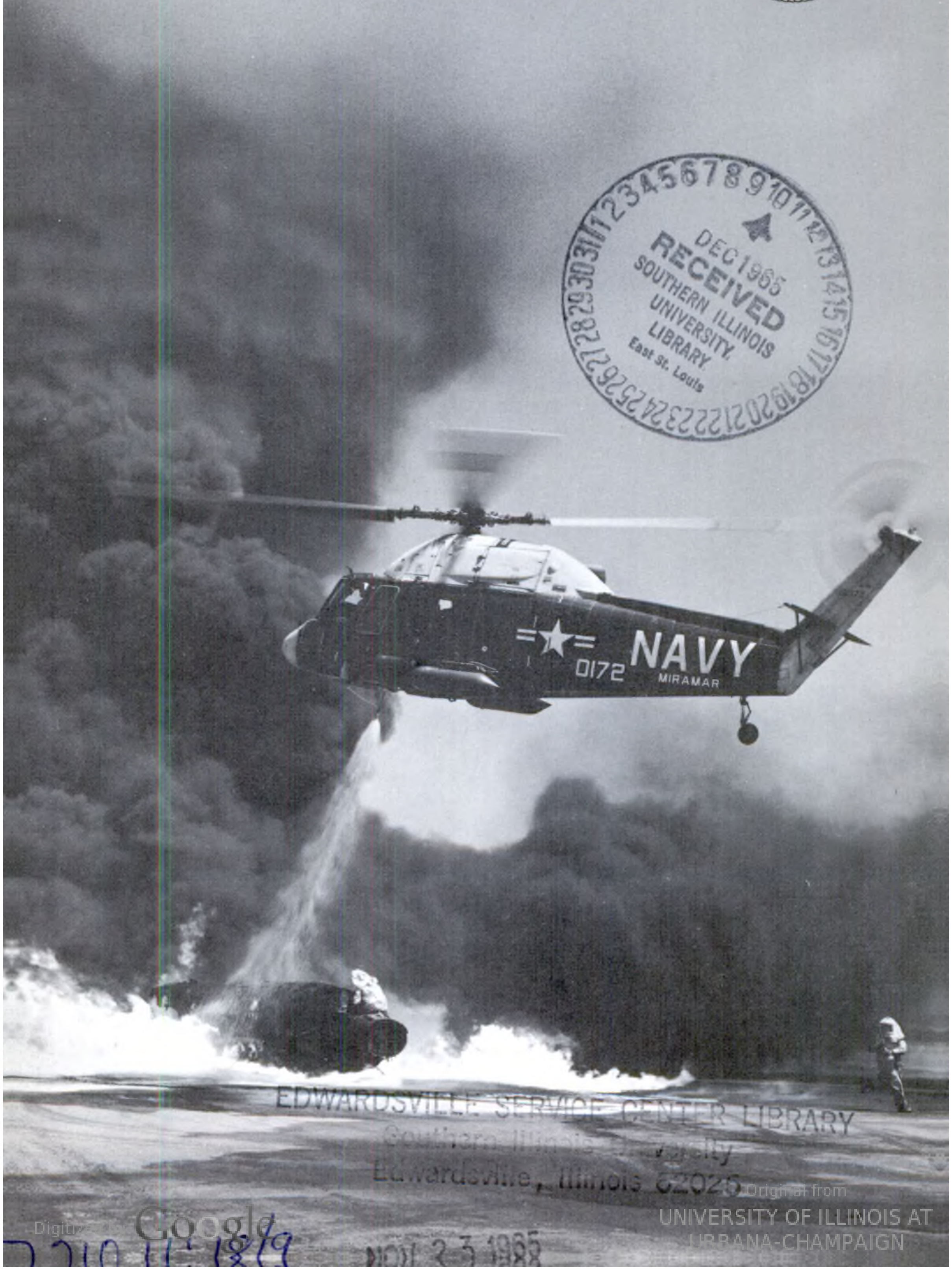
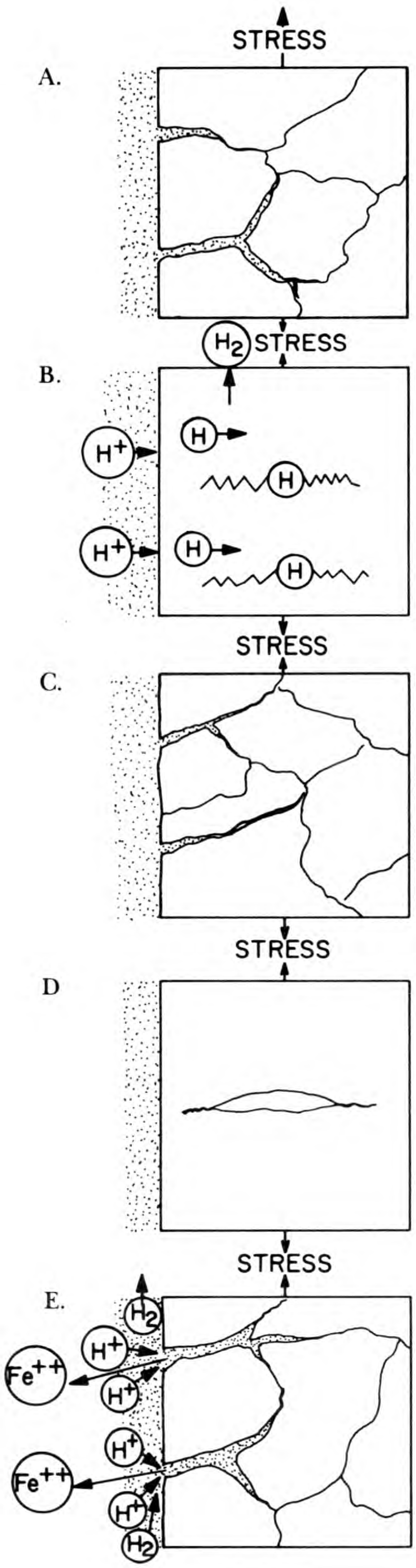
NAVAL RESEARCH

REVIEWS

SEPTEMBER 1965

DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH





A. STRESS CORROSION CRACKING.

Time to failure: 2 hours. Surface active agent penetrates grain boundaries. Simultaneous action of chemical corrosion and tensile stress. Anodic areas of metal attacked.

B. HYDROGEN EMBRITTLEMENT.

Time to failure: 3 hours. Cathodic reduction of H^+. Depends on tensile strength of alloy, but not on metallurgical structure. Cracking increased by polarizable ions at surface (*e.g.*, Hg^{++}, S^{--}, CN^-). Atomic hydrogen diffuses into metal from surface. Only cathodic areas attacked.

C. LIQUID METAL EMBRITTLEMENT.

Time to failure: 0.1 second. Liquid metal wets grain boundaries. Mutual solubility of liquid and solid may be very limited. Single crystals generally unaffected.

D. LOW-TEMPERATURE BRITTLE FRACTURE (NIL DUCTILITY).

Time to failure: 10^{-5} seconds. Occurs only below a critical temperature. Brittleness depends on alloy composition and method of manufacture. *Fracture not dependent on surface conditions.* Crack propagates at ~ 0.3 of speed of sound in solid. Time to failure strongly dependent on fracture stress.

E. INTERGRANULAR CORROSION.

Time to failure: 50 hours. Local penetration. Grain boundaries anodic to bulk metal. Stress not a factor, but reduction of surface area reduces mechanical strength. Severe local attack due to size of anode areas relative to cathodic areas in bulk. Metallurgical treatment greatly influences sensitivity of metal to both intergranular and stress corrosion.

Figure 1 — Catastrophic failure modes.

Liquid Metal Embrittlement

The Complete, Rapid, and Unpredictable Failure of High-Strength Alloys

R. C. Carlston
Metallurgy Branch
Office of Naval Research

The history of naval and aviation alloy development has been consistently in the direction of higher strengths and strength-to-weight ratios. To a large extent, the quest has been successful, giving modern-day high-performance aircraft, ships, and submarines performances undreamed of a few decades ago. Yet, as might be expected, nature has set up barriers to the unrestricted use of the higher strength alloys: these materials are susceptible to catastrophic (complete, rapid, and unpredictable) failures (Figure 1). This susceptibility can arise from stress corrosion cracking, hydrogen embrittlement, liquid metal embrittlement, intergranular corrosion, and brittle fracture below the nil-ductility temperature. It is ironic that the materials which are the strongest are often the most susceptible to one of these modes of failure. Thus the problem becomes one of the first magnitude in designing advanced naval structures for which materials having high strength or strength-to-weight ratios are a critical requirement. The prevention of a catastrophic failure requires the close cooperation of workers in the fields of design engineering, applied mechanics, metallurgy, and physical chemistry. Often the materials limitations can be "designed around," but this is a stop-gap solution suitable only when reliable controls over environmental and structural factors are lacking.

In spite of the large effort made in the last 15 years to understand all of these modes of catastrophic failure, serious deficiencies still exist in our basic knowledge of these mechanisms and our ability to control the fracture. Much of our approach to these problems has been failure analysis after the fact. Thus our ability to control the fracture is based largely on experience and emperical knowledge.

The intergranular corrosion mode, the only mode which involves material dissolution rather than fracture, is probably the best understood. It invariably arises when small-area grain boundaries become anodic to neighboring bulk metal because of a composition segregation at the grain boundaries. Since the current in the anode is identical to that in the cathode during reaction, the anode area, which is relatively small, has a large current density and thus is subjected to severe local attack. In principle, intergranular corrosion can be controlled by applying proper metallurgical techniques to equalize electrochemical potentials.

All of the other failure modes result in brittle fracture (the stress relief by cracking rather than deformation) and have many attributes in common. The first three can be considered to involve surface-active fracture* because in each case damage can be eliminated completely if certain critical environments are avoided.

