1996 NAVAL RESEARCH ADVISORY COMMITTEE SUMMER STUDY

Damage Control and Maintenance (for Reduced Manning)

September 1996

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Terms of Reference (TOR)

GENERAL OBJECTIVE

Identify science and technology opportunities, as well as policy and process improvements, to reduce onboard manning for damage control and maintenance of in-service platforms.

BACKGROUND

In 1995, NRAC conducted two studies: (1) Reduced Ship Manning reviewed how technology could be used to reduce ship manning; and (2) Life Cycle Cost Reduction assessed the impact of science and technology on life cycle cost initiatives of current Department of the Navy (DON) systems and projected acquisition programs. The recommendations of these studies were endorsed by the Chief of Naval Operations (CNO) and resulted in the initiation of the Smart Ship program.

In addition to identifying the potential for science and technology to significantly reduce ship manning and life cycle costs, the 1995 studies also addressed the policy and system changes needed to achieve these goals. It was also noted that the operational Navy voiced a recurring concern that manpower aboard ships was difficult to reduce because of damage control and maintenance requirements. After a review of these studies by the Assistant Secretary of the Navy (Research, Development, and Acquisition), it was concluded that a follow-up study was warranted to further explore these issues and opportunities.

SPECIFIC TASKING

a) Review previous studies, current program, training procedures, and regulations regarding these issues.

b) Review lessons learned from recent shipboard casualties to assess damage control processes, technology shortfalls, and manning requirements.

c) Examine perceived constraints imposed on reduced shipboard manning by onboard maintenance and damage control requirements.

d) Assess damage control policies and technologies being utilized by foreign navies.

e) Recommend specific demonstration projects, other technology transfer mechanisms, and policy changes to facilitate early fleet adoption of the most promising concepts.

SCOPE

The Damage Control and Maintenance Panel of the Naval Research Advisory Committee (NRAC) was tasked by the Assistant Secretary of the Navy (Research, Development, and Acquisition), with the Commander, Naval Sea Systems Command (NAVSEA) as the study sponsor, to "identify science and technology opportunities as well as policy and process improvements, to reduce onboard manning for damage control and maintenance of in-service platforms." The Panel considered the "science and technology opportunities" of the Terms of Reference in the broadest interpretation, from mature and state-of-the-art to developmental. Moreover, while the study focused on "in-service platforms," most of its findings and recommendations are equally applicable to new construction, (e.g., LPD-17, SC-21, and ARSENAL SHIP).

STUDY APPROACH

The study panel consisted of 15 members from academia and industry, including retired flag officers with extensive operational experience, and also Royal Navy representation. The Panel heard briefings from a broad cross section of the Navy's technical community on the topics of manning, damage control, and maintenance and visited several operational platforms and numerous installations, including several firefighting and damage control training facilities, the USS *Yorktown*, and the ex-USS *Shadwell*—the Navy's principal Research and Development (R&D) firefighting facility. The Panel also reviewed both the recent experience of the Royal Navy in their reduced manned Type 23 Frigate and the operational characteristics of Israel's SAAR-5.

FINDINGS

Ship Manning

As documented in 1995, the NRAC study on "Life Cycle Cost Reduction" revealed that the major cost of ownership of ships is incurred during the operation and support phase of the life cycle. During this phase, the dominant cost driver is manning, but reducing manning impacts the complex relationship of manpower requirements for operating, maintaining, supporting, fighting, and saving the ship. A rational approach to reducing manning requires a systems engineering approach with in-fleet demonstration of proof-of-principle.

SMART SHIP

The object of the SMART SHIP program is to systematically evaluate an operational platform (USS *Yorktown*) in all aspects of shipboard manning with a goal of significant reductions. The program includes the review of warfighting requirements, watch standing, preventive maintenance, damage control, and the introduction of technology to reduce manning requirements. In the judgement of the Panel, the SMART SHIP program has adopted a realistic approach with appropriate emphasis on damage control and maintenance and technology insertion. Currently, the SMART SHIP is evaluating a reconfiguration of the Damage Control Organization and procedures, which reduces damage control personnel from 125 to 61, and a reduction in preventive maintenance tasks by 30 percent.

Damage Control

Although damage control requirements are not the controlling factor in determining ship manning today, the manning difference between operating the ship (Condition III) and fighting the ship (Condition I) is marginal. However, the damage control requirements of fighting hurt will be the limiting factor in determining the crew size of in-service ships as well as new ships with more automation and less maintenance. Indeed, the emphasis on SMART SHIP is in reducing damage control personnel. In the next DON major ship acquisition, LPD-17 requires an additional 28 billets more than Condition III for damage control manning. The realization of reduced manning on in-service and/or new ships will require the crew to receive superior training and to be supported by user-friendly, capability-enhanced damage control equipment, and significantly improved communications and situation awareness capabilities. Technology opportunities include: replacing the Oxygen Breathing Apparatus (OBA) with Self-Contained Breather Apparatus (SCBA); replacing the Naval Firefighting Thermal Imager (NFTI) with the helmet-mounted infrared visor; incorporating the Hierarchical Yet Dynamically Reprogrammable Radio (HYDRA) and situational awareness systems like the Damage Control System (DCS), the Standard Monitoring and Control System (SMCS), and Integrated Condition Assessment System (ICAS). It is also the unanimous judgement of the Panel that the issue of affordable sensors for situational awareness falls into the category of critical enabling technology for reduced manning on both in-service and new ships.

Maintenance

Today's naval forces are faced with the existing Periodic Maintenance System (PMS), the availability and rapid influx of new technologies and a shrinking maintenance budget, (although an increased percentage of the DON's Total Obligation Authority). These maintenance-related issues were highlighted by various agencies during our study and reinforce several fundamentals about an efficient maintenance system as follows: it needs to look at function and not periodicity, i.e., it must be: (1) mission focused, (2) user friendly, (3) take advantage of emerging technologies and current knowledge, such as Reliability-Centered Maintenance (RCM), (4) consider life cycle costs during the acquisition of new ships, and (5) change the mindset from what "we have always done."

The Panel believes that the RCM methodology provides an enlightened approach to maintenance, determining what and when a maintenance action must be done while ensuring that any piece of equipment or system operates within its intended operational parameters. This maintenance concept focuses on function and timely, educated interventions to maintain equipment and systems as opposed to PMS, which focuses on a schedule, creating a repetitious, labor-intensive, and in some cases unnecessary process that may do more harm than good to equipment. The PMS approach to maintenance leaves much to be desired, particularly when reduced manning and system sustained reliability are the goals. RCM is function focused, reliability based, and a less labor-intensive maintenance system that should therefore be pursued. This approach has the potential to reduce the maintenance burden by thousands of crew hours per week per ship.

Ship Status Sensor System

If manpower expended on maintenance and damage control is to be substantially reduced, the ability to remotely and reliably determine the real-time status of the ship and crew must be expanded far beyond the current capability. In virtually any damage control scenario, knowledge of the location and status of crew members is essential, from the standpoint of establishing damage control team capability as well as planning casualty rescue efforts. "Electronic dog tags," or communication through a wireless sensor telemetry system, could easily provide crew location information and could report a general summary of individual status (by displaying such colors as red, yellow, or green). Similarly, early detection of fires (and other casualties such as flooding) is essential to minimizing losses associated with classification of fire type, monitoring its evolution, and allocation of resources. In the case of reducing manning for ship maintenance, accurate and timely knowledge of the status of various ship systems is also required. Current Navy systems such as DCS, ICAS, and the SMCS, provide the basis for performing situational awareness of the ship but are limited by the availability of affordable sensors.

MAJOR CONCLUSIONS

- SMART SHIP is one of the most innovative initiatives, to date, to establish the optimum composition of levels of shipboard manpower. It is the critical first step in reducing manning and must continue to be supported at all levels of the DON.
- A significantly smaller damage control crew will be a team with superior training, supported by timely situational awareness information, and outfitted with user-friendly, capability-enhancing damage control and communication equipment.
- Reengineering of the Navy's onboard maintenance policies and practices in accordance with current knowledge and emerging technologies will significantly reduce the manpower burden, saving thousands of crew hours per week per ship.
- The development of affordable sensors by utilizing micro-electromechanical systems (MEMS) and wireless telemetry has the revolutionary potential to reduce ship manning across the board for both in-service and future ships. An Advanced Concept Technology Demonstration (ACTD) investment should be made to realize these benefits.

MAJOR RECOMMENDATIONS

SMART SHIP

- Maintain:
  - Strong, visible, top-level Navy commitment
  - Stability of key personnel through rotation
  - Special funding basis beyond June 1997
  - Reasonable expectations
  - As a deployable asset
  - Active Navy technology community involvement
- Transition results into Fleet as soon as PROVEN... "ASAPr"

Damage Control

- Execute an acquisition and training master plan for the replacement and upgrade of damage control and communication equipment based on:
  - Systems approach
  - Approved organization changes
  - Operational requirements
  - Stable budget
- Develop alternative, more realistic firefighting training to better prepare shipboard firefighting personnel, e.g., private or ex-USS *Shadwell*-like facilities
- Incentivize repair party crew to maintain physical fitness, e.g., through in-fleet competitions

Maintenance

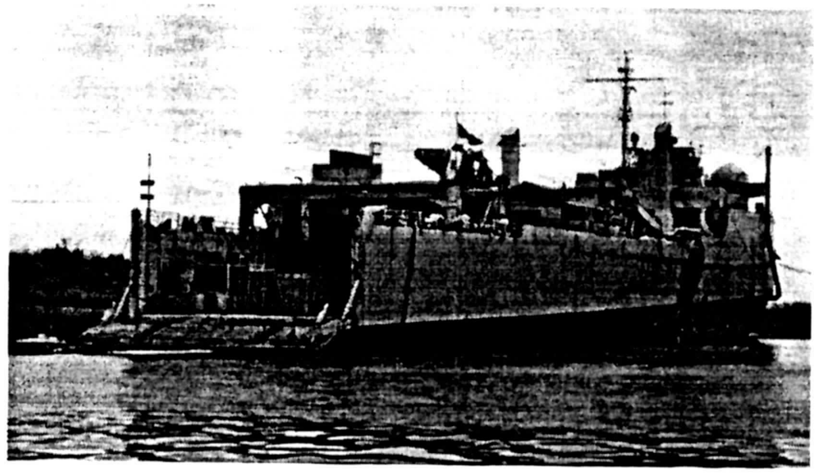
- Evaluate and modify, as appropriate, ship maintenance practices based on:
  - Available operational data
  - Feedback reports
  - Engineering analyses
  - Reliability-centered maintenance
  - Condition-based maintenance
- Insert cost-effective Commercial Off-The-Shelf (COTS) improvements as soon as PROVEN... "ASAPr"

Ship Status Sensor System

- A significant investment in micro-electromechanical systems with wireless telemetry for shipboard applications should be made now to realize the near-term benefit for retrofit to current ship inventory and to impact the pending new construction schedule.

