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CHALLENGES IN SUBMARINE DESIGN FOR SHOCK LOAD

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Summary. This paper is a discussion on the problem formulation regarding transient fluid-structure interaction (FSI) in the event of an underwater explosion close to a submarine structure. Much of previous work has gone into quantifying the shock impact on the pressure hull, with good results. Present challenges include finding the response of externally mounted structures and equipment. Of specific interest are flooded structures connected to the pressure hull. Computationally this represents FSI with a structure partially flooded having units elastically mounted within. The enclosed water is typically connected to the surrounding water restricted through a number of apertures.

1 INTRODUCTION

Shock design is an essential part in the design process of making a submarine. Not only because it has an impact on the structural manifestation of the vehicle but also because it sets requirements on systems and system solutions. Survivability when subjected to a shock impact from an underwater explosion is not only a matter of maintaining structural integrity, it also requires system functionality to a specific extent. This is generally dictated by operative capabilities necessary for survival. By regarding one of the basic requirements for survival, maintaining hull integrity, it is evident that shock resistance is vital for systems including e.g. valves, cable hull penetrators and hull penetrating shafts. By regarding operational requirements, it is also possible to specify an impact at which survivability means full functionality and no permanent deformations in the submarine structure. It is therefore imperative that the shock loads used in the design are correct in order to be able to use the full potential of materials selected or methods used in the design process.

2 THE SUBMARINE

The submarine can be regarded as a gas filled cylindrical body able to withstand hydrostatic pressure at depth. Onto this cylinder a number of units, e.g. platforms, machines, pipes, control surfaces and system components are mounted, both inboard and outboard. A number of hull penetrations are required to access outboard systems and to allow for transition of personnel or vehicles. To achieve a hydrodynamic shape and to cover many of the outboard units, a casing is placed onto the pressure hull. This usually also covers the forward pressure bulkhead, forming the rounded bow. The casing blends into the sail that also houses the masts (Figure 1).

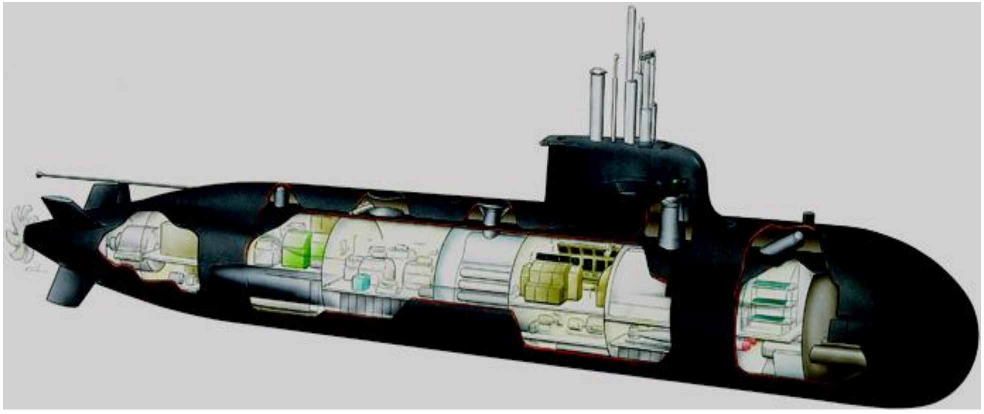

Figure 1. Cross-section of a single-hull submarine. The casing here covers the top of the pressure hull and forms the rounded bow in front of the forward bulkhead. The sail is seen with the masts hoisted.

The space between the pressure hull and casing is flooded, i.e. the casing bears no hydrostatic load when submerged. This is important as the dimensioning loads will differ from those applying to the pressure hull. As the submarine will have to operate on the surface as well as submerged, water has to be able to fill or drain the volume between the casing and the pressure hull. This is achieved through a number of holes in the casing allowing water to flow.

3 PRESENT RESEARCH AND CHALLENGES

Shock impact on a specific structural part is dictated by many factors, e.g. exposed surface area, material properties, mounting specifics, etc. However, certain properties have larger consequences than others. A shock wave impinging on an air-backed structure such as the pressure hull will impart a large impulse resulting in displacements, accelerations and deformations in the structure. The same shock wave will not affect a water-backed structure such as the casing in the same manner. This does not mean that a water-backed structure is unaffected by a shock wave but the response is generally less severe.

Much effort has gone into quantifying the shock impact on the pressure hull as the response of the hull constitutes the base acceleration of the mounted equipment as well as being the primary barrier to water ingress. Empirical data has been collected during the last 60 years in shock testing. Computationally this fluid-structure interaction has been handled using a partitioned approach with existing solvers, e.g. BEM (USA-code) and FEM (LS-DYNA), or by using shock response spectra and modal analysis. Correlation to empirical data and the ability to predict the hull response has been good.

Structures such as the casing and the sail has not been addressed to the same extent. This is one topic of the current challenges. These structures have a more complex interaction with the fluid as they are generally flooded. As stated above, the casing is a water-backed structure. However, it is attached to the pressure hull and will therefore be affected by the hull response. As the physical dimension of the casing is comparable to the pressure hull, there is a simultaneity of the responses of the hull and casing as the pressure wave progresses over and through the structure. A typical shock wave load history from an underwater explosion can be regarded as having a sharp, step-like shock front that tapers off exponentially with time. The pressure pulse length in space is of the same order as the pressure hull diameter.

Interaction between the casing and the water will occur both externally, a water mass with infinite boundary, and internally with the enclosed water mass. The latter is in contact with the external water mass through the drain holes in the casing. Fluid structure interaction effects will be significant. The material in the casing is also important as material properties combined with design will matter. The current work aims at assessing the response of the casing and to quantify the imparted load due to an underwater explosion using FSI. Full scale testing is also planned to validate the computations. A full scale submarine section intended for testing is under construction. This full diameter testbed will have a length in the order of 20 m and weigh 400 tons. It will therefore provide a full size shock testing environment for structural components, e.g. the casing and outboard equipment.

A related issue is the response of hull-mounted equipment under the casing described above. A common way to attenuate shock impact on a specific piece of equipment is to place it on a resilient mount, e.g. elastic rubber mountings or springs. The dimensioning shock load of a unit with a characteristic size and weight much smaller than that of the base structure, here the pressure hull, will primarily be the base acceleration. For mounted units under the casing, this is no longer necessarily true as it also will interact with the enclosed water volume described above.

A specifically interesting structure is the sail. It shares many of the conditions and specifics with the casing. By necessity it extends further out from the pressure hull and has additional purposes. It houses the masts, essentially a number of rigidly and/or elastically mounted heavy units. The sail has to act as a foundation for these when hoisted and as a housing when lowered. Additional requirements are thus put on the sail structure compared to the casing.

4 CONCLUSION

This paper outlines some challenges in submarine shock design. The shock response of the casing and elastically mounted units under the casing are currently investigated taking fluid-structure interaction into account.