THE IMPACT OF A DECADE OF INTENSE RESEARCH ON THE EFFICIENCY OF A TSHD

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ABSTRACT

"Lower cost per cubic yard dredged", efficiency, is nowadays quickly associated with "Jumbo" hopper dredges, as they have appeared in the market during the last decade. However, it is not only the effect of scale that improved the efficiency of the trailing suction hopper dredges. The replacement market for maintenance dredges initiated its own improvements, while market demands, including environmental ones, triggered other concentrated efforts.

The design, construction and operation of the different dredge models surfaced demands that lead to different design features being investigated and improved. The larger vessels invited to look into very deep dredging. The market addressed dredging of more compact materials, while a new target became that with less fuel - and with that propulsion power - higher speeds would be achieved, while reduced wave effects would allow more benefits from that higher speed.

During its existence IHC consistently spent substantial amounts for Research. Subjects for this R&D effort are triggered by a hybrid combination of technology-push and market-pull. The past decade the R&D resulted in a large number of useful applications.

This paper will address this research and the resulting advances in the areas of:
- hull shape, resistance and required propulsion power;
- hopper loading process, improving settling and discharging processes;
- load line revision for dredging draught;
- excavating technology with innovative excavating drag heads;
- specific automation;
- reducing time for "working up the crew" after delivery of a dredge through training

Illustrations with the latest generation dredges will document that the application of the recent R&D-results have jolted the efficiency of these dredges forward. Not the efficiency of the Jumbo's only advanced greatly, but also the medium sized hopper dredges in the 5,000 cu yd range, operated throughout the world including North America, profited.

The gains that proved to be possible during this decade showed that we have not reached the optimum dredge yet. The paper will conclude with a philosophy of what is expected to be ahead.

Keywords: Dredging, hopper settlement, compact fine soils, hydrodynamic ship design, wear prediction, automation, training

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INTRODUCTION

A decade ago[1)]it was already predicted that jumbo dredgers would continue to grow in size and they have continued to do so. In 2007 hopper dredgers of 50.000 m^3 (65.000 cubic yards) are being negotiated. But not only the jumbo dredgers have grown in size; the trend towards larger Trailing Suction Hopper Dredgers demonstrates itself in all sizes of hopper dredgers. Most significantly this trend is demonstrated in the evolution of smaller hopper dredgers during this decade: in a few incremental development steps the –in that time (1998)- new 85 m (280 ft) class of dredgers formed by HAM 311 (1994) and 312 (1997), both with hoppers of 3500 m^3 4600 (cubic yards), has grown into a highly economic state of the art design, of the 2004 born "Pallieter" class. This class was in some aspects further improved in "Marieke" and "Reynaert", (recently delivered to DEME), and has spatial (middle class) hoppers of not less than 5800 m^3 (7650 cubic yards). Tough their hoppers are much bigger, they still have kept a handsome length of near 85 m (280 ft) and a limited draught which makes them extremely capable for (fore) shore nourishment work. It may be clear that the latter development involved more than a mere scaling up.

Further this paper addresses some developments in the area of the hydrodynamics of the hull and improvements in the dredging installation, which have contributed to these very economic classes of dredgers.
All these improvements can not be considered isolated stand-alone developments. Without research based knowledge in the fields of hydrodynamics, ship structure, dredging technology and automation, the up-scaling would not be so economically and would not have resulted into a much lower specific energy per cubic unit dredged. Aiming for low CO_2 emissions, decreasing the energy per unit dredged is also contributing to a more sustainable world!

DEVELOPMENT DRIVES

With the hopper dredgers' growing sizes, capacities and efficiency in mind, the question may arise: what are the drives for these developments? We recognize two main drivers that require different approaches to respond to (although we admit mixed forms can possibly be recognized):

- **Competition**: a newly to be built vessel should at least be able to compete with its predecessors. Dredgers become more competitive both
    - by decreasing their operational cost , and/or
    - by increasing their yields and efficiencies.

  Incremental equipment development will therefore try to have both focuses.
- **Market developments**. New equipment should be capable to deal with new demands from the market, in particular to more extreme fields, conditions and soil types. These crossing border demands require fresh minds and back-to-the-basic approaches in research.

In case the life cycle of a product appears to have reached its saturation point, incremental development may become ineffective; in that case breakthrough technology is required.

DREDGING PROCESS AND MARKET DEVELOPMENTS

Reclamation dredging

In particular the Dubai dredging projects (the Palms, the World, etc.) have proven the thesis that Jumbo's have created their own reclamation market, which made these vessels specialists for that purpose. Therefore they are also labelled to be "Reclamation Dredgers". In the last decade a further increase of carrying capacity with a 10.000m^3 (13.000 cu yard) to about 35.000m^3 (46.000 cu yard) could be noted. Most of this was attained by lengthening of the vessel concurrent with an increase of the dredging depth. A further increase is expected, however to which one may express doubt whether or not the economy of scale is still applicable. The dimensions of even larger vessels will face navigational limits (with respect to manoeuvrability, available water depth etc.) of the dredging sites.

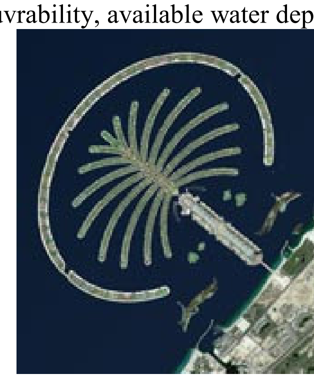


Fig.1. The Palm, Jumeirah

Deep dredging

Generally spoken, as the length of a suction tube is limited to what can be stowed on deck for sailing, the dredging depth of a TSHD can not be more than the ship length. The existence of Jumbo Dredgers made it possible to extend the dredging depth to 150 m (500ft) and beyond. This made it for instance possible to bring TSHD in action for the dredging of glory holes in arctic areas.
Of course these long drag arms required special designs, comprising of multiple joints suction tube arrangements with submerged dredge pumps and special over load buffers and swell compensator gear.
No doubt these types of deep off shore dredge operations contain a high risk element. In order to make the proper design decisions and to assist the operations, extensive dynamic behaviour research studies had to be carried out.

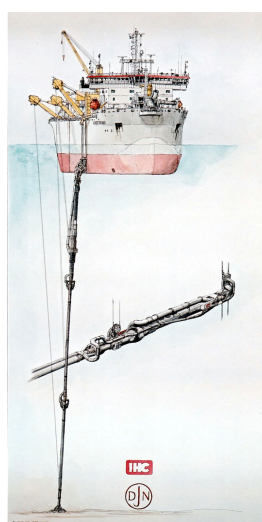


Figure 2. Deep Dredging installation for Vasco da Gama

Excavating drag heads for compact fine soils

Until recently when dredging compacted fine soils (d50 < 100µm) history documents it to be rather uneconomic to use a TSHD. That material was considered to be an area where cutter suction dredgers only would be successful.
Normally spoken application of Cutter Suction Dredgers would indeed be the most convenient way to do such a job. However, if the area to be dredged is in a navigable channel or is too much weather exposed (too heavy swell), then the more flexible characteristics of the TSHD make it the preferred type of dredge equipment.
The main problem of a TSHD dredging fine sands and silt is related to an insufficient capability to penetrate the soil deep enough, even when using the recent excavating drag heads. Although these drag heads are provided with jetting power and cutting means such as knives, pick points or chisels (which make them already capable to perform much better than erosion type drag heads), fine soils proved in the past to be hardly dredge-able by a hopper dredge.
From former research it was already known that the cutting force is the limiting factor for penetration. This penetration is limited by the available resultant of the balance of forces and momentum of the lower suction tube. (Gravity and drag head pressure difference should be capable to compensate for the digging forces.) In some cases operators had concluded to compensate the lack of available vertical force by adding weight, which proved to be helpful indeed, but caused heavier gantries, winches etc. A not so very sophisticated solution!