The NRAC Damage Control and Maintenance Panel was tasked by the Assistant Secretary of the Navy (Research, Development, and Acquisition), with the Commander of NAVSEA as the study sponsor, to "identify science and technology opportunities as well as policy and process improvements, to reduce onboard manning for damage control and maintenance of in-service platforms."

The Panel consisted of 15 members from academia and industry including retired Flag officers with extensive operational experiences, and representation from the Royal Navy (Table 1). The Panel was briefed by a broad cross-section of the Navy's technical community on the topics of manning, damage control, and maintenance (Table 2). Highlight visits included the USS *Yorktown* (SMART SHIP), the USS *Enterprise*, and a soon-to-be commissioned DDG-51, as well as training facilities at Norfolk, Virginia; Newport, Rhode Island; New London, Connecticut; and the ex-USS *Shadwell*, the Navy's principal R&D firefighting facility located in Mobile, Alabama. The Panel also had the opportunity to review the recent experience of the Royal Navy in their reduced manned Type 23 Frigate as well as the reduced manning innovation in the Israeli SAAR-5.



The ex-USS *Shadwell*: the Navy's principal R&D firefighting facility.

Firefighting party at ex-USS *Shadwell*: left to right– L. Ashey, CDR J. Farley, and D. Burke (NRAC Panel member).

The Panel considered the science and technology opportunities of the Terms of Reference in the broadest interpretation, from mature and state-of-the-art to emerging; while the study focused on in-service platforms, most of its findings and recommendations are equally applicable to new construction (e.g., LPD-17, SC-21, and ARSENAL SHIP). It was also inferred from specific tasking that the study was to review the progress of the SMART SHIP program, thereby providing continuity with last year's study. (Because of time and other constraints, the study scope did not consider intermediate and depot maintenance and non-manpower-intense damage control technologies such as insensitive munition, damage-tolerant structural design, or signature reduction.)

Table 1. NRAC Damage Control and Maintenance Panel.

Chairperson	
L. Raymond Hettche	Director, ARL, and Professor of Engineering Research, The Pennsylvania State University
Vice Chairperson	
Patrick Winston	Professor, and Director, AI Laboratory, Massachusetts Institute of Technology
Panel Members	
David Burke	Vice President of Engineering, Charles Stark Draper Laboratory
Walter H. Cantrell	RADM, USN (Ret.), Global Associates, Ltd.
Daniel L. Cooper	VADM, USN (Ret.), Private Consultant
Scott B. Halstead	Scientific Director, Infectious Diseases, Naval Medical R&D Command
Edwin R. Kohn	VADM, USN (Ret.), Private Consultant
Ronald E. Medrzychowski	Manager, Propulsion Plant Systems, Electric Boat Corp.
Leonard F. Picotte	RADM, USN (Ret.), American Systems Corporation
Karlene A. Roberts	Professor, University of California, Berkeley
William F. Weldon	Professor, University of Texas at Austin
David C. White	Executive Director, Center for Environmental Biotechnology, University of Tennessee
Henry T. Yang	Chancellor, University of California, Santa Barbara
John Trewby	RADM, Royal Navy, Ministry of Defence, United Kingdom
Executive Secretary	
Brian C. Thomas	CDR, USN, NAVSEA
ASN(RD&A) Sponsor	
George Sterner	VADM, USN, Commander, NAVSEA

Table 2. NRAC Panel Briefs and Visits.

1–2 May 1996 (Panel meeting)	
SC-21	CAPT Dennis Mahoney (SC-21 Program Mgr.)
Afloat Manpower Determination Requirements	CDR William Jacobs (NAVMAC)
Condition-Based Maintenance	CDR Pete Sisa (ONR)
Smart Ship	Dr. Terry Allard (ONR)
Ship Manning	Mr. Robert Bost (SC-21 Office)
Autonomic Ship	Mr. Robert Wilson (NSWC Carderock)
Shipboard Reliability Enhancement	Dr. Karlene Roberts (Hass School of Business)
Shipboard Damage Control	Mr. Fred Crowson (ASN I&E)

Table 2. NRAC Panel Briefs and Visits (cont'd.).

Major Ship Conflagrations	Mr. Robert Darwin (NAVSEA)
NRL Visit	Dr. Fred Williams (NRL)
3 May (NRAC visit)	
USS *Enterprise* (CVN-65)	
15 May (Panel visit)	
CNET	Mr. Jon Loesch (Training Specialist)
16 May (Panel visit)	
USS *Yorktown* (CG-48)	
5–6 June (Panel visit)	
Surface Warfare Officer School (SWOS)	CDR John Kunart (DC School Director)
Submarine School	MMCS Kevin Babcock (Instructor)
11 June (Panel meeting)	
Total Ship Survivability Trials	Ms. Angela Maggioncalda (NSWC, Phila.)
Damage Control System Demonstration	CDR Mike Butler (NAVSEA)
Corrosion Control Maintenance	Dr. John Sedricks (ONR)
Bio-Fouling Control	Dr. Randall Alberte (ONR)
Surface Ship Maintenance	Mr. Ken Jacobs (NAVSEA)
Type 23 Frigate (Royal Navy)	CDR Stewart Young (Royal Navy)
Ship System Automation	CAPT Robert Lowell (DARPA)
CVX	Mr. John Christian (CVX Program Office)
LPD-17/USS *Stark* (FFG-31)	Mr. Jim Fowler (LPD-17 Program Office), CDR Scott Barbour (LPD-17 Program Office)
12 June (Panel visit)	
CINCLANTFLT Nondevelopmental Item Facility	DCCM Lloyd Broughton (NDI Rep.)
COMTRALANT (Firefighting School)	LCDR Barry Muha (Training Coordinator)
PACFLT PEB	CAPT Bill Laz (Senior Inspector)
13 June (Panel visit)	
Afloat/Engineering/Fleet Training Groups (Atlantic)	CDR John Arnold (COS ATG)
CINCLANTFLT Maintenance Philosophy	Mr. Dave Thurston (CLF Maintenance)
26 June (Panel visit)	
Ex-USS *Shadwell*	CDR John Farley (NRL)
Ship Technology Program	Mr. James Gagorik (ONR)
27 June (Panel visit)	
Ingalls Shipbuilding	Mr. Larry Pratt (Engineering Specialist)
14–28 July (Panel briefs)	
Naval Science Assistance Program	Susan L. Bales (ONR)
Perspectives on Condition-Based Maintenance	David J. Nagel (NRL)
Fleet Maintenance Issues	Ruth C. Shearer (CINCPACFLT)
Type 23 Frigate	RADM John Trewby (Royal Navy)

As documented in the 1995 NRAC study on life cycle cost reduction, the major cost of ship ownership is incurred during the operation and support phase of the life cycle. During this phase, the dominant cost driver is manning, but reducing crew size impacts the complex relationship of manpower requirements for operating the ship (Condition III) and general quarters, or fighting the ship (Condition I). The determination of the number of billets assigned to a particular ship begins with the top-level definition of the ship's required operational capability and ends with the issuance of the Ship Manpower Document (SMD).

For the purposes of this study, it is instructive to compare the manning requirements in terms of Condition III and Condition I (Figure 1). In the former case, manpower requirements are calculated on an hours per work week basis. For example, watchstanding is a three-shift, eight hours per day, seven days a week operation. Major non-watchstanding billets are in maintaining and supporting the ship and in crew training. It is important to note that a Sailor assigned to watchstanding will have as much as approximately one third of his 80-hour work week assigned to non-watchstanding duties. Hypothetically, if we attempt to eliminate a watchstander and therefore three billets through automation, it would also be necessary to eliminate at least one work week reduction in a non-watchstand function before we could realize the benefit of automation.

