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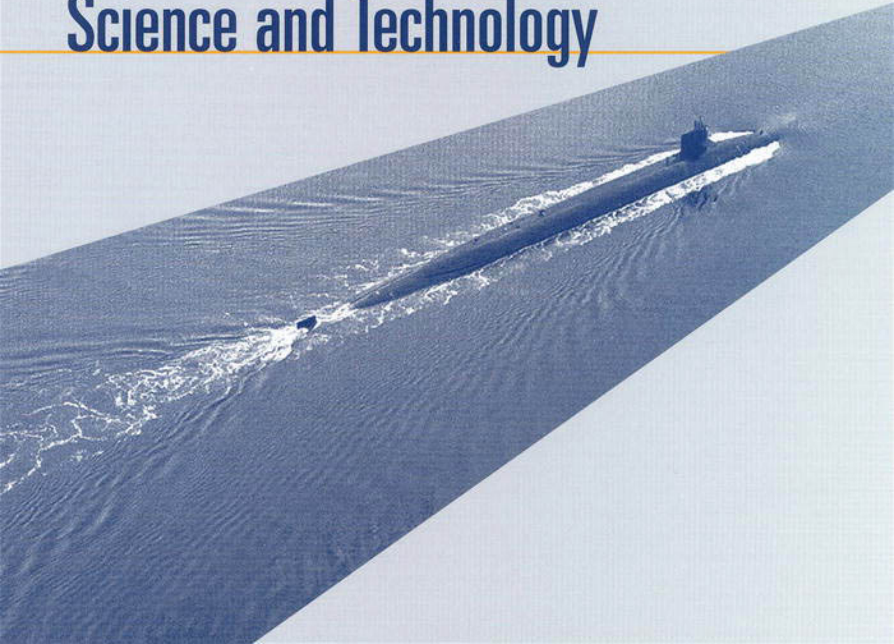
An Assessment of Naval Hydromechanics Science and Technology



An Assessment of Naval Hydromechanics Science and Technology

Committee for Naval Hydromechanics Science and Technology
Naval Studies Board
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

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Preface

The Department of the Navy maintains a vigorous science and technology (S&T) research program in those areas that are critically important to ensuring U.S. naval superiority in the maritime environment. A number of these areas depend largely on sustained Navy Department investments for their health, strength, and growth. One such area is naval hydromechanics, that is, the study of the hydrodynamic and hydroacoustic performance of Navy ships, submarines, underwater vehicles, and weapons. A fundamental understanding of naval hydromechanics provides direct benefits to naval warfighting capabilities through improvements in the speed, maneuverability, and stealth of naval platforms and weapons. This level of understanding requires the ability to predict complex phenomena, including surface and internal wave wakes, turbulent flows around ships and control surfaces, the performance of propulsors, sea-surface interactions, and associated hydroacoustics. This ability, in turn, stems from the knowledge gained from traditional experiments in towing tanks, from at-sea evaluations, and, increasingly, from computational fluid dynamics.

Historically, the Office of Naval Research (ONR) has promoted the world leadership of the United States in naval hydromechanics by sponsoring a research program focused on long-term S&T problems of interest to the Department of the Navy, by maintaining a pipeline of new scientists and engineers, and by developing products that ensure naval superiority. At the request of ONR, the National Research Council, under the auspices of the Naval Studies Board, conducted an assessment of S&T research in the area of naval hydromechanics. The Committee for Naval Hydromechanics Science and Technology was appointed to carry out the following tasks during this study: assess the Navy's research effort in the area of hydromechanics, identify non-Navy-sponsored research and development efforts that might facilitate progress in the area, and provide recommendations on how the scope of the Navy's research program should be focused to meet future objectives. Attention was given to research efforts in the commercial sector as well as international research efforts, and to the potential of cooperative efforts.