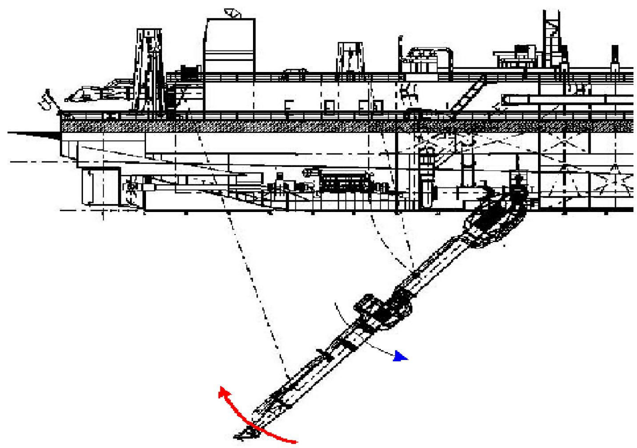


Figure 3. Equilibrium of forces and moments acting to a suction tube arrangement.

During earlier laboratory testing it was concluded that compacted fine soils are characterized by a very poor capability to be penetrated by water, which results into a shortage of water at the cut when excavating. This in its turn causes a large under pressure, or even vacuum, leading to high cutting forces and preventing the drag head to penetrate the soil more than a few centimetres (inches); with very low and unsatisfactory productions as a result. In order to overcome this physical limitation, IHC together with some project partners, started a research to find a solution.
A step back to the basics was needed. A new approach was proposed by adding water into the zone that suffers most from the lack of water. Many laboratory tests, both at Delft Hydraulics and MTI Holland, were carried out to confirm the expectations from that theory. That was only the start of a long way to develop not only the principle, but also the practical solutions to lead a water flow through the teeth and to shape the drag head for an optimum excavating process.
Taking into account that adding water into the cutting process takes time and that the effect is limited to a thin layer, adding a second row of teeth proved to bring relief. The newly developed drag head was named "Wild Dragon"® as it was tested on board the Dutch built Chinese dredger "Xin Hai Long", (New Sea Dragon).

Figure 4. Wild Dragon® drag head jetting power

The practical testing at the hardest banks in the Yangtze River banks turned out to be very successful. Production in some cases gained even more than 100% (see fig 5). Also in more clayey soils the drag head showed its advantages. *2, 3)*

In the mean time, also other than Chinese dredging companies have purchased "Wild Dragon®" drag heads; among them are American, Pakistani and Dutch dredging companies.

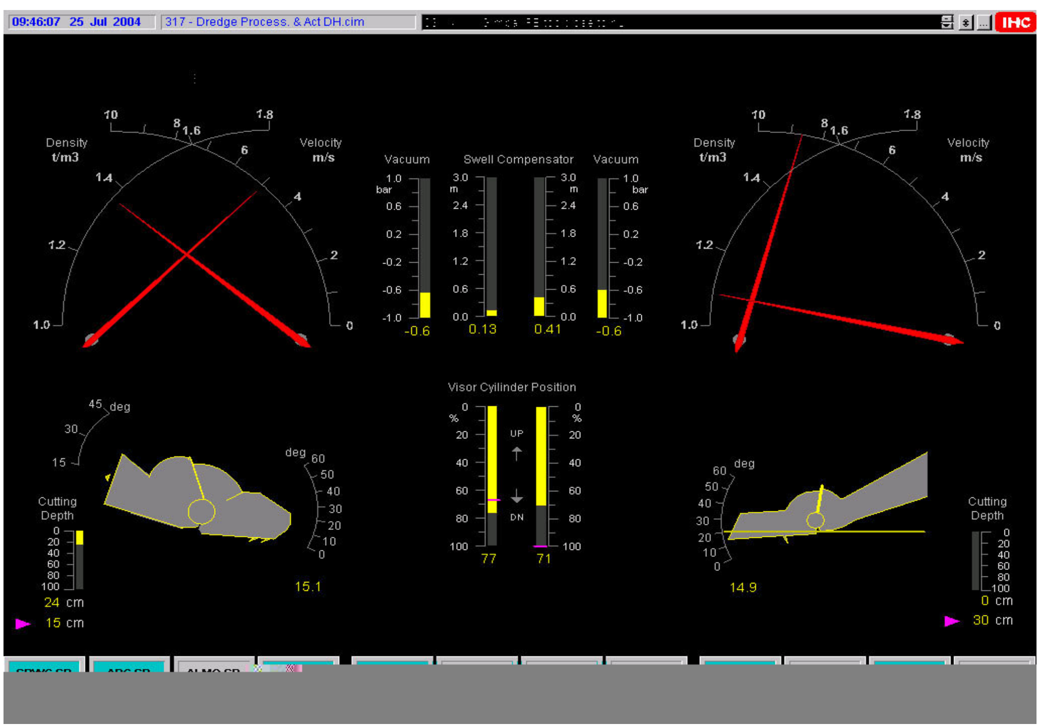


Figure 5. Wild Dragon® production (left) compared to a state of the art excavating drag head

Of course this drag head development has not come to an end yet. Further improvements and solutions, also for smaller versions, are studied.

Sophisticated hopper loading

In particular spoils of fine soils suffer from bad settling (sedimentation) when they enter the hopper. All benefits of research and development on the cutting and sucking of fine material are undone by severe overflow losses. Since a long time overflow losses have been the focus of a number of studies. Up until the 90's Camp's description of the sedimentation process (with some additions by others) defined for many years the state-of-the-art knowledge. Although some tried to improve Camp's model, it appeared to be limited in describing the actual process as a black box and thus could not be the basis for further hopper loading system improvements.
Good ideas are seldom born at one place only; it may be called a coincidence that two independent research efforts were started on hopper sedimentation processes in the same time. One research was carried out by some Dutch dredging contractors together with Delft University of Technology, as a PhD thesis study [4)]. The other research was started by IHC in co-operation with Dredging International (DEME) and was carried out at the MTI Holland laboratory using a 1:4 scale test hopper model (named 'Schanulleke') and was verified on board of the TSHD Antigoon.
Results of these (supplementary) researches have been reported at several occasions.[5)] The applications of this research into hopper designs have not yet been published widely.

