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This report comprises of two parts. Part one is concerned with the numerical studies carried out to assess the possible use of the rudder for LFE stabilisation of a frigate. Part two is a summary of the hard-ware design for the acceleration signal conditioning to be used in LFE control for the sea-trials.

1.0 Introduction

It has been shown in the previous numerical study (Tang [23]) that LFE stabilisation using active fins can be a feasible alternative to the conventional roll stabilisation strategy. Coupled with the recent renewed interest in rudder roll stabilisation (RRS), this leads to the idea of making use of the rudder for LFE stabilisation (RLS). Intuitively, as the rudder is located near the flight deck, good motion control for the flight deck would be expected with the proper tuning of the rudder control system. In this study, a review on RRS was first carried out, from which lessons were drawn from the experience gained in the development of RRS. A similar procedure to the LFE stabilisation using the active fins outlined in Tang [23] was applied in exploring the feasibility of LFE stabilisation by the rudder. Comparisons were made with RRS to assess the merits of RLS and based on this numerical study, conclusions were drawn.

2.0 Review

Traditionally, course-keeping control and motion control (notably roll motion) have developed along independent lines. The rudder has been used solely for heading control, and active fins, for example have been traditionally been used for suppressing only roll motions. However, during the early days, some active fin systems were found to interfere with the steering control of a ship. This stemmed from the fact that the fins would produce a net yawing moment if they were not placed near the longitudinal centre of gravity (l.c.g.) and also if they had a relatively large angle of depression. This was really an indication of the inadequacy of the traditional single input/output approach, which ignored the cross-couplings effects in the motion characteristics of the ship. However, this undesirable interference effect can be overcome fairly easily with proper fin configurations. For example, a pair of fins can be placed fore and aft of the l.c.g., producing only small net yaw moments, or using one pair of fins near the l.c.g.. In the case of rudder induced roll motion, it can be said that the first major reference was published in 1970 by Taggart [22]. In this paper, excessive ship rolling was reported to have been caused by the rudder, which was under auto-matic steering control. This type of rudder induced roll motion was first noticed in a high speed cargo ship, which had a large rudder, powerful steering machinery and an automatic steering control system. Similar ship types are susceptible to this undesirable steering behaviour. However, the importance of this work lies in the fact that it registered the potential use of the rudder as an anti-rolling device, which initiated the research and development of RRS.

In the early to mid-seventies, the potential use of the rudder for roll stabilisation was mainly explored by the British researchers, for instance, Cowley [9,10,11], Carley [8] and Lloyd [17]. Two major factors were recognised for RRS to be a viable stabilisation scheme. Firstly, the side force generated at the rudder acts below the centre of gravity of the vessel which provides a moment arm aganist rolling; and secondly, the natural roll frequency is at a frequency much higher than the frequency at which yaw oscillations are dominant, which allows an effective decoupling of the two motions in designing the controller. In these early studies, model testings, numerical studies and sea-trials were conducted to assess the feasibility of RRS. From the work by Cowley and co-workers, initial studies carried out with model tests and numerical models suggested that RRS was quite effective but was not as good as tank stabilisers. Compensators were needed in the control circuit to improve system performance, and roll rate feedback was recommended. On the whole, together with the experience gained from the sea-trials, it was suggested that RRS was good for ships with small GM, low roll damping and relatively long roll period. Hence, RRS seemed to be of limited application and interest.

However, it was the prediction of the destabilising behaviour of RRS on ship motions that had temporarily dampened the development of RRS. In Carley [8], a detailed study on the behaviour of the control characteristics of RRS was carried out using classical control theories, in which the transfer functions for the roll and yaw dynamics of a frigate were derived from sea-trials. In this work, the interactions between the course-keeping and sea-keeping functions of RRS were analyzed. It was found that there were strong cross-coupling effects between roll and yaw control using the rudder. This was particularly pronounced when the excitation frequency was about 0.02 Hz, where roll motions was excited due to the yaw response of the vessel. Basically RRS was only effective in suppressing roll motions around the roll natural frequency. At frequencies either above or below this frequency, the RRS system tended to amplify roll motion! Worse still, manual steering would also experience difficulties. The destabilising behaviour of RRS was also predicted by Lloyd [17], in which the numerical study was based on manoeuvring equations. This low frequency of encounter corresponded to a ship travelling at relatively high speed in quartering seas, which could increase the chances of the broach-to instability.

Despite the unfavourable findings of these works for RRS, it has nevertheless laid the groundwork for subsequent research into RRS. So far, the main concern has been with cargo ships and naval vessels. In Van Gunsteren [31], based on some full-scale experiments, it was suggested that RRS for small craft could be a promising alternative for reducing roll.

In the mid- to late seventies, research on RRS has mainly been carried out as part of a global program that examined the integrated control system of a ship. This approach was first advocated by Carley [7], in which the cross-coupling effects between yaw and roll motions were discussed and an integrated control system strategy to ship motion control was recommended. Broome [5,6] carried on along similar lines in examining the yaw-roll interactions of a merchant ship. It was suggested that, for the particular ship studied, the rudder would have about 16% of the effect of the fin stabilisers in influencing ship roll and that considerable improvements can be obtained if ship control systems are designed to reduce the interaction effects. The numerical model studied by Eda [12] has also high-lighted the strong coupling interactions between yaw, roll and the rudder in high speed operations. Using modern control theories, the work by Whyte [32,33] had in some ways injected new ideas and interests in RRS by re-iterating the feasibility of RRS. In these studies, various feedback signals to the fins, rudder and the combination of fins and rudder were examined based on optimal and sub-optimal design.

An optimal design is one which all the state vectors in the state space model of the system are used in the feeback loop, whilst sub-optimal design refers to the case whereby only some of the state vectors are used for feedback. It was found that, in general, roll rate was the most important feedback parameter.

