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UPGRADING MISSION CAPABILITY AND PERFORMANCE EFFECTIVENESS OF NAVAL SHIPS BY THE USE OF ACTIVE FIN STABILIZERS

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ACTIVE FIN STABILIZERS≡

INCREASED MISSION CAPABILITIES,

(6) Upgrading Mission Capability and Performance Effectiveness of Naval Ships by the Use of Active Fin Stabilizers,

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ABSTRACT

This paper discusses the overall upgrading of the operational capabilities and mission effectiveness of U.S. Navy Surface Combatant Ships by the use of active fin roll stabilization systems:

- explains that active fin roll stabilizer systems are presently the best available means for achieving roll stabilization;

- discusses in general the improved operational capabilities and mission effectiveness benefits to be derived from surface ship roll stabilization;

- discusses the apparent reasons for active fin stabilizers not being installed in recent U.S. Navy ships by addressing

  (a) deficiencies in existing installations of fin stabilizer systems and how these deficiencies are being corrected in existing systems and can be avoided in future designs; and

  (b) inability to quantify all of the benefits of active fin stabilizers;

- summarizes, for one of the few shipboard operations that can presently be quantitatively assessed, performance improvement predictions for various sizes of surface combatant ships equipped with fin stabilizers;

- describes the impact associated with installing active fin stabilizer systems on a specific ship; and

- concludes that the installation of active fin stabilizers will significantly increase the mission capabilities of U.S. Navy ships and that immediate action should be taken to more consistently exploit the unique benefits of fin stabilizers.

I. INTRODUCTION

The ultimate criterion for evaluating the hull form design of a ship should be the performance of the ship in realistic seaways. For a ship of specified displacement and length, underwater form basically determines the important absolute motion characteristics involving pitch, heave, and roll; and the above water bow design (freeboard, flare, etc.) determines the equally important relative motion characteristics involving the frequency of occurrence and severity of "green water" over the deck (or deck wetness). Consistent with the demands of a variety of other hydrodynamic performance factors and design constraints such as hull resistance and powering requirements, maneuvering and course stability, intact and damaged stability characteristics, ship arrangements, etc., the designer attempts to minimize, insofar as he is able, deck wetness and the ship's tendency to keel slamming; but these factors in combination with the reliable and effective stabilization of roll motion, essentially determine the seakeeping qualities of a fighting ship!

The importance of seakeeping performance to the mission effectiveness of naval combatant ships, particularly those of the U.S. Navy, is clearly demonstrated by the following short excerpt from a recent address by Vice Admiral R. E. Adamson, Jr., USN (COMNAVSURFLANT) (1) to the NAVSEA Seakeeping Workshop held in June 1975 at the U.S. Naval Academy:

"NOW LET ME GIVE YOU A RECENT EXAMPLE OF HOW 'SEAKEEPING' ABILITY HAS AFFECTED OUR SHIPS. ON A FLEET EXERCISE CONDUCTED SEVERAL MONTHS AGO, OUR SHIPS WERE SIMPLY NO MATCH AGAINST THE SEA AND WINDS FOR WHICH THE NORTH ATLANTIC IS NOTORIOUS. OUR COMMANDERS AND COMMANDING OFFICERS WERE FORCED TO FOREGO MANY OF THE OBJECTIVES OF THE EXERCISE IN ORDER TO ACCOMMODATE TO THE WEATHER. IN SOME CASES:

- o OUR SHIPS WERE FORCED TO SLOW TO PREVENT OR LESSEN THE IMPACT OF DAMAGE,
- o EXERCISES WERE CANCELLED,
- o WE COULD NOT REFUEL OUR SHIPS,
- o EQUIPMENT WAS DAMAGED AND,
- o PERSONNEL WERE INJURED.

HOWEVER, SEVERAL SOVIET WARSHIPS WHICH WERE IN COMPANY AS OBSERVERS DID NOT APPEAR TO SUFFER THE SAME DEGREE OF DEGRADATION WE DID. THEY STEAMED SMARTLY AHEAD AND APPARENTLY WITHOUT DIFFICULTY."

Kehoe (2) effectively illustrates, in a milestone ASNE paper, that the practice of fitting active fin roll stabilizers along with adequately designed ship bows on many destroyers of the Soviet and NATO fleets is the reason that they are able to maintain speed and continue operations in a seaway when nearby U.S. destroyers are forced to reduce speed and cancel certain operations. As shown in Tables 1 and 2 (which have been updated from those shown in Kehoe's ASNE paper (2)), Kehoe also points out that only three classes of U.S. destroyer type ships commissioned or launched since 1954 are equipped with active fin roll stabilizer systems, while all such Soviet ships are equipped with them. In addition to the Soviet Navy, the British Navy as well as other NATO Navies also follow a standard practice of fitting active fin roll stabilizers to all their ships, other than those specifically designed for low and zero speed missions, i.e., coastal and ocean survey ships, minesweepers, etc.

The inferior seakeeping performance of U.S. Navy ships is not a new issue. It is understood that U.S. Navy destroyer type ships in the Mediterranean have also encountered the same alarming experiences as those in the North Atlantic. Consequently, a number of investigations have been initiated over the past few years to determine corrective actions to improve the seakeeping performance of U.S. Navy ships. One of these investigations was NAVSEC's Comparative Naval Architecture work, which lead to Kehoe's ASNE paper (2). These investigations eventually resulted in NAVSEA conducting the aforementioned Seakeeping Workshop, which was attended by ship designers, researchers, and fleet operators, in order to develop a Seakeeping R&D Program Plan. In the Report of the Seakeeping Workshop (1), it was again concluded that ships of the U.S. Navy too often experience a significant loss in mission performance capability (aircraft landing, handling and maintenance; weapons handling and firing; sonar and sensor operation; underway replenishment; etc.,) due to speed degradation, deck wetness, slamming and rolling in a seaway of even moderate severity. It was believed by all participants that major improvements can be made if immediate actions are taken to implement the numerous recommendations presented in the Workshop Report (1). Two of these important recommendations are as follows:

"<u>Recommendation 1</u> - Require active fin roll stabilization on all future combatants of cruiser size and smaller.

<u>Recommendation 4</u> - Improve reliability of present day active fin roll stabilization systems."

These recommendations have been highly endorsed by COMNAVSURFLANT;

and the importance of fin stabilizers to the mission effectiveness of foreign navies has again been highlighted as a result of NAVSEC's recent studies of the Soviet's *KIEV*. These studies indicate that this 35,000 ton V/STOL cruiser is equipped with active fin stabilizers. Consequently, it is strongly believed that installation of fin stabilizers would be a significant step toward upgrading the mission effectiveness of U.S. Navy ships; thus, the purpose of this paper is to clearly present the technical rationale which conclusively supports this position.

II. TYPES OF ROLL STABILIZERS

Although there are many means (active tanks, passive tanks, bilge keels, gyroscopic stabilization, etc.) by which reduction of roll motions may be achieved, active fin stabilizer systems are the "best" method for higher speed combatant type ships in terms of a combination of effectiveness, cost, ship impact, practicality and simplicity of operation. This is not to say that there are no difficulties connected with fin stabilizers; for with any electrical-mechanical system, there are reliability, maintainability and availability requirements that must be satisfied. On balance, however, such systems offer the best means of achieving necessary roll reduction for higher speed ships.

Active Fin Roll Stabilizers

The reduction of a ship's rolling motion by the use of active fin stabilizers is a known fact. The amount of roll reduction that can be expected by using fins is a function of a given ship's size, number and size of fins, design of fin controller, ship speed, heading, and the existing sea conditions. For properly designed systems, and with a ship speed of approximately 12 knots or greater, roll reductions from about 50 to 95 percent can be expected at most headings in various seaways. Fins are less effective at low ship speeds because flow over the fin is required to generate the hydrodynamic forces which counteract and thereby reduce the ship's roll motions. The faster the flow over the fin, the larger the force which can be generated, i.e., in general as the ship's speed increases, the fin stabilizers become more effective.

Other Means of Roll Stabilization

Some other methods of roll reduction are discussed below, with indications as to why they are considered inferior to fin stabilizers, for use in combatant ships.

. Bilge keels are the most cost-effective system insofar as roll reduction is concerned, but since it is the Navy's practice that they be installed on all combatant ships, and the fact that they are less effective at high speeds, bilge keels will be ignored for the purpose of this paper.

. Active anti-roll tanks are conceptually desirable, since they do not depend upon ship speed to develop anti-roll moments, and are thus capable of low-speed roll reduction. However, the cost and ship impact of a good system are quite excessive. Also, active tanks are not as effective in roll reduction as active fins at speeds greater than 15 knots. Large tanks and a high capacity transfer system, necessary for an effective system, are expensive in terms of direct cost and ship impact. Furthermore, a complicated control system is required, or the anti-roll system may actually be de-stabilizing (i.e., increasing the ship's roll motions) under certain conditions.

. Passive anti-roll tanks have the disadvantage of active tanks, in terms of space required for the tanks. (It is emphasized that surface combatant ships are space limited.) In addition, they are not normally as effective in roll reduction as active tanks. The main advantage they have over active tanks is the lack of an expensive transfer system and the sophisticated control system (i.e., the "active" part). References (3), (4), and (5) provide an excellent technical description of the design of passive anti-roll tanks when low speed roll stabilization is a critical requirement.

. System of moving weights has sometimes been used or considered for use in reducing roll (6). However, ship impact is large; the systems tend to be complicated and mechanically unreliable; and their effectiveness is limited primarily to small craft.

. Roll stabilization by use of the rudder may be effective under certain conditions. However, the feasibility of this concept has only recently been established (7) and the hardware implications of the rudder and steering gear system have not been determined. Also, this system is not as effective in reducing rolling motions as active fin stabilizers, and is being investigated primarily as an alternative roll stabilization system for existing ships which do not presently have active fin stabilizers.

