SEVENTH FRAMEWORK PROGRAMME
THEME 7: Transport (including Aeronautics)

Energy Efficiency – Technologies and clustered Research Projects

Maritime Europe Strategy Action

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Innovation Show Cases

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Executive Summary

Energy Efficiency is one of today's key requirements in all transport modes. In this respect, ship propulsion plays a dominant role in maritime transport as it is a decisive element determining the overall efficiency of a vessel. Besides reducing the resistance of a ship, increasing propulsive efficiency promises the largest gains in reducing fuel consumption which are intrinsically linked with emissions. During the last framework programme a significant number of European research projects addressed maritime energy efficiency issues at various scales, including also further improved propulsion solutions. The present report summarises key findings from projects which have been identified as main Show Cases for successful developments. These have a major influence on energy consumption and can provide a significant contribution to the overall aim of reducing both, fuel consumption and harmful emissions during ship operation.

The first example is related to the optimisation of a retro-fit Energy Saving Device in the GRIP project using advanced CFD tools developed in previous EU research projects. The practical optimisation is demonstrated in a full scale application for a 54000 *tdw* bulk carrier. Energy savings obtained in this example are 6.8 % which translates into 350 *ts* annual fuel savings and reduced emissions of more than 1100 *ts* CO_2. A potential application of this technology to only a part of the world fleet of 53000 bulk carriers can have a significant impact on global shipping emissions.

The second Show Case originates from the STREAMLINE project which investigated a range of novel and unconventional propulsion solutions for new built ships. The particular example chosen here is a contra-rotating controllable pitch Pod propulsor – CRP which is pitched against conventional twin screw arrangements. This development leads to high savings or more than 15% of propulsive energy and associated fuel consumption and emissions. Based on a market share analysis of new built twin screw vessels the total energy and emission saving potential of the CRP concept is still very considerable at abt. 480000 *ts* of CO_2 emissions annually. In addition to this the CRP is also a valid alternative to single screw concepts as it provides an increased propulsive efficiency and significantly increased safety level.

These results indicate the large impact that successfully accomplished research projects can have. This opens up new business perspectives for the partners involved and helps to achieve key objectives of the European research strategy, namely providing more energy efficient and greener (maritime) products and increasing competitiveness. The work in TTG 1, task 1.4 however revealed also other important information. It is not accidentally that the two Show Cases presented here result from a string of consecutive EU research projects run over a longer duration spanning several framework programmes. This indicates that a consequent follow-up of a clear development concept can be finally successful and lead to impressive achievements. After having found severe gaps in form of quality and versatility of numerical simulation tools used in hydrodynamic optimisations concise requirements were formulated in the MARNET-CFD network during FP 5. Here different organisations came together to formulate a clear development strategy to improve the quality of the prediction methods and advance them to a level allowing to really improve the product ship. This was communicated to the Commission in form of inputs to the following work programmes and to the later formed Waterborne Technology Platform which included the advice in its strategy papers.

Necessary scientific and technical developments could be performed during the following 6th framework programme which offered the right opportunities for the proposed developments. First

tests at the end of these projects indicated that the quality of results obtained was sufficient to address technically relevant problems. This could be done during the following 7th framework programme in a number of projects of which STREAMLINE and GRIP have been identified here as being most successful. Partners in these two projects look back at a long line of consecutive developments which have led to commercially viable and accepted tools and techniques which help to considerably improve ship energy efficiency. This could be demonstrated in real life applications.

Background and Description of work

Task 1.4 Show cases description

Improving the visibility of European research activities and increasing the acceptance and support can be done best by presenting the successful results of such research activities. MESA sets out to identify a number of show cases from all 4 thematic technology areas. In TTG 1 – Energy Efficiency – dedicated show cases have been identified where scientific results have been achieved according to expectations, where demonstration activities have been successfully completed and where the potential of an innovation activity is likely to be – or has already been - taken up by industry. A description of these show cases, with clear identification of the R&D achievements implemented in the market and the impact assessment of the relevant innovation, will further be used as an input for the WP7 collection and dissemination as well.

Departing from the State-of-the-art analysis presented in MESA deliverable D 1.1 the energy efficiency group identified several successful developments in earlier framework research programmes and projects which have a clear perspective of short and medium term industry uptake and will – or have done so already – open up new business perspectives for the European Maritime industry.

1. Introduction

MESA TTG 1 partners discussed the approach for the presentation of project show cases in great detail. In absence of an overarching decision for a general format to be applied for show cases in all 4 TTGs it was decided to follow an approach that was agreed between TTG 1 and 3, basically. This is based on the following definition:

Def.:"*A show case is a project or a string of projects which successfully demonstrate a considerable improvement in terms of Energy Efficiency as a result of R&D developments".*

While the previous report "D 1.1 - Energy Efficiency – Technologies and clustered Research Projects" presented a compilation of relevant project results and achievements which form – beside external developments – a fundamental part of the state-of-the-art in Energy Efficiency, the focus here is put on those project results which clearly demonstrate – if possible on an economical scale – the benefits obtained from joined research at EU level.

1.1 "Show Case" selection

For the Energy Efficiency TTG, a first structure has been elaborated by the working group and presented already during a Project Workshop in Brussels in 2014. The main headings include:

1. Ship resistance
2. Ship propulsion
3. Prime mover
4. Auxiliary energy (conversion) (solar, wind (not for propulsion), seaway energy)
5. Other on-board energy consumers
6. Energy Management Systems
7. Ship operations
8. Lightweight Structures (as a cross sectorial topic together with the production TTG)

As indicted in Deliverable D 1.1 projects have been run in the majority of these areas, though often at different scale and with different focus. An analysis performed in Task 1.4 revealed that the most prominent areas having achieved successful developments which could and can be demonstrated in form of industrial applications relate to either area 2: ship propulsors and area 3: prime movers. While the most evident candidates having developed advanced and improved ship propulsors, namely the STREAMLINE and the GRIP project have contributed to the following success stories, TTG 1 partners were not successful to convince the consortia running the sequence of HERCULES projects to contribute to the present collection of Show Cases. Hence they are not included here. This however does not mean that the results obtained in the so far 4 subsequent projects dealing with the improvement of prime mover performance are inferior to those presented here. The HERCULES team members apparently decided to promote their results individually and hence refer to own marketing instruments such as the public web sites of their projects. For individual information please consult e.g. http://www.ip-hercules.com, http://www.hercules-2.com or http://www.hercules-c.com.

2. Show Cases

The following section provides descriptions of the selected Show Cases which have been identified by TTG 1 partners at the end of the first breakdown of energy efficiency technologies provided in D 1.1.

