Retrofit solutions for inland ships: the MoVe IT! approach

Robert G. HEKKENBERG  
Delft University of Technology, Department of Ship Design, Production and Operation  
Mekelweg 2, 2628CD, Delft, the Netherlands

Cornel THILL  
Development Centre for Ship Technology and Transport Systems  
Oststrasse 77, 47057 Duisburg, Germany

ABSTRACT
In MoVe IT!, a project in the European 7th framework package, it is investigated how existing European inland cargo ships can be retrofitted in order to improve their economic and environmental performance. In the project, experts from academia worked closely together with five ship owners to identify the most promising retrofit options for one of their ships and to elaborate them. In this paper, the MoVe IT! approach is discussed, as well as some key results. After a brief introduction to the project, an overview of all identified retrofit options is presented, followed by the selection of the options that were deemed most desirable. As an example of the MoVe IT! solutions, the elaborated hydrodynamic retrofit options for the coupled unit MS Herso I and barge Leonie are discussed in detail, followed by a short overview of the results of retrofit attempts for all ships surveyed within MoVe IT!. The paper is concluded with the most important lessons that were learned from the efforts to find good retrofit solutions for inland ships.

Key words: MoVe IT!, Inland ships, retrofit

1. INTRODUCTION: THE MOVE IT! PROJECT
The MoVe IT! project is executed within the European 7th framework package and is also funded through this research program. It started in 2011 and will finish in 2014. The project has 23 partners, nearly all of whom have contributed to the results that are presented in this paper. The partners are: MARIN, DST, Via Donau, Delft University of Technology, Center of Maritime Technology, Stichting Projecten Binnenvaart, TNO, ECORYS, Autena Marine, S.M.I.L.E.-FEM, University of Plymouth, Universitatea Dunarea de Jos Din Galati, Ship Studio, University of Belgrade, Compagnie Fluviale de Transport, Ship Design Group, Voies Navigables de France, SWERA SICOMP, ThyssenKrupp Veerhaven, Helogistics, Plimsoll, University of Budapest and Masson Marine Engineering. In the project it is attempted to find viable retrofit solutions for existing ships that will increase their environmental performance as well as their economics performance. The approach that is used is to first perform generic research into possible ways to improve the hydrodynamics, structure and drive train of inland ships in general and to apply the knowledge gained from that to five ships, four of which belong to project partners. These ships are the pushers Veerhaven X of ThyssenKrupp Veerhaven, Inflexible of Compagnie Fluviale de transport, Dunaföldvar of Helogistics, self-propelled dry cargo ship Carpe Diem of Carpe Diem shipping and coupled unit Herso I – Leonie of Plimsoll. The choice regarding the solutions that are applied to the five ships was made through a workshop in which the ship owners discussed the various options with experts from academia and industry, based on the preliminary results of the generic research. After this discussion, the
ship owners expressed their views on which retrofit options appeared most interesting to them and these options were researched in detail for that owner’s ship. In this way, it is ensured that the project results have the highest chance of actually being implemented, should they prove to be as beneficial as originally anticipated.

2. REASONS FOR RETROFITTING INLAND SHIPS

The average age of inland ships is above 40 years [Schinzel, 2008]. Assuming an annual constant percentage of new-built ships, this extraordinary average age is achieved when just about $\frac{1}{80}$ of the fleet is newly built each year. This implies that it will take about 80 years till all ships are replaced by possibly superior new ships. Even though the life span of engines is much shorter than that of the ship’s hull, it will still take several decades before all existing inland ship engines will be replaced by newer, cleaner and more efficient engines. This in turn implies that a retrofit solution that could be applied to all ships immediately is worth many times as much as an improvement with a similar effect that is applied to new ships. This pleads for retrofitable solutions for the particular market of such durable products as inland ships.

Furthermore, the long life-span of an inland navigating vessel bears the risk that equipment overages and that technically superior solutions meanwhile exist. In particular, this holds for technical equipment such as prime movers and gen-sets. Luckily, equipment is often relatively easy to replace. Improvement of the hull of the ship during its lifetime is much more complex. The hull as such can hardly be changed without incurring very high cost, even if meanwhile better optimisation techniques directly addressing the shape are available, such as dedicated CFD (computational fluid dynamics) codes. Despite all potential benefit, as the modification of an existing hull is too severe, there are hardly economically sound reasons to re-design the shape of an existing hull.

