# RUDDER ROLL STABILIZATION A CRITICAL REVIEW

BY

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ABSTRACT

In recent years the concept of using a warship's rudders to provide both the steering and the stabilizing functions has grown in popularity. The Swedish and Danish navies have ships utilizing rudder roll stabilization at sea and the new Dutch 'M' Class frigate is also to have such a system.

The article describes a study investigating the likely implications if rudder roll stabilization were to be adopted for R.N. ships and concludes that it is not a suitable alternative for active fine stabilization.

## Introduction

The Royal Navy has for many years used active fins in order to achieve roll stabilization for major warships. This is not to say that other methods of stabilization have not been employed if they have been appropriate. Examples of this are the use of controlled passive tanks in H.M.S. *Challenger*, where fins could foul diving equipments, and in the landing ship *Sir Galahad* where underwater appendages would be a distinct disadvantage. The better performance and easier installation afforded by active fins, however, has meant that it has seldom been challenged as the preferred method of roll stabilization.

In recent years however there has been a great deal of work published advocating the use of the rudders for ship stabilization purposes, this being generally referred to as Rudder Roll Stabilization (RRS). The emergence of this new technique merited a reappraisal of the approach taken for warship roll reduction by the Royal Navy.

## Rudder Roll Experience to Date

Much of the work on Rudder Roll conducted during the early 1970s[1,2,3] concentrated on demonstrating that the concept was feasible. The more detailed investigations that followed indicated differing opinions as to the practicality of adopting the technique. On one hand some studies[4,5] proposed that, despite its potential, the technique suffered from instability and adverse coupling problems resulting in vessels having an increased risk of broaching and control difficulties under certain conditions. However other work, conducted principly in the USA[6], Holland[7,8] and Sweden, has taken the opposite view, that rudder roll is not only feasible but realistic. Indeed sea trials have taken place in an 'S' class frigate of the Royal Netherlands Navy, leading to the decision to specify Rudder Roll for the 'M' class frigates now under construction. The Swedish and Danish[9] Navies also have systems at sea in a minelayer and patrol craft respectively. These studies have argued that RRS presents a 'something for nothing' situation in that two functions are being achieved from a system previously installed to provide only one.

## Rudder Roll Appraisal Study

In view of the claims being made and the interest shown in rudder roll, it was decided that the Ministry of Defence should conduct an appraisal of the technique. Since the basic concepts were not in question, the review concentrated on investigating the engineering implications of fitting a rudder roll system to a warship and to investigate the level of performance that could be achieved if such a system were adopted. It should be noted that the operational systems described above have been incorporated as enhancements of the autopilot. Hence, when in manual helm control the stabilization function is lost.

Rudder roll, if accepted for the R.N., would be adopted as a direct replacement for active fins, therefore throughout these studies a direct comparison was drawn between the two systems.

*Operational Implications*

The operational implications of adopting rudder roll rest very largely on the roll reduction performance that can be achieved. This affects all the following areas:

(*a*) Sea keeping
  (i) RAS
  (ii) helicopter operations
  (iii) manhandling operations.

(*b*) Weapon System operation.

(*c*) Surveillance System operation (radar, sonar).

(*d*) Crew efficiency.

*Engineering Implications*

The engineering implication aspects investigated were:

(*a*) Mechanical design.

(*b*) Safety.

(*c*) Availability, Reliability, Maintainability.

(*d*) Cost.

The first area of concern was the design of the steering gear required for rudder roll which would have implications on its installation. It is generally acknowledged that to have any effect rudder roll requires a faster rudder slew rate than used for conventional systems, the concern being that the consequence of this would be larger hydraulic systems and higher rated motors both requiring more space and demanding more from other ship services.

A further concern, of equal importance, was that of safety. It would be totally unacceptable to compromise the levels of redundancy currently adopted for ships' steering systems in order to achieve roll stabilization from the same system.

TABLE I—*Typical values for aircraft carrier and frigate*

| | *Rudder* | | | | *Fin* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Foil Area* | *Aspect Ratio* | *Moment Arm* | $\gamma_s$ | *Foil Area* | *Aspect Ratio* | *Moment Arm* | $\gamma_s$ |
| *Light Carrier* | 18·5 | 1·3 | 3·0 | 0·7 | 7·3 | 0·6 | 13·0 | 2·1 |
| *Frigate* | 8 | 1·4 | 2·3 | 1·6 | 5·3 | 0·7 | 7·0 | 3·3 |

The availability, reliability and maintainability of the system has obvious implications for both system safety and cost. Concerns in this area again stem from the requirement for the high rudder slew rates causing doubts about the extent of the failure modes present which would directly affect both initial production and through-life costs.

