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Design

SEMISUBMERSIBLE RIG

"The Reliable Solution with Minimal Thrust Losses"

Mikko Mattila & Jari Ylitalo
ABB Finland

Julian Soles
GlobalSantaFe

Introduction

This paper describes a co-operation of ABB and GlobalSantaFe (GSF) for developing of thruster system for Development Driller class semi-submersible drilling rigs.

This paper presents the requirements that operator has for propulsion system of drilling rig and a solution that fullfills these requirements.

For a drilling rig it is essential for DP operations to minimize the thruster hull interaction losses and therefore ABB and GSF have made a joint study to learn more about these losses and find a solution to give the best effective thrust for the operation. This study has been made at Krylov Ship Research Institute by the means of Computational and model scale experiments.

With the Computational method the scale effects and behavior of thruster jet have been studied. Computational method applied is state of the art RANS method.

The model test experiements give the most reliable results of the forces affecting to pontoons of the rig and this way it has been possible to quantify the losses due to thruster hull interaction. To minimize these losses the propeller shafline has been tilted in respect of pontoon bottom and the effect of different tilt angles have been studied.

Finally it has been possible to make comparison between other solutions available on the market.

The Development Driller Class

The Development Driller class of semi-submersibles are Friede & Goldman designed units configured for ultra efficient production (development) drilling. The nominal operating water depth is 7,500 ft and is designed to operate in moderate environments such as the Gulf of Mexico, West Africa and Brazil.

GlobalSantaFe has entered into a contract with PPL Shipyard in Singapore to build two of these new semi-submersible units. The design of these rigs is described in detail in a paper presented in Rio de Janeiro in October 2001 (Ref 1).

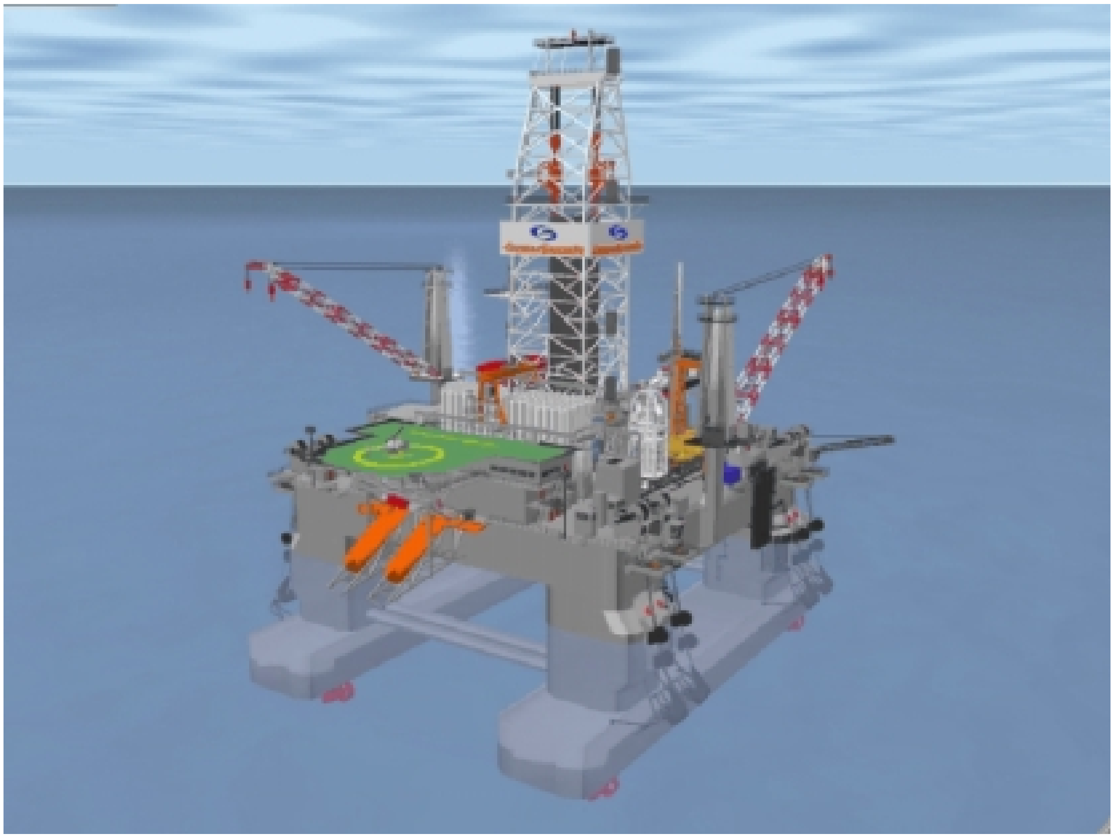

Fig. 1: Development Driller Class semi-submersible.

Both the new build semi-submersible designs are speculation builds and are currently not under contract. This has lead to requiring the maximum number of station keeping options and therefore the vessel has both an 8-point self contained mooring system and a full dynamic positioning (DP) system. The dynamic positioning system is capable of working in either thruster assist mode or normal DP mode, providing great operational flexibility throughout the development of any deep water reservoir.

It is expected that the vessel will spend the majority of its life moored and initially only a DP assist system was considered, but after investigating the incremental cost of moving to a full DP system the cost benefit of the full system was considered acceptable.

Typically modern semi-submersibles are fitted with azimuthing thrusters with nozzles, as they provide maximum thrust at low speeds and are capable of directing the thrust in the required direction by simply rotating the entire unit.

During the selection process of the thrusters for the Development Driller several key areas were looked at to evaluate each unit and manufacturer. The areas that were considered as key are,

- Through life reliability and maintenance
- Cost
- Performance
- Ease of installation/removal in field

The dynamic positioning system is designed to accommodate thruster failures for the designated maximum environmental conditions, even with this capability when a thruster fails it can result in operations stopping and down time for the vessel depending on the environmental conditions. Due to the high spread costs of deep water development rig down time is unacceptable and should a thruster fail the time to repair can be costly, therefore reliability is the highest priority in thruster selection.

