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Today's Navy—Echoes of the Past—Sounds of the Future

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ABSTRACT

Today's Navy is evolutionary. The only real progress is based on experience. We can guess at our needs and estimate performance, but the proof of success is a ship that operates. This paper will attempt to trace the evolutionary aspects of ship structural design and show how the new technology has been applied to ship designs, tested in the operating world, and modified based on experience. It will endeavor to show how new performance requirements have changed some of the Navy's approaches to design. Concrete examples will be used to illustrate the points made. Areas where Ship Structure Committee and SNAME work have been utilized will be identified, as well as areas in need of intensified attention.

In general, U.S. Navy ships are not prone to structural deficiencies in service. This does not imply that structural problems are nonexistent; we have some, but they are readily resolved. The Navy's good fortune in this regard is not a chance occurrence, rather it is a result of conscious efforts over the years to apply advances in the technology of new designs.

Naval ship design is a highly interactive and evolutionary process. Past experience from specific ship types is used to modify design procedures, motivate new areas of research, and improve later designs. The need to continually maintain a strong defense posture dictates backfitting of improved weapon and sensor systems on existing and often overaged warships. In this later context more stringent requirements of stress and flexibility are imposed on structures design with now "antiquated procedures."

A brief survey of service encountered structural deficiencies; their cause and resolution are discussed. Application of technology improvements resulting from Ship Structure Committee, Industry, and Government sponsored research is briefly traced. In particular, Navy experience in load criteria, design methods, material application, fabrication and education are discussed in relation to fleet support and new designs.

The opinions expressed herein are those of the authors and do not necessarily represent the official views of the Navy Department nor of the Naval Service at Large.

INTRODUCTION

In 1775, the first "American warship," the HANNAH, a small armed merchantman hired by General Washington, set sail to harass British supply ships off the coast of Boston. Two hundred years later American warships, including some of the largest moving structures ever built, sail the major oceans of the world carrying out our naval policies. In that two hundred year interval, the U.S. Navy has continuously kept pace with changing requirements and advancements in technology. The evolution of the U.S. Naval warship is a fascinating story and the impact of structural design in supporting this evolution is of unique interest to the audience at this symposium.

Today's cost effectiveness in meeting changing requirements was equally apparent in out early Navy. Our policy of supporting a strong merchant fleet had its beginnings in Revolutionary days when our Fleet was composed of armed merchantmen. (It wasn't until 1794 that Congress passed the Navy Act and provided for construction of six frigates. It should be noted that only three of these were completed--UNITED STATES, CONSTELLATION, and CONSTITUTION, all launched in 1797.)

Recognition of improvements in technology and their impact on naval structures also had early beginnings. The advent of steam as a means of propulsion led the Navy to commission a steam propelled ship, DEMOLOGOS, in the early 1800's. Of interest to this audience is the fact that DEMOLOGOS was the first twin hull ship and that she had "armor protection" consisting of five-foot thick timbers. Again, during the Civil War when the South produced the iron clad VIRGINIA from the remains of the captured USS MERRIMACK to wreak havoc on the Union blockade, the Union Navy rushed to completion its all iron-hulled MONITOR. History records how the operations of the VIRGINIA and its confrontation with the MONITOR changed the course of Naval Warfare. It is also interesting that two facets of Navy design are exemplified: the use of foreign technology in the adaptation of the fixed iron clad batteries of the Crimian War and the conversion of the partially destroyed MERRIMACK to the iron clad VIRGINIA.

This policy of converting hulls to other purposes has stood the Navy in good stead over the years. When Naval airpower started to come into its own, the first aircraft carriers were modified from existing hulls. It wasn't until 1934 that the RANGER, designed and built from the keel up as an aircraft carrier, was commissioned.

