The Design of the Ships' Hulls based on Application of Aircraft Wing and Fuselage Engineering Principles

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Abstract

This paper presents the application of new findings of fluid sciences in order to significantly reduce the overall ships' resistance and to improve the propulsion. "AFT OPT" technology applied to ship hulls originates from the transfer and application of principles used in the design of aircrafts. The application of these physical principles to hydrodynamical and hydromechanical principles using proprietary CFD software leads to a new design approach for the aft hull. Hull shape and lower hull resistance lead to a much better filled propeller disk, wake flow and rudder characteristics. As a result, the main engine power may be reduced by more than 6%.

1. Introduction

Corporate responsibility for environmental protection, sustainability and IMO regulations to limit emissions from shipping require more measures than ever before for maritime stakeholders.

For compliance w/IMO regulations, EEDI, CII, investors must apply all measures available to protect their investment on long-term basis. Besides fuel selection, design of ships' hulls is an option for sustainable compliance. Main unique selling points for the holistic AFT OPT solution include the facts that AFT OPT vessels always consume substantially less fuel – whatever fuel is used. AFT OPT vessels therefore establish a new "best-in-class" benchmark. Substantial OPEX reduction increases the competitiveness of market participants.

In order to generate OPEX savings already at the birthplace of ships evaluation of hull design and performance according to a speed profile must be added to the most important selection criteria in addition to "easy-to-evaluate" criteria "price + delivery time + performance at design speed", LRSD had invited and involved a limited number of interested parties for joint development projects (JDP). World's top container liner companies are involved in technology review, get access to model basin results to verify these new applied sciences.

The first contract has been signed with a leading Chinese ship building and financing group in 2023 for a series of container feeder vessels after technology verification and validation of superiority of AFT OPT. Ship model tests were executed, among others, at MARIN (NL). These vessels shall be built for a world leading container liner company.

A joint development project (JDP) and with a Korean Shipbuilding Group for ultra large container vessels started in April 2024, model tests shall be done in Q3/2024 in South Korea.

Earlier, the technology has been developed for and applied to optimize vessels at SVA Vienna (since 2018) and a bulk carrier at HSVA (2022) for the purpose of validating the technology as such. Classification societies and flag states are usually invited to join the tests at site as impartial witnesses.

2. Challenges in shipbuilding

Due to the holistic U-shape - common in shipbuilding - with attached bow and stern, there are only a few development opportunities to generate cost-effective advantages for the shipyard and the shipowner or charterer to increase their competitiveness. LRSD with AFT OPT offers a new approach and extends progress in ship technology.

The main problem is the increasing hull resistance due to the above proportion increasing block coefficient (volume resistance of the submersible part of a ship when fully loaded) and the displacement pressure due to the speed. All this increases the power required exponentially and the fuel consumption increases significantly while at the same time the propulsion efficiency is reduced.

Historically, the analysis of fuselage flow, the flow of air around the wings of aircrafts, led to the question at LR-Shipdesign, whether with a specific new approach can be made to improve the flow of water underneath of the keel from bow to stern and to modify the stern region. Slight bow modification allows to deliver best “starting point” for AFT OPT calculations and best results for the holistic approach as the water regime is interconnected from bow to stern.

Based on shipbuilding theories, the basic design conditions in new buildings are regulated by validated rules. However, not all solutions based on physical possibilities of fluid dynamics and especially fluid mechanics are applied nowadays in shipbuilding. Applied physics offers several possibilities that have previously been only used in aviation, but not in shipbuilding.

3. Original observations as basis for technology development of AFT OPT

3.1. MIRAGE 2000, Fig.1

The “area rule” (developed in 1943) influences the laminar flow through a negative pressure form on the wing/fuselage. This significantly postpones the separation of the flow of air from the aircraft’s body at a speed range close to speed of sound (transonic).

3.2. Wing airliner, Fig.2

Triangles and flaps used as vortex generators on the wing increase the resistance during normal flight operations only slightly. During take-off and landing, the angular position of the wing creates a very special type of vortex (“bag vortex”), which generates a higher lifting moment by compressing the flow and thus reduces the landing speed of an aircraft. This is necessary for safety reasons at slow landing speeds.

Fig.1: Mirage

Fig.2: Wing airliner

4. AFT OPT technology

AFT OPT is nothing less than a detailed analysis of the flow of water cells underneath of a ship’s hull – from bow to rudder – with a unique LRSD calculation and CFD approach with application of previously unutilised physical effects for ship design in order to create a more efficient hull form.