The renewed interest in RRS over the last decade and the subsequent successful installation of RRS system on-board ship could be said to have been sparked off by the work published in Baitis [1]. This work was the culmination of five year's research and development into RRS system for naval ships. The feasibility of RRS as an anti-roll device was successfully demonstrated in sea-trials with roll reduction up to 50% of r.m.s. motions. Roll rate feedback was the best compromise for simple control, when adaptive controllers were not available. It should be pointed out that the ship speed for the sea-trials was about 15 knots, which was far from the speed at which destabilising effects were suggested in Lloyd [17]. Following the recommendation in Whyte [33], Schmitke [21] performed some numerical studies on RRS using a ship motion computer program based on strip theories. Comparisons were made with an active fin system. Despite the better performance of the fin system in terms of roll motion reduction, it was suggested that this performance could be matched by up-grading the rudder actuator dynamics. The low cost in up-grading the rudder system would make RRS an attractive option. One important aspect in this work was the use of a band-pass filter, which effectively suppressed all the frequencies away from the roll natural frequency band. This may not be a easy task in practice as filters would incur phase-shifts in the system and also attenuation of the input signals.

At this stage of the RRS development, new impetus from the Swedish and Dutch has carried the concept of RRS back to the fore, and eventually brought to its practical realisation in the late 1980s. The Swedish effort can be summarised in the papers by Kallström and co-workers [13,14,15]. From their work, it was suggested that the minimum ship speed should be at least 10 knots and a rudder rate of 4 °/sec if RRS were to be effective. In general, 40 to 60% reduction in roll could be expected. The control system made use of a digital adaptive controller, which automatically optimises the demand signal for the specific sea condition or operation. This system seemed to have overcome the destabilising effect of RRS as demonstrated in sea-trials using a 35m fast-craft running at 35 knots in quartering seas. From eight ship years' operation of the RRS system, good performance has been reported across the range of ship types. The roll rate and roll acceleration signals have been used for feedback.

The Dutch work has been fairly well-documented in a series of papers by Van Amerogen et al [24-29] and Van der Klugt [30]. In their approach, model tests, numerical models and sea-trials were performed during the course of the development. The main problem discussed was rate saturation, which was due to the fairly sluggish rudder servo dynamics. It was suggested that a rudder rate of 15 °/sec would be required for RRS systems. During some sea-trials, the destabilising effects due to high speed operations in quartering seas were encountered, which high-lighted the limitation of the controller. This brought about the design of the adaptive gain control, which overcome the rate-saturation problem as well as providing optimal control gains.

The Danish installation was reported in Blanke [4], in which a new naval vessel was designed with three rudders for RRS purpose. The centre rudder was solely for course-keeping, whilst the port and starboard rudders served dual purposes - steering and roll stabilisation. From the sea-trials, it was shown that roll reduction of 35%-40% in quartering seas, 95% in beam seas and 50%-60% in bow seas were obtained. The roll-rate and roll angle were used for the feedback control. In this approach, it seems that the conventional fin system is merely replaced by two rudders with a more complicated control strategy.

Despite their early success with the prototype trials, the American team is still exploring the RRS system for different ship classes (see Baitis et al [2,3]). From their operational experience with the proto-type, it was found that rudder rate-saturation was a serious problem. A digital controller was used to up-grade the control system in order that optimal control could be achieved. A band-pass filter for roll-rate feedback was also experimented, but the phase-shift in the signal has made it an unworkable option. Instead, a high-pass filter was used to eliminate the low frequency interference to steering, and phase advance was also needed to copensate for the additional phase-lag incurred. For good roll reduction performance, it was suggested that a non-dimensional damping value between 0.35 to 0.5 would be desirable.

In a recent paper by Powell [18], it was concluded that the RRS approach is not advisable for the British Navy as the performance of RRS using existing steering equipment does not compare favourably with the active fins systems in service. This negative view seemed to have been derived mainly from the low rudder rate of 3 °/sec used for the study. However, the work by Roberts[20], in which the main interest was to study the yaw-roll interactions may bring forward a more favourable view of RRS or at least rudder assisted roll stabilisation to the RN.

Although successful RRS installation has been reported, research on RRS controllers is still quite active, for example Katebi [16] and Zhou [34]. In Katebi [16], different types of feedback control were explored using modern control theories. It was founded that roll-rate plus roll angle has limited advantages, roll angle and roll acceleration feedback interfere with steering, but that roll-rate alone was preferable. In Zhou [34], non-linear roll-damping could be taken into account, which made use of modern control theories and a technique called linear recursive prediction error. With continual research and refinements, the second generation RRS systems could be improved still further.

3.0 Numerical study and Discussion

It can be said that the main aim of LFE stabilisation is to reduce lateral accelerations on-board ship in order that crew members can perform their task more readily in supporting helicopter operations on the flight deck. This means that the demand for LFE stabilisation is basically of a short-duty cycle nature. Therefore, in the first instance, this study should concentrate on applying the existing rudder equipment before exploring other possibilities, such as requirements on rudder performance for effective RLS. As is evident from the review that, quite a combination of feedback signal have been suggested and used for RRS, namely roll-rate, roll-rate plus roll angle, roll rate plus roll acceleration and even sway velocity. However, by far the most often recommended feedback was roll-rate, which is simple and easy to obtain. Hence simple roll-rate and LFE-rate feedback to the rudder will be studied in some detail.

The low rudder rate has posed some problems to the effective use of the rudder for stabilisation purpose, as phase-lag would set in at high frequency, altering the phase of the stabilising moment in such a way that motion amplitudes would actually increase. To avoid rate-saturation, which is a non-linear problem, the rudder-rate limit, which is quoted as 6°/sec in Roberts [20], should not be exceeded. This corresponds to a r.m.s. value of 2.8°/sec for 10% exceedance. Furthermore, according to Amerogen et al[26], the rudder-rate would impose a limit on the maximum rudder angle possible, which is related to the roll natural frequency and rudder rate of the vessel. In the present study, this rudder angle limit would be about 10°, which corresponds to a r.m.s. value of about 4.5°. From the simulations, in most cases when the rate limit was staisfied, this amplitude limit was also satisfied.