Our fire power on Naval ships also improved over the years. The requirements of the Five Power Navy treaty of 1921 placed restrictions on the numbers and tonnage of warships. This led to building more armament into existing ships. The ability to get "more bang for the buck" was also premised on a history of ordnance development. For example, DREADNOUGHT, the British battleship that was supposed to make all other battleships obsolete, could fire no heavier a broadside than the newer U.S. battleships of that time. Even though DREADNOUGHT had two and a half times the main battery fire power of the U.S. ships, the U.S. ships had the main batteries arranged so that they could be fired simultaneously. These brief statements on ordnance improvements are included because arrangement of weapons, protection from weapons effects, and armor requirements all tax the ingenuity of the structural designer. Today's hulls, with even more sophisticated weaponry, are providing even greater challenges to the structural community.

We learn from the past to transition into the future. The complexity of the world today requires a more systematic advancement of our military and, for this symposium particularly, our structural capability. Our readiness to counter new threats and our ability to take advantage of advancing technologies require a strong capability to provide efficient hull structure. Our past history in procuring a DEMOLOGUS, in getting a MONITOR on the line in time, in converting existing hulls to aircraft carriers, in increasing fire power and depending on a strong merchant fleet, is continuing today. Our face to the Fleet and to the world today is represented by a strong research and development capability. It is the intent of this brief paper to outline unique Navy structural requirements, our experiences from Fleet service, and the directions that the Navy is likely to take in the future.

RESEARCH AND DEVELOPMENT

An assessment of Navy structural research reveals that Navy hull structural design has traditionally been supported by a strong technological base. It has been continuing Navy policy to strengthen hull structural technology through the vigorous support of Research, Development, Test, and Evaluation. This support comes in many forms, including the following:

- o Navy R&D Program elements
- o Ship Structure Committee support
- o SNAME panel and committee support
- o Interaction with other governmental agencies, and private and foreign agencies, involved in shipbuilding
- o Research in universities and colleges

In sponsoring our own and in

supporting other research and development efforts, we have continuously expressed and debated our methods and as a result we have reaped the benefits of constructive criticism. The success of our approach is evidenced by our operational Fleet today. Success in itself is not necessarily of overriding interest, but the methods of achieving success and overcoming mistakes and errors are. Our procedures and methods evolve from first principles, are nurtured by at-sea experience, and are predicted on sometimes unique Navy requirements. It is the constant iteration and feedback of basic principles, experience, and requirements that are used to continuously update our procedures, methods, and criteria.

Since the Ship Structure Committee's inception, the Navy has been a supporting member and has gained considerably from SSC's active R&D program. The SSC research program includes some tasks of primary interest to a few member agencies, but with the majority of tasks covering areas of interest to all members. Our areas of common interest are sea loadings, reliability, low cost construction, fabrication techniques, safety at sea, and a determined effort to further knowledge and encourage training of future ship designers. Such interests have fostered work in computer applications, methodology surveys, state-of-the-art assessments and work such as SSC's SL-7 program.

Navy participation with SNAME is somewhat different in that we do not ordinarily contribute funds directly to SNAME research. However, every SNAME panel and committee has at least one representative from our Navy engineering or research community. SNAME has also been the sounding board through which the Navy has spread the word about what we are doing and the means of getting critical comment. This effort and our own interaction with other maritime groups and educational institutions has provided all parties involved a wealth of structural information. It is safe to say that this interchange, often in the form of mutually supported programs, has resulted in a much stronger structural capability than would have been possible if we chose to do it all ourselves. The Navy has benefited and the maritime community has benefited.

The Navy applies the results of the various research programs into the development of design procedures and criteria. Unique programs usually generated by Fleet needs include such items as gun blast effects or protection systems, and are generally handled in house. More general requirements of interest to the entire maritime community, such as ship motion and sea spectra predictions, are supported heavily by the Navy, but information is also obtained from outside sources.

Proper interfacing of research and engineering permits implementation of meaningful R&D programs and minimizes fire-drill programs to solve immediate Fleet problems. These later type "hurry-up" efforts, while solving immediate problems, have a disruptive effect on longer range research efforts. This results in a pyramiding effect--the more fire drills, the less systematic research--therefore, even more fire drills in later years. Reorienting research programs because of Fleet requirements or other needs is an entirely different consideration. Reassessment of ongoing programs is necessary in order to prevent research for research sake and to insure that the research is directed toward real requirements and will result in useful criteria.

