JOURNAL OF SUBSEA AND OFFSHORE

SCIENCE AND ENGINEERING

VOLUME.4

DECEMBER 30, 2015

ISSN: 2442-6415

PUBLISHED BY ISOMAse

Journal of Subsea and Offshore
-Science and Engineering-

Vol.4: December 30, 2015

Contents

ISOMAse

International Society of Ocean, Mechanical and Aerospace
-Scientists and Engineers-

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International Society of Ocean, Mechanical and Aerospace
-Scientists and Engineers-

Journal of Subsea and Offshore
-Science and Engineering-, Vol.4

December 30, 2015

Critical Safety Elements in Subsea Asset Integrity Framework

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Paper History

Received: 30-October-2015
Received in revised form: 15-December-2015
Accepted: 30-December-2015

ABSTRACT

Safety incident provides valuable lessons learned for us to avoid similar situations from recurring. The 2010 BP Macondo incident set high impact in managing asset integrity in minimizing risk exposure. Asset integrity is defined as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment. Asset integrity management is a continuous process throughout the project lifecycle. Few subsea related oil and gas landmark accidents showcased that asset integrity must be maintained at the highest possible standard at all times. Due to the unique nature of subsea and high cost involvement, subsea asset integrity should be given high attention from the beginning of a project's lifecycle. Based on extensive literature review, critical safety elements such as performance standard, risk evaluation and mitigation, competency safety culture are identified. Existing asset integrity framworks are only focused on asset in operation stage and there is no robust subsea asset integrity framework during project phase. For further study existing asset integrity framework model will be studied to develop suitable asset integrity frame for subsea asset during project phase.

KEY WORDS: *Asset Integrity; Subsea, Project; Safety; Life Cycle*

1.0 INTRODUCTION

Managing asset integrity is vital for oil and gas companies because it is part and parcel of managing the risk portfolio. The 2010 BP Macondo incident set a precedent for many oil and gas companies to reevaluate their facility's asset integrity in managing their risk exposure. The downstream business has focused on asset integrity for a long time but the upstream sector has only recently shifted focus on asset integrity [33].

Exploring fossil fuel is getting ever more challenging whereby the search for new sources has expanded to complex geographical locations. Among all types of field developments, subsea developments have gained popularity. Expenditure for drilling and completing subsea wells, floating production platform and pipelines in the Asian region is expected to increase by 8% from year 2011 until 2015 [13]. Unlike topside facilities, subsea assets do not provide the same level of direct control of asset condition and only can have very little human interaction and intervention [40]. Subsea development is ever more challenging in deeper water and therefore close attention should be given during project execution phase. Subsea facility integrity management plan can be developed during the project phase when the designer's input and information on construction-led design changes can be obtained directly and easily incorporated [10].

2.0 LITERATURE REVIEW

2.1 Why Asset Integrity?

Every single incident provides valuable lessons learned for us to avoid similar situations from recurring. On 20th April 2010, an uncontrolled flow of water, oil mud, oil, gas and other materials rushed out of the drilling riser and drilling pipe on a dynamically positioned drilling vessel at approximately at 5000ft of water in the Northern Gulf of Mexico, the coast of Louisiana. Methane gas from the well under high pressure shot up in the drill column, expanded onto the platform, then ignited and exploded. This explosion caused the deaths of 11 workers, severe injuries to many others and the release of crude to sea. The leak continued for 87 days with spills of 4 million barrels and caused massive environmental damage [9]. A series of incident investigations were carried out to determine cause of the incident. Analysis of the available evidence indicates that when given the opportunity to save time and money, tradeoffs were made for certain things such as production because it was perceived that there are no downsides associated with the uncertainties [12]. The importance of asset integrity was neglected and it caused the downfall of Deepwater Horizon.

On 10 August 2011, an oil leak was reported from the Garnet F field resulting from the failure in a subsea flow line, 176km east of Aberdeen [14]. An initial investigation by Health and Safety Executives revealed that an audit of the safety management system for the leaking pipeline was due in 2008 and had not been carried out before the incident [6]. From the causal investigation carried out on the leak, Shell has increased awareness on reducing hydrocarbon leaks within operations and increased tremendous focus on asset integrity of subsea asset [42].

The Ekofish Brovo accident that occurred on 22 April 1977 recorded the largest oil spill in the North Sea. The production Christmas tree valve was removed and a Blowout preventer was not installed; the well kicked and an incorrectly installed downhole safety valve failed [29]. The failed safety valve resulted in an oil and gas release. The blowout resulted in a continuous discharge of crude oil through an open pipe 20 meters above the sea surface with estimated rate of 1170 barrels per hour, approximately 202,380 barrels of oil escaped before the well was finally capped 7 days later [23]. The official inquiry into the blowout determined that human error was a major factor which led to the mechanical failure of the safety valve including faults in the installation documentation and equipment identification and misjudgments, improper planning and improper well control [29]. Based on the investigation finding, there were a series of asset integrity requirement which were neglected and caused the accident.