Performance was a key issue, as it was the aim of the design team to optimise the size of the system so that the vessel was not over powered. This lead to the requirement that the thruster selected would need to be extremely efficient and use the power supplied to it to generate the most amount of thrust.

It is also becoming common practice to be able to change thrusters out in the field, as it eliminates the need to return to the dock to change out/repair the thruster and results in significant cost savings. This resulted in the size and weight of the units to be critical, as the vessels deck cranes needed to be able to reach to each corner and keel haul the thruster. During the sizing of the deck cranes this capability was a key factor.

Types of Propulsion units considered

- *Azimuthing Thruster*

The most common type of thruster used on semi-submersibles is the azimuthing thruster shown in Figure 2. The propeller is typically driven by an electric motor located directly above the thruster in the pontoons through a system of bevelled gears, this enables the electric motor rotation to be transmitted though 90 degrees.

Fig 2: Typical azimuthing thruster

To rotate the thruster about the vertical axis hydraulic steering gear is used, these typically can take up a large amount of room and also require a hydraulic power unit to drive them that can also be sizeable. Therefore trying to accommodate these types of thrusters into a small thruster room often poses a challenge.

- *Podded Propulsion*

The podded propulsion unit shown in Fig. 3 is driven by an electrical motor. The motor is located directly in line with the propeller that enables it to drive a thrust bearing located behind it and drive the propeller without the use of any gearing system, subsequently reducing transmission losses considerably.

The electric motor is cooled to the surrounding water eliminating the need for any cooling system to be installed and further reducing mechanical complexity. The unit is steered by an electric motor in the pontoon that takes up less space than the hydraulic steering units on the azimuthing thrusters and this also removes the requirement for a hydraulic power unit.

Fig. 3: Compact Azipod unit

This paper goes on to describe the features of the unit in greater detail and some of the key advantages of the podded propulsion over the typical azimuthing thruster, some of which are highlighted below.

- Reduced mechanical complexity.
- Reduced space requirements.
- Reduced ventilation requirements.
- Reduced noise levels
- No cooling requirements.
- No Hydraulic for steering.
- More mechanically efficient, no gearbox or crown gear.

- Improved thruster efficiency, whole unit can be tilted rather than just the cowling as is common practice on conventional thruster.

Due to the reasons listed above and the requirement to minimise the size of the DP system, the podded propulsion became the design of choice when selecting the type of thrusters to be installed on the Development Driller.

The Compact Azipod

The Azipod history

The original idea for the Azipod system was developed when the Finnish Maritime Administration began to seek better solutions for the operation of icebreakers in ice channels. An important feature of an icebreaker is that it must be able to break out of an existing ice channel. This is important when the merchant ships that are being assisted are using the ice channel and the icebreaker has to move around the operational area. To overcome this problem, the idea of a propulsion motor that could direct the thrust to any direction was created.

The first joint R&D project was the conversion of Seili, a waterway service vessel owned by the Finnish Maritime Administration, into the first Azipod ship in the world. This took place in 1989. The Seili continues to operate today, and its 1.5 MW unit has operated faultlessly since the conversion.

Kvaerner Masa-Yards and ABB made an agreement in 1992 to develop and market the unit jointly. In 1993 the name Azipod was registered.

The next ship to be equipped with Azipod was a 16 000 DWT product tanker, the M/T Uikku, built in 1978 in Germany. The conversion work of Uikku was done in 1993. The power of Uikku's Azipod unit is 11,4 MW. The ship was built to ice class 1A Super and the Azipod to DnV ice 10 class. In 1995, Uikku's sister ship the M/T Lunni was similarly converted. Both ships have been in heavy commercial use since conversion. Their combined operating hours total well over 40,000. Of these, about 15,000 hours were on ice-infested waters.

In 1997 Uikku became the first western cargo ship to navigate through the North-east Sea route. Uikku started its journey in Murmansk in western Russia in the beginning of September. Twelve days later Uikku arrived in Providenya, located in eastern Siberia south of the Bering Strait. The Uikku and The Lunni demonstrate the soundness of the basic design and construction chosen for the Azipod. The Azipod propulsion is the only way to make North-east Sea route economically viable because the ships can operate very safely without icebreaker assistance

The real breakthrough came when CCL (Carnival Cruise Lines) decided to choose Azipod for the Elation and the Paradise in the autumn of 1995. The power of each of the two units is 14 MW. This order actually set off the change of propulsor type for big cruise ships. The CCL Fantasy series actually started the electrical propulsion era for cruise ships. When Elation and Paradise belongs to that series we can say that no other series of passenger ships has affected so much the propulsion concept of cruise ships.

In the late 1990's the demand from the market and good experiences with larger units gave an clear signal to start development work for the lower power range units.

Today ABB have orderbacklog of over 100 units sold and more than 50 units delivered with accumulated operating hours exceeding 500 000 hours.

The unit

The compact Azipod unit consists of four main modules:

- Propeller, with or without nozzle
- Electric Motor Module
- Strut Module
- Power Transmission and Steering Module

All the modules can be dismounted for transport or for maintenance or replacement work. This feature also allows for partial deliveries to the shipyard on demand.

The fixed pitch propeller is driven by an electrical motor, directly mounted on the propeller shaft. The electrical power is controlled by an on-board frequency converter, and transmitted to the electrical motor via the power slip rings at the power transmission and steering module.

The electrical motor is cooled by the surrounding seawater through the motor housing. There is no need for any additional cooling media to the motor.

The azimuthing angle control is fully electrical, with a redundant variable speed controlled steering machinery, which together with the slip rings ensures free rotation.