To further amplify the above statements, the following sections briefly define some of our major requirements and criteria, and trace a portion of our experiences in defining hull strength and in introducing new materials and hull configurations into our present Fleet.

NAVY REQUIREMENTS

The Fleet operates primarily in peacetime; but, it must be designed for war. Therefore, the primary function of the hull platform (or structure) is to support, protect, and transport weapon systems--aircraft, guns, missiles, sensors, and troops. The need to fully support ships carrying weapons requires that we also develop platforms to carry support systems for repair, salvage, replenishment, hospital, and pollution control. Thus, Navy ships must be designed to provide a solid and consistent base for the operation of the weapon systems, resist the rigors of combat, function in a damaged condition, and interact with other support ships on the high seas to do jobs that are normally done in port or drydock. To adequately provide such a capability, it is necessary to actively pursue research into materials, hull loads and motions, hull distortion, design methods and fabrication procedures, and in the development of new hull types to meet future needs.

Militarily we must keep pace with a changing world, both from the standpoint of threat and from the standpoint of national economy. Our existing surface fleet is required to carry out new missions with improved weapon systems and to spend more time on station. Since the end of World War II rapid advances in technology have resulted in continued improvement and sophistication of our weapon systems. These advanced weapon systems are regularly backfitted into existing hulls. Hull designs of the 1940's and 1950's configured and sized to carry guns are now carrying sophisticated fire control and missile systems. Almost as fast as we retrofit new systems on some hulls, other hulls are being decommissioned. In fact our capital warship surface fleet as of December 1974 numbers 189 hulls compared to 308 hulls in 1960. In order to maintain maximum defense posture and to provide the same degree of freedom of the seas today, we must require a fewer number of now much older hull structures to provide the comparable on-station time that we expected of a much larger number of then much newer hulls in 1960.

These rigorous requirements on our hulls have been met in an admirable fashion. Achievement of today's requirements with yesterday's hulls was not by chance. Rather, it is the result of a conscious effort on the part of the Navy to sponsor, conduct, and utilize structural research and development over the years. Our hull designs of the 40's and 50's represented the structural state-of-the-art in those years. Later advancements in load determination, structural analysis and material characteristics and fabrication techniques have provided the capability to wring the last full measure out of these designs today. In addition, it has fostered a "why did it go wrong" attitude which seeks to determine causes, develop fixes, and build for the future drawing upon the experience gained from possible errors.

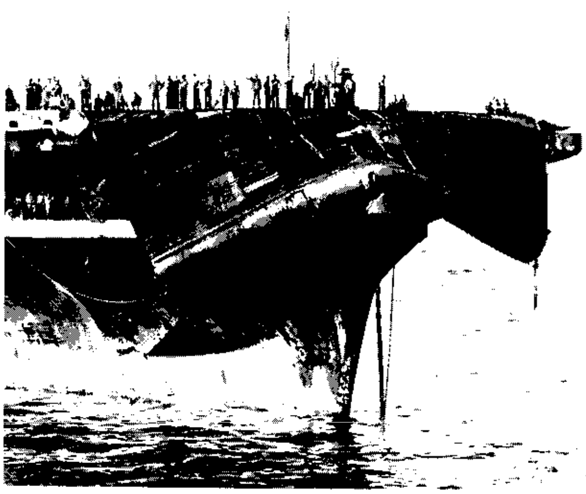

Fig. 1 Essex Class Aircraft Carrier Flight Deck damage due to storm operations - Why did it go wrong?