In other words, if the original design job was done with care, e.g. by an experienced team of researchers and designers (some model basins have more than 100 years of experience, thus longer than the average age of the current fleet), little would plead for conversion of an the existing design, except the replacement of over-aged equipment. However, the mission of the vessel could change during its lifetime, e.g. as it is resold or used in another service. If the demands for this service were not considered in the original design process, retrofitable solutions complying better to the ship in its new service are indeed an option.

Last but not least, combination of formerly not considered techniques or techniques that became available in the time between the original design process and the current service of the ship might be a good reason to retrofit the existing ship with these techniques; e.g. if modern manoeuvring devices such as bow thrusters can compensate for the reduced manoeuvring performance of resistance optimised rudders, the combination of a new bow thruster plus new high performance rudders might be beneficial if it can be retrofitted to the existing ship. The combination of the benefits of either would let the ship sail at the demanded manoeuvrability with at the same time reduced resistance and power demand. If the manoeuvring demands are reduced meanwhile due to another service, re-considering the steering arrangement could become an option as well. An overview of possible retrofit options is given in the following section.
3. OVERVIEW OF POSSIBLE RETROFIT OPTIONS

There are many different options to reduce emissions of existing ships and the most important of these are elaborately discussed in deliverable 7.1 of the MoVe IT! project [MoVe IT!, 2013]. In this document, the potential benefits of each retrofit option are discussed in terms of reduction of CO₂, NOₓ and PM emissions. The overview also contains an estimate of the investment cost of each retrofit option and an indication of its impact on the ship in terms of additional weight and additional required space. The overview is completed by expert opinions on the technical maturity of the various retrofit options and their overall suitability as retrofit options. The options that are reviewed in the document are listed in table 1.

Table 1 Overview of retrofit options

<table>
<thead>
<tr>
<th>CCR 2 - engine</th>
<th>Hybrid incl. battery</th>
<th>Waste Recovery</th>
<th>Heat Recovery</th>
<th>Azimuthing thrusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage IIIB - engine</td>
<td>All battery</td>
<td>2-stage TC + Miller timing</td>
<td>Stator-rotor system</td>
<td></td>
</tr>
<tr>
<td>CCR 4 - engine</td>
<td>Fuel cell</td>
<td>dual-fuel engines + electric transmission</td>
<td>Flexible tunnel</td>
<td></td>
</tr>
<tr>
<td>particle filter (open)</td>
<td>Fuel cell + reformer</td>
<td>SCR + DPF</td>
<td>Down gradient/wake panel/dynamic streamlining</td>
<td></td>
</tr>
<tr>
<td>Particle filter (passive)</td>
<td>Gas CNG</td>
<td>LNG engine + electric transmission</td>
<td>Dove tail (insert between ship and barge)</td>
<td></td>
</tr>
<tr>
<td>Particle filter (active regeneration)</td>
<td>Gas LNG</td>
<td>2-stage TC + SCR + DPF</td>
<td>Trapezes (insert between ship and barge)</td>
<td></td>
</tr>
<tr>
<td>Exhaust Gas Recirculation</td>
<td>Dual fuel engine</td>
<td>Bow thruster valves</td>
<td>Air lubrication</td>
<td></td>
</tr>
<tr>
<td>Selective Catalytic Reduction (SCR)</td>
<td>Solar power</td>
<td>Propeller nozzle, Schneekluth Wake Equalizing Duct</td>
<td>Alternative materials</td>
<td></td>
</tr>
<tr>
<td>Diesel-electric propulsion</td>
<td>Wind power</td>
<td>Propulsion system: better geometry, alternative blades</td>
<td>Lengthening and/or widening</td>
<td></td>
</tr>
</tbody>
</table>

As can be observed in table 1, the majority of reviewed options relate to the power system of the ship (yellow cells), which is in line with the previously drawn conclusion that retrofitting of machinery is easier than changing the hydrodynamics of the hull. There are, however, also several options related to hydrodynamics (blue cells), mainly in the form of appendages to the hull or adaptations to the propeller. Furthermore, the option to make the ship lighter, thereby carrying more cargo per ton of displacement and, as a result of this, using less fuel per ton of transported cargo is included in the overview (green cell). Finally, it is assessed what the benefits of lengthening and/or widening the ship are (red cell).
4. SELECTION OF THE MOST PROMISING RETROFIT OPTIONS

The ship owners participating in the MoVe IT! project discussed each of the options presented in table 1 with the experts who compiled the overviews of estimated benefits, cost, weight, space technological maturity and suitability as retrofit solutions for existing ships. From this discussion, the following candidate retrofit options emerged.