Figure 6. 1:4 scale hopper test rig "Schanulleke" at MTI Holland laboratories

Main conclusions from the IHC/MTI research on hopper loading were:

- Hopper separation, sedimentation and overflow processes can be best described as a gravitation separation with three layers: a stochastic 'mixture soup' which is fed by the mixture inflow (causing a density current) and that produces both a bed of sediment at the bottom and a layer of water at the top.
- The production of the bottom layer of sand, characterized by the sedimentation capacity (m^3/sm^2) or so called bed rise velocity (m/s), has a specific maximum depending on grain size distribution and density. This means that in operational conditions sedimentation will never be more, but most probably less.
- The efficiency of this separation process and therefore the actual sedimentation capacity is mainly determined by energy that should be dissipated before the particles can settle; i.e. the more equally the flow is spatially distributed the better (settled particles have no potential nor kinetic energy!)

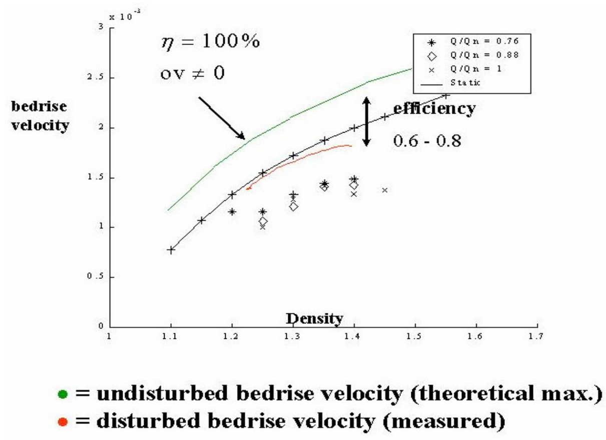


Figure 7. Undisturbed and disturbed bed rise velocity

The gained knowledge is now applied to several fields:

- *Prediction models*

From this research IHC could replace her existing sedimentation model within its hopper dredging prediction tools, by a fully new mathematical model that is based on the new insights.

- *Design*

Using the new prediction tool, the engineers are able to create a more balanced design of the dredge system (from drag head, dredge pump and driving power, suction pipe line to loading box and overflow systems). The hopper loading devices, such as the hopper loading box, were re-designed to comply with the sedimentation requirements.

- *Control*

Also improved loading procedures have been concluded, among which a procedure to dredge fines at a controlled (probably slower) flow, not only at the end but also at the start of the loading process, of course weight against the other aspects within the specific dredge cycle, mostly dependent on the sailing distance. In order to be capable to decrease the flow an adjustable pump drive rpm is strongly recommended. Based on the newly gained insights an advanced loading control strategy could be developed, which is due to be implemented into state of the art dredge automation.

Figure 8. Full scale testing of Hopper loading box of new design

STRUCTURAL DEVELOPMENTS

When studying hopper loading, hopper unloading follows. Different aspects were studied. Larger TSHD's would also imply a larger number of bottom dump doors, which is costly both from an investment as well as from a maintenance consideration. In order to reduce the number of bottom doors it was aimed to both increase the size as well as to re-arrange the bottom dump doors. A relative smaller dump area (total bottom door surface) appeared to be less a problem by taking advantage of improved hopper diluting systems, which was also beneficial for the wish to decrease the number of self emptying valves.
A hopper arrangement with a reduced number of bottom dump doors could particularly be considered using a mid-ship section with a V-shaped hopper. Arrangements with large bottom doors result however in much higher locally concentrated stresses. This problem could be managed by improved FEM based structural design methods and the application of newly developed materials, such as TMCP steels (Thermo Mechanically Controlled Process (Rolled)), which both have also contributed to more efficient and larger TSHD.
In order to gain knowledge on the maritime application of TMCP steels in Dutch shipbuilding an industrial research consortium was formed with the Royal Netherlands Navy and some Technology Institutions (TNO - Netherlands Organization for Applied Scientific Research and Delft University of Technology). This new knowledge could directly be applied into some new Jumbo TSHD in particular those with V shaped hopper spaces (see fig 9) and very large hopper dump doors. In large TSHD applications, TMCP steels appeared to be most effective at locations with high stress concentrations and fatigue sensitivity. Unless their large thickness, due to their fine grain structure and low Carbon Equivalent, TMCP plate inserts around bottom dump doors do not require preheating before welding.

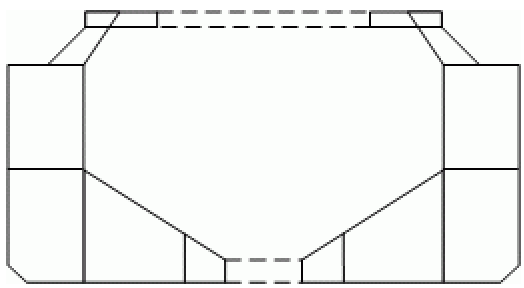


Figure 9. V shaped hopper, with one centre row of bottom dump doors

RESEARCHING WEAR TO DEVELOP A WEAR PREDICTION PROGRAM FOR MATERIAL SELECTION

In the total approach to lower the cost per unit dredged, maintenance cost is one of the elements to be evaluated carefully as it forms a substantial percentage of the total operational cost. Moving slurry causes wear on drag heads, cutters, pumps and pipelines. Replacement, repair and the labor cost to replace elements of the dredge installation and resulting down time, are cost elements that in some jobs can form one quarter of the cost per cubic unit dredged. This awareness challenged IHC again to a back to the basics approached R&D effort on material sciences. This led to a research program to analyze wear, starting with the definition of the basic elements causing wear. During this basic research, it was among others concluded that the shape of the grain (round, sharp edged etc) appears to play a dominant role in the overall wear process.[6)].
Subsequently IHC developed a model to predict wear on certain materials and measured actual wear. The models developed by IHC/MTI for the prediction of the wear installation make use of first principles, laboratory and field data and the appropriate mathematical modeling tool
Wear is to be considered a multivariable and random process and therefore in MTI's prediction models other parameters have been considered as well, such as mixture concentration and velocity, soil composition (quartz, calcareous, etc), relation mixture velocity to critical velocity. IHC's MTI Research and Development laboratory developed this wear prediction program, applying nine parameters. [7)]
Some of the data used by IHC/MTI to validate the models were recorded and supplied by contractors cooperating in developing the IHC wear research program.
This wear prediction program is estimated right now to be accurate for pipes. For dredge pumps it is considered to be still in a development stage. The laboratory tests that were performed at MTI to study wear, showed to follow more or less the same direction as the wear tests conducted by the TNO, but they were done independently. MTI

developed the so called WRF factor (Wear Resistance Factor for abrasive wear) and TNO (Netherlands Organization for Applied Scientific Research) developed a similar factor F40 (for both abrasive and impact wear).