These are few examples of oil and gas landmark accidents happened in the past decades with devastating consequences and showcased that asset integrity must be maintained at the highest possible standard at all times. Due to the unique nature of subsea and its' remoteness, asset integrity should be given high attention from the beginning of a project's lifecycle.

2.2 Definition

An asset is an entity from which the economic owner can derive a benefit in future accounting period by holding or using the entity over a period of time [21]. The Institute of Asset Management defines asset management as a set of systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan [31]. UK Health and Safety Executive (2009) KP3 program defined asset integrity as the ability of an asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment [52]. Subsea production systems can be defined as range in complexity from a single satellite well with a flowline linked to a fixed platform, to several wells on a template producing to a floating facility. Typical subsea production systems consist of wellheads and trees, sealines and end connections, controls, control lines, single-well structures, templates and manifolds, remote operating vehicle (ROV) and completion/workover and production risers [2].

2.3 Asset Integrity

Asset integrity can be divided into design integrity, technical integrity and operation integrity as illustrated in figure 1. Design integrity provides assurance that facilities are designed in accordance to governing standards and meet specified operating requirements without compromising on safety, accessibility, operability and maintainability [5]. Any facility asset integrity must evolve from the design phase and the integrity management plan is developed with incorporating hardware barriers [7].

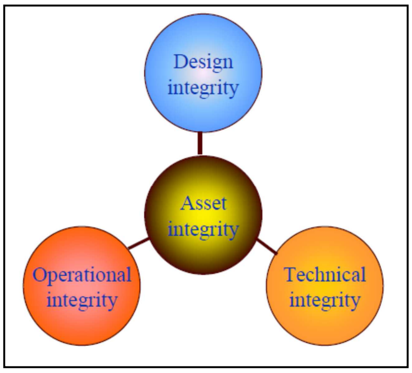

Figure 1: Sub groups of asset integrity [17]

Technical integrity is defined as the development of a design that is carried out by well trained personnel, who have been assessed to be competent in accordance with recognized, sound practices and procedures with adequate provision for reviews and audits to ensure the design intent is unimpaired in any way that could cause undue risk or harm to people or damage to the environment [19]. Asset technical integrity refers to a condition where the technical state of assets incorporates all related operations and business processes as one process to ensure that there will be no harm done to people, property or the environment [36].

Operational integrity addresses operating within an asset's operating envelope, as defined by technical barriers. Appropriate knowledge, required experience, adequate manning, competence manpower and reliable data for decision making are essential to operate the plant as intended throughout asset lifecycle [5]. Oil and gas companies have to manage assets without any incidents by managing the governance and integrity of its assets [39].

The objectives of asset integrity are to compliant to all national requirement, regulatory, company policies and standards; adapted to industry requirement and international standard and regulation; stay fit for purpose safe and operational under all circumstances; ensure all assets operate in safe manner, reliable within design parameter and efficient in its operation mode; ensure all suitable check, process and review in place to safeguard the asset ;ensure the asset design, construct, install, operate and maintain to a risk level tolerable to the ALARP concept; protect company reputation; achieve planned production forecast and follow operating and maintenance philosophy [18].

2.4 Asset Integrity Management

Most oil and gas companies use asset integrity management to manage asset integrity activities in various stage of an asset's lifecycle. Department of Mines and Petroleum refer to asset integrity as fitness for purpose (FFP) and used Figure 2 to illustrate asset integrity management [50]. The asset lifecycle can be divided into five phases; design, installation, commissioning, operation and decommissioning. The asset integrity strategies, policies, procedure and scheme are developed in early stage of assets when the failure frequencies are decreasing. During operation phase the asset design requires reappraisal and for the design life extension additional measure should be taken place. After the initial design life, asset failure frequency will increase.

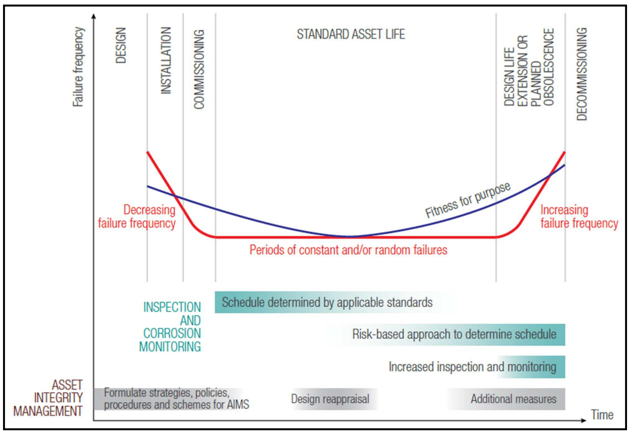

Figure 2: Fitness for Purpose graph

Asset lifecycle begins when a project opportunity enters the project funnel process. Careful consideration should be given between short term and long term benefits, between risks and reward profiles and associated costs when dealing with all stages of the asset life cycle to ensure the best value for money is achieved with asset integrity management. Phased project management processes, also known as stage and gate management processes (SGMP), is commonly used in macro and micro projects from early evaluation, to sanction the project and close it out [3] . At each project phase, the project team shall meet the requirements to move the project from current phase to next phase. In general, the SGMP aims to improve the decision making process by helping to manage the level of uncertainty and increase the quality of projects [41]. Table 1 shows the project phases associated with asset lifecycle.

