STREAMLINE

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Project	STREAMLINE – FP7-233896
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ABSTRACT:	The Annual Periodic Report contains an overview of the activities carried out during the reporting period. It describes the progress in relation to the project objectives, the progress towards the milestones and deliverables and sets out any problems encountered and the corrective actions taken,
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1. WP1: New Propulsion Concepts

WP1 comprises of WP11, WP12 and WP13.

1.1. WP11: Novel Application of Large Area Propulsion

Task 11.1 – 11.4: Preliminary design, Whole system optimisation , analysis and model testing and detailed design

Partners Involved: CHALMERS, SSPA, RRAB, CNRS

Objectives for the period

The objective for this period was to complete tasks for the LAP concept:

- T11.1 – Preliminary Design
- T11.2 – Whole system optimisation and analysis
- T11.3 – Model Testing
- T11.4 – Detailed design

Work progress for the period

CHALMERS
The work has progressed as planned and all objectives have been achieved.

CNRS
The work consisted of two parts corresponding to the validation for a Rolls-Royce tunnel case of a submerged propeller under a steady wave and to a SSPA test of an 8000 DWT tanker in irregular waves, including a scale effect study. Simulations have been conducted using the ISIS-CFD flow solver by ECN/CNRS using the sliding grid approach.

RRAB, RRMARINE

RMARINE has finished the design work on the single screw variant of the LAP with conventional propeller. The LAP concept is implemented into an adapted version of the 8000 TDW chemical tanker R&D design by Rolls-Royce Marine, Merchant Ship Technology & Systems. An aft ship layout of the redesigned vessel is made at a conceptual level covering mechanical, structural and design assessments. RR Marine has also supported the tasks 11.2, 11.3 and 11.7 in ship design and hydrodynamic related issues, like hull preparation, input and clarifications for CFD calculations, assessments of the results from the seakeeping tests and input to cost benefit analysis.

Significant Results

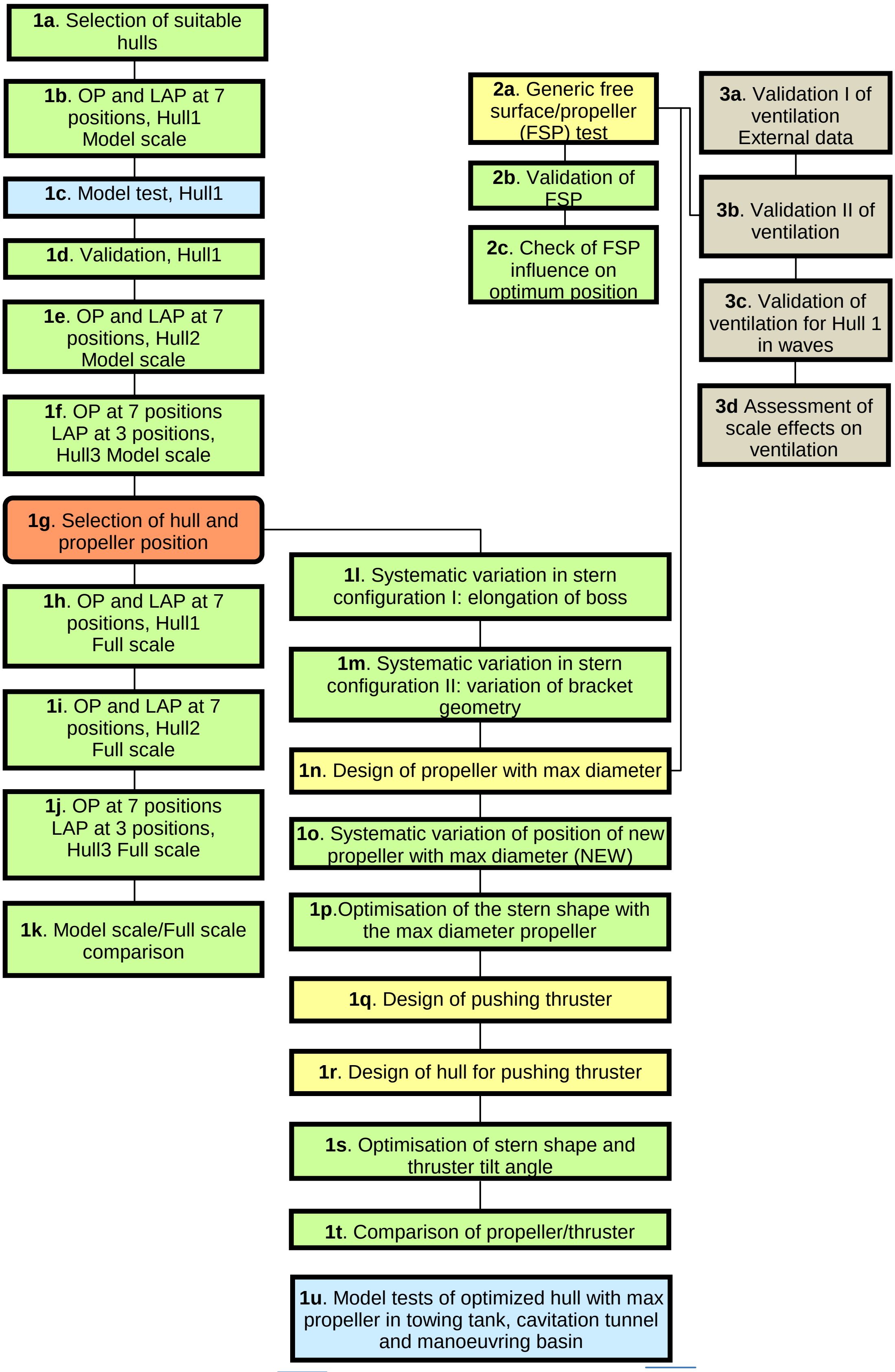


Figure 1: Flow chart of work in Tasks 11.1-11.3

Significant Results

The computed power reduction was 13.4% which should be compared with a measured gain of 14.5% (If the extra-large propeller is compared with the original case and both have rudders the measured gain was 13.5%). As shown in Deliverable D11.6, the zonal approach predicted a gain of 15.0%, without rudder in both cases. Since the purpose of the computations was to validate the results from the more approximate zonal approach using a potential flow free surface the good correspondence is reassuring.

Full scale predictions of the gain obtained with the extra-large propeller. The zonal approach was then used. As compared with the original configuration the gain was 12.5%, to be compared with the experimental gain extrapolated to full scale using the standard ITTC procedure. This gain was 13.5%.

Task 11.6: Optimised Configurations Single screw propulsion

Partner Involved: RRMARINE

Objectives for the period

The objective for this period within task 11.6 was to perform power prediction using physical or real propeller geometry rotating in real time.

Work progress for the period

In task 11.6 all four aft ship propeller configurations were analysed and the work reported.

Significant results

Table 1 shows delivered power on propeller for the four aft ship configurations. Both model test and CFD results are presented. The results are normalized to the model test results for the single screw configuration.

Table 1: Delivered power for the analysed vessels. The results are normalized with delivered power derived from model test for the single screw hull.

	P_D [-]	
	Model test	**CFD**
Single Screw	1.0	0.964
Twin Azipull	0.969	0.997
Twin Skeg	1.012	0.954
CRP	[-]	1.0

Task 11.7: Operational performance

Partners Involved: STENA, LLOR, WMC, RRAB

Objectives for the period

The objective for this period was to complete task 11.7. The deliverables objective includes D11.9.

Significant Results

Classification Aspects: In conclusion, the HAZID exercise identified the following critical risk items with appropriate recommendations to mitigate them and the necessity to establish 'appropriate procedures for maintenance and its implementation through adequate training of personnel'.

B) LAP-Conventional Shaft, LAP-single POD and Behind Hull (BH) BH-Twin Skeg, BH-Twin Azipull:

- Structural integration of Steering Gear compartment, Rudder into the Stern
- Damage to propeller by external impact or grounding on the propeller
- Propeller Boss, potential vibrations, potential fatigue
- Failure of the Gear Box
- Human Error. Crew not trained to operate the propulsion system in all sea conditions.
- Main engine not able to produce enough torque at low propeller rpms to manoeuvre in adverse sea conditions
- Steering Gear compartment cannot support weight of the propeller and the rudder in dock

C) LAP-Single POD, BH-CRP variants:

- Damage to pod slewing gear teeth
- Damage to Propellers
- Slewing bearing failure
- Control systems failure
- Bad maintenance and Human Error

A) IKH concept: It is generally observed that the Inclined Keel Hull (IKH) concept is not really different to that of a conventional propulsion system other than the loading condition with significant trim by stern in deep sea condition. The main observation made is that, this concept would need to bring the ship back to level trim in shallow water or port operation, which is done though management of ballast tanks. This necessitates the maintenance of redundancy in pumps, their operation and requires correct maintenance to be conducted in order to avoid pump or system failure or the blockage of pipes or ballast water tanks. Else, it may lead to restricted choice of ports or operations.