Information about these exposure conditions has been obtained more or less by experience; few fundamental guidelines exist to help the designer place limitations on the use of structural materials.

In the environmental cracking modes, actual corrosion or dissolution of materials is a minor part of the damage. The critical consideration is the penetration of deep cracks into materials under tensile stress. Ordinarily these materials have a ductile response to an applied stress, but when certain surface-active agents are present at a crack tip, the material is embrittled and can crack irreversibly and catastrophically before the design load is even reached. Since the fracture is brittle, there is not enough "give" in the material to accommodate the stresses and preserve structural integrity. Each crack reduces the structural cross section and the ability of a member to support stress. It should be noted that only the surface layers are embrittled; the bulk metal remains ductile. Perhaps less than one millionth of the atoms in the alloy are affected, but these are decisive in providing a path of weakness along which a fracture can develop. The amounts of the surface-active agents involved are so small that control and analysis of the composition of the surface is difficult. (Often only a monomolecular layer of an agent is sufficient to cause a fracture to develop.)

We want to examine here the essential factors of the most spectacular form of catastrophic failure—liquid metal embrittlement (Figure 2). In this mode, a particular solid metal can undergo brittle fracture intergranularly when in contact with a particular liquid metal. Some of these specific liquid-solid couples are shown in Table 1. Residual stresses imparted to the alloy during processing are often sufficient to permit fracture. The specificity of the action, the rapid time scale (instantaneous to the casual observer), and failure of an all-metal system without electrochemical action have intrigued investigators for a long time, but so far they have resisted a firm theoretical interpretation. In fact, it is interesting to show, as in Table 2, what we

*Dr. B. F. Brown, of the Naval Research Laboratory, has suggested the more general term "environmental cracking" to cover stress corrosion cracking and hydrogen embrittlement. It is extended further here to include liquid metal embrittlement so that all failure modes involving surface-active fracture are covered by the term.

know and what we would like to know about liquid metal embrittlement. It will be shown that liquid embrittlement can be most effectively studied as one manifestation of environmental cracking.

Liquid metal embrittlement was discovered as early as 1914, but the field lay dormant until the mid 50's when an interest in the overall problem of surface-active fracture began to develop in this country and abroad. The Russians have been particularly active under Academician P.A. Rebinder. Their work is directed largely toward understanding liquid metal embrittlement as an example of the Rebinder

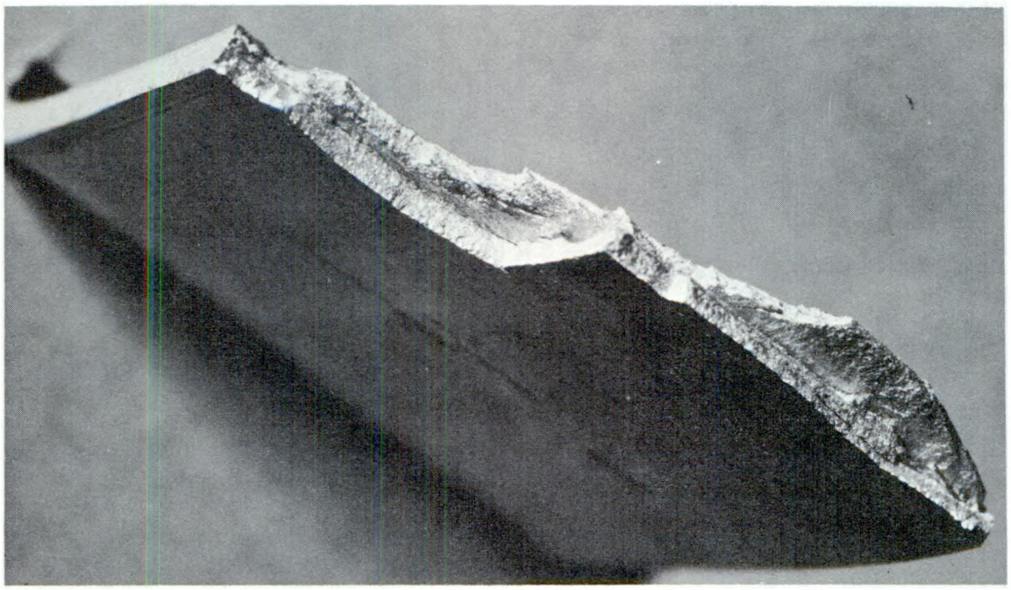


Figure 2 – Aluminum structural member that failed as a result of embrittlement by liquid gallium.

Table 1 – Embrittlement couples.

Solid Alloys	*Liquid Metals*											
	Hg	Cd	Zn	Ga	In	Tl	Sn	Pb	Bi	Te	Li	Na
Aluminum	X		X	X	X		X					X
Magnesium			X									X
Steel		X	X		X		X			X	X	
Brass	X				X		X	X	X			
Titanium	X	X										
Copper	X*								X		X	X
Tin	X			X								
Zinc	X			X			X	X				
Cadmium				X			X					

*Cu-Be alloy

Table 2 — Factors and problems in liquid metal embrittlement.

Known Factors	*Problems*
Single crystals immune.	Influence of liquid composition and relation of bulk to surface composition.
Liquid and solid usually have small mutual solubility; no intermetallic compound in binary phase diagram; liquid-solid couple is specific.	Surface energy considerations.
Tensile stress (applied or residual) required.	Amount of plastic deformation accompanying brittle fracture.
Liquid metal changes deformation from ductile to brittle; fracture generally intercrystalline.	Amount of fracture surface relative to quantity of liquid metal.
Embrittlement does not affect stress/strain curve of alloy (liquid metal limits total ductility or allowable stress at fracture).	Hydrodynamic aspects and electronic properties (for example, Fermi energy) of solid.
Fracture cracks propagate very rapidly (~200 cm/sec).	Role of diffusion processes in liquid and solid.
Fracture is delayed at low stress levels; (that is, there is a static fatigue limit)	Role of intrinsic yield strength.
Fracture stress dependent on grain size, yield strength, and stacking fault energy but not on tensile strength.	Relation of crack propagation to liquid velocity.
Crack initiation requires arrest of slip at grain boundaries.	Relation between embrittlement of salt crystals and metals.
Intergranular corrosion not important; embrittlement does not involve simple dissolution.	Rationale of grain-size dependence (validity of Petch-Stroh relation).
Embrittlement greatest just above melting point of liquid; changes of composition in either member of couple change degree of embrittlement.	Factors controlling time scale of fracture.
	Liquid metal embrittlement as a manifestation of environmental cracking.

effect, according to which the presence of monomolecular surface layers on a fracture surface affects greatly the bulk mechanical strength. The American work has been directed largely toward the phenomenological aspects of fracture theory. Much of the available literature is summarized in *Embrittlement by Liquid Metals,* by Rostoker, McCaughey, and Markus (Reinhold, 1960). The book describes several areas in which fundamental knowledge is required before a serious advance can be made: fracture mechanics, dislocation theory, surface phenomena, and the liquid state.

There are a number of reasons why the field of liquid metal embrittlement should be particularly exciting: the influence of surface chemistry on fracture mechanics is emphasized to a degree not possible in the other modes, a link between the atomic structure of solid and liquid is required in the analysis, certain fundamental aspects of fracture mechanics (for example, static fatigue or delayed fracture) can be studied in a unique fashion, and the time scale for failure is reduced so that a much larger output of data on fracture mechanics is possible.

The contract program of the Metallurgy Branch of the Office of Naval Research has been concerned with the fundamental basis for this phenomenon.* The work has gravitated along two main directions: isolation of the specific compositional dependence and the use of transmission electron microscopy. One of the surprising findings has been the extent to which the fracture of AgCl in certain electrolytic solutions (Figure 3) models the embrittlement of brass by mercury. In each case, the virgin stress-strain curve is unchanged by the environment, but both the allowable stress at fracture and the strain are greatly limited. In these soft crystals, the fractures occur in the plastic range (beyond 0.02 strain), but as the solid becomes harder, the

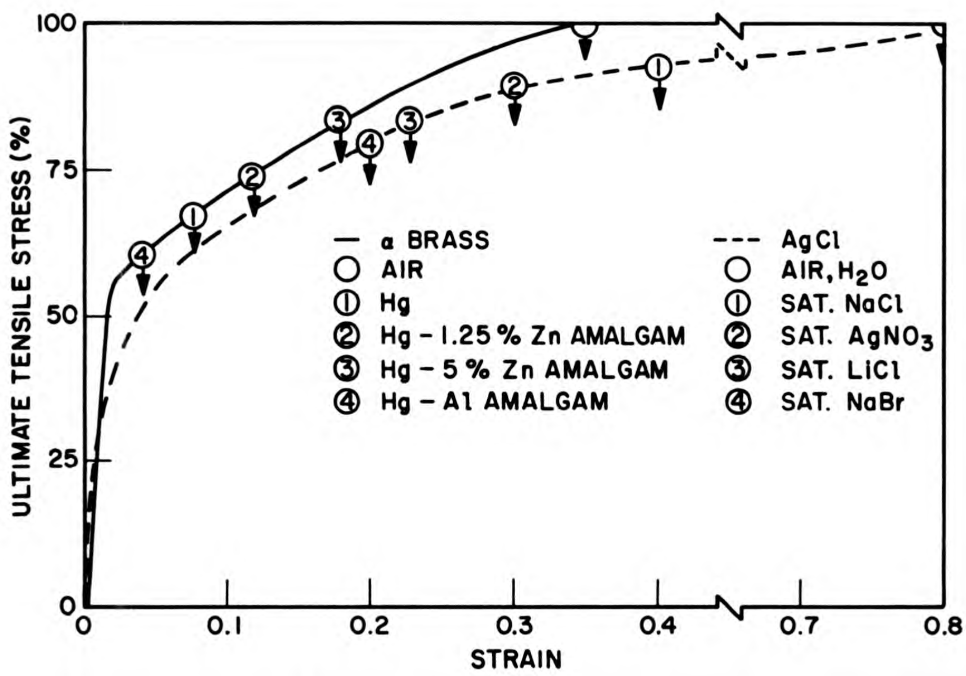


Figure 3 – Similarity of embrittlement of metals to embrittlement of salt crystals. Curves based on data from R. Rosenberg and I. Cadoff, *Fracture in Solids* (D. C. Drucker and J. J. Gilman, eds.), Interscience, New York (1963) and from E. Levine, N. Soloman, and I. Cadoff, *Acta Met.* **12**:1119 (1964).