Table 1: Project phases that associated with asset lifecycle

Scholar	Project Phases (Based on stage and gate management processes)				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Walkup Jr & Ligon [46]	Feasibility /Identify	Identify (broader development plan)	Definition (detailed development plan)	Execution	Operation
Alsayari, Lauritzen, & Alqurtas [26]	Concept Investigation	Strategic consensus	Strategic implementation	Installation & Evaluation	Closure
Adibhatla & Wattenbarger [4]	Screen candidate processes	Evaluate in depth	Field test on uncertainties	Commercial evaluation	Implementation, surveillance, operation

Asset integrity management is a continuous process throughout the project lifecycle. On average there are five phases in an asset's lifecycle including identify, evaluate, concept definition, execute, and operate as illustrated in Figure3. Heavy emphasis on design integrity should be made at the concept selection and concept definition phases to establish asset integrity. Upon starting the project execute phase, the focus will be on technical integrity. The process will be continued even after project has been handed over to the operation team in the operate phase. In the operate phase, the asset definitely needs to be maintained in order to maintain the integrity of the asset.

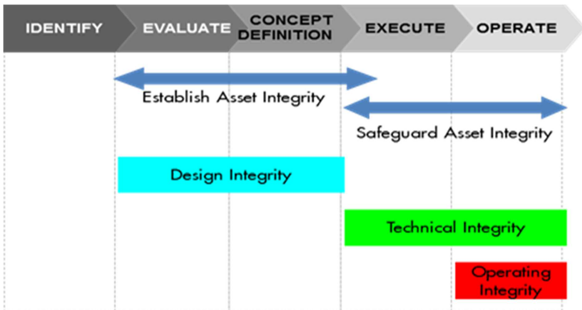

Figure 3: Illustration of asset integrity during asset lifecycle in project phases

3.0 CRITICAL SAFETY ELEMENTS

3.1 Performance Standard

In the asset integrity world, performance standard is defined as a measurable statement, expressed in qualitative or quantitative terms, of the performance required of a system, item of equipment, person or procedure and that is relied upon as basis for managing a hazard [51]. The performance standard themselves are compilation of references forming a continuous link from design standards employed to achieve the stated objectives of the barrier to the final audit functions and document location used to assure their proper implementation [11].

Performance Standards are divided into two groups; (1) initial application in the design, construction and commission phase and (2) ongoing application in the operational phase [15]. The specification can be combination national regulation, company policies and standard, industry requirement and international standard and regulation. Any deviation from performance standard requires stringent evaluation process with critical impact assessment. As cost cutting measure engineers or contractor always use excuses to deviate from performance standard. Therefore any deviation request carefully studied by panels before accepted for implementation. At each stage of asset lifecycle, after performance standards are developed the assurance process shall kick in. The verification scheme provides assurance that the suitable safety critical equipment has been identified and provided that they remain fit for purpose and are maintained in an operable and reliable condition to meet defined performance standard [25]. In some operators, the quality department oversees the assurance process with help of appointed specialist such as coating inspectors, welding inspectors, and HSE inspectors.

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3.2 Risk Evaluation and Mitigation

Besides maintaining compliance with required standard, many companies' face additional challenges on managing risk profiles by deploying effective risk management programs. Large risks with small returns are typically avoided and conversely, opportunity with perceived low or manageable risks and large gains are developed and added to the portfolio [35]. Structured risk analyses are performed using processes such as hazard and effect management process (HEMP), failure and effect analysis (FMEA), bow tie diagram, quantitative risk assessment (QRA) and qualitative risk assessment identifying hazards, assessing risk, selecting control and recovery measure and comparing the resultant risk to ALARP [47]. HEMP is one of the effective tools which identify hazard and potential risk, implements control measures, and maintains a documented demonstration that HSE risk have been reduced to level that is as low as reasonably practicable (ALARP) [37]. Recent study carried out classification of risk to distinguish decision scenarios into strategic decision, operational decision, instantaneous decision and emergency decision as way to improve decision makers to understand when term of "risk" used [48].

3.3 Competency

In the petroleum industry, operators demand rigorous safety standards and risk management to avoid any mistakes that put their reputation in danger. Therefore skilled workforce becomes crucial in managing risk in oil and gas projects. Asset integrity depends on a skilled workforce doing the right thing on a daily basis. Based on analysis of definition, it concluded that competencies are permanent characteristics of person, made manifest when performing a task or doing a job, related to the successful performance of a activity either work or of another kind, have causal relationship with job performance and can be generalized to more than a activity [1]. Each stage of asset requires competencies which may deal with a person's behavior in an office environment like soft skills and abilities in business and technical skills [20]. The industry code and local regulation define the minimum competency requirement for personnel who undertake some critical activities such as crane driver, professional engineer, welding inspector and so on. Failing to comply to the requirements, companies can face serious penalties. The competent people can ensure flawless asset delivery with due diligent asset integrity management.