Operational Analysis: A review of the operational and cost benefit analysis pertaining to the different variants pertaining to both the LAP and IKH concepts was undertaken in terms of their construction, maintenance, normal operation (docking, berthing, manoeuvrability, safe return to port etc.) and benchmarked against the same vessel with conventional twin screw propulsion system with a fixed or controllable pitch propeller. It is concluded that:

(i) LAP propeller concepts: A very realistic alternative for many ship types where the LOA is not restricted and where the propeller and rudder extending below the base line can be accepted. If operating completely submerged is critical for the higher efficiency, the wave profile must be investigated for a number of off-design conditions (incl. lower speed, varying wave angle and ship motions); alternatively, the machinery and shafting must tolerate RPM-fluctuations.

(ii) The beauty of Inclined Keel Hull (IKH) concept is the lack of additional and complicated systems; it is simple and robust both in construction and operation.

Cost-Benefit Analysis

(i) LAP system concepts, namely LAP-Conventional Shaft and LAP-single POD, are performing economically better compared to the conventional single screw propulsion system.

(ii) IKH concept is performing economically better compared to conventional single screw propulsion system considered.

1.2. WP12: Biomechanical Systems

Changes to the Description of Work

Within the original description of work, the operational testing of a full scale version of the Walvisstaart Pod was envisaged. The previous work completed in the detailed design was planned to be fed into the manufacturing process for the construction of the Pod and a suitable vessel, this would have been conducted outside the project and would have been funded by Walvisstaart. After the project completion, this vessel would have then been used by Walvisstaart to demonstrate the viability of their design and operational performance of the system. However, as a result of the financial crisis, Walvisstaart were unable to raise the necessary funding and the work was therefore not completed.
The structure of the work package was therefore changed to focus on the following aspects:

- Detailed design of the WSP in model scale;
    - Hydrodynamic aspects,
    - The blade motion patterns,
- Model scale WSP vessel design;
- Model scale construction, testing and evaluation.
- CFD computations to find operational performance and to validate the results.

Model scale design and testing

As the WSP is a complex system, MARIN first did a feasibility study to investigate if such complex system could be developed within the available time and budget. MARIN has completed work on the early design of the model test set-up. Within this design stage the following areas have been researched:

- How to measure the forces and dynamic loads applied to the blades;
- Electric mechanical drive and Direct electric drive;
- Scaling;
- Tolerance of the gears;
- Loading;
- Accuracy required.

There were uncertainties in the complex rotation of the blades, control systems, system tolerances, rotating reference disk, as well the level required for measurement accuracies. These uncertainties posed serious risks for the viability of the study which could have been solved if more time was available in the STREAMLINE project. As a result, the model scale design and testing by MARIN was discontinued.

CFD computations of operational performance

The aim was to apply the potential of enhanced CFD-based modelling developed within STREAMLINE to the WSP concept in full scale conditions.
Three progressive subtasks were therefore devised:

- Feasibility studies from 2D simplified model

This step was mandatory to precisely evaluate the risk in terms of possible CFD limitations. The dynamics of the WSP were precisely defined concerning the laws of motion in time of the rotating and oscillating bodies.

1.3. WP13: Distributed thrust

Task 13.5 – Evaluation and determination of achieved benefits

Objectives for the period
The achieved savings with regards to resistance and thrust were very well in line with the expectations. At the end of P2 however the exploitation of the achieved resistance- and thrust reduction in term of saved fuel was disappointing.
Therefore, an additional objective was defined for this period, i.e. the optimisation of the used rudder propellers, as their performance was found to be the likely cause of the disappointing fuel savings.

Work Progress for the period
By means of CFD calculation and intense cooperation with the industry partner in the team, ZF (formerly HRP) the performance of the rudder propellers was significantly improved simultaneously considering all practical and constructive constraints

Significant results
Power savings: 24.8% - 25.99%
Fuel Savings: 7%
POW performance increase: 21.5%

Task 13.6 – Operational Performance

Objectives for the period

In view of the poor fuel saving feature of the concept, the exploitation of the good resistance and thrust reduction of the concept (see task 13.5) should be further improved first, before using the sub-optimal figures of 7-8% fuel saving for an operational performance analysis.

Significant Results
Overall 25% performance improvement compared to bench mark test case.

2. WP2: Optimisation of State-of-the-Art Propulsion

WP2 comprises of WP21, WP22 and WP23

2.4. WP21: Advanced Screw Propeller Systems

Task 21.1: Experimental assessment and evaluation of advanced solutions

Objectives for the period

Aim of the Task 21.1 is to define a common baseline for design and optimization studies to be carried out in WP21 to optimize conventional screw propulsion systems.

Objectives for the present reporting period was the in-depth analysis of hull wake flow features of the STREAMLINE WP21 Tanker through results of Laser-Doppler Velocimetry (LDV) data from model tests (CNR-INSEAN).

Work progress for the period

Characterisation by model tests the hydrodynamic performance of the STREAMLINE WP21 Tanker taken as reference for state-of-art screw propulsion optimization studies.

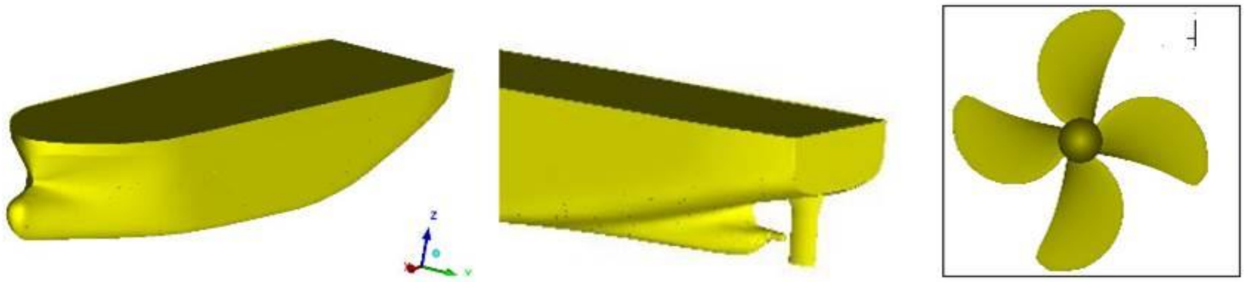


Figure 2: CAD model details of the STREAMLINE WP21 Tanker, a 7000 DWT single-screw vessel chosen as reference for state-of-art screw propulsion optimization studies in WP21.

Significant results

Laser-Doppler Velocimetry (LDV) measurements of the STREAMLINE WP21 Tanker hull wake flow were performed at the large Circulating water Channel of CNR-INSEAN. Results of model tests confirmed the existence of non-symmetric flow components in the propeller plane. Fluctuations are due to local separation of the boundary layer in the hull aftbody.

LDV data allowed a detailed statistical analysis to be performed which provides a better investigation of the spatial and temporal non-uniformity of the flow incoming to the propeller plane. In-depth information was provided by considering high order statistical moment of the axial velocity; in particular the 3rd statistical moment represented by the skewness coefficient. The skewness coefficient analysis proved also that in the regions where its value is far from zero and

the velocity intensity probability function is strongly asymmetric, a significant difference between velocity intensity mean value and most probable value occurs.
LDV data processing revealed regions over the propeller plane where such a distortion of the velocity distribution occurs.

Task 21.2: Shape optimisation – conventional propellers

Partners Involved: MARIN, CNR-INSEAN, HSVA, CNRS, FOI

Objectives for the period

The following case studies have been addressed in Task 21.2:

Table 2: Test cases for Task 21.2

Code	Description	Partner & Deliverable
P1	Optimised propeller for original hull H0, 5 blades	MARIN, D21.4 (design)
P4	Optimised propeller for original hull H0, 4 blades	CNR-INSEAN, D21.4 (design)
H1	Optimised hullform to fit original propeller P0	MARIN, D21.4 (design)
H2, P2	Optimised hullform H2 and propeller P2, 4 blades with increased diameter	MARIN, D21.4 (H2 design) MARIN, D21.6 (P2 design & CFD assessment) FOI, D21.9 ((CFD assess.)
H3	Optimised hullform to fit original propeller P0	HSVA, D21.4 (design)

Work progress for the period

MARIN
Viscous CFD analysis for an optimized tanker design in self-propulsion. The MARIN in-house CFD solver ReFRESCO was used and the simulations were done taking both the hull and propeller geometry into account. To combine the rotating grid around the propeller with the grid around the hull, sliding interfaces, were used.