The core result of AFT OPT technology application includes a slightly modified rear hull bottom area to keep the water flowing longer along the hull through displacement. This reduces energy losses and the energy gained is fed through the shape to the effectors of the propulsion comparable to a water jet.

The cascade effect: Less energy is lost from the hull, fewer waves are generated, and more water is directed towards the propeller disk. Furthermore, the wake field is more uniform, the better preconditioned water pattern reaches the propeller disk, so that the entire disk surface is filled more evenly. In consequence, both, propeller and a twisted rudder – designed to deal with the vortex flow and to increase propulsion – contribute to the much more efficient energy utilization. All this can be implemented in ship newbuildings with minimum commercial engineering effort compared with the OPEX savings. Fig.4 shows a design example for a 76000 dwt bulk carrier.

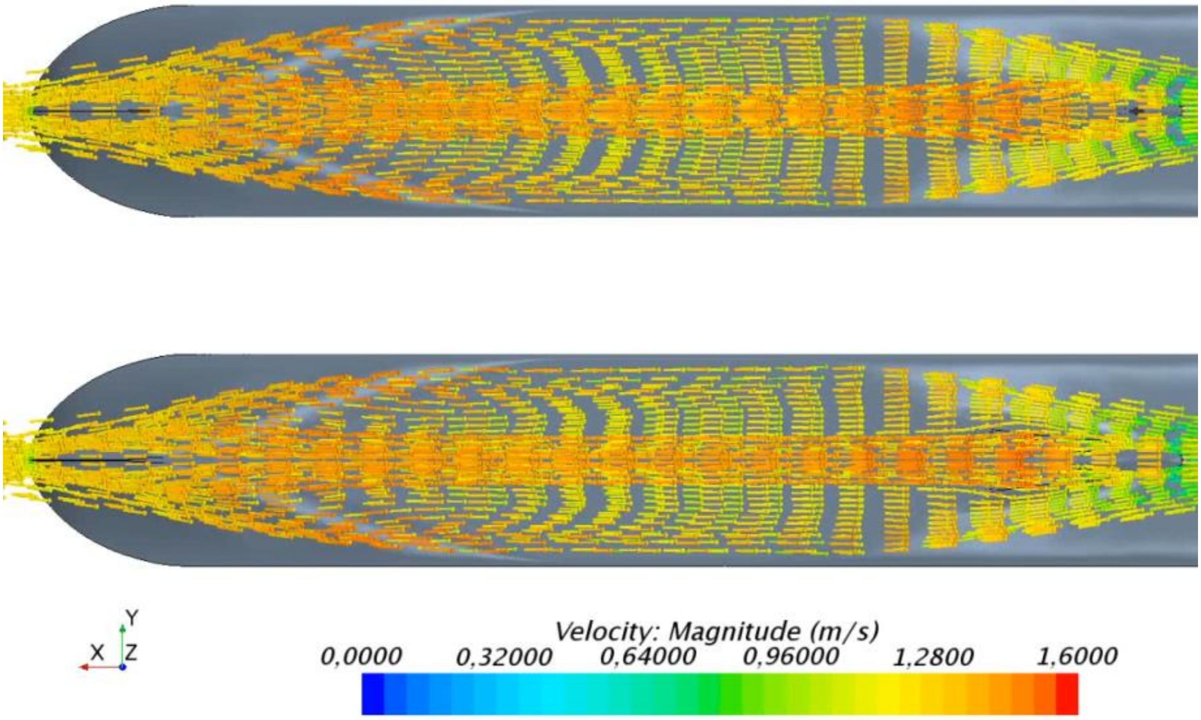

Fig.3: Influence of LRSD aft ship on the flow at the ship's hull. Original design (top) and LRSD design with narrower streamlines, closer in parallel to the x-axis