**Herso I:**
1) Improved propulsion, using a stator system
2) Lengthening by 20-25%
3) Application of ‘trapezes’ for sailing in coupled formation
4) Improved rudders with flow extender

**Veerhaven X:**
1) Optimisation of the stern form (tunnels)
2) Reduction of drag from the bow thruster gondola and reduction of the influence of the gondola on the main thrusters
3) Comparison of SCR + particle filter vs. NOx and PM reduction by injecting hydrogen into scavenging air system

**Inflexible:**
1) Improved power management and application of waste heat recovery
2) Removal of struts from the propeller nozzles
3) Changing of the rudders
4) Improved propulsion, using a stator system

**Dunaföldvar:**
1) Application of a shaft generator
2) Replacement of main engines
3) Removal of the flanking rudders

**Carpe Diem:**
1) ‘Softening’ of the fore shoulder
2) Replacement of the rudders
3) Shortening of the gondolas that house the propeller shafts

What becomes apparent from the overview of selected retrofit options is that the ship owners expressed very little interest in power-related retrofits. The reason behind this is that emission abatement techniques such as filters and catalysts can only lead to very limited fuel savings or even to an increase in fuel consumption, while there are little to no other economic benefits, thus making these techniques unattractive from an economic point of view. Other solutions like LNG, CNG, Fuel cell, diesel electric or all electric propulsion all require major modifications to the engine room and large investments, thereby making them unattractive as well. Emission reduction techniques are only considered for Veerhaven X, while Inflexible’s owner is interested in waste heat recovery and for Dunaföldvar different engines or generators are considered. The options that are deemed most interesting by the ship owners are those that lead to a reduction in fuel consumption, and thereby to a
reduction in fuel cost, but do not require a major investment. This implies that the ship owners were primarily interested in optimising the flow of water around the ship by means of solutions that do not require major adaptations to the shape of the hull itself. Especially replacement of rudders is deemed an interesting option by several ship owners, while two owners are also interested in using a pre-swirlstator in front of the propeller. A final interesting conclusion that can be drawn from the choices of the ship owners is that apparently there is no universal desirable retrofit solution for inland ships. This conclusion is supported by the MoVe IT! experts: in order to improve the performance of an existing inland ship, it is necessary to make an analysis of that specific ship and its operation. Since the design and operational profile of each ship is different, so are their strong and weak points. There is no single universal solution that works well for all ships. An elaboration of all retrofit options presented in this section may be found in [MoVe IT!, 2013], but the hydrodynamics-related improvement for the coupled unit Herso I – Leonie is also presented in the next section as an example.

5. CASE STUDY: HYDRODYNAMICS-RELATED RETROFITS OF HERSO I - LEONIE

The case study hydrodynamics-related retrofits for this publication are taken from the 5 ships surveyed within the MoVe IT! project. It is the self-propelled motor ship Herso-1, usually pushing the barge Leonie. Three mainly hydrodynamic measures were proposed for this vessel, being:

A. **Trapezes**, i.e. lifting bodies between the pushed barge Leonie and the bow of the Herso-1 with the target of enabling a smoother transition between the two different sized hulls. A smoother transition is reducing the wave resistance as fewer waves are generated and avoiding undesired, energy consuming vortices in the coupling area between the hulls.

B. **Rudders**; the resistance and manoeuvring effect of different rudders and rudder configurations was surveyed to advise on a suitable rudder configuration of comparable manoeuvring performance but reduced resistance.

C. **Flow extender (or cover plate)**: An innovative and retrofitable measure to reduce the resistance of some ships is the flow extender. This measure is a more or less flat plate, extending the area behind a tunnel or above a propeller, which is enabling the following benefits:

- The off-flow direction of the propeller is guided rather parallel, i.e. into the desired thrust direction, than following the buttocks at the stern.
- The recirculation zone behind the ship is reduced, as still slender waterlines can be applied, regardless the guidance of the flow under water. A massive transom with the same guidance effect would cause massive flow separation as it would be submerged over a wide and deep area at the stern.
- The unsupported rudder shaft length can be reduced as the lower bearing of the rudder can be integrated into the flow extender plate. This way, constructive benefits and weight savings are achieved.
- The cover plate could work as an end-plate to the rudder profiles and this way maximising the lift and minimising losses due to 3D effects at the rudder profile’s upper edge.
The cover plate, however, is increasing the wetted surface of the ship and though the flow velocity at least on top of the plate is low due to the separation zone there, additional frictional losses need to be outbalanced by the advantages as enumerated above.