*The stimulus for this program was given in large measure by Drs. Harold Liebowitz and Nicholas Perrone of the Structural Mechanics Branch, ONR.

fractures move into the elastic range. Figure 3 shows also how the fracture stress and elongation at fracture (indicated by arrows) change with environment. The reason for these specific chemical effects and the similarity in mechanical behavior in chemically diverse systems remains to be clarified. While there are similarities between salt embrittlement (so far found only in AgCl) and liquid metal embrittlement, it is well to point out from the data in Figure 3 that pure mercury is an embrittling solvent while water is not; the addition of solutes to the mercury may actually *decrease* the embrittlement while salt solutions may or may not embrittle. For convenience, salt embrittlement is treated here as liquid metal embrittlement, since both problems are amenable to the outline in Table 2.

The rationale of the effects of the salt solutions listed in Table 3 is puzzling at first glance but at present the thought is that the embrittling solutions favor highly charged complex ions of the type Ag_3Cl^{2+} or $AgCl_4^{3-}$. It is difficult to extend such concepts to metals. However, that the theory of electrolytic solutions should be so helpful in correlating fracture data is remarkable. There seems to be no other common factor to explain the specificity of the action.

Table 3 — Effect of aqueous solutions on mechanical behavior of AgCl crystals.

Embrittling Solutions	*Non-Embrittling Solutions*
0.1M $AgNO_3$*	H_2O
$AgClO_3$*†	NaOH†
AgF†	CsCl†
8M HCl	4M $MgCl_2$
$BaBr_2$†	6M NaCl (0.1M Hg^{++}, Cd^{++}, Zn^{++}, K^+ or Cs^+)
KCNS†	KNO_3†
$CuCl_x$ complexes in NaCl solutions	NaAcO†
3M NaCl	NH_4OH
2M NaBr	1M $BaCl_2$
1M NaI	
10M LiCl	
3M $Na_2S_2O_3$	
NaCNS†	
3M $CaCl_2$	

*Embrittling solutions are those that favor formation of $AgCl_4^{3-}$ complex ions in solution, except for $AgNO_3$ (and probably $AgClO_3$ and AgF), which favor formation of Ag_3Cl^{++}.

†Signifies a saturated solution. Experimentally, the embrittlement occurs more rapidly if the embrittling solution is also saturated with AgCl, presumably because $AgCl_3^-$ is immediately available.

Data from ONR reports by Westwood *et al* and Cadoff *et al.*

Table 4 — Common factors in environmental cracking.

Factors	*Cracking Modes*		
	Hydrogen Embrittlement	Liquid Metal Embrittlement	Stress Corrosion Cracking
Surface energy reduced in crack	X	X	X
Grain size dependence given by Petch-Stroh relation	X	X	X
Static fatigue (lower limit of stress for failure)	X	X	X (?)
Occurs in both alloys and pure metals	X	X	no
Materials fail in tension	(triaxial loading required)	X	X
Liquid or gas phase very specific	X	X	X
Metallurgical microstructure influences susceptibility	no (?)	X	X
Dependence on stacking fault energy	X	X (?)	X
Strain rate sensitivity	X	X	X
Grain boundary segregation required	no	no	X

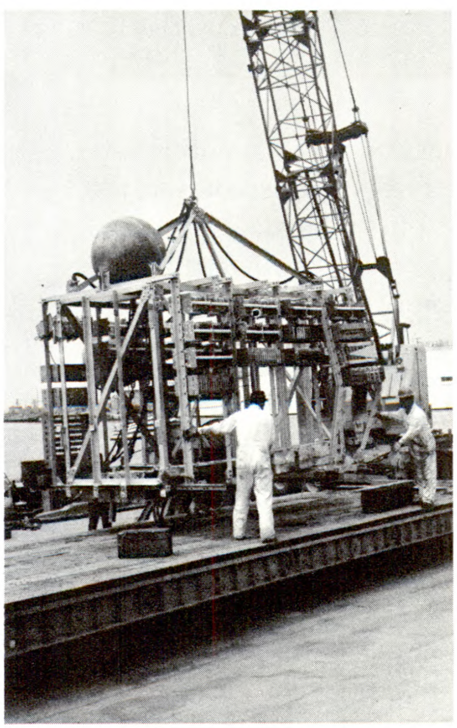
The behavior of the electrolyte is apparently a necessary, but not sufficient, condition for embrittlement. Susceptible grain boundaries are required (those in which a suitable degree of disorientation occurs where mechanical slip can be arrested), and it is quite possible that the highly polarizable ion Ag^+ is essential to the embrittlement. Its electron charge density should be quite sensitive to the environment. The even more polarizable salt AgI should prove to be a more interesting host.

Some of the other studies under way include transmission electron microscopy of the embrittlement of thin films *in situ* in the electron microscope. It is hoped that the high resolution available will shed more light on the basis for the brittle fracture and will enable investigators to establish the role of mechanical events on the atomic level, such as dislocation tangle and pile-up. Most of the materials susceptible to embrittlement by liquid metals normally are ductile and the dislocations are free to move. Somehow, the surface becomes an effective barrier, and dislocation motion is restricted.

The interpretation of all environmental cracking modes is in a state of flux, despite the continual attention given to it in recent years. The fact that the difficulties encountered in the study of liquid metal embrittlement (Table 2) resemble those encountered in the study of stress corrosion and hydrogen embrittlement tempts one to formulate a unified theory of surface-active fracture. The factors common to the three modes are shown in Table 4. One possible objection to this unified approach is that stress corrosion, as presently defined and understood, is concerned usually with electrochemical action and, in fact, can be modified drastically by changes in the electrical state of the metal. This objection may be too severe, and perhaps many of the traditional concepts will have to be ignored in getting to the root (literally and figuratively) of environmental cracking. Certainly the present theories cannot be taken as models for clear understanding.

However, time has brought about a general clarification of the relative factors involved in environmental cracking. It is quite probable that in each mode a different set of factors predominates. Further data of the type given in Table 4 are desirable. The pattern of interrelationships is a Rosetta stone awaiting a translator.

Construction Materials Tested at 6800-Foot Depth



Ocean-bottom sediments are more corrosive than the water above them, and titanium alloys do not deteriorate when submerged in the deep ocean: these two preliminary findings were made by the Naval Civil Engineering Laboratory, Port Hueneme, California, following the recovery of a 6710-pound submersible materials-test unit (STU) from a depth of approximately 6800 feet on the floor of the Pacific. This depth is the greatest at which an STU has been placed and recovered in the Laboratory's current deep-ocean program. The unit had been exposed for 13 months.

Additional findings indicate that some plastics are attacked by marine borers and that construction steels corrode less rapidly at great depth than on the surface.

Previously, submersible materials-test units were recovered from 2500- and 6000-foot levels after exposure periods of up to 35 months. The site of the studies is the Laboratory's deep-ocean test area 27 miles southwest of Santa Rosa Island in the Santa Barbara Channel group.

The recently recovered fourth unit carried an array of 1852 materials specimens, including welded and bolted metal panels and glass, woods, plastics, and fabrics. Some of the specimens on the 12-foot-square open-frame aluminum STU were submerged partly in ocean-floor sediments.

The NCEL tests are being conducted as part of a program aimed at developing construction and maintenance capabilities at all ocean depths. (See *Naval Research Reviews*, June 1965.)

STU 1-4 is returned to Port Hueneme after its recovery.

SPAD - An Experimental Satellite Position Prediction Display

Harvey G. Talmadge, Jr.
Robert J. Orsino
Data Processing Branch
Naval Research Laboratory

Shipboard personnel can compute and plot predicted satellite positions, but only by manual methods that involve considerable delay and tedious pencil-and-paper calculations. What has been needed for some time, as the satellite population continues to increase, is some type of equipment that will rapidly and accurately predict and display position and height of different classes of satellites at an arbitrary time, as well as determine when and where satellites tend to bunch or when a selected satellite would come within direct range of communication.

With Bureau of Ships support, scientists at the Naval Research Laboratory have designed a Satellite Position and Display (SPAD) equipment (Figure 1) that will generate and display such information electronically, in a matter of seconds, for as many as 10 satellites at one time.