The committee assessed the existing program in the following areas: maturity of and challenges in key technology areas (including cost drivers); interaction with related technology areas; program funding and funding trends; scope of naval responsibility; scope, degree, and stability of non-Navy activities in key technology areas; performer base (academia, government, industry, foreign); infrastructure (leadership in the area); knowledge-base pipeline (graduate, postdoctoral, and career delineation); facilities and equipment (ships, test tanks, and the like); and integration with and/or transition to programs in a higher budget category. Two key questions for the assessment were the following: (1) What technology developments that are not being addressed, or that are being addressed inadequately, are needed to meet the Navy's long-term objectives? and (2) To what extent do these technology developments depend on Navy-sponsored R&D?

A timely report was requested for use in the Navy Department's planning for its S&T investment, which includes identifying critical research areas (i.e., National Naval Needs) for Department of the Navy sponsorship. In a memorandum to all personnel at the ONR, Fred E. Saalfeld, Executive Director and Technical Director, ONR, wrote as follows:[1]

> The purpose of a National Naval Program [now called a National Naval Need] is to allow ONR to meet its responsibilities to maintain the health of identified Navy-unique S&T areas in order that:
>
> - A robust U.S. research capability to work on long-term S&T problems of interest to the DoN [Department of the Navy] is sustained;
> - An adequate pipeline of new scientists and engineers in disciplines of unique Navy importance is maintained; and
> - ONR can continue to provide the S&T products necessary to ensure future superiority in integrated naval warfare.
>
> The assumption of national responsibility for the support of a research area requires the long-term commitment of a significant level of investment. It can also have non-military benefits and applications unforeseen at the onset of scientific research. To assist in this effort, ONR should continue its efforts to encourage and exploit investment in these areas by other research sponsors. It is therefore imperative that U.S. superiority in these areas be maintained, even at the sacrifice of niche opportunities.

The committee met in Washington, D.C., for briefings by the Navy and by others in the hydromechanics community on September 14 and 15, 1999, and on October 20 and 21, 1999, holding parallel sessions on classified and international research. In addition to these group meetings, individual committee members gathered additional information to help the committee form its collective judgment. This included information from ONR research programs and funding, from Navy Department hydromechanics test and research facilities and development efforts, from research funded by the Air Force Office of Scientific Research and the National Aeronautics and Space Administration, and from professional societies. A subcommittee also attended a briefing entitled "Fast Ships," which was presented by Paul E. Dimotakis at the JASON[2] Fall Meeting on November 19, 1999. On December 8 and 9, 1999, the full committee met for the third and last time to finalize the report. The resulting report represents the committee's consensus view on the issues posed in the charge.

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[1]Memorandum from Fred E. Saalfeld to ONR, November 19, 1998.

[2]The JASONs are a self-nominating academic society that conducts technical studies for the Department of Defense (meets in July, August, September, and October and produces a report in November).

Acknowledgment of Reviewers

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's (NRC's) Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. The committee wishes to thank the following individuals for their participation in the review of this report:

Alan J. Acosta, California Institute of Technology (emeritus),
Christopher E. Brennen, California Institute of Technology,
RADM Millard S. Firebaugh, USN (retired), Electric Boat,
Lee M. Hunt, National Academies (retired),
Justin E. Kerwin, Massachusetts Institute of Technology,
Vincent J. Monacella, Naval Surface Warfare Center, Carderock Division (retired),
RADM Marc E. Pelaez, USN (retired), Newport News Shipbuilding and Drydock Company,
Robert C. Spindel, Applied Physics Laboratory, University of Washington,
Marshall P. Tulin, University of California at Santa Barbara (emeritus), and
Ronald W. Yeung, University of California at Berkeley.

Although the individuals listed above provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with the authoring committee and the NRC.

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Executive Summary

In this report, naval hydromechanics is defined as the study of both the hydrodynamic and hydroacoustic performance of naval ships, submarines, underwater vehicles, and weapons. For brevity, the report often uses just the term "hydromechanics," but the reader should clearly understand that this includes hydroacoustics, which is of unique importance to the Navy for reasons that are explained herein. During the Cold War, the Department of the Navy benefited greatly from a steady flow of new ideas in naval hydromechanics. The new ideas generated from research sponsored by the Office of Naval Research (ONR) and research in the Department of the Navy research centers were incorporated into platforms and weapons to improve their speed, maneuverability, and stealth. Continued advances in naval systems can be expected from more recent, current, and future research in hydromechanics. These advances should enable faster, more agile, and stealthier platforms and weapons suitable for operation in both the littorals and the deep ocean.