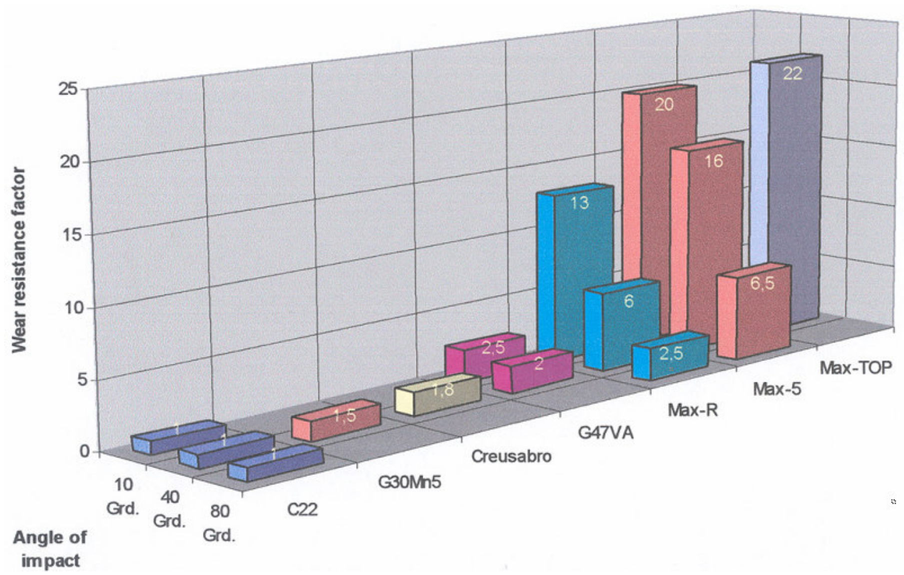


Figure 10

For different sieve analysis with specific grain shapes, wear can be reasonably predicted for various materials types including IHC materials used St37, Max 5, Cast Steel 47VA, etc. (fig. 10)

Updating the data base with recent measurements is a continuous process and will be the basis to provide a more accurate base for wear predictions. Electronic registrations of measurements via SCADA systems of parameters like velocity, provide accurate inputs,

The application of pipes with 58Rc-63Rc (Rockwell C) liners, widely applied on the large dredgers during the last decade, may seem as a ultimate wear resistant solution, however in certain conditions the program concluded, when using the lowest price per unit dredged as the decisive criterion, that one (1) inch thick mild steel would be a more economic solution than the lined pipes, in spite of the coarse material foreseen to cause considerable wear.

The wear research results have guided in certain designs to the decision to make not all pipes from the hardest material, but rather to look at the life expectancy of individual elements, such as straight pipes, elbows etc. and target an equal life time for each element, so that all pipes will be worn at about the same time and can be replaced (or turned over) in one and the same maintenance period, reducing down time.

The systematic back-to-the-basics research proves also to provide the critical factors to evaluate new wear resistant materials. That systematic approach did have some surprising results including IHC re-ranking some of its own wear resistant materials.

This program continues to be developed and to provide further validation and calibration of this program. It is foreseen many millions of pumped slurry will be logged yet to acquire actual measuring results from the field.

HYDRODYNAMIC SHIP DESIGN

Hull shape, resistance and required propulsion power.

Observing the hull of the newest hopper dredgers and comparing them with those of ten years ago, one can easily conclude that a real development has taken place during the last decade. Indeed, it has and several needs and requirements led to these developments. Already in former days this type of vessel was characterized by its limited freeboard, wide beam and a rather full hull. The speed of the hopper dredger was relatively slow, but her wave making was remarkable however, due to her full hull.
All these characters changed during the last decade (and some are changing yet). Generally speaking, the main reason for these changes is the never satisfied need for increase of efficiency. This increase of efficiency may consist of reduction of investment costs, a better performance of the vessel or a combination of these two.
Each change has an own origin. In this paragraph the change of each character will be dealt with separately.

Further freeboard reduction

Since decades hopper dredgers are allowed to have a reduced freeboard, mostly half the international freeboard. The capability of getting rid of the cargo by dumping through her bottom doors and arriving on the international freeboard in a few minutes, has made the reduced freeboard feasible and accepted.
Most of the hopper dredgers are of the multi-purpose type and just these vessels with their operational practise created a change in the attitude of the authorities. A hopper with a large volume intended for light dredging, but used for heavy dredging (as sand is), makes overloading possible. Being aware of the (generally) intrinsic good stability of the vessel, this seemed an attractive choice, especially in slender times, but overloading is illegal. European authorities were willing to investigate the increase of the maximum allowable dredging draught in favour of the economics of the dredgers, however.
In October of 1996 consideration about a major review of the existing guidelines started. Deliberation between Administrations of France, Belgium, Germany, United Kingdom and The Netherlands and the dredging industry (represented by the Dutch dredge organisation VBKO) had to lead to harmonised guidelines which should keep the hopper dredger safe at a deeper draught, but without harming ship's economics. A direct reason for this initiative was the request of the dredging industry to allow a further reduction of the freeboard when operating in restricted areas, provided the safety is not impaired. The result of this action was a further reduction of the dredging freeboard by 1/6 of the statutory freeboard. Nowadays the total reduction of the freeboard may be at the most 2/3 of the summer freeboard, so that only 1/3 remains. It must be said that this fraction has been chosen quite arbitrary, but there has to be a limit somewhere. Complementary to this further dredge freeboard reduction (damage) stability rules were upgraded to keep the safety level sufficient. [8)] Legislation by national authorities for the application of these guidelines has been made possible by IMO issuing new guidelines. [9)]

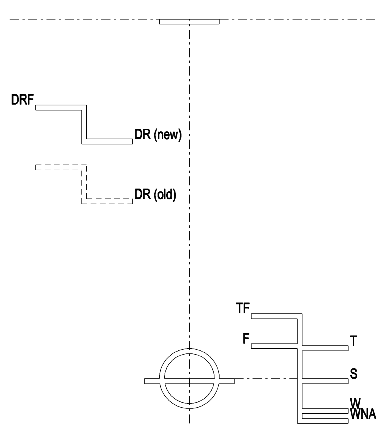


Figure 11: Updated freeboard mark of a new hopper dredger

Wider beam

One of the most notable effects on the design of the hull of a modern hopper dredger of the above mentioned freeboard reduction and accompanying rules, is the increase of the breadth. This increase is necessary because of the stability of the vessel. Not only the deeper draught, but also the nowadays more common V-type hopper and the presence of a bulbous bow have negative effect on the intact stability. On top of that the new rules are more stringent.
Fortunately, the hopper dredger is intended for jobs in shallow water. For new designs, the draught is restricted as far as possible to enable proper sailing in (extreme) shallow water. The "loss" of the buoyancy caused by this restricted draught will necessarily be dissolved by an increase of the breadth.

Figure 12. New generation hopper dredger "PALLIETER".

In the meantime, several hopper dredgers have been designed and build according to the new guidelines. In January 2004, IHC delivered a medium size hopper dredger of 5400 m³ (7100 cu yd) at only a length of 85 m (280 ft) , to the Belgian company DEME. This dredger, named PALLIETER, is a typical example of a wide body design with optimized main dimensions, based on both strength and stability. The actual dredging freeboard is only 1/3 of the summer freeboard. Now, the maximum draught is 0.24 m (11 ½ inch) deeper then allowed before, providing a benefit of 5% deadweight! This design proved to be so successful that is was followed by DEME's order for two sisters and two larger versions.

With a beam of 21.6 m (71 ft) and a dredging draught of 7.1 m (23 ½ ft) the B/T is 3.0, whereas in former days a B/T of 2.7 was normal.

Fuller hulls

In order to simultaneously further increase hopper load at relative lower investment cost, the length of the vessel's hull should be minimized. Because the beam was already relatively wide and the draught restricted, for stability and shallow water reasons, the remaining parameter to fulfil the need for increased displacement is the block coefficient, CB.