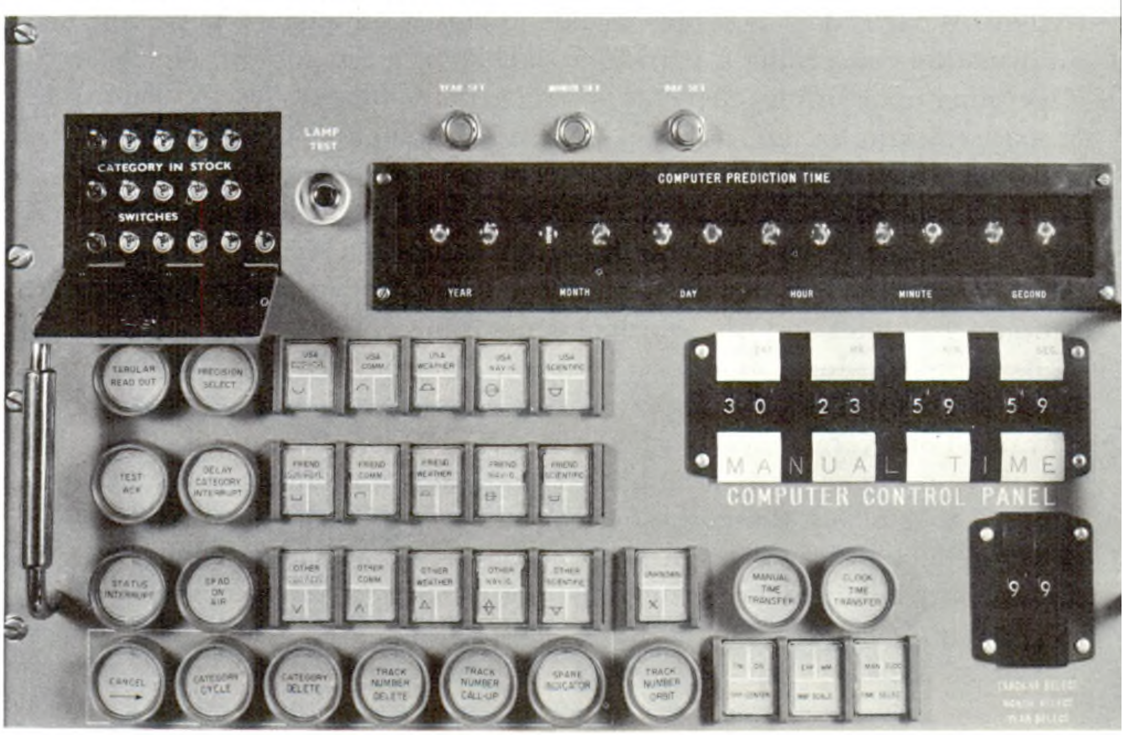
It should be pointed out at the beginning that SPAD is *not* a tracking system. What it does is simply make available to shipboard personnel information concerning a particular satellite or a category of satellites. Operating upon orbital elements and related information received from a space tracking facility, a model AN/UYK-1 computer selects up to 10 satellites, from a store containing information on 88 satellites, predicts their position and height, along with the position of the interested ship, and within one second displays this information on a rectangular world map (a modified Mercator projection) consisting of longitude and latitude grid lines and the principal geographic profiles.

By simply pushing buttons on the control panel (Figure 2), the SPAD operator can call to the display screen as many as 10 satellites from any or all of several different categories – for example, communications, weather, navigation, or scientific. These categories may be selected from U.S. satellites, those of other countries, or a combination of both. The satellites appear as bright dots on the screen, with identifying symbols beside them to denote category, track number (a computer memory address number), and height (up to 9900 miles).

Satellite positions can be shown in real time, or they can be changed at an accelerated rate, with time varying forward or backward, as

Figure 1 – Complete SPAD equipment as installed at the Naval Research Laboratory. The AN/UYK-1 computer (extreme right) feeds received data to the formatter (extreme left), which converts it to a form suitable for display. Tabular readout is at left of display console.

Figure 2 – Control panel of SPAD. The large number of buttons and switches is an indication of the system's versatility.



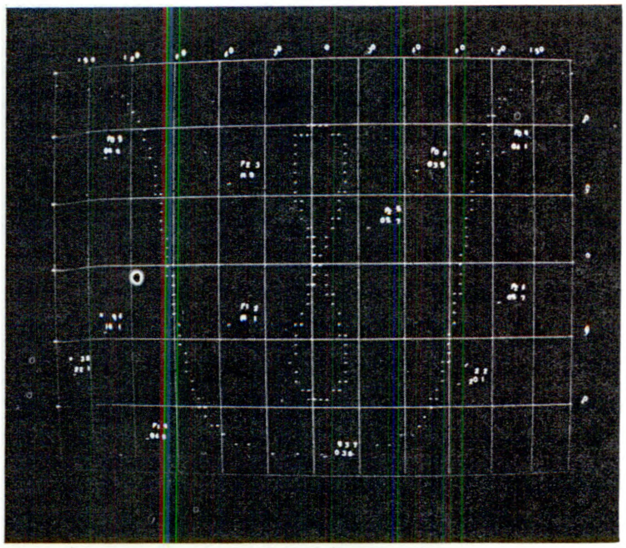


Figure 3 — Type of information available for viewing by the SPAD operator: a selected satellite on a conventional orbit of large inclination angle, interested ship, and ten other satellites selected by category. The figure-eight in the center represents the orbit of a synchronous satellite, although normally only one orbit is presented at one time.

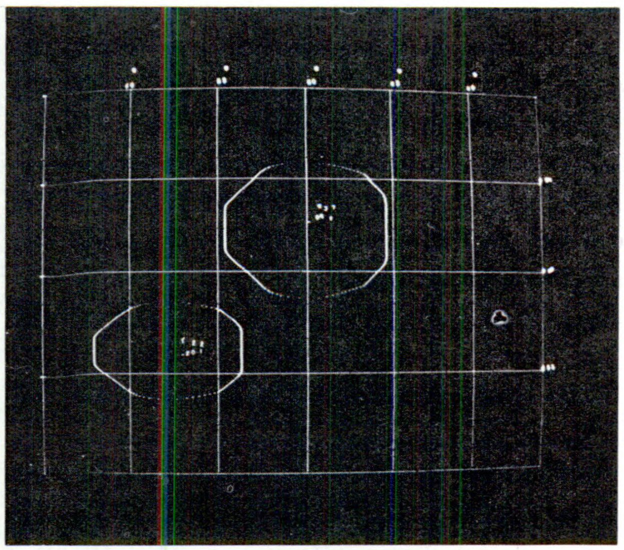


Figure 4 — Selected satellite and interested ship as they appear on 20° by 30° expanded display.

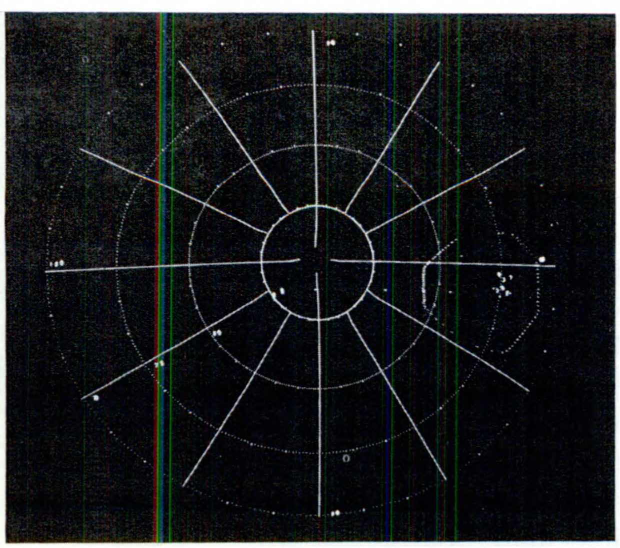


Figure 5 — Selected satellite as it appears on expanded polar display.

desired, so that the operator can tell, for example, where a certain satellite will be one minute, one hour, one day, or one month hence or where it was one minute, one hour, one day, or one month ago. Twelve lamps at the top of the control panel indicate the time—year, month, day, hour, minute, and second—in real time or at any other time of interest.

If the operator selects more than 10 satellites (say, for example, 16), only the first 10 called for will appear on the screen; the other six will "wait in line" until the operator pushes the category cycle button. Then the first group will be deleted, and the six "waiting" satellites will appear. The operator can delete or add a satellite, as desired, simply by feeding its track number to the computer. Speed of the AN/UYK-1 computer is such that SPAD operation is limited only by the operator's ability to request and assimilate displayed information.

A complete orbital path for a single satellite also can be generated (Figure 3). Or the same satellite, together with the position of the interested ship, can be viewed on an expanded display (Figure 4). In the expanded display, the selected satellite and/or the interested ship appear on an area 20° in latitude by 30° in longitude. A nearby vector dot denotes the satellite's position one minute previous. When the satellite moves to within 15° of either pole, the map projection automatically switches to an expanded polar display (Figure 5). Also, one can freeze the operation on the screen so as to study a satellite or a group of satellites at any desired moment.

Information from the tracking stations is received once weekly, which minimizes the time required of communication channels. Nevertheless, the operation can continue, with somewhat degraded accuracy, even if the weekly updating message is delayed.

Additional information, including a more accurate height reading, longitude and latitude accurate to 0.2°, height of satellite above the horizon, and pointing direction of the ship's antenna, is printed on a tabular readout after a delay of only 11 to 13.2 seconds.

As originally conceived at the Naval Research Laboratory, SPAD was to be an experimental equipment for use in determining what features would be desirable and feasible in a final version. Operation requirements for shipboard use are now being studied during an evaluation at NRL. The results have been so astounding that SPAD could become operational immediately, although there are still many refinements and increased capabilities that could be added. For instance, the AN/UYK-1 computer was selected because it is small, fast, already in Fleet use, and compatable with the Naval Tactical Data System. But the entire computer memory of 8192 words is used in storing the SPAD program and the data for only 88 satellites. A sister computer of greater memory and speed could provide SPAD prediction for many more satellites and at the same time meet other shipboard computer needs on an electronically time-shared basis.