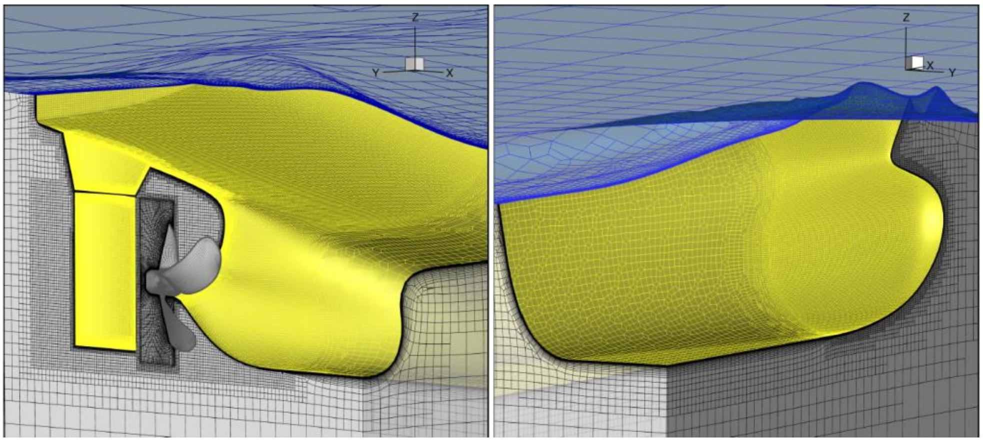


Figure 3: Overview of grid for optimized tanker with a structured grid around the propeller and an unstructured grid around the hull

HSVA
During the reporting period, the work of HSVA has been focused on the further hull optimisation of the STREAMLINE WP21 reference ship by developing an asymmetric aft-body design.
The work combined the methods developed and improved in the Work Packages 32 (RANS-BEM method) and 35 (Direct Modification Freeform Deformation (DMFFD) method) with an adjoint solver.

FOI
Two main configurations were investigated with LES in this task. The first is the baseline case which was also investigated in a towing tank. We denote this configuration H0+P0, which is standard notation in the project, where H0 indicates the baseline hull and P0 the baseline propeller. The second configuration is an optimized hull-propeller configuration, denoted H2+P2, which was produced by MARIN. In the simulations, a complete geometrical model of the propeller was included using a dynamic mesh method. The configuration H0+P0 was simulated in model scale to emulate the conditions in the model tests. The configuration H2+P2 was simulated in full scale as required by the project description of work

In addition to the assessment of configuration H2+P2 described above, FOI also within task T21.2 contributed to Deliverable D21.6. The contribution consisted of a complementary analysis of the LES-results for H2+P2 with results obtained for the same configuration by the other partners contributing to this deliverable.

Significant results

MARIN
The experimental results for propulsion show a reduction of delivered power of about 8% for the optimized tanker with respect to the reference design. In here the required thrust increases for the optimized design and the largest contribution of power reduction follows from a reduction in required torque. In the numerical results a smaller reduction in power of about 1-3% is obtained for different CFD solvers.

An evaluation of the pressure fluctuations on selected locations of the aft ship showed a good agreement with experimental results for the reference tanker with respect to the first blade harmonic. In general, slightly lower amplitudes were obtained compared to the measurement values. A comparison of pressure fluctuations on the same location between the two tanker designs shows a significant decrease of the highest pressure peak for the optimized tanker.

HSVA
The aim of the optimisation exercise was to maximize the wake objective function, which was set up for an even distribution of the axial velocity component while directing the tangential velocity in the opposite direction of the propeller rotation. A distinct asymmetric distribution of the sensitivity can be observed. The propulsion efficiency of the tanker was increased by 5%. However, this gain was accompanied by an increased resistance, mainly due to the rudder.

FOI
The optimized hull-propeller configuration (H2+P2) has been evaluated and assessed using LES in full-scale operating conditions. Detailed results concerning the following quantities have been obtained in the simulations:

1. The time-resolved flow around the propeller.
2. Time-resolved forces and moments on the propeller and its individual blades.
3. Pressure fluctuations (non-cavitating case). Mean and RMS-fluctuations in the whole domain, and complete time history of the pressure in a number of probes placed next to the hull above the propeller.
4. Flow-generated noise registered in a number of hydrophones placed in the water volume.

Task 21.3: Unconventional propeller design

Partners Involved: CNR-INSEAN, CNRS, FOI, MARIN

Objectives for the period

The following case studies have been addressed:

Table 3: Case studies for Task 21.3

Code	Description	Partner & Deliverable
P3	Optimised propeller with tip-raked blades	CNR-INSEAN, D21.5 (design) CNRS, FOI, CNR-INSEAN, MARIN, D21.7 (CFD assessment) FOI, D21.10 (CFD assessment)
P5	Ducted propeller with optimised duct geometry	MARIN, D21.5 (design)

Work progress for the period

Two design exercises were proposed by CNR-INSEAN and MARIN:

1. A tip-raked propeller designed through the innovative optimization technique known as Conformal Free-Form Deformation (CFFD) and developed in WP35 (CNR-INSEAN, design code P3)
2. A ducted propeller design based on duct shape optimization integrated with viscous-flow modelling by RANSE (MARIN, design code P5)

CNRS

Main contribution of CNRS was devoted to the CFD assessment of both original (H0-P0) and optimized (H0-P3) geometries in off-design conditions.

- Assessment of the codes to simulate the hull-rudder-propeller configuration based on the baseline design (H0-P0) has been achieved for RANS, LES, and hybrid RANS/BEM approaches in model scale as well as in full scale and off-design for RANS and RANS/BEM,
- Design and off-design conditions including free-surface effects have been investigated for the optimised geometries, in model scale and in full scale for RANS and RANS/BEM. For the latter, it is underlined that the results of experiments about the optimized geometries were not available at the time of reporting so that the computational results in model scale have been conducted in blind conditions.

FOI

Two main configurations were investigated with LES in this task:

- The first is the baseline case which was also investigated in a towing tank. We denote this configuration H0+P0, which is standard notation in the project, where H0 indicates the baseline hull and P0 the baseline propeller.
- The second configuration is an optimized hull-propeller configuration, denoted H0+P3, which was produced by INSEAN. In the assessment, FOI also compared with results obtained for configuration H2+P2 obtained in task T21.2.

Significant results

CNR-INSEAN

Results of the study by CNR-INSEAN showed practical performance improvement limits that can be achieved via advanced shape optimization. Expected performance improvements predicted from computational models used in the design procedure (solver PRO-INS, see WP34) indicated a 2% open water efficiency improvement close to design point with a peak of 2.6%. In behind hull conditions, a slightly lower propeller efficiency improvement not less than 1% was predicted.

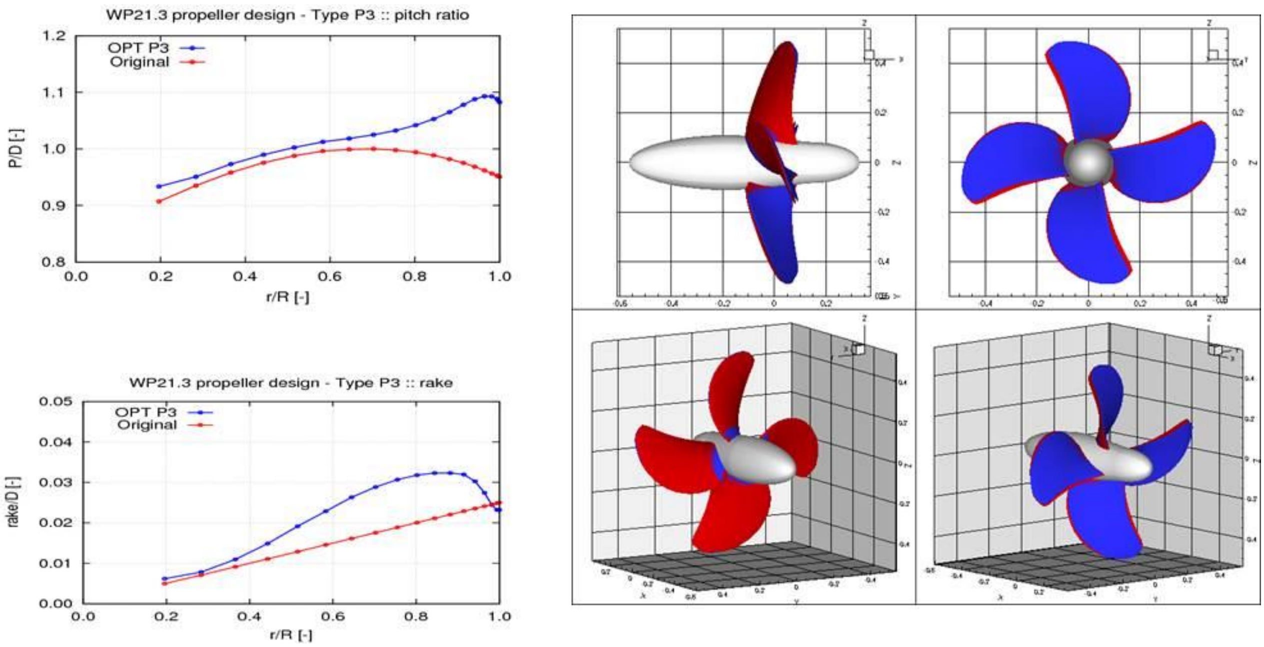


Figure 4: Retrofit propeller P3 for the STREAMLINE WP21 tanker obtained by Conformal Free-Form Deformation optimization modelling by CNR-INSEAN

MARIN

Results of the ducted propeller design by MARIN demonstrate that a combined improvement of both object functions can be obtained: compared to the duct 19A, both object functions are improved by more than 80%.

