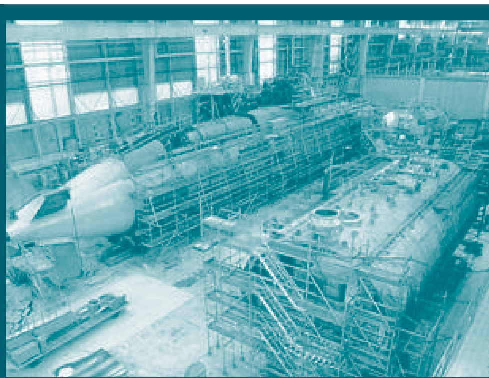
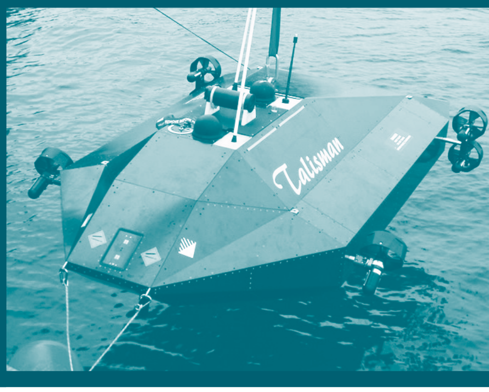
The Royal Institution of Naval Architects

Warship 2020:
Future Technologies in Naval Submarines





International Conference

WARSHIP 2020:
Future Technologies in Naval Submarines

17-18 June, Bristol, UK

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Applying Modern Process Automation and Optimisation Tools to the Design of Submarine Structures
D. Graham, QinetiQ, UK

Formal structural optimisation tools have been around for many years and they have been used successfully with advanced numerical methods, such as Finite Element (FE) analysis, in a wide range of applications. Modern developments are producing ever more integrated and powerful tools for automating and controlling simulation based design processes, an example being the Isight software provided by Dassault Systemes which integrates with their Abaqus FE software. It provides access to numerous sophisticated design assessment and optimisation routines and other bespoke software including Tosca for topology optimisation and fesafe for fatigue analysis. Within the Isight environment these disparate tools can be linked in structured workflows. These workflows can be automated and customised for specific applications and the following case studies are described:
• Minimum weight pressure hull design for different operating depths using traditional design formulae.
• Design refinement for weight reduction using linear elastic FE.
• Sensitivity of pressure hull collapse strength to shape imperfection using elasto-plastic non-linear FE.
The use of topology optimisation for the design of a detailed feature (a large penetration) and the inclusion of fatigue assessment in the design loop are also demonstrated.
For FE analysis to be truly integrated into the design process designers will have to have confidence in the accuracy of the method. Steps that have been taken to provide verification against analytical methods and validation against experimental data, specific to the design of submarine pressure vessels are discussed.

The design and hydrodynamic assessment of a submarine concept with off-axis propulsion
P. Crossland, QinetiQ, UK
R. Crocker, BAE Systems, UK
S. Machin, Submarine Delivery Agency, UK

The UK’s approach to submarine design is largely evolutionary, however, whilst future submarine hull form designs are likely to remain relatively conventional, changing naval strategy means that there is still sufficient justification to perform investigations into novel hull forms that have the potential to offer easier integration of required capabilities or provide the ability to incorporate novel technologies. Whatever the design, there will be a requirement to manage the safety of a submarine throughout its lifecycle and the approach adopted in the UK, developed from knowledge of hydrodynamics gained over a number of years assessing submarines with a conventional hull form design, is to provide a validated toolset and process that provides an understanding of the manoeuvring and control performance of that submarine. However, if a submarine hull form design changes radically, the tools and processes for evaluating performance need to be developed, in advance, to ensure the capability to evaluate that design is maintained. This paper describes a challenging design and hydrodynamic assessment exercise, in which BAE Systems – Maritime Submarines were tasked, by the Submarine Delivery Agency, to develop a concept design for evaluation by QinetiQ using their computation fluid dynamics and experimental assessment techniques. This work also provides the opportunity to de-risk novel design features to inform future underwater platform programmes and by undertaking a full manoeuvring and control evaluation of this design, the traditional testing techniques are challenged and developed.

Aft Perpendicular... an Afterthought
R. Dvorak, NAVSEA, USA

How do you define the length of a ship? What is the definition of the aft perpendicular? From Volume I of the Principles of Naval Architecture (PNA), the definition for the location of the aft perpendicular "is at the aft side of the rudder post, centerline of the rudder stock, or at the intersection of the design waterline with the aft end of the vessel." However, for US submarines, the location of the aft perpendicular has not typically followed PNA's definition. The location for a submarine's aft perpendicular has been at the end of the thrust device or at an obsolete design value. This paper will examine the technical details and implications of how we define the aft perpendicular on a submarine.