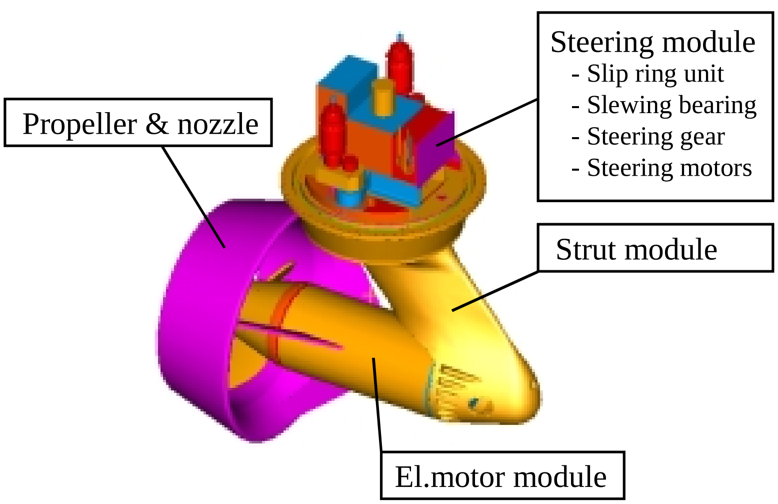

Fig. 4: Compact Azipod thruster.

The design of Compact Azipod includes features that make system a reliable and effective thruster solution for DP operations.

- Possibility to take full power also with reversed Rpm's
- Precise azimuthing control
- Azimuthing speed
- Possibility to the tilt the unit (both propeller and nozzle)

The nozzles around the propeller are normally directly in-line with the propeller shaft, so that the tip clearance between the propeller and inside of the nozzle is a minimum and uniform around the circumference. Should there be a large variation in tip clearance the pressure distribution across the propeller becomes significantly different between the top and bottom and causes thrust efficiency losses.

Compact Azipod pilot project

The first vessel equipped with Compact Azipod, M/S Normand Rover, was completed at the end of 2001, and is based on a UT 745E design by Rolls Royce Marine, equipped for DP class 2 requirements. Her two sister ships are designed to fulfill DP class 3 requirements.

Normand Rover is equipped with two compact Azipod propulsion thrusters in the aft, one azimuth thruster and two tunnel thrusters fore. The vessel has been designed for multifunctional usage, where a flexible arrangement and outfitting has been selected in order to enable a variety of operations, including platform supply and ROV support. Fig. 2 shows the general arrangement of the ship design.

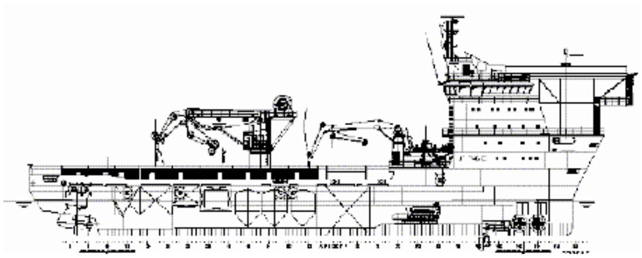

Fig. 5: GA drawing of the UT 745E multifunctional platform supply and ROV vessel.

Søviknes Verft had a tight delivery schedule from the arrival of the hull from Aker Tulcea in Romania on the 6th of June, to delivery of Normand Rover in mid November. The ready-to-mount pods were delivered from ABB's production facility and 14 days were allocated in the project plan for their mounting. But Compact Azipod proved it's readiness and simplicity to mount and the installation process was completed in only 7 days.

During the following sea-trials the Compact Azipod continued to impress and it met all technical specifications and expectations to maneuvering capabilities and transit properties. The ABB DP class 2 system with advanced functions, such as Follow ROV and Way-point Tracking, also showed a high performance level and contributed to shortening the total sea-trial time.Delivery of the vessel took place 16th of November to the owner after conducting seatrials successfully.

The Normand Rover was chartered to the Mexican Oil Company Pemex and is performing subsea services in the Gulf of Mexico on a two-year contract. Due to this contract right after delivery vessel went over North Atlantic and started working in the Gulf of Mexico mid December. In the end of June vessel had 4750 operating hours and today it is well over 5000 hrs in service. Today there are totally three vessels with Compact Azipod propulsion in operation.

Minimal thrust losses and how these were achieved

General

Due to the design of the semi-submersible the wake from a thruster interacts with the hulls and neighbouring thrusters and has been subject to many publisehd studies (Ref.2). To reduce the effects of thruster hull interactions it has become common to tilt the nozzles downwards and subsequently direct the wake away from the pontoons. For a conventional azimuthing thruster the further the nozzle is tilted downwards, the greater the efficiency of the unit is decreased resulting in a trade off between thrust gained and efficiency lost as investigated by Vartdal et al. 2001.

The joint study of ABB and GSF

- *The intention of the study*

The study was carried out jointly by ABB Oy (ABB) and GlobalSantaFe Corp. (GSF) to determine the optimum tilt angle of the Compact Azipod® thrusters for the GSF semi-submersible drilling rigs 184 & 185 currently being built at the PPL shipyard in Singapore.

The idea of tilting the thruster is to minimize thrust deduction, due to the presence of the rig hull and Coanda effect (The natural tendency for the propeller jet stream to follow the curve of the hull resulting in further loss of efficiency). Therefore by directing the thruster jet away from the hull will result in more effective thrust with less propulsion power.

In mechanical thrusters tilting of the nozzle with respect to the propeller has sometimes been used when aiming for these same benefits, however nozzle tilting in this case decreases the efficiency of the thruster and must be subtracted from the increased thrust. It would appear from available litterature that all previous studies in this area have been related to mechanical thrusters.

With the Compact Azipod®s the tilting can be arranged simply by adjusting the angle of the propeller shaft line relative to the horizontal plane. This is possible since there is no mechanical power transmission connections to the motor module. With the Compact Azipod® the decrease in unit efficiency does not occur since there is no change in the relative angle between the nozzle and propeller.

The Krylov Ship Research Institute (KSRI) was contracted to carry out a study that included computational investigation into the behavior of the thruster jet, as well as scale model tests to find out the actual thrust forces. In the scale model tests the existing models (propeller, duct and pod) from previous model tests where the optimum propeller and nozzle combination was investigated was used.