CNRS

The following table summarises the computed self-propulsion parameters performed by CNRS (full RANSE and RANS/BEM coupling with CNR-INSEAN BEM model) in full scale for the optimized geometries in off-design conditions.

Table 4: Summary of computational results by full-RANSE and hybrid RANSE/BEM model (CNRS, INSEAN).

	H0-P0		H0-P3		H2-P2	
	RANS	RANS/BEM	RANS	RANS/BEM	RANS	RANS/BEM
R_{TS} (kN)	146.5	146.5	146.5	146.5	150.8	150.8
Thrust T_S (kN)	187.8	178.2	177.3	178.0	182.9	179.0
Torque Q_S (kN.m)	128.1	118.0	124.9	117.0	133.0	111.9
N_S (rpm)	120.6	119.2	116.7	115.6	123.6	122.8
P_{ES} (kW)	1055	1055	1055	1055	1086	1086
P_{DS} (kW)	1618	1473	1526	1417	1721	1439
η_{DS}	0.652	0.716	0.691	0.745	0.631	0.755

FOI

The optimized hull-propeller configuration (H0+P3) has been evaluated and assessed using LES in full-scale operating conditions. In the investigation we focused on mechanisms related to flow-induced noise and vibrations. The optimized configuration compares favourably with the baseline. The main cause of this is however the decreased extent of the flow separation region upstream of the propeller. For a detailed analysis and comparison of these two configurations, as well as configuration H2+P2, see D21.10.

Detailed results concerning the following quantities have been obtained in the simulations, and are documented in the report D21.10.

- The time-resolved flow around the propeller.
- Time-resolved forces and moments on the propeller and its individual blades.
- Pressure fluctuations (non-cavitating case). Mean and RMS-fluctuations in the whole domain, and complete time history of the pressure in a number of probes placed next to the hull above the propeller.
- Flow-generated noise registered in a number of hydrophones placed in the water volume.

Task 21.4: Enhanced propeller rudder configurations

Objectives for the period

The following enhanced propeller/rudder layouts have been addressed in Task 21.4:

Table 5 : layouts have been addressed in Task 21.4

Code	Description	Partner & Deliverable
TR-LE	Twisted rudder, sections rotated about leading edge	Chalmers, D21.2 (design) CNR-INSEAN, D21.8 (CFD assess.)
TR-LE	Twisted rudder, sections cambered at trailing edge	Chalmers, D21.2 (design)
R1	Optimised axial position of rudder and propeller	HSVA, D21.2 (design)

Work progress for the period

Aim of the study was to analyse the hydrodynamic performance of the new rudders in operating conditions different from those addressed at design stage and to compare with the performance of the original untwisted rudder. CFD simulations considered conditions representative of an incipient turning manoeuver, with the STREAMLINE WP21 Tanker travelling in straight ahead motion at low speed (10 knots at full scale) and rudder at constant helm angles between -20 and +20 degrees.
This computational study has been performed by using the CFD model based on the hybrid viscous/inviscid RANSE/BEM solver developed by CNR-INSEAN in WP34 and obtained by coupling in-house solvers Chi-Navis (RANSE) and PRO-INS (BEM).

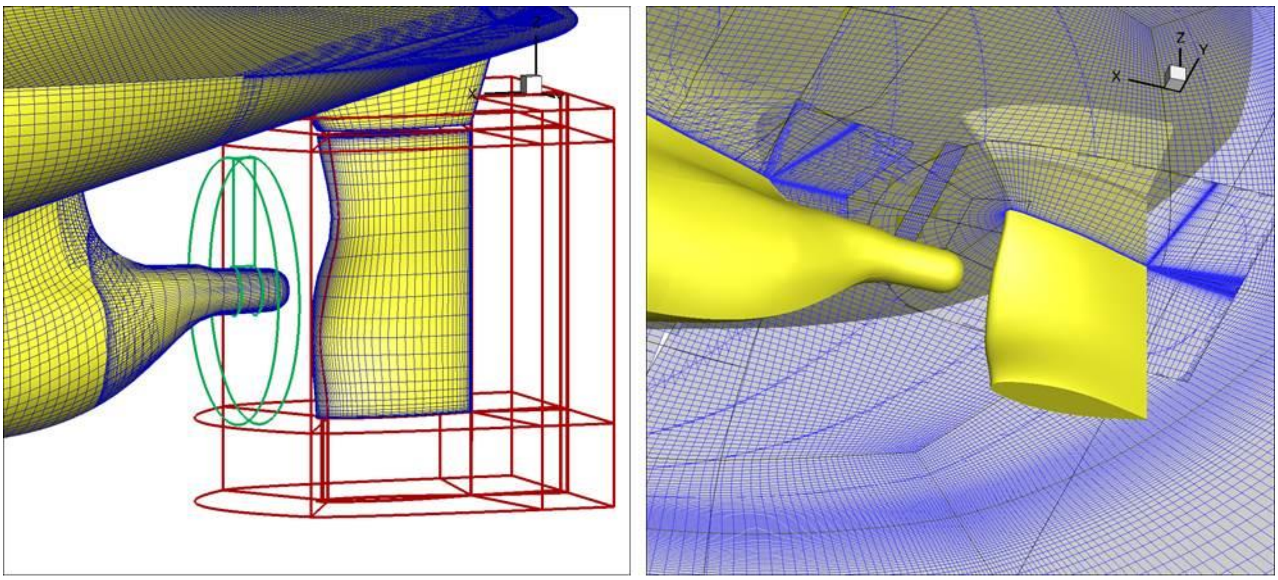


Figure 5: Details of the computational grid around STREAMLINE WP21 Tanker retrofitted with a twisted rudder. Grid blocking (left) and discretization cells (right) for RANSE solver Chi-Navis adopting a Chimera-type overlapping grid technique.

Significant results

For the comparative analysis between twisted and original untwisted rudders, the twisted rudder solution labelled as Leading-Edge twisted Rudder (TR-LE) was considered. This solution is characterised by chord wise sections twisted about rudder trailing edge (kept unchanged with respect to the original untwisted layout). Sections are also cambered with respect to the original symmetrical thickness distribution. Numerical predictions by Chalmers at design stage (design speed of 14 knots and zero helm angle) showed reduced negative pressure peaks as an effect of section twist with expected improvements of the cavitation bucket.
Computational studies carried out by CNR-INSEAN demonstrated that such twisted rudder design (TR-LE) is robust in that improved hydrodynamic performance is preserved over a relatively wide range of helm angles. Compared to the untwisted geometry, the twisted rudder at manoeuvring speed 40% lower than cruise and helm angle from 0 to 10 degrees (positive and negative) generally presents a smoother pressure distribution and lower pressure peaks in the leading edge region. Moreover, numerical results show that twisted rudder loads (axial, side force and moment) are fully comparable to those of the original untwisted rudder and hence the risk of reducing manoeuvring capabilities by introducing the new rudder design is not identified. The twisted design determines a very small increase of ship drag which should not penalise power requirements.

However, advantages in terms of pressure distribution over the twisted rudder surface tend to disappear as the helm angle is increased from 10 to 20 degrees (positive and negative) with the occurrence of stronger negative pressure peaks than on the original untwisted rudder. Results of the computational study showed that at low helm angles, the effective angle of attack of the flow incoming to rudder sections is mostly determined by propeller-induced swirl and hence twisted sections operate at low effective angle of attack. Nevertheless, the twisted rudder design exercise addressed here confirms that dedicated optimization of section twist distributions taking into account propeller induction over a target range of operating conditions can determine a consistent mitigation of the risk of rudder cavitation. The computational exercise comparing twisted and untwisted rudders showed also the capability of hybrid RANSE/BEM modelling as a valid support for design studies.

Task 21.5: Propeller-inflow improving devices

Partners Involved: CHALMERS, CNRS, TUHH, HSVA

Objectives for the period

The Task aimed at developing devices to alternate the inflow to the propeller plane of the original STREAMLINE tanker. The following layouts have been addressed in Task 21.5:

Code	Description	Partner & Deliverable
PSS	Pre-Swirl Stators	Chalmers, D21.3 (design)
VG2, VG6	Vortex Generators, two layouts	TUHH, D21.3 (design)
BLAD	Boundary layer Alignment Duct	HSVA, D21.3 (design)

Work progress for the period

Simulations have been performed on the baseline configuration and the retrofit configuration with Pre-Swirl Stators (PSS). LES results in both wetted and cavitating conditions with a fully resolved as part of the summary on the research on cavitation erosion. The unsteady propeller blade load was analysed, with reference to the unsteady ship wake, as well as the cavitation pattern and differences between the two configurations were commented on.