. Paravane stabilizers (otherwise known as "flopper-stoppers")are large, fin-shaped devices towed under water by means of cables supported by truss-type booms extended from each side of the ship. These stabilizers have been used on fishing traulers and other small craft, and are currently being evaluated by NAVSEC for potential installation on small, special purpose, auxiliary type ships (such as the T-AGOS). Obviously, paravane stabilizers are not suited for high speed combatants, but are primarily intended for very low speed stabilization of small ships and craft.

III. JUSTIFICATION FOR ROLL STABILIZATION

Regarding the need for and the benefits to be derived from roll stabilization, analytical predictions and test results constitute a primary means for quantification. However, equally, if not more, important is the favorable view of the operators in the Fleet. Even though this view may be based principally on judgment, it is significantly influenced by the operators' actual at-sea experience. Selected samples of views from the Fleet are, therefore, compiled in this section in order to substantiate the strong support of the Fleet for roll stabilization.

Need for Active Fin Roll Stabilizers

The need for improved seakeeping performance of U.S. Navy surface combatants is well documented. References (1) and (2) note the inferior seakeeping performance of U.S. Navy surface ships, particularly destroyer seakeeping, when compared with the seakeeping performance of equivalent Soviet ships. One paragraph from reference (2) will serve to illustrate this situation:

> "One former Carrier Division Commander voiced his concern that his destroyers appeared to be more restricted in course and speed than Soviet destroyers...He observed that (in beam seas) his destroyers appeared to roll considerably more than trailing Soviet destroyers...when he altered course...so as to reduce excessive rolling, he then had to consider reducing speed because of reports from his destroyers of frequent slamming and heavy deck wetness. Simultaneously, he oberved that trailing Soviet destroyers appeared to be riding well and were fairly dry."

Of all the various aspects of surface ship seakeeping performance, rolling motion is the most critical to the operational effectiveness of surface combatant ships. This statement is supported by the practical experience of ship operators. For example, CAPT James W. Kehoe, USN, Special Assistant for Intelligence at NAVSEC, after interviewing many ship operators in 1973, noted:

> "Shipboard experience represented by the Commanding Officers interviewed included all currently operational destroyer designs, from the World War II DD 692 SUMNER Class to the most recent DE 1052 KNOX Class construction with anti-roll fin stabilizers......It was the unanimous opinion of these operators that rolling motions are their most frequent source of tactical, material and personnel limitations."

Although roll motion has the most degrading effect on the operational effectiveness of surface ships, it is the one ship motion (compared to other ship motions such as heave and pitch) which can be significantly reduced. To underline the merits of active fin roll stabilizers, CAPT Kehoe, in his report of the above mentioned interivews recommended that an attempt be made

> "to get the Navy's senior ship acquisition decision makers, who have not operated at sea on a DE 1040 or DE 1052 Class ship, aboard one of these ships during rough weather to experence and judge for themselves the reality and merit of the benefits attributed to fin stabilization."

Benefits from Installing Active Fin Roll Stabilizers

Some of the specific shipboard functions/operations which contribute to surface ship system effectiveness and which are degraded by excessive roll motions are discussed in the following paragraphs. Obviously, the benefits to be derived from roll stabilization are directly related to the degree of roll reduction.

a. Improved Aircraft Operations. Roll motions limit the operation of aircraft from surface ships in high sea states. This is particularly critical for helicopters operating from small air-capable escorts (destroyers and frigates). In fact, COMCRUDESLANT stated that roll stabilization is "an operational necessity to support LAMPS launch and recovery during coordinated anti-submarine warfare operations." Even when the ship is not operating in sea states which totally prevent aircraft operations, roll motions may restrict speed and course flexibility, requiring the ship to head into the sea to allow aircraft to be safely employed.

b. Improved UNREP Capability. The same speed and course flexibility benefits, applying to aircraft operations, also apply to (connected) underway replenishment operations and VERTREP. The safety and extent of UNREP operations also increase as roll motion is reduced.

c. Improved Weapon/Sensor Performance. Although all modern weapon systems are stabilized to account for ship motions, some improvement in weapon and sensor performance can be expected through reduced roll, as a result of improved accuracy. If the inputs to the weapon stabilization systems (i.e., the ship motions) are reduced, it is clear that the error remaining after stabilization will also be reduced. In some cases, the improvement may be major. For instance, reports from Commanding Officers state that "optical target acquisition is improved at least 25%" with the use of roll stabilizers.

d. Reduced Wear on Equipment. Roll motions impose significant stresses on all kinds of shipboard equipment, particularly rotating machinery. These fluctuating loads result in increased wear for rotating parts and bearings, requiring more frequent maintenance and replacement than is necessary under static conditions. Consequently, reduced roll motions can extend the maintenance schedule for such equipment, resulting in cost savings and as easing of the maintenance load imposed upon the ship's crew.

e. Increases Speed in Waves. For most U.S. Navy ships up to and including cruisers, the maximum speed attainable in high sea states is limited by the motions of the ship, rather than by the power available from the propulsion system. Except for head and astern sea conditions, the limiting motion is generally roll. Consequently, reduction in roll motions should allow the ship to maintain higher speeds. To quote from the Commanding Officer of the USS SCHOFIELD (DEG 3), in a letter to COMCRUDESPAC of 15 October 1969: "The (roll) stabilizers have enabled SCHOFIELD to run in rough seas at speeds much higher than non-stabilized ships".

f. Improved Crew Performance. The effectiveness of personnel in performing all manner of shipboard activities is significantly degraded in environments imposing large roll motions on the ship. Figure 1, as presented in reference (8), shows qualitatively the effect of rolling on average personnel capabilities. The steep drop in personnel effectiveness in the range 5^o - 15^o roll angles is particularly noteworthy, since ships with roll stabilization can usually limit rolling to within 5^o over a wide range of speeds and headings up to a sea state 7 (significant wave height of 30.6 feet). The improvement in crew effectiveness from roll reduction appears in a number of separate forms: reduced fatigue, since sleep is easier and less energy is expended maintaining the body in an upright position; improved morale, arising partly from reduced fatique; improved performance in a number of functions, such as watch standing and maintenance is significantly reduced. Thus, underway maintenance is drastically improved, both because more time is available to perform this function, and because the crew can perform it more effectively. Although the benefits have never been quantified (since maintenance data are not recorded in a manner to allow quantification with respect to ship motions), feedback from the Fleet indicates significant improvements with reduced roll motions.

g. Increased Crew Safety. For obvious reasons, the safety of the crew is degraded in high-motion environments. Consequently, reduction in roll motions improves crew safety. A quote from reference (2) will serve to clarify the improvements related to human factors which are attributable to roll reduction:

> "(Increased effectiveness in the) general safety and welfare of the crew (is) immeasurable.....From 12 to 20 knots, the increase in safety and comfort is incalculable. Stability of the platform upon which the ship's company is working has

unquestionably reduced personnel hazards. At the same time, the amount of physical effort devoted purely to hanging on while performing maintenance or standing watches has been reduced. Obviously, effectiveness has increased."

IV. APPARENT REASONS FOR NOT INSTALLING FIN STABILIZERS

If it is obvious to many operators and ship designers that active fin stabilizers will significantly increase the mission effectiveness of surface combatant ships, then what are the reasons that they have not been installed to the same degree as in foreign warships? The apparent reasons range from the political - economic reasons of increased ship acquisition costs and shipbuilding schedule delays to the more technical-related reasons of concern about the reliability and maintainability problems with existing installations and of the inability to quantify all benefits. An analysis of the apparent political-economic reasons is outisde the scope of this paper. However, the following explanation of the apparent technical-related reasons should conclusively show that these potential problems can be avoided in future fin stabilizer designs, and further delays in installing fin stabilizers are not justified solely on the basis of these apparent reasons.

Maintenance Problems with Existing Installations

Fin stabilizers are not new to the U.S. Navy. To date, a total of six different stabilizer designs from three independent stabilizer vendors have been installed in various frigates.

All of these systems have exhibited serious reliability and maintainability problems, which are discussed below. The naval engineering community is well aware of the causes of these problems, and efforts are underway to correct them. Yet, despite the difficulties which have been encountered with these older systems, the critical need for fin stabilizers still remains. Furthermore, the ability to design a reliable and cost-effective fin stabilizer system is well within the present state-of-the-art. The maintenance problems with existing installations have definite known causes; and these problems can be corrected, in the case of existing installations, or avoided, in the case of new systems. They are by no means inherent to fin stabilizers, or to the U.S. Navy.

The problems with existing installations are largely a result of design deficiencies; inadequate personnel training; obsolescence of components; poor logistics support; and lack of technical manuals. In some cases, the stabilizer systems were located in a poor environment, with high humidity hindering maintenance efforts. As a result of these various problems, the systems have suffered from various deficiencies, including:

- excessive hull seal leakage
- no access to seals without drydocking
- erratic operation of the fin controller
- excessive leakage from hydraulic rams
- inoperative lube oil coolers
- malfunctioning servo systems

As a result of these deficiencies, questions nave been raised as to the desirability of continuing to use fin stabilizers. Even when the desirability of the fins was not questioned, the problems with existing systems have forced some ships to use them only for special operations in high sea states, and otherwise, to "save" them.

To solve the various problems which have afflicted the different stabilizer installations, a comprehensive improvement program is underway. This program covers operator training, technical documentation, short-term repairs, major modifications, and logistics support. Most of the problems are gradually coming under control. For instance, to improve operator training, a Naval facility training school has been established at Great Lakes, Illinois. Seal leakage, which accounted for about one-third of the Casualty Reports, has been brought under control through a ShipAlt; and no ship has shown up a second time with this problem after the new seal was installed. New maintenance procedures and much improved technical documentation support have also been provided to operators.