2.1 Evolution of Propulsion Projects

The two projects which are presented in more detail here are the GRIP and the STREAMLINE project, both run in the 7th framework programme. However, the fact that these projects have resulted in impressive, demonstrable results is not the work of a moment and cannot even be attributed to the project alone but is due to the longer line of evolution of projects developing key technologies which are later on transferred into practical, industrial applications. Each of the earlier projects added knowledge and capabilities and tools which are later used to achieve the useful results in both, STREAMLINE and GRIP.

The following graph indicates the evolution of the project over the duration of 3 framework programmes:

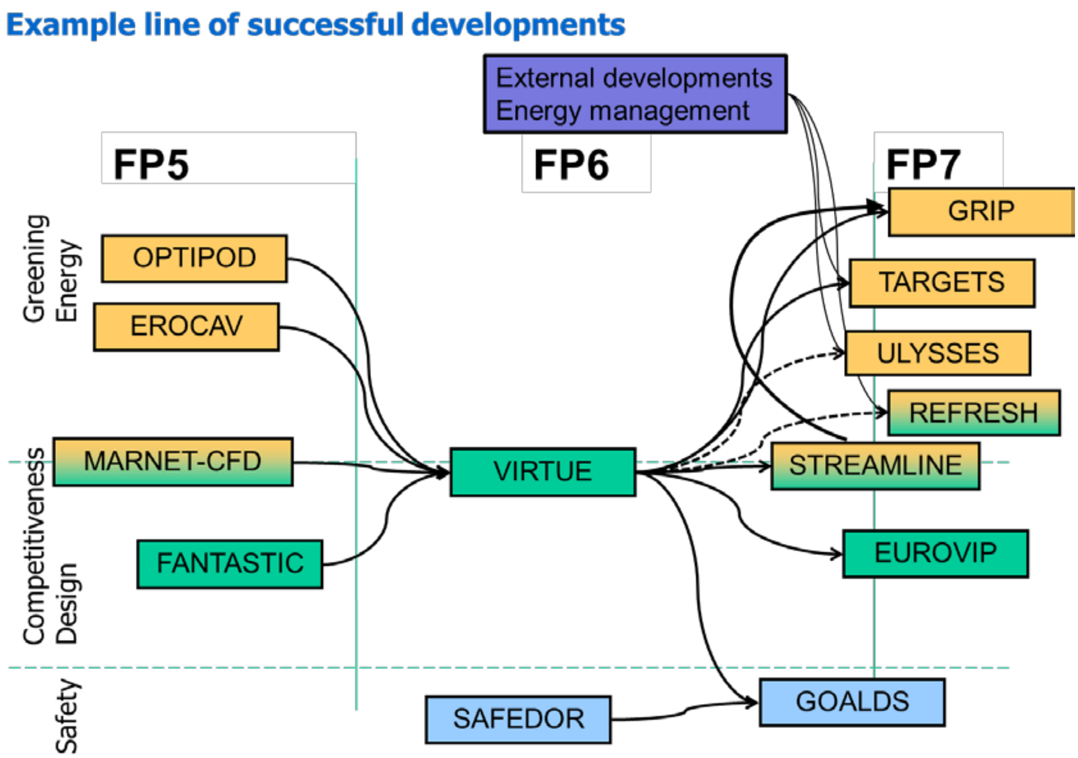

Fig. 1: "Evolution of EU research and development projects that lead to the STREAMLINE and GRIP results"

These developments span over a period of almost 12 years, starting in the 1990ies in the context of the 5th framework programme. The main influences and projects contributing to the line of developments were:

- **MARNET-CFD**: Thematic network in FP 5 provided a global collection of the state-of-the-art of maritime CFD technologies in the 1990ies and, together with the **FANTASTIC** project, a good demonstrator of capabilities and short comings of then technologies. Although functionality of CFD tools had been largely increased in the period from 1995 to 2003, a significant lack of accuracy and general trustworthiness of CFD results had to be stated at the time. This result lead to the formulation of the need for better / more accurate CFD codes.

- **VIRTUE**: The integrated FP 6 project was the direct result of findings obtained in MARNET-CFD. The entire project concentrated on the development of new and the improvement of existing CFD codes for maritime application. In a competitive environment of 20+ partners significant progress has been achieved in 4 main application areas: i) ship resistance, ii) seakeeping, iii) manoeuvring and iv) cavitation predictions. The formulation of standard test and validation cases for different codes in different areas / work packages and the open exchange of results in a collaborative spirit proved extremely valuable for the large progress made on a number of CFD codes which today represent the cutting edge of technology in maritime CFD. In this respect the VIRTUE project is the origin of today's maritime CFD capabilities in Europe.
- **STREAMLINE**: In direct continuation of the work performed in VIRTUE and using its results, the STREAMLINE project further enhanced the functionality and accuracy of the codes for complex propulsion problems. In parallel STREAMLINE was the first real application of the by them much improved flow codes. STREAMLINE provided demonstrations for rather unconventional propulsion solutions, e.g. the large area propeller or the Walvisstaart and looked into improved conventional propeller applications.
- **TARGETS**: The TARGETS project stands representative for a number of projects which were launched in the 2nd and 3rd Call of the 7th framework programme dealing with ship energy efficiency, such as ULYSSEES or REFRESH to name a few. Very many of them used CFD tools developed earlier to provide input to e.g. the energy management concepts and tools which were developed in the projects. The focus in these projects moved away from CF D development work to application in the context of real product development and thus entered a new level.
- **GRIP**: This holds in particular for the GRIP project. Here CFD tools developed in VIRTUE and further refined in follow-up projects such as STREMALINE were put to use to improve the hydrodynamic performance of ships and were finally tested and validated in dedicated sea trials which at the end proved the quality and accuracy of the previously predicted performance data.

This evolution of projects over the period of 3 framework programmes (FP 5 to FP 7) clearly indicates that a consequent follow-up of a clear development concept can be finally successful. A number of project partners in the GRIP project were already present when back in the FP 5 project FANTASTIC rather disappointing results were presented. Although the quality of the optimisation techniques could be demonstrated by then, it was clear that the overall accuracy obtained would never allow addressing complex problems such as the optimisation of propulsion improvement devices. Ten years and several projects further, this has now become a commercially viable and accepted technique which helps to considerably improve ship energy efficiency.

2.2 Show Case 1: Green Retrofitting through Improved Propulsion

Ship propulsion is a decisive element determining the overall efficiency of a vessel. Besides reducing the resistance of a ship, increasing propulsive efficiency promises the largest gains in reducing fuel consumption which are intrinsically linked with emissions.

The GRIP project provides a very good example: the development of a Pre-swirl stator energy saving device which was optimised in the project in a competitive exercise between different partners and full scale tested on a bulk carrier.