Competency based development is method deployed by many companies to evaluate and recognize competency and training requirement for the employees. The competency based development process involves (1) generating required job description, (2) building a competency model with set of skills (3) assessing each employee against competency model to identify gaps which competency level do not meet the standard require by the job and (4) generating and executing an individual development plan the closes the gaps [27]. Beside organizational capacity to provide adequate resources, it is important to provide sufficient diversity of perspectives to ensure that technical integrity problems are identified despite the cost and schedule pressures [22]. Most companies encourages their employee to undertake regular training which normally referred as 'Continued Professional Development' to sharpen the skills or to deepen knowledge to keep up to date with emerging technology or recognized best practices [32].

3.4 Safety Culture

Leadership is an important factor in achieving safety culture in organizations. According to Blair, Culture is often described as "the way we do things around here" or "unwritten rules" and culture arises from shared norms of behavior [49]. Corporate culture describes shared values within organizations which has strong influence among the member's attitude, value and beliefs in relation to safety and is now accepted to have strong influence over workplace accidents and injuries [8].Safety culture that demonstrated by leaders can be very powerful mechanism to drive employee's behavior in performing daily tasks. Employee must feel empowered to do the right despite pressure completing given task.

Value can be divided as intrinsic and extrinsic. Monetary value like promotions and bonuses is referred as extrinsic value; whereby belief, ethics and environmental concern are regarded as intrinsic value. A great safety leader is sensitive to intrinsic values and is deeply committed to health and safety [49]. A leader's action will reflect the value he or she believes. For example, leader must willing to spend resources as necessary for safety activities despite being tight budgeted, always engaging teams on safety initiatives despite a tight delivery schedule, participate in daily events like toolbox talks and being supportive of team intervention that could lead to delays on construction. By demonstrating the intrinsic value beyond the monetary value will influence the employee safety culture in organization.

The corporate culture of risk taking and cost cutting as highlighted in Mocondo blowout must be avoided [12]. A leader must refer as a safety coach or reference without fear as they "walk the talks" and not just provide lip service for safety including asset integrity. Having well documented procedures and specifications alone will not promise delivery of asset integrity. Competent personnel should be key part of integrity process and should able use their skills and knowledge to fix small, routine problems as they arise than wait and hope for system deal with later.

4.0 ASSET INTEGRITY FRAMEWORK

A framework for asset integrity will be useful for achieving the goal of ensuring assets meet its full life cycle usage or intention. Subsea asset integrity framework requires the systematic and continuous monitoring of activities from concept selection, detail engineering, procurement, manufacturing, construction, installation, commissioning, operation, inspection and maintenance to meet asset integrity objectives. The ultimate aim of the framework is for asset owner to demonstrate that the assets are safe and to prove that to various stakeholders.

According to Suyanto, subsea asset integrity management is defined as the management of subsea system or asset to ensure that it delivers the design requirements and do not not harm life, health or the environment throughout the required life [44]. Subsea facilities are unique and require special attention because the equipment doesn't have direct and manual access like topside equipment. Specific precautions have to be taken at the design stage to ensure that the adopted design solutions will not compromise the long term safe operation and also to develop monitoring techniques that will allow indirect conditions to be followed up, compensating for the lack of direct access for traditional inspection means [40].

Through extensive literature, the safety critical elements safety culture, competency, performance standard, risk evaluation and mitigation are discovered as part of asset integrity framework. As shown in Table 2, it can be concluded that existing asset integrity frameworks are only focused on asset in operation stage, there is a lack of standardization on asset integrity frameworks, and there is no available subsea asset integrity framework during project phase. For further study existing asset integrity framework model will be studied intensively to develop suitable asset integrity frame for subsea application during project phase.

Table 2: Asset integrity framework by various scholars

	International Association of Oil & Gas Producers [24]	Rahim, Refsdal, & Kenett [36]	Rocher, Perrollet, & Muir [40]	Sri-amorntham, Chinpongpan, & Chansakran [43]	Wenman & Dim [47]	Dutta & Madi [18]	Refsdal & Ostby [38]
Asset phase	Operation	operation	Operation	operation	operation	operation	operation
Design	X		X		X	X	
People	X		X	X	X		X
Plants	X		X	X	X	X	
Community				X		X	
Processes	X			X	X		X
Competence		X	X			X	X
Compliance		X			X		
Communication		X	X			X	
Collaboration		X					
Control		X	X		X	X	
Data collection			X		X	X	

4.1 Issues on Achieving Asset Integrity

Implementing and achieving asset integrity at any stage of asset life cycle can be very challenging. There are predominantly visible and invisible parameters that may impede the delivery of asset integrity. Many scholars conducted studies or compiled lessons learnt about asset integrity mainly during the asset's operation lifecycle. Bale & Edwards reported non-user-friendly procedures; poor handling of management of change, lack of experience, incompetent engineers, human error, improper training and lack of design review during the design phase can challenge the implementation of effective asset integrity management [19].