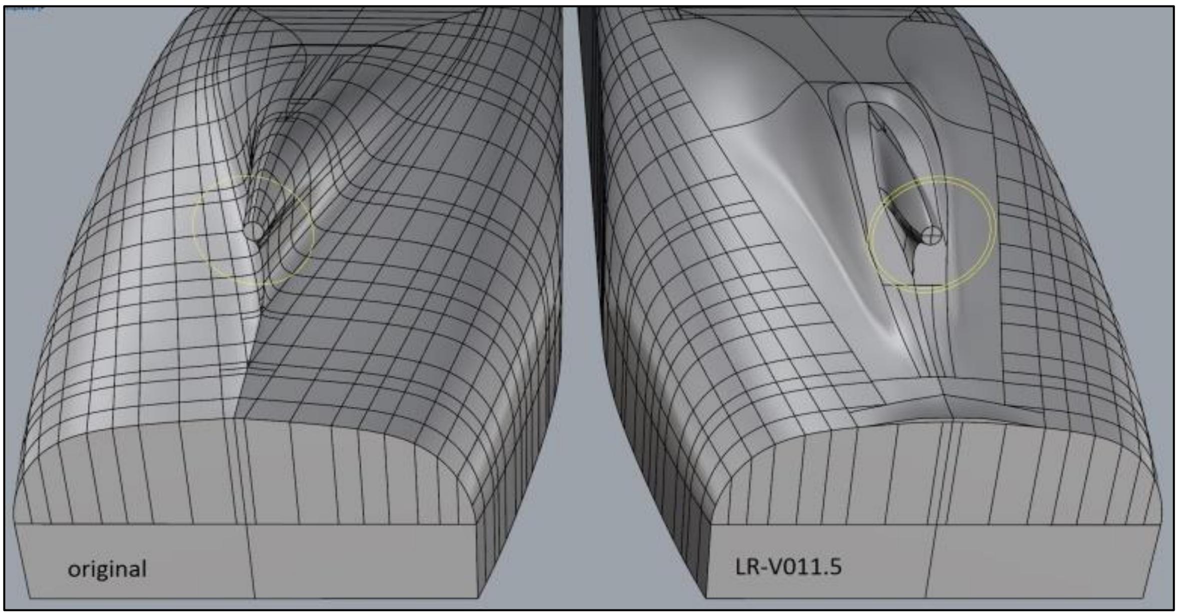

Fig.4: Bulk carrier tested in 2022 at HSVA; special shape of AFT OPT hull modification with 2 propeller options

4.1. Application of Coandă effect et al. to ship design

LRSD has investigated how to use the findings of fluid sciences (such as the “Coandă effect”, etc.) to significantly improve the overall ships’ resistance and propulsion for ship propulsion while adhering to the given shipbuilding regulations. LRSD has developed an own CFD software for this, as even latest standard programs for CFD only partially cover possible improvements. LRSD utilises the aft bow in connection with the ramp to apply the Coandă effect, for example.

LRSD always looks at the entire hull and on a holistic approach to record all parameters for an efficient hull design. The result of AFT OPT® technology application is a precisely calculated shape for aft ship bottom area and stern, designed for maximum improvement of hydrodynamics and propulsion and for hydro-mechanical optimisation of propeller and rudder.

4.2. Practical approach

LRSD follows the design specification with regards to sailing speed, design draft, main engine performance and the lowest ship construction effort while adhering to the freight volumes. The unique LRSD shape in the aft ships bottom area, the stern of the ship, improves the induced resistance and reduces energy losses due to displacement. An additional adapted pressure impulse is transmitted to the propeller for higher propulsion efficiency.

All this results in the following technical and physical advantages:

- The overall resistance of the hull decreases by reducing the peaks of the pressure fluctuations along the hull (by minus 3 to 6 %).
- The improved flow to the propeller means that more thrust can be generated at lower main engine speed, resulting in more efficient propulsion. The required power amounts to abt. minus 6-8% PD.
- In some cases (mainly for tankers, bulk carriers) minor modifications of the main engine room might be necessary as an adaptation to the modified aft ship lines. This will be done in accordance with the main engine manufacturer's requirements.

4.3. The physical effects, impressions, charts

Induced by the special AFT OPT form and input edges of the ship’s bottom semi-circular form, the applied pressure is reduced, and the water flow is accelerated due to the indentation. Thus, energy losses are reduced and the flow pattern along the edge lines (shoulder) and stern as well as the trailing whirl are optimized.

