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## OSH

Oil Sea Harvester

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Project coordinator name      Christian Gaudin  
Project coordinator organisation name AKER YARDS

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## 1. EXECUTIVE SUMMARY SUITABLE FOR PUBLICATION

The main purpose of this deliverable is to summarise all the work that was performed, the activities that were undertaken and the results that were obtained during the complete duration of the project, i.e. from December 2004 up to November 2007. This includes an outline of the scope of the project, the goals that have been set, the problems that were encountered in achieving these goals and the solutions that were given to such problems, for each topic or area of research. In particular, this report includes the following:

- An **introduction** outlining the project as well as the scope of this deliverable;
- Detailed discussion on the above-mentioned issues, spread across **ten sections** that form the main part of the report, each addressing a specific topic as follows:
  - analysis of needs and definition of technical requirements;
  - preliminary ship design;
  - development of the oil recovery tools;
  - optimisation of hydrodynamic performance;
  - testing and final development of the oil recovery system;
  - definition of oil recovery scenarios as well as other missions;
  - compliance with international rules and regulations;
  - detailed definition of the concept as a complete system;
  - techno-economic evaluation and cost-benefit analysis; and
  - dissemination and exploitation of the project and its results.
- **Conclusions** on the achievement of desirable goals as documented by the above items;

In the following sections the above topics are discussed in detail, offering a comprehensive view of the approach followed by the OSH consortium in establishing feasible and meaningful goals and achieving them. This discussion demonstrates that:

- there is scope for developing a concept such as the one proposed by OSH, based on existing shortcomings of the current oil pollution response infrastructure and the apparently increasing significance of the occurrence and effect of relevant incidents;
- the broad requirements of the oil pollution response community are addressed and met in a positive manner by the proposed concept;
- the set goals and objectives are approached with a view to overcoming any arising issues thus leading to a technically feasible and functional solution;
- the resulting design represents a novel and efficient approach to the increasingly important problem of marine oil pollution; and
- a comprehensive techno-economic analysis, accounting for an expanded operational profile that includes various alternative missions made possible by the vessel's multi-purpose configuration, indicates the economic viability of the concept.

OSH is the acronym for Oil Sea Harvester project, supported by the European Commission under the Sustainable Development, Global Change and Ecosystems thematic area, Sustainable Surface Transport Programme of the 6<sup>TH</sup> Framework Programme. The support is given under the scheme of STREP, Contract No. TST4-CT-2004-516230.

## 2. INTRODUCTION

The “Oil Sea Harvester” (OSH) project is addressing the need for vessels specifically designed to recover oil pollution at sea. The intention is to have a fast ship on transit, in order to be quickly on the scene of the accident, and to operate oil recovery tools when the spill is still well concentrated. It is then required to be able to operate in rather high sea states. Specific objectives include:

- to develop an innovative trimaran OSH vessel fitted with PODs for good manoeuvrability on site;
- to develop OSH oil recovery systems, a unique tool carriage holding the different tools;
- to develop OSH oil recovery scenarios and needed associated systems; and
- to address other complementary missions.

These are achieved through the following work plan in 11 work packages: project management (WP1), definition of OSH profile for oil recovery missions (WP2), preliminary ship design (WP3), design of oil recovery systems (WP4), hydrodynamics and tank tests (WP5), development and prototype testing of tools and tool carriages (WP6), definition of oil recovery missions and other missions (WP7), safety and rules compliance (WP8), final project integration (WP9), economic analysis (WP10), documentation and dissemination (WP11). These are outlined in the following section.

### 2.1. Outline of the project’s work plan

The overall objective of **WP1** is to manage the OSH project, ensuring that project objectives and deadlines are adhered to, to the full satisfaction of the Project Management Committee (PMC) and the EC. Also, it is to disseminate and prepare the commercialisation of the project results. These activities involve liaison with the Commission, technical co-ordination, monitoring and controlling of work progress according with the work programme, issues relating to cost registration and validation, budget control, reporting, invoicing and audit management.

Under this work package, it is ensured that standards and procedures will be correctly applied and that each stage of the project is completed to high standards. A quality plan was produced and implemented at the beginning of the project. This includes creation and managing of a dedicated web site for easy communication amongst consortium partners in a secure manner, as well as putting some discussion papers, unrestricted reports and published papers in public domain for the bodies outside of the project consortium.

This work package also includes technical coordination of the R&D and Innovation activities between the different work packages. Within each R&D and Innovation work package, the WP leader will be responsible for the timely execution of all technical tasks and the quality of work produced. Finally, this work package develops an exploitation plan for the dissemination of the project output, ensuring a full commercial utilisation of the developed technologies and the developed OSH product. This task was conducted in direct link with the dedicated technical work package WP11.

The objective of **WP2** is to clarify and finalise the setting up of the requirements for the OSH to be designed by the project, taking into account actual risks of oil spills in European waters, lessons learnt from recent spills, as well as the needs identified and expressed by national and regional authorities in Europe. The deliverable is a definition of the profile of the OSH, including its main required capacities (oil recovery ability, sea state definition, products to be recovered, storage, etc.).

The overall objective of **WP3** is to define a preliminary design that will be the starting point of the project regarding further optimisation of the vessel and integration of the tool carriage and

tools according to requirements defined in WP2. The different aspects that are dealt with in this WP are the following: preliminary lines and integration of the POD propulsion system; general arrangement drawing; preliminary scantling; weight evaluation; and performance evaluation

The goal of the development project under **WP4** is to develop an oil recovery system for offshore use, which is divided into two separate realms: oil recovery equipment based on the brush technology and on an alternative system (ESCA) suited for low viscosity oil; and transfer of the collected oil by pumping to the tanks of the ship

The wave height combined with the wind speed and the water current sets huge demands on the functionality of the equipment. Furthermore, in order to quickly transfer the collected oil in large amounts, the pumps and their required power have to be measured quite large. The quality of the oil (i.e. its viscosity), the temperature and various debris contained in the oil also greatly influence the recovery operation.

The overall objective of **WP5** is to assess the performance of the oil recovery system within the global ship performances required in operability and transit conditions for oil recovery, and its complementary missions (maritime surveillance, rescue, etc.). The global performance of the ship is concerned with: hull resistance in transit conditions; sea-keeping improvement both in transit and in operation in quite severe seas; performance of the oil recovery system in regards with the flow field and water elevations between the hulls.

The performances are assessed following three main stages: a CFD numerical optimisation including both reduction of hull resistance and sea-keeping performance requirements; a validation model tests campaign, including transit and operational conditions; and a performance review of the coupled ship / oil recovery system and recommendations to optimize the final design. Calibration of the numerical tools is also included

The objective of **WP6** is closely connected to WP4 and WP5 (development of the oil recovery tools and carriage and assessment of their performance). The task of this WP is to build the prototype of the oil recovery tools and carriage and to test it in as close as possible to offshore conditions.

The task includes the following steps: design and manufacture of a prototype model; speed tests of the brushes in different oils; stability tests of the equipment; test drives in basins with different kinds of oils; and recovered oil pumping tests.

The objective of **WP7** is to define the operational use for the OSH that was designed in the previous tasks. The purpose is to precise the integration of the OSH into oil spill response plans, as regards both the logistics of the response, the interaction with other means of recovery, and the monitoring of the pollution, from detection to drift predictions, including information sharing processes and guidance.

WP7 also includes investigating other possible missions for the OSH in order to improve its profitability, taking into account the compatibility of these missions with oil spill combating availability and operational constraints.

The objective of **WP8** is to coalesce the operational design of the project vessel with the constructional regulations associated with both Classification and (applicable) International or Flag State requirements. This involves not only detailed assessment at the WP8 stage but also ongoing review, monitoring and advice in previous Work Packages. In this aspect, this work package is to act as, in some respects, “technical referee” to the project.

In the work package **WP9**, all technical information of the different parts of the system derived from the other Work Packages will be assembled. The aim is to have a definition of the concept

as a complete system ready to be proposed to a potential customer and accurate enough to be able to evaluate the cost of the ship itself and the associated systems. It is intended that the different parts of the system are developed and validated enough during the project to be presented as a viable concept that could be further developed industrially.

The different aspects of WP9 are the following: parametric study with numerical models (based on the calibrated numerical models used in WP5, the objective of the parametric study is to derive the sensitivity of the ship performance to its main hull dimensions and mass distribution; the results will be used for the final ship drawings and configuration and for further ship evolutions); definition of the ship and the associated systems (tool carriage / tools); final drawings and specification; final scantling and strength analysis; vibration analysis; estimated price quotation of the ship itself and associated systems; determination of the overall performances to be warranted; construction of a virtual 3D prototype, which shows and demonstrates the oil recovery ability of the OSH concept.

**WP10** covers the economical analysis concerning the development and the operation of the proposed ship. More specifically, the main objectives of this work package are: to assess the economical potential of the specific investment; to incorporate and elaborate various categories of costs such as operational costs, maintenance costs, etc.; to pinpoint all associated benefits arising from the operation of the Oil Spill Harvester; and to present the overall financial and cost-benefit balance regarding the viability and the usefulness of the proposed ship.

Finally, **WP11** handles the documentation, the dissemination and the final report of the OSH project. More specifically, the main objectives of this work package are: the scientific dissemination of the project and of its results; the commercial promotion of the project and of its results; the exploitation of the project's concept and result to the shipping industry; and the formulation of the final project report, which includes the project's conclusions and proposes areas of future work.

## **2.2. Scope of this Deliverable**

The main purpose of this deliverable is to summarise all the work that was performed, the activities that were undertaken and the results that were obtained during the complete duration of the project, i.e. from December 2004 up to November 2007. This allows final conclusions to be drawn on whether the goals of the project have been achieved, the problems that arose were solved and the obtained results are satisfactory and in keeping with the originally defined scope and desired outcome of the project. This also leads to suggestions for future work, considering any observed shortcomings of the proposed configuration as well as any topics with scope for further improvement or development.

The structure of the main body of this document follows the breakdown of research topics as defined at the beginning of the project and listed in the summary of this report. In each of the ten main sections that follow, corresponding to a respective research area or technical activity, an outline is given of work that has been undertaken within that area as well as any related issues, such as: scope of the particular task/activity; expected end results; any data needed in order to achieve the related objectives; the approach that was followed in order to achieve these; any problems, bottlenecks or setbacks that were encountered and how they were addressed and overcome; main results that were obtained; and conclusions on the achievement of goals and on the obtained results, leading to and including any recommendations for future work.

In this way the present document offers a complete overview of the OSH project, reporting on all related issues and allowing the achievements of the project to be presented and appreciated in a concise manner.

### 3. ANALYSIS OF NEEDS AND DEFINITION OF REQUIREMENTS

The OSH project has been dedicated to the study and design of an oil spill recovery vessel liable to enhance notably the efficiency of response operations at a European level.

As a first step of this study, it was logical to perform an analysis of the needs (taking into account actual risks of oil spills in European waters, lessons learnt from recent spills, as well as the needs identified and expressed by national and regional authorities in Europe), and to deduct, from this analysis, the main requirements for the OSH to fit to this needs (abilities of the vessel and dimensional requirements associated).

The methodology consisted in performing successive investigations, leading to the final objective of the technical requirements, which would be a basis for the developments in the further steps of the project. The successive steps of this methodology were the following:

- A study on the characterization of marine spills in European waters, dedicated to get information about the nature and features of oil spills liable to occur in Europe (types, quantities, locations, environmental conditions, etc., based on both a traffic analysis and a statistical analysis of past accidents throughout Europe).
- An analysis of the real needs for improvement of the European capacity to deal with such risks, based on the previously conducted characterization of most potential oil spills, but crossing it with the means already existing to respond to such casualties in Europe, in order to identify the remaining gaps, to which the OSH could bring an answer. In other words, it consisted in bringing together the *risks* and *existing solutions*, to identify the *needs*, particularly as regards the identification of areas of priority, featuring both a high risk and a lack of adapted combating means.
- The definition of the main specifications for the OSH vessel, in order that the vessel should fit to the problematic and needs (capacities which would make the vessel adapted to the type of risk identified in terms of type of oil, quantities, sea conditions, etc., and which would bring answer to specific needs: speed, stability, ability to recover in bad weather, etc.).

The work performed under these three successive steps, and the results they led to, are briefly summarized hereafter.

#### 3.1. Characterization of marine spills in European waters

This first step of the investigation process was aiming at characterising technically the most potential oil spills liable to occur within the European waters, in particular:

- the types of oils and other hazardous cargoes which could be spilled in European waters;
- the volume and other characteristics of potential spills;
- the most probable locations of such spills and the associated weather and sea conditions;
- the evolution of spills (transport, weathering) due to these conditions; and
- the setting up of a selection of representative scenarios of oil spills in European waters.

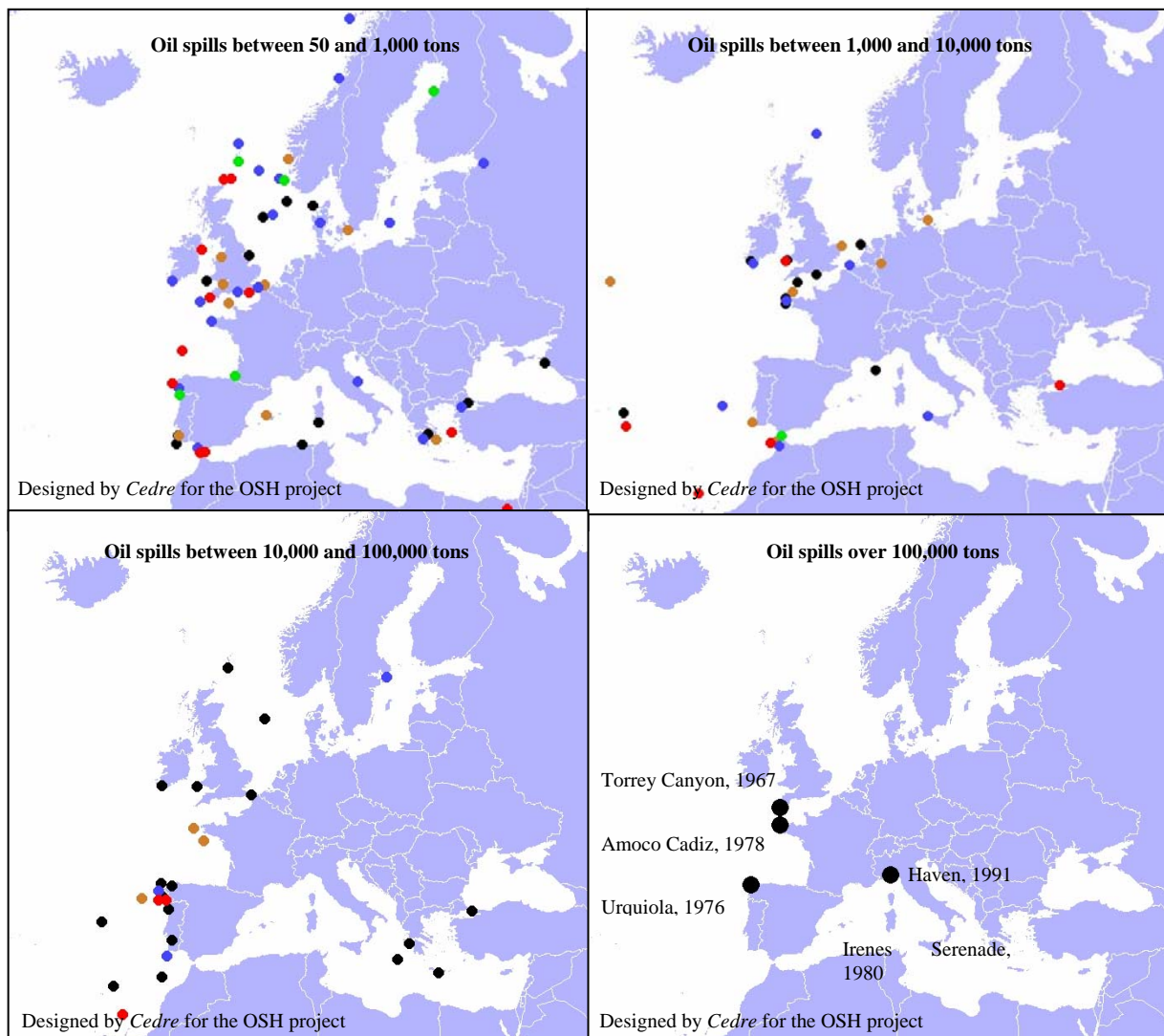
To that purpose, this first step of the study was based on several investigations:

- a bibliographic analysis of past studies concerning the fate and behaviour of oils when spilled at sea;
- an investigation leading to the identification of potential sources and scenarios for marine oil spills in Europe;
- an investigation on the pattern of maritime traffic inside the European waters (and, further on, of the maritime traffic specifically related to oil);

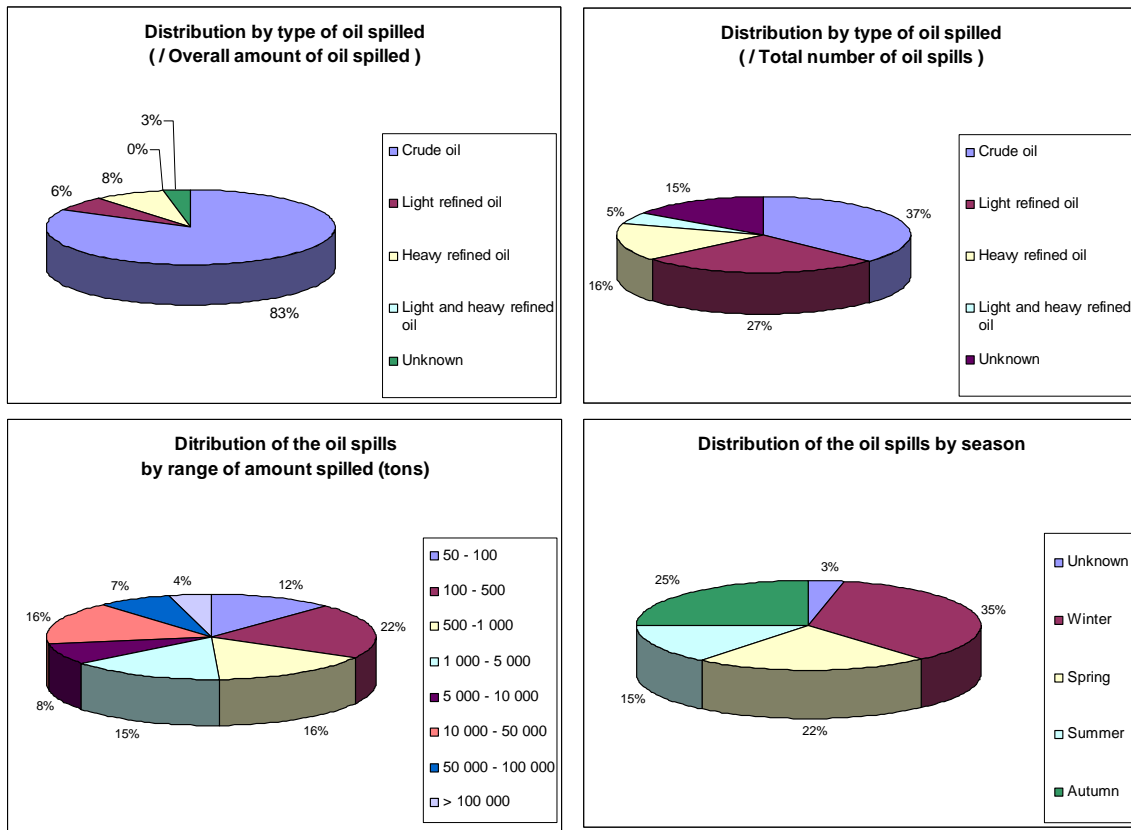
- an investigation on the statistical average weather conditions off the coasts of Europe; and
- a collection and statistical analysis of past pollution in the European waters.