Significant results

The simulations have shown that this advanced CFD analysis, using LES for the cavitating flow on a rotating propeller in behind condition, is now mature enough to be applied and give useful design input.

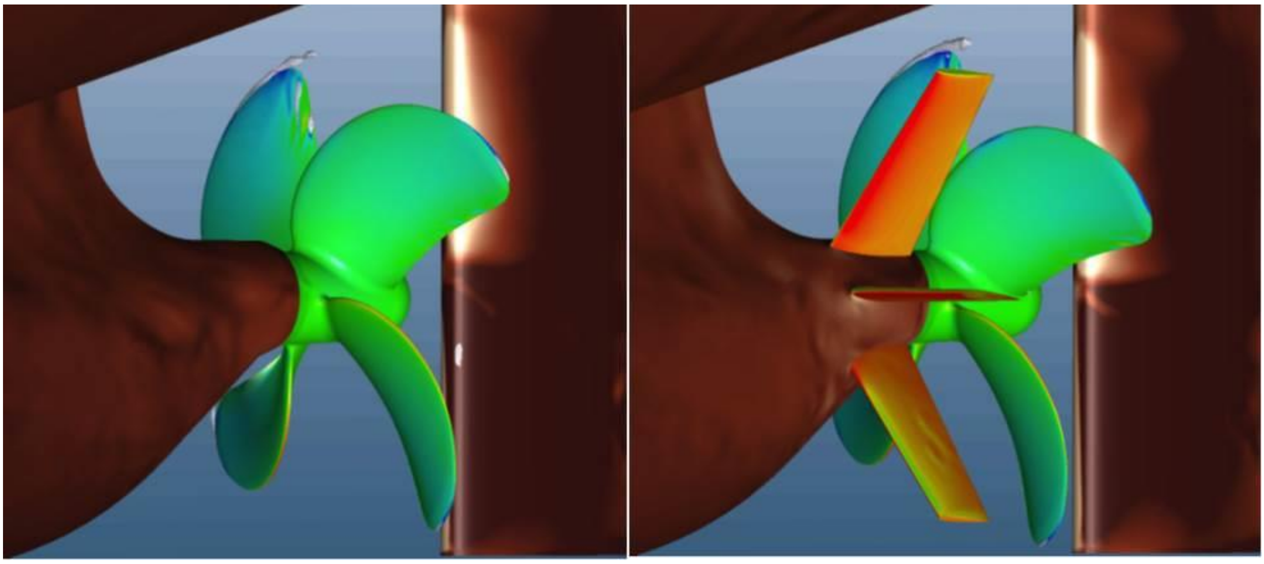


Figure 6: Example of simulated cavitation behaviour and achievable resolution in the baseline configuration (left) and in the retrofitted layout adopting Pre-Swirl Stators (PSS, right).

Task 21.6: Experimental assessment and evaluation of advanced solutions

Partners Involved: CNR-INSEAN, CTO

Objectives for the period

The activity under Task 21.6 during the third reporting period has been characterised by three sequential phases corresponding to three objectives:

- Review results of design and optimization studies performed in Tasks 21.2 to 21.5 and select a number of cases worth to be further analysed through model test;
- verify selected design and optimization studies through a full model test matrix;
- evaluate the effectiveness of the different optimised configurations (as input for operational assessment in Task 21.7) and compare performance improvements predicted by CFD models with results of model test verifications.
- Results of these activities have been documented in Deliverable D21.11 (evaluation of selected design cases and model test data) and in Deliverable D21.14, where the comparative analysis of optimised configurations and the assessment of CFD predictions versus experimental data is presented. The outcome of this Task has been used as input for operational assessment analysis carried out in Task 2.17, see below.

Work progress for the period

The new/optimised configurations were reviewed and a selection was made on the basis of expected performance improvements predicted by CFD models used at design stage. Configurations providing no improvements were discarded whereas those showing potential gains were selected for the successive phase.

Table 6: List of main design and optimization studies documented in WP21

Code	Author, Deliverable	Description
		Propeller
P1	MARIN, report D21.4	Optimised propeller, 5 blades
P2	MARIN, report D21.4, D21.6	Optimised propeller, 4 blades, diameter increased with respect to original
P3	INSEAN, report D21.5	Optimised propeller, 4 blades, tip-raked
		Rudder
TR-LE	Chalmers, report D21.2	Twsted rudder, leading-edge twist
TR-TE	Chalmers, report D21.2	Twsted rudder, trailing-edge twist
		Hullform
H1	MARIN, report D21.4	Hull aftbody optimization combined with original propeller and rudder.
H2	MARIN, report D21.4	Hull aftbody optimization combined with optimised propeller P2 and original rudder.
H3	HSVA, report D21.4	Hull aftbody optimization with original propeller and rudder. Machinery box constraint violated
		Inflow Improving Devices
PSS	Chalmers, report D21.3	Pre-swirl stator: 3 fins on port-side mounted on the gondola upstream the propeller.
VG2, 6	TUHH, report D21.3	Vortex generators, two layouts.
BLAD	HSVA, report D21.3	Boundary layer alignment duct.

Optimised layouts including 2 propellers, 1 new hull aftbody, 2 twisted rudders and 4 alternative inflow improving devices were manufactured at model scale by CTO (all cases) and by CNR-INSEAN (vortex generators only) from CAD models provided by partners responsible for the design.

The new components above have been combined into a number of optimised versions of the original STREAMLINE WP21 Tanker. Recalling codes H0, P0, R0 defining respectively, initial hullform, propeller and rudder, the alternative optimised layouts and the type of model tests performed for each layout are summarised in a Table. It should be noted that all the optimised layouts can be considered as retrofit studies with the exception of the layout combining optimised hull H2 and propeller P2 which represents a totally new design alternative to the original layout.

Code / Task	**Description**	**Model tests**
H0+P0+R0 Task 21.1	Original STREAMLINE WP21 tanker	Resistance and propulsion tests from Task 21.1 repeated (CTO) Cavitation and pressure pulses (INSEAN) Velocimetry by Stereo-PIV (INSEAN)
H2+P2+R0 Task 21.2	Optimised hullform H2 and propeller P2	Resistance and propulsion tests (CTO) Propeller open water tests (CTO)
H0+P3+R0 Task 21.3	Retrofit with optimised propeller P3	Propeller open water tests (CTO) Propulsion tests (CTO, INSEAN) Cavitation and pressure pulses (INSEAN)
H0+P0+TR-LE/TE Task 21.5	Retrofit with twisted rudders	Resistance and propulsion tests (CTO) Velocimetry by Pitot (CTO)
H0+P0+R0+PSS Task 21.2	Retrofit with Pre-Swirl Stator	Resistance and propulsion tests (CTO) Velocimetry by Pitot (CTO)
H0+P0+R0+VG-1/2 Task 21.2	Retrofit with Vortex generators	Resistance and propulsion tests (CTO) Velocimetry by Pitot (CTO) Velocimetry by Stereo-PIV (INSEAN) Cavitation and pressure pulses (INSEAN)
H0+P0+R0+BLAD Task 21.2	Retrofit with B-L alignment duct	Resistance and propulsion tests (CTO) Velocimetry by Pitot (CTO)

Table 7: Optimised versions of the STREAMLINE WP21 Tanker and model tests carried out in Task 21.6.

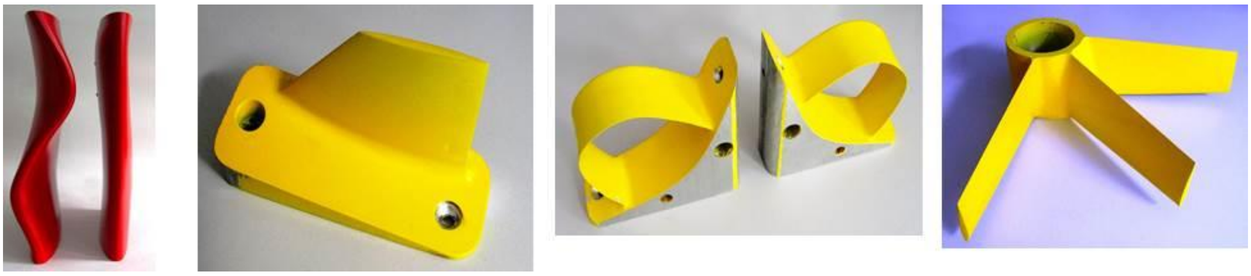


Figure 7: Some of the models manufactured for model tests of the retrofitted STREAMLINE WP21 Tanker. From left to right: twisted rudders, inflow devices VG2, BLAD, PSS.