2.2.1 Description of the Show case

The FP 7 project GRIP (Green Retrofitting through Improved Propulsion) has been launched to address industry needs for improving on-board energy consumption and emission reduction by installing Energy Saving Devices (ESD) on existing ships. The high demand for retrofitting is largely driven by four factors: the reduction of CO2 emissions, the fluctuating high fuel prices, effective regulations and the lifetime extension of existing ships. Although there is a remarkable market penetration already, it often remains highly uncertain whether these devices actually improve the performance of the complete hull-propeller system, and if so why. Some devices showed great promise in model tests, but failed in full-scale validations. For other devices, manufacturers claim proof of large improvements on real-size ships, but these claims cannot be verified by independent observers. Therefore, there is an urgent need for independent studies on the potential energy saving of such devices. The GRIP project addressed exactly this problem in a holistic approach.

Early Assessment Tool

Energy Saving Devices have been applied for quite some time with varying success. The field of application of an ESD is often not made clear by the manufacturer, which makes it difficult for a ship owner to select the best possible ESD for retrofitting his specific vessel. Reliable performance data of these devices is often not readily available. Therefore data had to be collected from suppliers, literature, CFD calculations and trial measurements of earlier projects, to provide a sound basis for an Early Assessment Tool which formed the first major deliverable of the GRIP project. This web based tool for public use is aimed at technical staff of ship-owners, consultants and others and gives guidance during a preliminary selection of ESDs. The tool is largely based on existing data and gives a general overview of the field of application for a number of ESDs, based on characteristic ship data.

CFD based design procedure

One of the reasons for the reluctance of ship owners to invest in ESDs is the uncertainty in the performance gains at full scale. This uncertainty is caused by a number of factors. A chief factor is that there is a level of uncertainty about predicted performance improvement which is often larger than the improvement itself. Therefore accurate model scale tests need to be extrapolated to full scale values which in turn have associated uncertainties. The GRIP project aimed to remove these uncertainties through the application and validation of the computational tools.

Newest CFD techniques available were used to set up a design procedure including the analysis of the hull-propeller-ESD interaction. Taking into account the interaction between propeller and hull, the characteristics of a propeller behind a ship were accurately predicted and the quality of the wake prediction behind the propeller was improved. Current CFD tools are now capable of capturing small deviations in the flow caused by the presence of ESDs. These new capabilities were used to accurately analyse the improvements on propulsion efficiency by an ESD. This is indicated in the comparison of predicted wake fields with and without ESD shown in the following figure.

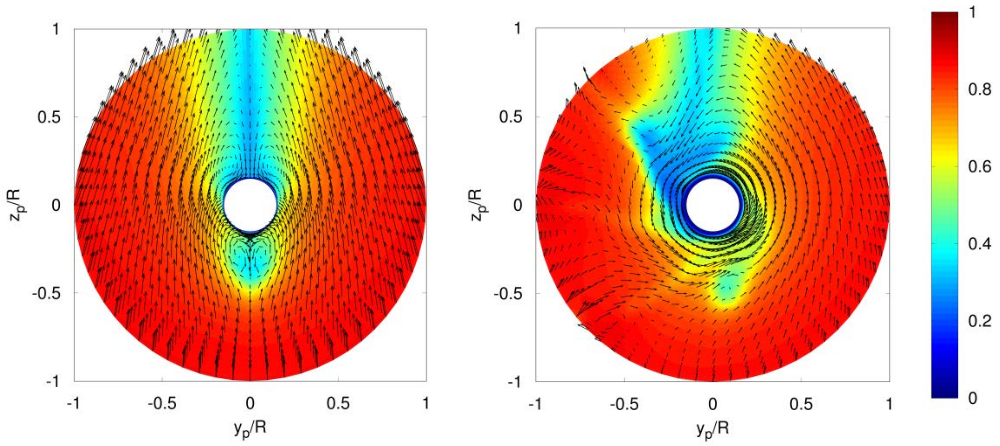

Fig. 2: "Propeller Axial Nominal Wake and Tangential Velocity Vectors: without PSS (left) and with PSS (right)"

The design procedure adopted by HSVA for the design of the Pre-Swirl-Stator (PSS) used later on the bulk carrier Valovine during sea trials is shown in the following figure.

The HSVA-PSS utilised a parametric model for the ESD which was developed earlier in the project. The entire design and analysis process was performed directly in full scale to avoid uncertainty of scaling effects for an ESD. The in-house RANS code FreSCo+ performed an initial baseline computation without an ESD to provide the necessary input data for the BEM method. The RANS-BEM coupling method analysed the achieved power gains due to the ESD variations in the self-propulsion design condition. The project partner Wartsila Netherlands B.V., confirmed there is no cavitation risk on the propeller due to the addition of the PSS. Afterwards, the construction, installation and structural aspects have been checked in a collaborative effort of the GRIP partners.

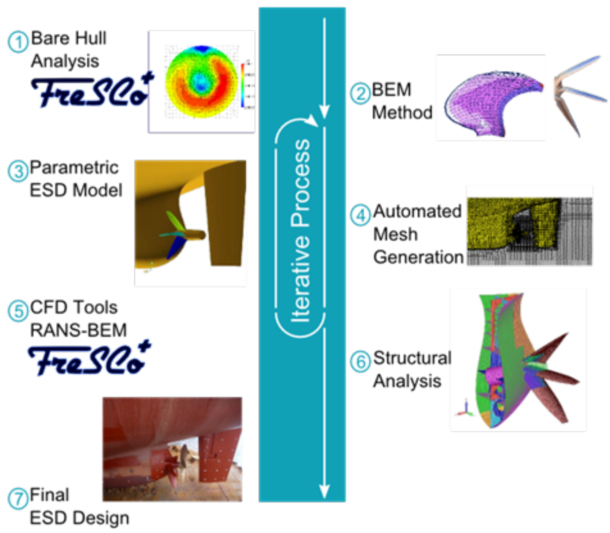

Fig. 3: "PSS Design Procedure (HSVA)"

Validation and Demonstration Case Study

After accomplishing the numerical uncertainty study and ESD design procedure evaluation in the early stage of the project, an actual ESD design case for the GRIP validation ship has been conducted by three partners resulting in three different ESDs: a pre-swirl stator (PSS) by HSVA, a pre-duct by MARIN and a rudder bulb by VICUS. The selected GRIP validation ship was a newly- built handymax bulk carrier of 182 meter length by partner Uljanik shipyard *(ULJANIK BRODOGRADILISTE DD)*.

Fig. 4: "MV Valovine during sea trials"

In a first step the different ESDs were designed and optimised by the three partners individually. These results were put forward in a competition for best performance. To check the results extensive cross validation by all partners (for all designs) were performed and the finally best solution was selected for demonstration.