The analysis of these diverse aspects led to an overview of the overall risk of marine spills in the European waters, as well as the identification of diverse suitable and areas of interest. The prospective aspects obtained through the traffic analysis could be well confirmed and specified by the statistical analysis regarding past accidents. Furthermore, a set of representative scenarios was established.

As a few illustrations of the work performed, some synthetic maps and charts that were issued from this study on past accidents are presented below.



*Geographical location and type of oil spilled during past accidents in Europe*



*Distribution of diverse criteria having characterized oil spills during past accidents in Europe*

### 3.2. Analysis of needs with respect to identified risks

A second step of the study was devoted to analyzing the real needs with respect to these identified risks, analyzing respectively:

- the needs expressed by authorities (at local, national, regional and European levels);
- the limitation of the existing European fleet of oil spill recovery vessels in relation to the actual threat of spills in European waters;
- the complementary antipollution means available locally or regionally, either in terms of recovery, or regarding the response logistics (detection, monitoring and drift predictions, guidance, etc.); and
- the experience from the use of oil spill recovery vessels in recent spills and incidents, both in European waters and world-wide.

These elements led in particular to the final identification of areas of first interest, featuring both a high risk and a lack of adapted means. In such areas, the positioning of an OSH would then appear liable to improve particularly the European capacity to recover oil spills offshore at any location. The following zones were identified as priority ones:

- the Baltic Sea, which is a particularly sensitive and closed area, while numerous potentially polluting wrecks were recorded there, and while the maritime traffic from Russia keeps on increasing; the area, although equipped with several vessels of limited size, has almost no ship featuring large storage capacity;
- the Western approaches to the Channel, which is a dangerous area characterized by strong currents, reefs, and statistically bad weather conditions, in which a lot of past accidents occurred, and where numerous potentially polluting wrecks are also recorded;

- the South-west Atlantic, off the coasts of Spain and Portugal, extending from the southern Bay of Biscay to the western approaches to the Strait of Gibraltar through Cape Finisterre, which is a particularly dangerous location, featuring joining tanker routes, and where an important number of past oil spills occurred in very frequently bad weather and sea conditions. However, the oil spill control capacity has been evolving there during the duration of the present project thanks to Spanish initiatives;
- the Eastern Mediterranean Area, reveals itself an area of high risks in terms of oil spills, which was demonstrated as subject to a heavy crossing traffic of oil through numerous islands and a quite carved coastline, along which a lot of past oil spills occurred. No recovery means of large storage capacity is present in this area, while the present projects are limiting to small vessels.

Several other areas would also benefit, to a lower extent, from an increase in their oil spill recovery capacity. The necessity of identifying a few priority areas, and the greater needs of the four locations presented above, led to identify them firstly. However, at a second level, it seems interesting to put also emphasis on the northern part of the North Sea, the western Mediterranean Sea, and the Black Sea, mainly around the Bosphorus Strait, which could equally benefit largely from an increase in their oil spill recovery capacity, once the one of the four main areas of interest would have been increased.

It must also be mentioned that the present analysis has been carried out at the beginning of the OSH project, and that the European capacity has been evolving since this study, notably through the possibility of assistance provided through EMSA, and more particularly in the previously spotted areas of priority, logically also identified as such by EMSA.

### 3.3. Definition of the main specifications for the OSH vessel

Finally, all these elements were crossed together in order to identify specifications for the vessel, in such a way that she should fit to the problematic and needs (capacities which would make the vessel adapted to the type of risk identified in terms of type of oil, quantities, sea conditions, etc., and which would bring answer to specific needs: speed, stability, ability to recover in bad weather, etc.). To that extent, the final specifications which were decided were the following:

- ability to perform the recovery of every type of persistent oil (all ranges of viscosities, and thickness from 0.1 mm to several dozens of centimeters, eventually up to 0.5 or even 1 m); considering the specificity of the existing oil recovery systems, this requirement should result in the necessity of disposing of several types of tool for the collection of the oil, depending of its type and properties;
- ability to recover in winds up to 35 knots, and in sea states up to 5 to 6;
- ability to arrive rapidly on the site of the accident, with a transit speed of at least 20 knots;
- ability to manoeuvre and perform the oil recovery at low speeds, down to 1 knot;
- ability to actually recover oil at a rate of more than 100 m<sup>3</sup>/h;
- capacity to work autonomously at full recovery rate for 3 days;
- storage capacity of minimum 3,000 m<sup>3</sup>, and eventually up to 6,000 m<sup>3</sup>, the whole capacity being equipped with heating coils, and being divided into several connected tanks in order to allow a multi-level decanting of the oil;
- possibility of deploying containment booms autonomously to confine and enlarge the skimming width in the case of thin slicks;
- discharge rate of more than 500 m<sup>3</sup>/h, and up to 1,000 m<sup>3</sup>/h if possible;
- possibility of protecting the crew in the accommodations in the case of toxic gases or explosive situations;
- presence of two remotely controlled skiffs able to deploy boom, one of them being equipped with sensors able to perform distant chemical measurements (toxicity, explosivity);
- ability to spread dispersant products with a dedicated storage capacity of at least 100 m<sup>3</sup>;

- capacity to host additional crew (at least 10 people, 15 if possible), in the configuration of exercises or oil spill recovery operations; and
- presence of a helideck in order to allow transfers, and the occasional or regular adding of a specific monitoring capacity.

These specifications were used as a basis for the starting of the next steps of the OSH project, particularly as regards the preliminary design which is presented in the following section.

## 4. PRELIMINARY SHIP DESIGN

The overall objective of the preliminary ship design is to define a preliminary design that is the starting point of the project regarding further optimisation of the vessel and integration of the tool carriage and tools according to requirements defined in the previous section.

The different aspects that are dealt with in the current section are the following:

- preliminary lines and integration of the POD propulsion system;
- general arrangement drawing;
- preliminary scantling;
- weight evaluation; and
- performance evaluation.

Hull lines design and general arrangement definition are closely related tasks. Therefore work was performed in parallel taking into accounts the different requirements derived from the definition of requirements described in the previous section or other technical requirements. These requirements will be for example related to the behaviour of the ship at sea, but also the arrangement needed to integrate tools, specific treatment and storage capacities (discussed in the following section). Furthermore, hydrodynamic calculations (discussed in section 6) were requested to start sooner in order to help choosing the best compromise for the preliminary design.

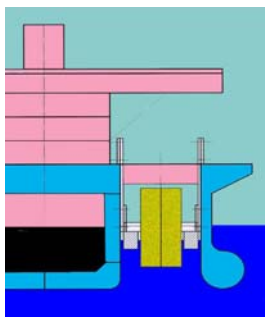
### 4.1. Hull design

The main qualities required for the considered ship are the following:

- a very good sea keeping characterised by weak platform motion at low velocity and in rough weather; and
- a high transit velocity.

These requirements are usually incompatible, a fast ship being generally uncomfortable at low speeds.

SWATH types of form (characterised by a low transversal inertia over displacement) lead to small platform motions (roll and heave) even at low velocity. An increased length associated to a reduced displacement favours speed. The proposed ship is an association of these two characteristics: a trimaran of 135 m length and 32 m of breadth composed of a main central hull and two lateral SWATH hulls.



The main hull dimensions are 133.6 m length by 14.9 m breadth (L/B ratio of 9) adapted for speeds greater than 15 knots and allowing the required capacity to be carried (6500 m<sup>3</sup> of products). Lateral hulls provide a good roll and heave damping and contribute to the comfort at sea without additional advance resistance. Moreover, this configuration creates between the hulls a confined zone protected from wind and swell and accessible to the recovery tools. Furthermore, an inverse bulbous bow induces a good pitch damping.

This hull form allows carrying the deadweight, keeping a limited advancing resistance and minimising of platform motions. The lateral hulls consist of cylindrical shapes linked by slender vertical structures, creating a protected area between the hulls.

The starting point of the OSH project was a preliminary concept (“form 1”) developed in 2001-2002 by CAT, for the French institute CEPM, with the collaboration of BEC and CEDRE.



To ensure a high level of general safety, the selected general arrangement is based on separating from each other two elements or functions whose common proximity could increase the risks of severe accidents (see figure above).

Numerous recovery installations exist depending on the product to recover. Underwater pump, brush or conveyor belt can be used according to the product viscosity. Ship design permits the necessary required tools to be adapted quickly. The two recovering areas located in a motionless area, between the main and lateral hulls (in the aft third of the ship) are equipped with one or two handling cranes.

In each recovery area, we propose the integration of a floatable tool carrier link to the hull by four pivoting arms. The tool carrier follows the remaining waves amplitude. It is constrained to the hull for pitch and roll but it can heave freely in order to keep its nominal draught. The front part built as an inclined step keeps a constant draught as well. Therefore due to the ship motion the oil is forced to climb on the inclined step and fall into a tank where it is collected by a pump. The water contained into the oil is separated on board after decantation, and physical treatment if necessary.

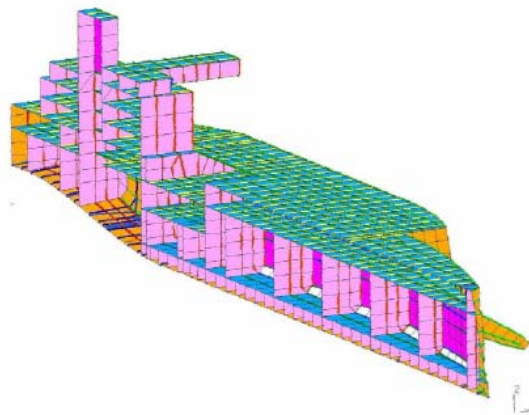
#### 4.3. Preliminary scantling and steel weight evaluation

Concerning the preliminary scantling, the characteristics of the amidships section resulting from the study are the following:

- Gross area of cross-section: 1.91 m<sup>2</sup>
- Neutral axis above base line: 5.84 m
- Moment of inertia / GY: 41.30 m<sup>4</sup>
- Moment of inertia / GZ: 46.95 m<sup>4</sup>
- Modulus at deck: 8.40 m<sup>3</sup>
- Modulus at bottom: 7.08 m<sup>3</sup>
- Typical frame spacing: 2.40 m

The grade A steel is sufficient concerning the rules criteria. All the cross section is made with this steel and the optimised scantling is integrated in the 3D FEM for the static analysis.

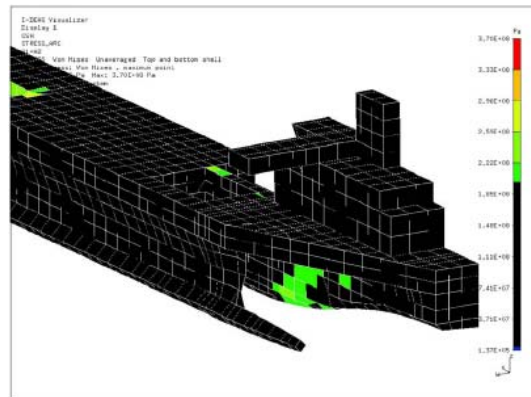
The global strength evaluation has been performed with rules criteria, which is 192 MPa allowable stress for steel grade A. Although the model does not take into account all details of the structure, the weight estimation of metallic hull is 4430 t. For hogging load, the maximum stress is located in the lateral hull, in one element, but it is a non-realistic peak stress. The maximum realistic stress is about 300 MPa located in the forward link between lateral hull and main hull. This part may require a structural reinforcement.



*Global FE model*

Around the recovery tools area at main deck, the maximum stress is 230 MPa. However, the recovery tool and the link with main hull are not modelled and the model meshing is not refined enough to well represent the real stresses. So the calculation indicates the stress level around this part, but not local strengths in the recovery tool link with the main hull. In the aft part, the maximum stresses appear under the engine compartments. In this area, an optimized arrangement of stiffeners should lead to decreased stresses. For sagging load, the most loaded zone is located in the front tank at frame X=126.4m, with 184 MPa peak stress. The maximum realistic stress is about 150 MPa in this frame. This stress level is also located in the forward

link between lateral hull and main hull, around the recovery tool area and under the engine compartments. The most loaded zones are the same as in the hogging case, but the stress level is always above the 192 MPa allowable stress. Globally, stress levels are high locally. A structural reinforcement and an optimised arrangement of stiffeners of the concerned areas would lead to acceptable stresses.



Maximum stress in aft part (hogging case)

**4.4. Technical specification**

- Length overall 138.50 m
- Length between perpendiculars 136.00 m
- Extreme breadth 36.90 m
- Waterline breadth 33.90 m
- Maximum draught 6.40 m
- Depth to main deck 10.75 m
- Depth to outside deck 14.00 m
- Propulsion
  - 2 pods of 13 MW each Mermaid type
  - Propeller diameter: 5.5 m
- Electricity production :
  - 3 GE type Wärtsilä 18V32, 50 Hz
  - Electrical power : 23 850 kW
- Speed at 90% MCR, full load: about 20 knots
- In transit consumption: about 4.5 t/h
- Recovery mode consumption: about 5 t/h
- Maximum pay load : 5 700 t
- Crew members and technicians 26
- Passengers 4
- Fuel capacity 500 m<sup>3</sup>
- Fresh water capacity 8 m<sup>3</sup>
- Grey water capacity 20 m<sup>3</sup>

## 5. DEVELOPMENT OF THE OIL RECOVERY TOOLS

An essential part of oil spill recovery operations is the pumping of the high viscous oils. This is presented as the state of the art of transferring high viscous oils. Specifically this report is concentrated on the pumping of the recovered oil on the OSH type recovery arrangement. The Positive Displacement Archimedes Screw type pump (PDAS) is presented in detail as the solution for the OSH oil transfer pumping requirements for oils of low to extremely high viscosities. The design and interfaces of the tools carriage and the recovery tools with the ship are also presented.

This work aimed at a double objective, based upon the realization of three main tasks:

- development of the oil recovery tools for recovering different kinds of pollutants in offshore conditions;
- development of the tools carriage; and
- development of the technology for transferring the recovered pollutants to the tanks on board the OSH.

### 5.1. Oil recovery tools

The state of the art of current oil recovery skimmers were dealt with widely as well as the impact of the weather and sea conditions, size of oil spill and type of oil, presence of debris, seamanship, vessel capability, boom configuration/performance, skimmer type, type and capacity of transfer pump, and finally the storage capability. The presentation of current technologies of oil skimmers dealt with the overall performance of the combined skimmer and transfer pump.

A skimmer may be free floating, side mounted on a vessel, built into a vessel, built into the apex of a containment boom, held by a crane or held by hand. Skimmer designs are based on the following principles (in alphabetic order): adhesion/oleophilic, air conveying, belt, filter, inclined plane/hydrodynamic, mechanical feeder, vortex, weir and combinations of these principles. In addition to oil recovery also handling of debris is a universal problem in almost all oil spill situations. Therefore the skimmer should be able to handle a lot of the debris normally found at a spill site: seaweed, kelp, plastic bags, aluminium cans, bottles, etc.