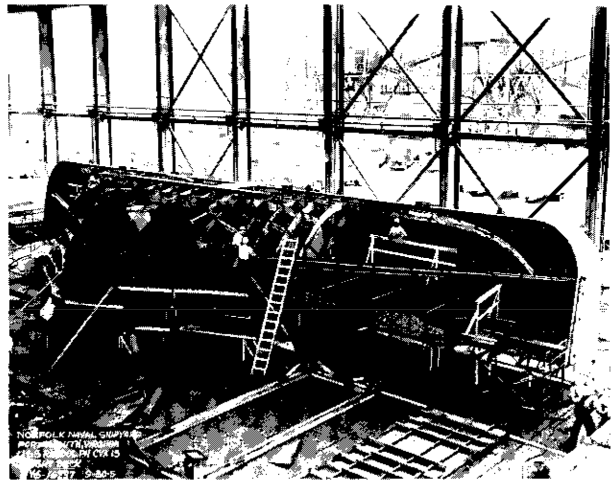

Fig. 2 Essex Class Aircraft Carrier Hurricane Bow designed to improve resistance to storm damage to Flight Deck.

A traditional Navy design begins with a concept based on Fleet needs. We must develop a system to do what we want and build a platform to carry that system. The platform requirements then suggest things we must know in order to do an adequate design. The increase in topside equipment suggests compensating reduction in topside weight leading to materials research to get the right material for that job. The speed and hull form raise questions of slamming design loads and reasonable, but not excessive, design bending moments. Design for large dynamic loads leads to research to determine load transmission paths, failure mechanisms, and ultimately improved details. Best efforts result in a design criteria and a platform is built, launched, and operated. Feedback from operations indicate areas where the criteria was weak. Research is then undertaken to improve the criteria and methods that the particular design can be fixed and future designs improved. In summary, we have a continuing cycle--Research-Design-Build-Operate/Test-Evaluate-Improve-Research.

CRITERIA EVOLUTION

Criteria can be formalized for any one of the many facets associated with Navy hull structures. For the sake of brevity, three different but mutually dependent areas are discussed as examples. The definition of primary hull strength criteria, the introduction of new materials, and the introduction of new hull concepts should be sufficient to overview Navy experience. Of particular importance is the fact that in all three areas Fleet feedback information played the major role in improving criteria.

Hull Strength

The Navy has had a continuing interest in basic structural mechanics. Hull girder design theory was based on the famous hogging and sagging experiments on the PRESTON and the BRUCE. Concurrent with evaluating these experiments, Frankland at the Experimental Model Basin was developing empirical relation ships for the design of plate stiffener combinations under in-plane loading based on past research--much of it by the Navy. Modifications to Frankland's work have been evolved through the years, but the basic plating formula remains valid. Even though the basic work was for steel construction, the plate formula has been found to be equally valid for aluminum and the basic formula has been recently reconfirmed by SSC sponsored work. Design curves for stiffened plating subjected to hydrostatic loading were developed on the basis of work reported by Hovgaard and many in different forms are valid today.

Armed with the above procedures, it was also necessary to develop suitable criteria for defining a standard wave and for establishing strength criteria for stiffeners.

There has been an interest for many years in establishing a good estimate of just how large a load a ship is likely to see in its lifetime due to bending in the waves. Originally, the wave bending moment was taken as that developed by the ship floating on the standard L/20 wave. As ships increased in size, the idea that this wave gave too large a bending moment was explored and in early 1950 the $1.1\sqrt{L}$ standard wave was adopted. Research has continued and newer concepts have been employed to verify the adequacy of the $1.1 \sqrt{L}$ criteria. Briefly, it was the objective of certain studies to examine a number of ship types under a severe sea spectrum for a simulated 20-year lifetime and to compare the results with those obtained based on the $1.1 \sqrt{L}$ wave. The findings indicated that for a full range of ships from 200 ft. to 900 ft. in length, bending moments based on a $1.1 \sqrt{L}$ wave agreed well with and were only slightly below the probable maximum bending moment based on sea spectra analysis.

Although the $1.1 \sqrt{L}$ wave is the criteria for Navy design, research is continuing into the sea spectra approach to design. The awareness that it is possible to mathematically model a ship through its probable life at sea, leads to attractive possibilities for design of more efficient structure, better utilization of high strength materials, and for reaching beyond conventional hull concepts. In addition, probable distortion and ship motion estimates make possible sensitivity studies on weapon systems which can lead to more efficient and accurate operation.

