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WARSHIP 2014: Naval Submarines & UUV's

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DAY 1 PAPERS:

08.30-09.00 **COFFEE & REGISTRATION**

09.05-09.40 **KEYNOTE,** *Vice Admiral Simon Lister CB OBE, Chief of Materiel (Fleet), Defence Equipment and Support, MoD, UK*

09.40-10.15 **IN SEARCH OF THE BEST DESIGN – A SYSTEMS ANALYSIS METHODOLOGY FOR SUBMARINE DESIGN**
M Nordin, Swedish Defence Research Agency and Chalmers University of Technology, Sweden.

This paper introduces a new coherent methodology for Systems Analysis (SA) as a tool for the search of the best submarine design for different mission types and under diverse conditions. In naval submarine design there are usually two critical objective attributes, i.e. systems effectiveness and cost, the first to be maximised and the second to be minimised. The new coherent methodology contains four major parts; a module for technical design in the functional domain based on a synthesised design approach, a module for prediction of related cost and an Operations Analysis (OA) module for systems effectiveness calculation. Finally, the first three parts, a combination of deterministic and stochastic models, are connected to a systems analysis module where the results are merged, analysed and evaluated by the design team and then presented to the decision maker and stakeholders for their decision in search of the best design. This approach invites customer participation within the framework of integrated project teams. With fewer iteration cycles and better predictions of systems cost, performance and effectiveness, this has generated deeper customer understanding and thereby satisfaction and acceptance.

10.15-10.50 **HIGH LEVEL CAPABILITY ANALYSIS OF SUBMARINE PLATFORMS**
Graham Hepworth, Karl Slater, QinetiQ GRC, UK

The Australian DSTO are currently developing an Integrated Platform Systems Model (IPSM) to enable high level performance analysis of submarine platforms to be carried out across multiple design configurations and option sets offered by different manufacturers. An application of this work is research into the influence of changing operational requirements on subsystem integration risks, design trade-offs, and the flexibility of different configuration options. QinetiQ GRC have been engaged by the DSTO to provide a fully parametric and generic submarine design within the Paramarine naval architecture design suite; which is representative of a modern SSK, and is capable of being remotely modified by the DSTO IPSM tool. This joint paper describes the background and scope to this integration project, and outlines the processes governing interaction between the two tools.

10.50-11.20 **COFFEE**

11.20-11.55 **FUTURE SUBMARINE PROGRAMMES: OBSERVATIONS / LESSONS**
Robert Budell, ThyssenKrupp Marine Systems GmbH, Germany

ThyssenKrupp Marine Systems with its operating units Submarines, Surface Vessels, and Services has a long shipbuilding tradition encompassing hundreds of years in Germany and Sweden. As one of the leading, global, design and system suppliers of submarines, ThyssenKrupp Marine Systems has acquired its experience serving nearly 25 countries and navies. Its ability to build highly-capable submarines in both its home shipyards as well as in the local shipyards of its customers has contributed significantly to the success of this private sector company. This presentation will offer observations and lessons learned from a multitude of projects, customers, and submarines which may serve as positive examples for the hard decisions involved in such a programme.

11.55-12.30 **SEA TRIALS AND DATA ANALYSIS OF THE ASTUTE CLASS SUBMARINES**
David Hooper, BAE Systems Maritime Submarines, UK

Advancements in the computing capability and integration of submarine systems have resulted in further advantages when measuring, recording, and processing data during sea trials. Ship's fit items on the Astute Class submarines such as the Platform Management System (PMS) and Ship Inertial Navigation System (SINS) are principally designed to provide information to the ship's staff during operation. These systems have also been utilised as the primary method of recording sea trials data. Bespoke tools, such as the BAE Systems Digital Inclinometers for inclining trials, provide new methods of recording data to improve the quality of trials results. They also increase the situational awareness for the Conducting Officer during the trial. The methods of data retrieval are compared between the Astute class and previous submarine classes. Details of the advantages these systems offer are discussed, as well as the challenges that remain.