Taking into account the advantages and disadvantages of all of the above mentioned serials, the stiff-brush-type channel mounted conveyor belt system was chosen as the ideal skimming method for the OSH concept. It collects oil of all types and is unhindered by floating debris or seaweed. Adverse weather conditions and choppy seas are common when combatting oil spills, but the brush conveyor belt can operate in these conditions without losing performance. Another major advantage of the system is that the recovered oil contains very little water, less than 5%, making maximum use of valuable storage volume.

With the brush conveyor belt deployed, the entire vessel becomes an oil slick processing system. The system uses the vessel's forward motion to deflect surface water and oil from the collection area between the hulls to the recovery unit for processing. An effective flow through the oil recovery channels is achieved by the forward speed of the ship. The skimmers are located so that pressure fluctuations caused by motions of the vessel and waves are minimised. The flow of water carries oil into the recovery channel where the oil is efficiently separated by the brush conveyor belt and removed from the flow.

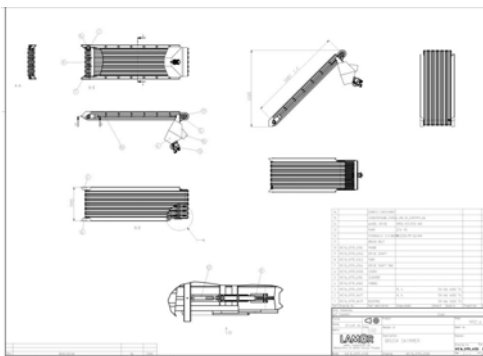
The patented Brush System lifts oil, seaweed and debris from the water which passes through the channel cleaned. Recovered oil and debris ride up the conveyor, are "combed" from the bristles and flow by gravity into a collection hopper. From this hopper the recovered material is pumped to the tanks by powerful Archimedes screw type oil transfer pumps.

A lot of attention has been paid to safety issues during the operation, and since the system deployment is automated as much as possible, it ensures the highest possible safety level in operation.

The recovery tools are to be assembled on a carriage located in the channels between the hulls. The idea of the carriage is to decrease the relative wave motion in respect to the skimmers. The platform of the carriage will be floating on the water surface and it will be connected to the hull by levers that allow the tools to move up and down, thus following the waves.

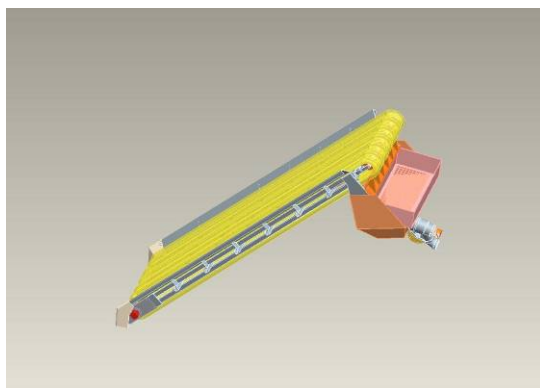
In addition to actual skimming and pumping technology also the environmental effects to the skimming operations in European waters were analyzed and taken into account when choosing the best suitable technology for the OSH vessel for rough wave conditions and being able to recover both light and extremely high viscous and emulsified oils. General oil behaviour and characteristics of oils were largely studied.

The general effective recovery capacity of oil for OSH is set to more than 100 m<sup>3</sup>/h. This capacity is quite easily achieved by brush skimmers of this scale in normal conditions. In a later stage during the research project the tests showed that the total recovery capacity of a two side system can vary between 2 x 219 m<sup>3</sup>/h (bitumen) and 2 x 810 m<sup>3</sup>/h (IFO 40 POR 80). However we have to take into account that the oil slicks are not uniform and therefore the skimmers will also encounter areas free of oil during the recovery process. In any case in a real oil spill recovery operation the high recovery speed and high oil encounter rate achieved because of this are one of the most important features of an oil spill recovery vessel. In relation to the oil recovery performance in the offshore conditions the methods of oil spill recovery and selection of oil skimmers to different environments and conditions are also handled.

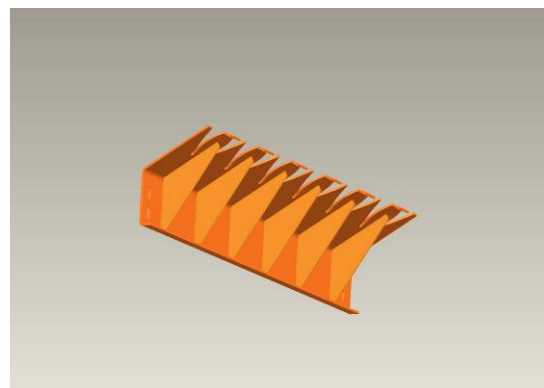


There will be altogether four skimmer units on the OSH (two on each side). The width of each unit is 2 m and the distance between the shafts is 5685 mm. The total weight of one skimmer brush unit is approximately 1000 kg. Some major changes to the current design of the brush conveyor belt were made to meet the OSH requirements.

The operation of the weir type skimmer was also investigated. This is a tool developed to recover light products with viscosity lower than 10 cSt and specific gravity. It would be located on the tool carriage aft of the brush skimmers, where heavy product has already been removed and the flow contains only the light one; thus the brush skimmers and the weir are working in tandem. This position allows to profit also of the flattening effects of brush skimmers.



*Brush conveyor belt with one transfer pump*



*Brush scraper*

## 5.2. Tools carriage

The skimming tools carriage is a floating unit located in the motionless channel between the main and lateral hulls of the OSH, holding the recovery tools complete of necessary ancillary equipments and systems. The tool must be constrained to the vessel against the longitudinal and transversal translations as well as rotations, while the links have to allow free vertical movements in respect to the vessel so that the local wave profile can be followed as far as possible.

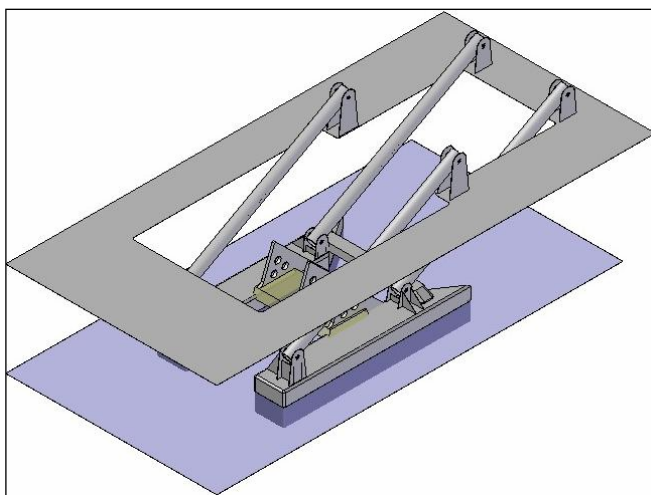
It has to be automatically deployed and recovered on the vessel main deck in the most functional and safe way. Two tools carriages are conceptually foreseen, one in each channel between the main and the lateral hulls of the OSH, i.e. one carriage at port side and one carriage at starboard side of the OSH vessel.

The development of the tools carriage has taken into the account the following main topics and requirements:

- overall dimensional constraints (e.g. breadth of the OSH side channel, minimum and maximum expected draught);
- weight and dimensions of the oil recovery tools and ancillary equipment and systems;
- height adjustment requirements for oil recovery tools;
- operating sea conditions constraints (maximum expected wave height and carriage motion);
- ship operating conditions (max roll and pitch); and
- motion induced loads.

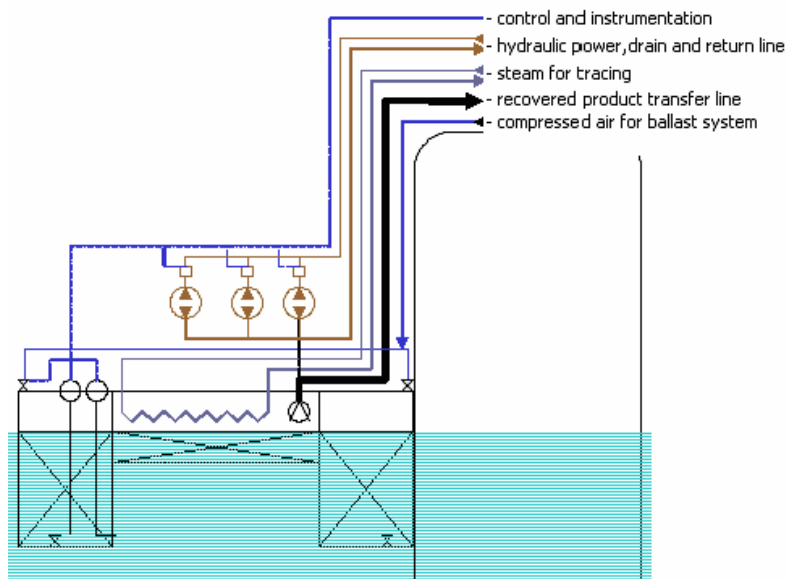
Single hull and double hull carriage type were preliminary screened in order to compare advantages and disadvantages of both alternatives, and the double hull type was selected as it better fulfils the operational requirements as well as the general layout of the carriage. The carriage hull consists of two lateral floaters properly shaped at forward to convey product to the brush skimmers located between them (angle of 30° from longitudinal axis). The floaters are connected by two crosspieces, one forward and one amidships, the latter equipped with three connecting plates that hold the brush skimmers.

The assumed length of the carriage (i.e. 11.5 m) has been validated by dedicated hydrodynamic calculations regarding influence of the carriage's length on relative wave elevation (i.e. wave height at the carriage front) and relative heave (i.e. the relative vertical motion between the carriage and the OSH), based on four possible carriage lengths (8m, 11.5m, 15m, 18m). The brush skimmers can slide +/- 0.5 m up/down from the design position on suitable sliding guides in order to be adjusted to the required draft conforming the recovery needs depending to the oil thickness; the adjustment is achieved by suitable cylinders hydraulically operated by a remote location.



All the tools are located between the floaters: the two brush skimmers are placed side by side in forward position supported by proper steel frames, the proposed weir skimmer is located astern hinged to an A frame by chain tackles. The arms have been sized according to the expected efforts acting on the tools carriage in extreme sea state are provided.

*Arms layout*



The interface requirements for operational needs and remote controls of the carriage require several interfaces to ensure a proper service of the carriage. All these were designed and presented in the report including e.g. the hydraulic and pneumatic requirements of the total system.

As mentioned earlier, for safety reasons the operations of both tools carriages are remotely controlled as well as

monitored from a dedicated console located in the Cargo Control Room of the OSH where at least the following functions are to be foreseen:

- oil recovery equipment operations:
  - ✓ oil transfer pumps, start-stop-speed (high and low viscosity recovered products)
  - ✓ water injection to the oil transfer pumps
  - ✓ brush skimmers control (speed, chain tensioner and vertical position adjustment)
  - ✓ operation of the debris handling tanks
  - ✓ weir skimmer deployment
  - ✓ process instruments monitoring
- carriage controls:
  - ✓ ballasting control and ballast tanks ullage
  - ✓ firefighting system activation
  - ✓ CCTV operation remote survey
  - ✓ carriage HPP remote monitoring and control

### 5.3. Transferring (pumping) equipment

The state of the art of transferring high viscous oils are addressed, especially the pumping and development of the technology for transferring the recovered pollutants to the tanks on board the OSH. The oil transfer capacity should be at least as much as the maximum capacity of the skimmers. To be able to design an oil transfer system not only the pump itself should be taken into consideration. The internal friction in the whole pumping line becomes critical when pumping high viscosity oils and there has to be means to decrease this friction.

There are a few other flow enhancing techniques. The most cost effective and simple technique is to inject water or steam as a lubricant between the viscous material and the inner walls of the pump and transfer hose. Special Annular Water Injection (AWI) technology is used to create a uniform sleeve of lubricating water. There is also a requirement on the pumps as the injected water should not be emulsified with the oil. This would inhibit the lubrication of the layer close the inner surface of the hose. This means that the flow in the pump should be continuous and as laminar as possible.

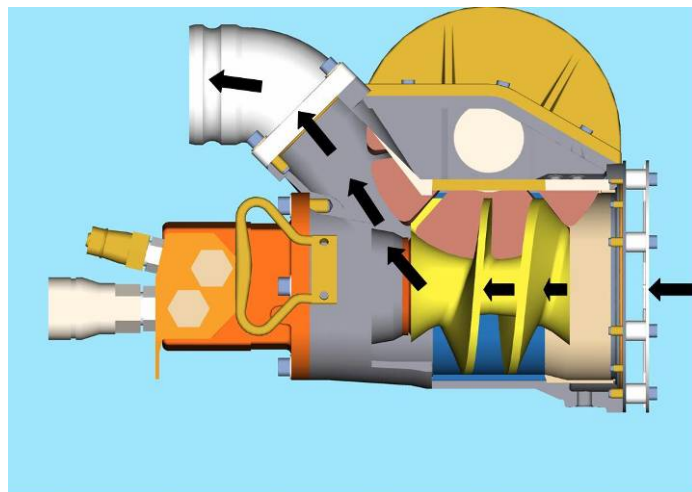
When recovering oil there is always much debris and solids mixed in the collected oil. This has all to go through the pumping system without clogging or damaging the pump. Therefore the pumps should be fitted with cutting capability to process smaller debris and the geometry and the clearances in the pump have to be large enough to let the solids go through. It is also

important that the drive motor and transmission system for the pump be capable of transferring sufficient power for this operation.

Pumps can be divided into two major categories, kinetic and positive displacement pumps. The presently most suitable pump for oil recovery operations is the Positive Displacement Archimedes Screw pump (PDAS). As the kinetic types of pumps are not suitable for pumping high viscosity oils, they were not dealt with in detail. Positive displacement pumps operate with a series of working cycles where each cycle encloses a certain volume of fluid and moves it mechanically through the pump into the system. Depending on the type of pump and the liquid being handled, this happens at relatively low rotational speed, very low shear (mixing energy), and with little influence from the back pressure on the pump. One other requirement for the pumps used in oil recovery operations is the ability to handle debris and solids.

Different flow enhancing technologies were handled referring to several tests and field experience of the oil spill recovery operations. Bulk heating, local bulk heating with a heating coil wrapped around the transfer pump, discharge side annulus ring water injection and inlet side annulus ring steam/hot water injection were examined in detail.

Of the pump types on the market the Positive Displacement Archimedes Screw pump is the most suitable for oil recovery operations. The GTA PDAS pumps selected for the OSH have a high discharge pressure (12 bar) and a superior geometry with only a small leakage and a small inner friction. This makes the GTA pumps suitable for pumping a wide range of liquids with viscosity from 1 cSt (water) up to 3.000.000 cSt (bitumen).



There has been a huge development in the oil transfer technology in oil recovery operations during the past decade. The Positive Displacement Archimedes Screw pump has been developed to a powerful tool for transferring extreme high viscosity oils. High pumping capacities are now achieved with small and handy units.

The most significant achievements have been achieved in the development of the flow enhancing water injection techniques. This has made it possible to decrease the friction in the oil transfer hoses by factors of 20 and more.

The pumping technology of today can pump oils with viscosity of up to 3 million cSt in 6 inches hoses very long distances. As the geometry of the pumps has been developed to have only small leakage, the same pumps can be used for lighter products as well.

## 6. OPTIMISATION OF HYDRODYNAMIC PERFORMANCE

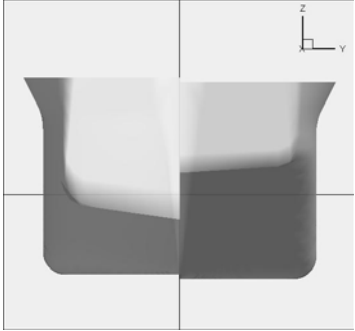
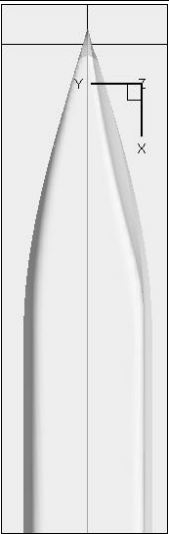
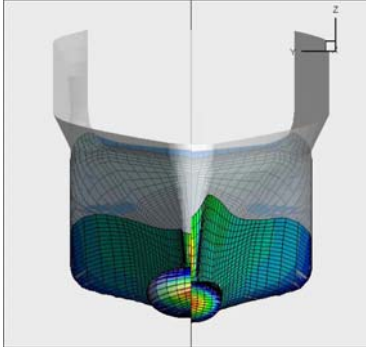
The overall objective is to assess the performances of the oil recovery system within the global ship performances required in operability and transit conditions for oil recovery, and its complementary missions (maritime surveillance, rescue). The two main tasks conducted within this were the following:

- the numerical optimisation of the hydrodynamic performances of the preliminary design with the following objectives:
  - ✓ to minimise ship resistance power requirement for the maximum target speed (transit phase)
  - ✓ to improve the sea-keeping behaviour of the OSH concept in both transit and operational conditions - for the oil recovery phase, it is then required to optimise the behaviour of the ship with the tool carriages deployed
- the experimental assessment of these performances.

In order to define specifications suitable for the hydrodynamic studies, input data were required from the definition of technical requirements, the preliminary ship design and the design of the oil recovery tools. In particular, these inputs allowed the specifications of the operational criteria concerning the behaviour of the ship (required transit speed, maximum motions or accelerations, etc.) and of the tool carriages (motions, loads, relative wave elevation, etc.), as well as the weather specifications (areas of interest where the OSH should be in priority operated, sea states characteristics), considered for the numerical optimisation of the preliminary design.