Occasionally solutions for new requirements lead to problems in previously troublefree areas. When such events occur we are really learning that the sea and sea loadings cannot be taken for granted and that design criteria safety margins must be sufficiently flexible to account for "unknown-unknowns" as well as for "unknowns." This in no way suggests that overly generous safety margins be applied, but that margins commensurate with the degree of uncertainty be applied. In fact, in many instances, establishment of more rigid margins can have minimal effect on structural weight but a large effect on structural strength. A classic example occurred in the case of the USS ESSEX, CV9.

Fig. 3 Essex Class Aircraft Carrier Hangar Deck buckling due to operation in stormy seas.

Originally, the hull was designed for a primary bending moment based on L/20 standard wave. The main deck, or hangar deck, structure was sized on the basis of compression loads due to sagging. The sagging load was not very large and very slim longitudinals were used (L/r* of over 100). Except for damage under severe operating conditions, the hull performed satisfactorily until the ship was modernized and a hurricane bow was added to prevent local damage to the flight deck and to improve resistance to launching loads from new and more powerful catapults. In heavy seas the bow slammed and the hangar deck buckled because of compression failure of the longitudinal stiffeners, a loading condition possible with the original bow but dramatically demonstrated on many occasions with the new bow. Further subsequent tests indicated that the slamming forces caused a bending moment in excess of the design moments. Criteria was changed to require large enough stiffeners to develop the yield strength of the plating in compression. Research results had indicated that longitudinals with an L/r* of 60 were adequate for this purpose. All subsequent designs have been based on an L/r = 60.

Other than this one notable exception, major hull damage due to hull girder failure has been a rarity. But now let us examine another type of problem--that associated with the introduction of new material into the hull structure.

Material Studies

The Navy has explored many ways to accommodate heavier topside equipment on existing hulls and on new designs. Various approaches have been utilized including lighter weight materials for equipments and for deckhouse structure. Glass reinforced plastics are being used for lightweight hull equipment and fittings--life rails, doors, ladders, etc., in addition to being used as deck house material on some small craft. Aluminum has been used for many years for the deckhouse structure and it might be useful to briefly trace the history of its introduction to the Fleet. Questions of cost and price will not be addressed. Suffice it to say that the dollar cost for material and fabrication and the systems price of reduced fire protection and fragment protection were carefully weighed against mission requirements in making the decision to utilize aluminum.

The transition from medium steel, a flaw tolerant material with considerable plastic reserve strength, that was familiar to the shipbuilding industry, to aluminum, a less tolerant rather unfamiliar material, was an educational experience. The earliest use of aluminum was in the form of plating riveted to steel beams and frames on some World War II and earlier destroyers. This was a weight-saving measure, but no real attempt was made to design an efficient aluminum structure. However, in the early 1950's, in an attempt to reduce deckhouse weight by 35-40 percent, the DD931 destroyer was designed with the first all-welded aluminum deckhouse.

Of the alloys available at the time, only 6061-T6 had the properties considered adequate for this purpose. The 6061-T6 alloy had been developed for use in mechanically fastened applications because of known undesirable properties when welded. Though the weld zone strength was 35-40 percent less than the base plate and the heat affected zone had poor elongation, it was felt that adequate design safety factors would overcome these deficiencies.

* $L/r = \dfrac{\text{Length of Stiffener}}{\text{Radius of Gyration of plate stiffener combination}}$

Meanwhile, both industry and the Navy were pursuing a joint program to develop weldable aluminum alloys with high as-welded strength that would be suitable for use in the marine environment.

Impetus was given to this joint program in the late 1950's when during a storm the USS MANLEY (DD 940) was engulfed in a huge wave that severely overloaded and damaged the deckhouse. In general, the aluminum deformed in a manner that would make ultimate design protagonists proud. However, the riveted connection at the deckhouse side to deck intersection failed and this coupled with the tearing apart of a butt weld in the deckhouse side lead to a catastrophic violation of structural and watertight integrity.