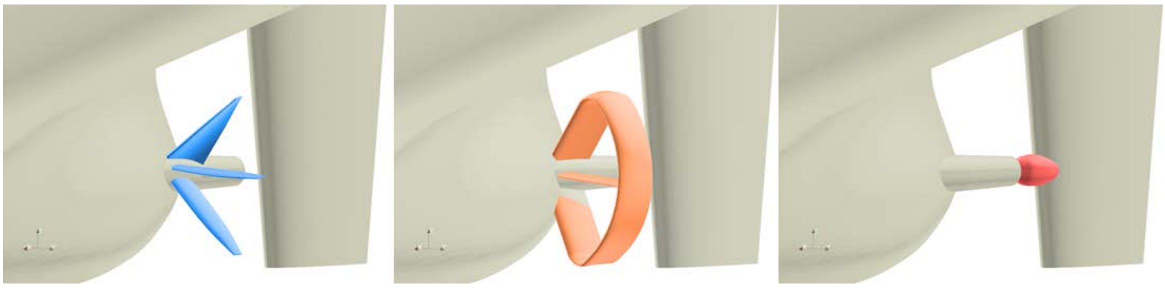

Fig. 5: "Contested ESD solutions for the GRIP reference ship"

HSVA's proposal for a Pre-Swirl Stator proved superior during the cross check exercise by all participating partners. The complete design, optimisation and evaluation procedure has been conducted in full scale following the design procedure shown above to investigate the complex interaction of hull-ESD-propeller.

During the design – optimisation process numerous parameters have been checked and optimised. Besides the number of fins and their placement local geometry, profiles and angle of attack have been varied. The following figure indicates the evolution of power savings obtained from main design variants used during the optimisation process.

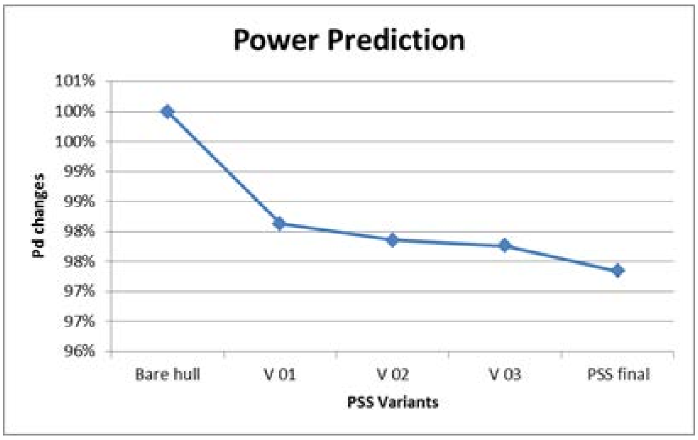

Fig. 6: "Power gain predictions of the PSS variants during optimisation steps"

The resulting design featuring 3 fins located on the port side in front of the propeller is shown in the following figure.

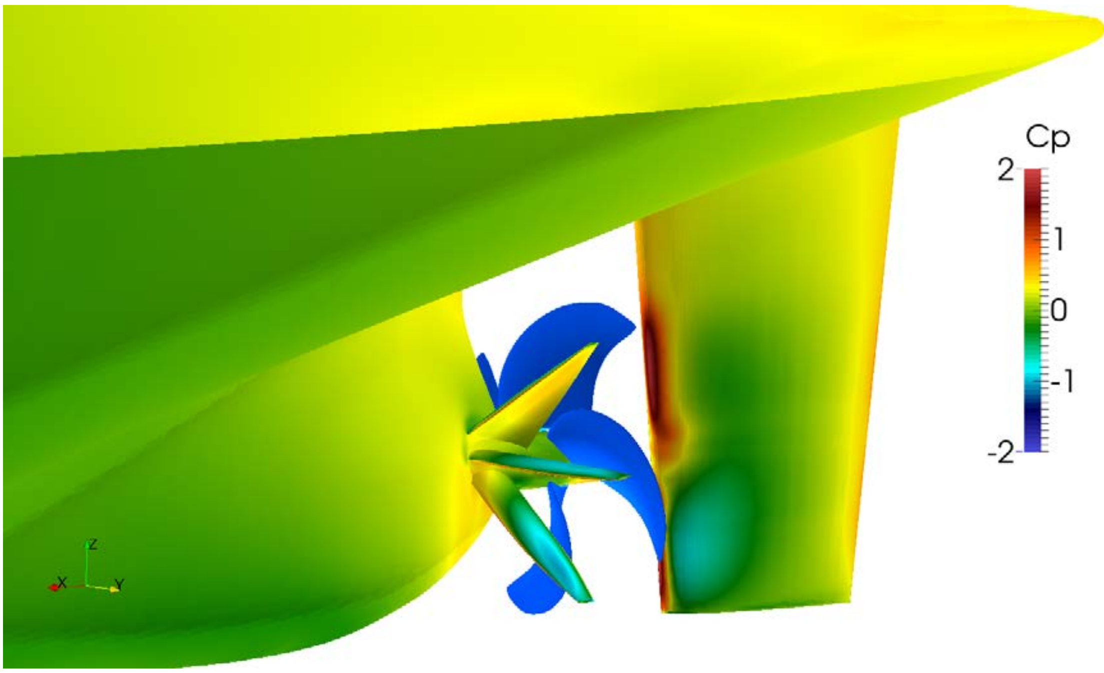

Fig. 7: "The Bulk Carrier with the PSS; Pressure distribution on the surfaces of hull, rudder and PSS"

After the hydrodynamic and structural analysis this PSS design has been constructed, built and installed on the actual built bulk carrier which then underwent extensive sea trials. The trials were organised so that first systematic measurements could be made for the "yard new" vessel without the PSS in almost ideal trial conditions with very limited wind and wave influences. After this the vessel returned to the yard and the PSS was installed in a dry-dock. The new installation is documented in the following figure.

Fig. 8: "MV Valovine during dry docking between the first and second sea trial – the new PSS has been installed and is freshly coated"

Immediately afterwards additional sea trials, this time with PSS, have been performed to find the difference between the two conditions. The second trial was performed again in nearly ideal trial conditions, with wind speeds around Beaufort 1 and a wave height of less than 0.2 metres. Instrumentation remained on the ship during the dry dock to reduce systematic errors and get maximum accuracy in measurements. A wave buoy was used to assess wave conditions. The speed trials were performed and analysed by MARIN Trials & Monitoring, according to the latest ITTC Recommended Procedures and Guidelines for speed/power trials. Cavitation observations has also been performed during pre- and post- trials, which confirmed that the PSS has no visible influence on the cavitation behaviour on the propeller and more favourably, the PSS has diminished the hub vertex coming out of the propeller during the first trial.

The trial resulted in a reduction of nearly 7% on power at equal speed (16kn) or an increase of 0.3 Knots on speed at equal propulsion power. This confirmed the effectiveness of the PSS. The actually installed PSS geometry has been measured via 3D laser scan technique and CFD predictions based on the measured geometry are compared to the sea trial results with good agreement. Since the PSS has been designed for a single design condition, a further step has been taken to examine it against off-design conditions to assess the life cycle performance of such a device.