The Improvement of Navy Life-Support Helmets

CAPT Roland A. Bosee, MSC, USN
Bureau of Naval Weapons
Bureau of Medicine and Surgery

Theodore J. Post
James F. Parker, Jr.
BioTechnology, Inc.
Arlington, Virginia

This article reviews recent efforts of the Navy to develop more effective life-support helmets for Naval aviators. A major advance toward meeting this objective was the holding of an invited symposium on the topic under the joint sponsorship of the Office of Naval Research and BioTechnology, Inc. The impetus for the symposium came from Dr. Gilbert C. Tolhurst, Head, Physiological Psychology Branch, Office of Naval Research, and CAPT W. L. Jones, MC, USN, Bureau of Naval Weapons and Bureau of Medicine and Surgery. The primary purpose of the meeting was to establish design parameters and to foresee problem areas before entering into the design of a new helmet.

The Bureau of Naval Weapons is presently implementing many of the recommendations of the symposium in a continuing effort to provide more effective life-support helmets for Naval aviators.

In November 1963, representatives of both military and civilian agencies concerned with helmet design and development attended a symposium in Washington, D.C., to consider the problems involved in developing improved helmets for aviators. Military representation included persons engaged in all phases of helmet development, including accident investigation; aviation medicine; research, design, and testing; and Fleet evaluation. Industry participation included persons concerned with research and development as well as with the testing and evaluation of protective helmets.

The basic objective of the symposium was to set up guidelines for a comprehensive program to improve life-support helmets. As a result of invited presentations and informal discussions, it was hoped to structure the knowledge and insights of the attendees into a central and meaningful source of information concerning the design of future integrated helmets.

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Design Requirements

The helmet is fundamentally a device designed to protect the pilot under adverse conditions, including ejection and aircraft crash. With the advent of jet aircraft, it was felt that the impact forces would be of such magnitude that the chances of survival would be virtually nil, regardless of the protective equipment worn. The development of the ejection seat seemed to eliminate this hazard. In theory, the need for impact protection was removed, or at least reduced, because in most instances the pilot would be gone at the time of the crash. We now have sufficient experience with the ejection seat to make some judgments as to how well this philosophy works in actual practice.

SUMMARY OF U.S. NAVY IMPACT ACCIDENT EXPERIENCE FOR PERIOD 1959-1963

ALL CATEGORIES (PROP, JET, HELICOPTER)

NUMBER	TYPE
4606	COLLISION WITH GROUND, PILOT IN AIRCRAFT
1586	COLLISION WITH WATER , PILOT IN AIRCRAFT
615	PILOT EJECTED
167	PILOT BAILED OUT

INSTANCES OF EJECTION OR BAILOUT = 11%

JET AIRCRAFT

NUMBER	TYPE
1572	COLLISION WITH GROUND, PILOT IN AIRCRAFT
285	COLLISION WITH WATER, PILOT IN AIRCRAFT
615	PILOT EJECTED
70	PILOT BAILED OUT

INSTANCES OF EJECTION OR BAILOUT = 27%

The table above presents a summary of Navy impact accidents for fiscal years 1959 through 1963. It is most surprising to note that for all categories of aircraft, only 11 percent of the aviators were able to leave the aircraft prior to impact. In the case of jet aircraft, only 27 percent of the aviators were able to leave before the crash. These statistics, of course, do not signify that the ejection is a poor or unjustified item of safety equipment. They mean simply that in a surprisingly large number of cases the aviator did not choose to, or could not, leave the aircraft. In addition, we have reason to believe that if better protective equipment had been worn, a number of the fatal jet crashes would have been survivable. This analysis indicates a very genuine rrequirement to provide an aviator's helmet with appropriate impact-protection qualities.

The provisioning of oxygen for a pilot is recognized as a singularly important function which the helmet must assist in meeting. The oxygen requirement brings with it many problems concerning weight, center of mass, and comfort. In addition, there is the matter of providing the oxygen. At present, oxygen is piped into the helmet and the expired gas spilled overboard. This arrangement creates a logistics problem for remote-area operation and operation from carriers. Rebreathing systems are being considered to solve this problem, but before they can be built into helmets, extensive engineering-design studies must be tested thoroughly.

Other functions which the helmet design must provide for are protection of the face from burns and protection of the face and eyes from wind blast and cockpit implosion. To a considerable degree, the design will be affected by the need for incorporating communications equipment into the helmet — not the communications equipment which is being used today but rather the improved and miniaturized components which are available currently and which could be provided. Finally, a relatively new requirement relates to protection from the excessive thermal radiation and visible energy from a nuclear detonation (see *Naval Research Reviews*, August 1965). Figure 1 shows an APH-5 helmet which has been modified to accommodate a special visor system designed for this purpose.

The foregoing discussion summarizes some of the more important functions of a life-support helmet. When establishing the means by which these functions are to be met, consideration must be given to several vital factors. Paramount among these is comfort. If the helmet

Figure 1 — An APH-5 helmet that has been modified to accommodate a visor designed to protect the wearer from intense visible radiation.

is not comfortable, pilots either will not wear it or will wear it improperly. Therefore, factors such as sizing, weight, ventilation, cooling, and stability play important roles in helmet design. Weight and center of mass also are very important. Under crash decelerations, helmet weight and head-helmet center of mass expose the wearer to the danger of "cervical stretch" and head displacement. Concussion and loss of consciousness can result.

Recommendations. The final session of the symposium was devoted to defining the specifications for an improved life-support helmet based on a consideration of the problem areas just discussed. For many functions, it was concluded that a definitive specification could not be prepared because of the limitations of our knowledge on those subjects. A simple statement to the effect that each of these functions was an area of concern to a design engineer was the most that could be done. The recommended specifications covered the areas of general characteristics of helmets, impact protection, vision, communications, oxygen systems, and comfort. A complete listing of these specifications can be found in the proceedings of the symposium.*

Navy Research and Development Program

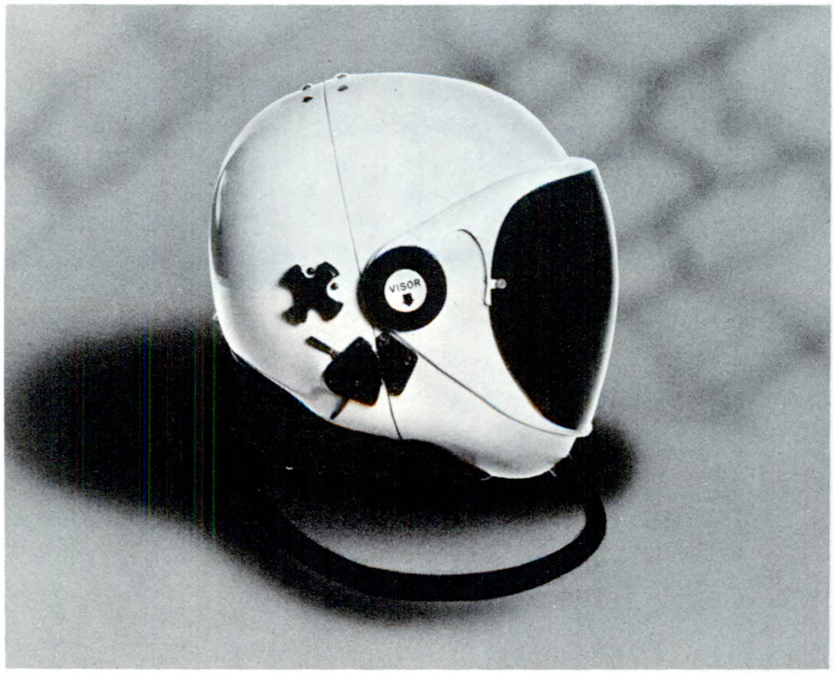
The Aerospace Crew Equipment Branch of the Bureau of Naval Weapons is continuing to conduct applied research directed toward the development of improved life-support helmets. For example, one of the symposium recommendations was that a family of helmets rather than one helmet for all classes of aircraft be developed. This recommendation is being implemented in the following manner:

Figure 2 shows the AOH helmet, which is a new design being considered for attack and fighter pilots. It presently is being procured in limited quantities for Fleet evaluation. One of its outstanding features is an internally mounted oxygen-breathing system with a full-face seal. This feature eliminates uncomfortable nose pressure which is present in an oral-nasal mask. The "clam shell" design enhances the helmet's retention qualities. The helmet has been tested successfully in a sled-run ejection of 568 knots, and it has been subjected successfully to windblast tests of 634 knots. Additional features include an integral visor-defogging capability and ducting for cooling purposes.

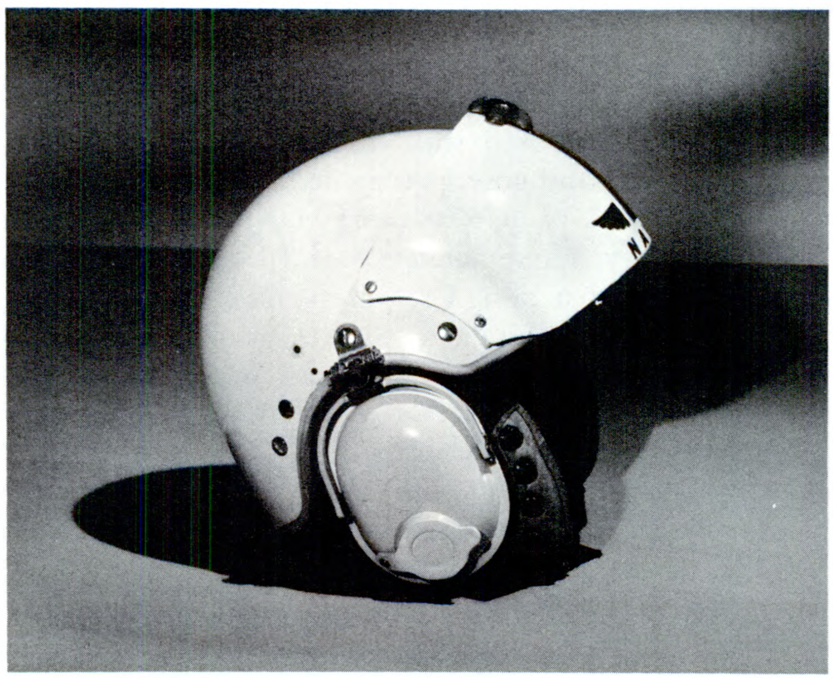
Figure 3 shows the BPH-2 helmet, which was designed for use by patrol-plane pilots. This helmet meets two unique requirements of patrol missions. First, the long duration of such missions requires that comfort be a paramount feature of the helmet. Therefore, the BPH

*"Effective Life Support Helmets." Proceedings of an invited symposium sponsored by the Office of Naval Research and BioTechnology, Inc., Washington, D.C., 31 October and 1 November 1963. BioTechnology Report 64-3.