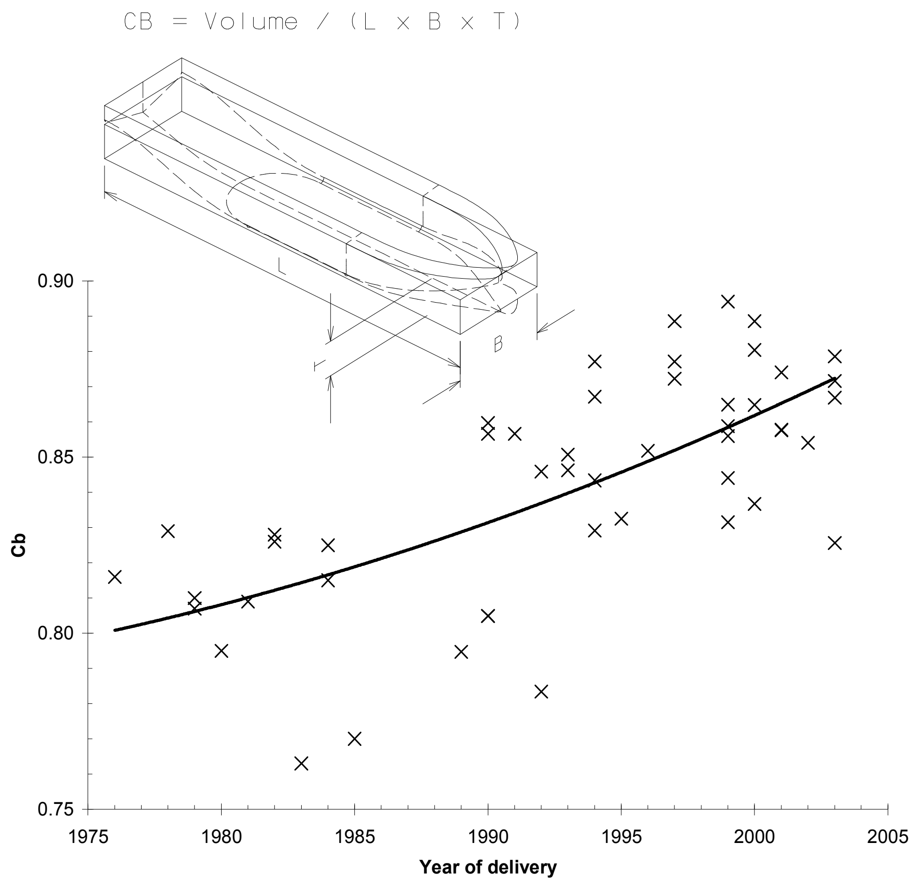


Figure 13: Trend of increasing CB

Although this CB is a simple factor, technically several problems must be solved to create an acceptable hull. These problems are mainly of a hydrodynamic nature. A hull with a high CB will induce:

- a higher resistance and thus needs more propulsion power at a given speed
- steeper bow- and stern waves, which may oblige to reduce speed in order to avoid hindrance of surrounding traffic or ship wash (shore damage)
- a more disturbed flow towards the propellers, which phenomena cause a significant drop in propulsive efficiency and serious vibration problems
- a larger hydrodynamic sinkage, called "squat", which give an additional restriction on sailing in extreme shallow water (also with effects to manoeuvrability)

To overcome all these inconveniences, the designer is obliged to investigate the possibilities of such a full hull by varying the shape. During the last decade IHC did a lot of research and development on this matter resulting into large improvements, which are reflected in several hopper dredgers, sailing throughout the world. In this research great advantage has been taken from recent developments in the field of Computational Fluid Dynamics (CFD) calculations. These calculations provided the possibility to evaluate many variants of a hull design before model testing.

By this approach the model finally tested could be of an already optimized design, which saved time and resulted into a significant improvement.
Of course these findings still had to be proven in reality and the predicted flows had to be validated by specific measurements. In next paragraphs we describe some of the issues in more detail.

Resistance & waves

For hopper dredgers the wave making resistance is a significant part of the total resistance. Roughly half the resistance consists of friction and the other half mainly consist of wave making. Because friction cannot be avoided reduction of the resistance must be found in a smooth wave pattern. Computational Fluid Dynamics proved very useful in an optimization process. For a smooth wave pattern with such full hulls, a bulbous bow was inevitable to enable a well shaped waterline. Where in former days a bulbous bow was "not done" due to such activities as the coupling of a floating pipeline at the bow, nowadays the speed of the vessel is more important.

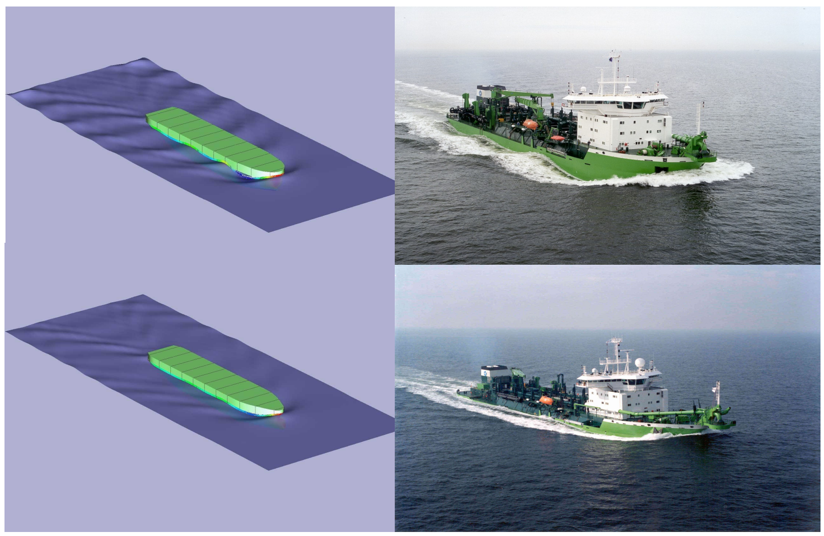


Figure 14: Comparison of the CFD results (left) and the real ships (right).

A benefit of 17% propulsion power at her service speed has been achieved with this optimization. Please note: in this example it concerns a sister ship where restrictions were valid for the extent of the alteration of the bow shape. For new designs benefits up to 25% are not uncommon.

Stern flow & propulsion performance

For a proper working propeller a well shaped stern with smooth transitions is required. Even when the hull is full this can be realized. First, the design condition must be agreed. Shallow water is commonly the condition wherein the hull must be optimized. This choice needs a totally different approach and leads to a different hull in comparison with hulls which are traditionally designed for deep water. Care must be exercised when shaping because such extreme hulls are very sensitive for resistance increase by only small changes. However, some is depending on the type of the hull. Traditional sterns with exposed shaft hoses are less sensitive, but the disadvantage of this hull is the internal space for the propulsion plant. Attempting to enlarge the hopper volume, the length of the engine room is the loser. Nevertheless, for the propulsion plant a certain length remains required and therefore this plant must be moved afterwards, resulting in a forced shape locally. This forced shape increases the resistance and spoils the flow towards the propeller. For that reason the so called "twin gondola" stern is introduced. This stern enables thus enlargement of the hopper and on top of that it excels in hull efficiency which is in favour of the speed of the vessel. Making the stern of the dredger fuller one can confine with well shaped gondolas around the propulsion gearbox. Also for the optimization of the stern the use of CFD is sufficient at first.