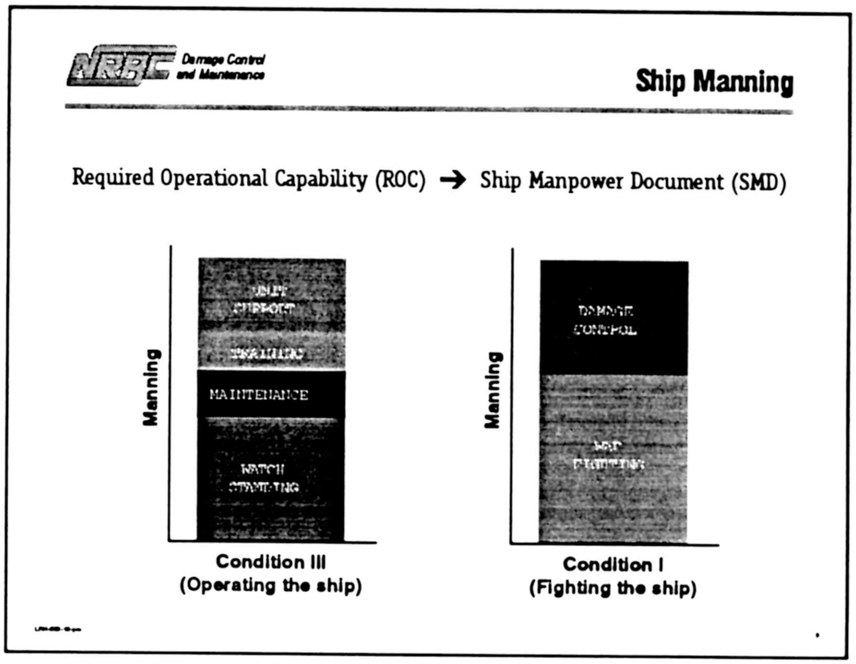


Figure 1.

In the case of Condition I, the manpower requirements are determined on an individual crew per function basis with crew assigned to either combat or damage control functions for a 24-hour period. According to the hypothetical example of reducing the operational crew by three billets, a similar reduction must be made in fighting the ship, again to realize the benefit of automation, assuming for this discussion that Condition III and Condition I have equal crew size requirements. This simplified example of a paralleled reduction between Condition I and Condition III manning does not consider the additional complications of in-port watchstanding.

Although an in-service ship's crew size is determined, usually, by operating manpower requirements, this margin between Condition III and Condition I is small (~5%). Moreover, naval doctrine requires U.S. combat ships to "fight hurt," that is, continue combat operations with as many as two major hits. Because of the requirement to fight hurt, damage control manning will be, most likely, the controlling factor in future efforts to significantly reduce manning of in-service and new ships. As indicated in Figure 2, it is apparent that a rational approach to reducing ship manning requires both a systems engineering approach, considering all functions of operating and fighting the ship, and an in-fleet demonstration of proof-of-principle. Only in this way can the warfighter be assured of the ability to operate, fight, fight hurt, maintain, support, train, and save the ship.

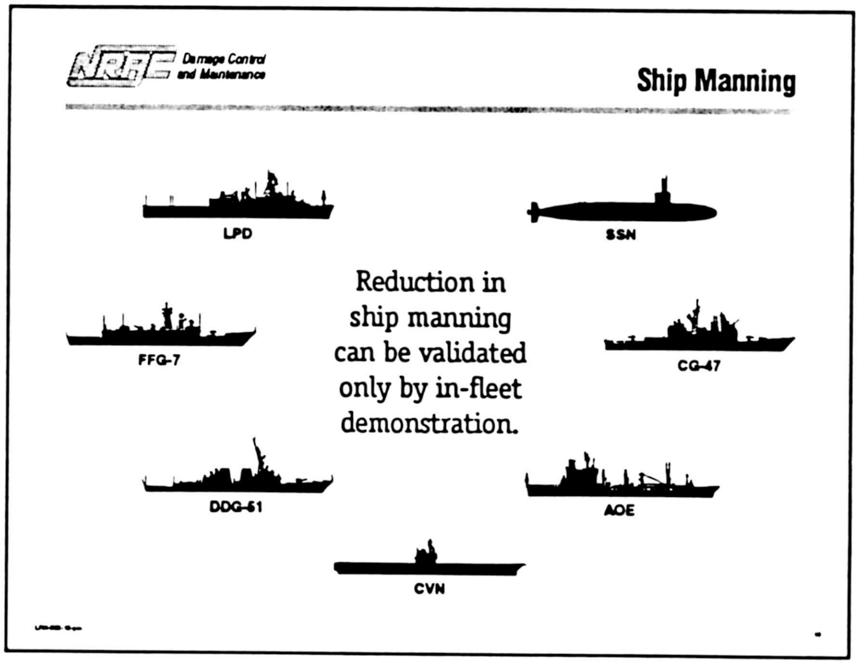


Figure 2.

STATUS AS OF JULY 1996

NRAC Damage Control and Maintenance

SMART SHIP: Status as of July 1996

- New prime advocate required.
- First assessment report: 30 June *1997*.
- 30 to 50 of more than 700 practical ideas will be used.
- Tele-maintenance planned.
- Damage control party reduced from 125 to 61.
- Potential 30% reduction in preventive maintenance crew-hours.

Figure 3.

As summarized in Figure 3, the USS *Yorktown* has continued on its track as a SMART SHIP despite of the loss of its champion, the former CNO. The leadership and energy have been provided by the Commander, Naval Surface Force, U.S. Atlantic Fleet (COMNAVSURFLANT). An evaluation period from December 1996 through April 1997 will result in an Initial Assessment Report scheduled for June 1997.

As would be expected in an endeavor of this magnitude, which captures the imagination of a wide range of activities and which fires the enthusiasm of its advocates, over 20,000 inquiries to the SMART SHIP World Wide Web site have been made. In excess of 700 ideas have been analyzed, and between 30 and 50 ideas are in the final stages of being studied and possibly inserted.

An onboard fiber-optic networked diagnostic system linked via satellite to shore is envisioned for the full implementation of the ICAS. Ready availability of this expertise ashore will relieve the requirement for certain skills and knowledges at sea.

Procedural reviews of both the damage control philosophy and shipboard instructions, and the USS *Yorktown's* Periodic Maintenance Program revealed a potential to incorporate actual reductions in the number of man-hours as well as total personnel necessary to properly execute the requirements. SMART SHIP damage control organization and procedures have been developed and approved. The previous DC personnel of 125 was reduced to 61, based on maintaining a ready (non-watchstanding) response team with the expertise and tools necessary to respond, assess, and combat all emergencies. This team is complemented by additional personnel as required.

A review of the PMS, using a Reliability-Centered Maintenance philosophy, has resulted in a 30 percent reduction in the PMS workload.

Even though no specific SMD reductions have yet been made, the ship has validated concepts by leaving its crew ashore when it goes to the operating areas. Despite the reduced manpower, the ship successfully functions.

APPROACH

As a direct result of the November 1995 NRAC study, titled "Reduced Ship Manning," the CNO specifically initiated the SMART SHIP Program. The objective was to systematically evaluate all aspects of shipboard manning with a goal of viable dramatic reductions. The program includes reviews of all aspects of ship operations including warfare requirements, watchstanding, preventive maintenance, damage control, and introduction of technology that can result in the reduction of shipboard manning (see Figure 4).

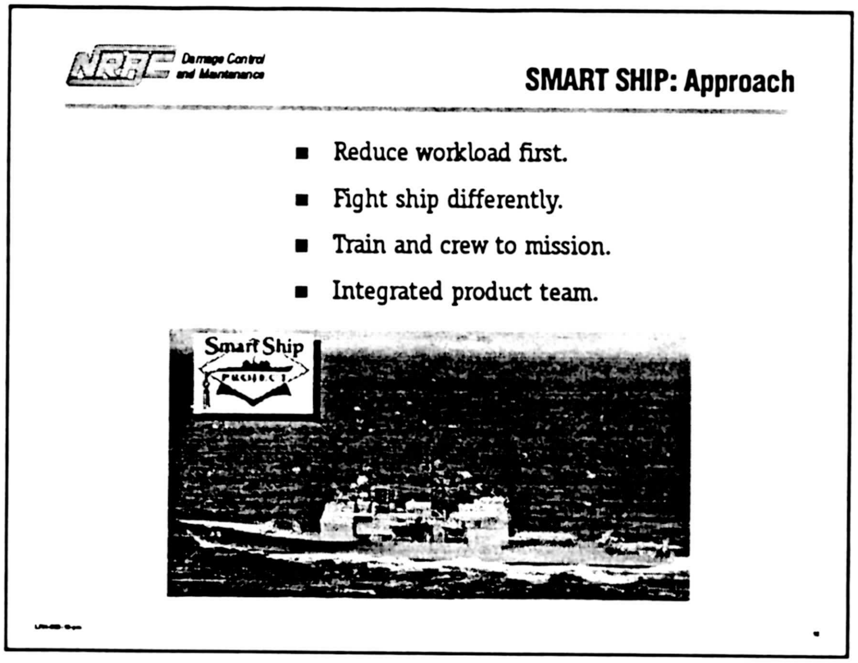


Figure 4.

The initiation of this program, which first concentrated on a single specific ship to ensure carefully controlled evaluations with the ultimate purpose of transitioning results to fleet-wide reductions, was both unusual and dramatic. On the other hand, deriving maximum long-term success requires both sustained will and dedicated continuing oversight by the highest levels of Navy leadership.

The process that has been established to promote credibility with the Fleet and to prove the viability of the premise, prior to initiation of any specific reductions, includes:

(1) A full test of new work procedures until they are proven to be both possible and not detrimental.

(2) Revision of the ships' warfighting philosophy in order to reduce unnecessary personnel redundancy.

(3) Analysis of the various ship missions, along with the necessary individual and team training. An adequate yet reduced core watch section will be augmented by crew trained for specific missions.

(4) An integrated product team is in place under an ONR leader. The ship, Fleet, SYSCOM, Warfare Centers, OPNAV, and ONR are team members. VADM Katz (COMNAVSURFLANT) serves as Executive Director of a Board of Directors with broad high-level membership.

TECHNOLOGY INSERTION

Technology improvements supporting the gathering and evaluation of operational information are in the process of installation on the USS *Yorktown* (see Figure 5), primarily during scheduled restricted availabilities. The core installation will provide command and control information for improved operation, support, reduced maintenance workload, and increased damage control effectiveness involving fewer personnel. Systems include fiber-optic Local Area Networks (LAN), Integrated Bridge Systems (IBS), ICAS, DCS, and SMCS.