The basic problems with the control and hydraulic systems have been more design-ralated, and less susceptible to simple corrective measures. However, to overcome these problems, two major stabilizer component modifications have been developed. One is a new modular solid state control package that, with minor variations, can be used on all the stabilizers. The other is a new hydraulic power package that use current production components and will be more tolerant of the shipboard environment. Both of these replacement packages are indended for installation on USS GLOVER (AGFF 1). When these modifications have been evaluated on GLOVER, and are known to be satisfactory, alterations will be issued to equip all frigates with the new controls and power packages.

Hence, although existing fin stabilizer systems have yielded significant mission performance improvements, they have also brought with them many problems. However, these problems are not inherent in the system. Many have already been corrected, and more will be corrected soon. Furthermore, these problems can be avoided in future systems by learning from past mistakes, by avoiding known design deficiencies, by centrally procuring new systems to definitive specifications and drawings developed by the Navy's engineers who are most knowledgeable of these problems, and by a thorough program of testing and evaluating prototype components/systems prior to introduction into the Fleet. Hence, there is a high degree of confidence in the effectiveness, reliability and maintainability of future U.S. Navy fin stabilizer systems provided the Navy is willing to procure these new systems to definite technical requirements based on the knowledge gained by the Navy in resolving the deficiencies of existing installations.

Inability to Quantify All Benefits

The many benefits of fin stabilizers are extremely difficult to quantify. In order to quantify each benefit described in the previous section, the cognizant equipment or subsystem designer must first determine the maximum allowable performance degradation due to roll motions for his shipboard function/operation. Given the degree of performance degradation and the ship's roll response, the maximum allowable performance degradation can then be translated into a maximum allowable roll response. Such a requirement then provides the basis for the ship designer to rationally decide, in the context of overall mission requirements, on hull proportions and the need for, and amount of, roll stabilization. However, only full-scale testing will provide a conclusive basis for validation and ultimate establishment of these performance degradations. In the next section, this approach is applied to quantifying the benefits of fin stabilizers for one shipboard operation for which such performance degradations have been obtained by full-scale testing.

V. EXAMPLES OF FIN STABILIZER PERFORMANCE PREDICTIONS

"Obviously, effectiveness has increased." - but increased by how much?

Considerable efforts have been made over the past few years to answer this paramount question, but to date only partial answers have been developed for a few shipboard functions/operations. The lack of a complete answer (addressing all roll motion sensitive shipboard functions/operations) for total ship system effectiveness is one of the primary reasons that fin stabilizers have not been installed in U.S. Navy ships.

Although most of the benefits to be derived from fin stabilizers can only be addressed qualitatively, some quantitative predictions of the performance improvements attributable to fin stabilizers can be developed. A few examples of these are presented in this section in order to give an indication of the order-of-magnitude of performance improvement for at lease one shipboard function/operation which can be expected from fin stabilizers for various sizes of surface combatant ships.

SEAKEEPING OPERATIONAL REQUIREMENTS

The techniques used to assess fin stabilizer effectiveness require that careful thought be given to specifying ship operational requirements in order to ensure that the desired mission capabilities are provided. The ship operational requirements must be stated in the following terms:

- Geographical Area(s) (e.g. North Atlantic, Worldwide, etc.) in which ship will be operating.
- Sea States or Wave Heights in which certain operations must be conducted.
- Ship Speeds and Headings at which certain operations must be performed.
- Percentage of Time (or operating profile) that ship must operate under the above conditions.

As shown in Table 3, seakeeping performance requirements specified in the Top Level Requirements (TLR) documents for recent ship designs have not clearly stated all of the conditions listed above, and some requirements, such as "Continuous Efficient Operation", are vague and ambiguous. The lack of definitive requirements has necessitated many interpretations by the ship designer and has resulted in the development of a seakeeping performance assessment technique that presents to decision-makers, in a meaningful manner, performance improvements due to design trade-offs such as a stabilized hull versus an unstabilized hull.

OPERATIONAL MOTION LIMITATIONS

An important shipboard operation which is severely limited by a ship's rolling motions is the handling, launching, and recovering of helicopters. Also, there are definitive Top Level Requirements for helicopter operations, as shown in Table 3, which must be met by the ship designer. Figure 2 is a typical plot which has been used to assess helicopter operational performance as a function of ship motions. This plot is based on extensive full-scale helicopter operations aboard the Interim Sea Control Ship (USS GUAM) and smaller aircapable ships (9), and numerous discussions with the Naval Air Development Center (NADC). Although the variation of helicopter operational performance with ship motion, as shown in Figure 2, may be somewhat qualitative, the following motion limitations on helicopter support operations are considered to be valid:

- Roll motions in excess of 5 degrees significant single amplitude which severely limit loading of aircraft ordnance and aircraft handling.

- Pitch angle of 3.0 degrees significant single amplitude.

It is emphasized that rolling motions in excess of 5 degrees significant single amplitude also severely limit Underway Replenishment (UNREP) operations and strike-down and strike-up of missiles and ammunition. However, in order to determine the improvements in total ship system effectiveness due to the installation of active fin stabilizers, similar quantitative motion limitations need to be developed for other shipboard operations which are sensitive to roll motions (e.g., weapon/sensor performance, underway maintenance, personnel performance, etc.).

SEAKEEPING PERFORMANCE ASSESSMENT TECHNIQUE

Assessing the seakeeping performance of the ship system in quantitative terms is a very complex and challenging task for the ship designer. Comstock and Covich (10) have recently developed one technique (and there are many other approaches) for assessing seakeeping performance which (a) pictorially gives a measure of a ship's seakeeping performance based on various motion limitations and (b) can integrate any number of ship operating profiles under varying environmental conditions to give a quantitative (or numerical) measure of a ship's seakeeping performance.

Figures 3 through 8 have been developed utilizing the seakeeping performance assessment technique of Comstock and Covich to evaluate the improvements in helicopter operational performance due to the installation of active fin stabilizers. Each of these figures shows the ship's speed varying radially and the predominant heading of the waves relative to the ship varying circumferentially. Since, for a given ship, the limiting roll motion responses for helicopter operations at a given wave height (or sea state) are symmetrical about the vertical centerline, the right-hand side of each figure shows the operational area of the ship with fin stabilizers and the left-hand side, without fin stabilizers. Therefore, one measure of the effectiveness of fin stabilizers is to compare for each figure the operational area on each side of the vertical centerline, since these areas define the regions in which helicopter operations can be conducted aboard a ship with or without fin stabilizers.

Figures 3 through 8 can also be used to determine the percentage of time that a ship with or without fin stabilizers can be expected to perform helicopter operations. These percentages can be determined by weighting the operational areas according to the speed-time profile (i.e., percentage of time at various speeds) specified for a given ship and the percentage of time at each heading. The resulting percentages for each wave height are further weighted according to the occurrence of each wave height, since wave heights occur with a particular frequency in different geographical regions of the world. For example, Figure 9, which is derived from reference(11), shows the percentage of time that a given wave height is not exceeded in the North Atlantic Ocean (for the all-year average). Similar long-term wave height distributions have also been developed for specific seasons (e.g., Winter) in the North Atlantic, for the Northern North Atlantic, etc.

Since the higher wave heights occur a small percentage of time, the significant short-term performance reductions in the higher wave heights are usually not reflected in the long-term performance predictions where the wave heights are stratified for a particular geographical area. Therefore, in assessing the seakeeping performance of a ship or the effectiveness of fin stabilizers, short-term predictions of performance/effectiveness should be presented for each of a number of wave heights (or sea states), as well as the long-term, stratified wave height predictions for a particular geographical area.

PREDICTED IMPROVEMENTS IN HELICOPTER OPERATIONS

Utilizing the motion limitations, Figures 3 through 9, and the performance assessment technique described above, the expected performance improvements relative to helicopter operations resulting from the installation of active fin stabilizers are predicted for a small frigate and a large cruiser, the ship characteristics of which are presented in Table 4. Also, speed-time profiles typical of a frigate and cruiser are used, and equal time at all headings is assumed. Therefore, the resulting performance measure, referred to as Helicopter Operational Effectiveness, is expressed in terms of the percentage of time that helicopter operations can be performed.

The predictions of helicopter operational effectiveness are made without consideration for a helicopter hauldown and traversing system; and the quantitative results presented herein for the benefits of fin stabilizers are not intended to justify fin stabilizers as an alternative system to a helicopter hauldown and traversing system. The experiences of foreign naval ships equipped with both fin stabilizers and a helicopter hauldown and traversing system indicate that they are able to perform helicopter operations in very high seas a much greater percentage of the time than ships equipped with only one of these systems. Furthermore, it is again emphasized that fin stabilizers provide similar benefits for many other shipboard operations.

The following discussions summarize the results of the performance improvement predictions and briefly explain the methods used to predict the roll motion responses of the frigate and cruiser with and without active fin stabilizers.

Small Frigate

The roll motion responses of the frigate with and without fin stabilizers were developed by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), using its single degree-of-freedom (for roll motion only) computer program based on the work of Conolly (12). The roll damping coefficients used in the predictions were determined experimentally, and the predictions for the stabilized frigate were developed for one pair of fins each with a plan area of 60 square feet.

The resulting predictions of helicopter operational effectiveness for the frigate with and without active fins in short-crested irregular waves (i.e., waves represented by two-dimensional spectra - wave frequency and direction in which the waves travel) are presented in Table 5.