Generally in projects, lack of compliance, incompetent engineering, communication breakdown, lack of collaboration within teams are key challenges to asset integrity [36]. Poor data and knowledge transfer from construction to operation, varying quality of risk management, inadequate maintenance and safety work practice and lack of continuous process improvement can impact asset integrity of facilities [34]. In subsea field applications, Suyanto stressed on new technologies, harsher environments, complex technical issue, high cost for inspection and intervention, limited inspection intervals and longer lead time for repair are impacting the subsea asset integrity [44]. Developing suitable and efficient subsea asset integrity frameworks alone will not guarantee effective asset integrity management implementation to safeguard the asset. The research will be focused existing challenges to create efficient framework to overcome the challenges.

4.2 Subsea Development and Asset Integrity challenges

Subsea developments in shallow, deep and ultra-deep water have become a cornerstone when compared to other development options. According to the DNV GL survey, 52% of respondents expect subsea technologies to absorb the strongest investment in the coming years [16]. However subsea developments have their unique nature. The subsea development in deeper water depth presents increasing challenges in higher development cost. Operational costs with subsea installation and intervention on subsea wells are increasing at a higher rate than the cost the hardware [45]. Ratio of installation or intervention cost of hardware has increased from 1:1 for shallow water to 3:1 for deeper water. Poor asset integrity management resulting in intervention or repair work would tremendously increase costs for an asset throughout its lifecycle. To avoid heavier costs during the operation phase and lower profit margins, the asset integrity should be managed effectively from the project phase. It is believed that the right combination of people, processes and technology can safeguard asset integrity and maximize profitability. Accidents in the oil and gas industry highlighted how important it is to have appropriate asset integrity management in place to prevent them before they become a reality [28].

5.0 CONCLUSION

The primary aim of a subsea asset management framework is to detail out strategies to manage the risks associated with assets in a very systematic manner with regards to retaining asset integrity throughout its life. Many studies carried out on oil and gas asset integrity happen during the operation phase after project teams have handed over the asset and for ageing assets, during a life extension program. Very little emphasis and studies were carried out about asset integrity during the project stage inclusive of concept design, detailed engineering, manufacturing, installation and pre-commissioning stages.

Asset integrity only focused on operating assets is not ideal and should be revisited for system effectiveness from the start of an asset's life cycle. Therefore, the existing asset integrity management framework and its implementation need to be analyzed to establish an asset integrity framework for subsea assets during the project phase. The objectives of the further research are to determine how project organizations can assure subsea asset integrity at the project phase, to identify obstacles of implementing subsea asset integrity during project phase and to develop asset integrity framework for subsea asset during project phase.

Current operation phase asset integrity implementation poses many challenges as reported in Table3 are requisite for the development of subsea asset integrity framework during project phase. Asset integrity assurance processes will be intensively focused on concept selection, pre-FEED, FEED, detailed design, manufacturing, installation and commissioning activities. The obstacles that can influence the successful implementation of subsea asset integrity will be studied. Based on the outcome of obstacles, the weakness and best practices of asset integrity will be evaluated for subsea asset integrity strategy. The identified strategy will be integrated to develop a subsea asset integrity framework for project phase. Robust and rigorous subsea asset integrity framework will safeguard subsea asset and provide assurance that subsea asset to perform its required function effectively and efficiently whilst protecting health, safety and the environment.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Higher Education of Malaysia for providing the scholarship for this study. R.J would like also like to provide her sincere gratitude to her husband Mr. Raj Thangavelu and her family for their fullest support throughout this study.

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Hydrodnamic Analysis of Underwater Propeller

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Paper History

Received: 1-October-2015
Received in revised form: 15-December-2015
Accepted: 30-December-2015

ABSTRACT

This paper presents a numerical study on hydrodynamic behaviour of underwater propeller for given performance conditions. Sound generated by a propeller is critical in underwater detection, and is often related to the survivability of the vessels especially for military purposes. The computations are conducted on the five bladed propeller. The RNG k- e turbulence model with modified eddy viscosity coefficient is used for the computations, and the modified coefficient is related to the vapor and liquid densities in non-cavitated regions for simulating the non-cavitating flow. In this project, a suitable propeller will be identified for its strength in Non-cavitating condition, geometric model will be generated using the CATIA V5,R20, numerical analysis is carried out in ANSYS15 using FLUENT software, the propeller is studied for its hydrodynamic behavior for its Pressure and Velocity Contours, Thrust and Torque coefficients and comparing them with standard Theoretical formulae. The flow field is analyzed with finite volume method (FVM Computed results are shown to be in good agreement with theoretical results.