The transition of any workload reductions being evaluated on SMART SHIP to the rest of the Fleet will require a manpower requirement model for the Measure Of Effectiveness (MOE) for both future technology insertion and operational concept changes. Flexible team operational concepts and damage control party reductions based on a matrix concept are revolutionary approaches that are not recognized in existing models. A number of approaches are under development to establish credible MOEs.

NRAC Damage Control and Maintenance

SMART SHIP: Technology Insertion

- Fiber-optic Local Area Network (LAN).
- Integrated Bridge System (IBS).
- Integrated Condition Assessment System (ICAS).
- Damage Control System (DCS).
- Standard Monitoring and Control System (SMCS).
- Measure of effectiveness model.
- Integrated on-demand training.

Figure 5.

REQUIREMENTS FOR SUCCESS

SMART SHIP has received strong support and interest from Department of Defense (DoD) leadership, as highlighted by the USS *Yorktown's* selection for the Hammer Award (for reinventing government) from Vice President Gore. The full potential for cost reduction through the reduction of workload onboard a ship has yet to be realized.

The attention given to the SMART SHIP by top-level Navy leadership must continue, the necessary resources must be protected, and plans developed for transition beyond the initial evaluation in June 1997. The enthusiastic SMART SHIP team, which has developed the program, will undergo personnel rotation. It is important to take whatever steps necessary to ensure that equally capable (albeit less experienced) members join the team, bringing new ideas and enthusiasm to the program.

A plan to transition validated concepts and improvements must be developed so that resultant manning reductions can transition to the Fleet sooner rather than later, building momentum toward the overall goal of an affordable yet effective future Navy.

While awareness of the program by the military and other government leaders is important for the program's success, it is equally important that unrealizable expectations not be created that will cause the ultimate performance to be disappointing. Likewise, although it is mandatory that the technical community be involved; SMART SHIP cannot be allowed to become an R&D platform for every good idea in the Science and Technology (S&T) pipeline.

These recommendations have several underlying themes. In order for the SMART SHIP initiative to have a chance to fulfill its promise, the Navy must actively and strongly support it. Moreover, the Navy and its supporters must believe that this is a primary and exceedingly important endeavor. The themes are:

- Without strong top-down oversight, it will not succeed.
- Without a visible, active method of transition to the Fleet, the SMART SHIP will never obtain the necessary credibility.
- Only strong leadership at all levels will ensure that frustrations and minor failures will not deter progress toward the goal.
- The technical community must be actively involved in the program—but must not be allowed to drive the SMART SHIP toward being a test vehicle.

FINDINGS

In accordance with the specific tasking of the Terms of Reference, the Panel was briefed on a major ship casualty, the USS *Stark* and major shipboard conflagrations, the USS *Cunningham*, USS *Enterprise*, and USS *Forrestal*. The common factors identified in major casualties are summarized in Figure 6.

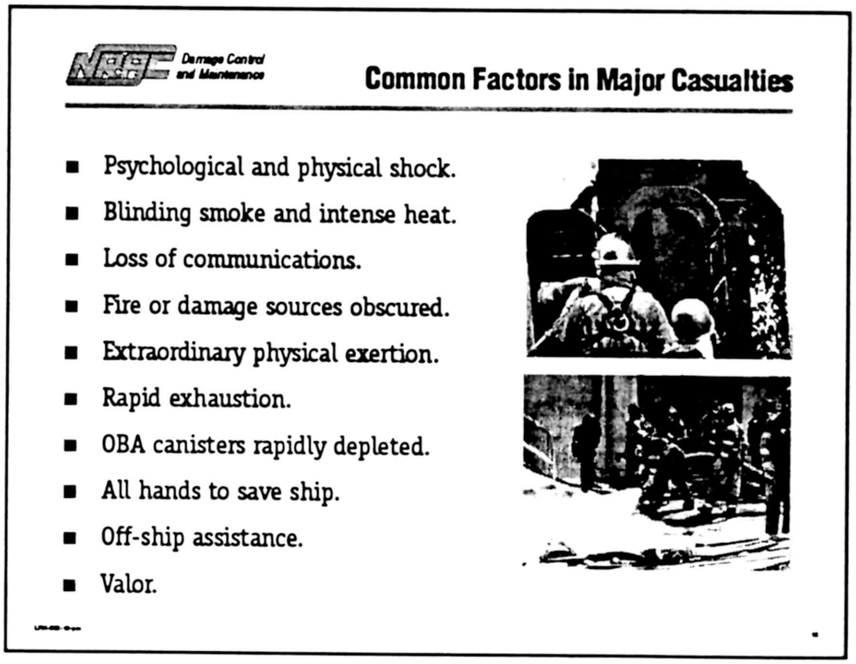


Figure 6.

The significant lessons learned from the USS *Stark* as well as observations of firefighting aboard the ex-USS *Shadwell* showed the need for training, particularly in teams, good rugged equipment, ready communications, and a need for user-friendly oxygen breathing apparatus. Firefighting is physically exhausting, and there is an essential need for the highest physical conditioning of the firefighting team. The USS *Stark* experience showed the blinding smoke, the intense heat, the inability to find the source of the fires, a rapid depletion of the supplies of OBA canisters, and the physical and emotional shock of knowing that shipmates were in dire conditions. Heroism by other members of the crew preserved the ship until trained firefighters from other ships came aboard and saved it. The crews from sister ships of the same class were particularly valuable as they knew where the supplies were located and where barriers could be set up. If other crews, firefighters, and equipment had not been available, or if the sea state had been greater than calm, the participants felt they would have lost the ship despite the valor and courage of all personnel.

The Panel was also provided a brief review of 15 serious shipboard fires, which resulted in greater than $1M in damage or where Sailors had been killed. Included in the presentation were video clips of the USS *Forrestal* and USS *Enterprise*; these films documented major flight deck fires that occurred during, the Vietnam War era and that resulted in 162 fatalities. These accidents illustrated the manpower-intensive effort of fighting a major, multicompartment conflagration, requiring a mass mobilization of the crew. These findings not only reinforced the importance for the entire crew to be trained in damage control fundamentals, but also brought a seriousness of purpose to the Panel's deliberations. Additional findings of the Panel relating to damage control are summarized in Figures 7a-b.

As previously noted, damage control requirements are not now the controlling factor in determining in-service ship manning. For example, in DDG-51, five percent of the crew is unassigned during Condition I. However, fighting the ship hurt will be the limiting factor if significant manning reduction is to be realized for both in-service and new ships. These findings are supported by the emphasis the SMART SHIP program is placing on reducing the number and size of the repair parties. In the new LPD-17, sufficient improvements have been made in ship automation and reduced manning design features. Damage control is now the controlling factor in LPD-17 manning, requiring 28 billets more than Condition III.

As already highlighted in the lessons learned from major shipboard casualities, it is imperative that damage control training be realistic, stressful, physically demanding, and team oriented. It is also important that the crew be trained with actual shipboard equipment, including firefighting ensemble, communications, infrared detectors, and breathing apparatus. Excellent physical condition is critical to an efficient repair party performance. Scheduled training time for aerobic exercise and a reward system for lowering the basal cardiac rate should be considered.

It was also noted by the Panel that environmental and budgetary constraints have greatly diminished the realism of firefighting training. Substituting a smoke-controlled or even smokeless propane fire trainer for a hydrocarbon fuel-fed fire will produce a false sense of security and may be counterproductive. In addition, budget constraints are presumably shifting training from shore-based to shipboard, which seems counter to the intent of this study.

NRAC Damage Control and Maintenance

Damage Control: Findings

- Currently, damage control requirements are not the ***controlling*** factor in determining manning of in-service ships.
- In the future, damage control requirements will be the ***limiting*** factor in determining reduced manning of in-service ships (e.g., SMART SHIP) and new ships (e.g., LPD-17).
- Damage control training essential. Must:
  - Be realistic and stressful;
  - Use shipboard equipment.
  - Emphasize teamwork
- Environmental and budget constraints diminish firefighting training realism.

NRAC Damage Control and Maintenance

Damage Control: Findings (cont'd.)

- Additional training has been shifted from shore-based to shipboard.
- Damage control situation assessment and communication are manpower intensive.
- New and improved procedures have not always been rapidly transitioned to Fleet.
- Use of commercial equipment increasing shipboard damage control effectiveness but must be incorporated in training curriculum.

Figures 7a and 7b.

There are also some instances where new and improved procedures for firefighting have not been expeditiously transitioned to the Fleet. The use of multimedia training methods should abate this problem. Finally, in our first-hand interviews with damage control experts, team training, enhanced communications, and situational awareness were the factors most cited to improve repair party effectiveness.

In accordance with the general objectives of the study, the Panel reviewed technology opportunities to reduce manning of the damage control organization. Many of these are available and need to be inserted into in-service and future ships. A comparison of manpower-intensive practices and manpower-saving technologies are shown in Figure 8.

The SCBA provides a more user-friendly breathing device (see Figure 9), which can reduce the training time required. The use of SCBA equipment was the topic of discussion during every training facility visit made by the Panel members. This piece of damage control equipment is highly desired by the Fleet as an OBA replacement for the following reasons:

- Life cycle cost of the SCBA is one-half that of the OBA
- Meets NIOSH requirements
- Already successfully used by firefighting trainers
- Utilized extensively by Military Sealift Command, civil firefighters, and foreign navies
- Sailors gain immediate confidence with the device with little training. Additional confirmation of that fact was made by a Panel member's participation during a firefighting exercise with the SCBA equipment at the ex-USS *Shadwell* facility.