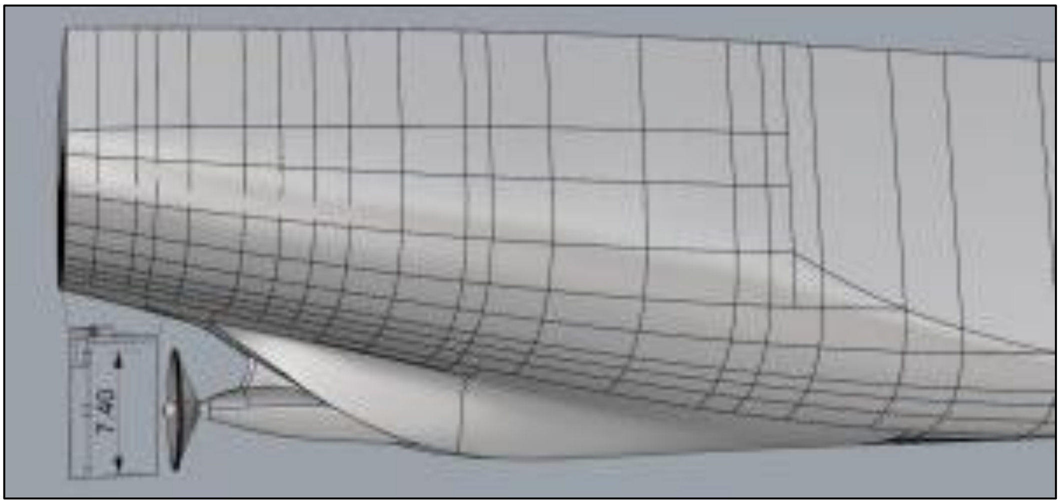

Fig.5: Bulk carrier, tested in 2022 at HSVA, Hamburg. 7.4 m propeller diameter

This system essentially improves the water flow to the propeller and rudder. The propeller gains more pressure due to a more uniform inflow, especially in the 12 o'clock position and by an adaption of the transmission and/or propulsion further savings are generated.

The resistance of hull without attachments was improved for container vessels and bulk carriers, by more than 3-4% in full scale (4-5% in model scale). The overall result for the container vessel and bulk carrier reached much more than 6% improvement in full scale with propeller and rudder attached during first trial. Further minor improvements can be made possible and verified in future tests.

Fig.6 shows of streamlines at the stern for a Panamax bulk carrier, as an example. Compare line thickness, smaller red zone in the aft area; reduced pressure regime, reduced resistance. Fig.7 shows the propeller wake for the same vessel, as determined in a steady-flow CFD analysis at model scale, Fig.8 the wave field. The better distribution of forces is recognizable already in model scale. The full-scale vessel should have an even better predicted wake flow in the propeller disc.

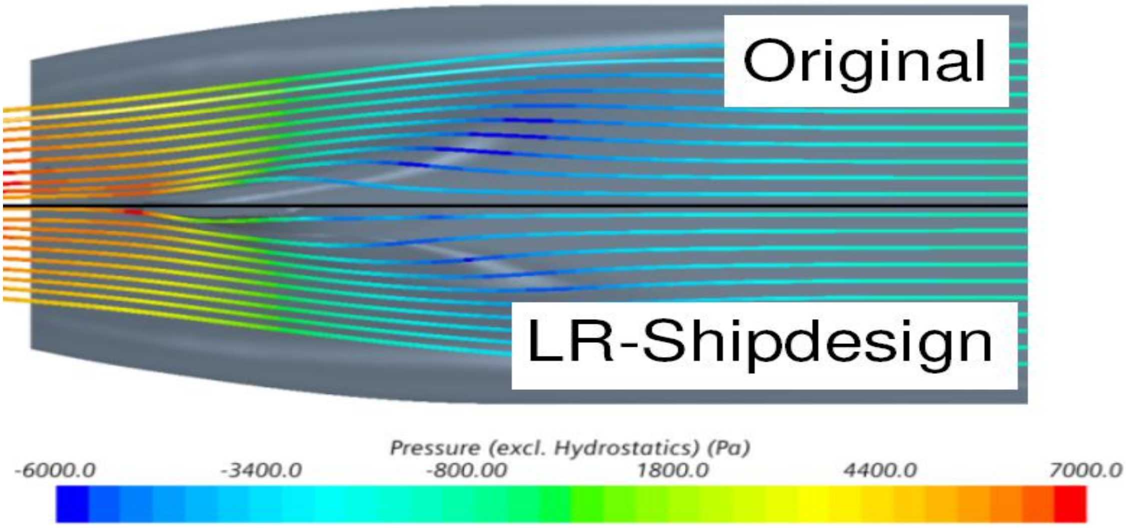

Fig.6: Streamlines in aftbody for original design (top) vs. LRSD AFT OPT (bottom)

