping Evaluation of a ferry conversion. Left: original design, right: Modification to fulfill Stockholm Agreement. Blume-Criterion, wave length equals LbP

Fig. 9 shows the comparison of a ferry before and after conversion. The original design shows a typical behaviour of such kind of vessel. Only quartering seas can cause problems to the ship and they can be avoided by the crew. The behaviour of the converted vessel looks significantly different: Now, also head seas lead to excessive rolling with negative consequences for the ecomfoet on board. Although the initial GM is increased by more than 2 (!) metres, the capsizing frequency takes twice the value of the original design. This result clearly indicates the usefulness of such kind of simulations on one hand and the fact that safety is a global issue.

4 Conclusions

The competition in the shipbuilding industry forces shipyards to increase the competitiveness of their products as well as their productivity. If European Shipyards want to compete against the Far East, this can only be done by intelligent products, which require intelligent engineering principles and powerful design tools. On the other hand, these new design processes require new engineering skills: The understanding of physical phenomena related to a specific design and the proper modelling of these phenomena by numerical algorithms and, of course, the adequate interpretation of the results. Within this respect, Europe has a clear advantage due to a very active and ongoing research and development infrastructure. Shipyards have to cooperate with the researchers and to establish research networks to exploit the research results. Within the frame of this network, Universities and other research institutes are the institutions that develop the basic tools to be applied by the industry.