NRAC Damage Control and Maintenance

Damage Control: Opportunities

MANPOWER INTENSIVE	MANPOWER SAVING
■ Oxygen breathing apparatus.	■ Self-contained breathing apparatus.
■ Sound-powered telephone.	■ Hierarchical Yet Dynamically Reprogrammable Radio (HYDRA).
■ Plotting boards.	■ Damage Control System (DCS).
■ Damage control assistant training.	■ Integrated Damage Control Training Technology (IDCTT).
■ Hand-held infrared viewer.	■ Helmet-mounted infrared visor.
■ Boundary watch.	■ Remote sensors.

Figure 8.

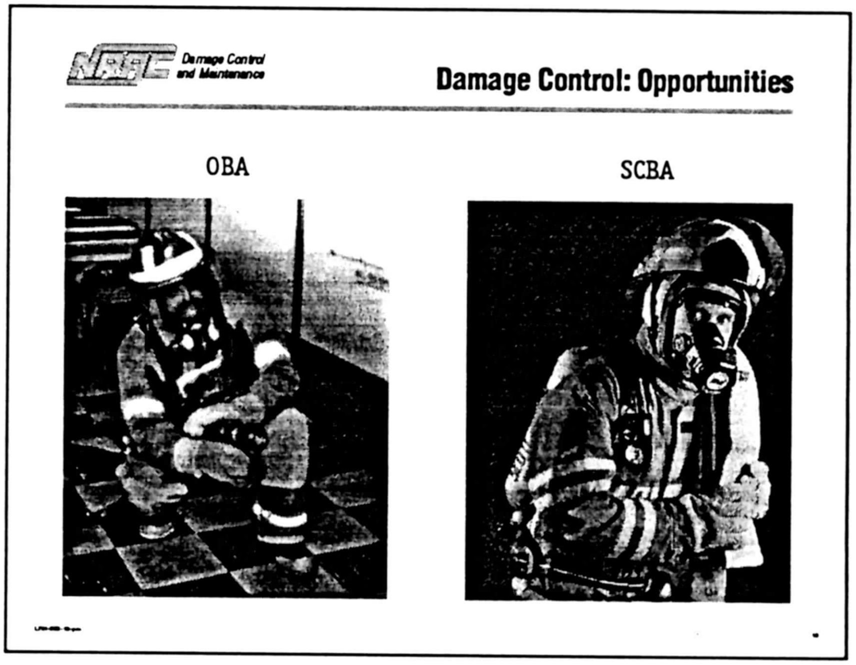


Figure 9.

Several opportunities exist where manning reductions can be safely made with minimal risk, but an acceptance of the trade-off between investment cost and personnel cost is required. The first area is communication. The dependable and reliable sound power (s/p) telephone system has been the core of intership Condition I communication. Manpower-intensive, sound-powered communication accuracy is dependent on the Sailor manning the phones. Accurately and clearly relaying information is dependent upon the Sailor's training, experience, and ability.

On some of our ships, the addition of the HYDRA or the Damage Control WIFCOM system has remarkably improved intraship communication with reasonable reliability. These systems eliminate the need for a middle man, the phone talker, which can reduce manning requirements for the Damage Control organization.

DCS will have the capability to provide concise "real-time" updates during a casualty. Updates will be instantly distributed to individual DCS workstations, thus eliminating the manual plotting requirements. Future capabilities will include the remote operation of valves and pumps to further enhance its functionality.

Extended use of multimedia training will make training for damage control more effective. It will provide less administratively burdensome Personnel Qualification Standard (PQS), and will be more user friendly for trainees. An Integrated Damage Control Training Technology (IDCTT) was demonstrated at the Surface Warfare Officer School, (Newport, Rhode Island) and was an excellent example of the use of multimedia CD-ROM technology to create situational damage control scenarios used for training.

The use of a helmet-mounted infrared visor would allow a firefighter to instantly assess the fire location without the use of an additional firefighter with a NFTI.

NRAC Damage Control and Maintenance

Damage Control: Conclusions

- Reconfigurations of the damage control organization (e.g., SMART SHIP) offers the greatest potential to reduce damage control manning.
- A significantly smaller damage control crew will be a superiorly-trained team, supported by timely situational awareness information, and outfitted with user-friendly, capability-enhancing damage control and communication equipment.
- Damage control training essential. Must:
  - Be realistic and stressful;
  - Use shipboard equipment;
  - Emphasize teamwork.

Figure 10.

The development of affordable remote smart sensors will have a revolutionary impact on damage control manning. Remote sensors will replace the "human sensors" required to assess damage and, in the future, will provide information necessary for automatic immediate actions during a casualty.

CONCLUSIONS AND RECOMMENDATIONS

Based on its findings, the Panel's conclusions and recommendations on Damage Control are summarized in Figures 10 and 11.

NRAC Damage Control and Maintenance

Damage Control: Recommendations

- Execute an acquisition and training master plan for the replacement and upgrade of damage control and communication equipment based on:
  - Systems approach
  - Approved organization changes
  - Operational requirements
  - Stable budget
- Develop alternative, more realistic firefighting trainers than the propane facility for firefighting professionals, e.g., private or ex-USS *Shadwell*-like facilities.
- Incentivize repair party crew to maintain physical fitness, e.g., through in-fleet competitions.

Figure 11.

WHY?

Before considering the Panel's findings regarding maintenance, it is instructive to review the reasons for performing maintenance as well as the current understanding of optimum maintenance practices, so-called reliability-centered maintenance.

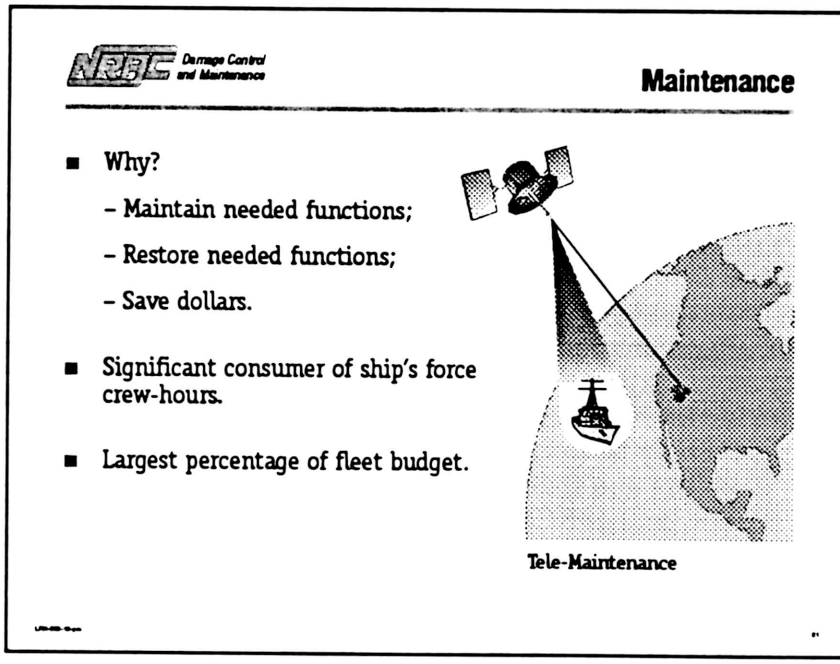


Figure 12.

As indicated in Figure 12, we do maintenance for three reasons: (1) to retain needed functions and capabilities; (2) to restore needed functions and capabilities; and (3) to reduce the cost of ownership. Each maintenance action must be evaluated against these basic reasons as part of the assessment process. The man-hour requirements of personnel work weeks devoted to maintenance are established for each class of ship and are a significant consumer of available ship's force man-hours. The intermediate and depot maintenance costs are established and are the highest percentage of Fleet operating and support costs (note: manpower costs are not borne directly by the Fleet). Thus, in reducing onboard (organizational level) maintenance, care must be taken to avoid just shifting the maintenance ashore. The maintenance should be eliminated, if possible, or reduced, and wherever it is performed, it should be at the lowest cost.

The evolution of maintenance knowledge and practices can be illustrated by the accompanying chart. This diagram shows the prevailing understanding of failure models over the past six decades where the vertical axis indicate the conditional probability of failure and the horizontal axis represents time. The early viewpoint, beginning with the first generation, was that the failure rate gradually increased, followed by a precipitous increase during a wear-out period. Periodic preventive maintenance calls for repair or replacement actions shortly before the wear-out period to preclude failure, that is, to cost effectively extend the useful life of the asset. During the intermediate period (1960-1970), the failure model included the existence of a break-in (also called infant mortality or burn-in) phase of the life cycle, defining the classical bathtub shape of conditional probability of failure versus time relationship (see Figure 13). In a 1978 study by United Airlines on aircraft machinery, four additional failure modes were identified. Moreover, the most prevalent failure behavior (68 percent of those examined) was a constant probability of failure after the burn-in period. For this type of failure behavior, there is no rationale for determining a periodic maintenance intervention. Rather, the optimum maintenance practice here is to monitor the condition of the asset and to intervene at appropriate times on the basis of appropriate diagnostic/prognostic predictions. The modern trend in maintenance, reliability-centered maintenance, not only takes into consideration the different failure modes and optimum maintenance practices (preventive, corrective, or condition directive), but also considers the consequences of failure in an operational context. For example, the most cost-effective alternative for noncritical equipment may be to run them to failure and then replace. The goal of RCM philosophy of maintenance is illustrated in Figure 14. Namely, condition-based maintenance will reduce the need for corrective and preventive maintenance and thereby significantly reduce the manpower and cost burden of maintenance.