KEY WORDS: *Thrust and Torque coefficients; FVM.*

NOMENCLATURE

K_T	Thrust Coefficient
K_Q	Torque Coefficient

1.0 INTRODUCTION

Thrust is a reaction force described quantitatively by Newton's second and third laws. When a system expels or accelerates mass in one direction, the accelerated mass will cause a force of equal magnitude but opposite direction on that system. The force applied on a surface in a direction perpendicular or normal to the surface is called thrust. In mechanical engineering, force orthogonal to the main load (such as in parallel helical gears) is referred to as thrust [1].Torque, moment or moment of force, is the tendency of a force to rotate an object about an axis, fulcrum, or pivot. Just as a force is a push or a pull, a torque can be thought of as a twist to an object. Mathematically, torque is defined as the cross product of the lever-arm distance vector and the force vector, which tends to produce rotation. Loosely speaking, torque is a measure of the turning force on an object such as a bolt or a flywheel. For example, pushing or pulling the handle of a wrench connected to a nut or bolt produces a torque (turning force) that loosens or tightens the nut or bolt [2, 3].Ships and under water vehicles like submarines, torpedoes and submersibles etc., uses propeller as propulsion.

The blade geometry and its design are more complex involving many controlling parameters. The hydrodynamic analysis of such complex3D blades with conventional formulas will give less accurate values. In such cases numerical analysis (Finite Element Analysis) gives comparable results with experimental values Such complex analysis can be easily solved by finite element method techniques [4]. In the present case propeller consists of five blades. The diameter of propeller is 0.4 m and hub to propeller diameter is 0.389. In the present simulations for prediction of non-cavitating hydrodynamics of propeller is carried out at rotating speed of propeller at 780rpm and the flow speed at 7.17m/s using of Thrust and Torque coefficient equations coupled with RNG k- e turbulence model computer code based on cell-centered finite volume method (FVM) on unstructured meshes for viscous flow field around propeller. These results are compared with theoretical formulae. [5]This paper addresses the flow behavior and normal force acting on a plate subject to oscillatory flow for KC numbers ranging from 1.4 to 105. For this purpose

3D CFD simulations were conducted on a U-shaped water tunnel configuration believe to be the same used .In their experimental investigation. With each flow oscillation vortices are shed from the tip of wall-mounted bilge keel plates installed at the middle of the water tunnel. The strength of such vortices is characterized by the KC number as first described .The KC number is calculated. The normal force on the plate can be characterized by drag and inertia components associated with coefficients Cd and Cm respectively. [6] The present thesis deals with modeling and analyzing the propeller blade of an underwater vehicle for their strength. A propeller is a complex geometry which requires high end modeling software. The solid model of propeller is developed in CATIAV5R20. Auto mesh is generated for the model using ANSYS Workbench. Hydro Dynamic analysis of aluminum alloy propeller is carried out in ANSYS- CFD FLUENT using SIMPLE for pressure and velocity coupling and Least Square Cell based for spatial discretization and second order up wind momentum and pressure equations first ordered time implicit scheme with time step 0.000254 and k-ε turbulence model are used. The Thrust and Torque coefficients are obtained are well validated with Theoretical formulae. The Theoretical formulae are referred from [7].

2.0 NUMERICAL INVISTIGATION

Self-propulsion simulations are time dependent due to propeller rotation. However, the body force propeller models often used in the simplified hull-propeller interaction analysis are usually incorporated with time-averaged flow fields and therefore steady flow approaches can be applied. In other applications of ship hydrodynamics, flow fields are inherently unsteady.

For spatial discretization, finite-volume method (FVM) with formally second-order accuracy was predominantly adopted. This seems to indicate that an increasing number of CFD practitioners in ship hydrodynamics prefer unstructured grids mainly due to ease of meshing and time-saving they offer. In these calculations turbulence effects were considered using turbulence models, as the k-e RNG models, with the modification of the turbulent viscosity for multiphase flow. To model the flow close to the wall, the standard wall-function approach was used, and then the enhanced wall-function approach has been used to model the near-wall region (i.e., laminar sub layer, buffer region, and fully-turbulent outer region). For this model, numerical scheme used is segregated implicit solver. For the model discretization, the SIMPLE scheme was employed for pressure-velocity coupling, second-order upwind for the momentum equations, and first-order upwind for other transport equations (e.g., vapor transport and turbulence modeling equations [4].

The most used time discretization scheme is the first-order Euler implicit scheme. In cases where steady flow solutions are computed, the Euler implicit scheme is the natural choice for the unsteady solvers since time accuracy is not needed and a large time step is desirable for faster convergence. The hydrodynamic values such as thrust (Kt) and torque (Kq) coefficients and the other selected values were measured in this numerical research work.

2.1 Computational Mesh:

Mesh adaption/refinement/generation techniques that can adapt to the shock front have been found to be a key ingredient in achieving accurate solutions for this kind of flow fields. Modeling, geometry, computational domains, boundary conditions, topology, meshing method and mesh size and turbulent method have significant effects on a fruitful numerical analysis and accuracy of simulation. Meshing strategy is divided in two divisions. Hybrid unstructured a mesh means that the tetrahedral elements for flow fluid fields, while structured mesh means that the hexahedral mesh is totally used for meshing on the solid surfaces. In contrast, the results of simulations with structured mesh elements usually have more accuracy than tetrahedral mesh elements results. CFD simulation data were verified with existing tests results.