12.30-13.05 **VIDAR-7 – THE SMALL SSK FOR THE 21ST CENTURY**
Tom Gibbs, BMT Defence Services Ltd, UK

The trend of the growing global proliferation of submarines is well recognised [1] and many nations are seeking, or have acquired, small diesel electric submarines to defend sovereign interests. The market is dominated by the design offerings in the 1500-2000te range, however this size of submarine is often beyond the economic reach of many nations aspiring towards a submarine capability. A number of nations operate 'midget' submarines (less than 350te), however this size of submarine is often incapable of the range, endurance and truly independent operation of the more conventional sized submarine. Therefore there exists a gap in the spectrum of submarine designs for a small, affordable 'pocket' or 'utility' submarine of the order 700te. This paper concludes by presenting the output of the design space exploration and the subsequent concept design developed to address this need. The BMT Vidar-7 is a 700te submarine which offers signature performance, endurance, range and combat capability comparable with larger design solutions, at a much reduced size and cost.

13.05-14.05 **LUNCH**

14.05-14.40 **CONCEPT AND PHILOSOPHY FOR ASSURING SUBMARINE SAFETY,**
Mari F. Persson, ThyssenKrupp Marine Systems AB, Sweden

The safety concept and philosophy at TKMS AB is a combination of adherence to established safety design standards and safety rules, experience based engineering design principles and practices, cooperation with skilled customer and end-user and by including the different areas and aspects of safety. Safety is an essential characteristic of Submarines and must be considered through all stages in the submarine program. In order to create and design safe products, while our systems are becoming increasingly sophisticated and the degree of integration increases, it is important to focus on all aspects of the technical system including aspects such as organization and communication being part of the system. Complexity theory and systems thinking provides new opportunities to understand and include the necessary holistic approach to safety. For doing this, it is essential to include different areas of competences within the safety organization and to continuously challenge common assumptions, encourage critical thinking and have a high degree of education within the various safety areas. A key issue is to have the ability to understand the different areas of safety competence.

14.40-15.15 **ADAPTABILITY IN PRINCIPLE, IN DESIGN, AND IN PRACTICE- APPLICABILITY OF THIS CHARACTERISTIC TO THE MODERN NAVAL SUBMARINE**
N. Whybrow, Babcock International Group, UK

In 2012/13 Babcock and Frazer Nash developed and reported on the Hydra SSK concept family in part to explore the practical application of modularity in naval submarine as a means of assisting the sustainability of a medium size submarine enterprise. This paper will further explore the viability, practicality and potential benefits of adaptability in design at whole boat and major system levels and will derive those principles which may be applied in order to realise it. Since optimisation against any specific characteristic may distort a design if pursued too far the paper will discuss bounds and measures of benefit – including the potential to offset uncertainty in requirements or technology maturity - and the 'price' at submarine whole boat level of introducing and retaining features and margins intended to provide adaptability. Whole boat examples of these adaptability features and margins will be considered using the Hydra SSK and other representative models and real platforms to confirm principles and isolate examples realised in practice. The paper will conclude with proposals for the balance of features to be included in a modern naval submarine design and programme.

15.15-15.50 **COMPUTER SIMULATED TRENDS IN DESIGNING A FUTURE UNMANNED UNDERWATER VEHICLE 'MOTHER-SHIP' SUBMARINE**
I.M. Purton, D.J. Andrews, University College London, UK,
A. Mistry, Babcock International Group, UK

A computer program, written in the programming language Matlab, has been constructed to simulate the characteristics of numerous submarine designs, each with their own unique set of design requirements. By using the computer program, a large data set of submarine designs have been collected, and the resultant designs have been displayed on a plot to identify the Pareto front for a cost versus submarine capability relationship. This paper shows how this computer program has been validated by comparing individual submarine designs to typical modern day submarines (SSNs, SSBNs and SSGNs). The comparison includes submarine options with differing types of pressure hull arrangements including multihulls.