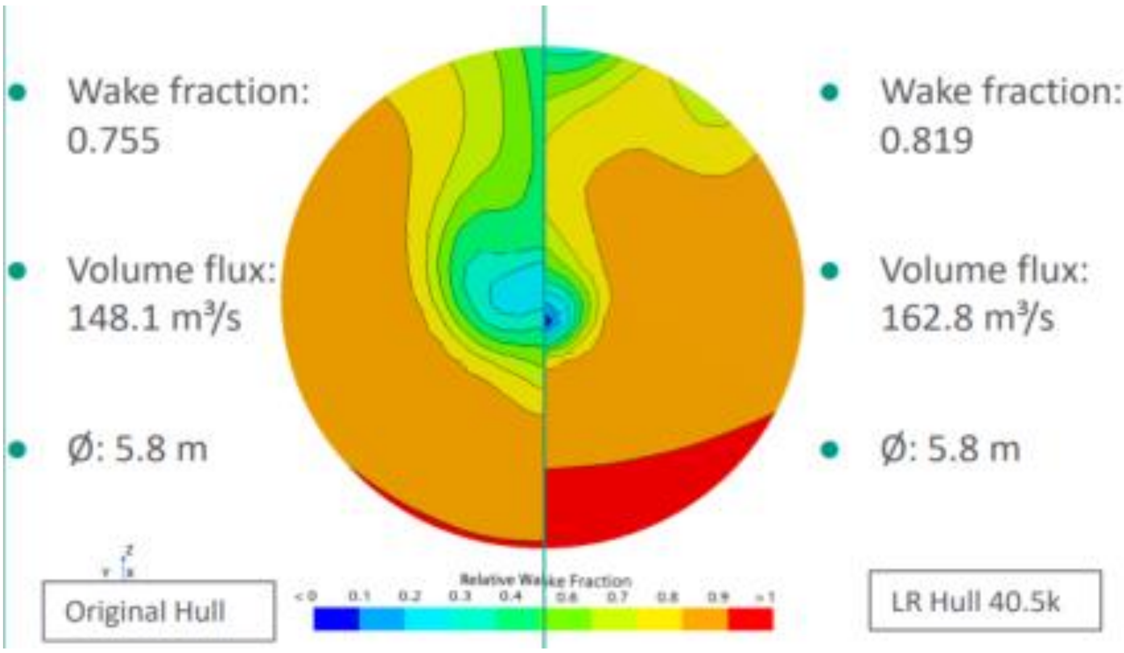

Fig.7: Wake field for bulk carrier at 14 kn, original hull (left) and AFT OPT (right)