Significant results

Results of model tests on the optimised layouts compared to the original ship design provided a unique dataset for the qualification of design solutions as a means to improve the propulsive efficiency of an existing ship either via retrofits or via a completely new design.

Results of model tests and extrapolation to full scale provided a clear picture of the range of hydrodynamic performance improvements that is possible to achieve through advanced CFD-based design and optimisation. Main findings are that the totally new hull aftbody design (H2) has delivered improvements of hydrodynamic performance of about 8-9% of delivered power over a range of ship speed. A small part of this improvement is due to a 2% reduced hull resistance, whereas modified hull lines that allow to fit a 6% larger diameter propeller P2 is identified as the main source of reduced power requirements to achieve propulsion conditions.

If a new hull aftbody represents a major deviation from the original design and large performance variations can be expected, efficiency gains can also be obtained with a limited cost through retrofitting devices. This is the case of replacing the original screw with a new propeller from a shape optimization study preserving main geometry and operating conditions of the original screw. The case addressed in WP21 presents propeller P3 with an increased open water maximum efficiency of more than 3% achieved through the optimization of the blade shape (chord, pitch and rake) and same diameter of the original screw. In this case, the improvement of efficiency at advance ratio corresponding to propulsion conditions behind hull is modest (below 1%) and the resulting variation of delivered power is marginal.
Improvements of delivered power in the order of 1-3% are obtained by retrofitting the original layout with twisted rudders, whereas a lower 1% reduction of power is established by adopting the proposed pre-swirl stators design.

Other inflow devices determine higher power demands at design speed between 1-4%. Nevertheless the capability of these devices to modify the inflow to the propeller is demonstrated from results of velocimetry measurements. The combined design of inflow device and propeller can make possible to achieve sensible improvements of the quality of the inflow to the propeller with corresponding lower pressure pulses and vibratory loads transmitted to the shaftline.

Task 21.7: Operational performance

Partners Involved: STENA, LLOR, WMC, CNR-INSEAN, RRAB

Objectives for the period

Examine and assess operational aspects for advanced screw propulsion systems developed throughout WP21 in order to ensure a rapid and efficient deployment of the developed technologies. The activity includes the following aspects:

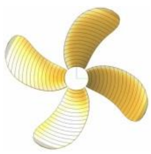
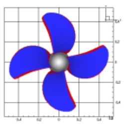
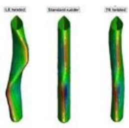
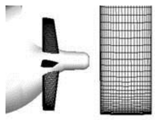
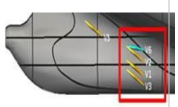
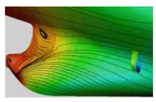
- Classification
- Operational performance analysis
- Cost Benefit analysis to ensure the benefits to the operational users.

Work progress for the period

The most part of the activity addressing operational aspects were accomplished during the third reporting period, following the completion of model tests assessing the performance of the optimised configurations designed in WP21.
The following activities have been accomplished:

- Assessment of Classification aspects through a series of meetings within LR and discussions among the operational aspects team (LLOR, WMC and STENA), WP design team lead by INSEAN, in continuation with the workshops held on 10th Aug 2011, 14th Sept 2011.
- Operational Analysis starting with a workshop among the operators on 15 August 2013, and subsequent discussions among the Operators to finalize the ship owner's, i.e. end-users perspective on operational and practical aspects.
- Cost Benefit Analysis among the Operation aspects team WP21 leader INSEAN and Rolls-Royce

Significant results

WP21: Advanced Screw Propeller systems Reference Ship case: Hull (H0)+Propeller (P0)+Rudder (R0)						
	Propellers		**Twisted Rudder**	**Inflow improving devices**		
	P2	**P3**	**R1**	Pre Swirl Stator (**PSS**)	Vortex Generator (**VG**)	Boundary Layer Aligning Device(**BLAD**)
						
Modified Ship Cases	(**H2**+**P2**+R0)	(H0+**P3**+R0)	(H0+P0+**R1**)	(H0+P0+R0+**PSS**)	(H0+P0+R0+**VG**)	(H0+P0+R0+**BLAD**)

The following conclusions were obtained.
<u>Classification aspects</u>

1. It is assessed that the designs for the propellers P2 and P3 meet the classification requirements for propeller blade scantlings based on available design data. Further verification will need to be conducted as the design matures to ensure the fillet radius at the root of the blade conforms to the Classification requirements. The fitting between the propellers and propulsion shaft and the manufacturing process would also need to be assessed prior to acceptance for installation on board a classed vessel.
2. The twisted rudder design would be considered under special consideration as it is a nonstandard profile which falls outside the scope of the Rules and IACS S10. However other than that it would be appraised in the same way as a standard rudder using lateral force calculations to work out the rudder moment and rudderstock dimensions.
3. The inflow improving devices are not considered essential equipment within the scope of Classification. However the connection to the ships structure would need to be assessed to ensure that damage to the device would not damage the hull structure of the vessel.
4. From the above it can be concluded that whilst some of the concepts presented vary from the standard currently used they still fall within relevant chapters in the Classification rules and thus would be able to be appraised for installation on board a classed vessel should detailed design be envisaged. The passive nature of the systems also seem to suggest that no change to current maintenance, survey and docking cycles will be required should the proposed Advanced Screw Propeller system be proposed for a Classed vessel.

<u>Operational analysis</u>

The operational analysis review indicates that the simplicity of the modifications to improve hydrodynamic performance of the reference vessel would mean that very little change would occur to the vessel. This in turn makes all the different ‘Advanced Screw Propeller systems’ concepts practically feasible options due to their inherent passive functioning for both new building or retrofitting purposes.

<u>Cost-benefit analysis</u>

Cost benefit analysis indicates that among the different ‘Advanced Screw Propeller System’ concepts, the P2 Propeller option combined with hull modification (H2) is more economically viable, but can only be applied to new builds. Out of the remaining concepts, which are all indeed retro-fit options, twisted rudder R1 is more economically viable.

2.5. WP22: High – Efficiency Water-Jet at low speed

Task 22.2: Numerical methods development / System analysis

Partners Involved: RRAB, SSPA

Objectives for the period

Carry out numerical simulations of the self-propulsion test setup and compare the results with the experimental results

Work progress for the period

During the report period, SSPA have been performing numerical simulations using RANS-VOF for calculating the bare hull resistance at a number of vessel speeds as well as self-propulsion calculations of the new inlet design in both auxiliary channel open and auxiliary channel closed conditions.
For the bare hull resistance calculations, the resistance coefficient was calculated along with the wave pattern.
In the self-propulsion tests, the flow rate through the water jet pump was calculated along with the delivered power.

Significant results

The outcome of the numerical simulations is that they are in good agreement with the model test results. At the low speed the calculations under predict the resistance with approximately 7%,but at higher speed the deviation is smaller and about 2 to 4% which is in the acceptable range. The deviation at 10 knots is likely to be related some deviations seen in the wave patterns. The deviation at 12.5 knots is thought to be related to the transom clearance not being correctly predicted as the model tests showed that the transom is dry at 12.5 knots but as can be seen in the result from the numerical simulations shows the transom to still be partly wetted.

Table 8: Predicted resistance and difference from measured model scale data

Vs [kn]	Vm [m]	F_{nLpp} [-]	R_{tm} [N]	ΔRtm [%]	$1000xC_{Tm}$ [-]	ΔC_{Tm} [%]
10	1.878	0.398	32.506	-6.9	13.802	-7.0
12.5	2.348	0.498	74.263	-3.7	20.288	-3.7
30	5.635	1.195	137.096	2.0	8.674	1.9

For the propulsion cases, the maximum difference between the computed and measured flow rate is approximately 3.8%, whereas the maximum difference between the predicted and the measured delivered power is 17%.The calculations suffer from slow convergence and the results presented are not considered to be fully converged yet. In addition, the grid quality and grid resolution issues are two likely reasons leading to the modelling errors. The main features like wave pattern and the shift of critical speed for transom clearance are in consistence with the experiment observation. It is however not possible to explain the performance difference between the case with the bypass opened and the bypass closed due to different extent of errors for the two cases. More study of the influence of discretization scheme for the VOF equation and grid sensitivity are needed.

Task 22.5: Vessel propulsion test in towing tank

Partners Involved: SSPA

Objectives for the period

Carry out self-propulsion tests of a vessel with both a baseline inlet and the newly developed inlet. Provide experimental and validation data for numerical calculations

Work progress for the period

Inlets of the baseline design as well as of the proposed new design were manufactured to fit into an existing ship hull.
With the ship hull, bare hull resistance measurements were made on the model hull before the self-propulsion tests with the different inlet designs. During the self-propulsion tests, the hull model was fitted with one inlet design at the time along with a stock waterjet pump from SSPA as well as necessary measuring equipment.