### 6.1. Numerical optimisation of the OSH performances

The general objectives of the optimisation is to have a fast ship on transit (target speed of 20 to 25 knots at a light displacement of 8000 tons), in order to be quickly on the scene of the accident, and to operate oil recovery tools (at speed from 1 to 3 knots) when the spill is still well concentrated; it is also required to operate oil recovery tools in rather high sea state.

					
Optimized transom stern	Initial transom stern	Initial bow	Optimized bow sections	Optimized bulbous bow	Initial bulb
Optimization of the depth of the transom stern		Optimization of the initial bow sections (without bulb)		Optional bulbous bow	

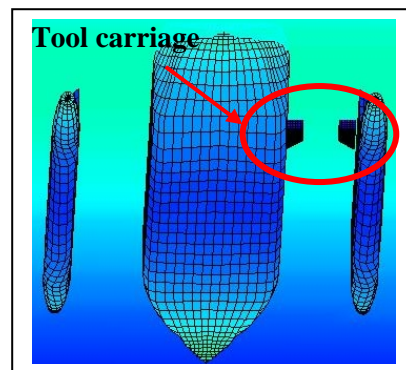
*Optimization of the transit speed: examples of main hull lines modifications studied*

At a preliminary stage, only modifications of global design parameters have been considered, to define the best options for improving the nautical qualities of the existing design. First recommendations were defined for the improvement of the preliminary hull design: side hull cross section diameter about 3.5 m, longitudinal position of the side hulls putted forward (+10m), best longitudinal location of the tool carriage (distance from silent point for the transit phase, and oil recovery criteria) about 70 m from aft perpendicular.

During the second stage of the optimisation process, the influence of both global and local design parameters has been investigated:

- global design parameters: diameter of the circular section of the side hulls, length of the side hulls, longitudinal position of the side hulls; and
- local design parameters: bow sections of the main hull, depth of the transom stern of the main hull as well as slope of the buttock line, bulbous bow on the main hull (calculations with and without bulb, with several bulb geometries : length, width and submergence of the bulb).

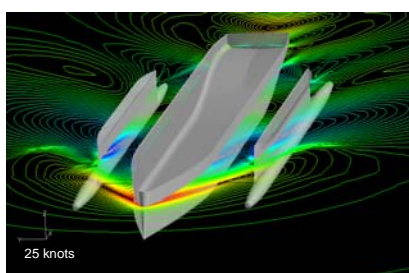
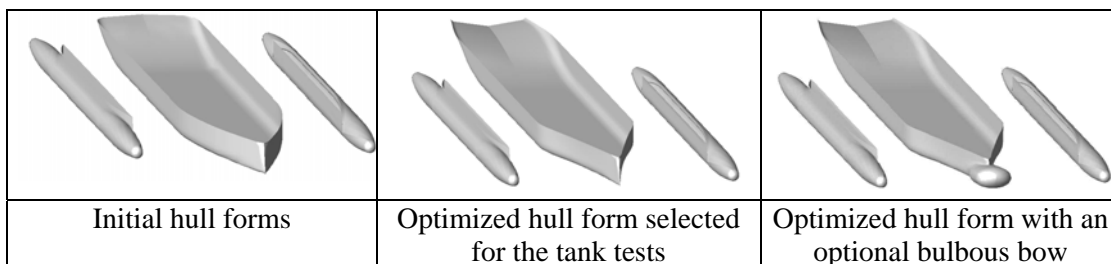
For the optimisation of the oil recovery performances, the seakeeping software selected has been improved. New modules have been developed, which allow the simulation of multiple bodies configuration (oil recovery configuration), including: the ship, the (floating) tool carriage and the kinematic link between the ship and the tool carriage. Thanks to this new version, it is possible to directly analyse the dynamic behaviour of the tool carriage, and also to evaluate directly the loads in the arms linked the tool carriage to the ship.



An optimised ship geometry has been defined in order to update the general arrangement of the ship. The main differences between the initial design and the optimised one are the following:

- main hull: thinner bow sections, transom stern lowered (and optional bulb);
- side hulls: diameter of the (round) sections increased, length not modified, longitudinal location modified (side hulls putted forward).

Figures below show comparisons of the initial hull form, and of two optimised designs (with or without bulbous bow); the optimised design selected for the tank tests is the one without bulbous bow.



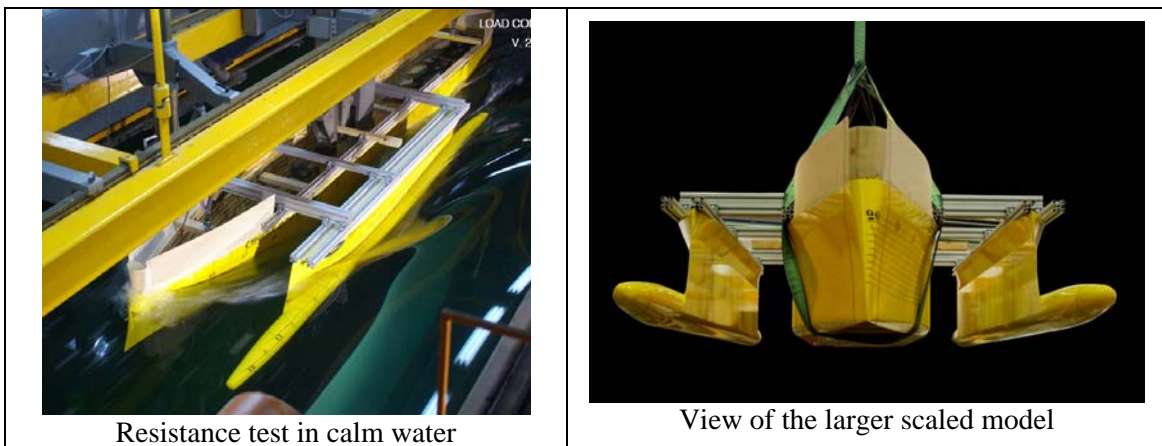
Resistance computation in calm water: example of wave pattern at 25 knots

**6.2. Experimental assessment of the OSH performances**

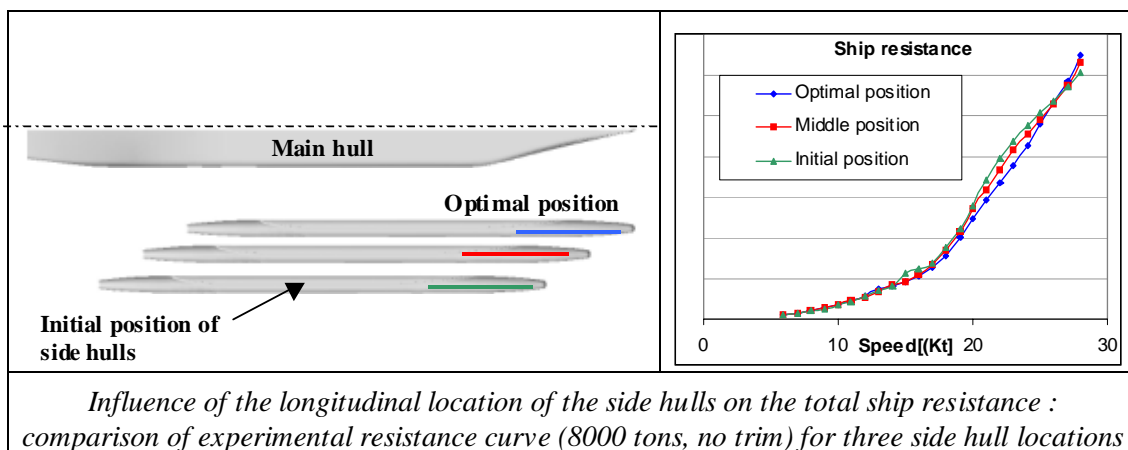
The experimental campaign has been carried out by CEHIPAR in Madrid. The goal of the tank tests is to assess the hydrodynamic performances of the ship during the two main operational phases (transit and oil recovery operations), as well as the operational performances of the tool carriage holding the oil recovery equipments.

The first part of the experimental campaign consisted in performing resistance tests in calm water, in order to assess the powering performances of the OSH concept. During the second part of the experimental campaign, sea-keeping tests in the oil recovery configuration were performed, with a scaled model composed of the ship and of the two tool carriages linked to the ship by rotating arms. Finally, sea-keeping tests in the transit configuration (tool carriages folded) have been carried out.

➤ Resistance tests in calm water



Globally, the experimental tests have confirmed that the geometrical modifications of the initial ship design allowed an improvement of the powering performances of the OSH concept. The maximum speed predicted experimentally (about 23 knots in calm water) is slightly lower than the one predicted numerically, but in agreement with the OSH mission requirements (transit speed of at least 20 knots).

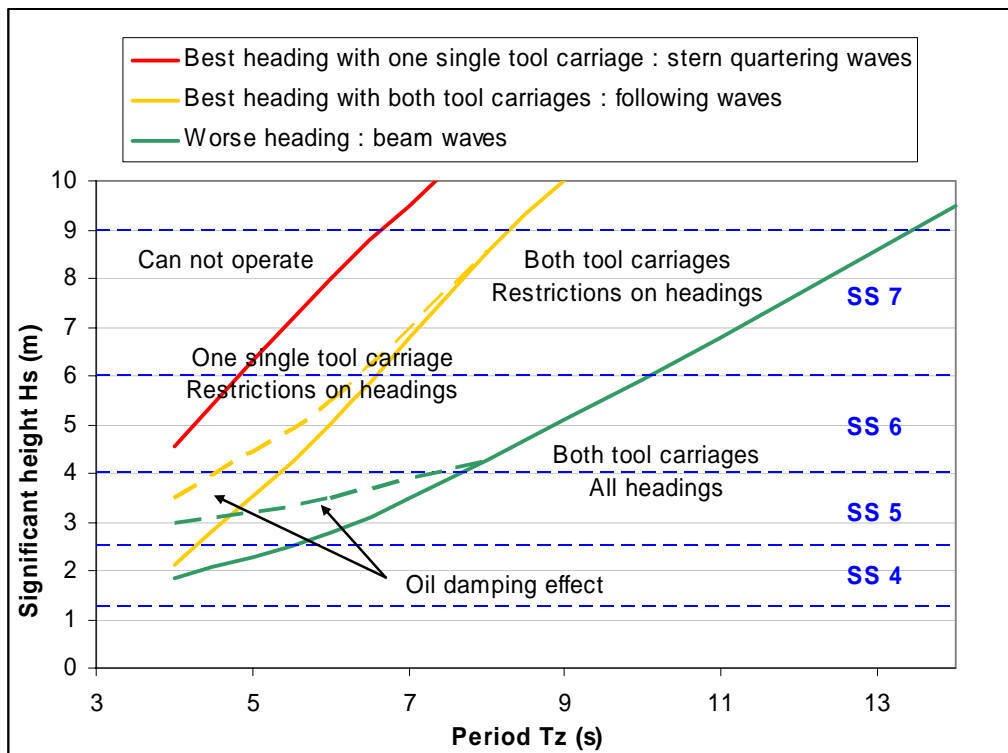
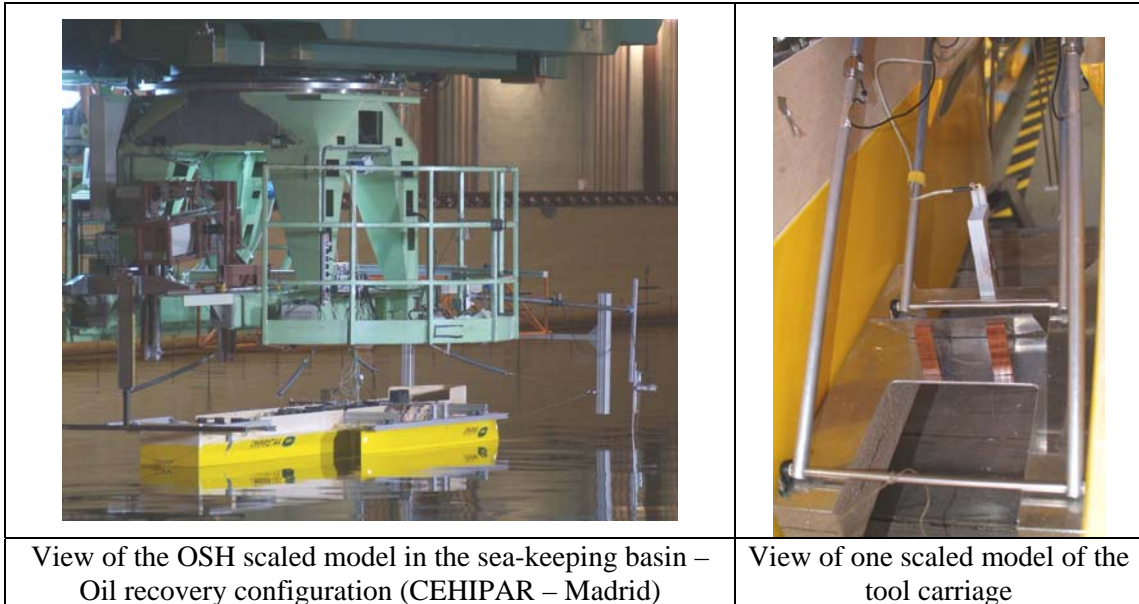


Within the numerical optimization process, the influence of the longitudinal location of the side hulls on the total ship resistance has been investigated. It has been observed numerically that the ship resistance can be reduced by pulling forward the side hulls, and that the extreme fore position was the optimal one, which was not intuitive. Resistance tests have then been carried out for different longitudinal locations of the side hull; the trend identified numerically has been

effectively confirmed by the experiments. In the figure above, the resistance curves for three longitudinal side hull locations are compared: initial position, intermediate and extreme fore locations.

➤ Sea-keeping tests

The most important objective of the sea-keeping tests was to assess the oil recovery performances of the OSH concept.



Summary of the oil recovery performances of the OSH concept versus the sea states characteristics (Significant wave height, zero up-crossing period)

Globally, the sea-keeping tests have confirmed the good oil recovery capabilities of the OSH concept in rough weather; for example, the experimental tests have confirmed that the oil recovery tools, located on both sides of the main hull, can be operated together for a sea state 6

(significant wave height of 5 m, and peak period of 12.4 s corresponding to a zero up-crossing period of about 9 seconds).

Results of both numerical simulations and experimental tests show that the performances of the OSH, for the oil recovery phase, depend on the sea state period, the heading and the number of tool carriages used. Without any restrictions in headings and with both tool carriages, the maximum sea state is 4/5 for the shortest wave periods and up to sea state 7 for the longest ones. By choosing the best heading for the protected tool carriage, the OSH can operate in a sea state 6 with short waves or in a sea state greater than 7 with long waves.

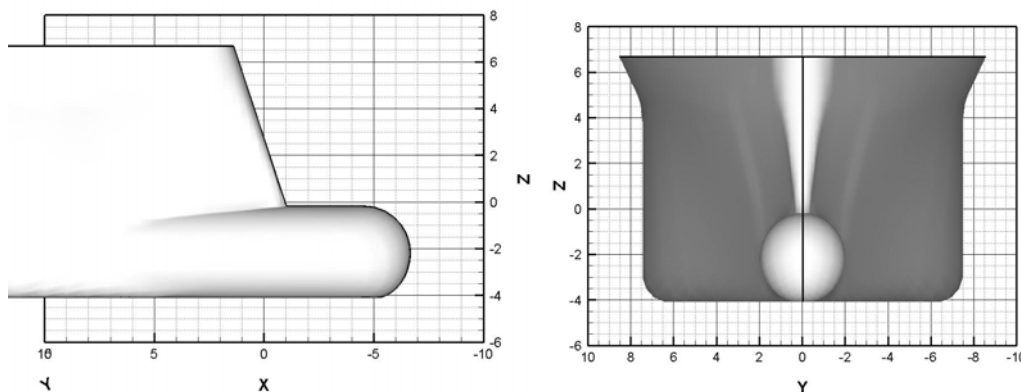
All these operability limits and the different domains of use of the OSH are plotted on the previous graph.

### 6.3. Results of the optimisation process

Work achieved within the optimisation exercise has shown that the OSH concept has very good hydrodynamic performances, both in sea-keeping and powering, in agreement with the OSH mission requirements. Globally, the experimental tests have confirmed that the numerical optimisation of the initial ship design allowed a significant improvement of the performances of the OSH concept.

Therefore, only minor modifications has been recommended for the final design:

- to fit a bulbous bow on the main hull, in order to increase the transit speed - on the basis of numerical results, a speed gain of 0.3 to 0.4 knots can be reached (depending in particular on the bulb length);



- to increase the freeboard at the bow of the tool carriage - as observed experimentally, the waves came sometimes over the tool carriage freeboard and by increasing it, the oil accumulation on the carriage hulls can be avoided.