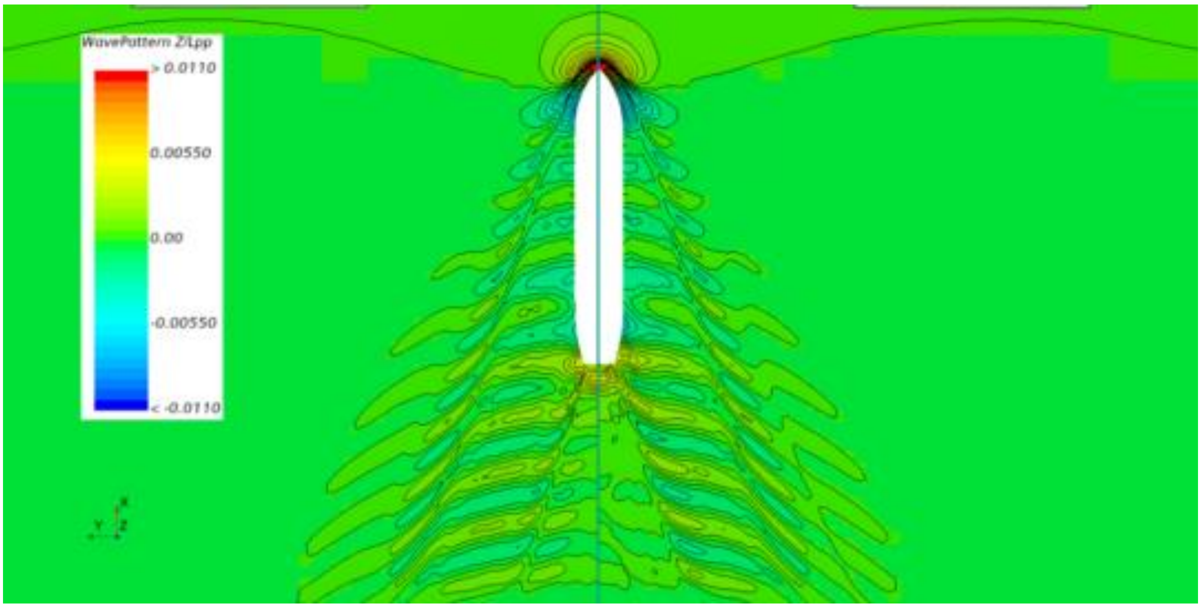

Fig.8: Wave pattern for bulk carrier at 14 kn, original hull (left) and AFT OPT (right)

Figs.9 and 10 show the hull geometries for another illustrative example, namely a 2900 TEU container ship. Figs.11 to 14 show CFD results for the full-scale ship. Note the equalizing effect of the AFT OPT design in each case. The new bow section improves the overall pressure distribution and thus wave formation, Fig.11. Fig.13 shows the very even wake distribution in the propeller disc, which enables high propeller efficiencies. Fig.14 shows streamlines in the aftbody, forming a slight vortex, but without stall.