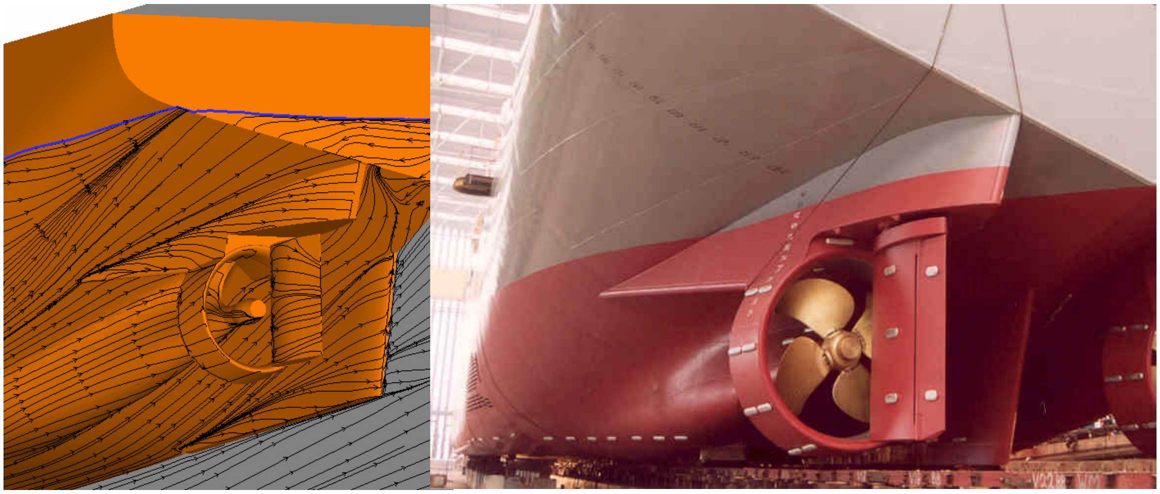


Figure 15: A twin gondola stern, CFD result (left) and reality (right)

To show the effect of the application of a twin gondola stern on the position of the aft hopper end bulkhead, figure 16 is added. The vertical reference (dotted) lines show a gain of three frame spaces which can the bulkhead moved afterward.

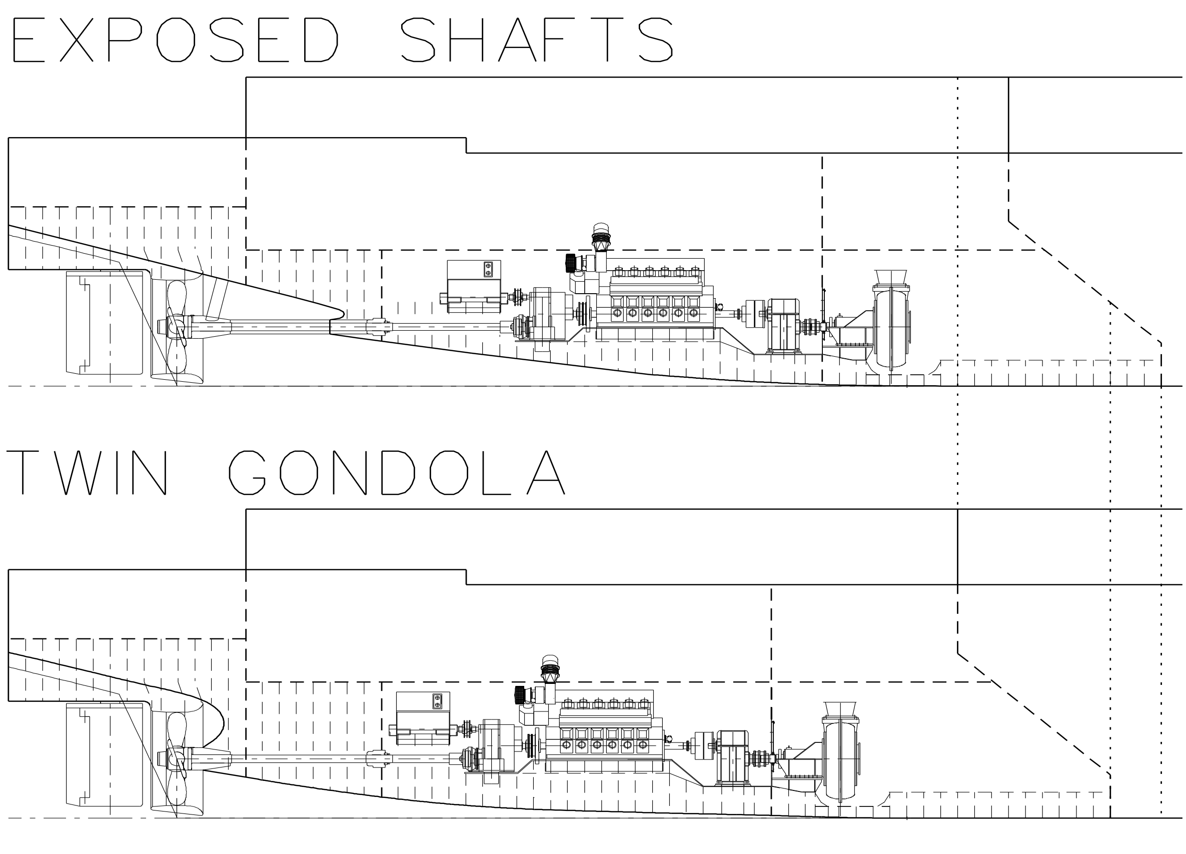


Figure 16 Longitudinal sections over the propulsion plant of different sterns

When the optimization process has been finished the hull must be tested at model scale and finally the propulsion performance must be measured during sea trials.

Validation

To avoid discussions about the validity of computer simulations and the scale effects of model test, measurements at full scale have been carried out too. For that reason DEME's hopper dredger UILENSPIEGEL was subjected to full scale measurements in the European research project EFFORT. [10] Full plane windows were fitted in the stern to measure the flow towards the propeller with Laser Doppler Velocimetry (LDV) techniques.

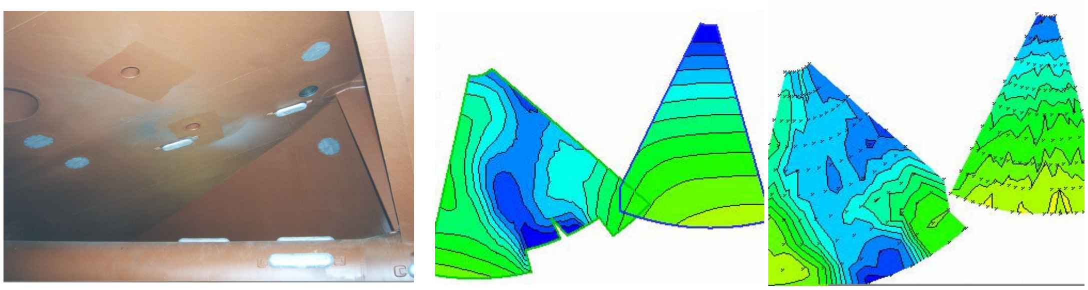


Figure 17. The stern of the UILENSPIEGEL equipped with windows for LDV measurements (left), a calculation result (middle) and a measurement result (right) of axial flow.