*Rudder Roll Performance Objectives*

From these reviews of operational and engineering implications, the performance objectives of a rudder roll system are defined as follows:

(*a*) To obtain acceptable performance in roll stabilization in order that ship operational capability is not adversely affected.

(*b*) To obtain equivalent performance in yaw control to a dedicated steering system without compromising the levels of redundancy necessary for this essential system.

(*c*) To achieve the above two objectives taking due consideration of the installation constraints and support requirements which affect both unit production and through-life costs.

## Factors Affecting Roll Reduction Performance

It is widely recognized that using the current steering equipment with an alternative autopilot control algorithm will not produce a system capable of meeting the roll reduction performance objective. It is therefore necessary to make changes to the design of current steering gear in order to attempt to achieve this.

The effectiveness of any roll stabilization system is dependent upon the magnitude of the stabilization moment that can be applied to the ship. A measure of this effectiveness is given by the ratio of the stabilization moment to the heeling moment per degree and is known as the equivalent waveslope capacity, where waveslope capacity is defined by the following equation:

$$\gamma_s = \frac{\varrho A V^2 C_L R}{1000\, g\, D \overline{GM} \sin 1^\circ}$$

where $\gamma_s$ = equivalent waveslope capacity
$\varrho$ = density of seawater
$A$ = area of foil
$V$ = ship speed
$C_L$ = lift coefficient
$R$ = lever arm
$D$ = ship displacement
$\overline{GM}$ = metacentric height

From this it is apparent that, for a given ship, the equivalent waveslope capacity, and hence stabilization performance, can be altered by making changes to the foil area, the lever arm and the lift coefficient, which is in turn affected by the chosen aspect ratio. Typical values for a frigate and a light carrier are in TABLE I and a comparison of the available lever arm for both ship types is shown in FIG. 1.

One further factor, which must also be considered at this stage, is the angular slew rate of the stabilizing surface. Active fin stabilizer systems typically have slew rates of around 37 degrees per second; this ensures that fin motion remains in phase with the rolling motion and also allows the fin to generate the largest possible stabilizing moment as early as possible. In comparison to this, rudders typically have slew rates of the order of 3 degrees per second. It is generally accepted that a slew rate of this order is inadequate for a rudder roll installation and that a faster rate is required.