Significant results

In the resistance tests the measured signals were:

- Model speed, W_m
- Towing force, R_{Tm}
- Vertical trim change at station 20, ΔT_F
- Vertical trim at station 0, ΔT_A

In the self-propulsion tests, the following signals are measured besides the signals measured in the resistance tests:

- Shaft speed, n_m
- Shaft torque, Q_m
- Force from auxiliary channel jet, F_{jm} (for the cases where the force from the flow leaving the auxiliary channel was measured)

Task 22.6: System evaluation and reporting

Partners Involved: RRAB

Objectives for the period

- Summarizing report of the work carried out
- Estimation of fuel savings
- Investigate the scalability of the technology
- Technical assessment of full-scale marine applications and recommendations of further work

Work progress for the period

The results from the different tasks have been summarized.
The possibility of building the new inlet design has been evaluated for different sizes of inlets as well as evaluating the potential of fuel savings.
Also the possibility of improving the performance of the design has been evaluated and some area of potential improvements presented.

Significant results

In general there is a very good agreement between the different tasks. There are some deviation between the numerical and the experimental results but the differences are likely a results of convergence and model size and could in most cases be solved by increasing the number of cells or increasing the calculation time. There are some issues with correcly predicting the critical speed where the transom besomes dry and since a small deviation in prediction of the critical speed can generate a large deviation in predicted performance, this is locally affecting the the calculation results.
The results from the different model tests are in very good agreement and the only deviations seen are related to the bollard pull where the towing tank does not show any difference where the cavitation tank tests do. This is considered to be consequence of the towing tank tests being carried out at atmosphric conditions which limits the blockage effect of cavitation at a given operating point.
With the inlet being a low speed inlet intended to also work at high speed, the inlet is performing better than the baseline at low speed. The increased performance at low speed can be used to reduce the fuel consumption at low speed, or reducing the time at low speed, in maneouvring, and thus allow the top speed to be reduced, still maintaining the same time table which could potentially save more fuel. However, in order to save fuel by reducing the maximum speed, the efficiecny at high speed must not be significantly worse than the baseline. With the large differences in performance achived with the proposed design, the business case, built on reduced top speed, is not possible to generate and the investment cost will not pay back.

Task 22.7: Operational performance

Partners Involved: STENA, LLOR, WMC

Objectives for the period

Examine and assess the operational aspects for the following in order to ensure a rapid and efficient deployment of the developed technologies, namely ‘High Efficiency Water Jets’

- **Classification aspects** The High Efficiency Water Jets will be assessed for the classification and safety aspects.
- **Operational analysis** The High Efficiency Water Jets will be assessed based on its operational performance.
- **Cost Benefit analysis** The High Efficiency Water Jets will undergo a cost benefit analysis to ensure the benefits to the operational users.

Work progress for the period

- Assessment of Classification aspects through a series of meetings within LR and discussions among the operational aspects team (LLOR, WMC and STENA), WP design team lead by RRAB, in continuation with the earlier workshops held on 10th Aug 2011, 14th Sept 2011.
- Operational Analysis starting with a workshop among the operators on 15 August 2013, and subsequent discussions among the Operators to finalize the ship owner’s, i.e. end-users perspective on operational and practical aspects.
- Cost Benefit Analysis among the Operation aspects team and WP22 leader Rolls-Royce (RRAB)

Classification Aspects:

- As the incorporation of an 'Auxiliary Channel' to a water jet (STREAMLINE Design) is only at its concept design stage, a full numerical analysis to the rules was not feasible, but it is understood that mechanically the water jet is of a standard design commonly fitted to service craft and fast passenger ferries. Therefore the requirements of the class rules can be applied in their entirety.
- The use of the auxiliary channel does mean that the integration to the ships structure and closing device does need to be considered more carefully however should not pose a problem in terms of classification. Its effect on impeller loads needs to be assessed in terms of its fluctuation. If the same is above the rule requirement of 20% of maximum mean load, this needs further assessment.
- The strength of the hull structure in way of the tunnels is to be maintained and the structure is to be adequately reinforced and compensated as necessary.
- The use of shape memory alloys would need to be specially considered as they are not commonly in use within the marine industry. As the duct forms part of the ships structure then the material would need to be investigated in far more detail.

Operational Analysis indicates that:

- STREAMLINE design (new water jet concept) pertaining to incorporation of auxiliary channel into the water jets does introduce some risks (new design, new materials, moveable parts etc).
- Considering that the reference (BASELINE design) design offers better efficiency at high speeds compared to the new (STREAMLINE design) concept, owners will be reluctant to switch to the new water jet concept unless the risks can be mitigated or the inferior performance at high speeds can be rectified.

Cost- Benefit Analysis indicates that

Incorporation of 'auxiliary channel' into Waterjet at a very nominal cost does show gains in performance at low speeds, but reduced performance at high speeds and hence is not an economically viable option for ships with significant amount of annual operational time at high speeds.

2.6. WP23: Advanced Pods

Task 23.1: Contra-rotating podded propulsion

Partners Involved: RRAB, SSPA, CNR-INSEAN

Objectives for the period

For the third period three different tasks remained for the ICP and the CRP concepts.

- Finalise the analysis of CRP-Pod and ICP layouts by computational hydrodynamics models
- A pushing ICP was designed with the aim of higher efficiency and better cavitation performance. This work contained design of pod house and propellers and redesign of hull, manufacturing for model tests, open water tests and resistance and self-propulsion tests in SSPA's towing tank.
- The work with the CRP was performed to study the manoeuvrability properties of the CRP. It is relatively well known how a single pod acts, but there is very little knowledge how a pod acts behind a main propeller regarding steering forces. Therefore captive tests in SSPA's towing tank were performed to study this behaviour. Based on the tests computer simulations of performance in manoeuvre and sea keeping using the pod or two small rudders beside the pod for steering will be carried out.

Work progress for the period

CFD-analysis
During the third reporting period, CNR-INSEAN was in charge of finalising computational studies of the alternative CRP-Pod and ICP layouts started during previous periods.

The aim of the study was to characterize by CFD the hydrodynamic response of the two propulsors operating in behind hull conditions. Results of numerical simulations were then compared with results of model test data available from experimental work carried out in the same Task.

ICP

The present work has been divided into two parts;

- Design of pod and contra rotating propellers.
- Towing tank tests of the design including open water test, resistance and self-propulsion test.

CRP
The CRP-solutions has previously been tested both in towing tank and in cavitation tunnel and the results have been presented previously. The aim of the new tests was to examine the manoeuvring behaviour of the hull for different setups.

Significant results

CFD-analysis
A computational model based on a hybrid RANSE/BEM solver has been used to characterise the hydrodynamic behaviour of CRP-Pod and ICP propulsors. The study had two main objectives:

1. to demonstrate the capability of the proposed computational model to describe main hydrodynamics features of the two propulsors with particular regards to operation in behind hull conditions, and
2. to use results of this computational study to compare the hydrodynamic performance of the alternative CRP-Pod and ICP layouts.

Numerical predictions of CRP-Pod efficiency differ from measurements for less than 2%, whereas ICP efficiencies are under predicted of 8% ($h_{(A+F)}$) and 13% (unit efficiency).

ICP

The self-propulsion test for the improved ICP indicated a required shaft power is PDT= 10.0 MW at design speed VS=20kn. The predicted power is around 12% lower than the original twin-skeg hull.

CRP

Based on the captive model tests and the simulations carried out, the following conclusions can be drawn:

- The speed is significantly reduced when operating in severe weather conditions, especially when one of the propellers is stopped. In the most severe weather conditions, Bft 8 and 9, the speed may in these cases drop to 1-2 knots
- Both propellers provide, when run alone (the other being stopped) high lateral forces, even with for zero deflection of the pod unit. This lateral force may be up to 20% of the thrust produced.

Only pod deflected:

- When using only the pod it is possible to control the ship in all weather conditions tested when running both propellers. The conditions tested covers wind velocities up to 22.6 m/s mean wind and significant wave heights up to 5.6 m (the most severe conditions that may be expected in the Baltic)

Task 23.2: Cavitation and ventilation behaviour of podded propulsors in service conditions

Objectives for the period

Computational study in operational service conditions (free ship running in head or oblique waves) will be conducted to evaluate the instantaneous flow distribution around the pod and quantify the risk of ventilation.

Work progress for the period

Comprehensive series of tests performed within Deliverable D23.3 on a scaled model in depressurised wave basin of MARIN are used for assessment of CFD tool and to evaluate the scale effects.

Significant results

No ventilation was detected either in model scale or in full scale conditions. If it was detected on the model test in the wave basin it was very slight.

The scale effect on the thrust was found to be weak that can be explained that the propeller on the pod is further from the hull than a screw propeller, then less sensitive to variation in the boundary layer thickness on the hull.

The other conclusion is that the computed flow field (both in direction and in intensity) entering the propeller was considered as accurate: even through the flow field was not measured we can consider with confidence the predicted correlation between the dynamics of the axial thrust component and the dynamics of the velocity field in front of the propeller during a wave period.