- *Definition of the tilt angle*

The Angle between the assembly block mounting flange and the motor module shaft line is the Compact Azipod® tilt angle α. The tilt angle describes how much the propeller shaft line is tilted with respect to the mounting flange plane (and thereby with respect to the rig hull). See figure below.

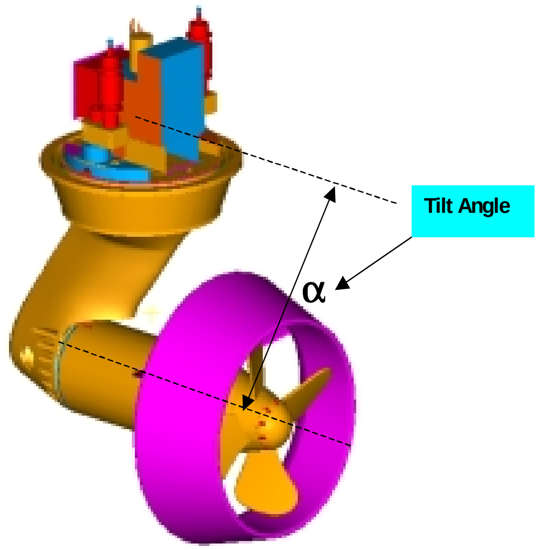

Fig. 6: Main parts and modules of Compact Azipod®

- *Computational method*

First the behavior of the slipstream of the working thruster was studied with the computational flow simulation. The computational method applied was the so-called RANS-code (Reynolds Averaged Navier Stokes) developed by KSRI. With this method it is possible to calculate the viscous flow with different Reynold's numbers. Calculations were carried out for two Reynolds numbers: model ($Rn=4.405\times10^6$) and full scale ($Rn=1.113\times10^8$). Reynolds numbers $Rn = \frac{U_0 D}{\nu}$ was calculated in regards of reference length – propeller diameter D=2R, and reference speed – linear speed of the tip of blade $U_O=2\pi nR$ which was selected because conventional reference speed – flow velocity in the infinity in front of the propeller in subject case of bollard pull is equal to zero. Coefficients of total thrust of propeller and duct as well as torque coefficient were determined as $K_{TD} = \frac{T}{\rho n^2 D^4}$, $K_Q = \frac{Q}{\rho n^2 D^5}$ and taken without allowance of scale effect. Computational conditions are presented in Table 1.

Figure 7 shows the pontoon arrangment of the Development Driller, and also the definition of pontoons A and B that are discussed throughout the rest of the paper.

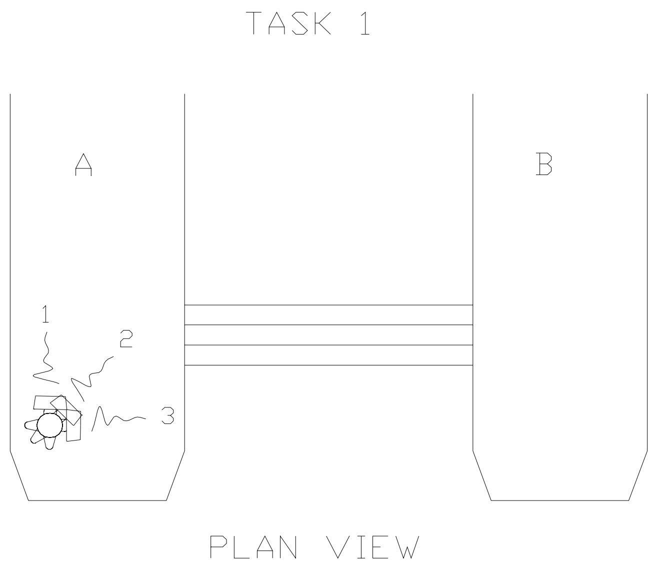

Fig 7. Definition of thruster position and direction of jet/wake relative to pontoons A and B.

Table 1.

	Model	Full scale
Propeller rotational speed n, RPS	40	3.3
Rn	4.405×10^{6}	1.113×10^{8}
K_{TD}	0.364	0.364
$10K_{Q}$	0.264	0.264

Initially calculations were carried out for the propeller jet in infinite liquid space (ie. open water condition). Computational investigation allowed to determine the increase of the jet diameter for model and full-scale conditions as it was necessary for preliminary estimation of interaction of the jet with the pontoons. The computational area was restricted by 11 propeller diameters to each side in transversal direction, 11 diameters in front of propeller and 25 diameters downstream of the propeller. The number of computational points in the grid in the axial, transversal and vertical direction was equal to 50×44×44. Near the propeller axis the grid was more frequent. The calculated axial speed, V_X, distribution in the jet along the section via jet axis is presented in Fig. 8 and 9 for model and full-scale conditions. For easier comparison geometric dimensions of the computational area are presented for full-scale conditions. It is clear from the presented Figures that the full scale jet is more narrow than for the model Rn, and is in good agreement with general ideas on scale effects in viscose liquid.

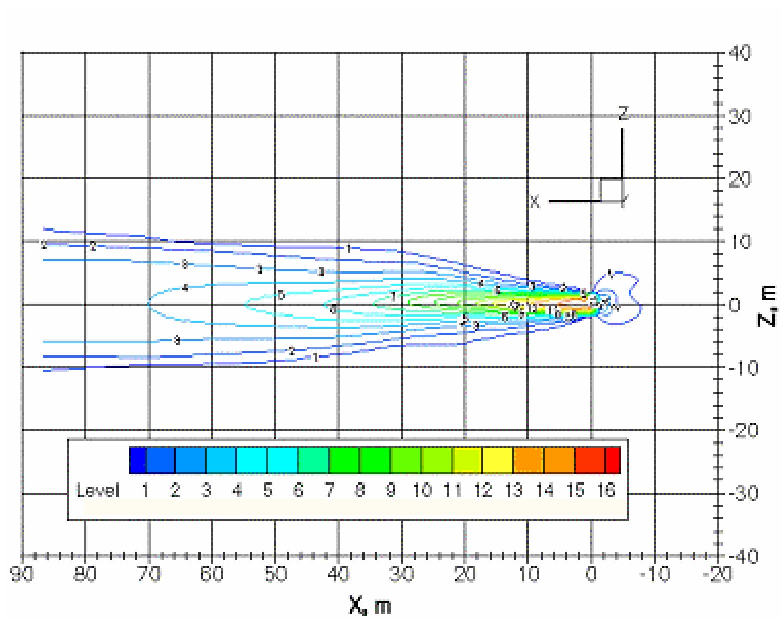

Fig. 8: Distribution of axial velocity V_x in propeller jet. Model condition.