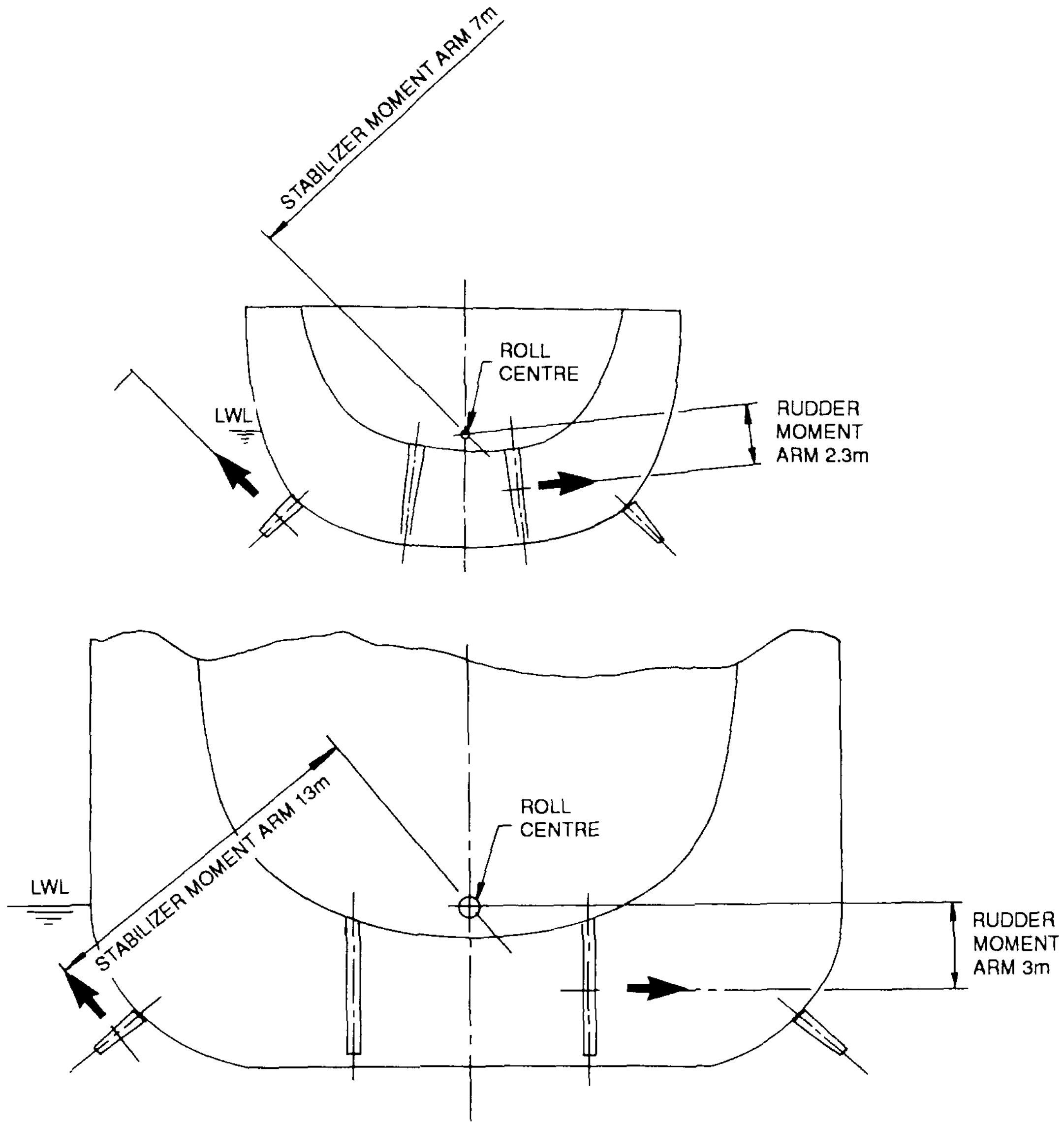


FIG. 1—RUDDER AND STABILIZER MOMENT ARMS FOR FRIGATE AND CARRIER

## Measures to Produce an Effective RRS

It is thus apparent that, for an RRS system to be effective, changes in rudder and steering gear design are needed. Measures to improve aspect ratio, foil area, moment arm and slew rate are therefore discussed.

### *Aspect Ratio*

The main reason for the selection of low aspect ratios for stabilizers is to ensure that stall does not occur over the range of fin operation. This results in the lift coefficient for a given angle of attack being lower than is the case for higher aspect ratios. This does not present a problem in this case due to the high angular slew rate of the fin, which ensures that a suitable lift coefficient is achieved soon after the demand is made. In order to provide the necessary steering performance rudders use higher aspect ratios to enable high lift coefficients to be achieved at lower angles of attack. The stall angle in this case occurs within the operational envelope of the rudder, albeit usually within the last 25% of the range. It is therefore considered that there is more to be lost than gained in making any changes to the current selection of rudder aspect ratio.

*Foil Area and Moment Arm*

Increases in the area of the foil are also linked with the available moment arm. As was shown in FIG. 1, the moment arm currently provided by the rudder is, at best, a factor of three lower than is achieved by a stabilizer fin. It is this aspect of rudder design that will require the most attention. Increasing the rudder moment arm can be achieved by moving the rudder centre of pressure further from the roll centre. Methods of achieving this are:

(*a*) Increasing the rudder outreach; or

(*b*) Angling the rudders outboard.

Increasing rudder outreach can be achieved by increasing the rudder span, reducing the height above the baseline of the after cut-up, or mounting the rudder on a skeg. The primary limitation affecting each of these options is the need to ensure that the blade does not extend beyond the ship's local beam or the keel. In addition, the latter two options will require alterations to the ship's lines near the stern which would have serious effects on ship powering and resistance and the interaction between the propeller and the hull.

Angling the rudders does provide a marginal increase in the moment arm; however the penalties in taking this option include increased risk of aeration and cavitation due to the rudders being brought closer to the surface and poorer yaw performance as the rudders are now outside the propeller race. By far the worst penalty, however, is the impact that this would have on the hydraulic complexity due to the necessity, even for moderately angled rudders, to dispense with the normal mechanical linking. This would also adversely affect the steering system failure modes.

Thus the only method of improving the available moment arm worth further consideration is that of increasing the rudder span. This will, of course, increase the bending moments in the rudder stocks and the bearing loads.

*Rudder Slew Rate*

The values of slew rate given above indicate that fin slew rates are some twelve times larger than those of rudder systems. To increase the slew rate by this much is clearly not practical, as this would require unacceptable increases in the size of the hydraulic system and place loads on the steering gear that are unlikely to be sustainable. Therefore a compromise figure between these two extremes is necessary.