Submarine rescue operations: state of the art and new developments
I. Gomez Tapia, TSI, Spain

During the successive periods of belligerence in this last century, the usefulness and efficiency of submarines in naval defence sector has been widely proven, being nowadays high value strategic assets for nations interests. For this reason, the need of improving these vessels is incessant. In fact, submarines are currently involved in a deep renovation process due to the new technologies developed and the emergence of new building countries. The improvement of submarines will undoubtedly make them safer for their crew, but contingency measures will always be essential in the event of an accident.
This paper will try to define the state of the art of submarine escape and rescue operations, from the perspective of protocols and available equipment based on the NATO STANDARD ATP/MTP- 57, all encompassed within the operations of the ISMERLO (International Submarine Escape and Rescue Liaison Office) organization.
Furthermore, this paper will introduce a new system under development, named AUVHIVE. AUVHIVE focuses on underwater detection, using autonomous drones and artificial intelligence to determine the position of distressed submarines. In these cases, time is an essential factor that runs against the probability of survival of the crew. Since AUVHIVE is designed for a rapid air deployment and for operating while preparing the rest of the rescue operation, it can suppose a great advantage within current rescue protocols.

Assessment of Automatic Target Recognition in Mine Hunting; Command, Control and Communication (C3) of autonomous vehicles in the sub-surface domain.
M. H. Roberts, C. S. Soper and W. P. L. Biggs, QinetiQ, UK

This paper describes an exploration of Human Autonomy Teaming in relation to adaptive (i.e., operators trigger changes to control mode) and adaptable (i.e., system triggers changes to control mode) modes, during synthetic trials. As part of an ongoing program of research focussed on autonomous vehicles in the maritime domain (i.e., Maritime Autonomous PLatform Exploitation (MAPLE)), this paper reports an assessment of Command, Control and Communication (C3) activities associated with sub-surface Unmanned Vehicles (UxV), obtained during a ‘Mine Hunting’ Automatic Target Recognition (ATR) experimental scenario.
The assessment includes analysis of the Instantaneous Self Assessment of Workload, Trust Questionnaires, and qualitative data, obtained from Royal Navy personnel with experience of managing warfare and tactical picture compilation in relation to sub-surface UxV C3 user Interface functionality. This paper utilises both quantitative and qualitative methodologies to analyse ratings, comments and observations.
The findings are presented in terms of the differences between adaptive vs. adaptable task control, with the main aim of seeking to understand advantages / disadvantages of each type of control mode in the sub-surface mine hunting domain. In general, this experimental work demonstrates that Military personnel prefer to be in control of triggering shifts in autonomy level (i.e. adaptable) and that ATR can be implemented successfully, certainly for the sub-surface mine warfare environment. Additionally, this paper describes the next steps in the ongoing MAPLE research program. Specifically an upcoming series of experiments, which will further inform human machine tasking / role allocation and elucidate the Human Factors considerations associated with UxV C3.

Hydrodynamic loads and flow structure analysis for a surfaced submarine using captive model experiments
A. Conway, Defence Science and Technology Group & Australian Maritime College, Australia
C. Kumar, QinetiQ, Australia
A. Rolls, Australian Maritime College, Launceston, Australia
A. Fowler, Defence Science and Technology Group, Australia
A. Cameron, Defence Science and Technology Group & QinetiQ, Australia

Submarines are required to operate on the surface for significant periods of time, for example during transit in shallow waters. However, as they are designed primarily for submerged operations, their surfaced sea-keeping behaviour may be poor. Furthermore, the wave making resistance of the vehicle increases in the surfaced state, substantially impacting on its powering requirements. The bow wave encountered when operating in a surfaced state applies a downward heave force and a bow down pitching moment, impacting the vessel’s sea-keeping performance. These interactions are complex, and a combination of numerical simulations and experimental programs is often employed to provide insight. A captive model experimental program was undertaken at the Australian Maritime College Towing Tank facility to generate data at model scale for a 1.69m BB2 generic submarine geome_try operating on the surface in calm water. The experiments consisted of two stages. Firstly, a new calibration technique was employed to produce high quality loads measurement. Secondly, a series of straight line and static angle of drift measurements were undertaken at two Froude numbers. Force measurements were complemented with surface flow field visualisation of bow wave height and flow structures in the bow region. The data generated included the hydrodynamic loads and detailed, time-averaged flow structures on the surface, which will be used to study the behaviour of the vehicle and validate numerical tools. The force measurements showed highly repeatable loads with well-defined trends in both sway and heave, critical to generate coefficients for submarine manoeuvring simulations.