This failure coupled with other problems in early aluminum deckhouses taught the designers several important lessons:

1. Design with a new material on the basis of strength requires good knowledge of the magnitude and character of the expected loads. In cases such as a deckhouse, where the maximum load that can develop is unknown, the material should be proportioned so that the maximum strength for a given weight of structure can be developed.
2. Avoid designs where a single failure can have catastrophic consequence--the fail safe concept.
3. Consider the environment in which the material is going to work and make sure that it is suitable.
4. Be prepared for unexpected problems. Production and operations will influence the new material in ways that test results cannot anticipate.

In applying lesson #1 to the deckhouse design, it was determined that with transverse framing large panel loads exceeded the strength of the rivets, but that framing the deckhouse longitudinally permits load transfer to more substantial structure. In addition, longitudinal framing would have backed up the weak welded butts and, acting as a crack arrestor, eliminated the coupling effect of bottom connection-butt weld failure. Deckhouses are now longitudinally framed.

In addition, the Navy eliminated 6061-T6 from single failure structure and added redundant structure to large structures as a safety measure--additional cross bracing in aluminum elevator trusses, for example.

The development and use of the 5000 series alloys has not been without reference to lessons #2 and #4. For a few years, several different 5000 series alloys were used until the 5086 and 5456 alloys were selected as the best to give highest strength compatible with the degradation experienced when welded and most resistant against stress corrosion cracking. After several years of service experience, the H321 temper in these two alloys began to show signs of exfoliation. This exfoliation most often occurs at the exposed edges of plating where the magnesium tends to dissolve from between the layers of aluminum giving a leafy (mica) appearance. Coatings were developed to protect the edges of plates on ships in service and industry introduced the H116 and H117 tempers developed to correct this situation.

While research was going on to develop more weldable aluminum, the connection interface between the steel hull and aluminum deckhouse was also undergoing development. The Navy replaced rivets with two-piece fasteners that were mechanically swaged together. These fasteners provided a more efficient joint and didn't require the skill to install that rivets did. It should be noted that these fasteners have also replaced rivets in steel connections; such as, the gunwale and bilge strake connections. While improving the situation, these fasteners did not completely solve the problem of connection failures. The maintenance costs at the hull deckhouse connection have been excessive. Therefore, when a bimetallic product, made by explosion or roll bonding aluminum to steel, became available, the Navy conducted tests that certified it for marine use and began using it for the hull deckhouse connection.

The Navy has also developed whole hull designs in aluminum--the LCU, the PG's, many small boats, hydrofoils, and, in addition, designs and trade off studies evaluating the economic and technical qualifications of aluminum for capital ships. This evolution of aluminum as a major Naval shipbuilding material has not been done alone. Industry, design agents, and SSC have contributed significantly to the overall program.

New Concepts

Unique ship types are also a part of the Navy evolutionary process. Many ship types are to do jobs that only the Navy does and present peculiar problems because of their mission. For example, aircraft carriers have many features that require special design techniques. Protective systems require special steels, special model tests, and special analysis methods not required in other ship designs. Large elevators, a system for landing aircraft, and a system for launching aircraft require design techniques not normally used in other designs. Constant feedback of problems and continued research developments increase the efficiency and combat strength of these ships. Landing craft, tenders, minesweepers, and rescue ships are other examples of unique ships that have design problems that generate research requirements and in turn advance our knowledge in structural mechanics. A more appropriate example of a new concept in hull type, despite its history in small sailing craft and small ships, is the catamaran.

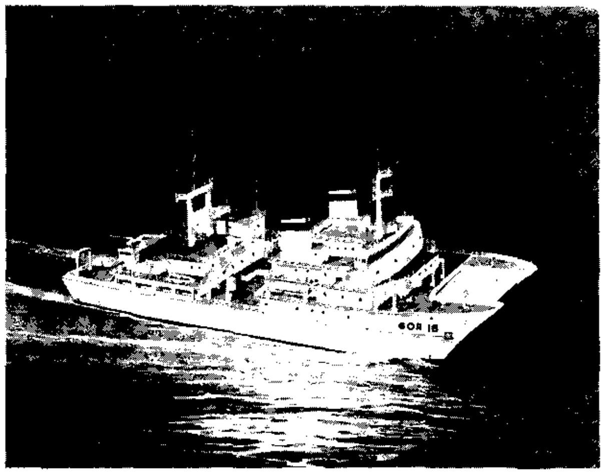

Fig. 4 USS HAYES Navy Catamaran Research Ship.