ıre 2 — The AOH hel-
, designed for attack
fighter pilots.



ure 3 — The BPH-2
met, designed for pa-
-plane pilots.



helmet has a sling suspension to enhance fit and ventilation, and it has a minimum profile, to reduce weight and increase comfort for prolonged wear. Second, because normal conversation is necessary between patrol-plane crew members, the BPH helmet includes aural ports in the ear covering.

Figure 4 shows the SPH-2 helmet, which is used by helicopter crewmen, who require especially effective sound attenuation. This need

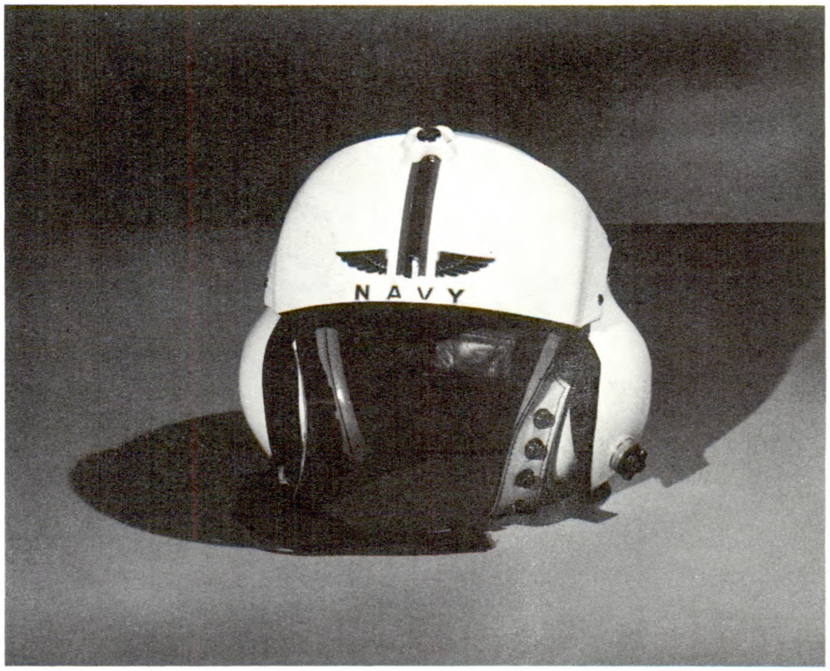


Figure 4 – The SP[illegible] helmet, designed for h[illegible] copter crewmen.

is met through the use of an inner foam liner and oversized earphone pads, which give the helmet a convex profile. To counteract the sizing difficulties inherent in a helmet that contains a liner, seven different liner sizes are used with three basic shell sizes. The result is seven helmet sizes and good percentile coverage.

This family of helmets represents the present procurement practices of the Navy. These helmets conform to proper design requirements to the extent that design requirements are presently understood. However, in some instances, the design requirement and its associated specification are only a best guess. In other cases, testing methods do not exist to verify whether or not the helmet conforms to a design requirement. To rectify this situation, the Bureau of Naval Weapons is sponsoring research to improve or develop new methods for designing and testing helmets. Some of the problem areas which this research is directed to are identified below.

A helmet's ability to resist displacement relative to the head is as important as its ability to attenuate impact. Displacement can occur during deceleration, when the head is "flung," resulting in a torque being applied to the helmet. Test methods are presently being developed to measure the stability characteristics of helmets under this condition.

Also being developed are test methods to determine the center of mass of the head when a helmet is worn. Center of mass is a factor in concussions caused by "cervical stretch" during crash decelerations. Little is known now concerning head-neck dynamics when the body is exposed to severe deceleration forces. Factual data on this subject are necessary in determining whether future helmets must incorporate head-helmet restraint systems. Therefore, the Navy is conducting preliminary studies of head-neck dynamics. The investigations are expected to lead to the development of a head-neck dummy which can be adjusted to yield the same head displacements as those of human subjects over the same deceleration time period.

A fourth study concerns helmet fit and its influence on comfort. Present helmet-sizing systems are based on an early anthropometric survey which appears to have been biased. Accordingly, the Navy, through the Aerospace Crew Equipment Laboratory, is surveying 1600 Naval aviators as a first step in developing a new sizing system.

Finally, the Bureau of Naval Weapons is sponsoring a continuing program to refine current helmet design specifications. The revised specifications will reflect the results of current research and the knowledge obtained from a systematic compilation and assessment of other information related to helmet design.

Outlook for the Future

The preceding discussion has highlighted the various Navy programs being carried out to provide more effective life-support helmets for aviation personnel. These programs have already resulted in the procurement of the family of helmets described earlier. The continuation of these efforts should result in improvements in the following three areas.

Test Methods. New testing techniques which yield objective measures of helmet characteristics are a major requirement. Of particular interest are methods which compare the effectiveness of two or more helmet designs regarding a single design characteristic.

Precise Specifications. Many current helmet requirements (comfort is one example) and their associated specifications are at present merely best guesses. A definitive and exhaustive set of design specifications is needed. These specifications must relate to the design of helmet communications and oxygen systems which will represent substantial improvements over those in use today.

New Helmets. It is anticipated that the development of precise specifications and test methods will result in the procurement of a new generation of life-support helmets for aviation personnel. These new helmets should represent an "order-of-magnitude" of improvement over current helmets.

Research Notes

Admiral Harold G. Bowen
First Chief of Naval Research

Admiral Harold G. Bowen, the first Chief of Naval Research, died on August 1 in Providence, Rhode Island – the city in which he was born 81 years ago.

The former Navy Engineer-in-Chief (1935-39), Director of the Naval Research Laboratory (1939-41), and Navy Secretary Forrestal's right hand for seizure and operation of vital industrial plants crippled by strikes or inexperience during the war, was a man who got things done. He was also a thinker – a man who found time to consider deeply fundamental Naval problems and to come up with realistic solutions.

One of these problems concerned patents. The Naval bureaus had had a history, in some important instances, of letting Navy inventions slip through their fingers into commerical hands. By the 'thirties the Department had a Patent Section, but it did not cover adequately the field activities. At NRL, Bowen set up a rigid patent-protection procedure and established a local patent office. He also took steps to remove the slight taint of "commercialism" that had formerly discouraged civil servants from obtaining patents.

While Admiral Bowen was Director of NRL, he thought a great deal about the need for a high command to coordinate and direct the total research effort of the Navy. He reiterated his idea whenever a person of influence would listen. Consequently, when the Office of Patents and Inventions was established in October 1944 – according to recommendations contained in the Dearborn Report (Mr. R. J. Dearborn, President of the Texaco Development Corporation and Chairman of the Committee on Patents of the National Association of Manufacturers, made a survey of the patent situation in the Navy at the request of Secretary Forrestal) – Admiral Bowen was ordered to take command. A thorough revamping of the Navy patent system and a multimillion dollar saving in royalty payments followed.

The recommendations of the Dearborn Report were extended further, on May 19, 1945, with the establishment of the Office of Research and Inventions. This new bureau-level office embraced not only the Office of Patents and Inventions, but the Secretary's old Office of Research and Development, the Naval Research Laboratory, and the Bureau of Aeronautics' Special Devices Center. A directive of February 1946 allowed ORI to assume coordination of Naval research contracts granted by the various bureaus. Admiral Bowen was the first Chief of the Office.

On August 1, 1946, in accordance with Public Law 588 of the 79th Congress, the Office of Naval Research was created to assume the functions of ORI. Its head became the Chief of Naval Research.

Admiral Bowen was a 1905 graduate of the Naval Academy, and he held a master's degree in mechanical engineering from Columbia University. He retired from the Navy in 1947.

Extinguishing Aircraft Crash Fires from the Air

A 15-year search for efficient materials and equipment that could be carried and applied by an air-sea rescue helicopter (the Seasprite) culminated recently when personnel of the Naval Research Laboratory successfully extinguished a mock-up airplane crash fire. The vehicle is to be used as a rapid means of getting a two-man rescue team to a crashed burning aircraft and extinguishing the fire so that aircraft personnel can be rescued. The Bureau of Naval Weapons is now completing design and installation requirements for providing Naval air stations with the system for crash-rescue operations in areas which are inaccessible to existing motor vehicle crash-rescue fire-fighting equipment.

The crash-rescue fire-fighting helicopter carries a pressurizes 60-gallon tank of the NRL-developed perfluorocarbon solution, called "light-water," which is pumped through a spray nozzle on the aircraft's starboard side. The chemical solution forms a special surface-active water film over gasoline, jet fuel, or any other flammable fuels so that they can't burn. The technique was developed by chemists and chemical engineers conducting fire research at the Naval Research Laboratory. It was tested and perfected at the Miramar Naval Air Station, California, in July of this year.