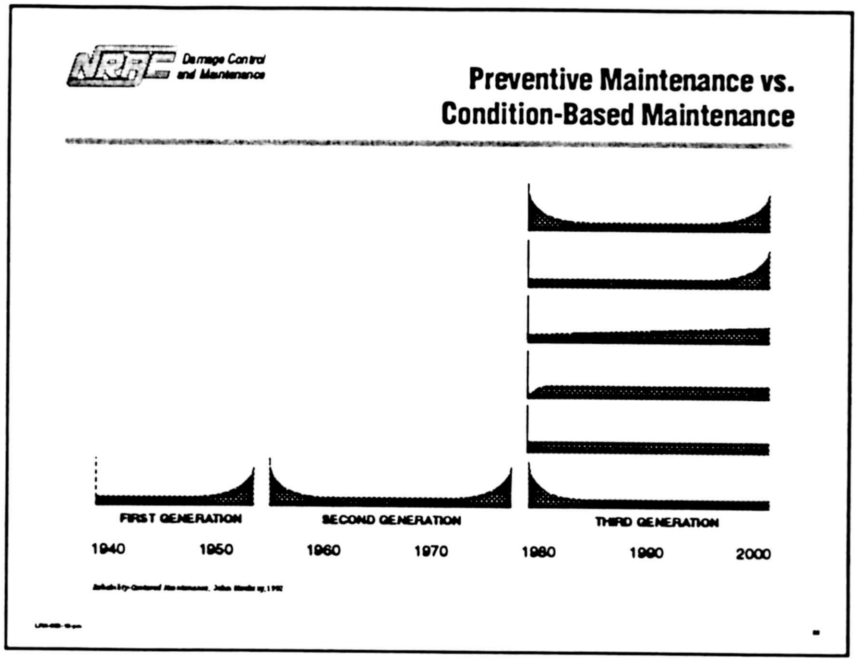


Figure 13. (*Reliability-Centered Maintenance*, John Moubray, 1992)

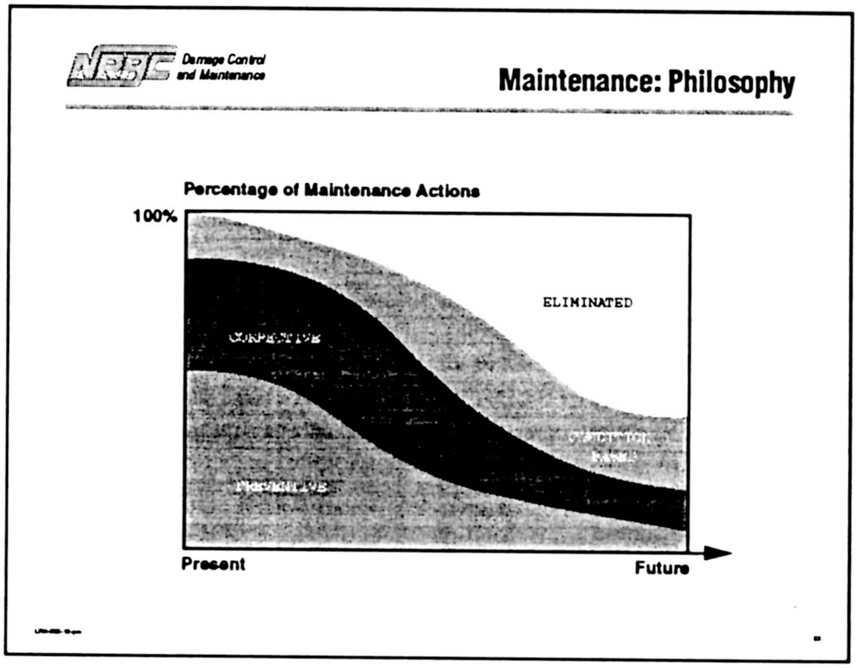


Figure 14.

FINDINGS

Today's naval forces are faced with several challenges in the area of maintenance (see Figure 15a-b). These include the existing PMS, the rapid emergence of new technologies, and a shrinking maintenance budget. These maintenance-related issues were consistently highlighted by the various commands interviewed during our study. The basic type of onboard maintenance that supports our naval force today is the PMS, which is both repetitive and labor intensive. NAVSEA and the British Navy are assessing an RCM approach to maintenance, which determines what must be done to ensure that any equipment on system continues to fulfill its intended function in its operational context. As previously discussed, RCM is a process used to determine the requirement of any physical asset in its operating context. It is noted, the Royal Navy is committed to a systematic, progressive program of implementing RCM within the next year on the Hunt Class MCMV, and

NAVSEA is studying a similar system.

RCM is a maintenance concept that focuses on the timely, informal intervention to maintain equipment and systems. This is in contrast to PMS, which focuses on scheduled repetitious, labor-intensive, and in many cases, unnecessary actions. In fact, at times, PMS perhaps may do more harm than good to equipment. Aside from the technological content, the lack of responsiveness of the PMS feedback system is demotivating to a ship's force. We believe that this function-focused, reliability-centered maintenance system should be pursued. A program to systematically implement this concept should proceed with the knowledge that the full impact on existing ships will be realized as cost-effective, implementing technology becomes available.

NRAC Damage Control and Maintenance

Maintenance: Findings

- Onboard maintenance requirements (PMS):
  - Crew-power intensive;
  - Not reflective of current knowledge, operational experience, and technology;
  - Typically excessive and increases over life;
  - Feedback resolution slow and demotivating.
- Maintenance efficiency impacted by quality of training.

NRAC Damage Control and Maintenance

Maintenance: Findings (cont'd.)

- Existing and emerging technologies can provide benefits:
  - Reliability-centered maintenance;
  - Tele-maintenance;
  - Integrated Condition Assessment System (ICAS);
  - Condition-Based Maintenance (CBM);
  - Nonpolluting, antifouling coatings;
  - Corrosion prevention, detection, and control;
  - Cost-effective sensor systems.
- Reduced lifecycle costs incentivized in LPD-17 acquisition.

Figure 15a-b.

From these maintenance principles, several fundamentals are reinforced. Notwithstanding the difficulties associated with technology insertion in both legacy and non-legacy systems, some opportunities do present themselves. As highlighted in the November 1995 NRAC Report on Life Cycle Cost Reduction, the greatest opportunity to influence and achieve significant reductions associated with maintenance and damage control is during the design, development, and acquisition phases. It is during these phases that these fundamental changes are best addressed and most easily implemented. To achieve significant savings over the life of the ships, an additional initial investment may be required. If these costs can be spread over several platforms or programs and the appropriate technology leveraged to other classes or programs, the costs could be significantly reduced. The LPD-17 program, with its emphasis on life cycle cost reductions and leveraging technology among associated platforms and programs, is an example that must be emulated in all new acquisitions.

Backfit of technology to existing ships and/or systems is clearly more difficult because the initial opportunity discussed above is obviously no longer available. Technology insertion remains limited by costs and/or availability of funds. A few of the available technology opportunities are listed in Figure 15b. However, the SMART SHIP program clearly demonstrates that sufficient opportunities are available to reduce manpower requirements in existing ships to warrant an aggressive approach to revision of concepts, policies, and practices, and to insertion of emerging technologies. A program to install improvements validated in SMART SHIP into existing ships in a timely manner must continue to receive top priority.

Concurrent with the validation of new approaches to maintenance in SMART SHIP and with the establishment of a new maintenance concept incorporating Condition-Based Maintenance (CBM) and RCM principles, opportunities exist to reduce the current burden imposed by PMS. Clearance of the backlog of PMS feedback reports and an objective review of current PMS requirements based on engineering data that is now available could reduce the maintenance man-hour requirements without compromising the safe, reliable, and cost-effective operation of the ship.

NRAC Damage Control and Maintenance

Maintenance: Conclusions

- Preventative maintenance is a major consumer (~20%) of ship force man-hours.
- Clearance of the backlog of PMS feedback reports and an objective review of requirements based on engineering data that is now available (but not where the requirements were established) would significantly reduce this burden without degrading the safety, reliability, and cost-effective operation of the ship.
- Reengineering of the Navy's onboard maintenance policy and practices in accordance with current knowledge, such as Reliability-Centered Maintenance, and emerging technologies such as Condition-Based Maintenance will significantly reduce the ship force manpower burden, saving thousands of crew hours per week per ship.

Figure 16.

CONCLUSIONS AND RECOMMENDATIONS

The Panel's findings regarding maintenance leads to the conclusions and recommendations summarized in Figures 16 and 17.

NRAC Damage Control and Maintenance

Maintenance: Recommendations

- Establish Reliability-Centered Maintenance (RCM) as the official maintenance policy and practice for all U.S. ships and identify a date when such procedures will be fully operational.
- As a necessary first step in establishing RCM policy, perform an immediate top-to-bottom review of all PMS against available data, feedback reports, and underlying tenets of Reliability-Centered Maintenance. No changes will compromise safety, combat readiness, or cost-effectiveness. Promulgate changes immediately.
- Program managers for new ships must be aware of and have access to all relevant technology, concepts, and practices that reduce the cost of ownership in maintenance and be prepared to invest in their insertion.
- Technology insertion must be leveraged in both the back-fit and forward-fit directions.

Figure 17.

FINDINGS

As summarized in Figure 18, the findings of this study show that training content, methods, and doctrine are key enablers in achieving reduced shipboard manning. Training needs to address the specific issues of integrated new technologies and reduced shipboard manning. Reduced manning often fails to adequately deal with the growing complexities of modern warfare. Because of these complexities, most warfare tasks will need to be executed by teams rather than individuals. Team training is essential.

Training: Findings

- Training content, methods, and doctrine are evolving concurrently with changes in ship manning utilizing:
  - Multimedia aids;
  - Distance learning;
  - Interactive CDs.
- Lack of realism in damage control training leads to complacency.
- Changes lead to less sensitivity to complexity in less redundance and unknown risk.