Because ship and submarine hydromechanics are so specialized, they are not priority areas for other agencies, nor are they the focus of industrial research efforts. Thus the Department of the Navy must provide the necessary support if it wishes to ensure that U.S. naval forces always benefit from superior technology. Accordingly, the committee recommends as follows:

- *To enable the Department of the Navy to maintain superiority in naval hydromechanics and to allow the necessary resources to be devoted to this aim, ONR should designate naval hydromechanics as a National Naval Need.*[1]

The committee is concerned that ONR support for research in ship and submarine hydromechanics and, in turn, the output of new ideas and technology have declined over the past decade. The current

[1]As stated by Fred E. Saalfeld to the Office of Naval Research (ONR), National Naval Programs (now called National Naval Needs) are those science and technology areas that are uniquely important to the naval forces and whose health depends on ONR investment. See the preface for additional discussion.

system relies partially on funding made available from major acquisition programs, which in turn produces dramatic variations in the funding for naval research. This arrangement adversely impacts ONR's ability to maintain a research program focused on the long-term S&T problems of interest to the Department of the Navy—guaranteeing a pipeline of new scientists and engineers and developing products that ensure naval superiority. The work associated with variable funding from major acquisition programs is naturally oriented to the needs of the acquisition programs and therefore tends to be shorter-term and less adventuresome in scope than is required to produce revolutionary changes in technology. Today's 6.1 research will support new ship concepts a decade from now. The committee therefore sees the need for a stable base of funding outside of the acquisition programs for ONR, specifically for work in naval hydromechanics at the 6.1 level. Based on its judgment, the committee recommends as follows:

- *ONR should implement the following changes in research policy as it relates to hydromechanics:*

1. Funding for 6.1 should be less focused on immediate needs and more focused on broad, long-term research on fundamental problems in naval hydromechanics such as linear and nonlinear wave dynamics, including wave breaking, air entrainment effects, and air/sea interactions; all aspects of cavitating and supercavitating flows, including inception, noise, and damage; drag reduction and other aspects of flow control; surface and submerged wakes; hydrodynamic sources of noise; internal wave generation and propagation; and vortex dynamics and turbulence unique to naval surface and subsurface vehicle/sea interaction.

2. The 6.1 resource base should be stable and should be protected from the larger funding fluctuations associated with major acquisition programs.

3. In the 6.1 area, ONR should promote a culture of bottom-up research, which can bring novel developments and lead to solutions for unanticipated problems that may arise in the future.

The committee is concerned that the Department of the Navy does not have an integrated, long-term plan for science and technology (S&T) programs aimed at developing and exploiting new platform concepts for ships and submarines. It therefore recommends as follows:

- *ONR, in conjunction with the relevant Office of the Chief of Naval Operations and the Naval Sea Systems Command/Program Executive Office organizations, should formulate and maintain an integrated 6.2/6.3 plan for technology development and demonstration aimed at new platform concepts for ships and submarines and using the results of long-term basic research under ONR sponsorship. Key features of this plan should include (1) significant advances in a 15-year time frame, (2) clearly articulated goals in the related hydromechanics areas of signature reduction, drag reduction, propulsive efficiency, and seakeeping/maneuverability, and (3) the examination of concepts that could achieve these goals. Demonstrations necessary to ensure the validity of predicted performance should be described. The investment required and the resulting payoffs in terms of improvements in stealth, speed, cost, and payload capability should be assessed. The plan should guide 6.2/6.3 research and development efforts. The planning process should involve experts from the industry that engineers and builds naval systems; these experts must have long-term vision. The plan should also (1) require and accommodate innovative and competing approaches, (2) foster collaboration between the Department of the Navy, academia, industry, and, where appropriate, foreign organizations, (3) identify opportunities for areas of fundamental research, and (4) stimulate concepts for spin-off to commercial applications.*