Large Cruiser

The roll motion responses of the cruiser with and without fin stabilizers were developed by Hydronautics, Inc., using its three degree-of-freedom computer program based on the work of Webster (13) and Barr and Snkudinor (4), and estimating the contributions of the fins by treating them as lifting surfaces with their cross-flow drag being negligible. The predictions for the stabilized cruiser were developed for two pairs of fins each with a plan area of 100 square feet.

The resulting predictions of helicopter operational effectiveness for the cruiser with and without active fins in short-crested waves are presented in Table 6.

DISCUSSION OF RESULTS

It should be noted that there are many short-comings in the computer programs for predicting roll motion responses. Both methods briefly described above use a quasi-linear approach to solve a very non-linear problem (i.e., predicting roll motions). For example, correction factors are applied to the DTNSRDC program in order to compensate for deficiencies in the single degree-of-freedom approach which ignores the cross coupling effects of yaw and sway . On the other hand, the Hydronautics program accounts for the cross coupling effects for three degrees-of-freedom, but available methods for estimating the roll damping coefficients are very empirical and less satisfactory, since roll damping is of viscous nature and potential theory is not applicable.

Although the analytical methods for predicting roll motion responses are limited in their capabilities to accurately predict (in an absolute sence) ship performance, it is strongly believed that the approach described in this section, when applied in a consistent manner, can be used with confidence in quantitatively assessing the relative performance improvements of a ship with fin stabilizers as compared to the same ship without fin stabilizers. Consequently, based on the results presented in Figures 3 through 8 and Tables 5 and 6, it is concluded that active fin stabilizers significantly improve the operational effectiveness of a wide range of surface combatant ships.

VI. SHIP IMPACT OF INSTALLING FIN STABILIZERS

The installation of fin stabilizers has an impact on ship arrangements, weight, power, speed and cost. However, if the decision to install active fin stabilizers is made early in the ship design, proper provisions can be made to integrate the fin system such that the impact would be minor when compared with the significant benefits attributable to the installed system. Table 7 presents some of the ship impacts for various sizes of active fin stabilizer systems (reference (14)).

A quantitative assessment of the impact of a typical new frigate design is summarized below for a fin roll stabilization system consisting of one pair of 60 ft^2 active fins.

Estimated cost per ship	$800,000
Approximate internal volume required	1000 ft^3
Approximate power required	150 KW
Approximate weight of fin system	25 tons
Approximate speed loss in calm water	0.1 knot at sustained speed
Approximate weight of additional fuel oil to maintain range, or approximate reduction in range	14 tons, or 150 miles

It is noted that although fin stabilizers may result in slightly greater calm water resistance due to the increased wetted surface of the fins, there is evidence (15, 16) that in seas of sea state 4 and above, the resistance of a stabilized ship is less than that of a ship with bilge keels only. Also, with the installation of active fin stabilizers, the bilge keels aft of the fins are usually eliminated in order to avoid interference with and degradation of fin performance; and this slight reduction in the total wetted surface of the bilge keels tends to reduce the impact on speed loss in calm water due to fin stabilizers. In addition, speed predictions cannot be made with an accuracy of 0.1 knot. Consequently, this impact is considered negligible.

In calculating the endurance range of a ship, the endurance speed in calm water is used, as well as a margin which crudely accounts for such uncertainties as added resistance in waves. By stabilizing the ship, the reduction of the ship's resistance in waves should offset the increase in calm water resistance due to the installation of fins. Thus, the impact on the endurance fuel or range is also considered negligible.

In summary, a typical fin stabilizer system will have a slight impact on the ship, but the above serves to illustrate the relatively minor price to be paid for the significant benefits of roll stabilization.

VII. NEED FOR IMMEDIATE ACTION

The previous analysis was an attempt to quantify the benefits to be realized by only one of many shipboard operations as compared to the costs/ship impact of installing active fin stabilizers. Similar quantitative cost-benefits evaluations of fin stabilizers have been performed over the past several years for specific ship designs in order to justify the installation of fin stabilizers. With the exception of one or two recent ship designs, these cost-benefits analyses have not convinced the program managers that fin stabilizers should be installed in their ships. Some of the apparent reasons have been explained in previous sections of this paper. Also, as previously explained, the Soviet Navy, as well as the Royal (United Kingdom) Navy and other NATO navies, appear to have an established practice of installing fin stabilizers in all combatant ships of cruiser size and smaller. It is strongly believed that another reason why the U.S. Navy has not adopted such a practice is its emphasis on quantitatively proving that fin stabilizers are beneficial.

The cost-benefits evaluation of fin stabilizers is a complex, lengthly and expensive process. A truly complete cost-benefits evaluation cannot be performed until the performance degradation (or motion limitations) of all shipboard functions/operations that are sensitive to roll motions are quantified to the same extent as that of helicopter operations. The cost alone of the research and development that would have to be undertaken to quantify all of the benefits of fin stabilizers would approach that of initially installing such fins in the entire FFG-7 class.

Furthermore, the Navy's ship design community cannot affort to waste its decreasing manpower resources in continually justifying, for each new ship design, a practice (i.e., installation of fin stabilizers) that has been adopted by every other major navy in the world. Even in those few cases where program managers have been convinced of the benefits of fin stabilizers, decisions to install the fins have been delayed such that the ship design and procurement have been seriously affected. Consequently, there is a critical need to establish initial requirements for active fin stabilizers early in the ship design process.

Since all of the benefits of fin stabilizers cannot be quantified at this time, specifying inclusive operational or performance requirements in the TLR will not ensure that fin stabilizers will be installed. Therefore, the requirements for fin stabilizers should be officially stated as follows:

(1) Combatant ships displacing less than 20,000 tons shall be equipped with active fin roll stabilizers unless it can be demonstrated that mission performance will not be improved thereby.

(2) For combatant ships with a displacement of 20,000 tons or greater and other surface ships, active fin roll stabilizers shall be installed whenever the results of studies demonstrate improved mission performance.

Further delay in the U.S. Navy adopting such a practice will seriously increase the likelihood that future U.S. Navy combatant ships will continue to be built with seakeeping qualities inferior to those of our Allies and, more importantly, to those of our possible adversaries. Immediate action must be taken to ensure that adequate financial resources are committed to improving our ships, rather than to proving that our ships need improvement!

VIII. ACKNOWLEDGEMENTS

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16. Shmirev, A., et al, "Ship Motion Stabilizers", Russian Publication, 1961.

Table 1 U.S. FIN INSTALLATIONS

SHIP	YEAR	YES	NO
DD 692 FRAM 11	1944		X
DD 710 FRAM 1	1945		X
DE 1006	1954		X
DD 931/DDG 32	1955		X
DD 936/DDG 31	1956		X
DE 1033	1959		X
DDG 2	1960		X
DLG 9	1960		X
DLG 16	1962		X
DLGN 25	1962		X
DE 1037	1963	X	
DE 1040/DEG 1	1964	X	
DLG 26	1964		X
DLGN 35	1967		X
DE 1052	1969	X	
DLGN 38	1972		X
DD 963	1975		X
FFG 7	1976		X

Table 2 USSR FIN INSTALLATIONS

SHIP	YEAR	YES	NO
SNORYY	1949		X
KOLA	1950		X
RIGA	1952		X
TALLIN	1953		X
KOTLIN/KILDIN	1954	X	
KRUPNY/KANIN	1959	X	
PETYA 1 & 11	1961	X	
KNYDA	1962	X	
KASHIN	1963	X	
MIRKA	1964	X	
KRESTA 1	1967	X	
MOSKVA	1967	X	
KRESTA 11	1970	X	
KRIVAK	1970	X	
KIROV	1972	X	
KIEV	1975	X	

TABLE 3 TYPICAL SEAKEEPING PERFORMANCE REQUIREMENTS
(AS GIVEN BY TLR)

PERFORMANCE REQUIREMENTS	ENVIRONMENTAL CONDITIONS
OPERATION OF EMBARKED HELICOPTERS	SEA STATE 5 (SIGNIFICANT WAVE HEIGHT 12 FT: WIND VELOCITY 24 KNOTS)
REPLENISHMENT AND STRIKEDOWN UNDERWAY	SEA STATE 5(SIGNIFICANT WAVE HEIGHT 12 FT; WIND.VELOCITY 24 KNOTS)
CONTINUOUS EFFICIENT OPERATION (OTHER THAN REPLENISHMENT AND OPERATION OF EMBARKED HELICOPTERS)	SEA STATE 6(SIGNIFICANT WAVE HEIGHT 18 FT; WIND.VELOCITY 28 KNOTS)
LIMITED OPERATION AND CAPABILITY OF CONTINUING THE MISSION WITHOUT RETURNING TO PORT FOR REPAIRS AFTER SEA SUBSIDES	SEA STATE 8(SIGNIFICANT WAVE HEIGHT 50 FT; WIND VELOCITY 42 KNOTS)
SURVIVABILITY WITHOUT SERIOUS DAMAGE TO MISSION ESSENTIAL SYSTEMS	SEA STATE 9 (HURRICANE CONDITIONS; WHEN SHIP EXPERIENCES MAXIMUM WAVE AND WIND CONDITIONS)

TABLE 4 CHARACTERISTICS OF SHIPS USED FOR FIN STABILIZER EFFECTIVENESS PREDICTIONS

	FRIGATE	CRUISER
Length Between Perpendiculars (LBP), ft.	408	666
Maximum Beam (B_{max}) at Waterline (WL), ft.	45	76
Draft (T), ft.	14	22
Displacement (Δ), long tons	3400	17,000
Block Coefficient (C_B)	0.45	0.53
Prismatic Coefficient (C_P)	0.61	0.53
Section of Maximum Area Coefficient (C_X)	0.75	0.90
Distance from Vertical Center of Gravity to Metacenter (GM), feet	3.4	6.6
Distance from Keel to Vertical Center of Gravity (KG), ft.	18.7	28
Distance from Keel to Vertical Center of Buoyancy (KB), ft.	9.2	12.8