Submarine Maneuvers in a Simulator
C. E. Guedes do Nascimento, E. Aoun Tannuri, Escola Politécnica da USP, Brazil

The thesis consisted in implementing a numerical model of a submarine in the Numerical Offshore Tank of the University of São Paulo (TPN-USP) based on the concepts of maneuverability of vessels. This thesis consisted, among other studies, of adapting the numerical model of the TPN, making the necessary changes to allow not only surface vessels, but also submersibles and submarines to be simulated. The final product is that the Numerical Offshore Tank is now also capable of simulating submarines, allowing for various tests and analyzes related to maneuverability; in addition to all the possibilities that this new tool offers.

Estimation of damage caused by the impact of an exercise torpedo on a submarine pressure hull structure
R. Castillo, Chilean Navy, Chile
N. Bradbeer, UCL, UK

Realistic training is a key enabler of submarine capabilities; it is difficult to completely simulate a torpedo attack in training without launching a physical weapon. While exercise torpedoes have no warhead, they can run at significant speeds and the uncertain consequences of an accidental collision with the target platform preclude numerous navies from this practice. Recent publications have detailed deformations obtained in laboratory tests when the impact of a scaled model of an exercise torpedo against a scaled submarine structure is simulated in several configurations. In one of them, the empirically obtained response has been successfully numerically modelled using ANSYS. This paper describes the development of a full-scale model. Using LS-DYNA explicit solver, previously performed laboratory tests were modelled for validation, obtaining satisfactory results. Built on this performance, a 1:1 dynamic simulation of an impact of a 533mm exercise torpedo against a submarine hull model was performed, and numerically predicted stresses and deformations recorded. Results suggest that high transient stresses generated by the impact may become the driving safety hazard. However, this type of exercise, conducted under controlled conditions (depth of the attacked submarine and torpedo speed), could lead to an overall risk level deemed as acceptable for its performance.

The Variation of an Underwater Vehicle's Sail Resistance with Reynolds Number and Longitudinal Location
D. Pook, G. Seil, D. Ranmuthugala, Defence Science and Technology Group, Australia
T. Keith, University of Tasmania & Defence Science and Technology Group, Australia
M. Renilson, Pacific ESI, Australia

The resistance of an underwater vehicle will be affected by the size and location of appendages. Due to flow interactions, the pressure component of an appendage's resistance is affected by its location on the hull. This was investigated using Computational Fluid Dynamic (CFD) simulations of the BB2 submarine geometry, with the resistance of the sail considered for different longitudinal locations. The sail resistance was broken down into pressure and viscous contributions. Scaling of the viscous contribution with Reynolds number showed good agreement with the ITTC'57 frictional correlation line. For low Reynolds numbers, the pressure component of the resistance was a drag. However, for high Reynolds numbers, the pressure component of the resistance was a thrust although the net sail resistance remained a drag. Simulations of the sail mounted on a flat plate for varying Reynolds numbers always showed a pressure drag, indicating the numerical modelling was correct. To further study the change in the resistance pressure component, the location of the sail was varied fore/aft along the hull. When the sail was located further aft, the pressure force was in the drag direction at high Reynolds numbers. For the standard BB2 geometry, the sail pressure thrust at high Reynolds numbers was attributed to the favourable streamwise pressure gradient downstream of the bow. Even though the BB2 sail is mounted on the parallel mid-body, there is still a streamwise pressure gradient that modifies the sail pressure force. The paper highlights the importance of Reynolds number and location when determining appendage resistance.

Effective measurement approach, and decision horizons, for model based mission planning for an Unmanned Underwater Vehicle (UUV)
C. Fletcher, Shoal Engineering Pty. Ltd., Australia
S. Anstee, K. Pringle, K. Slater, Defence Science and Technology Group, Australia

Defence Science and Technology Group has developed tools suitable for application to a variety of systems modelling. They marry models built in the Modelica language to open source software scripting and management tools, creating a re-configurable digital twin. This paper provides results from a series of studies of a large UUV, considering it's performance under conditions of uncertainty using a strict mathematical definition for measure-of-effectiveness developed by Reed and Fenwick1 that is design independent.2 The approach removes the need to evaluate utility, using instead ratios of probability under uncertainty to evaluate and compare decisions in design and operation. Our work extends from previous studies3 examining optimal choices faced during design and operation of a UUV by considering the time horizon over which such analyses are undertaken. Currently these types of analyses can prove useful in supporting decision making at the design and acquisition stages of procurement, and this paper demonstrates their further utility for managing risk, by evaluating branches and sequels typically encountered by operators during mission planning.4 The benefit of the approach is highlighted through a worked example of the Echo Voyager Extra Large UUV (XLUUV) undertaking a long range mission utilising efficient approximate design drag models developed by Renilson.