Unstructured mesh elements production is almost automatic while hexahedral mesh elements generation is not automatic and should be generated manually. On the other hand, for flow field meshing, sometimes, the geometry is not compatible to use the hexahedral mesh elements, so unstructured mesh elements have better results and convergence of solution is nice [8]. Therefore, we used the hybrid unstructured mesh elements for rotational domain, in which we utilized the stationary and rotational domain for full scale propeller simulation for propeller with five blades. Auto mesh option is used in this project. Convergence is checked with element sizes 10 and 12.Close results are observed for element size 10 and 12.Element size 10 is used for mesh generation. After discretization number of elements in the domain are 7363445.The meshed figure of the propeller enclosed with its domain is shown in figure 1:

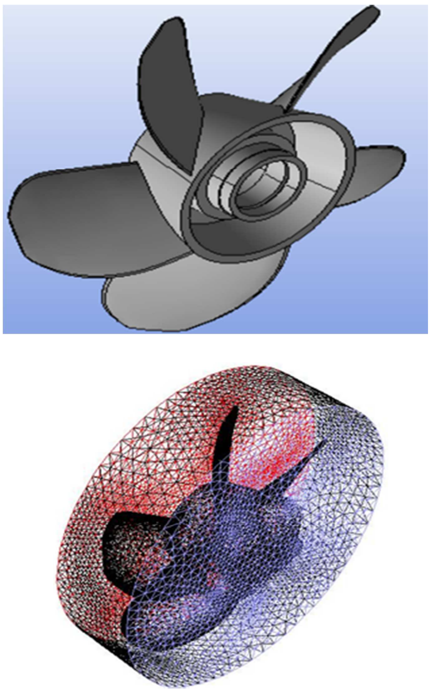

Figure 1: Geometry & meshed model of the propeller with its domain.

3.0 RESULTS AND DISCUSSIONS:

In the present case propeller consists of five blades. The diameter of propeller is 0.4 m and hub to propeller diameter is 0.389. In the present simulations for prediction of non-cavitating hydrodynamic behaviour of propeller is carried out at rotating speed of propeller at 780rpm and the flow speed at 7.08m/s these are shown in Table 1. The strength of the propeller is very much importance to warship designers and military strategists for many years. So in this case an attempt is made to prediction of hydrodynamic strength of propeller using of CFD Fluent software with k-e computer code based on cell-centred finite volume method (FVM) on unstructured meshes for viscous flow field around propeller and comparing these results with theoretical formulae.

Table 1: Principle particulars of propeller model.

Diameter of the Propeller	0.4m
EAR= A_E/A_0	0.58
No. of Blades	5
Hub ratio	0.389
Series	Naca

3.1 Analytical Procedure for Hydrodynamic Analysis in a Blade section by using CFD output i.e., Thrust, Torque:
The thrust and torque coefficients are none dimensionalized as follows

$$K_T = \frac{T}{\rho n^2 D^4} \tag{1}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \tag{2}$$

where T is the thrust, Q is the torque, n is rps and D is diameter of the propeller.

Here we use the output, which is obtained from the computational dynamic analysis i.e., Thrust, Torque value.

As from CFD analysis we obtained Thrust as 2230.8372 N and Torque as 446.166 N-m.
Therefore, Thrust (T) = 2230.8372N

Thrust coefficient $K_T = \dfrac{T}{\rho n^2 D^4}$

$$= \frac{2230.8372}{2770 \times (13)^2 \times (0.4)^4}$$

$K_T = 0.208$

Torque (Q) =446.166 N-m.

Torque coefficient $K_Q = \dfrac{Q}{\rho n^2 D^5}$

$$= \frac{446.166}{2770 \times 13^2 \times 0.4^5}$$

$= 0.09181$

3.2 Analytical Procedure for Hydrodynamic Analysis in a Blade section by following standard design formulae:
The following mathematical formulae are enclosed with reference [7]

Brake power $P_B = 85HP$ or $63.3844KW$

Ship speed $V_S = 7.08\, {}^{m}\!/_{s}$

RPM (n) = 840

Speed of Advance $V_A = V_s(1-w)$ (3)

$V_A = 11.6981\ knots$

Shaft power $P_S = P_s \eta_s$ (4)

$= 83.3HP$

Loading constant $P_D = P_s \eta_S$ (5)

$= 81.634\,HP$

Power coefficient $B_p = P_D^{0.5} n / V_A^{2.5}$ (6)

$$= 15.0571$$
$$= 15$$

From the chart of type B series of 5-blades shown, the value of $B_p = 15.0$ is read. The point of intersection ${}^{b}\!/_{w}$ the B_p line and optimum line (in red line) was traced to get $({}^{P}\!/_{D})$ = 0.91, $\eta_0 = 0.662$ and $\delta_{opt} = 155$,Diameter of the propeller D= 0.4m.

Having determined the pitch, diameter and delivered horse power of the propeller, the thickness blade, the thickness blade, the blade area & hub (boss) diameter from the ratios stated for these in the type B series chart for 5 blades design are as follows:
Number of blades (Z) = 5

Blade area ratio $\left({}^{A_E}\!/_{A_0}\right) = 0.58$

Blade thickness ratio $= 0.112$

Blade Area (Disk area) $A_0 = \dfrac{\pi D^2}{4}$ (7)

$A_0 = 611.1427\ ins^2$

Weight of all blades is equal to total thrust acting on the propeller

$w = T = 1.982 B_{tf} \varsigma Y R^3$ (8)

$= 2824.2389\,N$

Now, we can use this obtained weight/ force as thrust value[7], Therefore, the thrust T = 2824.2389N.