3.1 Forced rolling

Unlike the fin forced roll option within the sea-keeping program, which has been reported to give reasonable comparisons to sea-trial data, the rudder forced roll predictions have not been given much attention. Therefore, the first task would be to establish some confidence in the computer program predictions with the rudder. Fig.1 shows the rudder forced roll response of two frigates. The sea-trial data are for Newship, which was used in the last study (Tang [23]), whilst Nk denotes the vessel for the LFE trials. It can be seen that the computer model agrees quite well to the measured data. The good comparison is somewhat fortuitous as the wake and the effect of the propeller are not modelled. However, from a ship dynamic view-point, it would not be unreasonable to make a comparative study based on this model, especially when low frequency yaw-roll interaction is so well predicted. As for the ship Nk, the roll response spectrum has a wider band near the resonant frequency, which suggests that this vessel would be susceptible to a wider range of wave excitation frequency. The yaw responses are given in fig.2, which are typical of the sea-trial data from other classes of frigates. There are only small differences between the two ships and the steering characteristics of the two ships should be very similar. Fin forced roll was also performed in order to have a feel for the effectiveness of the rudder. It can be seen in fig.3 that for Newship, rudder is as effective as the fin in forced roll, whilst for Nk the rudder is in fact more powerful. Therefore, if additional roll stabilisation is needed in Nk, the rudder should be considered.

3.2 High speed destabilisation

It was pointed out in Carley [8] and LLoyd [17] that roll amplification would occur at low frequency of encounter with RRS. In order to check this effect, the computer model was run at 15 and 30 kts at various wave angles with a roll rate feedback of 5 (compare to traditional 2.5.2 control in fins). The results for Newship are given in fig.4-6. It is apparent form fig. 4. and 5 that while good reduction both in roll and LFE were obtained at 15 knots, motion amplification did occur in the quartering seas region when the ship is running at 30 kts. This corresponded to the 0.02 Hz predicted in Carley [8] and Lloyd[17]. From fig.6, the rudder-rate response did not show any abnormal behaviour in the quartering seas region and in fact the activities were relatively low. Generally speaking, roll and LFE reduction was about 30 to 40%. A similar simulation was performed with Nk (fig.7-9). The results shown similar trends to those with Newship, in which instability was also encountered at low encounter frequency. However, the rudder activities were higher in achieving a similar level of motion stabilisation to Newship, which indicated that the performance of the rudder system in Nk could be improved.

3.3 Tuning for RLS

Following the tuning procedure given in Tang [23], the rudder system was tuned for LFE stabilisation. It has been suggested in Lloyd [17] that the roll angle gain should be zero. However, it was found that in general, the roll angle gain derived form the tuning procedure is fairly small near the roll natural frequency. Also, if the k1 term was set to zero, negative gain term for k2/k3 would result. Furthermore, some preliminary comparisons with the two cases did not show any major differences when the motions near the natural roll frequency was examined. Because of these factors, the three term controller has been used. As the last LFE stabilisation was based on Newship, coupled with the better performance of its rudder, it was decided to use Newship again in this part of the investigation.

It can be seen in fig.10 that, unlike tuning for the active fins where a minimum response was found at certain tuning frequencies, the resulting LFE seemed to lessen with decreasing tuning frequency. This should not be realisable in practice as at low frequency, the yaw induced roll interference would put a lower limit to the tuning frequency. In order to select the *best* tuning frequency, it would be easier to make a comparison of the different sets of tuning in a sea-way. In this comparison, the ship speed was set at 20 kts. The gain levels were selected by trial and error till the rudder rate at beam seas would be just below the rate limit of 2.8°/sec. This was a rather time-consuming process and therefore in some cases, as can be seen in fig.13, the maximum demanded rate is slightly above the limit. The resulting LFE and roll responses with different tuning are given in fig.11 and fig.12, where case B denotes the lowest tuning frequecy whilst case G denotes the highest tuning frequency. As evident from the responses variation among different tuning, it has followed a similar trend to the tuning curve in fig.10 i.e. more reduction can be achieved at low tuning frequency. Slight destabilising effects are shown in the high frequency tuning cases. Therefore one may conclude that the lowest tuning frequency should be used. However, as suggested earlier that the lower tuning frequency would interfere with the yaw motion, it should be possible to show this from the simulations. One way to assess this would be to look at the response spectrum value for yaw response at the lowest frequency component. If yaw motion is affected, the spectral value would increased. A plot of this yaw response value for different tuning are given in fig.14. It can be seen that, indeed, the lowest tuning frequency has the highest yaw response, especially in the quartering sea region which has a value almost four times the unstabilised case. Therefore, in deciding which tuning frequency is best, the yaw response in RLS should also be taken into account. Judging from fig.11,12 and 13, case C would be a better compromise.

To check for destabilisation at high speed, the ship speed chosen was 30 kts, and the same procedure to the 20 kts case was followed. In fig.15, the destabilising effect of RLS in roll is strongest with low tuning frequency at quartering seas, but the margin is not excessive when compared to the RRS case in fig.5. Also in fig.16, the LFE response shows quite favourable reduction for the low tuning frequency cases. Furthermore, from the rudder rates in fig.18, the demand shows fairly acceptable variation for the low frequency tuning. The yaw response at low frequency has increased compared to the 20 kts, but the trends are very similar. From the rudder rate response in both speeds, it is quite clear that highest rudder demands are in beam seas. However the worst roll and LFE response are at quartering seas. So if the gain can be increased in this region, the RLS can be made more effective. By the same token, if destabilisation is sensed, a reduction in gain should alleviate the situation. Hence an adaptive controller is desirable if RLS were to perform more effectively. This is not dissimilar to the automatic gain control of the Dutch RRS system.