The Oceanographic Air Survey Unit

The first aircraft squadron organized specifically to conduct oceanographic research was established on July 1 at the Naval Oceanographic Office. The squadron, named The Oceanographic Air Survey Unit, consists of four C-121 super constellations and one C-54 Skymaster.

In 1953, the Oceanographic Office began using aircraft for its Project Magnet. These planes have logged over one-half million survey miles in support of a world-wide magnetic charting program. A super constellation has been employed since 1963 to gather surface temperatures and wave profiles for the Antisubmarine Warfare Environmental Prediction System (ASWEPS). Oceanographic planes have been used also for about four years in an intensive ice-research effort in the Central Arctic Basin.

Training Submarine Crews for Battle

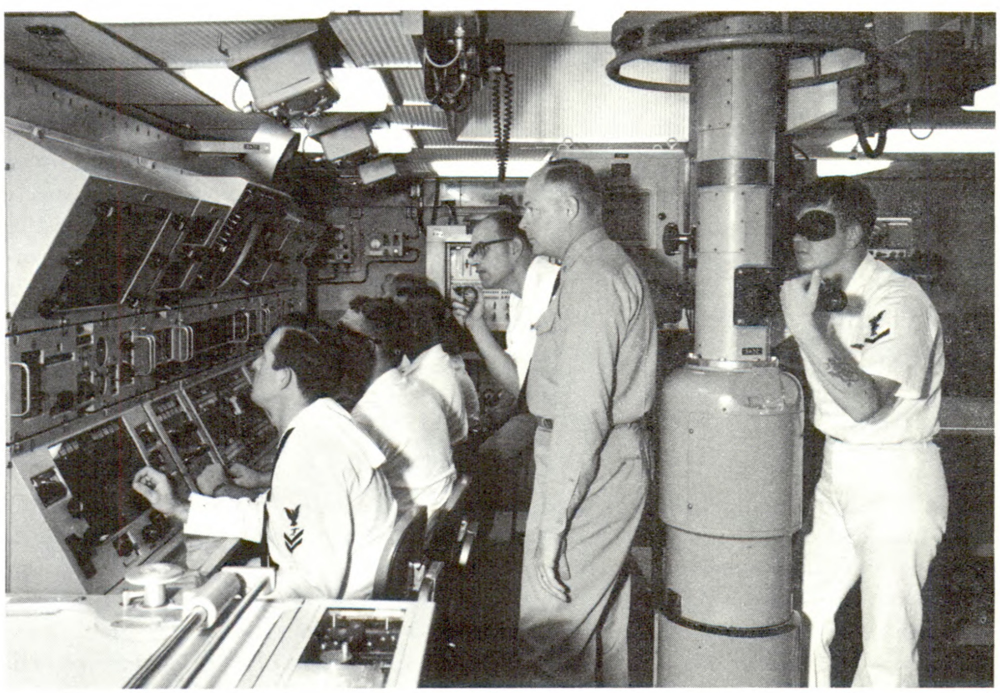
An electronically controlled simulator consisting primarily of three submarine attack centers, each a copy of a center aboard one of three classes of nuclear submarines, has been built by Honeywell, Inc., for the Naval Training Device Center. By means of the simulator, which has been set up at the Naval Submarine School, New London, Connecticut, future crews of U.S. nuclear submarines are now learning the intricacies of underwater warfare.

The "brains" of the device, a digital computer, makes possible the simulation of virtually all of the jobs performed by attack-center equipment, such as launching torpedoes, manning communications equipment, and tracking sonar and radar targets.

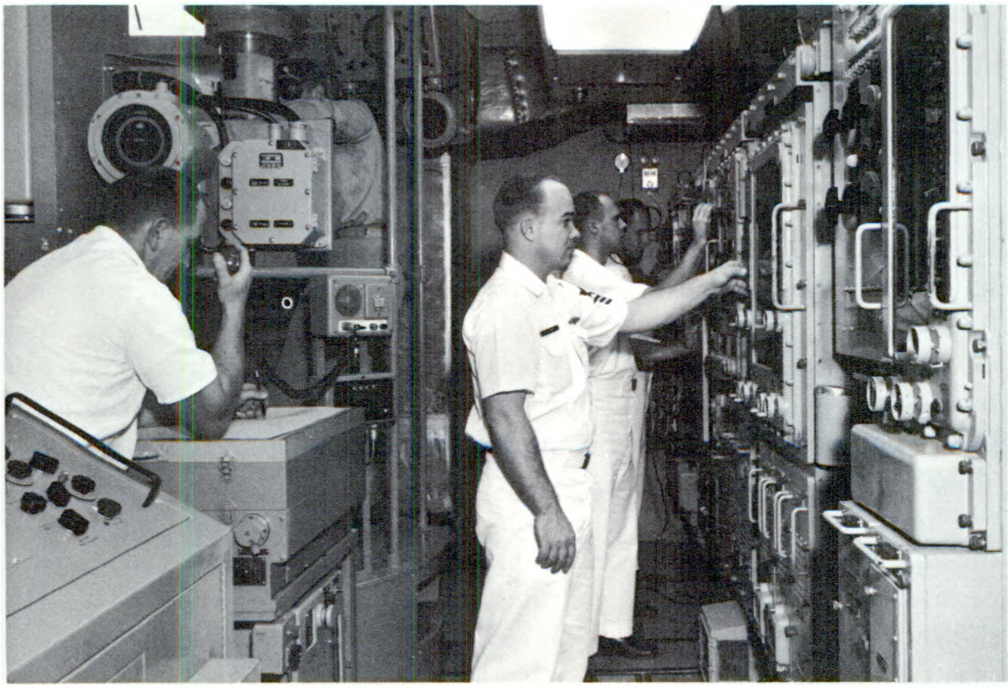
The "big picture" of the war games is controlled and observed in an auditorium-like room called "the tactical display room." From this room, officers can coordinate the overall action of the three attack centers. As many as 24 submarines, surface ships, and planes may be brought into the maneuvers when all three centers are participating in an exercise. Movements of the vehicles are recorded with colored tracks on a projection screen that represents the hundreds of square miles of ocean in which the battle is fought. The maneuvers may be conducted in real or compressed time.

The seating capacity of the tactical display room is 48 persons. At the back of the room is the control panel – the master instructor's console – where the general outlines of the problem are initiated for all three attack centers. In areas adjoining each attack center, instructors sit at similar panels, unseen by the trainees, and direct that center's part in the battle. Projection screens, similar to but smaller than the one in the tactical display room, unfold the story of the battle's progress.

Without the simulator, the only way adequate training could be given in complicated sea-battle operations would be under vastly more expensive operational conditions at sea.



Battle conditions prevail in submarine attack center number three of the attack-center trainer. Trainees operate fire control systems (left) and periscope (right). Fire control systems are among the operational equipment in the attack center, an exact duplicate of its counterpart on a real sub.



Fire control system is manned by trainees in attack center number two of the submarine trainer.

Control panels call the shots for realistic exercises going on in attack center number three (background) of the attack-center trainer. Console in left foreground is for the assistant program operator; the one at right is for the program operator. Display screen is at far right. During a training exercise, curtains are closed so that trainees can't see the consoles.

Inventions

Studying the Effects of Large-Scale Explosions in a Shock Tube

Studies of the effects of large-scale explosions by direct observation have been both expensive and dangerous to conduct. To circumvent these limitations, Mr. W. S. Filler of the Naval Ordnance Laboratory devised a shock-amplifying device that permits approximations to be made of large-scale effects from small-scale explosions. The patent for this invention, No. 3,184,955, entitled "Explosive Driven Conical Shock Tube," was issued on May 25, 1965.

The device consists of a rigid tube of frusto-conical configuration, at the apex of which provision is made for inserting and firing an explosive charge. Pressure-responsive transducers are located within the shell wall and within the conical cavity. They are connected by appropriate circuitry to timing devices and an oscilloscopic display.

The amplification factor of the device is related to the angle of the shock tube. For example, a 22-degree-angle tube provides an amplification factor of 62, which means that a .5-gram explosion in the tube produces an effect at a sensing device that is equivalent to that of a 31-gram blast in free air. A 2-degree-angle cone possesses a theoretical amplification factor of 10,000. Although in actual practice, the factor proves to be about 3000, corresponding to an efficiency of approximately 30 percent, the achievement appears to be quite spectacular.

Rapid Replenishment of Guided Missiles at Sea

The Fast Automatic Shuttle Transfer (FAST) is a mechanized replenishment-at-sea system for transferring guided missiles from a supply ship to the magazine of a combatant ship. Missiles such as TERRIER and TALOS come in two parts, *i.e.*, the missile and the booster, which have to be mated to form an integrated weapon and then placed in a magazine.

Previously all of this was done by hand and required from 15 minutes to better than half an hour for each missile. In an effort to overcome these manual and time-consuming steps, Bert M. Randall, of BuShips, invented the "Missile Handling and Mating System" (U.S. Patent No. 3,141,375). The system is designed to receive a missile or booster every 90 seconds during replenishment. It mates the missile and booster and delivers the mated round to ready-service stowage at the rate of one complete round every 6 minutes. Since there are two systems,

—Continued on back cover (inside)

On the Naval Research Reserve

Twelfth Annual Naval Reserve Research Seminar

The Twelfth Annual Naval Reserve Research Seminar was held at the Naval Research Laboratory in Washington, D.C., from June 7 through June 18, 1965. The seminar was sponsored by the Office of Naval Research and scheduled by NRL. NRRC 5-9, which is headquartered at the Laboratory, assisted with arrangements. LCDR Raymond R. Neill, USNR, and LCDR E. B. Bissett, USNR, both members of NRRC 5-9, served as seminar co-chairmen and assisted with tour schedules and other arrangements.