Thrust coefficient $K_T = \dfrac{T}{\rho n^2 D^4}$

$K_T = 0.2635$

For finding of Torque value we have to use

Torque $Q = F \times d/2$

$Q = 564..8477\,Nm$

Torque coefficient $K_Q = \dfrac{Q}{\rho n^2 D^5}$

= 0.09168

3.3 Pressure and Velocity Profiles:

From CFD Analysis we directly obtained Thrust and Torque, Pressure and Velocity contours by taking 1000 iterations in k-ε turbulence model by taking time step size equal to 0.000256.The convergence graph is shown in fig 2.

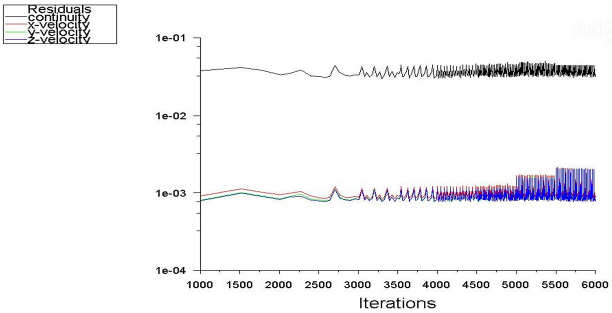

Figure 2: Convergence graph

The graph represents the convergence history of the propeller sound pressure levels.

The convergence criteria are considered as the difference between the values of the succeeding and preceding are in the range of 0.001.

The figures 3 & 4 represent the Contours of the Pressure and Velocities at various sections of the propeller.

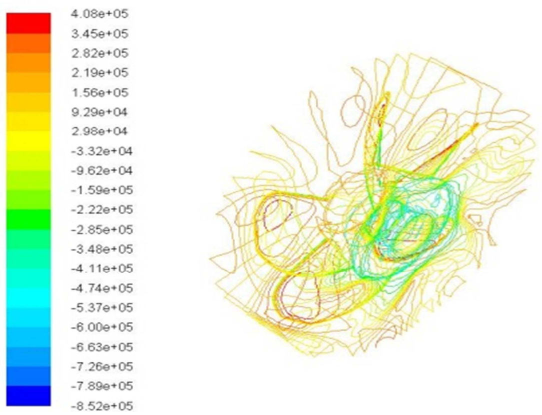

Figure 3: Contours of Static Pressures (Pa) representing inlet, outlet, outer, wall solid.

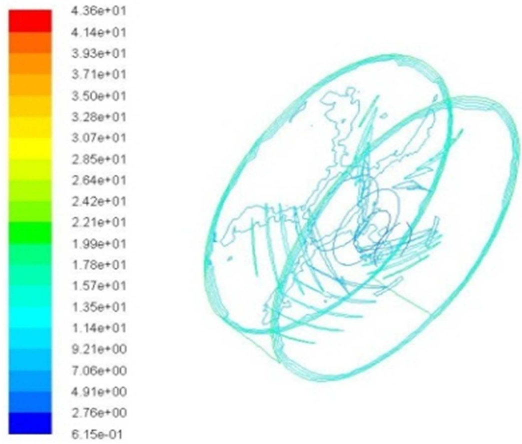

Figure 4: Contours of Velocity (m/s) of inlet, outlet, and wall solid.

4.0 CONCLUSION

The propeller is assumed to be operated at 780 rpm with forward velocity of 7.08m/s for prediction of thrust and torque coefficients.The convergence is obtained after completion of 1000 iterations for this k-ε turbulence model is used.The Thrust coefficient values obtained from both ways are as follows,0.208 & 0.2635. The Torque coefficient values are obtained from both ways are 0.09181 & 0.09168. The Thrust and Torque coefficients obtained from both CFD and Formulae are quiet acceptable and within the ranges.

5.0 ACKNOWLEDGEMENTS

The authors wish to express their sincere gratitude to Sri V. Rama Krishna, Scientist'D', NSTL, Visakhapatnam and Mrs. C. Neelima Devi, Assistant Prof., University College of Engineering, Vizianagaram,JNTUK.

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Published

ISOMAse
Resty Menara Hotel
Jalan Sisingamangaraja No.89
Pekanbaru-Riau, INDONESIA
http://www.isomase.org/

Edited

Building P-23, Room: 314
Department of Aeronautics,
Automotive & Ocean Engineering,
Faculty of Mechanical, Universiti
Teknologi Malaysia, MALAYSIA
http://web1.fkm.utm.my/

Printed

Teknik Mesin
Fakultas Teknik,
Universitas Riau, INDONESIA
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Organized

Ocean & Aerospace Research
Institute, Indonesia
Pekanbaru-Riau, INDONESIA
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ISSN: 2442-6415

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