These steps proved necessary and especially the results of the last one assured us that we are on the right way in shaping the dredger's hull.

Summary (hydrodynamics)

All these above mentioned investigations lead to a significant increase of the efficiency of the modern hopper dredger with respect to the following parameters:

- Deadweight: reduced freeboard
- Dimensions: decreased length and increased breadth and fullness
- Speed – power relation: improved hull shapes
- Properties in shallow water: flow research with CFD
- Hopper volume: application of the twin gondola stern type

Finally the effect on the economics of the hopper must be evaluated. This is not simple due to the diversity of hopper dredger designs. Nevertheless, the last decade several hopper dredgers with a perpendicular length of 85 m (280 ft) have been built and it is quite interesting to observe figure 18 which presents the growth in transport capacity of this category as a result of extensive research. The transport capacity is the product of the deadweight and the maximum speed and is expressed in unit tons.knots.

It could be supposed that extensive research is essential to enable the design of even more efficient hopper dredgers. One may conclude that figure 18 confirms this thesis clearly.

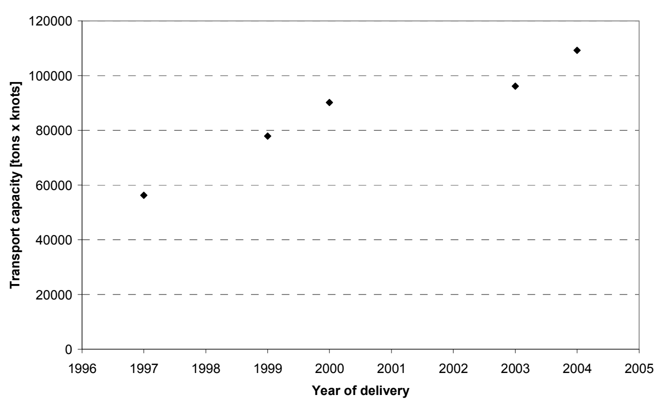
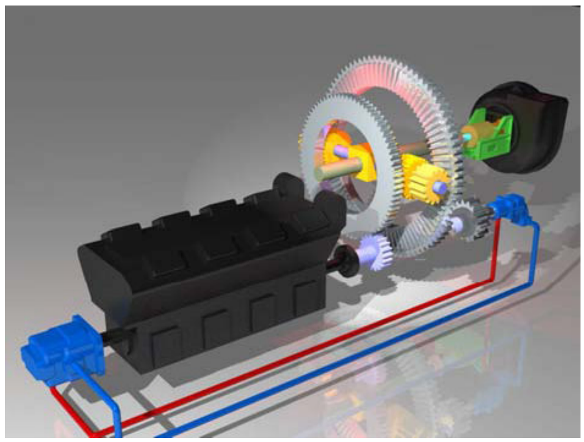


Figure 18: The transport capacity of the 85 m category hopper dredgers

OTHER DEVELOPMENTS

Variable pump speeds

The need to make the dredge pumping process more controllable, as learned from amongst others the researches on hopper loading, but also for pumping ashore operations, led to the development of a continuous variable gearbox (IHC Variblock), which turned out to be a good alternative to frequency controlled diesel electric drives. After a prototype testing on a stationary dredger, Boskalis decided to apply this mechanical drive to their new building medium hopper dredgers "Waterway" and "Coastway". Of course this variable gearbox could also provide controllable pump speed at pumping out the hopper (rain bowing or shore discharging). [11)]
The patented system consists of a planetary gearbox with crown wheels; as fig. 19 shows, the speed is controlled by an additional power line using a hydraulic pump and motor system.



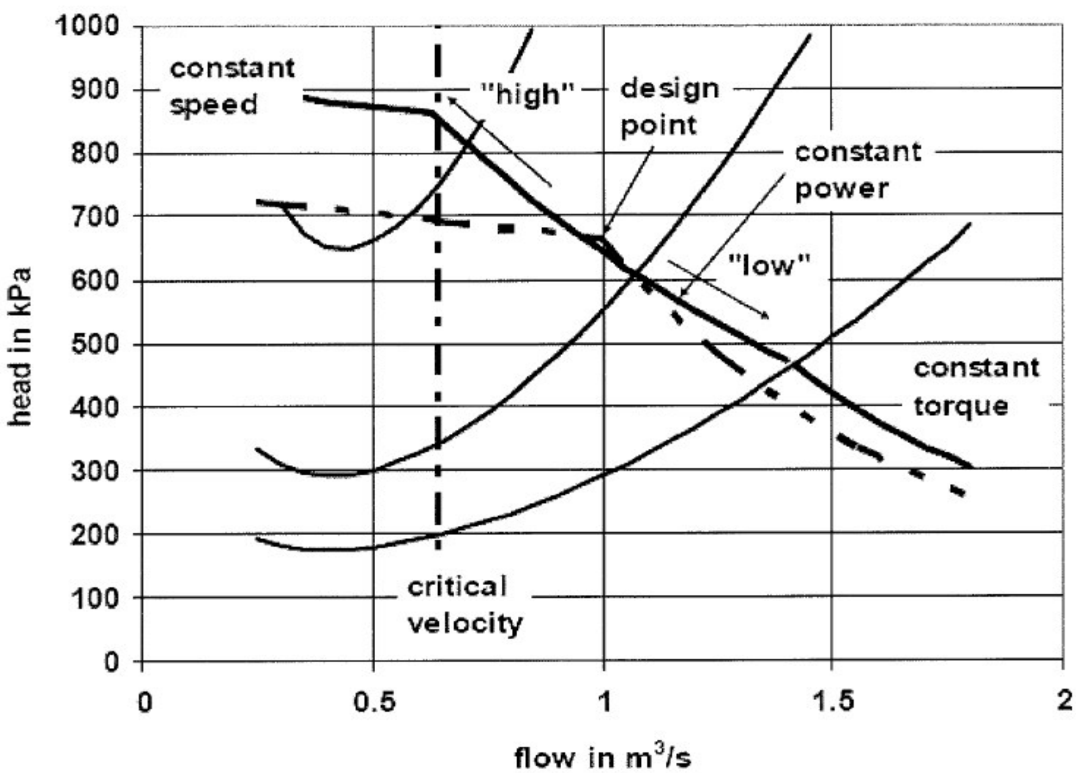


Fig 19. IHC Variblock, working principle and characteristics

Dredge control systems and dredge automation

No doubt, the dredging process is very complex and difficult to be controlled manually. State-of-the-art multi purpose dredge measuring and control systems can generate a number of up to 5000 I/O (input/output signals) and even more. This can hardly be managed using stand-alone control systems, not to mention the very extensive cabling system that goes with it. Already twenty years ago a development started to a more integrated approach using a combination of PLC and PC based SCADA, systems joined together into a data-network. These integrated systems came to maturity last decade, with the addition of dynamic position and tracking (DP/DT), survey, radar and Conning systems. Anyway, the applied DP/DT systems have been developed specially for trailing dredging. That meant that some dredging specific naval architectural knowledge had to be incorporated into the system. Also special control (patented) algorithms had to be developed that makes the system capable to deal with variable currents and dredging forces.