15.50-16.20 **COFFEE**

16.20-16.55 **TOWARDS A UUV LAUNCH AND RECOVERY SYSTEM ON A SLOWLY MOVING SUBMARINE**
R. A. Irani, D. Kehoe, B. Spencer, Rolls-Royce Canada Limited, G.D. Watt, Defence Research and Development Canada - Atlantic (DRDC), Canada

Unmanned Underwater Vehicles (UUVs) will play important roles in future naval operations by mitigating risk during dangerous tasks such as mine hunting and reconnaissance missions. However, a reliable UUV launch and recovery system (LARS) for naval platforms, especially submarines, has yet to be developed. This paper summarizes work on a Defence Research and Development Canada project to develop such a system for submerged slowly moving submarines under waves and adapts the active dock from this work to concepts for a small UUV LARS installed under the deck but outside the pressure hull of a generic 70 m long diesel submarine. The LARS is located in free flooding, plausibly sized cargo space aft of the submarine's sail. The paper focuses on system design considerations and LARS characteristics particular to UUV deployment from submarines. A range of UUV sizes are considered to highlight various system limitations and advantages, and various charging and data transfer possibilities that can be integrated into the cargo hatch are discussed. The goal is to explore the various technical issues a UUV/submarine LARS system faces to provide guidance for future UUV deployment strategies.

16.55-17.30 **HYDRODYNAMIC INTERACTION EFFECTS ON AN UUV OPERATING CLOSE TO A SUBMARINE**
ZQ Leong, D Ranmuthugala, I Penesis, Australian Maritime College, University of Tasmania, Australia

This paper outlines the steady-state interaction forces and moments acting on the UUV at different fixed speeds and relative positions to the submarine, with an aim to identify the regions where adverse effects of the interaction are minimal.

17.30- **GENERAL DISCUSSION & EVENING DRINKS RECEPTION**

Submarines & UUV's

014, Bath, UK

DAY 2 PAPERS:

08.30-09.00 COFFEE & REGISTRATION

09.05-09.40 DCNS UPDATES ITS HYDRODYNAMIC DESIGN PROCESS FOR SUBMARINES

Pierre GUILLOUET, DCNS, France

During the design process of a submarine, it is necessary to freeze the external shape early in the preliminary project. In order to accelerate the conventional hydrodynamic design process based on complex and long towing tank test campaigns, DCNS has decided to invest in a CFD tools panel called "Virtual Towing Tank". As the CFD tools have developed and become much more reliable on the one hand and the available computer power has strongly increased these last years on the other hand, the Virtual Towing Tank is used extensively to assess the various hydrodynamic layouts, at least during preliminary project design phases.

09.40-10.15 BOW SHAPE DESIGN FOR INCREASED SURFACE PERFORMANCE OF AN SSK SUBMARINE

Bas Overpelt, Project Manager MARIN, Netherlands

In the era of U-boats, submarines were sailing most of the time at the surface and submerged only just before an attack. In those days, submarines were of slender hull shape with an especially narrow bow to reduce wave making resistance. With the introduction of snorting, nuclear propulsion, improved aerial and later satellite reconnaissance, submarines were not only able but even forced to remain submerged for long periods of time. This has lead to new designs of submarines with hull shapes based on the Albacore research, solely optimized for underwater hydrodynamic performance and good flow characteristics for sonar operations. Nowadays, these conventional diesel-electric blue water submarines still spend a significant amount of time in transit at the surface with high wave making resistance as a result. This leads to a too low transit speed compared to commercial ships navigating the same waters, relatively high fuel costs and large submarines due to the required bunker capacity in order to have reasonable range. Therefore, the Dutch Defence Materiel Organisation (DMO) and the Maritime Research Institute Netherlands (MARIN) have performed a study on the submerged and surfaced performance of a typical 4000t SSK with three different bow shapes. This paper describes the design and evaluation of the alternative bow shapes and shows how this can be used to evaluate which bow shape fits best in various operational profiles.