3.4 RRS and RLS comparisons

Having obtained reasonable performance from RLS, the next step would be to explore the rate feedback option to see how these RLS alternatives compared with the conventional RRS approach.

A ship speed of 20 kts was used in these simulations and the rudder rate was adjusted as in the last section. Fig.19 and 20 show that roll rate feedback in RRS performs far better than RLS, and that the three term feedback is better than rate feedback in RLS, both in terms of LFE and roll reduction. The rudder rate (fig.22) in RRS shows a fairly broad response, counter-acting roll in most headings as compared to a very high demand at beam seas for the RLS system, which has little influence at other headings. The yaw response in fig.21 also suggests better performance by RRS. A comparison of the response spectrum from RLS and RRS may reveal the reason for the difference in performance. In fig.23, the roll and rudder spectrum for the two strategies in beam seas are shown, where the l denotes RLS and the r denotes RRS. It is obvious that the rudder in the RRS case counteract the roll motion far better especially near the roll natural frequency. Near this frequency, the rudder activities in RRS is about five times the corresponding RLS system value, whilst the rudder in RLS shows a relatively high response at high frequency, which does little to suppress the dominant rolling near the natural period. This high rudder response at high frequency is almost certainly due to the sway term in the LFE feedback.

The ship speed was increased to 30 kts in order to compare the severity of motion destabilisation in the different cases. From fig.24 and fig.25, destabilisation in RRS is more severe in terms of magnitude, while in the RLS systems, it tends to affect a larger range of headings, i.e. frequency of encounter, but with lower destabilisation level. The yaw response in fig.27 shows similar features to the 20 kts case in fig.21. The response levels are 30%-70% higher at this speed. The rudder rate in RRS has decreased with increasing forward speed, whilst in the RLS system, rudder rates show a marked increase in activities near the bow seas region. Therefore, different feedback controls exhibit different speed dependencies.

In a conventional active fin system, there is an automatic speed dependent gain to optimise fin operation. This gain generally reduces with increasing speed. In the case of the rudder, a similar speed dependent gain should apply. Different feedback gain levels were then applied to the RRS system to ascertain the effect of gain level on the motion. The results are given in fig.28-30, where the '+' sign denotes twice the gain level i.e. 10 and the '-' sign denotes half the gain. Increasing the gain, causes motion destabilisation to become more severe, whilst a reduction in the gain alleviates the situation. However, the destabilisation is still present. The rudder rate in fig.30 shows that the response does not vary linearly with the gain.

Conclusions

Some experience on motion stabilisation using the rudder has been gained using the sea-keeping program. The two stabilisation strategies, namely rudder roll stabilisation RRS and rudder LFE stabilisation RLS, have been investigated and comparisons have been made to assess the two approaches. Based on the simulations, the following conclusions are made:

(i) The rudder forced roll option in the sea-keeping program gives reasonable roll motion prediction. The destabilisation effects of RRS at low encounter frequency has also been predicted, which is consistent with results from earlier works. This has further increased the credibility of the sea-keeping program for rudder application.

(ii) On the whole the RRS approach performs better than RLS, in terms of motion reduction, rudder response and the likelihood of steering interference. However, motion destabilisation at high speed in the RRS system is more severe compared to RLS.

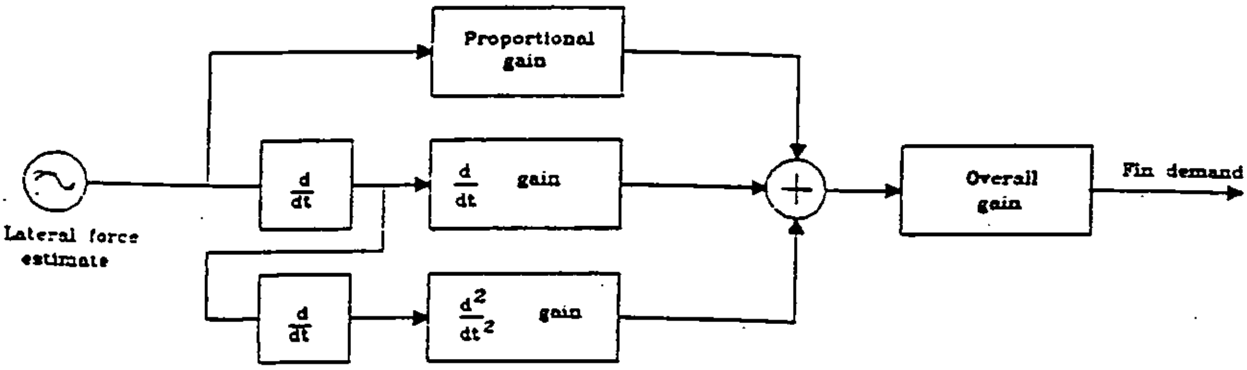
(iii) The tuning procedure that has been adapted from the active fin system gives reasonable feedback gains for motion reduction in the RLS system. The level of motion reduction is better than those derived from simple rate feedback control for the RLS strategy, but the likelihood of steering interference increases.

(iii) Despite the relatively low rudder rate imposed, the RRS system with roll rate feedback gives reasonable motion reduction (30%-40%) at 20 kts ship speed. The destabilisation effect at low frequency encounter could be lessened with the *correct* control of the gain level.

This part of the report briefly describes the design and components of the electronic hard ware that modifies the LFE signals into a suitable form for the fin stabiliser controller supplied by Brown Brothers Ltd. The design criteria and some of the limitations governing the design are discussed.

The fin stabiliser controller supplied by Brown Brother Ltd. is a relatively modern system, which makes use of digital control as compared to the analogue circuits employed in the conventional controllers in the RN. This new design has imposed greater demand on the accurate design of the LFE circuitry as well as the complexity.