The vertical force required from the aft control surfaces to enable a submarine to maintain a level turn
H. Kim, Australian Maritime College, Australia
D. Ranmuthugala, Defence Science and Technology Group, Australia
M. Renilson, Pacific ESI, Australia

When a submerged submarine turns in the horizontal plane it experiences a complex flow around the hull, casing and sail. This results in out-of-plane loads in heave and pitch. To design the Aft Control Surfaces (ACS) such that adequate force can be applied to counteract these out-of-plane loads it is necessary to understand their magnitude. The motion of a submarine can be simulated using a coefficient based model, however such a model has limitations in predicting the out-of-plane loads. An alternative approach is to apply a fully coupled model using Computational Fluid Dynamics (CFD) to predict the complex flow around the submarine. This can give a better prediction of the force required by the ACS to maintain a level turn. However, such a model requires significant computational resources and is not ideal for the early concept phase of a submarine design. In this paper manoeuvring predictions of the BB2 generic submarine with X-plane ACSs in the horizontal plane using a coefficient based model are compared with those from a fully coupled CFD model, and results from free running model tests. The difference in the required vertical force from the ACSs predicted using the two methods are compared and analysed against the measured results from experiments. Possible improvements to the coefficient based model to better predict the vertical force required from the ACSs are discussed. This will enable such a model to be used to assist in the design of the ACS at an early stage of the submarine design cycle.

Ancillary Battery Technology – Where it Came from and Where it's Going
M. Moody, D. Mitchell, BMT, UK

After the commercialization of electricity in the late 1800s, the useful applications of electricity on marine vessels became apparent. In that time the benefit of using electricity, and specifically batteries, to power submarines was exploited due to the fact that no exhaust is required, allowing the submarine to dive without snorting. The modern solid-state power electronics revolution in the 70s and 80s created technology that supported more sophisticated battery charging systems with better control and voltage/current optimization to meet the specific needs of different battery types. In parallel, batteries themselves were continually improving and becoming safer. With the expansion of the renewable energy and electric car industries, more research is being carried out on battery technologies than ever before and so too does the potential for their use on submarines. This paper discusses the use of batteries in auxiliary applications used onboard submarines and the challenges faced when selecting a battery technology and the supporting infrastructure for a given application. The paper concludes that the selection methodology for the optimal battery solution is not only dependent on the technology available but also on its intended use, safety measures required and the economic viability of the solution.

An Innovative UCL Concept Submarine Design for an All-electric Boat
R. Pawling, UCL, UK

The UCL Submarine Design Course is a three-month short course in which groups of students develop a submarine concept design to meet a broad user requirement. The course covers the broad process of submarine design, from the development of a concept of operations and subsequent cost-benefit analyses to the design of primary structure and propulsion and hotel systems. The requirements set each year are notable for a "special feature", a novel aspect that requires some innovation on the part of the students.
This paper will summarise the eight designs developed by the 2019 cohort, and in particular detail an all-electric submarine for use in the Baltic and North sea. Codenamed "Renewable", this 1500tonne design features battery-only propulsion with the ability to use ROVs to recharge from a dispersed power infrastructure based around existing and expanding offshore wind farms. This paper will cover the general CONOPS behind the design, the technical solution developed by the students, and conclusions regarding the viability of all-electric submarines in the near future.

Design of Delta Wing Autonomous Underwater Gliders for Long Term Sustainable & Stealth Reconnaissance Using Numerical Studies
G. Mukesh, R. Vijayakumar, Indian Institute of Technology, India

Autonomous Underwater Gliders (AUGs) are a unique source of collecting the oceanographic data for varying depths with longer endurance than other types of unmanned underwater vehicles. The buoyancy driven propulsion mechanism assists in diving deep into the ocean, collect data, resurface in saw-tooth and spiral motions. There have been various hull-forms introduced for this purpose starting from (Stommel, 1989) - Torpedo hull, XRay Flying-Wing Glider, etc., all of which have seen an improved understanding of the hydrodynamics associated with the hull-form of the gliders. The saw-tooth motion represents the glider's capacity to cover larger distances with a smaller angle of attack thereby achieving an increased range for the same power included within the hull batteries. In this paper, a design study of delta wing hull-forms, which are proven to have better longitudinal motion characteristics, is proposed to arrive at an optimized hull form which can be used for long term reconnaissance missions without affecting the ambient noise of the ocean, remaining in stealth to assist submarines with valuable data. Delta wing hull forms are varied using different NACA sections and numerical analysis of the obtained hull forms is performed to arrive at the hydrodynamics, namely, the drag, lift forces and coefficients for varying angles of attack, using commercial CFD software – StarCCM+. These results are then compared against each other to derive the optimized hull form which can use less battery for its motion underwater. This is achieved by plotting the longitudinal motion of the glider in Matlab using in-house code.

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