As the following figure indicates, the PSS shows an improvement in power requirements over a large range of speeds from 12 to 16 kts where comparisons were made.

Fig. 9: Speed trials results without and with PSS”

2.2.2 Show case Impact and Potential

GRIP [*Green Retrofitting through Improved Propulsion*] has developed key technologies for CFD-based design and analysis as well as production and installation / retro-fitting of Energy Saving / Propulsion Improvement Devices. The concept is applicable to both, new vessel designs as well as retro-fits. It has been applied to a full scale demonstrator (54000 tdw bulk carrier) and demonstrated 6.8% power / fuel savings during consecutive sea trials.

GRIP – Demonstrated Impacts:	
Vessel fuel savings:	350 ts annually,
CO2 emission reduction:	1120 ts annually.

Using data from the latest IMO Green House Gas Study (2014) allows to present a prospect on the global potential that GRIP developments have when applied to bulk carriers worldwide. Even if only a more limited individual savings potential per ship of 4.5% (compared with the 7% in the present study) is applied this could result in almost 8 Mio ts of CO_2 emission reductions.

Global Potential:	
World Bulk Carrier Fleet:	53000
Annual Fuel consumption:	55 Mio. ts
Possible fuel Savings:	2.47 Mio. ts [based on average savings of 4.5%]
Possible emission reductions:	7.9 Mio. ts

Even if not all of the above market potential can be accessed by European shipbuilders, the GRIP project opened up a considerable market perspective for European providers of retro-fit solutions.

2.3 Show Case 2: A Novel Propulsion Concept using CRP Pods

Further improved propulsion concepts have been developed in the FP 7 project **STREAMLINE** [Strategic research for innovative marine propulsion concepts] which covered a large range of novel, alternative and optimised conventional propulsors. The entire range of new propulsion concepts is shown in the following figure 10.

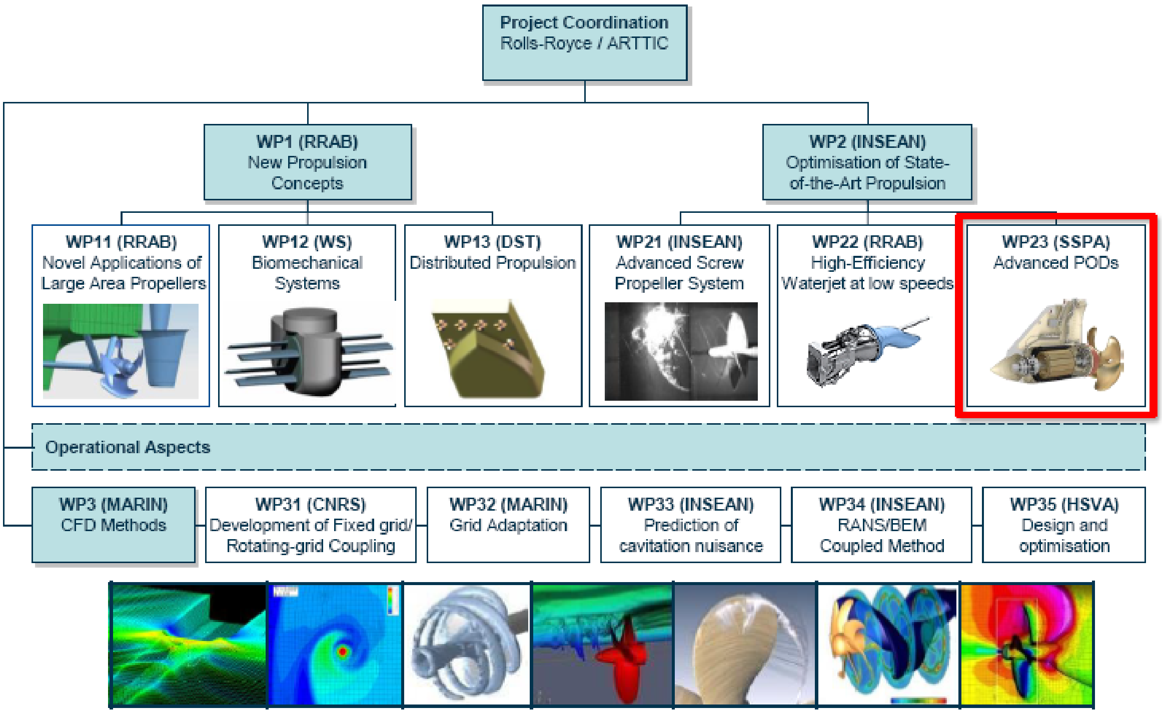

Fig. 10: "STREAMLINE - Propulsion Concepts"

The STREAMLINE project set out to develop, analyse and optimise ship propulsion alternatives, ranging from conventional propellers to radically new concepts such as biomechanical systems and the aft mounted Large Area Propeller. A very promising concept was the Contra rotating Pod Drive proposed by Rolls Royce which was part of the work performed in WP 23 highlighted in the above figure. This was developed for a medium sized (twin screw) RoRo vessel and positioned against a standard design featuring a conventional twin screw arrangement.

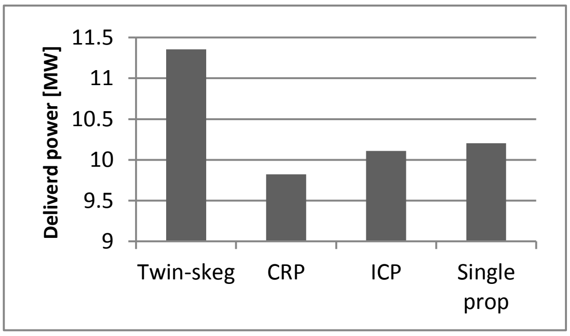

Fig. 11: "Power requirement for 4 different propulsion solutions for a twin screw RoRo vessel"

The main objective of the Pod related work performed in was to investigate new types and operational aspects of podded propulsion. Besides energy savings this related to the exploration of the effect of seakeeping conditions on the cavitation and ventilation behaviour of a podded propeller and the improvement of the reliability of full scale predictions. The CRP features an aft mounted contra rotating Pod drive (AziPull thruster) which too regains rotational losses from the forward propeller. Both propellers are of controllable pitch type. The CRP concept is positioned as an alternative to conventional twin screw arrangements and promises significant increases in efficiency. In the STREAMLINE project comprehensive model tests have been performed for several design alternatives which were pitched against the standard twin screw arrangement. An equivalent mono-skeg hull was designed and fitted with the CRP, an alternative pod design from SSPA and a pure single screw ship with an optimised propeller.