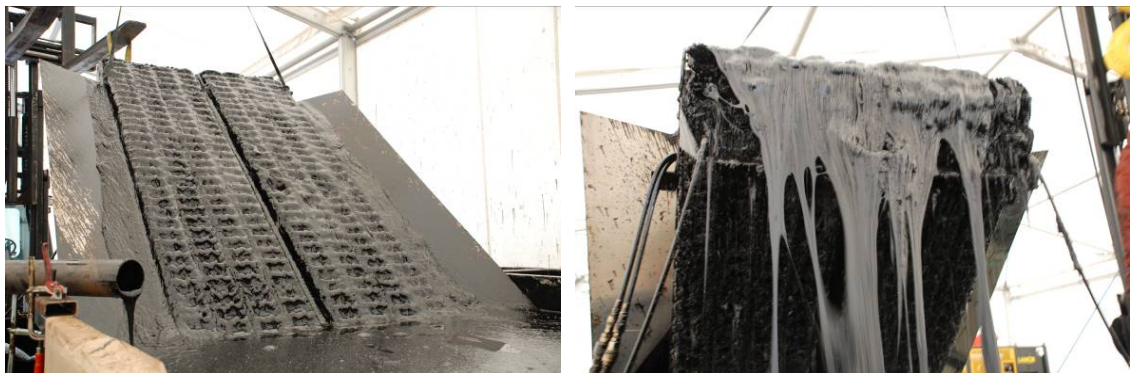
Finally, another output of the work achieved consists in practical recommendations for operations (transit phase and oil recovery phase):

- transit phase: it was shown experimentally that the powering performances at high speed are better if the ship has a static trim (by the stern) - it is therefore recommended to ballast the aft part of the ship for transit;
- oil recovery phase: the operational configuration of the OSH depends on the sea state encountered - oil recovery operations can be carried out with:
  - both tool carriages in low and medium sea states, without any restrictions in heading;
  - both tool carriages, for the best couple of headings (head/following waves), in high sea states; and
  - one single tool carriage (i.e the most protected one), for the best couple of headings (stern quartering/bow quartering waves), in very high sea states.

## 7. TESTING OF THE OIL RECOVERY SYSTEM

The final steps of the development of the oil recovery system on board OSH included modifications made to the system following a test series made at CEDRE in France. There were also a series of tests made under the supervision of Bureau Veritas after modifications were made to the brush skimmer conveyor belt according to the experience and results from the CEDRE tests. A discussion on the recovery of light oils with the weir skimmer and a description of the pumping system for the recovered oil on board OSH are also given.

A prototype of the brush conveyor skimmer was tested and the tests show that the skimmer can easily reach the required capacity on the OSH. After the CEDRE tests one of the approx. scale 1:1 of four skimmer units (1+1 on each side) was tested. The tests showed that the total maximum recovery capacity of a two side system can vary between 2 x 219 m<sup>3</sup>/h (bitumen) and 2 x 810 m<sup>3</sup>/h (IFO 40 POR 80). This test result was certified by Bureau Veritas.



This work aimed at a double objective, based upon the realization of two main tasks:

- building of a prototype; and
- testing of the prototype with oils of various viscosities.

The construction and the selection of the size of the prototype of the brush conveyor skimmer, the test arrangements, the conclusions of the tests and the final modifications of the system indicated by the tests are presented. Moreover the pumping of the recovered oil on board OSH and the recovery system for light oils by a weir skimmer are described. The test series made at CEDRE in France stands as a basis for the final design. First the design of the prototype and the test arrangements were described, then the conclusions from the tests and finally the actual improvements on the recovery system indicated by the tests are presented.

### 7.1. Construction of the prototype

The target for the design and construction of the prototype was that the test should as close as possible correspond to the environment to be encountered by the OSH. According to the specification OSH should be able to operate in sea-state 5-7 depending on the heading.

The motions of the hull and the tools carriage have thoroughly been investigated and reported in section 6. The damping of the waves by the hull has been clearly shown in these calculations and the model tests that have been done.

For the model tests the most important criteria was the relative wave height. This defines a minimum length of the skimmer in full scale. For the test series it has been stated that the performance should be tested with different types of oil, from light viscosities to extremely heavy materials.

In view of only the motion and wave criteria the prototype could easily be scaled, however the most interesting aspect to the tests is the new larger and more robust brush type for different viscosities. As there has not been found any scaling law to scale the viscosity in view of the behaviour on the brushes, it was decided to use the full scale brushes.

The prototype included all new features such as the large brushes and 1" chains for robust design. The drive motor is directly connected to the lower shaft and the chain spanners are in the upper shaft. The chain spanners in the prototype are manually operated by a screw, as they will be hydraulic and automatic in the full scale skimmer.

The pumping of the recovered oil was handled by a GTA 115 m<sup>3</sup>/h positive displacement screw pump with options for water injection on both inlet and outlet side.

## 7.2. Testing of the prototype

The tests were made in a large open water basin at CEDRE in France. In one end of the basin there was built a 1.5 m wide channel by inserting a concrete wall. The water depth of the channel was about 2.4 m. In one end of the channel there was a wave maker to produce waves by an oscillating plate.



*Test arrangements*



*Wavemaker*

To simulate the advancing of the OSH, there was one propeller pump in front of the skimmer and one behind. These propeller pumps produced a flow through the both openings in the ends of the 1.5 m wide channel. The oil was spilled to the water surface in front of the skimmer before the tests.

The main parameters of the tests were: flow speed, wave height, type of oil, viscosity of the oil, speed of the brushes and thickness of the oil layer. Many critical aspects were carefully taken into account regarding the scaled model compared to the real size vessel. Especially working with sticky viscous oils in narrow channels and small scaled equipment is way more challenging than with real size equipment arrangements.



The tests were done under detailed procedures in order to evaluate the performances of the oil recovery system in conditions which should be as close as possible as the foreseen implantation of the system between the hulls of the OSH vessel. The skimmer was positioned, for the tests, in full width of a canal allowing the generation of current and waves, as well as the spilling of real oil. Oil properties, sea state, current and related brush speed,

influence of the size of the testing arrangement, influence of a minimal sea state, wave damping effect by the oil and influence of the brush belt speed were taken into account in the tests.

Basically the skimmer performed well in the tests and it can be concluded that it will reach the specification of more than 100 m<sup>3</sup>/h. The actual capacity depends however on many other factors than the skimmer itself. The tests indicated a few problems in the system and the test arrangements and these problems caused the results not to be as high as expected. The biggest problem during the tests was to get the thick oil flowing to the skimmer. The oil stuck to the sidewalls of the channel and the flow produced by the propeller pumps was not strong enough to detach the oil from the walls. The situation on the full scale OSH will however be better as the channel is much wider. The channel width on the OSH is 8 m, whereas it was 1.5 m in the tests. This will decrease the negative effect of the sidewalls.

Because of this there was another test made under the supervision of Bureau Veritas. One recovery channel of the OSH consists of two approx. 2 m wide brush conveyor belts and one of these belts with 1:1 scale was tested and the results were excellent. The maximum recovery capacity of one 2 m wide conveyor belt varied between 109,5 m<sup>3</sup>/h (bitumen) and 405 m<sup>3</sup>/h (IFO 40 POR 80). There are four similar units in the OSH, two on each side, so these maximum test results can be multiplied by four to get the total recovery capacity of the OSH vessel.

The final selection for light oil skimmer is a normal weir skimmer. It is located behind the brush skimmer and the skimmers can be used either separately or simultaneously. The weir skimmer permits an intake flow of about 1000 m<sup>3</sup>/h of water and light product at the OSH speed of 2.5 knots. This high flow rate can be managed by a centrifugal pump, differently from the brush skimmer's volumetric, low speed pumps. The fluid collected by the weir skimmer is pumped to gravity separators on board the ship.

### 7.3. Analysis of the test results

The objective of these tests was to ensure that the oil recovery system to be installed onboard the OSH fits well to the initial requirements, which were defined for the vessel in terms of oil spill recovery ability. To that purpose, the performances of the skimmer and pump were measured using real oil, and positioning the recovery system in a configuration which should be as close as possible to its foreseen implantation on the vessel, and for multiple environmental conditions.

Moreover, the analysis of these results allows formulating many observations, and proposing several improvements liable to enhance the performances of the system. These diverse points are summarized below.

The following observations are induced by the results:

- the results demonstrate that the skimmer complies with the OSH requirements;
- the measured performances were penalized, as compared to the OSH full size system, by certain aspects of the necessary limited test arrangement:
  - a higher viscous layer effect due to close walls;
  - a weaker forcing to the skimmer due to a limited current;
- the trials demonstrated the virtuous effect of the presence of a minimum sea state;
- the trials demonstrated the virtuous effect of the oil for damping the high sea states; and
- the trials demonstrated the existence of an optimum brush speed, dependant mainly on the oil slick viscosity and thickness, and current speed (too high brush speed: generation of a locally inversed stream; too low brush speed: good dynamics for recovery, but the flow rate then suffers from the low speed).

Furthermore, the following technical lessons are noted in view of potential optimizations:

- the trials demonstrated the interest of adding a water curtain on the walls, in order to decrease the adherence of oil and increase the efficiency of the recovery;
- the trials demonstrated the interest of positioning a screw behind the skimmer, in order to force a current through the brushes and increase the efficiency; and
- the trials demonstrated the need for investigating the aspect of the brush fixing, which caused difficulties during the tests.

The overall efficiency of the OSH does not only depend on highly effective skimmers. The system has to be able to feed the skimmers with the spilled oil. It was seen in the model tests that the thick oil easily sticks to the sidewalls of the channel. This would prevent the oil from flowing in the channel between the hulls and hence prevent the oil from reaching the skimmers. Even if the situation on the full scale OSH for many reasons is not as difficult as in the model tests, it was decided to add water jets on both sides of the channel to ensure that the oil is not stuck to the sides of the ship.

## 8. OIL RECOVERY SCENARIOS AND OTHER MISSIONS

The OSH project has been dedicated to the study and design of an oil spill recovery vessel liable to enhance notably the efficiency of response operations at a European level. In parallel to various technical developments, which have been presented in the previous sections (design and tests of the vessel and the oil recovery tools), a specific work was also devoted to study and design the exploitation which could be made of the OSH, particularly through its operational use, both in crisis time (oil recovery) and in “peacetime”. To this extent, the work carried out devoted to this objective aimed at a double purpose:

- to precise the operational use of the OSH in “crisis time” by studying:
  - the potential integration of the OSH into a response framework according to existing oil spill response plans, particularly as regards the logistics of the response and the interaction with other existing means of recovery at a European level – this aspect is therefore more particularly logistical; and
  - the possibilities of optimizing the efficiency of this use, by investigating particularly the aspect of the monitoring of the spill, from detection to drift predictions, and by including them into the design of a prototype decision support tool – this aspect is therefore more particularly technological.
- to investigate other possible missions for the OSH in “peacetime” in order to improve its profitability, taking into account the compatibility of these missions with oil spill combating availability and operational constraints.

### 8.1. “Crisis time”: use of the OSH within response frameworks

In order to precise the operational exploitation of the OSH in crisis time, a first aspect of the study consisted in investigating the diverse existing frameworks for combating pollution at sea in Europe, in order to consider the potential use and integration of an OSH vessel within these frameworks. To this extent, a review was conducted on these existing frameworks for combating pollution at sea, at various and progressive levels:

- at national level in the EU Member States;
- at national level in EU Member States’ neighbouring countries;
- at regional level through diverse agreements enforced within Europe;
- at European level through the implication of European structures; and
- at international level through the involvement of IMO and private companies.

For these diverse levels, numerous aspects were investigated: general policies, frameworks enforced for intervention, frameworks enforced for cooperation with other countries or entities, associated equipment, participation in past oil spills and resulting experience, etc.

As regards first general considerations taken out of this study and which could be evoked in a few lines, it can be noticed that the investigation of the various policies enforced in Europe and in neighbouring countries demonstrated that mechanical recovery is, when applicable, considered to a large majority as the primary option to combat pollution at sea. Mechanical recovery is associated, in most of the countries, with various means, among which oil recovery vessels. However, their repartition appears relatively heterogeneous throughout Europe. In this context, the study showed that, to any of the considered countries, extended support and means, among which specialized oil spill recovery vessels, are available in the event of a major pollution. It can be the case either through regional agreements, but also through contracting with public (including EMSA) or private organizations of European range and able to provide requesting countries with extra response capacity. The recent and foreseen evolution of the fleet even tends to strengthen and harmonize the capacity for response throughout Europe, with particular emphasis on large capacity vessels, but still without bringing answer to specific aspects demonstrated as key matters through practical experience of past oil spills (as demonstrated by the studies discussed in section 3), such as the ability to intervene quicker on the site of the accident, or the ability to operate in rougher seas than the OSRVs allow it today,

which are the major specific points of the OSH project. In that sense, the study of the present organization and situation demonstrates that there is room and interest for the integration of a vessel such as the OSH.

Beyond this, and to introduce further on some results which came out of this study, it can be noted that the investigation of the diverse existing frameworks for combating pollution at sea in Europe, allowed defining more precisely what could be the operational use of the OSH.

First, the description of the functioning of regional agreements, more or less built on the same principle, provides a good view of what would be the operational use of an OSH vessel within a joint response operation; basically, a country in which an accident would occur, would request assistance from other entities (countries or organizations) through the cooperation mechanisms enforced. This country would then be provided by them with extensive means, eventually including vessels, and would be the authority in charge of response. On this basis, the OSH, whoever his owner (private entity, country, Europe, etc.), as well as other OSRVs, would be put under the command of this authority coordinating the action. The authority defines working zones for each vessel depending on the data received from aircraft performing spotting missions, models, etc.; once in the area, the vessels have latitude to locate oil patches and operate the recovery in what they estimate the best way, provided it is compatible with the particular instructions given by the coordinating authority (e.g. for the use of dispersants).

Second, the review of the existing associated means, and the experience gained from past accidents, open tracks for particular uses of the OSH complementarily with other means, particularly on logistical aspects (coordination of a fleet, support to other means).

Third, the review of the diverse entities and of their role and relations also indicate several possibilities for a potential exploitation and ownership frameworks for the OSH vessel. The objective of the study could of course not be to pretend to indicate whom, or which entity, must be the owner of the OSH. However, it led to present various scenarios for the ownership or chartering of a vessel such as the OSH, which scenarios could be envisaged after having studied the existing frameworks, and having taken into consideration several constraints (economical, technical, operational, etc.). Four scenarios for ownership were analyzed (government, regional or European organism, private company, shared investment), and interesting aspects were found out on the ideas of shared investments (by public or private entities), and the concept of pools of vessels of comparable complementary missions, which aspect is particularly connected to potential “peacetime” activities as presented below.

Finally, under this study, fictive scenarios of intervention of the OSH on an oil spill were also proposed, including scenarios involving cooperation with another FP6 funded project, EU-MOP, which is oriented on oil spill recovery using numerous automatic small units.

## **8.2. “Crisis time”: possibilities for efficiency optimization**

In addition to this aspect of the integration of the OSH into response and ownership frameworks (which aspect is more particularly logistical), a study was also conducted on the possibilities of optimizing technically the efficiency of this use, once on the spot (which aspect is more particularly technological).

Effectively, beyond the vessels’ oil recovery capacity itself, which is mainly relevant to the features of its equipment (skimmers, pumps and storage capacity), the experience gained from numerous major oil spills in the past underlined the fact that efficiency could be gained on the overall operation, from aspects other than this of the capacities of the equipment themselves, and particularly through:

- the possibility to monitor the spill from the vessel, from detection to drift prediction; and
- the possibility to carry out nighttime oil spill recovery operations.

To this extent, a bibliographic survey was conducted on these major aspects. Various equipment and techniques were identified, including:

- equipment and techniques available to detect, characterize and map oil slicks;
- tools available to mark and track the slicks' position in real time (mainly marking buoys);
- models available to forecast the slicks' evolution, in terms of both drift and weathering; and
- technologies available for communication in order to exchange these data.

This bibliographical study led to identify the most recent and high performance techniques available today to enhance the overall efficiency of an oil spill recovery operation by the OSH, thus completing the definition of the potential optimized use of the OSH in “crisis time”.



*Very recent systems today allow getting real time wheelhouse information about the location of oil slicks around the vessel (which proves extremely difficult visually), using the bare signal from the radar (Here: the SeaDarq system tested at sea by Cedre and the French Navy)*

### 8.3. “Crisis time”: design of a prototype mission planning system

As a last step of the work carried out on the use of the OSH in “crisis time”, the optimization of the efficiency of the OSH while performing an oil recovery mission was also tackled through the design of a prototype mission planning system. The objective of this tool, called OGS – Operating Guidance System, is to provide the shipmaster with the guidance for the steering of the OSH ship during all phases of an oil recovery operation.