Pictures on A., B. and C. could be found in Hiba! A hivatkozási forrás nem található. and Hiba! A hivatkozási forrás nem található. It should be noted that thus far none of the measures is realised on the actual ship. Therefore, all photos are taken from the model, built at a scale of 1:16 in the facilities of DST, the Development centre for Ship technology and Transport systems in Germany.

Fig. 1 Model of Herso-1 and Leonie with (right) and without (left) trapeze transition piece

Fig. 2 Rudder configurations for Herso-1 (left: 3D model original, middle physical model, right proposed)

The benefit of the trapeze transition is in evidence already in Hiba! A hivatkozási forrás nem található. and becomes even more apparent in Hiba! A hivatkozási forrás nem található.

Fig. 3 Picture from under water high speed video recording of Herso-1 and Leonie with (left) and without (right) trapeze transition piece
The measured 18% resistance reduction for the ship with trapezes compared to the case without trapezes is well in line with the calculated resistance reduction of 20% from CFD calculations, see Hiba! A hivatkozási forrás nem található, and also the disturbed flow in the coupling region is well predicted by CFD.

The situation is more complex in the case of the proposed rudder- and cover plate configuration. As the quadruple rudder arrangement is apparently required to safely manoeuvre the convoy with Leonie, just removing the outer rudders is not an option as long as the achievable rudder force is not the same.

It was, therefore, decided to combine the measures cover plate and twin rudder as this way the cover plate can act as an end plate for the rudders and (partly) compensate for the potential loss of rudder force delivered by the wing rudders.

![Fig 4 Flow in coupling region without (left) and with streamlined transition (right)](image)

The beneficial effect of the cover plate is apparent in Fig. 1 and in the CFD results in Hiba! A hivatkozási forrás nem található.

![Fig. 1 Picture from under water high speed video recording of Herso-1 and Leonie with original (left) and proposed (right) arrangement at stern](image)
The wake behind the ship is much smoother in the right of Fig. 1 than in the picture on the left and the slipstream of the propeller is guided beneficially into horizontal off-flow condition, where the thrust is ideally exploited to balance the resistance of the ship as can be seen in Hiba! A hivatkozási forrás nem található.

Fig 6 Picture from CFD results on Herso-1 without (left) and with (right) cover plate

However, seen the given width of the transom, the cover plate cannot be wide enough to cover the upper edge of the twin rudder at large rudder angles. At such angles it loses the effect of an end plate and the rudder force is decreasing. The comparison of measured and calculated rudder forces and the relative comparison of the original arrangement compared to the proposed can be found in Hiba! A hivatkozási forrás nem található.

Fig 7 Relative improvement (left) and validation CFD results on Herso-1 (right)

All calculations and model tests have been conducted at at least two water depths. This way, a source of knowledge and data was established, in particular as much of the data was also acquired in full scale trials measurements. Though being just a sample, the test case of Herso-1 and Leonie is representative in many regards:

- She is one of the many ships of category IV, i.e. less than the current standard GMS 110m ships (Va), that catch up in cargo competitiveness by regularly pushing a barge (this way she also is representative for the subject scale enlargement)
• Originating from a period when the cover plate was not applied, she has been showing that such a plate is beneficial.

• Contrary to the originally envisaged hull-shape modifications, which turned out to be too complex compared to the expected benefit, cover plates can now be seen as one of the few retrofitable improvement measures affecting the shape of the hull.

• The lateral force measurements in general showed the potential of rudders for the sake of energy saving. However, in particular for the rather large rudder angles known in inland shipping, the current rudders have their right to exist if high lateral forces are required at large rudder angles.

6. SUMMARY OF TECHNICAL RESULTS OF ALL RETROFIT OPTIONS

For all ships under investigation in the MoVe IT! project, an evaluation was made of the investment cost, potential fuel savings and changes to the ship’s cargo carrying capacity. These are elaborately discussed in [MoVe IT!, 2013], but summarized in table 2. For an overview of the overall implications of these solutions for the economic and environmental performance of the ships, the reader is referred to Schweighofer et al. [2014].