10.15-10.50 VALIDATING DESIGN METHODS FOR SIZING SUBMARINE TAILFINS

Mark Bettle, Defence Research and Development Canada - Atlantic (DRDC Atlantic), Canada

A significant design challenge to providing the desired stability, manoeuvrability, and control characteristics for a submarine is sizing the tailfins. A recent analysis of a generic submarine shape using the DRDC submarine simulation program (DSSP) showed the submarine to be very unstable in both the horizontal and vertical planes. This geometry-based tool estimates hydrodynamic coefficients, predicts stability characteristics, simulates six degrees of freedom (6 DOF) manoeuvres, and determines safe operating envelopes. It uses analytical/semi-empirical methods which are amenable to rapid analysis and design; its simulations run more than an order-of-magnitude faster than real time. DSSP was used to find the appropriate adjustment to X-rudder size to achieve a desirable level of stability while retaining adequate maneuverability and control. The manoeuvring characteristics for the original and revised models are compared by performing several 6 DOF manoeuvring simulations with DSSP. To validate these analyses without incurring the large expense of experiments, computationally intensive computational fluid dynamics (CFD) predictions are compared with the DSSP load predictions

10.50-11.20 COFFEE

11.20-11.55 PREDICTION OF THE VARIATION IN DEPTH AND ATTITUDE DUE TO HIGH SPEED SUBMARINE OPERATIONS NEAR THE SURFACE

C Polis, D Ranmuthugala, J Duffy, Australian Maritime College, University of Tasmania, Australia. M Renilson, Australian Maritime College & Higher Colleges of Technology, UAE

This paper describes the variations in the projected path and orientation that result from the forces and moments generated in the vertical plane at high transient speeds by a submarine operating near the surface. Prediction of the behaviour of a submarine when operating close to the free surface is important to be able to assess the merits of competing designs, determine its safe operating envelope, and hence to develop procedures and limitations for safe operation when close to the surface.

11.55-12.30 FULL AUTHORITY SUBMARINE CONTROL USING A MODEL PREDICTIVE CONTROL ALGORITHM

Nathan Thomas, Stirling Dynamics, UK

This paper concentrates on the control aspects of FASC, rather than the inceptor stick, introducing a Model Predictive Control (MPC) algorithm which enables integrated control of depth, pitch and hydrostatic trim of the submarine. The MPC method is suited to the multi-input multi-output nature of the control problem and naturally accounts for the limitations on hydroplane travel and rate, trim/ballast tank contents and pump rates. The effectiveness of the control algorithm is assessed by means of depth changing and sea keeping performance tests. These tests are conducted across the entire speed range and also demonstrate the behaviour when transitioning between high and low speeds. The potential benefits of the MPC method are discussed along with implementation issues. Benefits of the FASC technology for future submarine autonomous performance and safety are summarised.

12.30-13.30 LUNCH

13.30-14.05 BATTERY CHARGING TECHNOLOGIES FOR MODERN SUBMARINE REQUIREMENTS

Arndt von Drathen, Senior Manager at MTU Friedrichshafen GmbH, Germany

New battery technologies promise to increase underwater endurance and performance significantly. Crewing challenges demand a higher degree of automation as well as a reduced degree of equipment maintenance. Reduced budgets lead to longer operation of platforms and therefore increased periods between overhauls as well as increased availability periods of spare parts. Finally, emission legislation gains more relevance even for special applications like submarines. The paper describes these new boundary conditions and the available technologies as well as the resulting design of an advanced submarine charging unit to meet such requirements of a modern submarine. Details of the technical operating characteristics, new functionalities and maintenance in relation to submarine availability provide a first glance on how proven COTS components in combination with submarine specific ones will improve the performance of future submarines.