Figure 18.

Training: Conclusion and Recommendations

CONCLUSION

- The smaller crews of future ships will be a highly skilled, knowledgeable, proficient, and cross-trained team.

RECOMMENDATIONS

- Develop damage control training that is realistic, stressful, and uses shipboard equipment;
- Increase team training opportunities;
- Consider risk and situational awareness in adoption of new technologies, operations, and training.

Figure 19.

The Navy is taking aggressive action to provide shipboard training in content, methods, and doctrine utilizing distance learning through interactive CDs, tele-training to complement tele-maintenance, and eventually virtual reality programs. We strongly endorse this effort and urge aggressive implementation throughout the Fleet.

However, in the area of highly stressful and critical damage control functions, there is an acute need for training to emulate actual conditions. For example, it is imperative that firefighting be realistic with the obscuring smoke, the difficulties in communication and source location, and intense heat of the real experience. This emulation of actual conditions also applies to other damage control scenarios such as flooding, shoring, and controlling hazardous material spills. This needs to be done with the stress of the real event so that in real emergencies, uncertainty and confusion are minimized and repair parties will maximize the utilization of their skills and equipment. Realistic training with situational awareness decreases the risks of unpredicted complications that, in the past, have been compensated for with redundancy in manpower.

CONCLUSION AND RECOMMENDATIONS

The conclusion and recommendations for the training portion of this study are reported in Figure 19.

NEEDS

If maintenance and damage control manpower needs are to be substantially reduced, then the ability to remotely and reliably determine the real-time status of the ship and crew must be expanded far beyond today's capability. These needs are summarized in Figure 20.

NRAC Damage Control and Maintenance

Ship Status Sensing Needs

DAMAGE CONTROL	MAINTENANCE
■ Crew location and vital signs	■ Machine health and performance
■ Atmosphere	■ Contamination of critical fluids
■ Fire evolution and classification	■ Status of ship utilities and consumables
■ Flooding	■ Corrosion
■ Structural damage	■ Sensor status
■ Chemical, biological, or radiation hazards	

Figure 20.

Damage Control

In virtually any damage control situation, knowledge of the location and status of crew members is essential–from the standpoint of establishing damage control team capability as well as planning casualty rescue efforts. "Electronic dog tags" communicating through a wireless sensor telemetry system could easily provide crew location information and could report a general summary of individual status (red–yellow–green).

The ability to detect the presence of flammable atmosphere in each and every ship compartment offers the opportunity to avert fire casualties before they occur. Early detection of fires is essential to minimizing fire-associated losses and the ability to classify combustibles feeding a fire and monitor the evolution of a major fire are critical to planning damage control response and allocation of damage control resources.

Similarly, knowledge about the extent and rate of flooding is essential to determining the exact location and cause of such damage as well as planning and guiding damage control response. Knowledge about the extent and severity of structural damage would allow the path of a weapon through the ship to be determined. Such knowledge would also be useful in determining the operational capability of the ship after a major casualty. The ability to perform real-time detection and monitoring of chemical, biological, or radiation hazards throughout the ship would clearly guide damage control response to these casualties as well as acting as a real-time monitor of clean-up activities.

Maintenance

Accurate and timely knowledge of the status of various ship systems requires not only a wide variety of installed sensors, but intelligent and expert processing of sensor data. This is necessary both to reduce the quantity of data being handled and to ensure that critical trends are detected as soon as possible. Current Navy systems such as the ICAS and the DCS provide the basis for performing this function. The availability of intelligent, programmable sensors, capable of initial data reduction, trend analysis, and alarm raising, will greatly extend this capability.

A variety of liquid level sensors, pressure sensors, and flow sensors combined with electrical voltage, current sensors, and smart inventory control tags for critical supplies will provide virtually complete knowledge of the current status of ship utilities and consumables. Chemical and biological sensors, similar in design and construction to those used for detection of hazards, can be used to detect the presence of chemical contaminants or growth of biological organisms in fuel, oil, water, or food stores. Early detection of such problems allows any resulting damage to be minimized and the ship status to be realistically assessed.

The Office of Naval Research (ONR) Condition-Based Maintenance program is focused on developing the technology and understanding of failure mechanisms required to detect precursors of machine failure. This capability is necessary to accommodate the recommended shift toward less manpower-intensive maintenance methods. A primary impediment to the implementation of CBM will be the availability of a suite of affordable, reliable sensors necessary to monitor health and performance of various machinery systems.

Corrosion prevention and corrosion-related repairs account for a major fraction of all maintenance manpower requirements. A number of efforts, including the ONR CBM program, are developing sensors for detecting precursors of corrosion. Such a detection capability widely installed in corrosion-prone ship spaces would allow just-in-time maintenance to be performed in lieu of repairing major corrosion damage.

False alarms are the bane of any highly automated detection system and if a ship status sensing system is to be effective in reducing maintenance and damage control manpower requirements, then reliability must be a major concern. This goal can be achieved through improving individual sensor reliability as well as providing redundant sensors and/or basing alarm functions upon multiple sensor inputs. The corollary to false alarming is a failure to alarm and this can be addressed by including a sensor status reporting function in the system.

REQUIRED SENSOR CHARACTERISTICS

The establishment of a comprehensive Ship Status Sensor Systems (S^4) will require the installation of a large array of sensors throughout the ship as well as making provisions to sense crew location and status. If the benefits of S^4 are to be realized, these sensors must be affordable and reliable. Since more than 80% of the cost of a sensor channel in a modern shipboard system such as ICAS is associated with wiring and installation, the availability of wireless sensors will have a major impact on costs. Furthermore, since the connection between the sensor and the central terminal is typically the most vulnerable part of the system, wireless operation should lead to substantially improved reliability. Wireless sensor technology for shipboard use is under development today in the Defense Advanced Research Projects Agency (DARPA) Ship Systems Automation Program.

Sensors in use with systems such as ICAS today are typically discrete devices incorporating an assembly of a sensing element, signal conditioning and processing components, and a power supply. Much of the cost as well as sources of many reliability problems in such sensors are associated with this assembly of discrete components. The drive for increased capability coupled with improved reliability and reduced cost in the electronics industry led from large assemblies of generalized components to more compact assemblies of more specialized components and finally, to large-scale integrated circuits that are in effect single, highly specialized components. The application of this approach of sensor development has led to the evolution of MEMS in which all sensor components, including mechanical sensing elements, are produced on a single silicon chip. As with microelectronics, this results in the transfer of investments from an assembly of individual devices, each one slightly different, to up-front design and layout to produce very inexpensive, virtually identical devices in volume. While the most obvious result of MEMS technology is miniaturization (and this is beneficial to the S^4 application), the most important results are the reduction of per-unit cost and a dramatic improvement in reliability through the elimination of interconnects between discrete elements. These two advantages offered by MEMS-based sensors are essential to the realization of a successful S^4. MEMS design and fabrication technology is currently being developed by DARPA and ONR.

As previously discussed, the dramatic increase in installed sensors required to realize the benefits offered by the S^4 concept brings with it the very real risk of generating a data overload that could actually mask the evolution of critical problems. Since much of the information generated by the sensor network during normal system operation is of little interest, it is important that the sensor itself be able to monitor trends and check current data against present alarm levels without sending a continuous data stream to the central terminal. However, in the event of an alarm or other change in status, sensor reporting should ideally be reprogrammable from a central point.

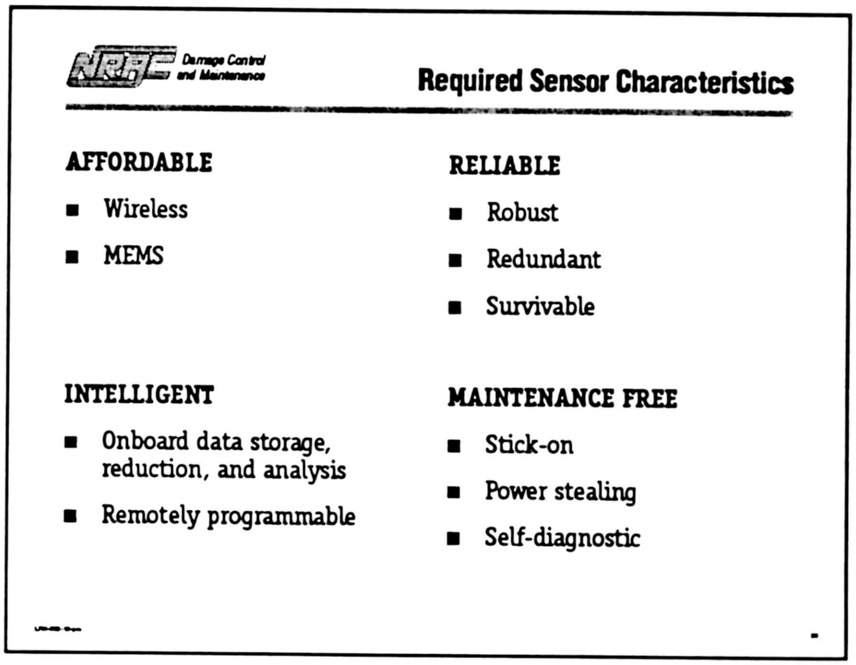


Figure 21.

It is essential that maintenance man-hours saved by application of the S^4 concept not be consumed in installing and maintaining the sensor network. The sensors should be easily installed, such as stick-on, encapsulated cards. Ideally, they should derive power from their environment. Photovoltaic, thermoelectric, acoustic, or motion-powered devices can be envisioned. Such an approach is consistent with MEMS technology, which typically requires modest power. Additionally, self-diagnostic features should be incorporated into the MEMS sensors to minimize the time and effort required to locate sensor malfunctions. A summary of the required sensor characteristics is listed in Figure 21.