• *Continuous channels of communication should be established between the research, design, and operations communities to ensure the effective use of research results and to inform researchers of specific problems as they arise. It is anticipated that improved communications at the Department of the Navy and between the department and the industrial and academic communities will lead to a stronger research program with significant future payoffs for the Department of the Navy.*

The committee expressed concern about various aspects of the Department of the Navy's research centers. There are numerous facilities and they are large, but they do not have the world-class instrumentation needed to do cutting-edge hydromechanics research. Few of the facilities appear to have been qualified to the careful level required for high-quality research. Some of the facilities appear to be idle more than one would expect in view of the research needed to match the imaginative developments that are occurring in commercial ships. If the Department of the Navy were to provide a financial incentive for commercial organizations to use these facilities, much as NASA does with its wind tunnels, a higher quality of facility and better support might become available to both military and commercial users of the facilities. Computational fluid dynamics (CFD) at the centers is expanding in importance and effort, yet world-class computing facilities are not available and some of those doing CFD work on naval problems are not in the mainstream of modern CFD developments. This concern is not limited to CFD researchers. Overall, while several of the researchers in the Department of the Navy's centers are highly regarded in the research community, that number is small compared with total staffing, and they are spread across a number of different facilities. The Department of the Navy hydromechanics research centers are a national asset and should be supported accordingly. Therefore, the committee recommends as follows:

• *The Department of the Navy should take the following steps to ensure that high-quality S&T is conducted at the hydromechanics research centers:*

1. *The Department of the Navy should consider retiring some of the less advanced facilities at the centers so that the rest can be improved and supported by better technical know-how and more manpower.* Facilities that have shown no significant work or major instrumentation upgrades for a long time (say, 10 years) should be considered for decommissioning.
2. *The Department of the Navy should aggressively pursue advanced measurement techniques (e.g., noninvasive, holographic, ultrasonic, and velocimetry techniques).*
3. *The maintenance and upgrade of hydromechanics facilities at the Department of the Navy centers should be funded from a separate source not linked to the S&T program.*
4. *The fundamental basis for experimental work at the Department of the Navy's centers should be strengthened.* Experts from the different centers should be involved in intercenter scientific committees promoting the scrutiny and discussion of issues such as design and upgrade of facilities, qualification and documentation of the characteristics of an adequate facility, development and acquisition of new instrumentation and measurement techniques, physical interpretation of data, and evaluation of the scientific merit of the proposed experiments and the results obtained. Funding allocations should be based not only on the merit of proposed work but also on a track record of significant contributions from past work. The high quality of the Department of the Navy centers can be maintained by regular internal and external peer review and an emphasis on the refereed publication of research results.
5. *A more active collaborative relationship between university and center researchers should be facilitated to take advantage of the strengths of both and to create a stronger overall research effort.* Top-notch researchers from universities and other research institutions should be involved in research at

the centers. The centers should use university researchers as active members of working teams in technical and scientific matters, design, facility upgrades and modifications, instrumentation design, and data presentation and interpretation of results. In addition, facilities and their use should be subjected to periodic evaluation by external experts.

6. *The quality of the research and technical management staffs should be improved over time by providing a more attractive research environment for the best and brightest university graduates.*

The committee is also concerned about the declining base of expertise and the lack of emphasis on naval hydromechanics in the research community that supports the Department of the Navy's needs. It therefore recommends as follows:

• *ONR should establish an institute for naval hydrodynamics (INH) subject to the following guidelines:*

1. *The INH should capture the best talents and the largest body of knowledge in hydromechanics from the United States and foreign countries.* It should leverage existing funding and ensure a well-coordinated approach to research in hydromechanics.

2. *The INH should be directed by a highly qualified scientific leader.* The management style and philosophy should be in tune with the intellectual creativity expected of participants in the INH.