Fig.9: Side view 2900 TEU container vessel, LRSD design

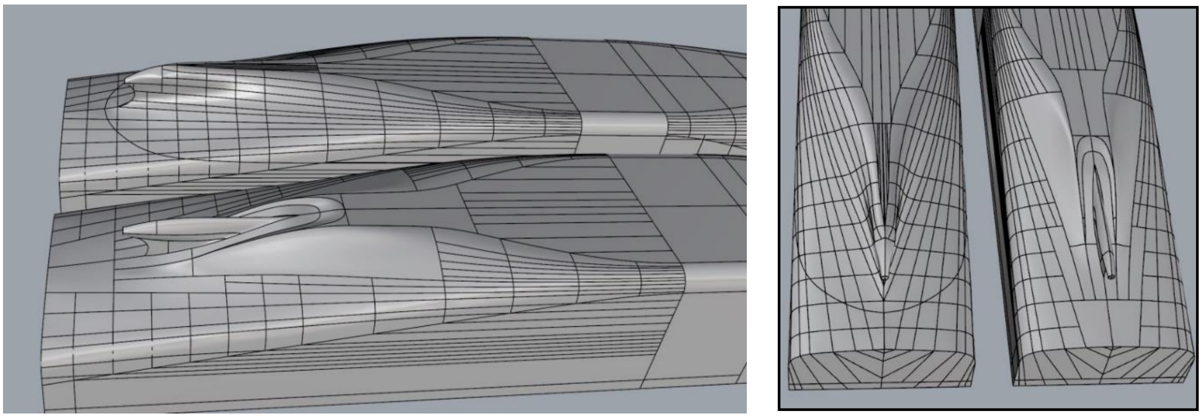

Fig.10: 2900 TEU container vessel designs, original vs. AFT OPT

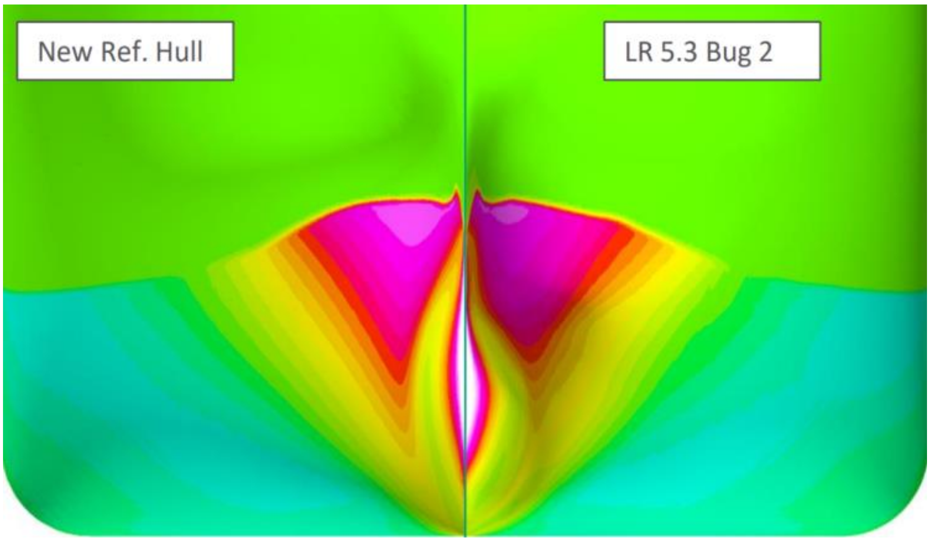

Fig.11: Pressure distribution on bow area for 2900 TEU container vessel

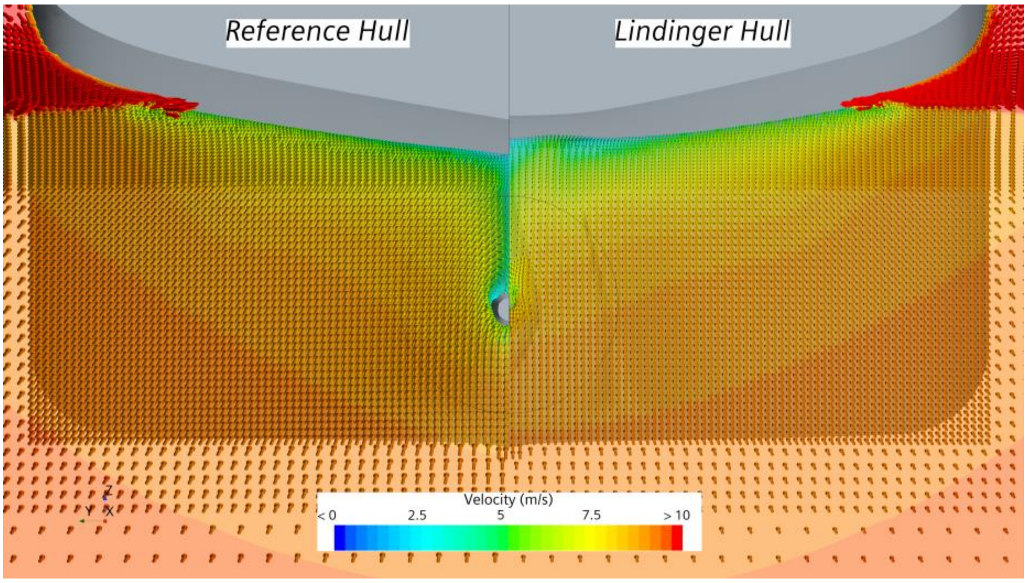

Fig.12: Velocity field 1 m upstream of propeller for 2900 TEU container vessel

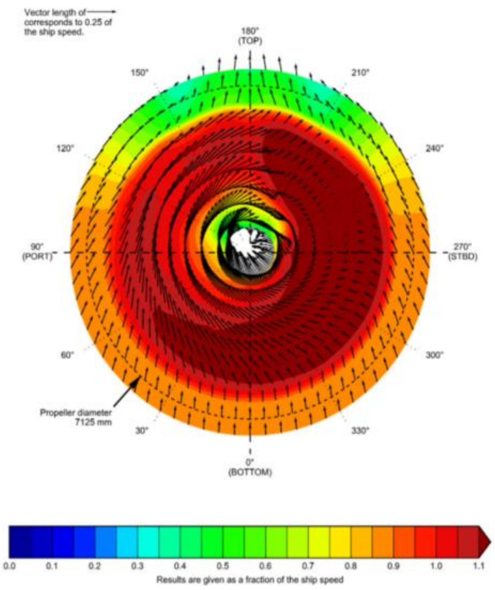

Fig.13: Wake distribution for 2900 TEU container vessel at 19 kn (AFT OPT dsign)