## Selection of Ship Parameters for RRS Study

It was therefore concluded that the only design changes which could feasibly be made to the current design of steering gear, in order to improve its RRS capacity, were to extend the rudder span and to increase the rudder slew rate. It was necessary therefore to determine the extent to which these could be altered. Since the dimensions of the rudder would affect the slew rate calculations it was necessary to establish the rudder geometry first.

As already stated, extending the span is a compromise between improved moment arm and increased risk of damage if the rudder is allowed to extend below the keel line. In practice the bottom of the propeller disc extends below the keel line and it was therefore decided that to increase the rudder span in line with the propeller would not constitute a significant additional risk. This allowed a 33% increase in the rudder span. Using this revised rudder span, computer modelling was undertaken in order to determine a suitable rudder slew rate. The modelling was undertaken for three sea states and two wave encounter angles. The results of these stimulations at FIGS. 2 and 3 indicate that variations in encounter angles have little effect on the slew rate profiles. In all cases, roll reduction performance appears to saturate in the region of 10 degrees per second with relatively flat profiles thereafter. In order to be sure of selecting a slew rate that was safely in the 'flat' region of the profile, and bearing in mind the reservations regarding large increase in slew rate, a rate of 15 degrees per second was chosen for the Rudder Roll study.

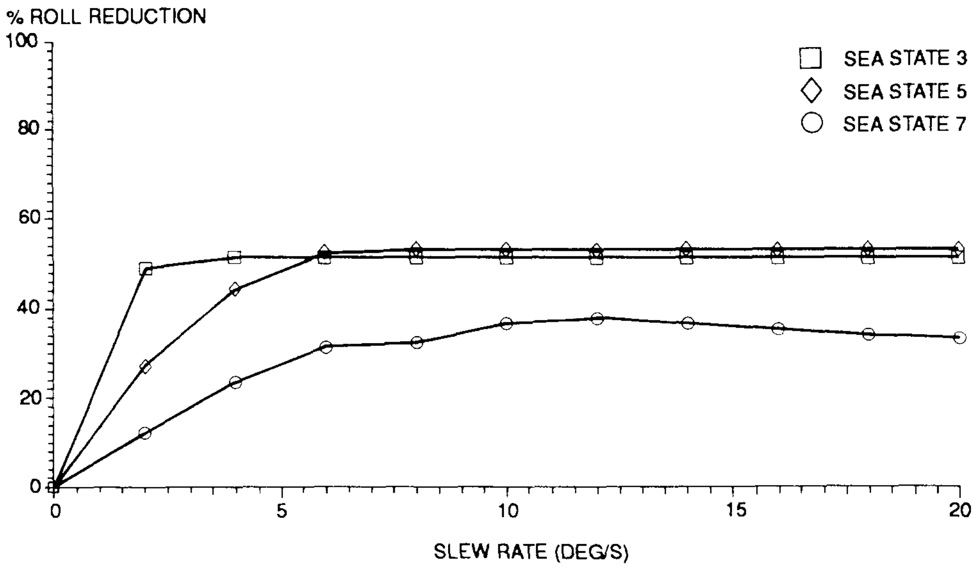


FIG. 2—PERCENTAGE ROLL REDUCTION V. SLEW RATE AT WAVE ENCOUNTER ANGLE OF 110°

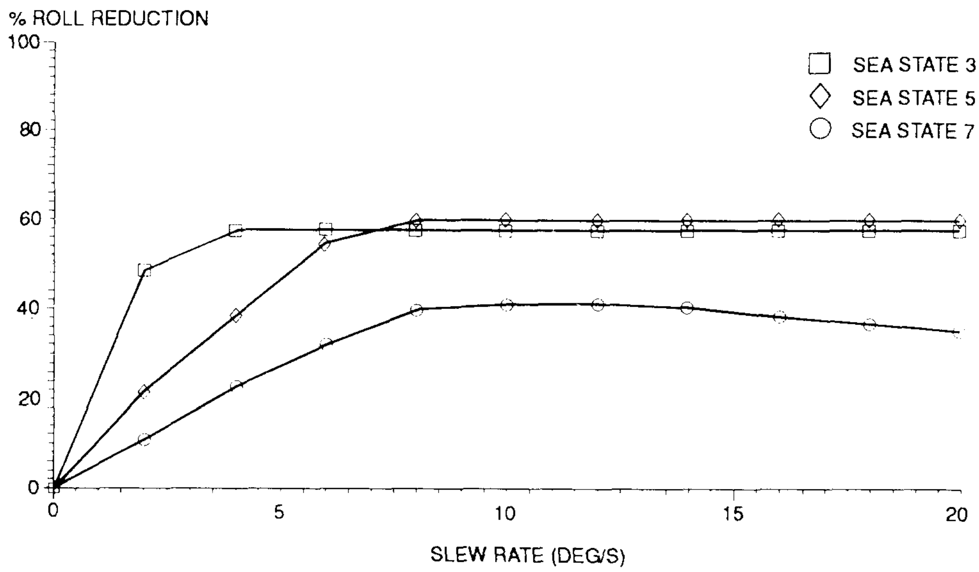


FIG. 3—Percentage roll reduction v. slew rate at wave encounter angle of 150°

## Rudder Roll System Performance

In order to assess RRS performance, computer simulations were carried out on mathematical models of a frigate. Two models were used: the first corresponded with that of the current ship configuration, including its active fin stabilization system; the second included the modifications discussed above. This involved changing the rudder geometry and increasing the angular slew rate to 15 degrees per second.

Seas were modelled in the simulation program by using a Pierson-Moskowitz two parameter spectrum. This sea model produces waves of the correct height and period, and in the correct distribution for a typical North Atlantic swell. However, the wave shapes themselves are not typical, having a sharper crest and a flatter trough than is normal, although this does have the advantage of eliminating the confused sea pattern caused by the more usual short-crested multi-directional seas.