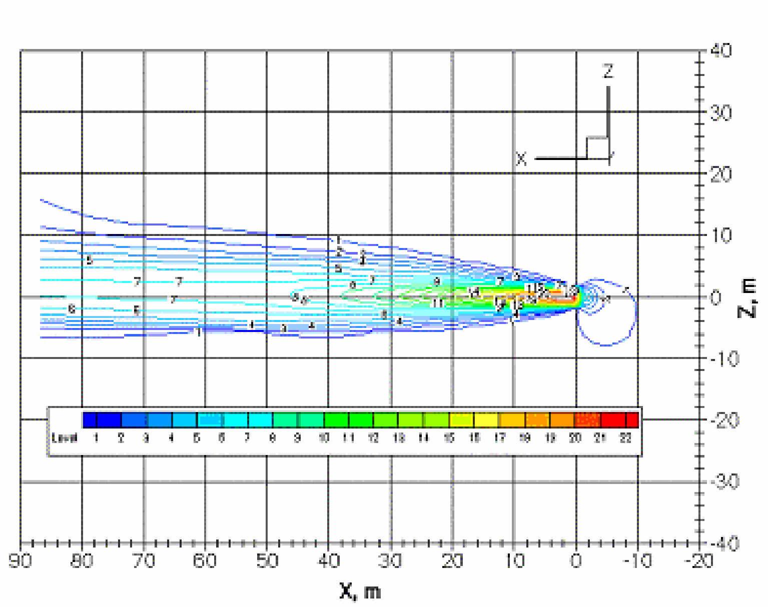

Fig. 9: Distribution of axial velocity V_x in propeller jet. Full scale condition.

The next condition studied with calculations was the development of the jet under an infinite plate. The main aim of this investigation was to estimate the force interaction of propeller jet with the hull of the pontoon where the thruster is installed. The bottom of the pontoon was simulated by an infinite plate, therefore the impact of plate edge was excluded from consideration. Dimensions of computational space was 11 propeller diameters (D) to each side in transversal direction, 11D upstream, 35D downstream, the depth of the zone is 11D below the propeller axis, which was taken at 3.31m below bottom of the hull. The number of grid points in axial, transversal and vertical directions was equal to 55×44×40 (more frequent grid near the axis).

The axial velocity distribution, V_X, in the vertical section via the propeller center for model conditions is presented in Fig. 10. It is clear from the Figure that at the some distance from the propeller the jet attaches to the plane and downstream the jet is fully attached along the lower hull. At full scale Rn the picture is similar, except that the point of attachment was 2-3 meters further downstream compared with the model scale results.

For analysis of force interaction between jet and pontoon let us consider viscous tension τ distribution on the plate surface as it is shown in Fig. 11. Jet swirl effect demonstrated itself in some distortion of jet from axial direction to the direction of swirl, as it is seen in the Figures. For model Rn the jet attached to the plate surface at 16 m from the propeller disk in full-scale dimensions. At full scale conditions this distance is equal to 18 m. Therefore when propeller is directed to perpendicular to centerline of the pontoon, jet attachment to the bottom will not take place. Maximal action of the jet onto the pontoon will take place when the jet is directed along Centerline of the pontoon. Total friction force was determined by integration of friction tension on the surface corresponded to bottom of the pontoon. Integrating area is marked in Fig. 11. Calculated friction force for the model was equal to 5.2% from propeller thrust for model and correspondingly 2.2% for full scale conditions. This data for model test is in quite reasonable agreement with previous experience of the tests at pontoon – like flat bottom models (thrust deduction at bollard pull astern). So, the results allowed to conclude that interaction of the jet with the pontoon A where thruster is installed is not negligible only when the thruster is directed along centerline, but even for this case friction force is rather small especially for full scale conditions.

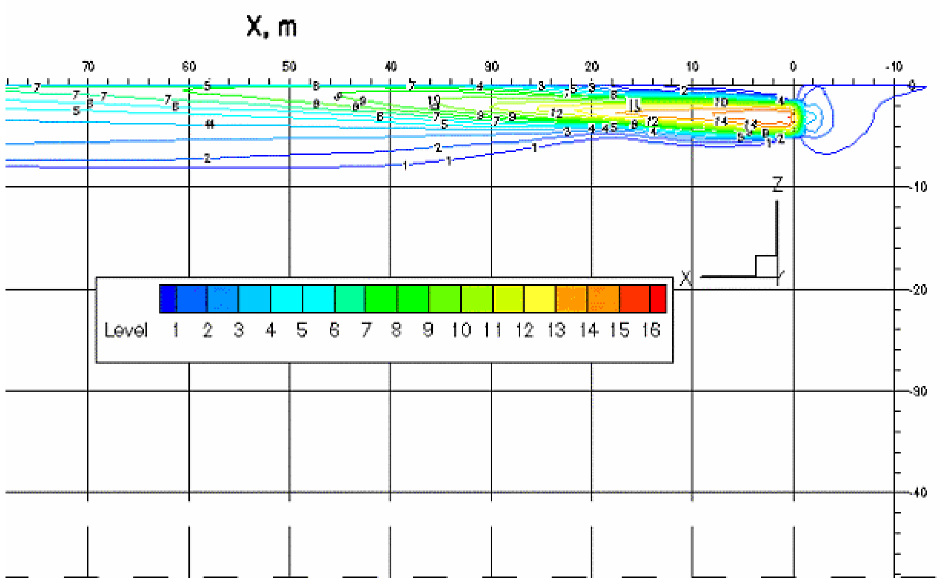

Fig. 10: Distribution of axial velocity V_x from propeller jet near flat plane.