<table>
<thead>
<tr>
<th>Ship</th>
<th>Retrofit option</th>
<th>Investment costs (€)</th>
<th>Δ fuel consumption</th>
<th>Δ Ship capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herso I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Lengthening 20%</td>
<td>200.000</td>
<td>+3% to +5%</td>
<td>310.2 t</td>
</tr>
<tr>
<td>2</td>
<td>Trapezes</td>
<td>100.000</td>
<td>-10% to -15%</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Stator system</td>
<td>40.000</td>
<td>-10% to -11%</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>Rudders + flow extender</td>
<td>Tbd</td>
<td>tbd</td>
<td>N/A</td>
</tr>
<tr>
<td>Dunaföldvar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Shaft generator</td>
<td>50.000</td>
<td>No benefit</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>Remove flanking rudders + placement of BT gondola</td>
<td>215.000 - 265.000</td>
<td>-5% to -7%</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>New engines</td>
<td>1,425.000 - 1,700.000</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>Veerhaven X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Improvement of stern</td>
<td>N/A</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>Improvement of bow thruster gondola</td>
<td>N/A</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Installation of SCR</td>
<td>200.000 to 250.000</td>
<td>0%</td>
<td>N/A</td>
</tr>
<tr>
<td>Inflexible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Waste heat recovery</td>
<td>&gt;&gt;20.000</td>
<td>8400 to 42000 kWh/year</td>
<td>N/A</td>
</tr>
</tbody>
</table>
From table 2, several things become apparent. Most notably, no improvements could be found for Veerhaven X. This vessel is probably one of the most well engineered inland ships in existence today. It is the result of continuous development of ThyssenKrupp’s pusher fleet and the extensive cooperation between the company, shipyard and model basin DST. It is therefore not surprising that effective retrofitable improvements could not be found. Of all other solutions, the stator system appears to hold most promise, although it still needs to be proven on full scale for river applications. In all cases, investment cost does not exceed €320,000, with the exception of the replacement of Dunaföldvar’s engines. For the rudders and flow extender on Herso I, no final figures are available yet. Considering the fact that the existing engines are at the end of their life, however, this high investment is unavoidable in order to keep the vessel in operation anyway.

7. LESSONS LEARNED
This paper has summarized some of the key results of the MoVe IT! project, which are described in more detail in, among others, [MoVe IT! ,2013] and [MoVe IT!, 2014]. From the results of the MoVe IT! project, several important lessons can be learned, the most important of which is that there is no single retrofit solution which is effective for all ships. It is important to realise that effects of changes to a ship strongly depend on the base-case situation. A good example is the changing of a rudder configuration. For a large, relatively fast ship with a small single propeller and elaborate steering gear, large improvements may be possible, while for a smaller, slower ship that has multiple propellers, changing the rudder configuration will have a vastly smaller effect. Also, changes to the hull of the ship will only be beneficial if the existing hull performs very poorly in a certain area. The studies done within the context of MoVe IT! show that there is no ‘magic bullet’ which will improve the performance of all inland ships. Each ship should be improved on a case-by-case basis.

Furthermore it is important to keep in mind that the cost of retrofit solutions is an important factor. The performance of a ship can be changed in many ways, ranging from simple actions that only affect a small part of the ship (e.g. changing the shape of the bow thruster gondola or removing a rudder) to very large modifications like replacing a drive train or reshaping the stern of the ship. Since fuel consumption of inland ships is typically quite low compared to e.g. seagoing ships and benefits are in the order of magnitude of a couple of
percent, expensive solutions will have a long payback time, well beyond the typically accepted timeframe of 3-5 years. When considering modernization options, it is therefore crucial to not only look at the potential benefits, but also to find cheap modernisation options. Apart from this, it is important to note that the ship owners involved in the project have expressed little interest in applying filters and catalysts to their ships, despite all the efforts that have been put into the promotion of these solutions in the past years. This is unsurprising considering the fact that these options have little to no fuel saving potential and are therefore economically unattractive.

One of the crucial complications of modernizing ships is knowledge of their performance. A proper diagnosis of their long-term performance is required to make a thorough analysis of the main points for improvements. Furthermore, many potential solutions relate to the flow around the stern of the ship, the rudder and the appendages. Calculation methods like CFD are only just reaching the level of maturity that these flows can be properly modelled, but outcomes are still insufficiently reliable to base improvements on. This leaves only experimental (model) tests as a reasonable optimisation method, but this requires a substantial amount of effort and budget. A second crucial complication is the fact that there is often only a limited amount of documentation about the design of the ship available. This makes it difficult to assess the current condition and performance of a ship.

8. ACKNOWLEDGEMENTS

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