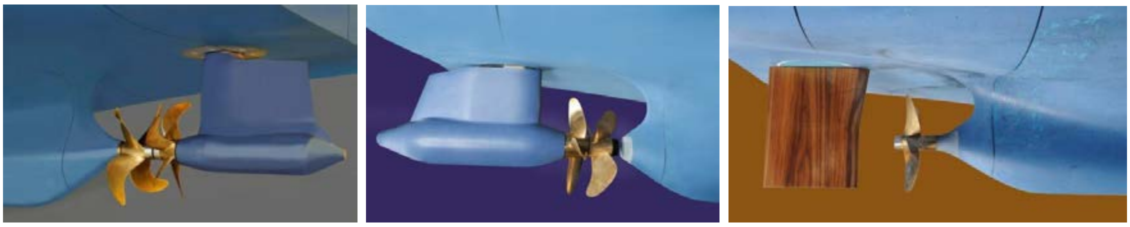

Fig. 12: "Alternative propulsion concepts being model tested in STREAMLINE"

These configurations were validated through a thorough model test campaign at SSPA including 4 different twin screw arrangements which were compared for a RoRo vessel. The CRP arrangement clearly marked the highest power savings at 15.6 % compared with the baseline (twin screw arrangement). The model tests confirmed the findings of earlier CFD analysis.

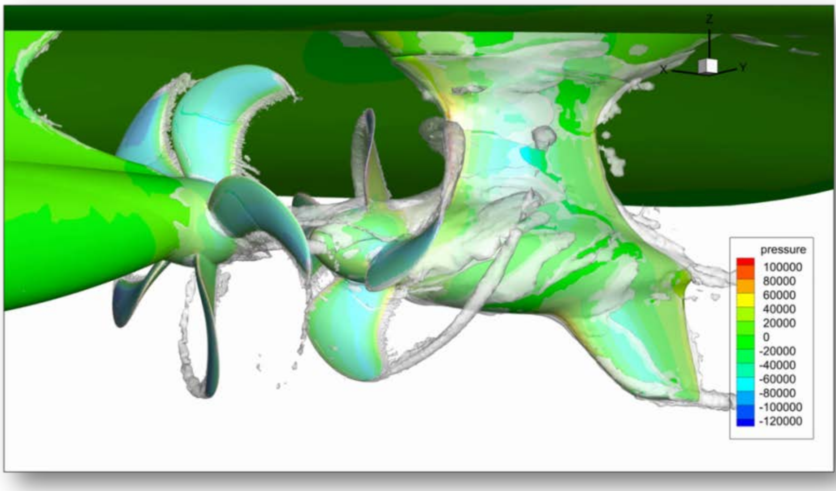

Fig. 13: "CFD simulation (pressure, vorticity) of the Propeller - PoD combination"

This convincing propulsion approach lead to a first order placed with Rolls Royce for a CRP installation with a total power of abt. 3000 kW.

2.3.1 Description of the Show case (2)

The background and evolution of this particular development is described in Rolls – Royce' own words:

"When Feadship asked us to provide the propulsion for their innovative new 'Breathe' hull design requiring a number of different propulsion modes for different conditions, we weren't sure it could be done, " says Göran Grunditz. "We'd been researching contra rotating propulsion on and off for over thirty years but we knew we had not delivered something this radical before and there were still a number of risks to mitigate."

So began a 5 year programme which combined state of the art hydrodynamic research with the development and adoption of ground breaking new design tools. The result sits below a striking new vessel the 83 metre Feadship Savannah which claims to be the first hybrid motoryacht. Featuring an eco---friendly blend of single diesel engine, three gensets, batteries, propeller, azimuting thruster and a streamlined hull shape the vessel offers improved fuel economies of thirty per cent, quiet cruising at low speeds on battery power, and extra speed when going flat out. Further innovation includes a floating superstructure, an underwater lounge, and 'open' aft deck areas.

Fig. 14: "Motor yacht Savannah – 1st CRP Installation"

A unique combination of existing products

Rolls---Royce contribution to the vessel's pioneering electro---mechanical propulsion platform was a unique combination of a number of existing but separate products in a new way.

A large controllable pitch propeller, rotating in a counter clockwise direction, when viewed from aft, was installed in front of an Azipull unit with its propeller rotating in the opposite, clockwise, direction to create a contra rotating propulsion system located along the centre line of the vessel. The aft propeller operates in the rotational slipstream of the forward propeller and recovers energy from the swirl it creates. This is energy which would otherwise be lost making the system much more efficient than a conventional twin screw.

The Azipull also provides excellent low speed manoeuvrability so there is no need for additional low speed manoeuvrability device --- such as typically, a tunnel thruster mounted in the skeg. That means less drag saving fuel and further contributing to energy savings.

But the skeg, located in front of the forward propeller, also presents a challenge. The skeg creates a reduced flow of water over the first propeller. This improves overall efficiency of the vessel. However, that flow is non-uniform and at the propeller causes noise and vibration. That meant a special, bespoke, propeller design was need to maximise efficiency with minimum noise.

Fig. 15: CRP installation for motor yacht Savannah”

Back to the future

“To develop the system we began by reviewing the existing research which had been done, going back as far as the eighties,” said Göran Grunditz.
A key challenge identified from that review was the extent of the dynamic loads this configuration places on the aft propeller blades operating in the slip stream of the forward one. This is at its worst when the Azipull is being used to steer. These dynamic loads could increase wear on internal bearings and gear wheels causing them to fail prematurely. They could even damage propeller blades especially on the aft propeller.
One of the factors that helped solve this was that at high speeds, in contra rotating mode, the vessel doesn’t use the Azipull to steer using separate rudders instead. The rudders also serve to limit the freedom of movement of the Azipull at high speeds further reducing the risk of high dynamic load. At slow speeds and when operating in DP mode the vessel is manoeuvred using the 360 degrees thrust vectoring of the Azipull whilst the forward propellers blades can be put into feathered position. This means that excellent manoeuvrability is obtained from the Azipull with marginal impact from the forward propeller”
Designers also worried about the way in which the natural frequency of the Azipull corresponds to the blade pass speeds of the propeller blades. A contra rotating propeller uses a lower than normal shaft speed and experiences different excitation frequencies compared to a conventional propeller. This means that the torque is higher for the same power leading to lower than normal safety margins of gearwheels when dynamic loadings are considered. In this case, investigations indicated that in some of the operational modes the blade pass rotation speed was quite close to the natural frequency of the Azipull unit. This can successively lead to harmful vibration and noise.
In response Rolls---Royce designers worked with the yard and another specialist supplier to mount the Azipull on specially designed elastic supports. This was something never done before. The supports were designed to reduce the impact of the vibration caused by the propeller something sea trials confirmed. “We studied the vibrations in detail and we found some resonances but they were all low in magnitude so there was no need for any restrictions, such as RPM,” Jahn Terje Johannessen, told in---depth.