Fifty-four Reserve Officers from many of the States attended the program of lectures, presentations, demonstrations, and field trips, which covered a broad and varied program of scientific research and engineering studies of interest to the Navy. The highlight of the opening-day session was a stimulating and informative speech by RADM John K. Leydon, USN, Chief of Naval Research. He emphasized the rare opportunity afforded the attendees at this seminar in being introduced to NRL's wide range of scientific research programs, which are directed at the increasingly challenging technical problems that arise in developing a more effective and modern Navy. He described NRL as "a place in touch with the future" and as "one of the foremost physical research laboratories in the world." The decade ahead, he considered, will be a "new era in Government scientific research," in which selective judgment and skillful foresight will be in ever increasing demand in the direction of research programs.

Cordial welcoming remarks and interesting introductory comments on NRL's organization and broad research endeavors were provided by CAPT T. B. Owen, USN, Director of NRL.

On the first day of the seminar, NRRC 5-9 served as host at a luncheon that featured remarks by CAPT Owen and an up-to-date presentation on the Research Reserve Program by CAPT D. J. Mooney, Jr., USNR, Special Assistant to the Chief of Naval Research for Research Reserve. Luncheon speakers were introduced by CAPT L. A. DePue, USNR, chairman of the seminar and Commanding Officer of NRRC 5-9.

During the two-week seminar, informative and well-planned descriptions of various NRL scientific research programs were presented by all of the scientific and service divisions of NRL. Technical tours within the Laboratory were made to all of the major research facilities, including the Reactor, "Hot Cell," Van de Graff Accelerator, and Magnet Laboratory. Tours were made also through the shops of the Engineering Services Division, and a brief description of the NRL Technical

Library was provided. A one-day visit was made to NRL's Chesapeake Bay Annex, which is about an hour's trip from the Laboratory. There, descriptions were given of projects related to radio astronomy and signal research with the 150-foot parabolic dish antenna, large research antenna arrays, Combat Information Center, radar data processing, and target presentation. A trip to the Bureau of Naval Personnel was scheduled to permit out-of-town officers to review their personal file jackets.

The attendees, who came from varied walks of civilian life, but who, in general are technically and scientifically oriented in professional backgrounds or interests, were provided an educational opportunity of considerable value and a stimulating overview of the center of internal research programs for the Navy.

Fourteenth Annual Training Device Center Seminar

The Fourteenth Annual Research Reserve Training Device Center Seminar was conducted from May 24 to June 4, 1965, at the Naval Air Station, New York, by personnel from the Naval Training Device Center, Port Washington, New York, under the auspices of the Chief of Naval Research.

The reservists were welcomed by CAPT C. R. Pingrey, USNR, of the Naval Air Station, and CDR D. M. Phillips, USN, of the Naval Training Device Center.

Although the seminar was conducted by the NTDC, its content was not limited to discussions on training devices. As the theme developed, consideration was given to the political and economic problems which force this country to maintain strong Armed Forces; the types of forces that are necessary; the operational, equipment, and personnel problems we face in maintaining these forces; and the ways we are training our personnel to maintain and operate our complex equipment.

In addition to speakers from the Army, Air Force, and Navy, including representatives of the Chief of Naval Operations, Bureau of Naval Weapons, Bureau of Naval Personnel, Bureau of Medicine and Surgery, and Office of Naval Research, prominent guest speakers were Mr. George A. Beebe, Director, Institute for International Order, New York; Dr. Willey Ley, internationally known professor, author, and space-flight consultant; and Dr. Paul Conroy, Chief of Professional Training, U.S. Information Agency.

On June 3, a banquet was held at the Naval Air Station Officers' Club. The principal speaker was COL Bernt Balchen, USAF (Ret). COL Balchen, a Congressional Medal of Honor holder, is well known as the pilot for Amundsen, Byrd, and Ellsworth during their polar ex-

Reservists listen intently to Dr. Willey Ley during an informal discussion at the NTDC seminar.

plorations, and for the support he gave to the Norwegian underground resistance during World War II.

Also during the two-week period, field trips were taken to the United Nations building, NTDC, and the Grumman Aircraft Corporation.

CAPT D. J. Mooney, Jr., USNR, of the Office of Naval Research, brought the reservists up to date on the latest developments in the Naval Research Reserve Program.

Antisubmarine Warfare Seminar

The Sixth Annual First Naval District Research Reserve Seminar was held at the Naval War College, Newport, Rhode Island, July 18-30, 1965. The Antisubmarine Warfare Seminar was conducted by members of NRRC 1-1, Boston, under the chairmanship of CDR Merrill Callum, USNR, Commanding Officer of NRRC 1-1. Seventy-six Naval Reserve officers from the nine Naval Districts attended the seminar. Of those in attendance, 20 were past or present commanding officers of Naval Reserve Research companies.

The more than 50 speakers provided a broad, comprehensive review of the many different aspects of antisubmarine warfare. After welcoming remarks from VADM C. L. Melson, USN, President of the Naval War College, and from RADM W. B. Sieglaff, USN, Commandant of the First Naval District, RADM T. F. Caldwell, USN, Deputy Director, ASW Programs, presented the keynote speech. RADM D. W. Knoll, USN, Oceanographer of the Navy, described the submarine environment and its complexities.

CAPT T. Rudden, USN, outlined the role played by the new ASW Systems Office, directed by RADM C. A. Karaberis, USN. Other officers, including CDR Francis C. Fogarty, USN, Commanding Officer of the USS NAUTILUS, reported on current tactics for surface, airborne, and undersea units. Other speakers reviewed current ASW equipment, such as the SQS-26 sonar and the operational ASW torpedoes. The P3A aircraft system was described by CDR H. B. McCaulley, USN, Program Officer for ASW Patrol Aircraft, Bureau of Naval Weapons.

A major portion of the seminar was devoted to a review of current research projects. Work performed in the Office of the Chief of Naval Material for Development was described by CDR N. W. Gokey, III, USN, ASW Surface Warfare Officer; CDR C. L. Otti, USN, ASW Air Warfare Officer; and CDR S. Savage, USN, ASW Sub-Surface Warfare Officer. CAPT Ray and CDR Hawk, of the Bureau of Ships, discussed ship design and countermeasures. CDR F. H. Baugaman, USN, of the Naval Air Development Center, reviewed his A-NEW Project for improved airborne ASW equipment. Mr. D. A. Venn, of the Naval Research Laboratory, explained the work being done in his area to integrate the various electronic systems aboard ship and to develop standard modules for shipboard electronic equipment. Mr. A. Avery, Director of the Food Science and Engineering Division, USN, R&D

Present and past commanding officers of Naval Research Reserve companies assemble aboard the USS GAINARD (DE 706) during the Antisubmarine Warfare Seminar. Top row, left to right; CDR Merrill Callum, NRRC 1-1; CAPT A. R. Lyle, NRRC 8-9; CAPT J. H. Avery, NRRC 13-1; CDR Frank D. Hansing, NRRC 5-10; CAPT R. J. Bobber, NRRC 6-8; and CDR L. H. Roberts, NRRC 6-4. Bottom row, left to right: CDR Charles Davis, NRRC 1-1; LCDR H. C. Francke, NRRC 6-3; LCDR G. Abraham, NRRC 5-9; LCDR L. L. Kupferberg, NRRC 5-3; and CAPT A. S. Soltes, NRRC 1-1.

Facility, Naval Supply Center, Bayonne, New Jersey, described the pioneering work his division has performed in applying modern engineering techniques to the problems of food storage and preparation aboard submarines. Mr. R. V. Lewis, of the U.S. Navy Underwater Sound Laboratory, discussed the basic sonar research being conducted in the BRASS Program; and Mr. H. French, of the Navy Hydrographic Office, outlined the ASW Environment Prediction System being developed by that office.

CAPT David Marker, USNR, and CDR Eleanor Kehoe, USNR, of ONR Washington, discussed the latest official policy decisions relating to the ONR Reserve Program, officer retention, promotion, and other matters at one seminar session.

Field trips by the members of the seminar began with a visit to the Navy Electronic Warfare Simulator (NEWS) of the Naval War College, a $10 million facility that presents realistic simulation of tactical situations. Here, an antisubmarine attack by a hunter-killer group was demonstrated.

A second trip brought the seminar members to the Submarine Signal Division of the Raytheon Company, where recent developments in sonar were reviewed by the Raytheon staff. Seminar members toured the test facilities where the sonar development work is conducted.

A trip to the nearby Naval Underwater Ordnance Station offered the officers an opportunity to inspect the latest torpedoes and the test facilities used in their development.

A day aboard the USS GAINARD (DE 706) permitted the visitors to observe demonstrations at sea on a ship of the sort employed in ASW operations. The visit included a tour of all operating spaces. A day at the Woods Hole Oceanographic Insitution completed the scheduled field trips. Here, members of the WHOI staff reviewed such matters as sound paths in the sea, instrumentation, deep-diving research vessels, and peculiarities in the behavior of marine life which affect sonar performance.

The combination of the excellent Newport summer weather, the stimulating speakers and field trips, the excellent meals at the closed mess, the opportunity to initiate new friendships and renew old ones made this seminar a rewarding one for the attendees.

Inventions—Continued from page 24

one on each side of the ship, this could mean a saving of about 10 hours per total load, which would be of immeasurable value in getting a ship back on the line.

The invention can be used for any two-piece weapon installation if varied to suit the particular missile and ship configuration. To date it has been installed on four ships.

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IN THIS ISSUE

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EDITOR: Richard D. Olson

During a test run, a special chemical fire-quenching solution is sprayed on a burning aircraft to open a path so fire fighters can reach the pilot's compartment. The rescurers were lowered from the helicopter by a quick-descent device. Both the fire extinguishant and the technique were developed at the Naval Research Laboratory (see story on page 21).

NAVSO P-510