Task 23.4: Operational performance

Partners Involved: Lloyd's Register (LLOR), Wilh.Wilhelmsen (WMC), Stena Rederi (STENA), SSPA, Rolls-Royce (RRAB)

Objectives for the period

Examine and assess the operational aspects for the following in order to ensure a rapid and efficient deployment of the developed technologies, namely 'Advanced POD Systems'.

- Classification aspects - The Advanced PODS will be assessed for the classification and safety aspects.
- Operational analysis - The Advanced PODS will be assessed based on its operational performance.
- Cost Benefit analysis - The Advanced PODS will undergo a cost benefit analysis to ensure the benefits to the operational users.

Work progress for the period

- Conduct of one day HAZID workshop among the designers, manufactures, operators by LLOR on 4th April 2013 at SSPA, Göteborg.
- Assessment of Classification aspects through a series of meetings within LR and discussions among the operational aspects team (LLOR, WMC and STENA), WP design team lead by SSPA, in continuation with the earlier workshops held on 10th Aug 2011, 14th Sept 2011.
- Operational Analysis starting with a workshop among the operators on 15 August 2013, and subsequent discussions among the Operators to finalize the ship owner's, i.e. end-users perspective on operational and practical aspects.
- Cost Benefit Analysis among the Operation aspects team, SSPA and WP23 leader RRAB

Significant results

Classification Aspects
In the absence of engineering details, the HAZID team had assumed common generic design for Contra Rotating Pod (CRP) and Integrated Contra-rotating Pod (ICP) propulsion units, e.g. (i) the powering by either electrical or hydraulic means and (ii) power transfer through a slewing ring with bearing. In conclusion, the HAZID identified the following critical risk items and the appropriate recommendations to mitigate them along with the need to 'establish appropriate procedures for maintenance and its implementation through adequate training of personnel'.

- Damage to pod slewing gear teeth
- Damage to propeller blades
- Slewing bearing failure
- Control systems failure and
- Failure of one of the ICP Propellers for the single motor drive design case
- It is recommended that if ICP design is based on single screw system, evaluation of a detailed engineering and safety justification, including the appraisal of a Failure Modes and Effects Analysis (FMEA), needs to be undertaken. This is to verify that sufficient levels of redundancy and monitoring are incorporated in the podded propulsion unit's essential support systems and operating equipment in order to mitigate all the identified risks including those listed above.

Operational Analysis

- Conventional propeller and pod working together offer improved propulsive efficiency, enhanced manoeuvrability, redundancy and flexibility with respect to the changing operating conditions.
- Both CRP and ICP will be more expensive and complicated in installation and operation.
- A single propulsion unit cannot offer the same level of redundancy as the combination of pod and propeller though the manoeuvrability and flexibility will be similar.
- In the short term, CRP is considered to be much more realistic and practicable, cost effective and more reliable than ICP, however, in long term, ICP may become cost effective when it gains popularity and becomes part of mainstream technology.

Cost-Benefit Analysis:

- Cost benefit analysis considering a twin screw reference ship indicates that CRP is economically superior compared to that of the conventional propulsion system, whereas the ICP is economically inferior compared to that of the conventional propulsion system.

3. WP3: CFD Methods

WP3 comprises of WP31, WP32, WP33, WP34 and WP35.

3.7. WP31: Development of Fixed Grid and Rotating Grid Coupling

IN ACCORDANCE WITH THE DOW, ALL WORK WITHIN WP31 HAS BEEN COMPLETED DURING PERIOD 1 AND PERIOD 2

3.8. WP32: Grid Adaption

IN ACCORDANCE WITH THE DOW, ALL WORK WITHIN WP32 HAS BEEN COMPLETED DURING PERIOD 1 AND PERIOD 2

3.9. WP33: Prediction of Cavitation

Task 33.3: Coupling hydroacoustics models and CFD solvers

Partners Involved: MARIN, CNR-INSEAN

Objectives for the period

Following the original work plan, task activities have been completed by end of the previous reporting period (P2) and reported in Deliverable D33.6. Additional analysis on results for the coupling between CFD hydrodynamics data and Ffowcs-Williams & Hawkings (FW-H) hydroacoustic models were carried out by CNR-INSEAN for presentations at the WP33 meeting held in April 2013.

Work progress for the period

A milestone achieved in WP33 regards the generalization of Ffowcs-Williams & Hawkings (FW-H) hydroacoustic models for applications to the analysis of ship propeller pressure pulse emissions.

Significant results

The coupling of the FW-H model and DES hydrodynamics data allows a detailed and comprehensive description of mechanisms of emission and propagation of pressure fluctuations induced by a propeller operating in the complex flowfield of the hull wake to be achieved. Results of numerical studies presented at the last WP33 meeting held in April 2013 have been used to provide guidelines for the correct interface between FW-H hydroacoustics and CFD.

Task 33.4: Numerical simulation of cavitation erosion

Partners Involved: CHALMERS

Objectives for the period

Document findings in terms of summarising guide lines and explore the possibility to use CFD in erosion risk assessment.

Work progress for the period

The physical mechanisms contributing to cavitation erosion has been summarised in order to act as a guide on how to perform a visual assessment of the erosion risk based on CFD,.
A review of published erosion indicator functions have been performed and presented in D33.7.
compressible solver techniques developed within STREAMLINE have been tested for erosion assessment, and an indicator function taking advantage of the benefits (of taking compressibility into account) has been developed.

Significant results

In order to give a nuanced and rather conservative reporting, the most significant results is probably to be able to report that more work is needed to achieve CFD based erosion risk assessment based on a single indicator function. First step would be to run a set of the proposed indicator functions using the same flow solver on the same case, in order to actually be able to rank them.
On the other hand, High-fidelity CFD are now deemed reliable enough to provide a decent basis for a visual assessment of cavitation erosion, following the philosophy of the EroCAV handbook.

3.10. WP34: RANS/BEM Coupled Method

Task 34.2: Implementation & improvement of RANS/BEM interfaces

Partners Involved: HSVA, CNR-INSEAN, CNRS

Objectives for the period

The task was completed and Deliverable D34.2 was submitted during the previous reporting period (P2). Activity in the present reporting period was limited to analysing the performance of the hybrid viscous/inviscid model in numerical studies under WP21 and WP23.

Work progress for the period

In Task 34.2, three hybrid viscous/inviscid models were developed and validated by combining different in-house computational models, as summarised in the following table.

partner	Viscous-flow solver (RANSE)	Inviscid-flow solver (BEM)
CNR-INSEAN	Chi-Navis	PRO-INS
CNRS	ISIS-CFD	PRO-INS
HSVA	FreSCo+	QCM

Significant results

All numerical applications reveal that all the hybrid RANSE/BEM solvers have been developed to a very good level of robustness and accuracy. Considering main flow features, the overall agreement among the first solution (by hybrid viscous-inviscid model) and the latter two (by full viscous-flow solvers) is apparent, although the computational effort required by the hybrid model is 10 to 50 times lower compared to RANSE solvers and even much higher compared to LES solvers.

Task 34.3: Computational prediction of propulsion factors behind ship, power and RPM

Partners Involved: MARIN

Objectives for the period

Analysing the performance of the hybrid viscous/inviscid model in numerical studies under WP21.

Work progress for the period

In task 34.3, MARIN developed and validated a hybrid viscous/inviscid model obtained by coupling the viscous-flow RANSE solver PARNASSOS and the inviscid-flow BEM solver PROCAL. Application of this hybrid solver to computational studies addressing the design of propelled ship configurations under WP21 were started during the second reporting period and were completed in the present reporting period.
Specifically, some effort has been spent by MARIN to analyse the capability of the hybrid PARNASSOS/PROCAL solver to correctly simulate ship propulsion conditions by comparing results with those obtained through a full-RANSE simulation of the ship with rotating propeller.

Significant results

The comparative analysis shows the capability of the hybrid model to describe main ship propulsion factors with accuracy comparable to what can be obtained using a much more demanding full-RANSE model. This proves the appeal of hybrid RANSE/BEM models as design tools.

3.11. WP35: Design and Optimisation

<u>Task 35.2: Enhanced Numerical Optimisation</u>

Partners Involved: HSVA, CNR-INSEAN,

Objectives for the period

Activity in the present reporting period was focussed to improve shape manipulation algorithms used for propeller optimization studies in WP21.

Work progress for the period

The innovative shape optimization methodology developed by CNR-INSEAN in WP35 and based on a very general Conformal Free-Form Deformation Technique (CFFD) was applied to propeller optimization studies in WP21.

Significant results

The procedure to determine radial distributions of parameters chord, pitch, skew, rake, maximum thickness and camber, and offsets of blade sections at selected radial stations from an arbitrary 3D description of the propeller blade shape has been validated by considering the original propeller of the STREAMLINE tanker as a test case by CNRS-INSEAN.