TABLE 5

PREDICTED FIN STABILIZER EFFECTIVENESS FOR A SMALL FRIGATE

HELO OPERATIONAL EFFECTIVENESS	IN SEA STATE 5	IN SEA STATE 6	IN SEA STATE 7	ALL YEAR AVERAGE IN NORTH ATLANTIC
WITHOUT FIN STABILIZERS	70%	20%	0%	50%
WITH FIN STABILIZERS	100%	100%	30%	95%

Notes: Sea States 5, 6, and 7 are represented by significant (average of the one-third highest) wave heights of 10.2 feet, 16.9 feet, and 30.6 feet, respectively

TABLE 6

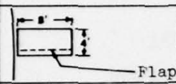
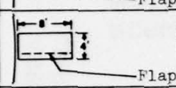
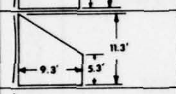
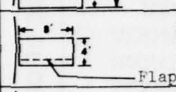
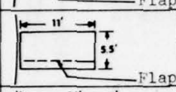
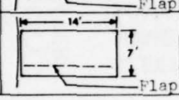
PREDICTED FIN STABILIZER EFFECTIVENESS FOR A LARGE CRUISER

HELO OPERATIONAL EFFECTIVENESS	IN SEA STATE 5	IN SEA STATE 6	IN SEA STATE 7	ALL YEAR AVERAGE IN NORTH ATLANTIC
WITHOUT FIN STABILIZERS	100%	45%	15%	75%
WITH FIN STABILIZERS	100%	100%	30%	95%

Notes: Sea States 5, 6, and 7 are represented by significant (average of the one-third highest) wave heights of 10.2 feet, 16.9 feet, and 30.6 feet, respectively

TABLE 7

Ship Design Impact Data for Active Fin Systems

Installation	Fin Planform	Fin Area 1 Side	Total System Weight	Weight: Group 518·	Weight: Group 113	Internal Volume 1 Side	Control Power	Maximum Angle/ Flap Angle	Time Stop to Stop	Maximum Design Lift	Comments
DE 1040 Class Sperry		32 ft^2	(Manual) 13.5 L.T.	-	-	134 ft^3	20 HP	$\pm 25^{\circ}$	~2 sec	23 L.T.	
DE 1040 Class Denny-Brown		32 ft^2	16.5 L.T.	~17.7 L.T.	4.4 L.T.	277 ft^3	20 HP	$\pm 23^{\circ}/33^{\circ}$	1.3 sec	23 L.T.	
DE 1052 Class Sperry		74 ft^2	20.5 L.T.	-	-	226 ft^3	50 HP	$\pm 30^{\circ}$	2 sec	38.4 L.T.	
DE 1052 Class Denny-Brown		77 ft^2	27.7 L.T.	25.4 L.T.	6.0 L.T.	308 ft^3	75 HP	$\pm 30^{\circ}$	1.6 sec	38.4 L.T.	
Sperry Gyro Fin		32 ft^2	34 L.T.				25 HP			16.5 L.T.	Retractable Lost Buoyancy = 14 L.T. Total
Sperry Gyro Fin		60.5 ft^2	54 L.T.				40 HP			31 L.T.	Retractable Lost Buoyancy = 26 L.T Total
Sperry Gyro Fin		98 ft^2	96 L.T.				75 HP			50 L.T.	Retractable Lost Buoyancy = 34 L.T. Total

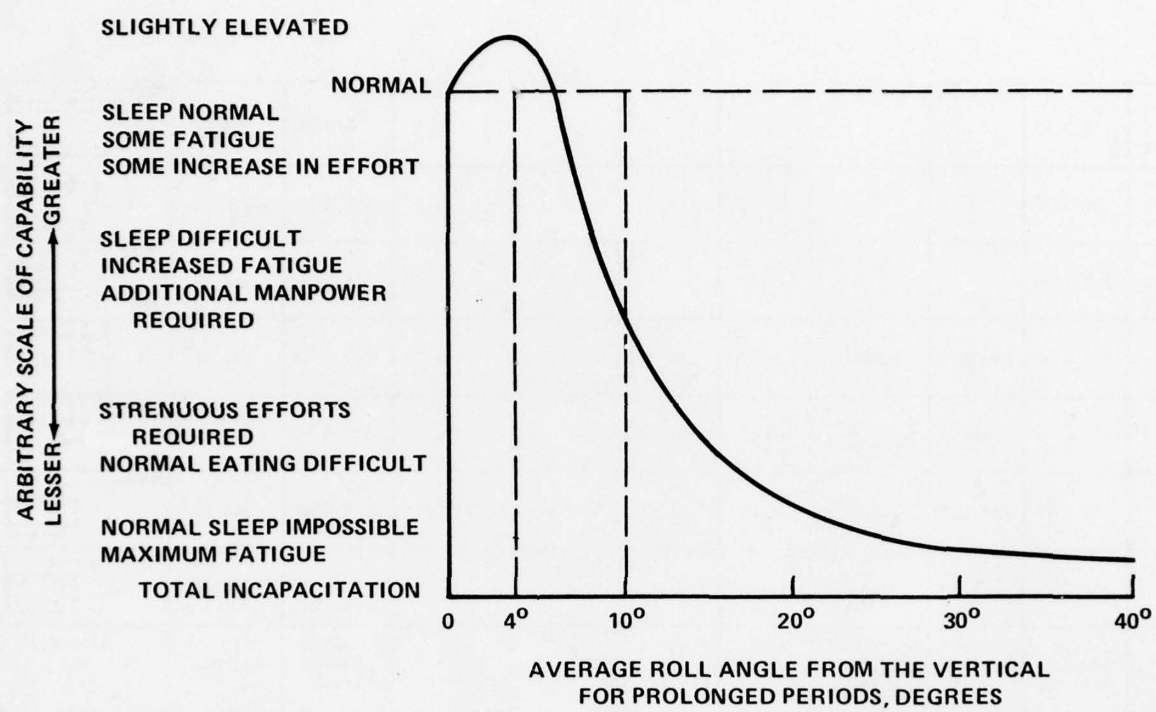
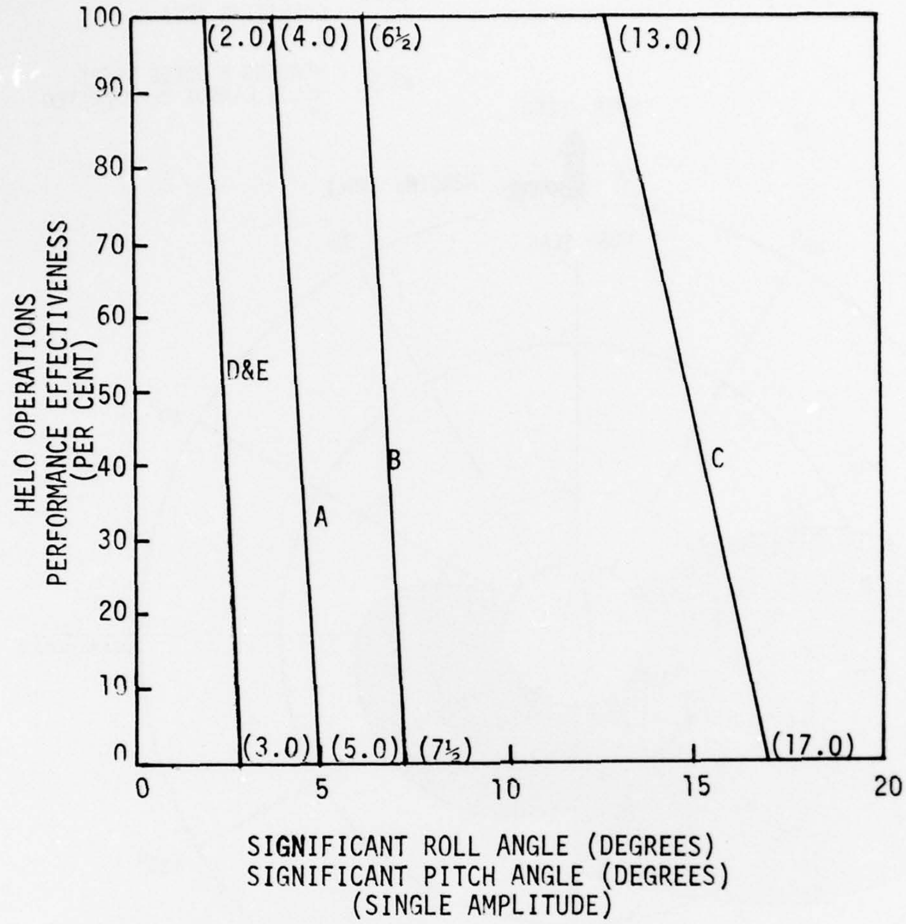


FIGURE 1 QUALITATIVE ASSESSMENT OF ROLLING MOTIONS ON PERSONNEL PERFORMANCE



A-EFFECT OF ROLL ANGLE ON HELICOPTER HANDLING (MANUALLY).

B-EFFECT OF ROLL ANGLE ON HELICOPTER LANDING/TAKE OFF OPERATIONS WITHOUT HAULDOWN, SECURING AND TRAVERSING SYSTEM.

C-EFFECT OF ROLL ANGLE ON HELICOPTER LANDING/TAKE OFF OPERATIONS WITH HAULDOWN, SECURING AND TRAVERSING SYSTEM.