The simulations compared roll reduction achieved by both models and the rudder activity of each. These simulations were conducted at 12, 18 and 30 knots and for a number of encounter angles ranging from bow to quartering seas.

The roll reduction results are shown in FIGS. 4, 5 and 6 and indicate that, for all speeds, fin stabilization provides greater levels of roll reduction. The performance of an RRS system is markedly less, especially in conditions of bow and quartering seas.

Two aspects of rudder activity were investigated—the maximum rudder angles required to provide stabilization and maintain course, and the frequency of rudder movements. FIGS. 7, 8 and 9 indicate that the maximum rudder angles required for the ship fitted with RRS are far larger than those for a fin-stabilized ship. In addition, the frequency of movement of the rudder was also much greater for the rudder roll case.

## Engineering Assessment

The engineering assessment of rudder roll considered the design implications of fitting and operating the machinery required, the safety of such a system and the costs involved.

*System Design*

Increasing the span of the rudder has the effect of increasing the rudder weight by 25%. The torque required for this larger rudder will also depend upon the chosen slew rate. Torque curves for increasing values of slew rate are shown in Figure 10 and indicates that for the chosen slew rate of 15 degrees per second, the torque requirement will increase by 30%. This can only be achieved by increasing the dimensions of the rudder stock or by specifying an enhanced material specification, or both. Whichever method is adopted, the rudder stock bearings will experience higher loads. In addition the stock will be rotating at a higher rate. It is therefore highly likely that improvements in bearing materials will be necessary. The largest alterations necessary, however, will be in the hydraulic system. Calculations indicate that flow rates in the order of 50 gallons per minute are necessary to achieve the slew rates required, this compares with the present equipment which has a flow rate of around 20 gallons per minute. This represents a flow rate increase of some 250%, requiring a large uprating of both the pump and the motor.

*System Safety*

In order to maintain the currently specified safety requirements it has been necessary to maintain the policy of providing sufficient levels of redundancy. Whilst this does not present a problem in the case of the control system, it does have great significance in the case of the mechanical elements of the system. It has already been established that the motors, pumps and other associated equipment will be substantially larger, and this will obviously impact on the necessary space requirements.

In addition to the need to include high levels of system redundancy, it has also been necessary to include mechanisms in which the stabilization mode