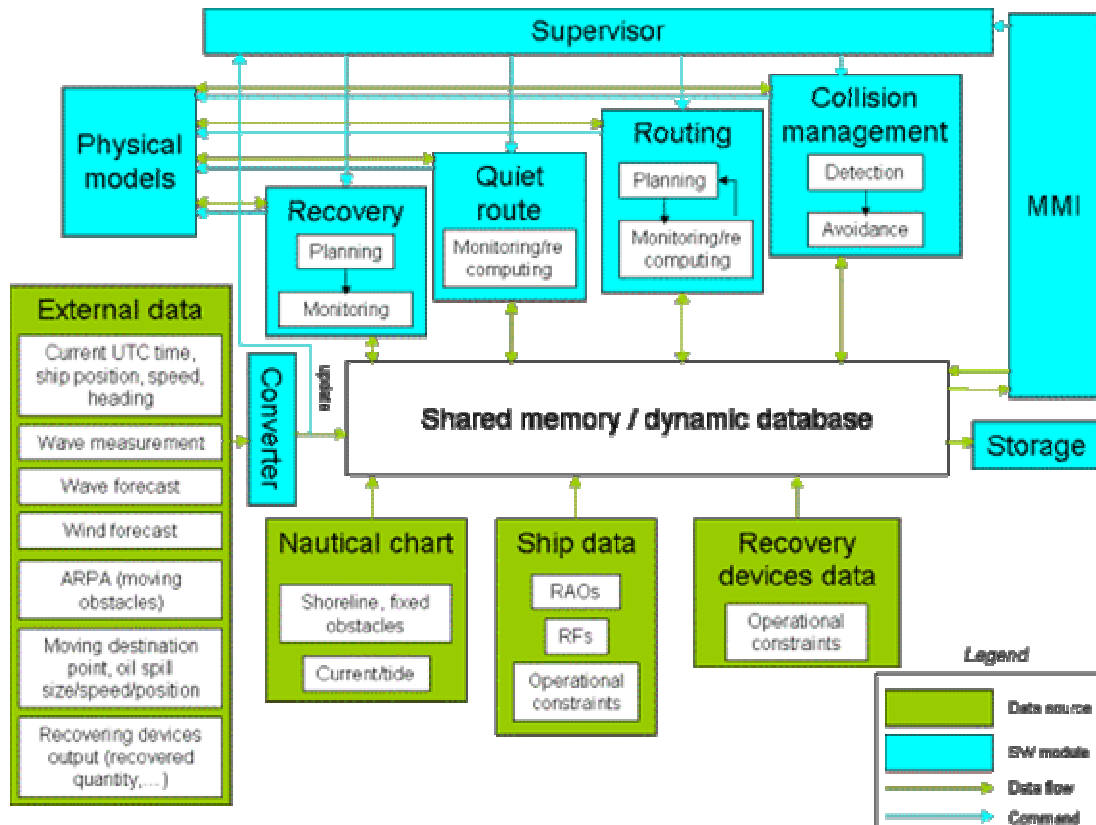
Three main phases have been identified for the oil recovery operations:

- weather routing: to find the optimum trajectory and velocity profile to go from an initial location to the oil spill area, accounting for the ship characteristics, meteocean forecasts (with regular updates), oil spill position drift in time, forbidden zones (e.g. other accidents at sea) and several possible (user selectable) objective and constraint functions;
- quiet route: to help the shipmaster adjusting the current ship heading and speed temporarily during the ship transit to the oil spill area in order to perform one-off operations requiring low ship motions for instance (e.g. preparation of the oil recovery devices, transfer of equipment between the OSH ship and another one); and
- recovery: to help the shipmaster to determine the best oil spill sweeping strategy (main direction of sweeping across the oil spill, ship velocity during recovery), accounting for the oil spill size and position variations in time, for the ship and recovery devices operational constraints and for other constraints related to the presence of fixed obstacles or shoals.

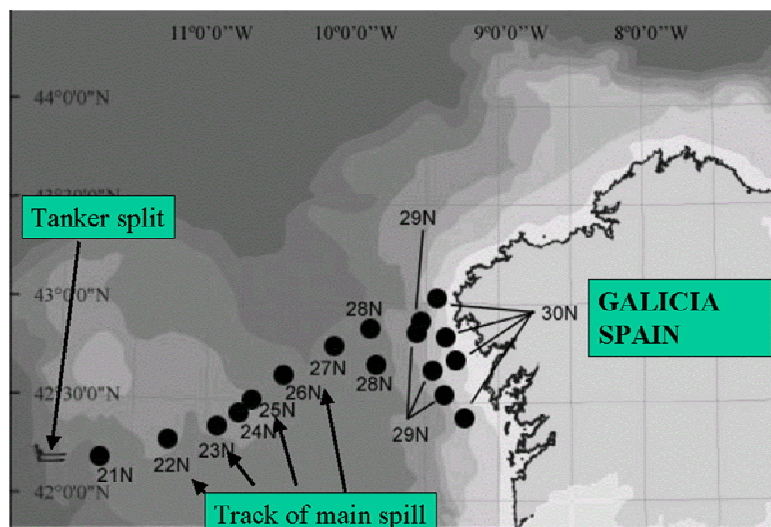
In addition, a collision avoidance function can be activated. Based on the continuous input of detected moving objects around the OSH ship (delivered by an onboard ARPA radar for

instance), this function detects the risks of collision route and proposes a route deviation avoiding collision with the smallest possible deviation from the initial route.

The functional and technical specifications of the OGS have been defined covering the following topics: operation functions, calculation methods and problem discretization, required input data (as from the results of other studies of OSH project, and also data outside the project), required physical models (as from the results of other studies of OSH project, and also data outside the project), general software architecture and man-machine interface. The following general architecture was designed:



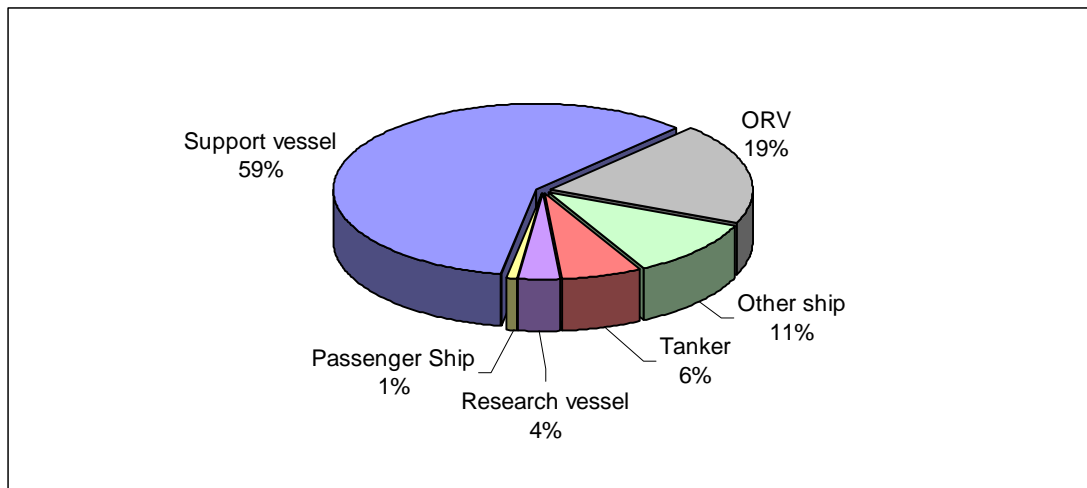
These specifications made a complete description of the system. A prototype development was performed covering oil recovery, routing and quiet route operations integrated in a man-machine interface. Simulation experiments were performed with this prototype in simplified scenarios in the case of the Prestige accident near Spain (November 2002: 2<sup>nd</sup> major *Prestige* oil spill, when the tanker split in half with a release of 20,000 tonnes, as shown in figure hereafter): optimization of OSH vessel routing from Brest to oil spill near Galicia coast, OSH oil recovery of the drifting oil slick before it reaches the coast.



#### 8.4. “Peacetime”: other missions

Finally, the aspect of the exploitation of the OSH in “peacetime” was investigated through a study of other possible missions for the OSH, while she would not be involved in oil spill recovery operations, in order to improve her profitability, taking into account the compatibility of these missions with oil spill combating availability and operational constraints.

This analysis of possible other missions is first based on the analysis of existing ships used for oil recovery missions in Europe. The figure below puts into evidence that the ships used for oil recovery missions are mostly support vessels.



*Oil recovery vessels in Europe*

In a second step, different categories of ships are identified, and technical, operational and economical aspects are checked according to OSH criteria. These categories are:

- cargo ships;
- tankers;
- support vessels;
- research vessels; and
- other ships.

It appears from this study that several missions can be envisaged for the OSH, apart from her main oil recovery mission. The design of the ship allows her to perform, with no major design modification, tanker activities, supply and more general support missions. Besides, the time of operation of the ship can be shared between these different alternative missions. Furthermore, the open deck area makes possible to adapt a number of specific tools (winches, cranes, etc.) and turns the OSH into a very flexible platform.

The best optimised use of the OSH, considering the OSH constraints and taking advantages of the ship specificities, appears to be a supply ship, with the ability to deal with emergency situations (rescue and fire-fighting abilities).

The economical analysis (see section 11) determines the best profitable combination of these possible missions to make the OSH economically attractive during her non-pollution-related activities.

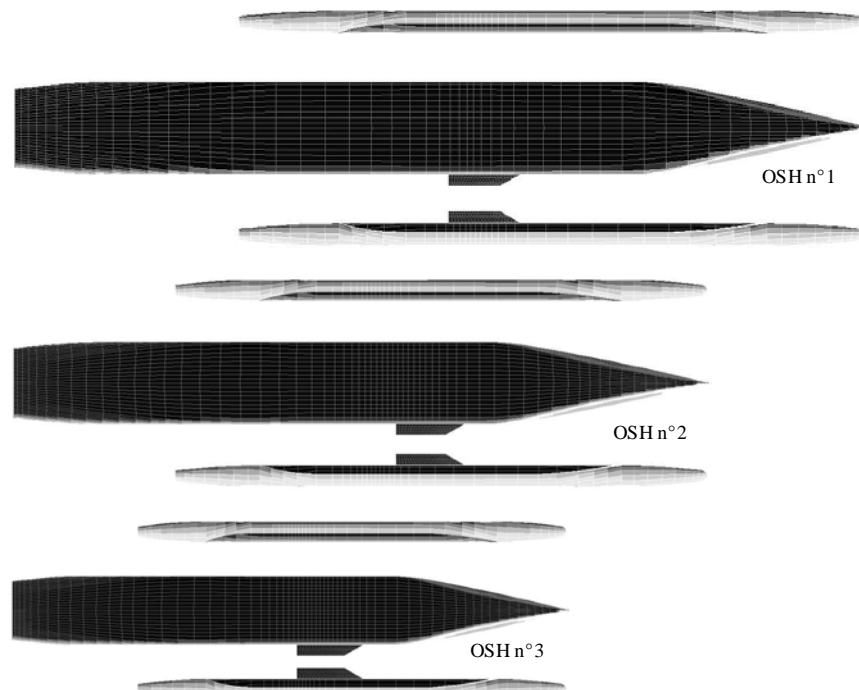
## 9. DETAILED DEFINITION OF THE COMPLETE SYSTEM

Following the work described in the previous sections, all technical information of the different parts of the system is assembled. The aim is to have a definition of the concept as a complete system ready to be proposed to a potential customer and accurate enough to be able to evaluate the cost of the ship itself and the associated systems.

The aim is to give a technical definition of the ship. To succeed, all the technical information such as the optimised and updated drawings of the tools carriage or hull forms have been verified and assembled. During the project, the members of the consortium have decided to increase the profitability of the OSH (to make it easier to sell to a potential customer) by giving to the OSH the possibility to accomplish other missions than recover oil at sea. A new version called “multi-purpose” version has been developed and the work made in preliminary ship design had to be updated. Global performances have been evaluated thanks to work of BEC and Cehipar. NTUA has developed a 3-D model in order to show how exactly the OSH looks like and how she can operate in high sea states.

### 9.1. Operational performance sensitivity to the overall size of the ship

The influence of the overall dimensions of the ship on its operational performances (transit and oil recovery configurations) has been assessed by means of numerical simulations and of extrapolation of experimental results. For that purpose, two smaller designs derived from the optimised concept have been studied; smaller ships could be of interest for maritime areas for which a smaller storage capacity is a priori required. These smaller designs have a full displacement of 9300t and 6800t respectively (compared to the full displacement of 12000t for the optimised design).



*Upper view of the two smaller designs and of the final design of the OSH*

The powering performances study is based on the results of the model tests that have been extrapolated to different scales, and allows the estimation of the required installed power to reach the same maximum speed (about 23 knots) as the optimised OSH concept.

The sea-keeping performances of the two smaller designs have been studied numerically, using the Hydrostar software. Results of sea-keeping calculations indicate that decreasing the size of the OSH does not change significantly its operational performances, both in transit and oil recovery configurations. The good oil recovery performances of the three designs is mainly due to the fact that the motions of the tool carriage are not influenced significantly by the motions of the OSH: the tool carriage is linked to the vessel only by rotating arms, that allow free motions of the tool carriage; moreover, the tool carriages are located between the hulls, where the water agitation is reduced. Whatever the size of the OSH is, it will be able to operate with both tool carriages and without any restrictions in headings in about 50% to 60% of all the sea states, and it will be able to operate with at least one tool carriage and with restrictions in headings in about 92% to 98% of all the sea states.

## 9.2. Final system specification

The final system presented is the technical definition of the ship and the associated systems (tool carriage / tools) with an estimation of the building cost of such a system. The design presented is the final design of the multi-purpose version of the OSH. It is an optimised version of the initial design.

### Propulsion:

- Pump jet pods (PPH type from Converteam) or equivalent:
  - Unitary power: 13 MW
  - Propeller diameter: 5 m
- Retractable azimuth thruster (2 MW from Brunvoll or equivalent):
  - 8 pole motors
  - Estimated thrust: 33 tons
- Tunnel thruster (1 MW from Brunvoll or equivalent):
  - 6 pole motors
  - Estimated thrust: 13.5 tons

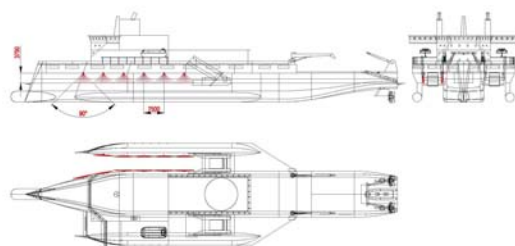
### Electric Production:

- 2 gas turbines Siemens SGT-500
  - Electrical power: 17000 kW
  - 11.0 kV, 60 Hz
- 2 generator sets type Wärtsilä 6L20 type
  - Power: 1110 kW at 900 rpm
  - Alternator power: 1055 kW, 60 Hz

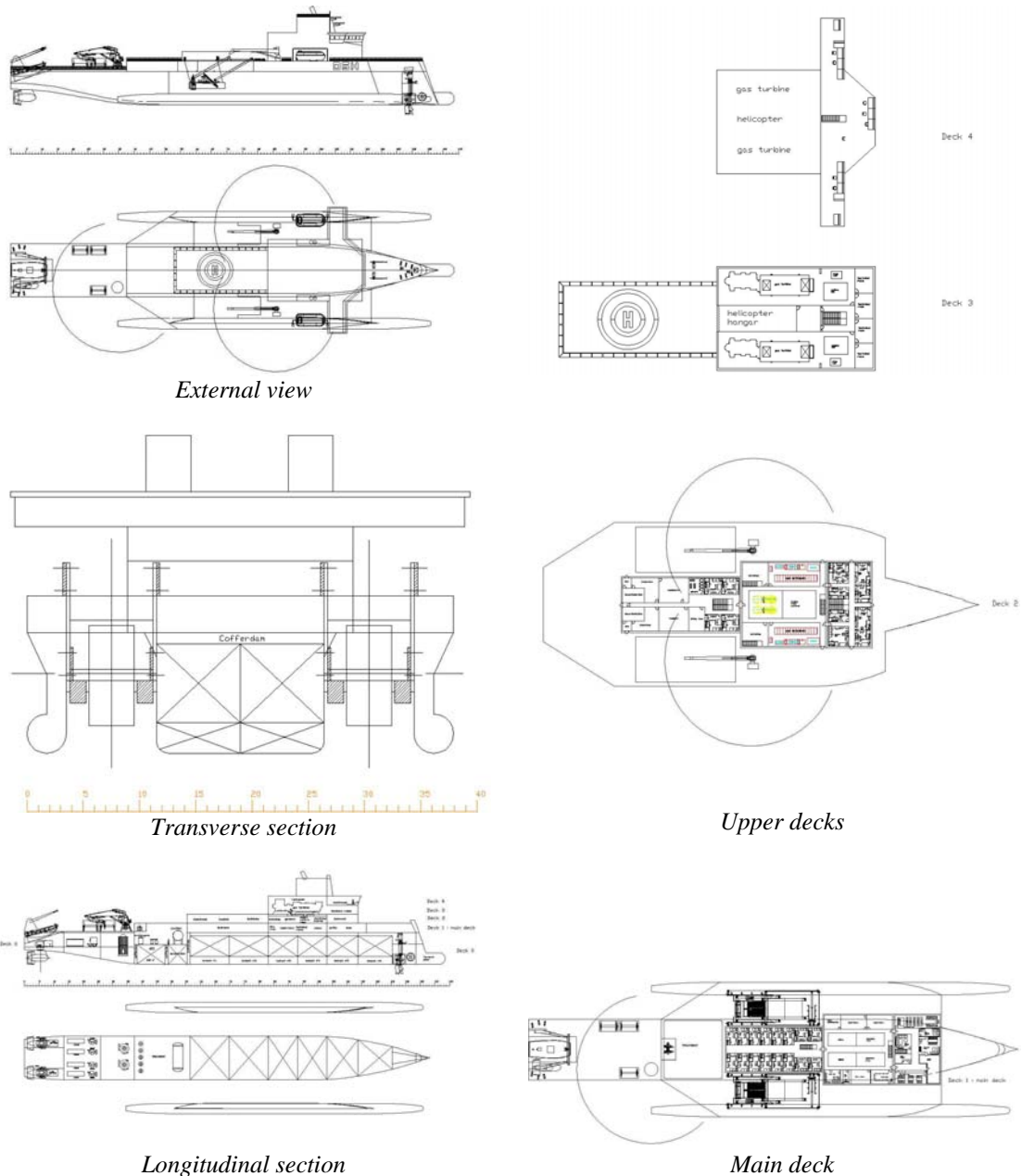
In order to save space and optimise the dimensions of the superstructure, it was decided to replace the initial three generator sets with two gas turbines. Moreover, in order to start the gas turbines and to supply power at quay or when anchored, two generator sets have been added. Also, two bow thrusters have been added to make the ship more manoeuvrable than it was.