According to Brown Brothers Ltd., the LFE signal input will be processed as illustrated in the diagram below:



The LFE signal input to this system has to be in synchro form, which is basically a digital interface signal required for the computer based controller. The analogue signals from the accelerometer therefore not only have to be conditioned in additional circuitries for the interface, but also needed to be converted into digital form. Once the signal is in digital form, another converter is needed to convert this digital signal into the required synchro form. This process is quite complicated compared to conventional analogue designs. An illustration of this signal process is given in fig. 2.1. This signal process will be described in two parts, which deal with the analogue and digital circuits separately.

Analogue Signal

This part deals with the accelerometer, the signal conditioning circuitry and the power supply.

(i) Accelerometer

For the sea-trials, the accelerometer should be robust, of high accuracy and resolution with low noise properties. Above all, it must be of high enough quality for control purposes. The linear accelerometers produced by Schaevitz have been suggested to have the required standard as some of the products have been used in control systems. The accelerometer A223 $\pm 1g$, with a natural frequency of 95Hz from the LSB series has been selected. Apart from the required properties, it can also withstand 100g shock loading, which would be a desirable feature in the sea-trial environment. However, the accelerometer should be protected from sea water.

(ii) signal conditioning

Under the sea-trials conditions, the accelerometer would register signals from a wide spectrum of frequencies. A band pass filter should be used to limit the frequency to the region relevant to the motion control otherwise unnecessary demand on the controller would degrade the stabilizer performance. A high pass filter ($>$ 0.002 Hz) is used to remove the very low frequency components, which are effectively d.c. signals. This is compatible with the controller function which does not compensate for list. A low pass filter ($<$ 10 Hz) is used to remove high frequency signals, which could arise from ship vibrations. From computer simulations, the response from these filters have a linear range between 0.01 Hz to 7 Hz (see fig.2.7). The phase response should also be good so that phase-lag would be minimal. Fig. 2.8 shows good time response. As yaw response is about 0.02 Hz and high frequency motion would be much less than 1Hz, the frequency range of the filters are adequate. A gain control is needed for the final tuning of the signal level for maximum sensitivity but at the same time within the overloading limits. The gain control range is designed between $\pm 0.2g$ and $\pm 2g$ for ± 5 V output, the voltage limit for the analogue to digital converter. This range was selected on the basis that the maximum acceleration level would be 0.5g corresponding to a roll angle of 30°. To prevent overloading from excessive motions, power failure or accidental stray signals, a clipping circuit for ±5V was installed before digital conversion. An overall impression of this analogue signal process can be seen in fig. 2.2.

(iii) power supply

A stabilised and regulated power supply is essential for the safe operation of the digital and analogue circuits of the LFE signal hardware. The power supply unit should prevent spikes and high voltage surges in the main power supply on-board from damaging the electronic hardware. The design of this power supply unit is shown in fig. 2.6.

Digital Signal

This part deals with the analogue to digital converter (ADC), the digital to synchro converter (DSC) and the functions of the necessary hardware required to operate this signal process.

(i) ADC converter and auxiliary circuit

The selection of this piece of electronic hardware is normally quite straight forward. However, due to the high accuracy required by the controller, a minimum of a 14 bit signal is necessary. A 16 bit converter would complicate the auxiliary circuit requirements further, whilst a 12 bit converter would degrade the resolution. The main concern in designing the auxiliary circuit is to remove stray glitches such as narrow spikes within the digital system. To achieve this, the sample and hold is triggered to hold the level of the analogue signal. After a short time delay the A to D is triggered to convert analogue level stored in the sample and hold. As the A to D takes a set time to convert the input to digital outputs, a time of at least twice this value is delayed before triggering the temporary store. This pulse is narrow, so that the possibility of a change in the sample and hold level or false bits from the A to D or any other spikes in the analogue signal, that occurs at the same time as this pulse is very remote. The sample and hold circuit is then released to follow the input signal until triggered again. The cycle time taken is one millisecond. This time should not introduce any significant phase delay into the signal. The temporary store is required before the D to S because the digital outputs from the ADC cannot be guaranteed to remain stable during conversion. A clock pulse is needed to synchronise the sample and hold and the trigger and store operations described above.

(ii) DSC converter

The DSC converter is a specialist chip which converts the digital signal into an analogue three phase signal for the controller. For synchronisation purpose, a reference source from the ship is required. For detail information of this chip, the manufacturer's manual should be consulted. Fig. 2.5 shows some of the main signal input\output ports. An overall view of the signal process is shown in fig.2.2.