Model condition.

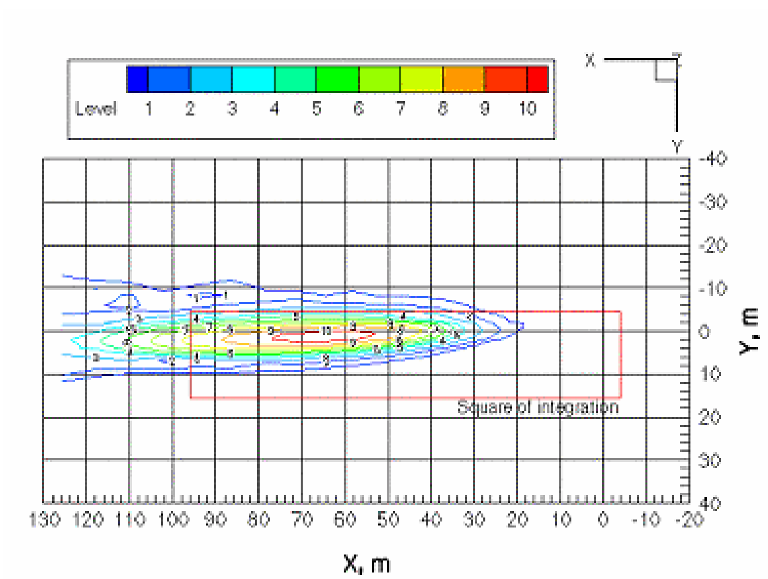

Fig.11. Viscous tension distribution on the plate surface.

All the previous calculations were performed without a tilt angle, as the main aim was to study the behaviour of the jet rather than to study the actual differencies between tilt angles. Finally calculations for the case of 7 degrees downward inclination of the thruster axis was performed. The dimensions of the computational zone were kept without modification. The number of grid points were increased to 92×44×56 though.

The distribution of the axial velocity across the vertical section though the propeller center is presented in Fig.12 for the full-scale condition. It is seen that the jet does not touch the pontoon and there was no influence on the thruster jet from the pontoon.

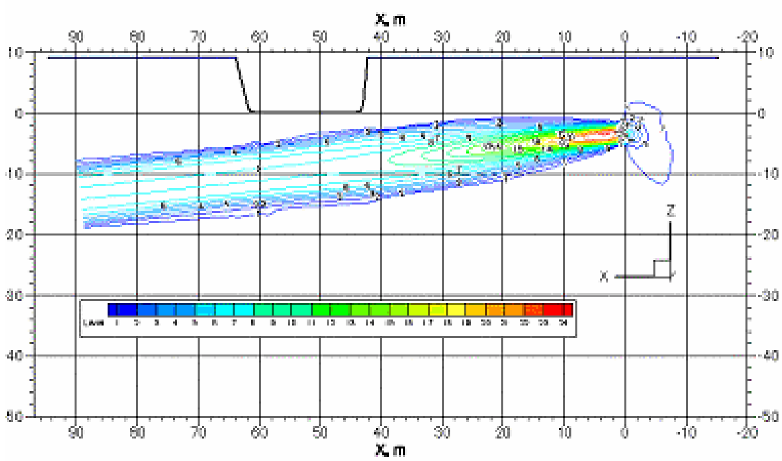

Fig.12. Impact of the propeller jet to pontoon B, showing the axial velocity V_x distribution through the center of the propeller disk.

Based on the computation results for development of the jet in an infinite area, it can be assumed that the investigation of the force on pontoon B induced by the jet from the thruster installed on pontoon A is the most important from the point of thrust deduction. Computations were carried out for simplified configuration: pontoon A where the thruster is installed was not simulated, pontoon B was considered as infinite in axial direction. Such a simplified model was found as optimal to minimize the rational scope of computations. The main task of the computation was to invetsigate the thruster jet flow, and also help to estimate scale effects in the model test results.

It is considerd that the more reliable results are those from the model experiments. The exclusion of pontoon A is in Figure 12 is based on the results of the computation of development of the jet under the flat plate (Figure 10), which showed that when jet developed in transversal direction the transverse length of the hull was much too short for the attachment of the jet. Also the assumption of the infinite length of the pontoon B can have some impact on the results (Figure 11), but it can be useful in providing some estimation of the expected force during the model tests.

- *Experimental method*

In the experimental study the existing models of propeller, duct and pod dummy manufactured for the original propeller and nozzle model tests were used. The experiments were carried out in the depressurized towing tank at KSRI as the models used were built to suit the measuring equipment used in this particular tank. Two models of the pontoons of the rig were also manufactured.

The length of these pontoon sections were determined during the preliminary study of the jet behavior, where it was concluded that when the jet is not directed along the hull there is no need to represent the full pontoon sections as the jet of the thruster does interact with the whole length of the pontoon.

The instrumentation used included the propeller open water dynamometer, thruster dynamometer, force gauges for nozzle and pod dummy force measurements and multi component dynamometer for planar forces acting on the pontoons. During the tests different tilt angles were studied.