### Specific equipment:

Some specific equipment have been modified. The number of cranes is three. The tools carriage has been modified by Navalimpianti because the previous one was too large for the multi-purpose version of the OSH. Some specific equipment have been added. A small boat with free fall launching has been placed on the after deck. It will be used to deploy floating booms at sea.



In order to increase the flow of oil between the main hull and the side hulls, a system of sweeping arms can be installed. The concept of the sweeping arms is the following: during the recovery operations at a very low speed of 1 to 3 knots, the forward part of the side hulls can open itself on the outside like a door opens around a pivoting arm.



### 9.3. Global performances

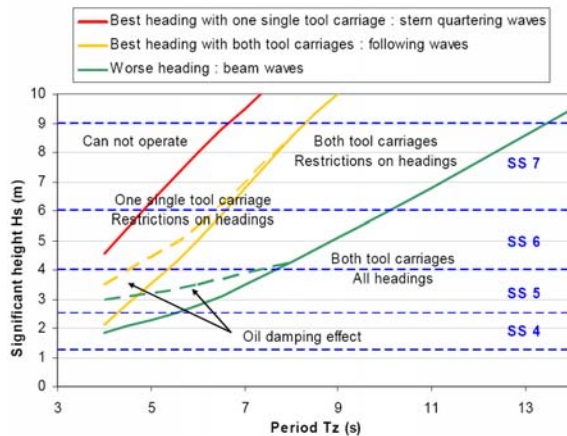
The main performances of the OSH are:

- the powering performances of the OSH have been measured during the model test phase and the test results show that, with an installed power of 26 MW, and assuming an overall efficiency of 0.7, the maximum speed of the OSH will be around 22 knots;
- the sea-keeping test with forward speed, and additive results from numerical simulations, show that the sea-keeping criterions for the transit phase will be satisfied up to sea state 6, and even sea state 7 for very short or very long waves; and
- the sea-keeping tests in oil recovery operations, and the numerical simulations, show that the operability criterions for the oil recovery phase, depends on the sea state period, the heading and the number of tool carriages used - without any restrictions in headings and

with both tool carriages, the maximum sea state is 4 for a short period and up to 7 for a very long period, while by choosing the best heading for the protected tool carriage, the OSH can operate in a sea state 6 with short waves or in a sea state greater than 7 with long waves; the recommendations for the captain of the OSH are:

- to operate with both tool carriages for all headings in low and medium sea states;
- to operate with both tool carriages for a chosen heading in high sea states;
- to operate with one single tool carriage for a chosen heading in very high sea states.

All these operability limits and the different domains of use of the OSH are plotted on the graph below.



The newly developed tools have been tested in as realistic an environment as possible and the results are that the equipment will fulfil the specifications for the OSH. The recovery capacity will be more than 100 m<sup>3</sup>/h and the tools can work in the environments specified.

#### 9.4. Virtual 3D prototype

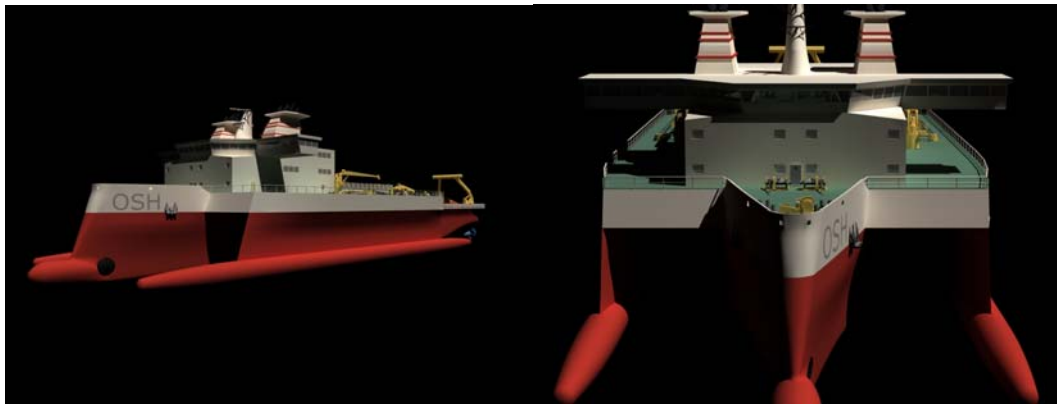
This task is aiming at building a virtual 3D prototype demonstrating the oil recovery ability of OSH. The task was naturally split into two subtasks:

- 3D prototype creation: creation of the 3D-model of the exterior of the ship, covering: hulls and superstructures; oil recovery tools; and tools carriage and its integration with the ship.
- CG animation: creation of a CG animation of the oil recovery process based on oil recovery scenarios.

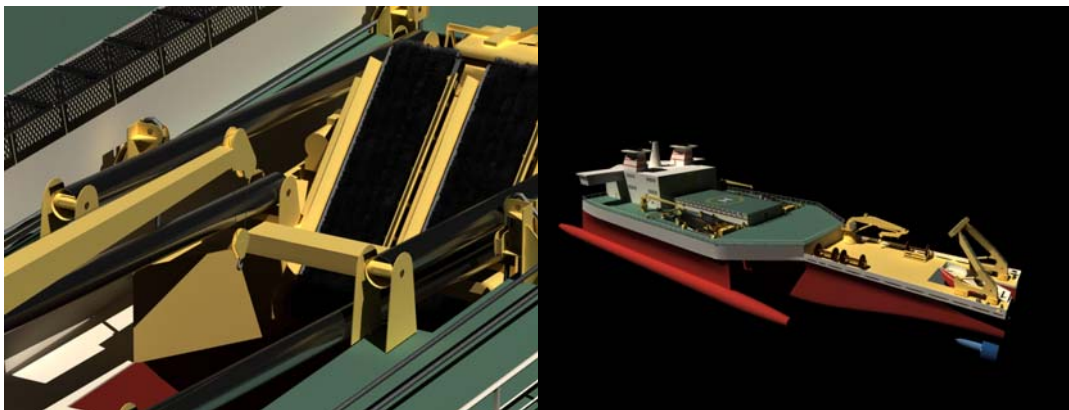
The scenario considered for the creation of the CG animation (video) has as follows:

*After an oil tanker accident, an oil spill spreads on the sea surface. The camera focuses on a plane that passes by looking for the oil spill spot. The spill is spotted and the information is passed to the OSH vessel. The vessel is quickly approaching the area and we get an overview of the ship. The vessel's helicopter takes off to evaluate the extent of the spill and to provide initial guidance for the recovery process. The OSH vessel enters the spill area and the recovery process begins. The vessel capabilities and functions are demonstrated: manoeuvrability, oil recovery and storage. The recovery of the oil spill continues until her oil-recovery tanks are fully loaded.*

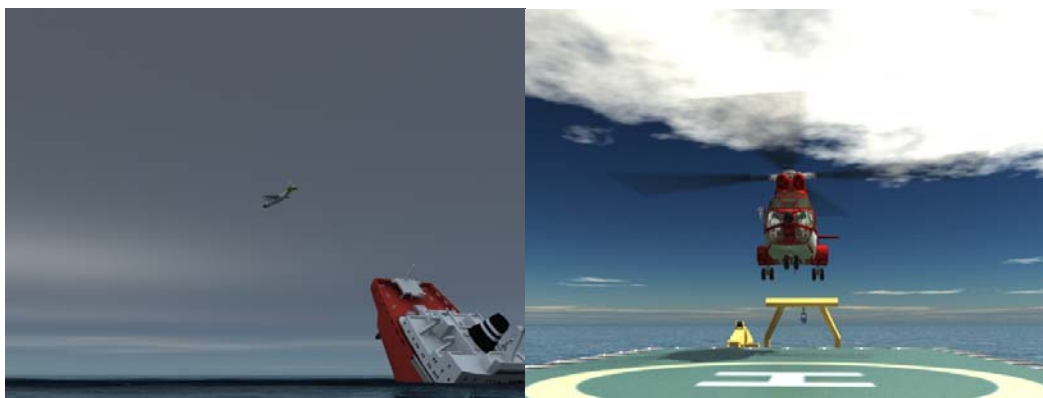
In the following page some indicative pictures are given in order to demonstrate the outcome of this task. The first four pictures depict photorealistic renderings of the 3D-model prototype along with the integrated oil recovery tools' models. The following four pictures contain frames from the CG animation depicting oil spill spotting, helicopter takeoff and details of the oil recovery process.



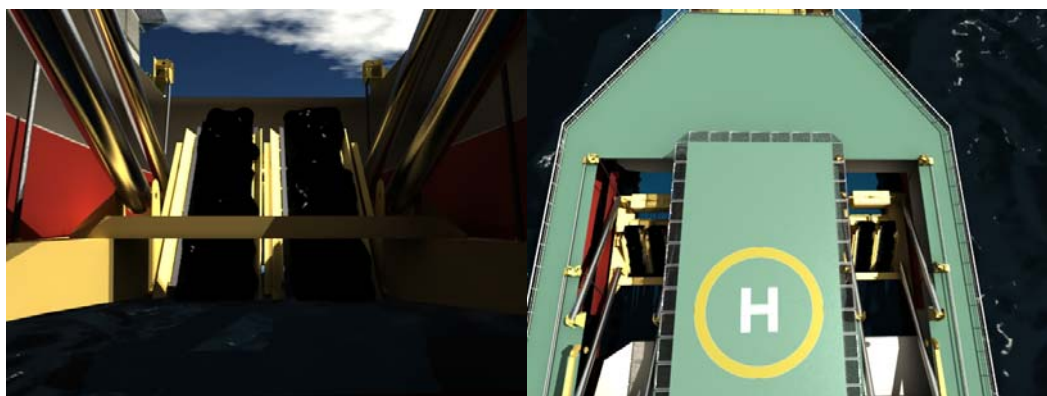
*Side and front photorealistic renderings of OSH ship's 3d model prototype*



*Close up of oil recovery tool and carriage and rear view of 3d model*



*Oil spill spotting and OSH helicopter taking off*



*Oil recovery process in action: close up and top view*

## 10. TECHNO-ECONOMIC ANALYSIS AND EVALUATION

A comprehensive economical analysis concerning the development and the operation of the proposed ship is fundamental in order to investigate the commercial viability of the project. More specifically, the main objectives of this work are: to assess the economical potential of the specific investment; to incorporate and elaborate various categories of costs such as operational costs, maintenance costs, etc.; to pinpoint all associated benefits arising from the operation of the Oil Spill Harvester; and to present the overall financial and cost-benefit balance regarding the viability and the usefulness of the proposed ship. In this process three main stages are identified:

- definition of the main cost factors;
- definition of expected benefits; and
- cost-benefit analysis, balancing these and therefore indicating the viability of the project.

These are outlined below.

### 10.1. OSH costs

At a first stage, the main cost factors are defined in order to evaluate the expected costs (initial and running) of the investment. These are:

- initial building cost;
- crew wages (OSH is initially supposed to operate in 3 shifts, periodic cost);
- fuel cost;
- administrative cost (periodic cost);
- insurance cost (periodic cost); and
- maintenance cost and miscellaneous (periodic cost).

The oil price heavily influences operational expenses, since the engine consumption is high because of the installed power. Furthermore, the three shifts and the stand-by mode of the OSH vessel lead to high operational expenses. These factors are at first unfavourable, however no conclusions can be drawn before these are balanced against the associated benefits, which are expected to be significant.

In any case, as already discussed in section 8, the usability of the vessel in other missions must be examined, since the oil spill recovery missions have a random occurrence and fixed income sources must additionally finance the project. The investigation of such an expanded operational profile can lead to more favourable overall results.

### 10.2. OSH benefits

The definition of expected benefits from the operation of the OSH vessel follows; these are divided into two categories, namely social and private ones.

The social benefits, the most important ones, have to do with the pollution (coast contamination) prevention, environment protection and the protection of the tourism and fishing industries. IMO standards are used in order to estimate social benefits from combating oil spills (60000 euro per oil ton).

As far as the private benefits are concerned, OSH is considered a very efficient method for collecting oil spills, so the end user who will pay for its services (the state or the ship owner) can be expected to prefer it to other alternative solutions in view of its increased capabilities and overall efficiency.

The estimation of potential costs caused by an oil spill is of paramount importance for contingency management and effective combat operations, in order to minimise environmental and economic impacts. There are normally five different cost categories considered:

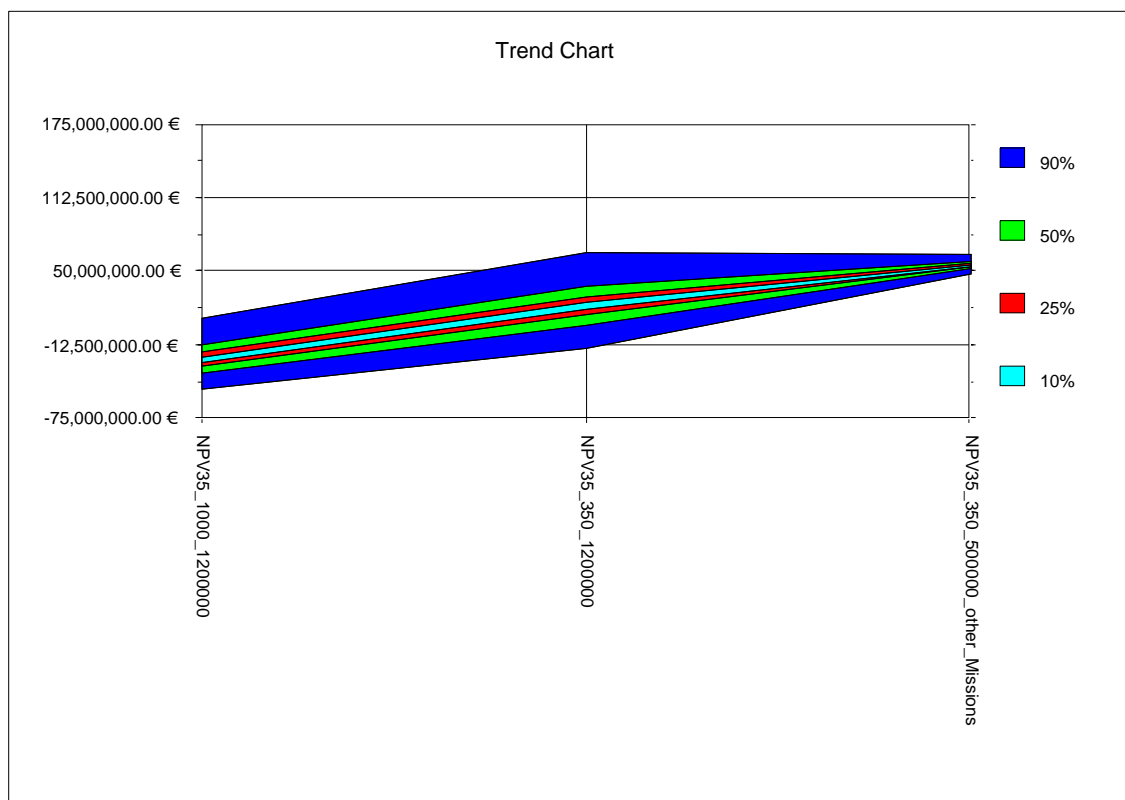
environmental damages; socio-economic losses; clean-up costs; research costs; and other expenditure. Of these five different cost categories, environmental damages can not be directly assigned with monetary values in real economic terms. Environmental damages caused by an oil spill lead to a degradation of a natural resource and, consequently, to a decrease of their services in the aftermath of the incident. In a study on the cost of oil spills, four main types of costs involved in oil spill accidents were identified: clean-up costs, compensations of damages, cost for preventative measures, and indemnification to the shipowner.

Socio-economic losses, as a result of coastal or marine pollution, affect several economic groups, such as fishermen and hotel owners, all suffering monetary losses. These losses generally consist of income losses and property damages. Both of these issues contribute to an integral part of third party claims in an admissible compensation scheme.