When it was decided to design certain auxiliaries as catamarans to take advantage of the large working space and stable platform provided by such a hull, there was not much information available on hull design loads or ship motion loads. A commercial design, the E. W. THORNTON had been built in 1962 and provided some guidance. However, sufficient information on which to base a prototype design was not available and a research program in load determination and ship motion was undertaken.

A large model--two hulls joined by an aluminum cross structure--was tested at NSRDC. Because of facility limitations only moderate sea conditions could be generated and analytic predictions were made for more extreme conditions by Webb Institute. The tests and analytic work were coordinated and used to develop a design procedure for predicting dynamic loads and designing an all Navy ASR 21 catamaran and an ABS certified AGOR 16.

In addition, an SSC project examined the technical limits of catamarans. It compared 8 different design methods including that used by the Navy. The report of the project SSC 222 provides a comprehensive state-of-the-art look that can be used in future designs. From the Navy's standpoint the complex space frame computer model of the AGOR 16 used by the investigator was most beneficial in some follow on work that resulted from operational experience.

Contentment with these accomplishments was shortlived for when the first catamaran went to sea, we were surprised by two things. First, along with a dramatic decrease in rolling motion was an equally dramatic increase in pitching motion. Second, slamming from these motions was severe enough to cause severe structural damage to the cross structure.

The Navy instituted a research program to find out how to reduce the motions and to determine what the slamming loads should be. This program included ship motion studies, structural modification, and full-scale testing. As a result, an underwater foil was added connecting the two hulls, and the cross structure was redesigned for more realistic loads. All three catamarans have had these changes. With a year's successful service from the modified USS HAYES, we can now say our technology has advanced to the stage that a successful catamaran design can be done from inception. This was not achieved without the cooperation of all facets of the Navy community.

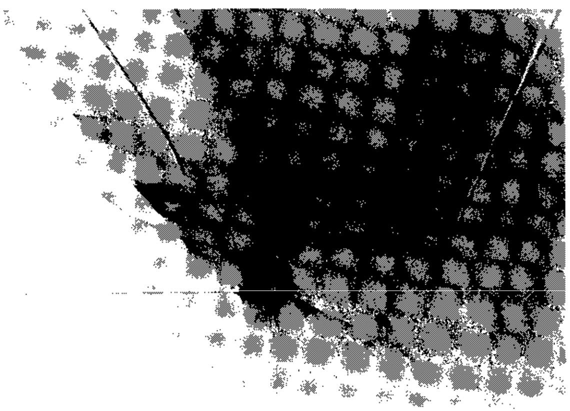

Fig. 5 USS HAYES storm damage to the cross structure due to slamming.

FUTURE PROJECTIONS

In the main, conventional displacement ships will make up the majority of the Fleet for the foreseeable future. However, the Fleet will be augmented on an increasing scale by what may be termed High Performance Craft--hydrofoils, air cushion vehicles, and low water plane twin-hull craft. The Navy is currently involved in an extensive research plan to develop the potential for such craft because their high speed and maneuverability make them attractive candidates for Naval use. The basic questions of size, payload, and use are under investigation. As the technology develops and their virtues become known, more and more of such craft will be integrated into the Fleet. It is certain that a commercial spin-off will result from our efforts and the entire marine community will thus benefit. From the structural standpoint, we will be developing the technology in fabrication and producibility techniques--how to make it good, make it cheap, and make it last. It is important to mote that fatigue, fail safe and optimum design concepts take on a deeper meaning than with conventional hulls. The designer must get deeper into fabrication and operations than he has before. Material trade-off studies and new and innovative ideas are the hall mark of these designs. More time and effort will be spent in monitoring the structural response of high performance hulls. Feedback for improvement of follow-on designs will be more positive and timely than for conventional designs because we don't have the experience or the data base on which to work.