3. *A small central facility should support the INH. This facility should be open to all INH participants.*

4. *The form of the center should be carefully determined. One attractive option would be a virtual center that uses distributed assets and extensive Internet communication. The virtual center would have a management committee and a small central supporting entity.* The new NASA Astrobiology Institute organized by the NASA/Ames Research Center, the European Research Community on Flow, Turbulence, and Combustion, and the NASA Institute for Advanced Concepts are models for virtual centers. Virtual centers could draw upon researchers anywhere at any time. Although the idea is relatively new and relatively untested, it is very promising, and the committee recommends that it be given serious consideration. Alternatively, the center could be modeled after the jointly managed NASA/Stanford Center for Turbulence Research and the independently managed Institute for Computer Application Science and Engineering, at NASA/Langley.

The committee believes that if the resources to support the initiatives recommended above can be found from new sources or budgetary rearrangements, the Department of the Navy will be in a good position to maintain its technical superiority in hydromechanics in the decades ahead.

1

Introduction

In this report, naval hydromechanics is defined as the study of the hydrodynamic and hydroacoustic performance of naval ships, submarines, underwater vehicles, and weapons. The importance, value, and contributions of naval hydromechanics science and technology (S&T) to the success of naval forces can best be understood from a historical perspective. The era most relevant to the purpose of this study extends from the formation of the Office of Naval Research (ONR) shortly after World War II to the present. During that period, the technical accomplishments of naval hydromechanics are epitomized by those of the David W. Taylor Model Basin (now the Naval Surface Warfare Center, Carderock Division (NSWCCD)). Some examples of its accomplishments, along with other examples from two white papers on naval hydromechanics written by Marshall P. Tulin[1] and Thomas T. Huang,[2] are described here.

- After World War II, basic hydromechanics research was conducted to support submarine construction and operation. A series of 24 body-of-revolution hulls (DTMB Series 58) were tested in a towing tank to determine their resistance, motion stability, depth and course-keeping control, and ocean surface effects at high speeds. An optimal axisymmetric hull shape had minimum resistance and a mild pressure gradient enabling the development of a hull boundary layer suitable for placing control surfaces upstream of a single-screw propeller. This basic research provided the Navy with a concept for a superior submarine that had reduced flow resistance, more effective control, and highly efficient propulsion. This submarine concept could improve not only the speed but also the stealth performance. A 20 percent gain in propulsion efficiency could be achieved by using the wake-adapted single-screw propeller instead of twin-screw propellers. The axisymmetric hull provided the minimum circumferential inflow variation to the propeller, which drastically reduced propeller-induced noise and cavitation.

[1]Tulin, Marshall P. 1999. “Naval Hydrodynamics: Perspectives and Prospects.” Santa Barbara, Calif.: Ocean Engineering Laboratory, University of California. September 14.

[2]Huang, Thomas T. 1999. “Contributions of Fundamental Hydromechanic Research to Advancing Fleet Technology.” Crystal City, Va.: Newport News Shipbuilding and Drydock Company. December.

• The Navy's first research submarine, the USS *Albacore* (SS 569), was built to evaluate at sea the innovative ideas of control and propulsion that had been derived from the basic research program, and it provided firm support for these ideas. With this submarine, the Navy, the science and technology community, and the shipbuilding industry stepped outside the traditional technology box of the fleet submarine. The fundamental data obtained on a new hydrodynamic hull, control surfaces, and propulsion, along with the utility of low-carbon, high-yield-80 structural steel, became the foundation of U.S. submarine design and construction for the next half century. The development of the high-speed submarine hull form is a prime example of a technological breakthrough. It enabled a submerged submarine to travel well in excess of 30 knots. More importantly, when combined with the parallel development of nuclear propulsion, it resulted in the U.S. Navy's first truly high-speed submarine. The research foundation and technical expertise made possible by sustained investments in Navy S&T substantially enabled this revolutionary advance in naval warfare capability.