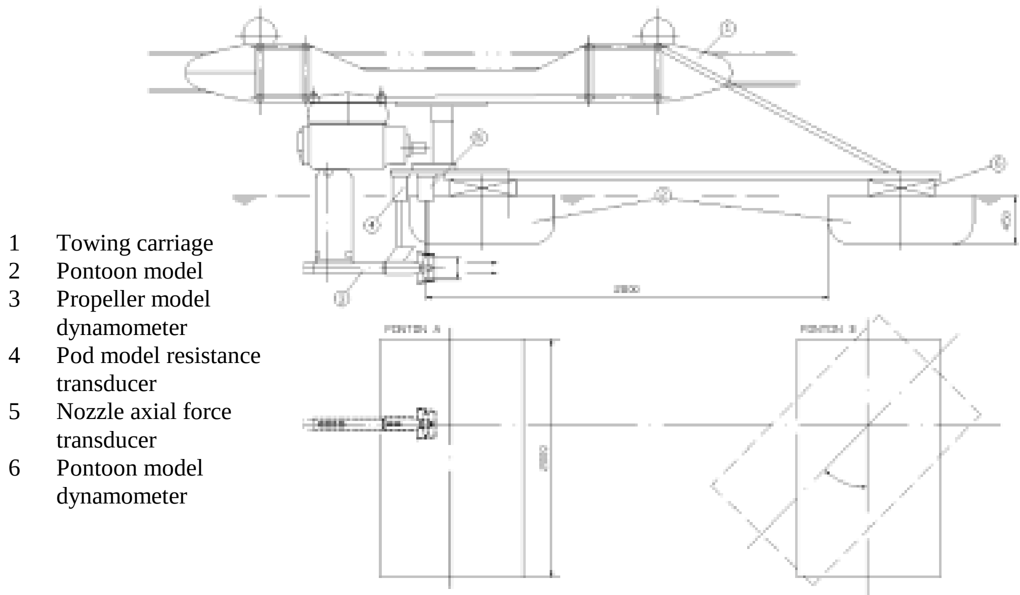

Fig. 13: Experimental setup for determination of interaction between thruster and platform hulls.

The problem was divided into different parts so that it would be possible to understand where the different interaction losses are coming from. First the interaction of thrusters with the pontoons was studied with only one thruster fitted to the end of the pontoon. The test setup for this arrangement is shown in Fig. 13.

When the jet is directed perpendicular to the centerline of pontoon thrust deduction on hull B was reduced by increasing of tilt angle γ. At γ = 3.5° the thrust deduction reduced by approximatley 50% compared to the zero tilt angle result, and at γ = 7° the thrust deduction was practically zero. The results of this test is presented in Fig.14.

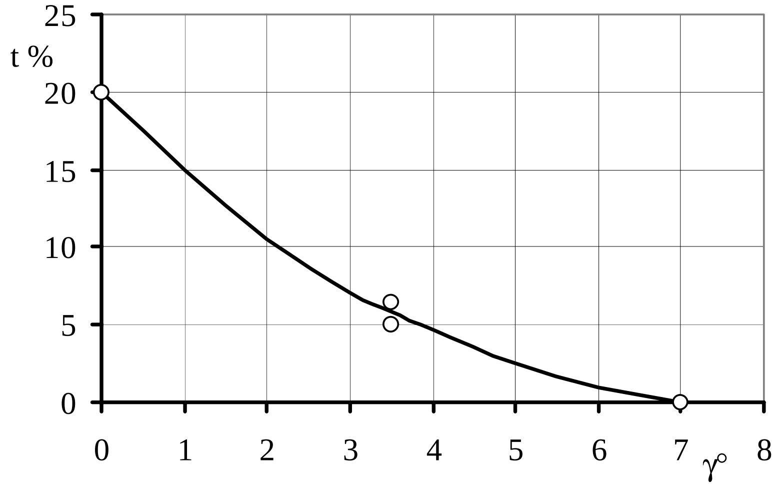

Fig. 14: Thrust deduction coefficient as a function of tilt angle at α=0°

When rotating the thruster by upto 45° relative to the centerline of pontoon the thrust deduction force was reduced. The results for tilt angle γ = 0 and γ = 3.5° are presented in Fig.15, where α = 0° represents the jet being directed perpendicular to the centerline of the pontoon.

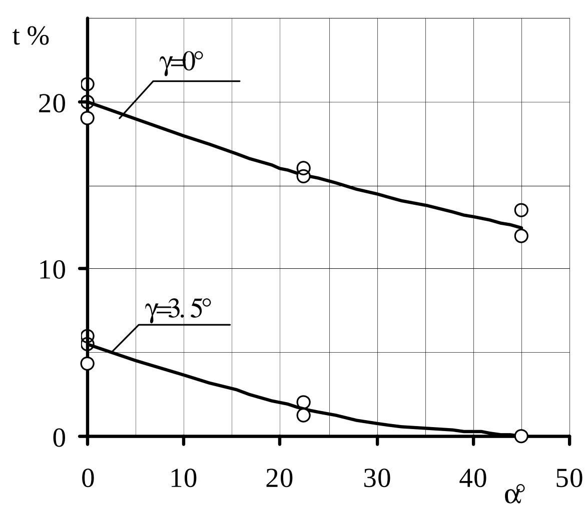

Fig. 15: Thrust deduction coefficient as a function of turning angle.

The function of thrust deduction coefficient versus tilt angle, γ, when the jet is directed along the hull is presented in Fig. 16. It is clear that when the jet is developed along the hull parallel to the bottom at γ = 0, t = 7%.

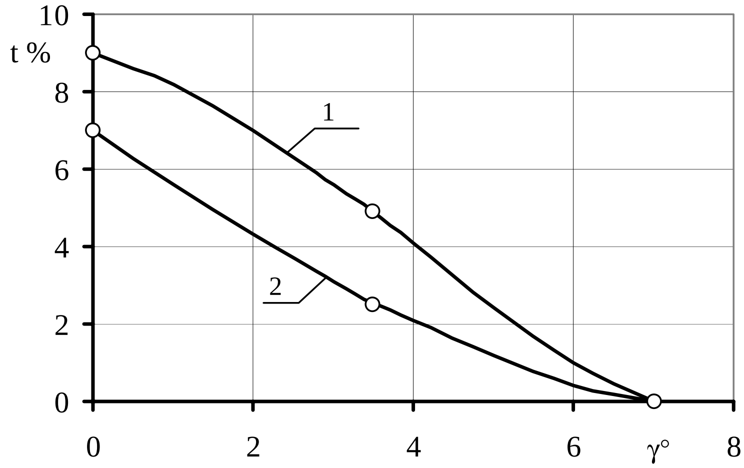

Fig. 16: Thrust deduction coefficient as a function of the tilt angle when the jet is directed along the hull.