SENSOR GENERIC FUNCTIONS

Developing a sufficient knowledge of real-time ship status to allow a substantial manpower reduction without increasing risk will require the installation of a large number of sensors (1,000s). This in turn creates the danger of being inundated with data, most of which is of little use until some out-of-specification situation occurs. In order to avoid overload, it is necessary that the individual sensors have some degree of intelligence, preferably remotely programmable. This will substantially reduce both the data rate required for communication and central data storage requirements. For example, in the case of a temperature sensor in a paint storage locker, it is not necessary to report the temperature under normal conditions. The sensor should locally store sufficient data to determine average temperature fluctuations and only if the locker temperature exceeds some preset limit should an alarm signal be sent to a damage control watch station. Once an alarm is received, the damage control officer may desire to reprogram the sensor to provide real-time temperature or even rate-of-rise information. Depending on the nature of the parameter being monitored, some automatic action may be desired upon generation of the alarm. In the example above, it may be desirable to automatically activate a sprinkler system and close ventilation dampers when locker temperature exceeds a certain preset level. In summary, it is necessary for sensors to collect data, reduce the data to produce desired information (i.e., alarms), and communicate that information to the appropriate stations. Additionally, in certain cases, it may be desirable to enable a certain sensor or sensor combination to initiate certain immediate actions.

NRAC Damage Control and Maintenance

Ship Status Sensor Systems: Conclusion

- The development of affordable sensors for situation awareness of the ship's status will have a revolutionary impact on reducing manning for in-service and future ships. Enabling technologies include:
  - Micro-electromechanical systems (MEMS);
  - Wireless telemetry communications.

Figure 22.

CONCLUSION AND RECOMMENDATION

In accordance with the above discussion on ship status sensor systems, the Panel's conclusion and recommendation regarding the development of affordable sensors are summarized in Figures 22 and 23.

NRAC Damage Control and Maintenance

Ship Status Sensor Systems: Recommendation

- An Advanced Concept Technology Demonstration (ACTD) investment ($30–50M over the next 3 to 5 years) in emerging wireless telemetry and bi-directional communications sensor technology for shipboard applications should be made now to realize the near-term benefit for retrofit to current ship inventory and to impact the pending new construction schedule.

Figure 23.

The recommendation of a significant investment in the development of affordable sensors is made with an appreciation of the declining budget and competing priorities for R&D funds. However, it is because of the potential to reduce manning and save dollars that the Panel unequivocally endorses this recommendation. As illustrated in Figure 24, 80% of the in-service combat ships will be in the Fleet in 2020. The expeditious backfit of these technologies will result in savings of hundreds of millions of dollars. These savings will help to retain current force size, i.e., number of ships, and will possibly be used to recapitalize needed new ship construction. The retrofit of these technologies will also serve as a test bed for insertion in the Navy's tentative new ship construction schedule shown in Figure 25. Hence, an investment in these technologies now will reduce the risk for insertion in new platforms and pay a high return on investment for most of the 21st Century.

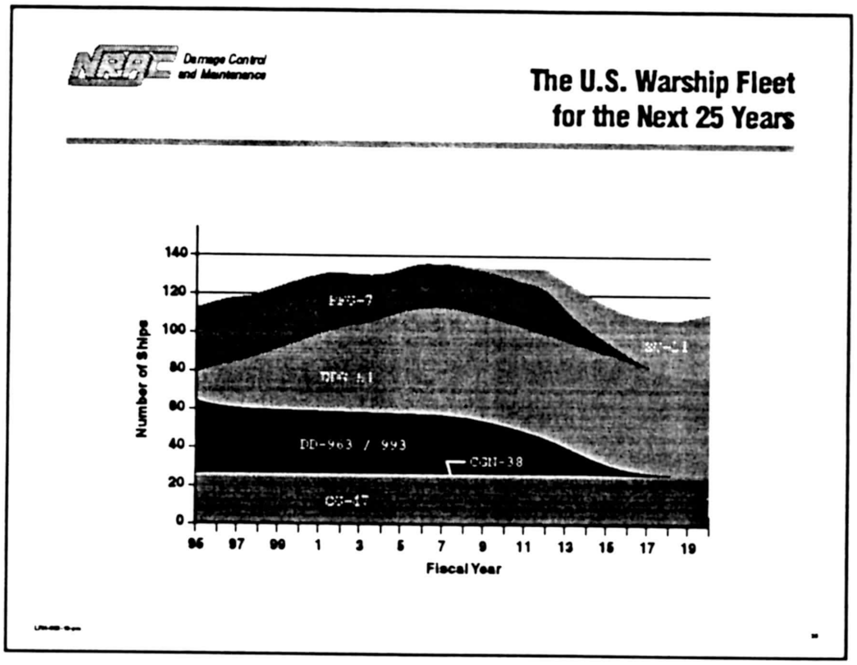


Figure 24.

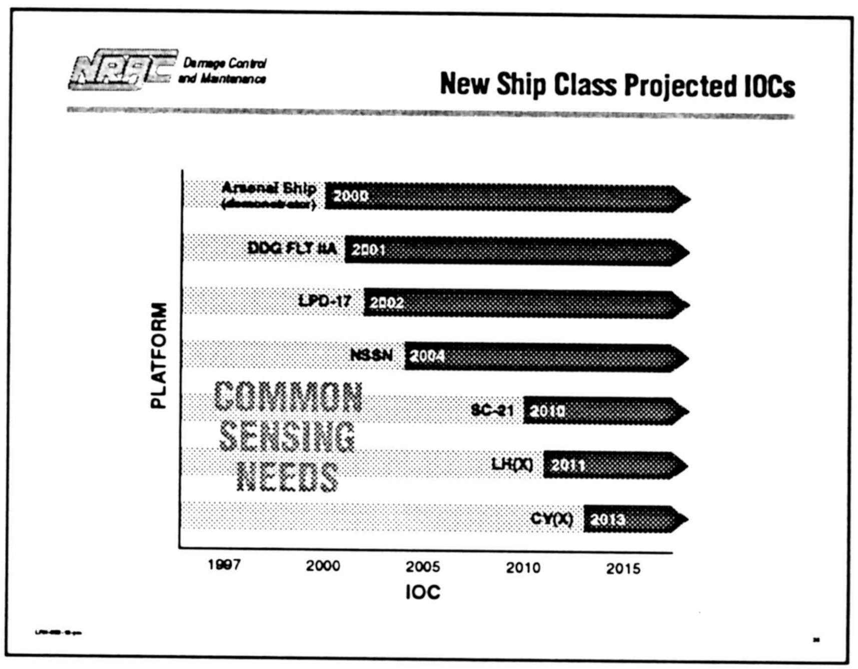


Figure 25.

Acronyms

ACTD	Advanced Concept Technology Demonstration
AI	Artificial Intelligence
AOE	Fast Combat Support Ships
ARL	Applied Research Laboratory
ASN (I&E)	Asst. Secretary of the Navy (Installations and Environment)
CBM	Condition-Based Maintenance
CG	Guided Missile Crusier
CGN	Guided Missile Crusier (Nuclear)
CINCLANTFLT	Commander in Chief, U.S. Atlantic Fleet
CNET	Chief of Naval Education and Training
CNO	Chief of Naval Operations
COMNAVSURFLANT	Commander, Naval Surface Force, U.S. Atlantic Fleet
COMTRALANT	Commander, Training Atlantic
COS ATG	Chief of Staff, Advanced Training Group
COTS	Commercial Off-The-Shelf
CVN	Aircraft Carrier (Nuclear)
CVX	Multipurpose Carrier
DARPA	Defense Advanced Research Projects Agency
DC	Damage Control
DCCM	Damage Control Master Chief
DCS	Damage Control System
DDG	Guided Missile Destroyer
DoD	Department of Defense
DON	Department of the Navy
FFG	Guided Missile Frigate
HYDRA	Hierarchical Yet Dynamically Reprogrammable Radio
IBS	Integrated Bridge System
ICAS	Integrated Condition Assessment System
IDCTT	Integrated Damage Control Training Technology
IOC	Initial Operational Capability
LAN	Local Area Network
LCDR	Lieutenant Commander
LH	Amphibious Warfare Ship
LPD	Amphibious Transport Dock Ship

MCMV	Mine Countermine Vessel
MEMS	Micro-electromechanical Systems
MMCS	Machinists Mate Senior Chief
MOE	Measure Of Effectiveness
NAVMAC	Navy Manpower Analysis Center
NAVSEA	Naval Sea Systems Command
NFTI	Naval Firefighting Thermal Imager
NIOSH	National Institution of Occupational Safety and Health
NRAC	Naval Research Advisory Committee
NRL	Naval Research Laboratory
NSWC	Naval Surface Warfare Center
OBA	Oxygen Breathing Apparatus
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
PACFLT PEB	Pacific Fleet Propulsion Examination Board
PMS	Periodic Maintenance System
PPBS	Planning, Programming, and Budgeting System
PQS	Personnel Qualification Standard
R&D	Research and Development
RADM	Rear Admiral
RCM	Reliability-Centered Maintenance
ROC	Required Operational Capability
S&T	Science and Technology
S/P	Sound Power Phone
S^4	Ship Status Sensor System
SC-21	Surface Combatant–21st Century
SCBA	Self-Contained Breathing Apparatus
SMCS	Standard Monitoring and Control System
SMD	Ship Manning Document
SMD	Ship Manpower Document
SSN	Submarine (Nuclear)
SYSCOM	Systems Command
TOA	Total Obligation Authority
VADM	Vice Admiral
WIFCOM	Wireless Communications