Innovative research and design tools:

Designers made extensive use of innovative Computational Fluid Dynamic (CFD) tools to design and validate the vessel's ground breaking propulsion system.
"Based on the work in the STREAMLINE project we developed a tool to evaluate the performance of the CRP set up; predicting efficiency for combinations of propeller pitch and RPM," Rikard Johansson said. "This tool was validated against model tests that were carried out at Rolls---Royce own cavitation test facility in Kristinehamn Sweden". Conventional design tools could not do this because of the influence of the swirl The combination of advanced CFD methods, validated and extended in scope by cavitation testing at model scale allowed Rolls---Royce to estimate the optimum power distribution for the forward and aft propeller and optimum shaft speeds and propeller pitch for both giving a starting point for detailed design.
Another set of design tools were needed for the detailed design phase. These needed to take account of interaction effects. For example the implications for the design of the aft propeller of the velocities generated by the forward one were explored.
CFD was used to model both open water and in behind effects. In the latter the interaction between the ship hull and the two contra rotating propellers was simulated so the dynamic loads that could be expected on the Azipull could be predicted. The former, where there is no ship hull present and the flow in front of the propellers is undisturbed, was used to map out the core characteristics of the design. For example the optimum relationships between propeller pitch and RPM to validate the design prior to model testing.
"CFD tells us a lot," says Rikard Johansson. We found additional information from CFD simulations developed in STREAMLINE, for example we used it to explore the implications of the swirl on the rear propeller. It also allows us to go through multiple design loops before arriving at the optimum design. It's also cheaper we don't have to manufacture a set of blades for every study we want to do. Model testing is much faster once you have the model equipment and validates the fundamental physics of the CFD model which enables us to trust the results of the simulations. A particular strength of Rolls – Royce is our ability to combine CFD with testing".
The complexity of number of variables to be explored in the design of the propulsion system cannot be understated. The Savannah has a number of propulsion modes for different operations – boost, high speed mode, diesel electric mode, range (lower speed / fuel efficient), manoeuvring, and non---sailing. The control system is expected to switch between modes smoothly and without disturbing the passengers by creating noise and vibration, something which sea trials confirmed. Achieving this added significant complexity to both the control system and from a hydrodynamic perspective which had to be understood before the system's on---board controller could be programmed for optimum performance.
"Only Rolls – Royce could have developed and produced the ground breaking Contra Rotating Propulsion system for this innovative vessel," says Göran Grunditz. "It required an extensive primary research base built up over years, the ability to develop innovative computer design tools, undertake experimental validation and turn that design into a physical reality which can be manufactured and serviced."

2.3.2 Show case Impact and Potential (2)

The potential energy savings attainable with the CRP concept are considerable as indicated in the analysis performed in the STREAMLINE project. Using a similar approach as for the first show case in

2.2.2 the potential impact of the concept has been evaluated. The major difference here being that a CRP will not be installed in a retro-fit project but only for newbuildings. This limits the number of possible applications compared to the ESDs shown in the first case. Figures below are estimates for twin screw ferries and RoRo vessels. Still the overall amount of energy savings and emission reductions is quite considerable and – as the example above shows – there are more application areas for CRPs in other ship types.

STREAMLINE CRP –Impact:

Vessel fuel savings:	≈ 1100 ts annually,
CO_2 emission reduction:	≈ 3500 ts annually.

Global Potential:

Based on a global fleet statistics (Psaraftis, Fairplay[1]) it was estimated that around 140 vessels between 15 – 25 (*1000) tdw would be suitable for a CRP propulsion unit. This would lead to the following savings:

Possible fuel Savings:	151,500 ts.
Possible emission reductions:	480,000 ts.

3. Factors for success / obstacles

During the work on the present report a number of factors which proved relevant for the final success of the developments performed in – European – research projects have been discussed and identified. In summary they can be described as:

- Technological success often stems from a series of projects or strategic lines of development rather than a single attempt to solve an isolated problem. This emphasises the need for continuous development to keep upfront of the competition.

  Examples for this assessment are the chain of hydro projects starting in FP 5 and leading to results in FP 7 and later H 20202. This evolution has been shown in the context of the two Show Cases presented here (see Fig. 1.) Another example is the line of HERCULES projects on engine developments which has led to significant improvements of engine performance over a similar duration and span of projects and framework programmes.

- The succession of projects during the past period raised the TRL of different concepts from ideas / basic research to full scale technical application marking the end of a development line. The two examples mentioned above clearly demonstrate that a long term planning and the support of the funding schemes through the subsequent framework programmes has delivered the requested results.
- Market uptake does not come automatically once a project objective has been fulfilled. History is full of examples in which excellent, mature technology has not been accepted or taken up after

[1] Psaraftis, H., Kontovas, C., CO_2 Emission Statistics for theWorld Commercial Fleet, WMU Journal of Maritime Affairs, Vol. 8 (2009), No.1, 1–25

the developments were accomplished. This is often due to rapidly changing market and overall conditions.

- Even for the propulsion improvement / energy saving devices shown in the first Show Case there are examples which prove differently. A lot of this technology has been – conceptually – developed in the 1970ies, after the 1st oil crisis in 1973. After a short period of success all had been “forgotten” in the 1980ies when fuel prices dropped again. The rise of fuel prices and operating cost during the first decade of the new millennium has led to further increased interest in fuel saving technologies and thus created a sound basis for the developments in a number of successful projects. However, the economic situation of the past two years with – again – rather low oil price levels has led already to a diminishing interest in costly technology, at least in those areas where no other boundary conditions call for reduced energy consumption and emission reductions.
- These “other boundary conditions” mainly result from rules and regulations. At present the main drivers for energy efficiency improvements appear to be environmental regulations, e.g. the introduction of the EEDI in ship design / building and the introduction of ECAs around the major trade areas in Europe and the US, with Asia following at a slightly lower pace. The latter appear to have the dominant influence on the technical evolution of ships with a focus on emission reductions resulting from the use of cleaner fuels and / or the installation of exhaust gas cleaning systems such as scrubbers. Despite their indisputable effect on the greening of shipping operations both technologies have only a limited impact on energy efficiency. The importance of improved energy efficiency will only rise in a tighter economic environment or further enhanced statutory rules for the design of energy efficient ships.

4. Summary and Conclusions

The MESA TTG 1 Show Cases are constituted from successful projects in the field of ship propulsion. These have a major influence on energy consumption and can provide a significant contribution to the overall aim of reducing both, fuel consumption and harmful emissions during ship operation.

The first example is related to the optimisation of a retro-fit Energy Saving Device in the GRIP project using advanced CFD tools developed in previous EU research projects. The practical optimisation is demonstrated in a full scale application for a 54000 *tdw* bulk carrier. Energy savings obtained in this example are 6.8 % which translates into 350 *ts* annual fuel savings and reduced emissions of more than 1100 *ts* CO_2. A potential application of this technology to only a part of the world fleet of 53000 bulk carriers can have a significant impact on global shipping emissions.