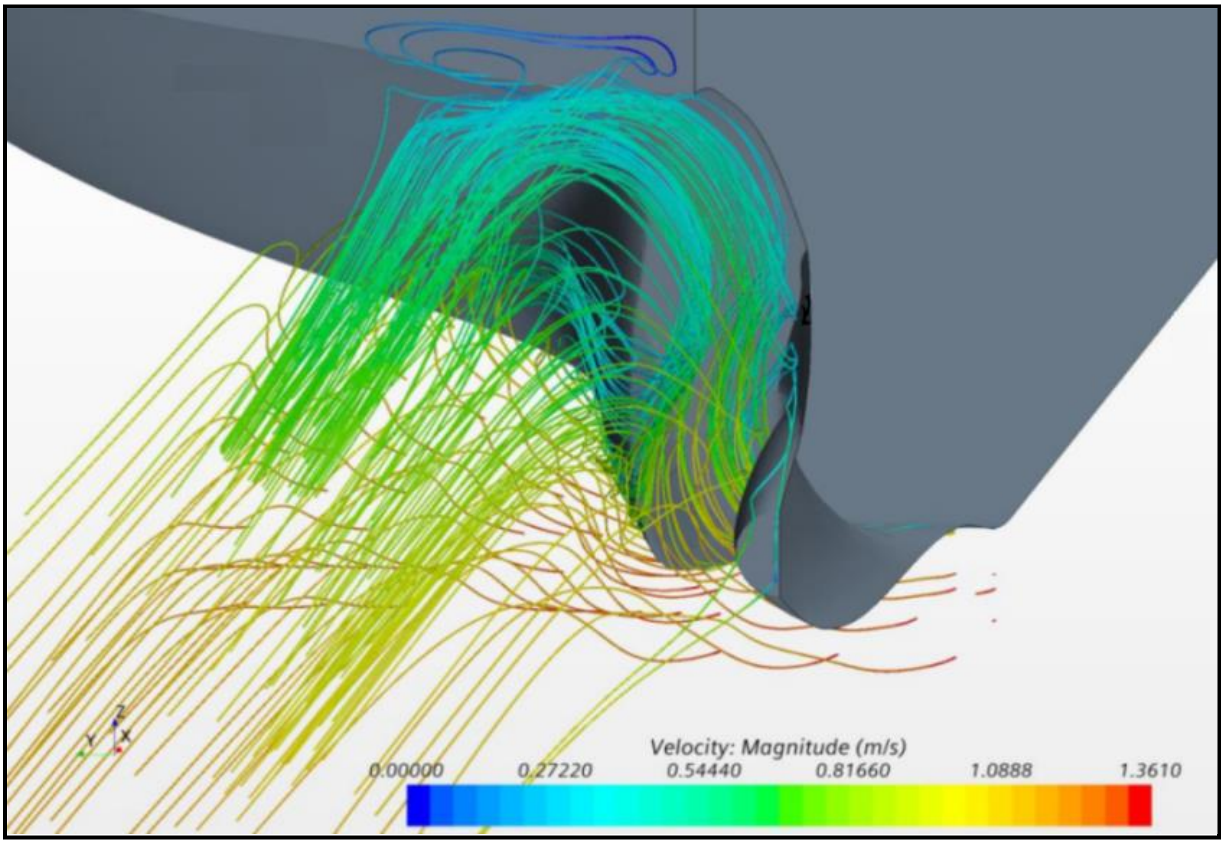

Fig.14: Aftbody streamlines for 2900 TEU container vessel (AFT OPT design)

5. Resume

The competitive advantages of the Patented Lindinger Hull are as follws:

- Fuel reduction of more than 5% (up to 10 %) during regular operation just due to the innovation AFT OPT; benchmark always: "best design" without AFT OPT
- Substantial main engine power reduction accordingly
- Lower main engine RPM at design speed
- Better rudder efficiency, especially at a neutral steering angle of ±4°
- Effectiveness of AFT OPT over the entire speed/draft range
- No attachments or ESD required; therefore, no additional (ESD) maintenance expenses
- Enhanced efficiency of the propeller due to increased thrust, reduced suction value and slip
- Less vibration and lower noise level due to the smoother propulsion
- Propeller with less weight is possible (smaller thickness possible)
- Reduced drifting tendency of the hull during sailing
- Functional for all semi-glider and displacement hulls
- Applicable for single screw vessels and for twin screws as well

6. Conclusions

Ships are only sustainable future assets when combining all latest requirements of builder and user. Ship owners should not be shy to use their purchasing power to combine more economical ship building know-how with their own ship operational requirements. The cost for new merchant vessels is relatively low compared with the OPEX during a ships' lifetime. AFT OPT helps the ship owner and the party paying for fuel to stay ahead of other market participants. The savings have been confirmed by renowned ship model basin and classification society DNV.

Result of AFT OPT application:

- Reduction of main engine power demand for same cargo load, speed, draft, by at least 6% compared with so-called “latest optimised design” which was based on traditional or proprietary design technologies.
- Analysis of all ship model basin test result shows that full scale results for the real vessels will be better than in model scale. Here, however, we report model scale results only.
- Statements of Fact (by class, flag state) and worldwide patents for hull lines issued including of China, South Korea, Japan, EU.

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