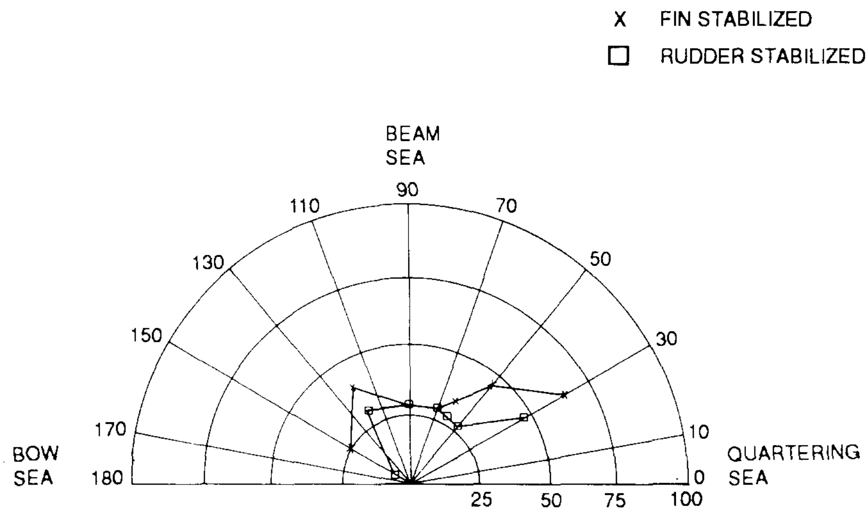


FIG. 4—PERCENTAGE ROLL REDUCTION AT 12 KNOTS

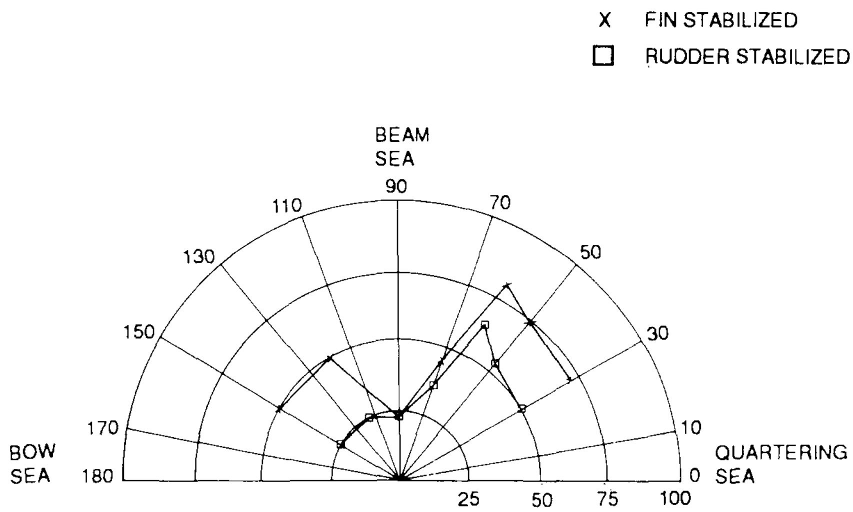


FIG. 5—PERCENTAGE ROLL REDUCTION AT 18 KNOTS

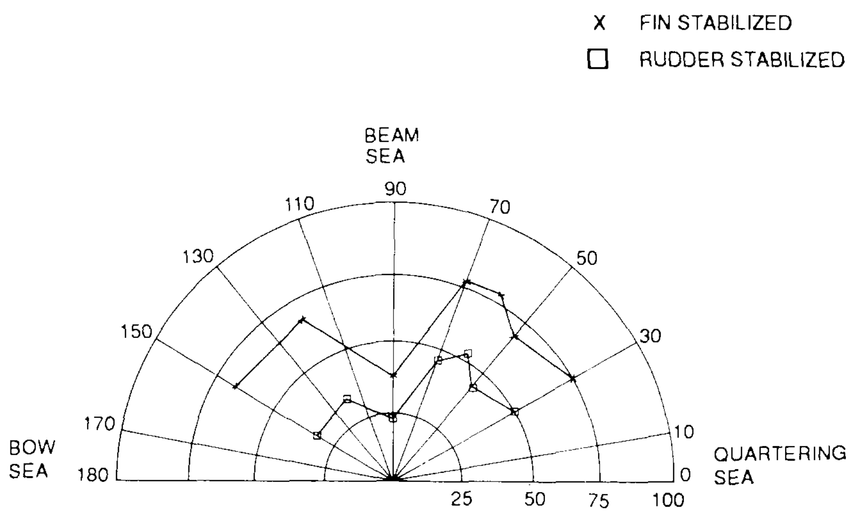


FIG. 6—PERCENTAGE ROLL REDUCTION AT 30 KNOTS

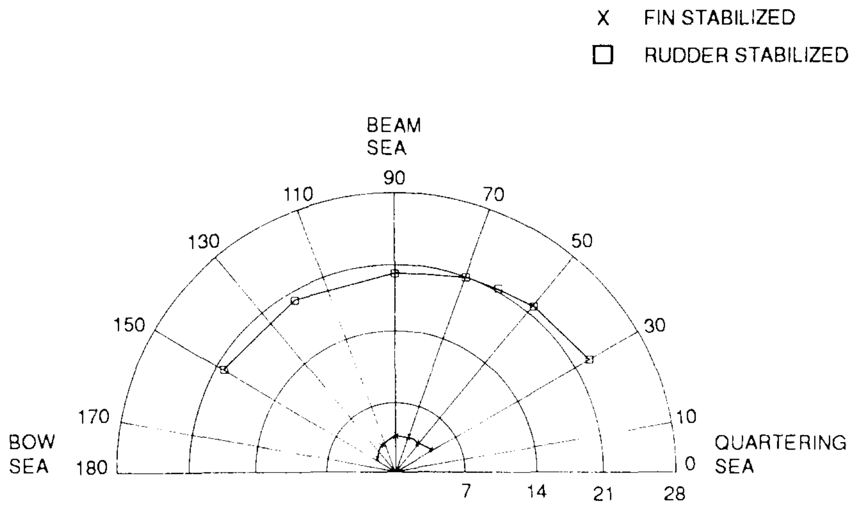


FIG. 7—MAXIMUM RUDDER ANGLE AT 12 KNOTS

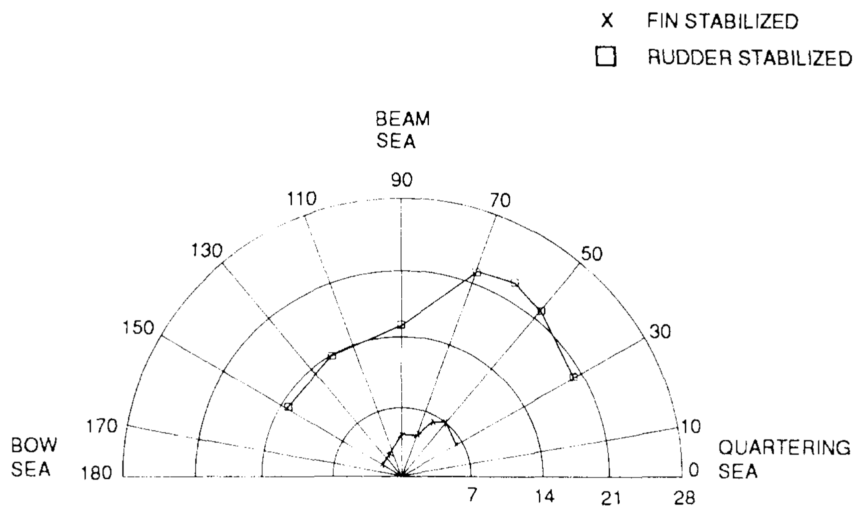


FIG. 8—MAXIMUM RUDDER ANGLE AT 18 KNOTS

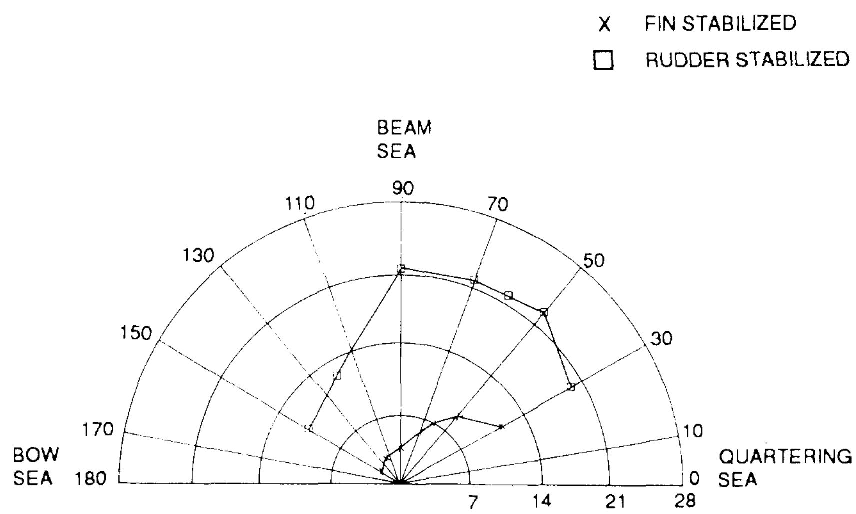


FIG. 9—MAXIMUM RUDDER ANGLE AT 30 KNOTS

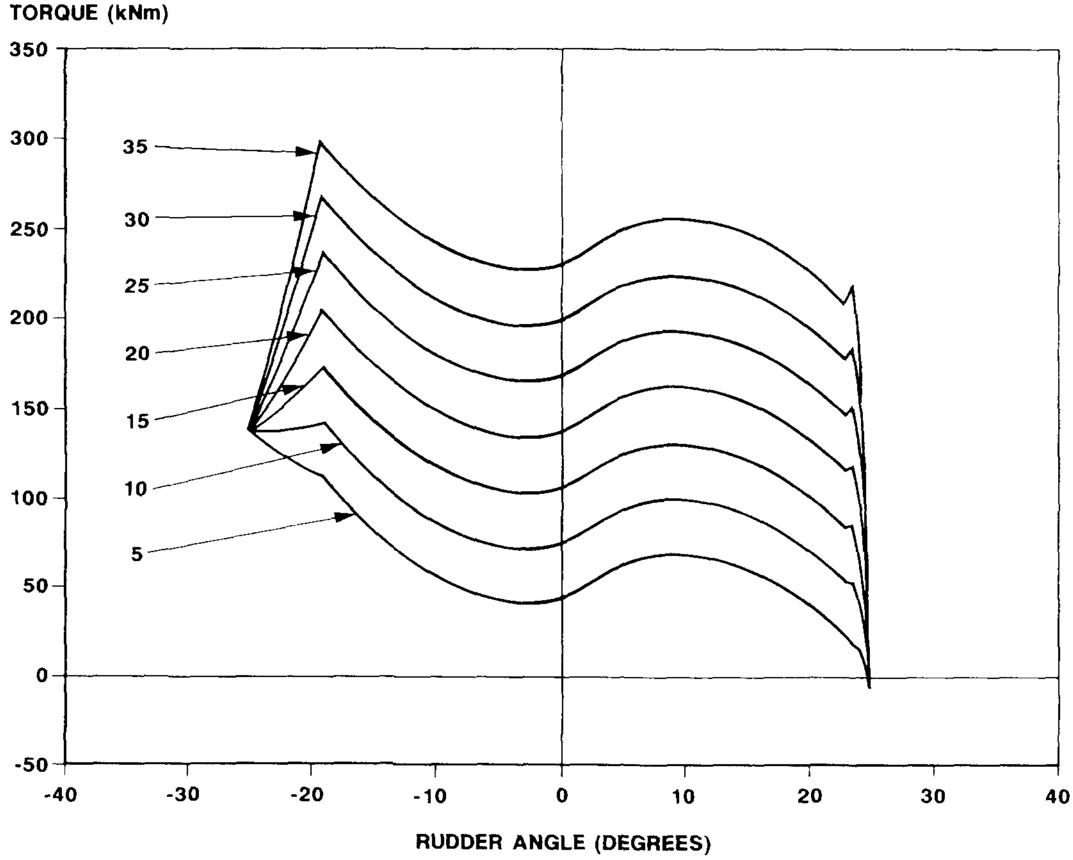


FIG. 10—RRS STABILIZING TORQUES AT VARIOUS SLEW RATES (5 TO 35) IN DEG./SEC. SHIP SPEED 18 KNOTS; STEERING OFFSET ZERO

is disabled under certain circumstances in order that the steering function is not compromised. This will increase the complexity of the control system and have repercussions for aspects of ship and weapon system operation.

*Costs*

It is difficult to draw meaningful cost comparisons between ships fitted with a tangible fin system and a ship fitted with a hypothetical rudder roll system as discussed in this paper. Initial estimates, however, indicate