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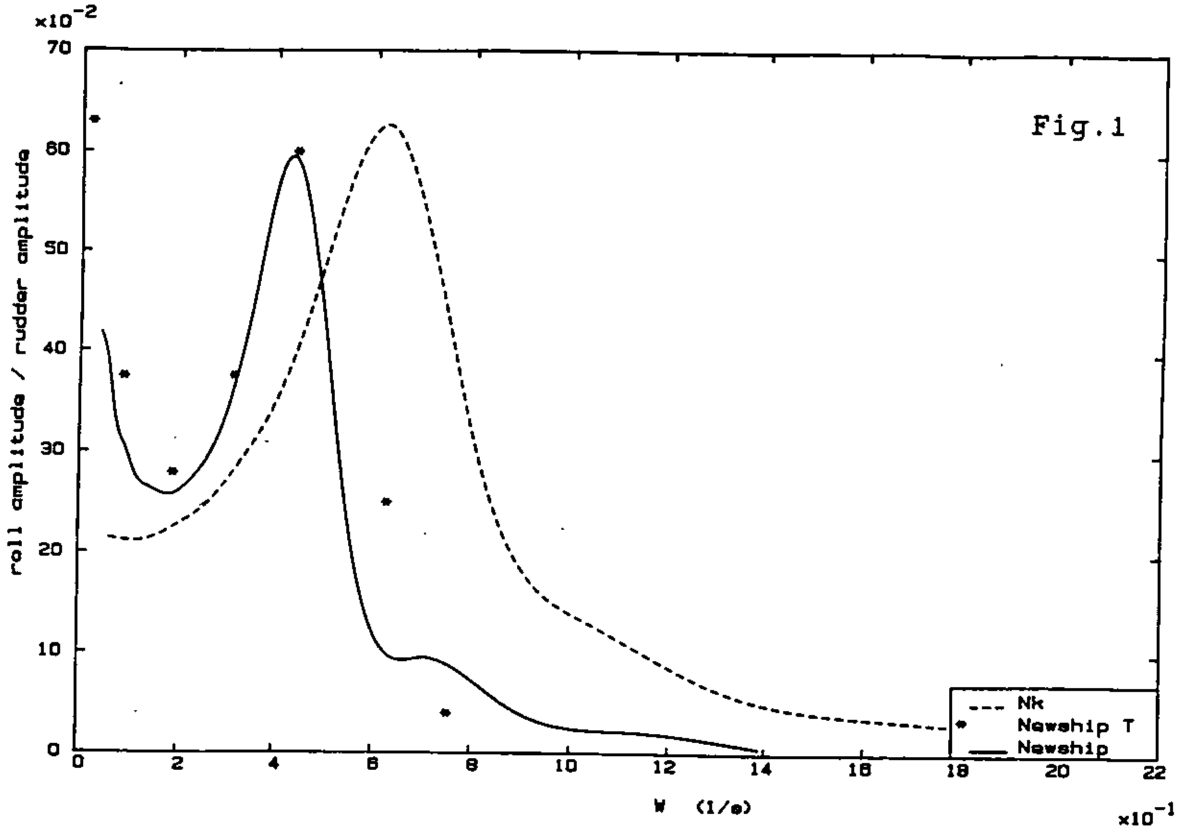
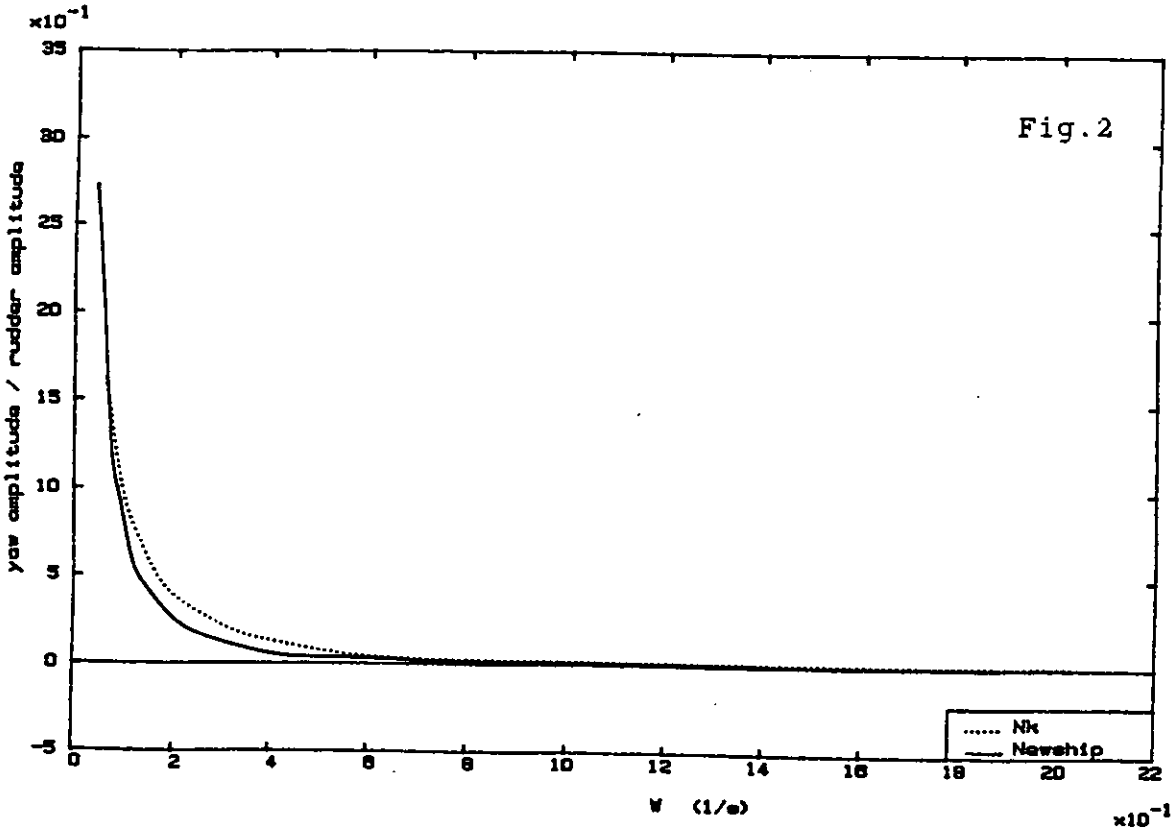