D-EFFECT OF PITCH ANGLE ON HELICOPTER LANDING/TAKE OFF OPERATIONS WITHOUT HAULDOWN, SECURING AND TRAVERSING SYSTEM

E-EFFECT OF PITCH ANGLE ON HELICOPTER LANDING/TAKE OFF OPERATIONS WITH HAULDOWN, SECURING AND TRAVERSING SYSTEM

FIGURE 2 - VARIATION OF HELICOPTER OPERATIONAL PERFORMANCE WITH SHIP MOTIONS

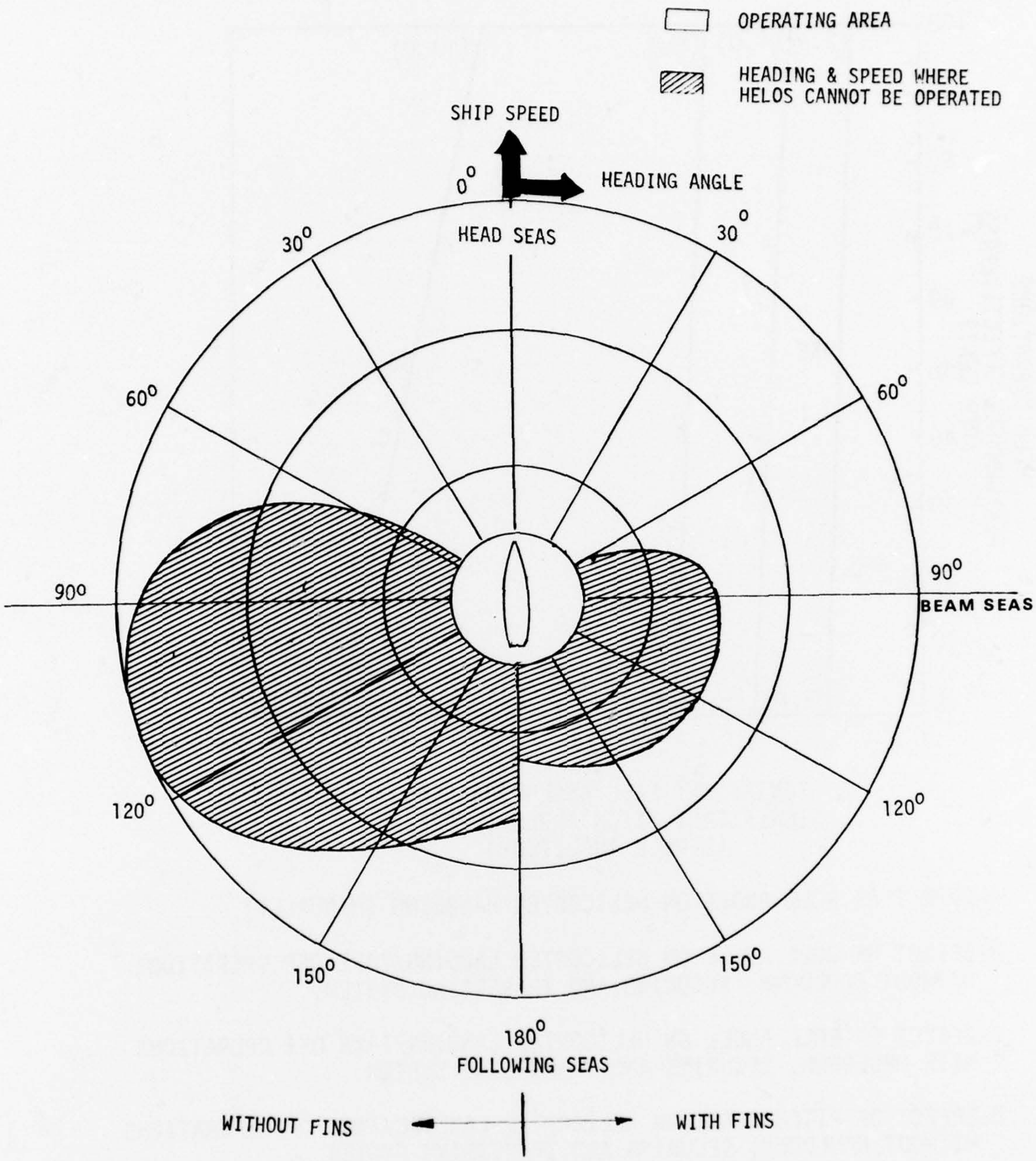


FIGURE 3 HELICOPTER OPERATIONAL ENVELOPES FOR A FRIGATE WITH AND WITHOUT FIN STABILIZERS IN SEA STATE 5 (SIGNIFICANT WAVE HEIGHT OF 10.2 FEET)

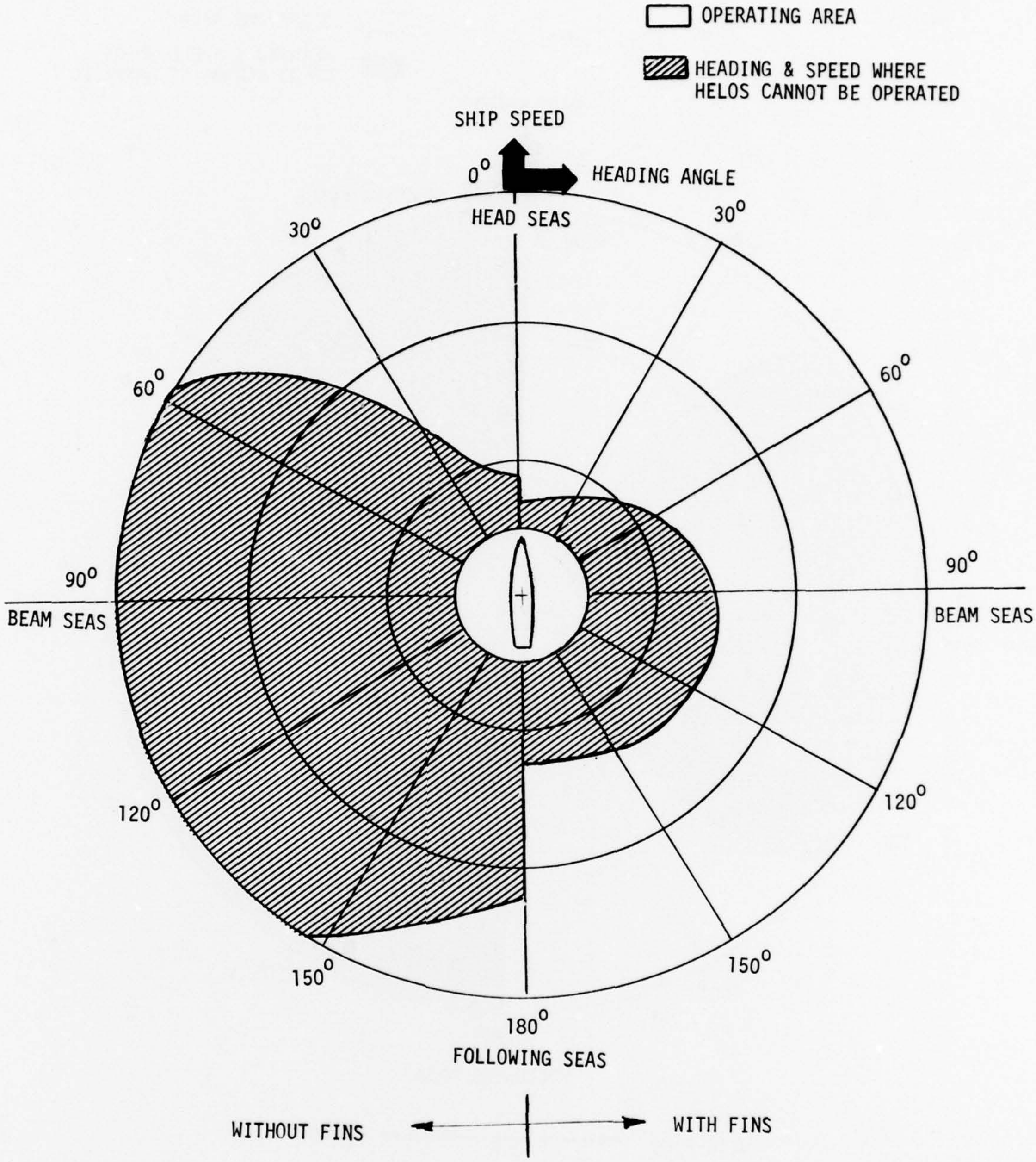


FIGURE 4 HELICOPTER OPERATIONAL ENVELOPES FOR A FRIGATE WITH AND WITHOUT FIN STABILIZERS IN SEA STATE 6 (SIGNIFICANT WAVE HEIGHT OF 16.9 FEET)