Figure 20. Integrated dredge automation; DP/DT, survey (DTPS), Radar, navigation and Conning

Recently a further step in the development of integrated dredger automation has been made with the introduction of a single operator hopper-dredger control desk. In this control desk both navigation and dredge control are integrated and automated in such a way that they can be operated simultaneously by one person. This required among others the development of a more advanced suction tube winch control.
This new bridge concept has first been applied on board DEME's TSHD "Marieke". DEME's first experience appeared to be very satisfactory.

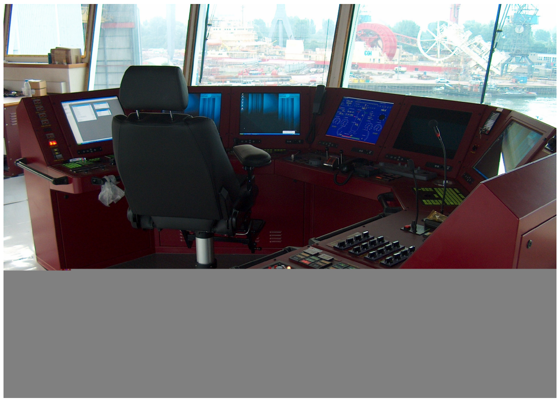


Figure 21. Single operator hopper dredger control desk (integrated dredging and navigation desk; first applied at TSHD Marieke)

TRAINING

In addition to becoming more efficient, modern dredgers have become increasingly more complex and capital intensive. The need for an increase in efficiency can not only lead to focussing on the machine itself, but also on the people required to operate this tool.
In addition to teaching basic dredge knowledge, it is also vital to train the crew of new dredgers with specific operational skills. This can of course be done onboard, however in general this will lead to a loss of production and to an increased risk of damaging the dredger.
New software and faster computers opened the door a state-of-the-art alternative: realistic simulators. During the last decade IHC Systems developed a new generation of dredge simulators. In addition to an accurate knowledge based simulation of the dredging process, these simulators are provided with realistic three dimensional imaging (as used in gaming!), creating the ideal environment to practice skills in realistic, but conditioned situations.

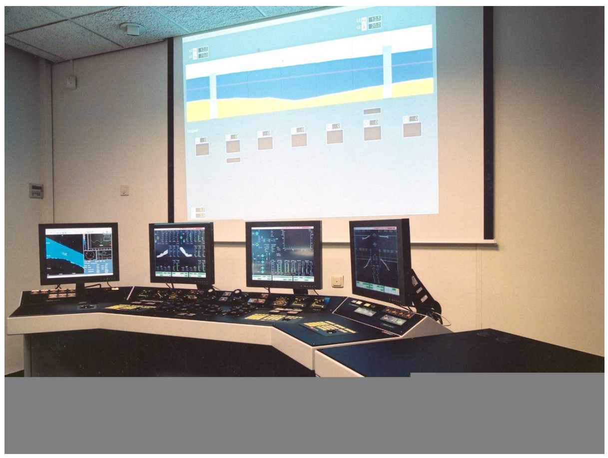


Figure 22. New generation hopper operator training simulator console

Training has become an essential part of dredging operation. Over the past decade the labour market has changed. Recruitment of western crew becomes more difficult, while growing fleets and improved leave schedules require more crewmembers. This resulted into a need of globalisation: new crew members are now also recruited from other than Western seagoing nations. Some nationalities have little experience in dredging yet. In order to be able to manoeuvre safely and efficiently in this changing labour market with increasing numbers of new comers, training institutions, like IHC's Training Institute for Dredging (TID), provide state of the art extensive training programmes. *12)*

IN WHAT DIRECTION IS FUTURE R&D FORESEEN TO GO?

Predictions for future developments are always subject to a large amount of reservations. Within these realm of reservations, we can however identify at this moment trends in the following subject areas:

- *Sustainability*

Also the dredging world is challenged to more sustainable dredging. Therefore research needs to be focussed more then before on the impacts of dredging on the environment. Also CO_2 and NO_x emissions should be reduced. This requires more efficient engines and alternative fuels, but also new solutions to reduce ship resistance and more efficient dredging techniques. Further new materials will need to be developed that stand longer and/or produce less impact on the environment while wearing and at the end of ship's life.

- *Automation*

The increasing lack of experience of new operators will need to be compensated by artificial intelligent automation systems. This means that these systems will be self-learning; they will be made able to autonomously conclude from process signals the best operational set points and control strategy. In fact they do what operators do when they learn from their experience; but computers can do that much faster and do not become tired or diverted.

- *Ship structure / materials*

Ship building is an old art. By application of new materials (super high tensile steels, carbon reinforced plastics etc.) and more sophisticated structural concepts (like sandwiches) ship weights and production hours will be reduced.

- *Dredging technology*

Most dredging technologies of today have been developed step by step (incrementally). Their development life cycles often come to a saturation point. The situation in which the first idea was born can sometimes hardly be recognized anymore in our daily practise. It is expected that new challenges will therefore increasingly need to be encountered by a more first principle or "back to the basics" approach. This means an open mind development where one will look around to other fields, in order to take advantage from cross-fertilization with other science fields. A good example of that approach is considered the recently developed Wild Dragon® drag head technology. Also in other fields technology barriers will be sought out and levelled.

- *Life Cycle Support*

There is a trend with dredging companies towards outsourcing there maintenance to specialized equipment companies, like IHC. In order to anticipate on this trend new efficient knowledge based services are developed.

CONCLUSIONS

- "Lower cost per cubic yard dredged", efficiency was mainly associated with "Jumbo" hopper dredges, as they appeared in the market during the last decade. However, it is clear that not only the effect of scale improved the efficiency of the trailing suction hopper dredges. The replacement market for maintenance dredges initiated its own improvements, while market demands, including environmental ones, triggered other concentrated efforts.
- The design, construction and operation of the different dredge models surfaced demands that lead to different design features being investigated and improved. The larger vessels invited to look into very deep dredging. The market addressed dredging of more compact materials, while a new target became that with less fuel - and with that propulsion power - higher speeds would be achieved, while reduced wave effects would allow more benefits from that higher speed.
- A quick innovative response to market demands requires pro-active research. Subjects for this R&D effort are triggered by a hybrid combination of technology-push and market-pull. The past decade the R&D, especially with its back-to-basics approach, resulted in a large number of useful applications.
- Training has become an essential part of dredging operations. Training simulators can contribute efficiently to develop skills for inexperienced crews. Inexperience will also be compensated by a next generation, artificial intelligence based automation.
- Future challenges will be first of all sustainability driven. A step forward from stagnating incremental development needs a first principle approach with cross-fertilization from other science fields.

The concentrated Research and Development efforts during the past decade have advanced the efficiency of IHC's hopper dredge technology and resulting designs and deliveries significantly: the price per cubic unit dredged can stay in line with the market, in spite of serious price increases.
Curiously, the advances raised an appetite to investigate even more, rather than that it created a feeling of achievement. Numerous subjects are on the slate to be researched, but the principle applied successfully during the last decade, back to the basics with research based knowledge, will continue to govern the selection criteria.

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