1-with dummy thruster located at the other end of the hull;

2-without dummy thruster present.

At γ = 7° thrust deduction force is equal to zero for all investigated turning angles. This means that there are no thruster/hull interactions present. Thus it is advisable to accept the tilt angle γ = 7° based on these results. In this case the loss of thrust proportional to cos γ will not exceed 0.8% of the maximum thrust of the unit.

The presence of the dummy thruster (non operated, propeller locked) in the jet at opposite end of pontoon led to increasing of the thrust deduction to 9-10% at tilt angle γ = 0 and γ = 3.5°. At γ = 7° the interaction was absent even in presence of the thruster dummy.

The rresence of the locked thruster on hull B when jet was perpendicular to centerline resulted in an increase in thrust deduction (t=30%) at γ = 0 and α = 0. This additional thrust deduction rapidly reduced though with increasing tilt angle or turning angle and at 7 degrees tilt it vanished completely.

With these results it was concluded that with 7 degrees tilt angle the presence of another thruster on the neighbouring pontoon or on the other end of same pontoon will have no effect on the effective thrust force.

- *The conclusions of the study*

From the computational study it became clear that the interaction forces have significant scale effects and thus values from the model scale results are over estimating the actual interaction forces. Additionally the behaviour of the propeller jet can be understood more clearly. The computational results didn't show the presence of the Coanda effect and thus the thruster/hull interaction losses were coming purely from viscous forces between the jet and pontoon bottom.

When comparing the computational results and experiemental results it can be seen that the computational results are slightly exaggerated and the reason for this is most probably simplifications in the computational model. The most important feature of computational results is the qualitative results that explain the process of jet development.

As the model scale values from the model experiments were scaled directly to full scale from the difference between model and full scale Reynolds numbers, the values achieved include a "safety margin".

As previously described the thrust deduction due to the interaction between the wake, the hull and neighbouring thrusters can be significant (up to 30 % of thrust), but by applying the tilt angle these losses can be avoided without making any compromises in thrust from the unit when using Compact Azipod propulsion.

Based on the results of this joint study it was a straight forward decision to decide that 7 degrees is the optimum tilt angle for Global Santa Fe rigs 184 and 185.

COMPARISON TO MECHANICAL THRUSTERS

As mechanical thrusters don't have capability to tilt the propeller shaft due to the gearing required for power transmission, the Compact Azipod has a disticnt advatage over the mechanical thrusters. There are different approaches between different mechanical thruster manufacturers, one solution is to accept that there will be some losses due to thrusters/hull interaction and the other approach is to tilt the nozzle. As previously mentioned the tilting of the nozzle will decrease the efficiency of the unit alone.

If the mechanical thruster is assumed not to have a tilted nozzle, then the improvements in thrust losses of the Compact Azipod over the mechanical thruster are comparble to the results for 0 and 7 degrees tilt described earlier in the paper.

As previously described these losses can be up to 30% of the thrust compared to the no losses achieved with a 7 degrees tilt angle using the Compact Azipod. Naturally these extreme losses will be avoided with banned zones in dynamic positioning (DP) control software, but typically losses are between 10 to 20 % of the unit thrust. Therefore by using the Compact Azipod the selected unit can be 10% less powerful than would be required by a mechanical thruster.

The following comparison of the tilted nozzle of a mechanical thruster is based on data presented by Vartdal & Garen [ref. 3]. Allthough the application is not identical some comparisons can be made and it is applicable to all rig applications.

The simplest cases to compare are when the thruster is directed perpendicular to or along the centerline of the pontoon. The other angles have a different behaviour as thruster thruster interactions take place at different angles due to the different locations of the thrusters, but it should be noted that the thruster thruster interaction is not dependent on how the flow is directed. When the thruster wake is sideways so that the slipstream is directed towards other pontoon (if the slipstream is directed outwards the losses with both systems is close to zero) the tilted nozzle is reported to have losses of 4 to 6 % of unit thrust compared to the zero losses with Compact Azipod. This could be attributed to the differences in the pontoon geometries and separation though.

The other case is when the thruster jet is directed along the pontoon and in this case the tilted nozzle shows losses of about 4 to 5 % of unit thrust. When the thruster jet is directed towards the other thruster the losses will be about the same for both systems ie. about 60 % of total thrust, but these situations should be avoided by DP control software.

The thrust loss due to the tilting of the nozzle only to 8 degrees was found by Vartdal to be 2% in open water, compared to less than 0.8 % reduction with Compact Azipod when tilting the shaft as well. This means that if the both units would have same bollard thrust, the tilted nozzle would give in average 1.2 % less effective thrust than the Compact Azipod without the presence of the vessel hull.

The reason for the difference in the thrust reduction between these two solutions is that when nozzle is tilted with respect to the propeller shaft some of the benefits of the nozzle are lost. The only reason that the Compact Azipod experiences losses here is only due to fact that the thrust is directed 7 degrees upwards from horizonal plane.

CONCLUSIONS

The Compact Azipod is a new simple and reliable, but yet an efficient thruster that has well over 5000 hours of operational experience with pilot installation in offshore operations.

The Results of Computational method give a better understanding of the interaction of thruster jet and drilling rig pontoons. With this method the presence of Coanda effect hasn't been verified. Calculations have been carried out both in model scale and in full scale condition and these results give a clear indication that the scale effects have significant importance in effective thrust of the thrusters.

With Scale model tests the optimum tilt angle of the shaftline with respect to the pontoons was found for the Compact Azipods on the Development Driller. With this tilt angle it has been possible to get get rid of thruster hull interaction effects.

A comparison with Compact Azipod and mechanical thruster with tilted nozzle has been made and this gives a 4 to 5 % advantage in thrust for Compact Azipod without taking into account the differencies in mechanical losses (about 5%) and electric motor efficiencies (3%). When taking into account all the differencies the Compact Azipod could use 12 % less power than a mechanical thruster to give same effective thrust.

References

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