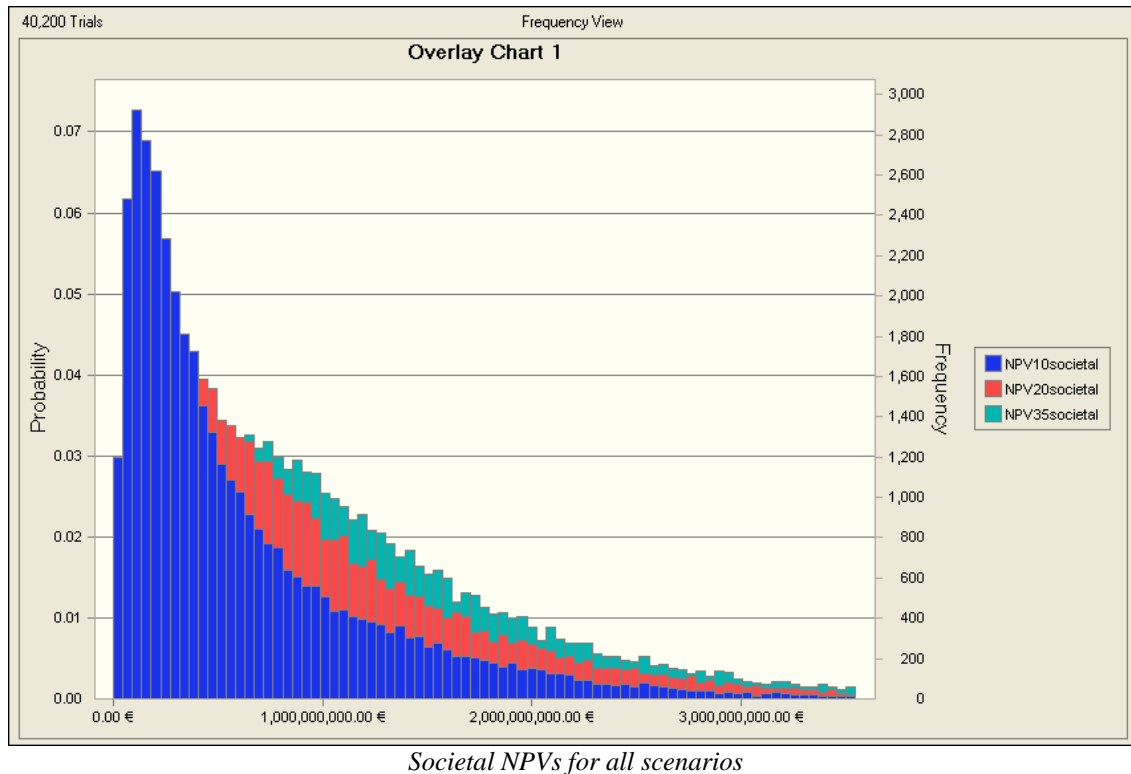
**10.3. Cost-benefit assessment**

In the cost-benefit analysis, the cash flow method combined with Monte Carlo simulation is used. All possible operational states of the vessel are simulated (based on statistical distribution of accidents and oil pollution). In order to evaluate the CBA, specific criteria such as NPV and IRR are used, providing numerical distributions for each criterion. A number of conclusions can be drawn from this analysis.

According to the analysis the OSH vessel can be profitable with private or with social criteria under specific conditions. In such a context, the OSH project is economically viable in a 35-year time horizon with a very high probability. Favourable scenarios depict the ability of the vessel to pay back in private terms within a time period of 10 years. Unfavourable scenarios estimate that paying back in private terms is not feasible within 35 years. In societal terms, however, the OSH vessel is profitable under all operational scenarios. In fact, in societal terms the OSH can be very profitable even at 9000 €benefit per tonne of oil collecting. The results regarding social benefits depict the ability of higher OSH hire rates. This can lead to operational profiles without the need of other missions.



35-year NPV trend chart for different scenarios



A daily hire of 1 M€ combined with a threshold of 350 ton of oil spill is the base towards a profitable private investment. A higher threshold (e.g. 1500 ton) must be combined with higher hire rates (e.g. 1,5M€). Such a high hiring rate is necessary due to several factors; these are: the scarcity of the occurrence of large oil spills; the high initial required capital to be invested for the construction of the ship; the high operational expenses of the ship, even at stand by mode; and the oil consumption of the engines. On the other hand, such a high hiring rate can be justified by the fact that the OSH, due to its efficiency, accomplishes the oil recovery task very fast, within 1 to 3 days for the vast majority of cases, which is of course very desirable, since it prevents the oil spill from spreading and having catastrophic consequences for the environment.

The investment presents high level of risk derived by the randomness of the oil spill accidents. However, a small number of large oil spills in its operation record can easily amortize the cost of the project. Such events are likely in a one- or two-decade time period in the Mediterranean Sea or the Atlantic. Sensitivity charts show the effect of early major accidents to the overall profitability of the vessel.

This CBA generally favours the attempt of constructing, operating or hiring the OSH vessel. The study has been based on the oil spill occurrence patterns of the last 30 years in the Mediterranean Sea. As maritime traffic and international trade are expected to rise, it is a rather safe assumption to expect that such catastrophic events will continue to occur in the next 35 years despite the contemporary strict regulations for shipping safety, which is a necessary condition for the economic viability of the OSH vessel.

It must be stressed that this analysis did not assume any subsidies which could be an extra incentive for a potential private investor to proceed with the construction of the vessel. Furthermore, paying back is guaranteed within the life cycle of the vessel if supported by other missions (offshore activities; using the OSH vessel as a tanker vessel is not a crucial factor in overall profitability). These two additional aspects can greatly improve the overview of the project in financial terms.

## 11. DISSEMINATION AND EXPLOITATION

As with any research project, it is important to communicate the progress of work and the achieved results to the widest possible range of interested parties. To this end a focused documentation and dissemination effort has been undertaken, the main objectives of which include: the scientific dissemination of the project and of its results; the commercial promotion of the project and of its results; and the exploitation of the project's concept and result to the shipping industry.

Within this context, conference and journal papers form part of the dissemination effort, while the exploitation effort includes the organization of symposia and workshops targeting the familiarization of the OSH concepts to all possible recipients. Both these have the commercial promotion of the project in view.

### 11.1. Dissemination

A web site, which can be found at <http://www.osh-project.org>, has been created for the project (see indicative screenshot of home page). It includes a "members-only" part which is available only to partners with the main purpose of uploading and downloading project documentation and a public part which is of interest for the dissemination effort. The latter part offers information such as project summary, partnership, newsletters and contacts. The web site is comprehensive in terms of contact details and links to the consortium as well as in outlining the scope and objectives of the project. It also offers possibilities for the presentation of results and of the overall progress of the related work, having been in this aspect regularly updated to include current versions of the executive summary and newsletters.



In addition to this web site, a quarterly OSH newsletter was being issued during the entire duration of the project offering up-to-date information on the project's objectives and results. The quarterly issues of this newsletter within their scope offered a reasonably comprehensive insight of the progress of the project, thanks to appropriate contributions and input from most partners. Indicatively, issue #9 (which included the 2<sup>nd</sup> year summary report), is shown here:



A dissemination database has been generated and was being constantly updated, ultimately covering the period up to late 2008. This database listed dissemination opportunities available to partners (such as conferences, exhibitions etc.) and recorded actual participation of partners in these events.

As far as direct dissemination in the form of papers/presentations etc. is concerned, this includes a number of papers and presentations given by partners in conferences and workshops, articles

in relevant journals, as well as other dissemination activities such as inclusion of specific references to the project within company brochures or other similar documents and promotional material. It seems reasonable to expect that more papers and articles can be produced after the end of the project, when the work is completed and results are obtained and evaluated. To this end the dissemination database should be of significant assistance.

Furthermore, a poster has been designed which can be used to communicate the project in media ranging from exhibitions to journals or magazines. Finally, a flyer has also been designed aimed at offering increased distribution possibilities. It includes a brief outline of the project and its objectives as well as contact information. The OSH poster and flyer provide basic information on the project in a condensed and easily communicable form. The OSH poster and flyer are shown in the figures to the right and below respectively.

**11.2. Exploitation**

A workshop focusing on oil pollution control issues has been organized by NTUA in Athens, Greece in 9 June 2006. This workshop included sessions dedicated to relevant EU projects and one session in particular was dedicated to the OSH project. Furthermore, a workshop focusing on marine pollution counteraction methods is being organized in Madrid, Spain on 24 January 2008. This workshop will include a presentation dedicated to the OSH project.

The Athens workshop has been successful and productive, both in organization and in content. It was well attended by people within the shipping community and industry, from Greece as well as from around Europe. In this sense it was a good forum for familiarizing some important players in the oil pollution control field with the project, its goals and objectives, as well as bringing them up to date with the progress already achieved in the first half of the project's duration.

The presentations given by OSH partners provided comprehensive information on the project, both in terms of its goals and objectives and in terms of the actual progress achieved up to that period. An overview of the project was first of all given, which was important as this was the first occasion on which it was presented to the shipping community. This also included the argument for the scope of the project, by way of outlining the shortcomings of the current oil spill response situation and presenting the way in which they are being addressed by the OSH system. As for specific topics, they were well covered within the scope of results that could be presented at that point in time. Apart from the description of the overall concept and relevant configuration, this also included reports on the hydrodynamic hull optimisation and the resulting design, as well as on the development of specific tools and systems for the OSH vessel.

In general the workshop participants expressed their interest in project OSH and offered positive comments on its scope and on the planned approach. This was important as it was an indication that the project was moving in the right direction in addressing the needs of the maritime community with regard to the issue of oil pollution control. Furthermore, specific inquiries and suggestions were made, which in turn indicated that the workshop participants showed active interest as well as support in the project and the approach followed by the OSH consortium.

**MARINE POLLUTION & NEW METHODS OF COUNTERACTION**  
FINAL EU-MOP PROJECT WORKSHOP | 24<sup>th</sup> JANUARY, MADRID'08

**Funded by:**  
  
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**Hosted by:**  
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The Madrid workshop is expected to be well attended by people within the shipping community and industry, from Spain and Portugal as well as from around Europe, including anticipated EU participation. In this sense it is a good forum for bringing them up to date with the results achieved as the project will by then have reached its completion. Thus this workshop is another important opportunity for the project's presentation and promotion.

The presentation to be given on the OSH project provides comprehensive information on the project, both in terms of its goals and objectives and in terms of the actual results achieved. An overview of the project is first of all given, which is always important whenever it is being presented to the shipping community. This also includes the argument for the scope of the project, by way of outlining the shortcomings of the current oil spill response situation and presenting the way in which they are being addressed by the OSH system. As for specific topics, they are well covered within the scope of results that can be presented within a single presentation.

Overall the experience gained from the Athens workshop was positive and valuable, as is the inclusion of OSH in the Madrid workshop. Apart from offering good fora for the presentation of the project, they also produce useful and, in the case of the Athens workshop, particularly positive feedback.

## 12. CONCLUSIONS

This report documents the work that was performed, the activities that were undertaken and the results that were obtained during the complete duration of the project. In this context the scope of the project, the goals that have been set, the problems that were encountered in achieving these goals and the solutions that were given to such problems are outlined for each topic or area of research.

After large-scale and high-profile accidents such as those of the Erika and the Prestige, Europe chose to finance the OSH consortium in order to develop a solution against oil spills. In particular, the OSH project is addressing the need for vessels specifically designed to recover oil pollution at sea. The intention is to have a ship that in essence forms a complete and self-containing system with the purpose of attacking an oil spill and having a number of positive features, including:

- high transit speed, in order to arrive quickly on the scene of the accident and operate oil recovery tools when the spill is still well concentrated;
- good sea-keeping performance at that speed, allowing minimal effect of weather conditions on the required transit time;
- good sea-keeping performance at very low (recovery) speed, enabling recovery operation in high sea states;
- good manoeuvrability at same speed, enhancing the functionality and recovery efficiency;
- a specialized and efficient oil recovery system that can tackle oil slicks of all types and viscosities at very high recovery rates and oil separating levels;
- a hull arrangement that facilitates the installation of the above system and its performance under adverse weather/sea conditions;
- high carrying capacity and autonomy, leading to increased efficiency in combating large oil spills; and
- a versatile multi-purpose configuration featuring specialized equipment, enabling the vessel to perform a number of varying missions and thus enhancing her potential in terms of both usability and commercial viability.

All these goals have been approached with a view to generating feasible and efficient solutions and this has been achieved as outlined below.

The main required qualities of, on one hand, good sea-keeping at low velocity and in rough weather and, on the other hand, a high transit velocity are usually incompatible, a fast ship being generally uncomfortable at low speeds. The OSH design addresses these apparently conflicting requirements by combining the characteristics of a SWATH-type hull, characterised by a low transversal inertia over displacement thus leading to small platform motions even at low velocity, with those of an increased length associated to a reduced displacement, which in turn favours speed. The association of these two characteristics leads to the generation of a trimaran configuration with a long main central hull and two lateral SWATH hulls.

The optimisation process resulted in a design that satisfies the above requirements, as confirmed by the comprehensive testing campaign. In particular, the vessel can achieve high speeds of up to 23 knots in transit in calm seas. Furthermore, thanks to the good seakeeping characteristics, only minor speed reductions are observed at higher sea states. Finally, equally good seakeeping performance at very low speeds allows oil recovery operations in significant sea states, ranging from SS 4/5 up to SS 7 (depending on the wave period) for no restrictions in heading and use of tool carriages and reaching SS 6 up to very high sea states over SS 7 (again depending on the wave period) by operating in optimum headings and, if necessary, using only the best protected tool carriage.

As for the requirement for very good manoeuvrability at low speeds, in order to position the ship regarding the oil slick or another ship (ship in difficulty needing pumping action or other oil recovery ship), this is achieved by applying a solution featuring two pods which, apart from its excellent manoeuvrability, also offers good efficiency at transit velocity. The large lateral submerged surface provided by three hulls also constitutes a drift limiting factor.

In order to optimise the oil recovery performance, the stiff-brush-type channel-mounted conveyor belt system was chosen as the ideal skimming method for the OSH concept. It collects oil of all types and is unhindered by floating debris or seaweed; it can also operate in adverse weather conditions and choppy seas without losing performance. Another major advantage of the system is that the recovered oil contains very little water, less than 5%, making maximum use of valuable storage volume. The testing of the configuration specified for the OSH concept showed that the total recovery capacity of a two-side system is very high varying between 2 x 219 m<sup>3</sup>/h (bitumen) and 2 x 810 m<sup>3</sup>/h (IFO 40 POR 80). The high recovery speed and high oil encounter rate achieved are among the most important features of an oil spill recovery vessel.

The oil recovery system is complemented by specialized pumping equipment that allows efficient transfer of these high rates of recovered oil to the vessel's carrying tanks. The pumping arrangement features positive displacement archimedes screw pumps (PDAS), presently the most suitable pump for oil recovery operations, capable also of handling and processing debris and solids. In addition, the most cost-effective and simple flow enhancing technique, which is to inject water or steam as a lubricant between the viscous material and the inner walls of the pump and transfer hose, is applied; in particular, special annular water injection (AWI) technology is used to create a uniform sleeve of lubricating water.

Furthermore, the vessel's trimaran configuration offers an additional advantage, creating two protected channels in which the oil slick is guided to the oil recovery system. The recovery tools are therefore assembled on a carriage located in the channels between the hulls. The idea of the carriage is to decrease the relative wave motion in respect to the skimmers. The platform of the carriage is floating on the water surface and it is connected to the hull by levers that allow the tools to move up and down, thus following the waves. The system uses the vessel's forward motion to deflect surface water and oil from the collection area between the hulls to the recovery unit for processing. An effective flow through the oil recovery channels is achieved by the forward speed of the ship.

As was desirable, the vessel's scope of performance, particularly with regard to large-scale incidents, is enhanced by an increased capacity and autonomy. The oil storage capacity is significantly higher than existing vessels at 6000 m<sup>3</sup> with a corresponding maximum payload of 5700 t. In addition, it has the capability to work autonomously at full recovery rate for 3 days. Combined also with very high recovery and discharge rates, these characteristics make the OSH concept very well suited for combating large oil spills in an efficient manner.

Finally, the exploitation of the OSH while not involved in oil spill recovery operations, in order to improve her profitability, was investigated through a study of other possible missions, taking into account the compatibility of these missions with oil spill combating availability and operational constraints. The optimisation of the efficiency of the OSH while performing an oil recovery mission was of course tackled through the design of a prototype mission planning system, it was however important to expand the overall operational profile as it is conceivable that oil recovery missions may employ the vessel only for a small percentage of time. This led to the generation of a multi-purpose final version of the vessel, featuring forward superstructure with large deck areas carrying various equipment and tools as well as a helideck.

It appears from this study that several missions can be envisaged for the OSH, apart from her main oil recovery mission. The design of the ship allows her to perform, with no major design modification, tanker activities, supply and more general support missions. Besides, the time of

operation of the ship can be shared between these different alternative missions. Furthermore, the open deck area makes possible to adapt a number of specific tools (winches, cranes, etc.) and turns the OSH into a very flexible platform. The best optimised use of the OSH, considering the OSH constraints and taking advantages of the ship specificities, appears to be a supply ship, with the ability to deal with emergency situations such as rescue and fire-fighting. The economical analysis determines the most profitable combination of these possible missions to make the OSH economically attractive during her non-pollution-related activities.

It has therefore been demonstrated that the OSH concept possesses a number of positive features making it a particularly attractive tool in the fight against the increasingly important problem of marine oil pollution. Its merits include: a high transit speed; good sea-keeping performance at that speed as well as at very low speeds; good manoeuvrability at very low speeds; high recovery rates combined with large carrying capacity and autonomy; ability to handle oil slicks of all types; and a multi-purpose configuration. These give the OSH significant advantages such as: quick arrival on the incident scene; extended scope of efficient oil recovery operations, both in terms of weather conditions or sea states and in terms of type and size of oil spills; and versatility in complementary missions, ranging from tanker and supply to rescue and fire-fighting.

As an overall conclusion, it can be said that all the studies and final tests have clearly demonstrated that the OSH can sail in high sea states, and thanks to its excellent behaviour in sea keeping its tools can operate efficiently in harsh conditions to recover oil at sea, even the very viscous oils like the Erika one. It therefore represents a very comprehensive, efficient and feasible solution that is believed to be of great benefit and interest to the European Agency for Safety at Sea.