Rudder forced roll response



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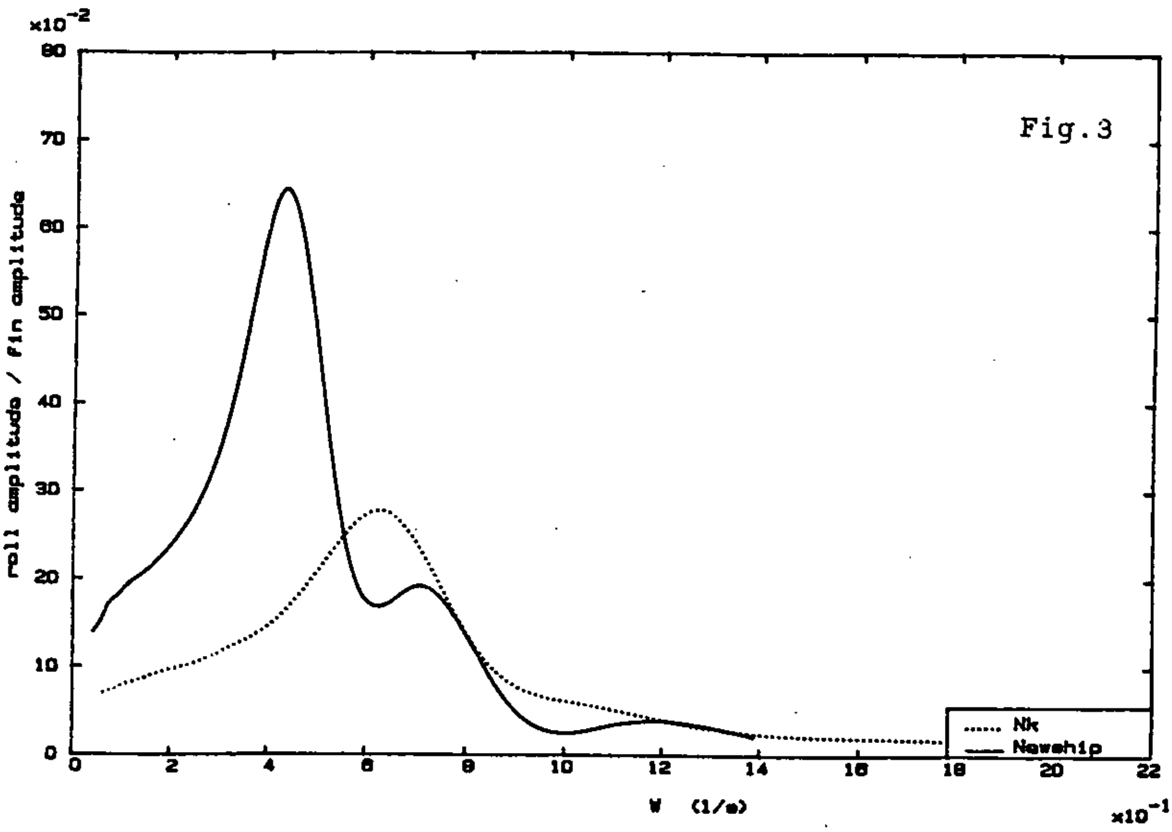
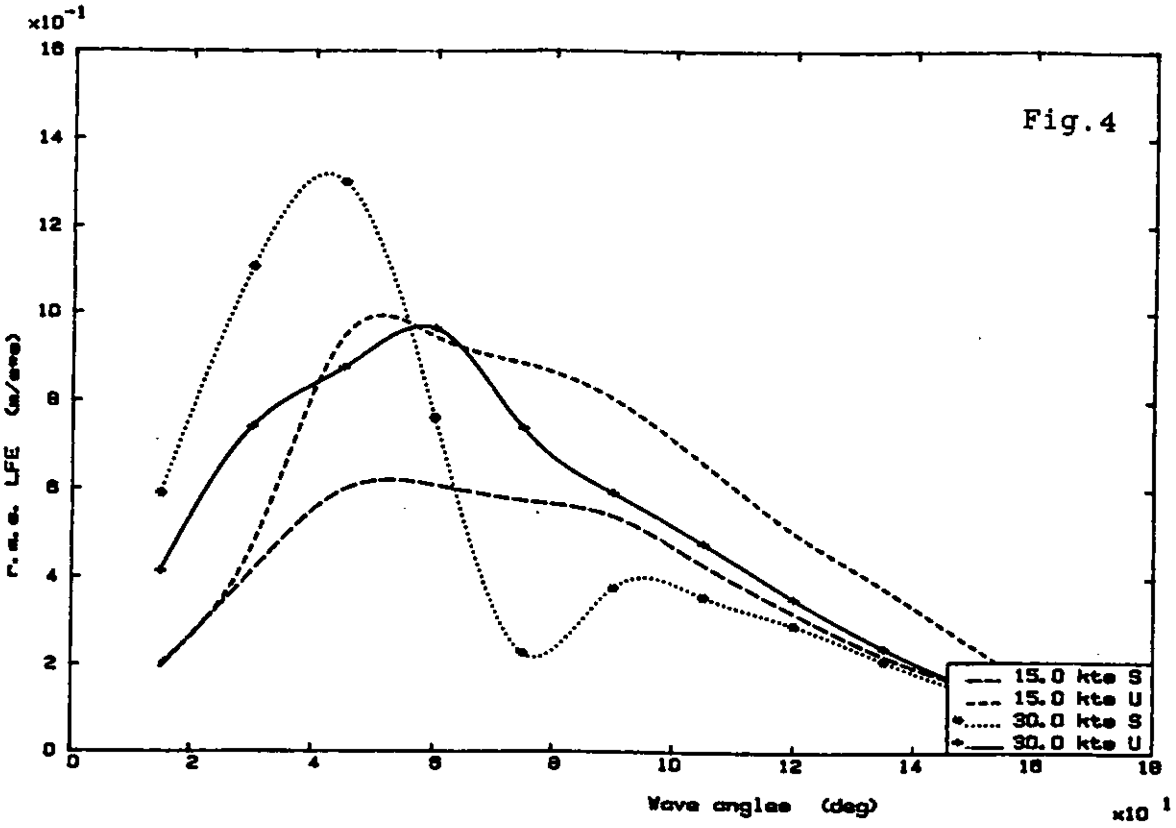
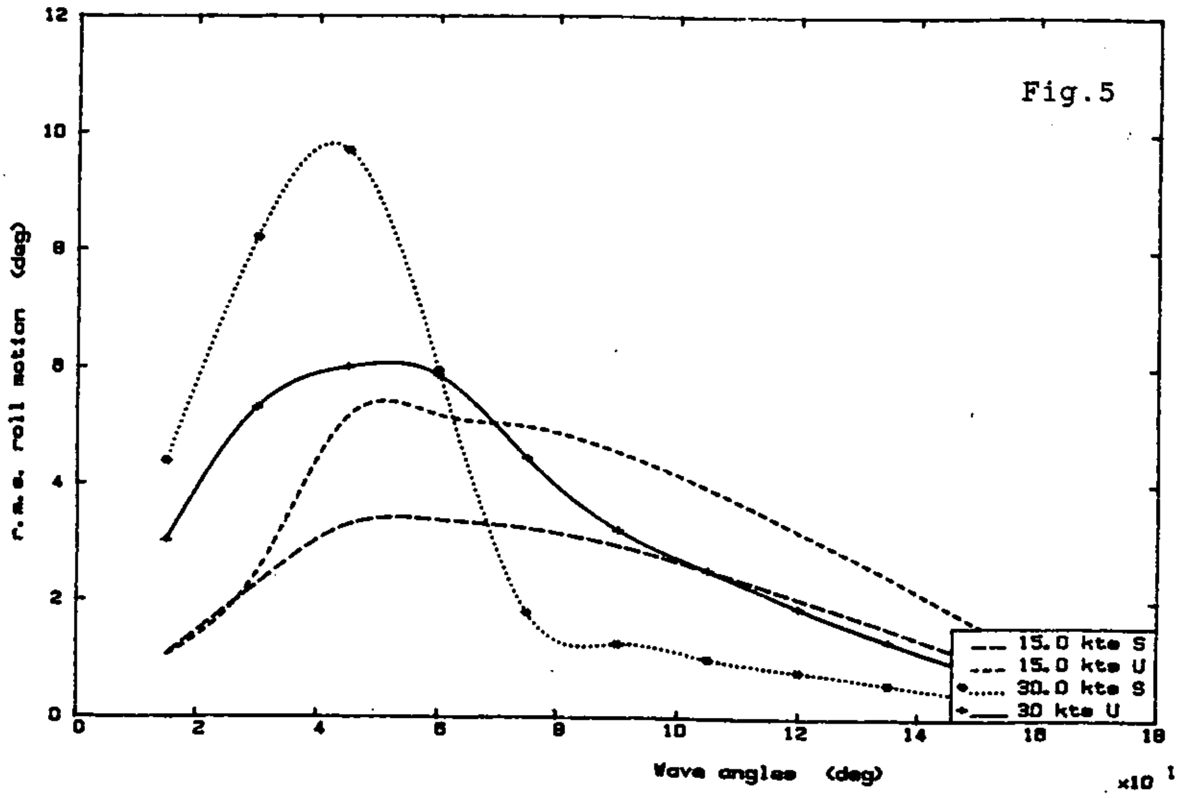