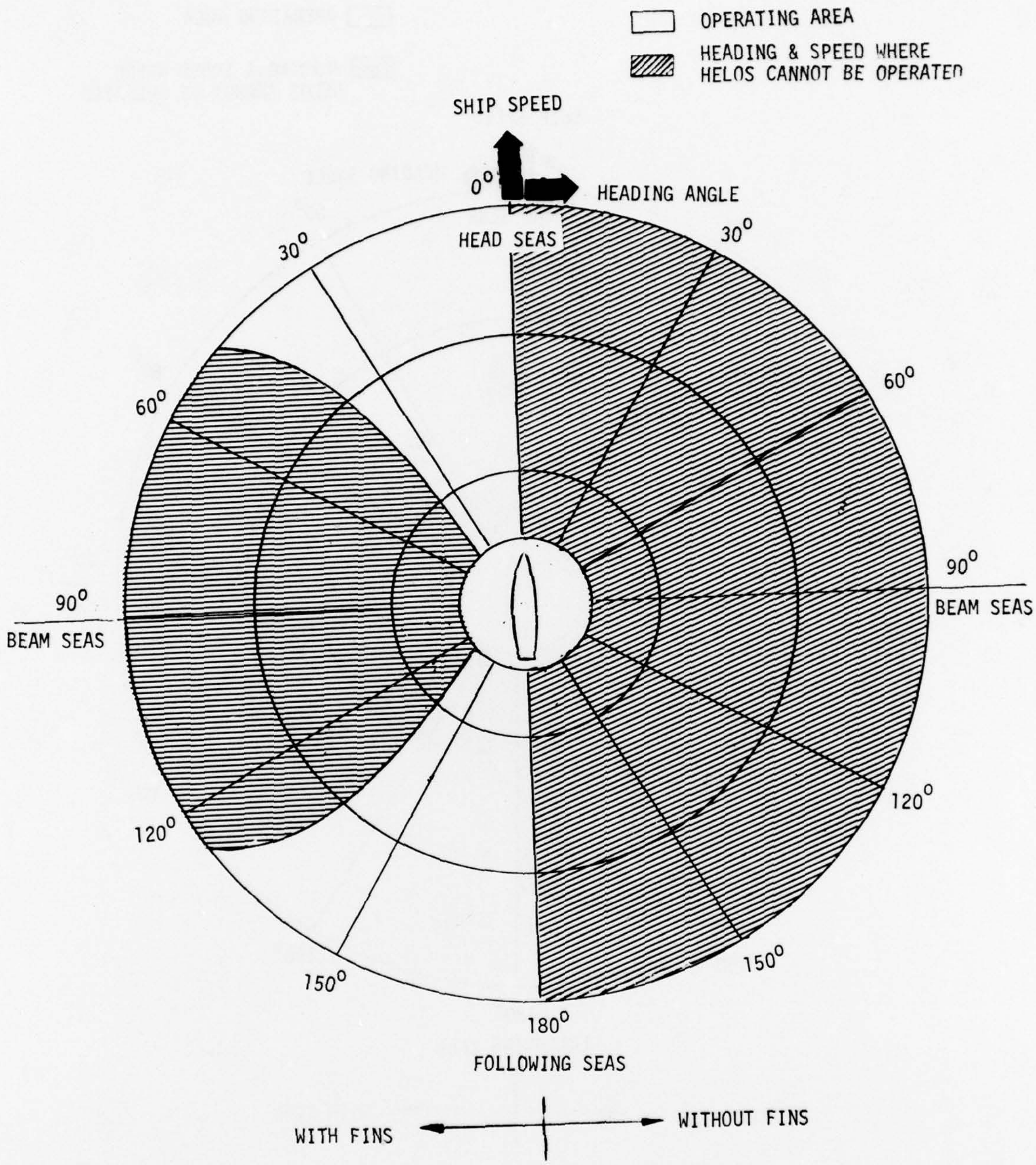


FIGURE 5 HELICOPTER OPERATIONAL ENVELOPES FOR A FRIGATE WITH AND WITHOUT FIN STABILIZERS IN SEA STATE 7 (SIGNIFICANT WAVE HEIGHT OF 30.6 FEET)

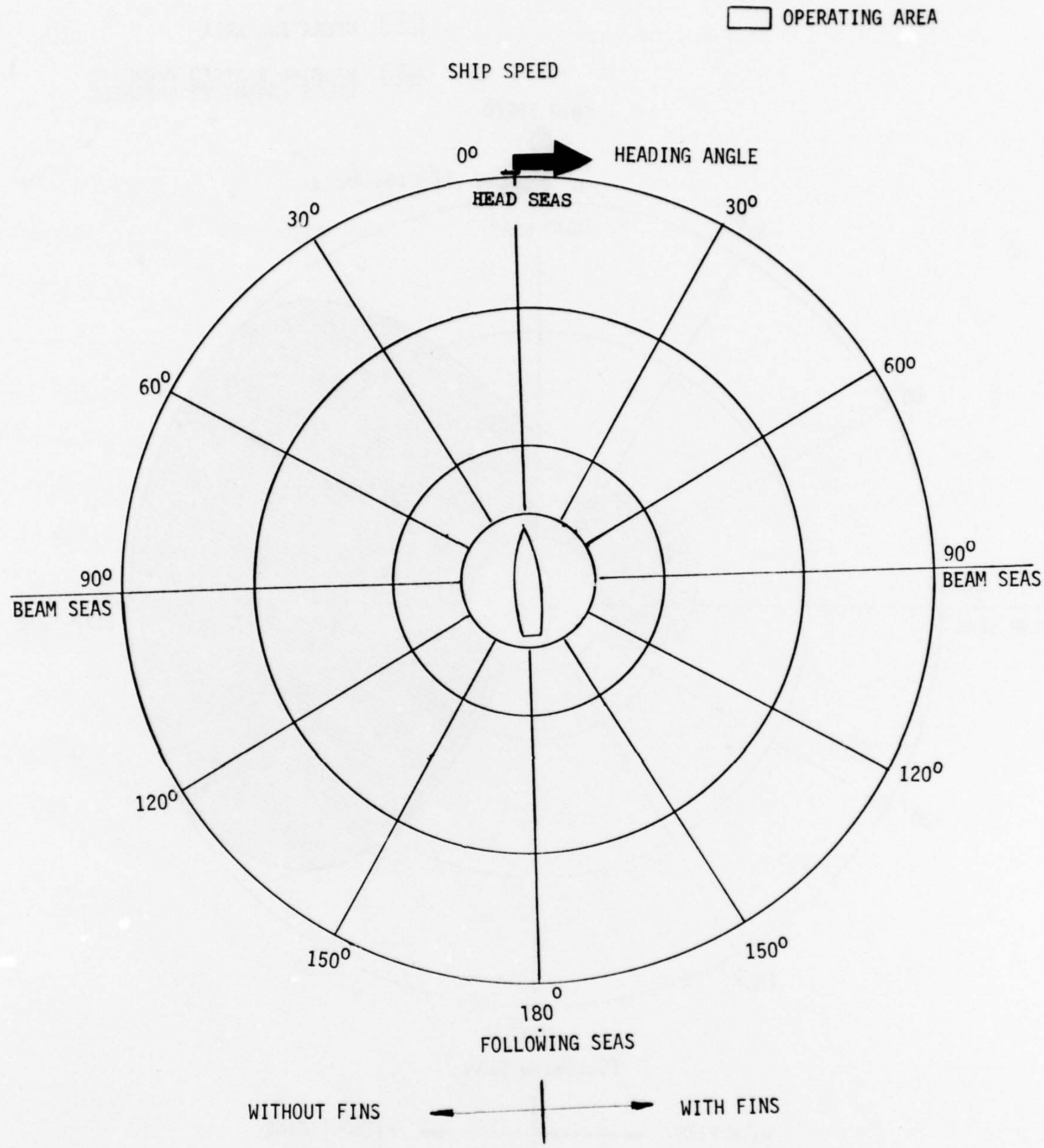


FIGURE 6 HELICOPTER ENVELOPES FOR A CRUISER WITH AND WITHOUT FIN STABILIZERS IN SEA STATE 5 (SIGNIFICANT WAVE HEIGHT OF 10.2 FEET)