• Equally important to the continued superiority of U.S. submarines have been the sustained improvements in submarine stealth. The sudden increase in submarine speed and endurance produced an urgent need for quiet propulsion for stealth and for effective control for submarine safety. This drove the hydromechanics S&T community to continue to improve the stealth and hydromechanics performance of the submarine fleet. A long-term national S&T research program was implemented to solve the acoustic side effects of sustained submerged high speed and to meet the threat of the Soviet submarine fleet during the Cold War period. Fundamental and applied stealth and hydromechanics research was vigorously pursued in the Navy's laboratories and in universities, under the sponsorship of the ONR. Hydromechanics innovations ranging from advanced propeller designs to reduced hull acoustic radiation have enabled a large reduction in submarine signatures. As a result of a broad range of technological developments, U.S. attack and ballistic submarines have maintained an underwater acoustic advantage over the submarines of all other navies.

• The Small Waterplane Area Twin Hull (SWATH) ship concept was developed from the technology base and design methods established by sustained investments from Navy 6.1, 6.2, and 6.3. This concept permits greatly improved seakeeping and seaway performance, particularly in small and medium-sized ships. Innovative design configuration capabilities were also developed, including the unique steering system embodied on the TAGOS 19 and a number of semiactive and active control system concepts. SWATH technology has been applied commercially to a large (12,000-ton) passenger/cruise ship and to all-weather ferries and hydrographic and survey ships. At present, about 40 naval and commercial SWATH ships have been built worldwide.

• Surface ship hull form technology and design methods have been applied to recent classes of surface combatants, resulting in superior seakeeping, powering, and acoustic performance. This major performance advance is a direct result of years of investment in hull form technology R&D.

• Continued compilation of the variability of sea conditions and their statistics has improved the seakeeping design specification for surface combatants, and satellite ocean wave observations have provided timely guidance for ship operations. The basic understanding of ship response to the ocean waves associated with different sea states has improved the ability to design surface combatants with better seakeeping characteristics, less deck wetness, cost-effective shell plating and hull girders, and improved helicopter landing and takeoff operations.

• The sustained development and implementation of numerous innovations in the fleet have reduced energy consumption and operating costs for U.S. Navy ships. Innovations include new, environmentally acceptable, effective hull antifouling coatings; improved hull and propeller cleaning and maintenance programs; and stern modifications that permit fuel savings of 3 to 10 percent for several classes of surface ships. All of these advances are supported or enabled by a sustained capability in hydromechanics research and design.

- In the late 1970s, the Navy needed to improve the target acquisition range of the Mk 48 torpedo. A limiting factor in the performance of the acoustic array was a basic hydrodynamic phenomenon, the noise caused by the transition from laminar to turbulent flow. The Naval Undersea Warfare Center (NUWC) developed the methodology to optimize array diameter, acoustic window thickness, transition location, and cavitation index and to resolve the key issue of window deformation under hydrodynamic loading. Experiments determined the location and intensity of the transition region, so that techniques to predict transition location could be validated. These advances in technology capabilities led to a substantial reduction in self-noise and a major improvement in torpedo performance.
- Hydrodynamic modeling based on theoretical and experimental research has played a critical role in the development and improvement of fleet weapons by providing estimates of forces and moments experienced by these vehicles during launch and maneuvers. Hydrodynamic force and moment predictions generated through this research were used as inputs to vehicle launch and trajectory simulations and throughout the development and design process. This process was instrumental in the development of Mk 46 and Mk 48 torpedo hardware and software and to a succession of advanced weapons such as the advanced capability and Mk 50 torpedoes.
- Basic research in hydromechanics and naval technical expertise have enabled advances in propulsor design through enhanced simulation and experimental methods that directly and indirectly reduced the noise signatures of Navy submarines, weapons, and tactical-scale vehicles. Substituting a single rotation propulsor for the traditional counterrotating propellers has meant indirect noise reduction due to machinery simplification while maintaining high efficiency and off-design performance. Using alternatives to traditional propulsor design reduces propulsor-radiated noise.