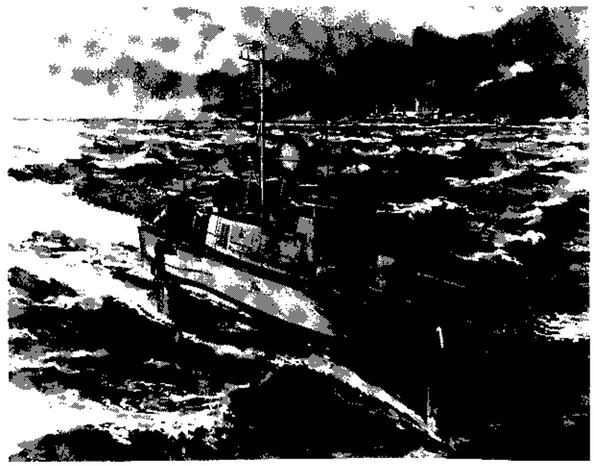

Fig. 6 PCH 1 - Navy's newly developed hydrofoil craft applying new technology to improve military capabilities.

SUMMARY

The intent of this paper has been to show the evolutionary nature of Naval ship design with particular emphasis on the role of hull structures. Newer ships are improvments on past ships, and improvements in other Naval systems influence and modify structural requirements. In times of peace, a technological war continues. We must retain the offensive capability to combat any potential enemy's defenses while maintaining the defensive capability to negate his offensive thrust. As weaponry improves, the platform that carries it must improve. No nation is so self-sufficient that it can abandon its rights to use the high seas. Just as the maritime community must improve its techniques to insure a fair share of the shipping market, the Navy must improve its techniques to guarantee the seas remain free for our use under any conditions. These requirements have lead to research programs for industry such as those conducted by SSC and SNAME and are the basis for a continuing need for the Navy to have a strong realistic research program. Out of all of this, we have defined some common goals for our research efforts.

Economy

Spend R&D dollars wisely; the return must be worth the investment.

Support those programs offer ing economy of operations.

Design/Analysis

Effective utilization of computers requires improved knowledge of ship motions in a seaway in order to optimize design details.

Fabrication

Fabrication techniques must be improved if we are to make effective use of stronger light weight materials. Increased automation in all phases of the design/fabrication process implies added cost effectiveness.

New Concepts

Specific needs generate concepts for different ship types. Our R&D programs must be geared to solve the problems of these innovations.

It has been Navy policy, and will continue to be Navy policy, to share with the entire maritime community the results of the Navy surface ship structural mechanics R&D program and to supplement our own work with that done under the auspices of SSC and SNAME.

ACKNOWLEDGMENTS

Special credit is given to the unnamed many who through the years have done the work and made the decisions that have advanced the Navy's technological base. Special thanks must go to NSRDC which does the tests and research and to the operating fleet that takes the ships to sea and uses them. Finally, thanks to the NAVSEC Word Processing Center which advances the state-of-the-art in yet another field.

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SSC-193 Development of Matematical Models for Describing Ship Structural Response in Waves by Paul Kaplan. January 1969.

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<u>Navy Design Data Sheets,</u>
<u>Navy Disseminates its Design Methodology</u>

SWBS	TITLE
DDS074-1	Riveting, steel or aluminum
DDS100-1	Reinforcement of openings in structure of surface ships other than in protective plating (amended 7 Nov 1950 and 15 Jan 1954)
DDS100-2	Opening in decks and bulkheads for stuffing tubes and pipe (amended 26 Mar 1952)
DDS100-3	Structural design of flat plating and stiffeners subject to water pressure
DDS100-4	Strength of structural members
DDS100-5	Strength of glass reinforced plastic structural members
DDS100-6	Longitudinal strength calculation
DDS130-1	Structure design of aircraft handling decks
DDS150-1	Design of foundations and other structures to resist shock loadings
DDS170-1	Staved polemast
DDS170-2	Tripod mast
DDS170-3	Four-legged mast