that the cost of increasing the size and complexity of the rudder system is likely to be of at least the same order as that for the procurement of a fin system.

## Conclusions

This study has shown that the rudder stabilization technique can produce worthwhile levels of roll stabilization for frigate sized ships. Despite this, however, the performance available from such a system falls short of that available from the present fin systems.

In order to achieve the performance levels described, changes are required to both the rudder geometry and angular slew rate, with consequent increases in the required space envelope for installation.

In addition, achieving the required safety standards for the primary (steering) function compromises the availability of the secondary (stabilizing) function.

It has therefore been concluded that the MOD would not at present consider substituting rudder roll stabilization for the use of active fins.

However, the study has shown that for small vessels, where active fins would not have been considered and hence no roll stabilization provided, the use of a rudder roll system could be considered.

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# MACHINERY CONTROL AND SURVEILLANCE

## RECENT ACHIEVEMENTS AND FUTURE AIMS

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ABSTRACT

Digital Machinery Control and Surveillance systems are now in operation in the Type 23, the Single Role Mine Hunter, the AOR and the BULLDOG Class update, with digital surveillance systems in VANGUARD and UPHOLDER Class submarines. The appropriate shore trainers are coming in to use. Combination of individual systems into Integrated Platform Management Systems and the use of Intelligent Knowledge Based Systems are being considered.

### Introduction

At the two previous ship control systems symposia[1,2] I gave brief reviews of progress along the technical pathway which has taken Machinery Controls and Surveillance (MCAS) technology from the analogue electronics applications of the 1970s to the exploratory applications of digital systems on shore and then to the decision in 1982 to go to a more embracing digital system for the Type 23 frigate and later the Single Role Mine Hunter.