The second Show Case originates from the STREAMLINE project which investigated a range of novel and unconventional propulsion solutions for new built ships. The particular example chosen here is a contra-rotating controllable pitch Pod propulsor – CRP which is pitched against conventional twin screw arrangements. This development leads to high savings or more than 15% of propulsive energy and associated fuel consumption and emissions. Based on the market share of new built twin screw vessels the total energy and emission saving potential of the CRP concept is still very considerable at abt. 480 kts of CO_2 emissions annually. In addition to this the CRP is also a valid alternative to single screw concepts as it provides an increased propulsive efficiency and significantly increased safety level.

The results of the Show Case study indicate that the most successful projects stem from a string of consecutive EU research projects run over a longer duration, indicating that a consequent follow-up of a clear development concept can be finally successful and lead to impressive results.

When back at the beginning of the last decade the partners in the FP 5 project FANTASTIC presented results many were disappointed with the rather poor quality especially of the CFD results obtained. Although the quality of the optimisation techniques could be well demonstrated by then, it was clear that the overall accuracy obtained would never allow addressing complex problems such as the optimisation of propulsion improvement devices and even the quality of the predicted ship resistance at the time would certainly not be able to challenge traditional experimental testing. It was with the help of the work in the MARNET-CFD network that organisations came together to formulate a clear development strategy to improve the quality of the prediction methods and advance them to a level allowing to really improve the product ship. This was communicated to the Commission in form of inputs to the following work programmes and to the later formed Waterborne Technology Platform which included the advice in its strategy papers.

Ten years and several projects further, several of the old partners in both, MARNET-CFD and FANTASTIC contributed to the successful developments in GRIP and STREAMLINE. They look back at a lengthy line of consecutive developments which now have led to commercially viable and accepted tools and techniques which help to considerably improve ship energy efficiency.

5. Appendix 1:

5.1 Project References:

		Project reference	Web Site
1	EU	2020 INTERFACE	
2	EU	ADEC	
3	EU	ADOPT	
4	EUREKA (Ended 2004)	BALTECOLOGICALSHIP	
5	EU	BB-GREEN	
6	EU	BEAUTY	
7	EU	BESST	http://www.besst.it/BESST/target.xhtml
8	German Gov-sponsored	BIOCLEAN	
9	Private?	BMT Defence Services Ltd, UK	
10	EU	CALYPSO,	
11	EU	CLEANENGINE	
12	Joint Industry (Mainly Finnish)	CLEEN-FCEP	
13	EUROSTARS	CONNORESS	
14		CREATING	
15	EU	DEECON	
16	German BMVBS	e4ships	
17	EU	ECO-REFITEC	
18	EU	EFFORT,	
19	National Swedish Shipbuilding Institute SSPA	EFFSHIP	http://www.effship.com/index.htm
20	EU	ENGINE EFFICIENCY (Fluid Interactions for Engine Efficiency)	
21	F	EONAV	http://en.polemermediterranee.com/Ship-and-nautical-industry/Ships-of-the-future/EONAV
22	D	EPROSYS-HF	
23	EU	EROCAV,	

24	Deutsche Bundesstiftung Umwelt (DBU)	E-Ship 1	
25	EU	FANTASTIC	
26	EU	FASTPOD	
27	EU	FELICITAS	
28	EUREKA (Norway & German Gov)	FellowSHIP	
29		Finnish Fuel Cell programme	
30	F - D	FLIPPER (MARTEC)	
31	D	Form-Pro	Via: www.hsva.de
32	Joint Research Project with wellknown German Shipyards	Gas-Pax	
33	UK TSB & TSDL	GLEAMS	
34	Joint initiative (Danish Maritime Cluster)	Green Ship of the Future (GSF) / GREENSHIP	http://www.greenship.org/
35	EU	GRIP	www.grip-project.eu
36	Involves ETN	H2IGCC	
37	D	HAI-TECH	Via: www.hsva.de
38	EU	HANDLING WAVES	
39	EU	HELIOS	
40	EU	HERCULES A	
41	EU	HERCULES B	
42	EU	HERCULES C	
43	GR	HYBRID (NTUA-SDL)	
44	Scottish Government with ERDF	Hybrid Ferries	
45	EU	HYMAR	
46	EU	INOMANS2HIP,	http://inomanship.eu/
47	F	IWEST	
48	EU	JOULES	http://www.joules-project.eu/Joules/index.xhtml
49	EU	KAPRICCIO	Via: www.hsva.de

50	D	KONKAV (I - III)	
51	TSB	LCS	http://www.lowcarbonshipping.co.uk/index.php?option=com_content&view=featured&Itemid=101
52	EU	MARINECFD	
53	EUROSTARS	MARIPEM	
54	EUREKA & TSB	MARITIME CCS	
55	EU	MC-WAP	
56	EU	METHAPU	
57	F	Navire démonstrateur Océan Vital	
58	EU	NAVTRONIC	http://www.navtronic-project.eu/mainmenu/home.html
59	GR	NEWDRIFT (NTUA-SDL)	
60	EU	NG²SHIPI/F	
61	D	NoWelle	Via: www.hsva.de
62	D	PerSEE	Via: www.hsva.de
63	EU	PLUG	
64	EU	POSE2IDON	http://www.poseidon-ip.eu/
65	FCH-JU	PURE	
66	EU	REFRESH	http://www.refreshproject.eu/
67		Rensea	
68	Lloyd's Register, Enterprises Shipping and Trading, Hyperion Power Generation and BMT	Research Consortium	
69	EU	RETROFIT	http://www.retrofit-project.eu/
70		Sailboat Zero CO2	
71	EU	SEAKERS (for yachts)	
72	EU	SEAROUTES	
73		SEKTE	
74	EU	SHOPERA	
75	EU	SMART-H2	
76	EU	SMOOTH	
77	S	SPIRETH	Swedish Energy Agency, the Baltic Sea Action Plan Facility Fund (Nordic Investment Bank), the Nordic Council of Ministers’ Energy & Transport
78	EU	STREAMLINE	www.streamline-project.eu
79	EU	TARGETS	www.targets-project.eu

80	EU	TEFLES	http://tefles.eu/
81	EU	TEN-T Priority 21	
82	D	TUG Design	Via: www.hsva.de
83	EU	ULYSSES	http://www.ultraslowships.com/
84	UK TSB	Vessel Efficiency I	
85	EU	VIRTUE	www.virtualbasin.org
86	EU	VRSHIPS-ROPAX2000 (NTUA-SDL)	
87	LIFE	WINTECC	
88	LIFE	Zemships	