14.05-14.40 VALIDATION OF SUBMARINE BLOW ALGORITHMS FOR FLOOD RECOVERY

P Marchant, N Thompson, D Cosserat, QinetiQ Ltd, UK

This paper describes the work that QinetiQ has undertaken to improve the blow algorithms used for flood recovery simulations of UK Royal Navy submarines. This work included the conduct of a small scale trial blowing high pressure air from a single bottle, similar to those used on a submarine. The trial results are compared with those calculated by various simulation methods in order to assess the suitability of the blow algorithms.

14.40-15.15 THE CURRENT STATE OF RIM DRIVE TECHNOLOGY AND ITS APPLICATION TO SUBMARINE PROPULSION

Lucy Elizabeth Collins, Paul Wrobel, University College London, UK

The essential characteristics for a naval submarine propulsive device are low speed and high torque, with a diameter no greater than 70% of that of the hull (due to efficiency reductions caused by wake effects). These characteristics are very demanding for the drive train leading to large, heavy and expensive design solutions for equipment such as gearboxes, main turbines, shafts and bearings. In some cases, the operational demands have caused in-service issues e.g. excessive material wear and power limits. However, the design of a rim driven device readily lends itself to these ideal characteristics of low speed, high torque and as such; there may be great potential in applying this technology to submarine propulsion. This paper provides a review of rim drive technology in terms of its design and current maturity as well as discussing its potential applicability to submarine propulsion.

15.15-15.45 COFFEE

15.45-16.20 ADVANCED NUMERICAL MODELLING TECHNIQUES APPLIED TO SUBMARINE STRUCTURES RESEARCH AND DEVELOPMENT, DESIGN, BUILD, AND REFIT AND REPAIR

Derek Graham, QinetiQ, UK

This paper will present a high level summary of the applications of advanced numerical modelling to the analysis of submarine structures, particularly the pressure hull. It will describe the use of both tried and tested methods, and developing features, of commercially available Finite Element (FE) analysis software packages. The applications considered range from fundamental analysis of the collapse process, which supports future design developments and assessment of current structures, to assessment of in-service issues such as corrosion, cracking, repair and grounding. The work combines state-of-the-art modelling techniques with a pragmatic approach to finding solutions which can be implemented by Future Submarine and In Service teams alike. To have confidence in these solutions, it is essential that they are validated against experimental data. Diverse sources such as pressure hull collapse models, tested as much as fifty years ago, to bespoke weld panel tests and standard fatigue tests have been accessed to validate the analyses presented.

16.20-16.55 ENABLING AN OPTIMISED HIGH STRENGTH STEEL PRESSURE HULL BUILD STRATEGY BY THE USE OF UNDERMATCHED WELDS

Stephen Brooke, MoD, UK

Recent classes of UK naval submarine pressure hulls have been designed and built using quenched and tempered high strength Q1(N) steel with matching weld consumables. To increase operational capability for future designs the UK MOD has been investigating the use of higher strength steels. Construction in such steels brings the need for stringent process controls to avoid the potential of weld defects, in particular hydrogen cracking which brings the potential for increased costs and lead time. The use of "under matched" welding consumables (where the filler has a lower tensile strength compared with the parent metal) to mitigate this risk has been advocated across a number of sectors even though it goes against welding norms. For such a practice to be approved for UK naval vessels, in particular submarines, the consequences of such a change from tradition both in terms of joint pr operties and the knock on effects on operational capabilities need to be understood e.g. what effect does a given level of undermatching have on the maximum diving depth a vessel can withstand before structural collapse; implications for welding processes; fatigue life; shock resistance etc. The paper references the use of such a design configuration used by other navies and describes recent MOD trials to provide a body of evidence to gain such knowledge and approval, including results from fatigue, shock, mechanical and hydrostatic testing backed by analytical modelling.

16.55- GENERAL DISCUSSION

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