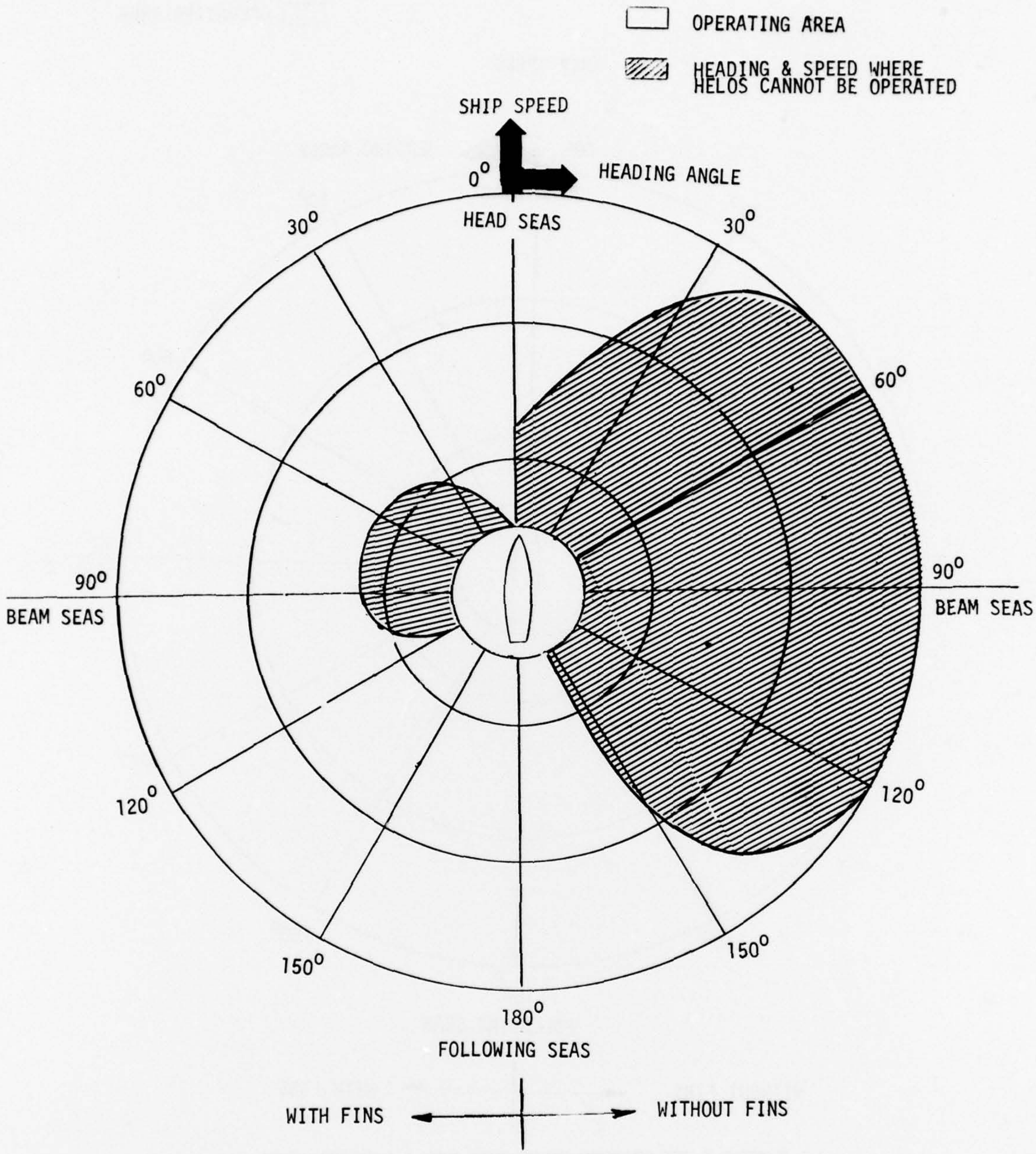


FIGURE 7 HELICOPTER OPERATIONAL ENVELOPES FOR A CRUISER WITH AND WITHOUT FIN STABILIZERS IN SEA STATE 6 (SIGNIFICANT WAVE HEIGHT OF 16.9 FEET)

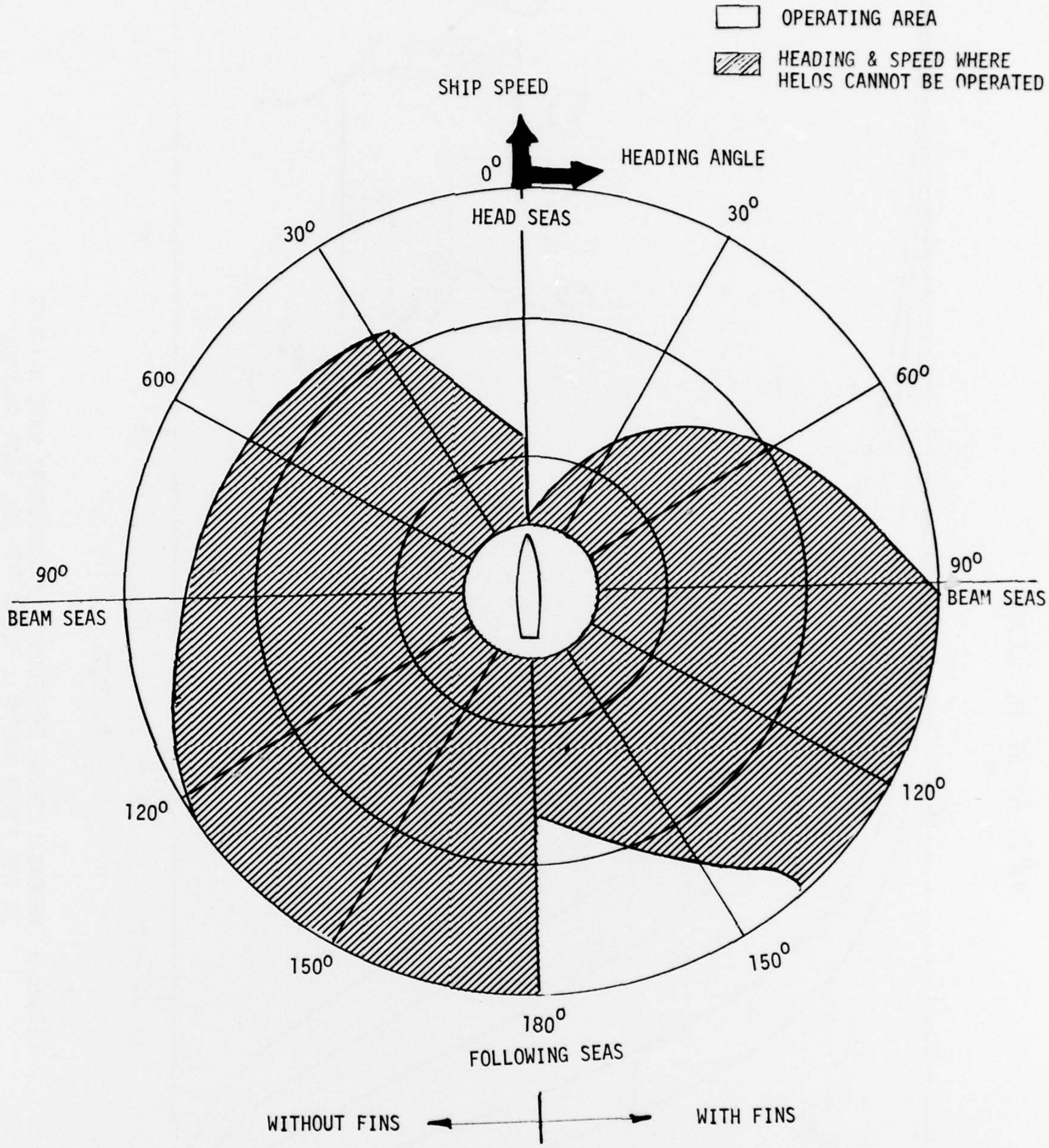


FIGURE 8 HELICOPTER OPERATIONAL ENVELOPES FOR A CRUISER WITH AND WITHOUT FIN STABILIZERS IN SEA STATE 7 (SIGNIFICANT WAVE HEIGHT OF 30.6 FEET)

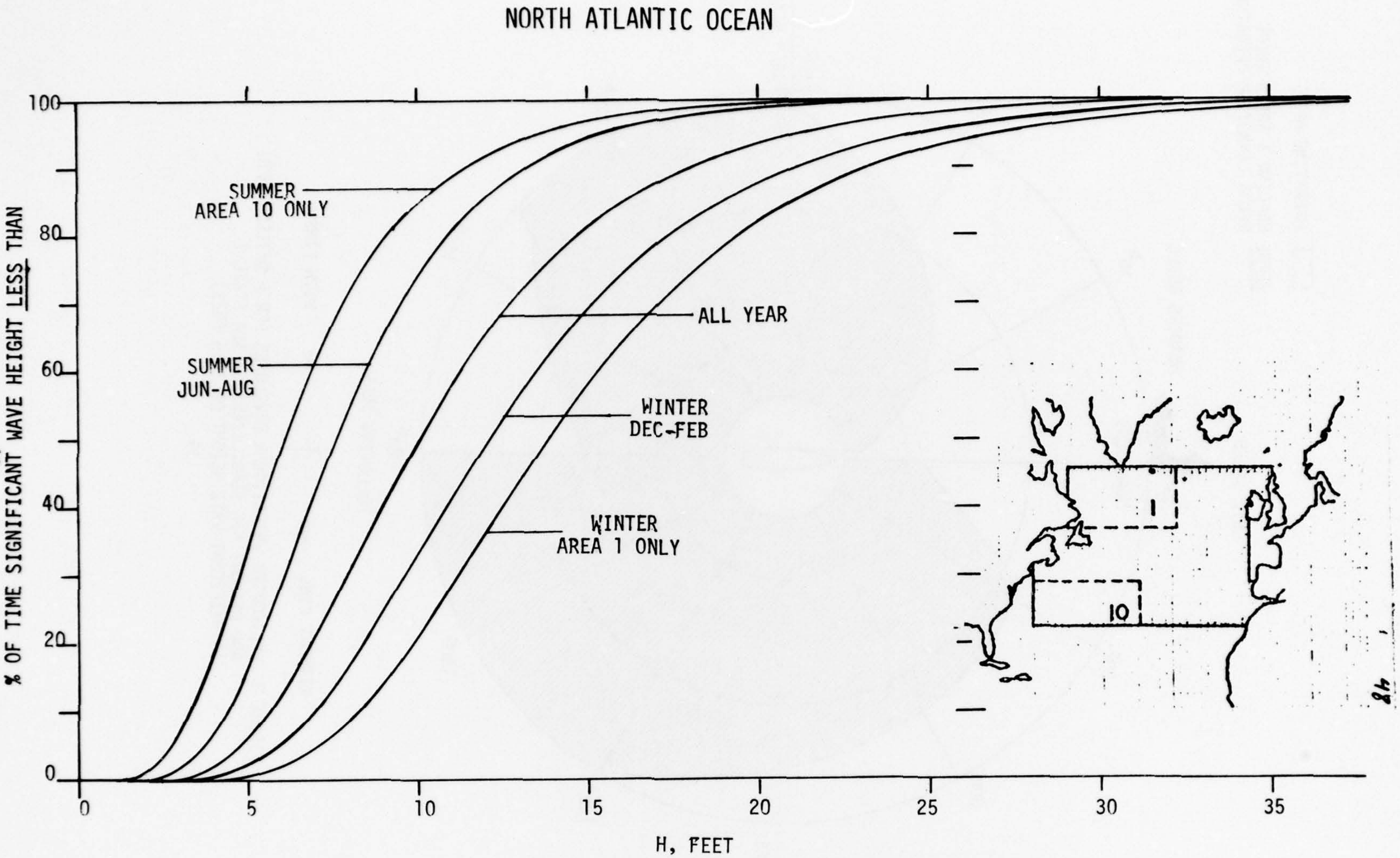


FIGURE 9 PROBABILITY OF EXCEEDENCE OF DIFFERENT WAVE HEIGHTS IN THE NORTH ATLANTIC OCEAN FOR ALL YEAR AVERAGE