Fin forced roll response 20 kts



LFE response with rudder stabilisation 5.5m 12.4sec Newship



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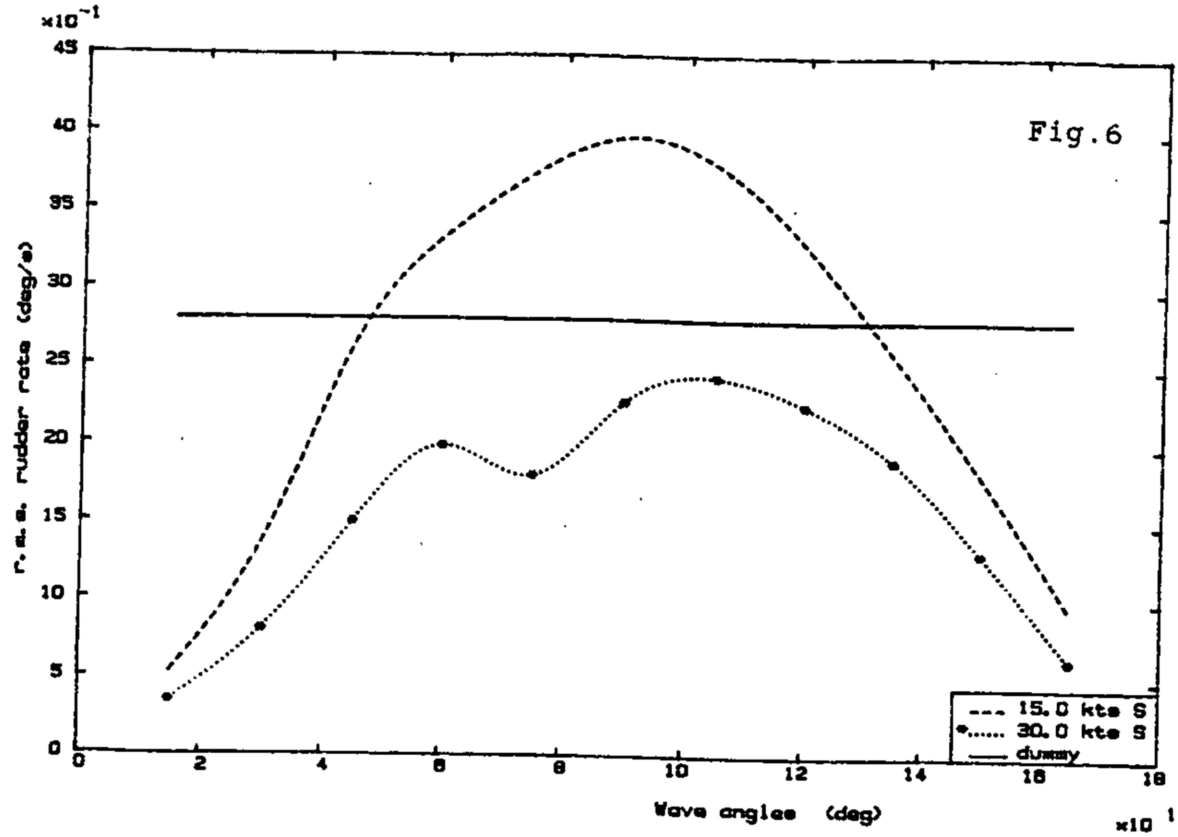
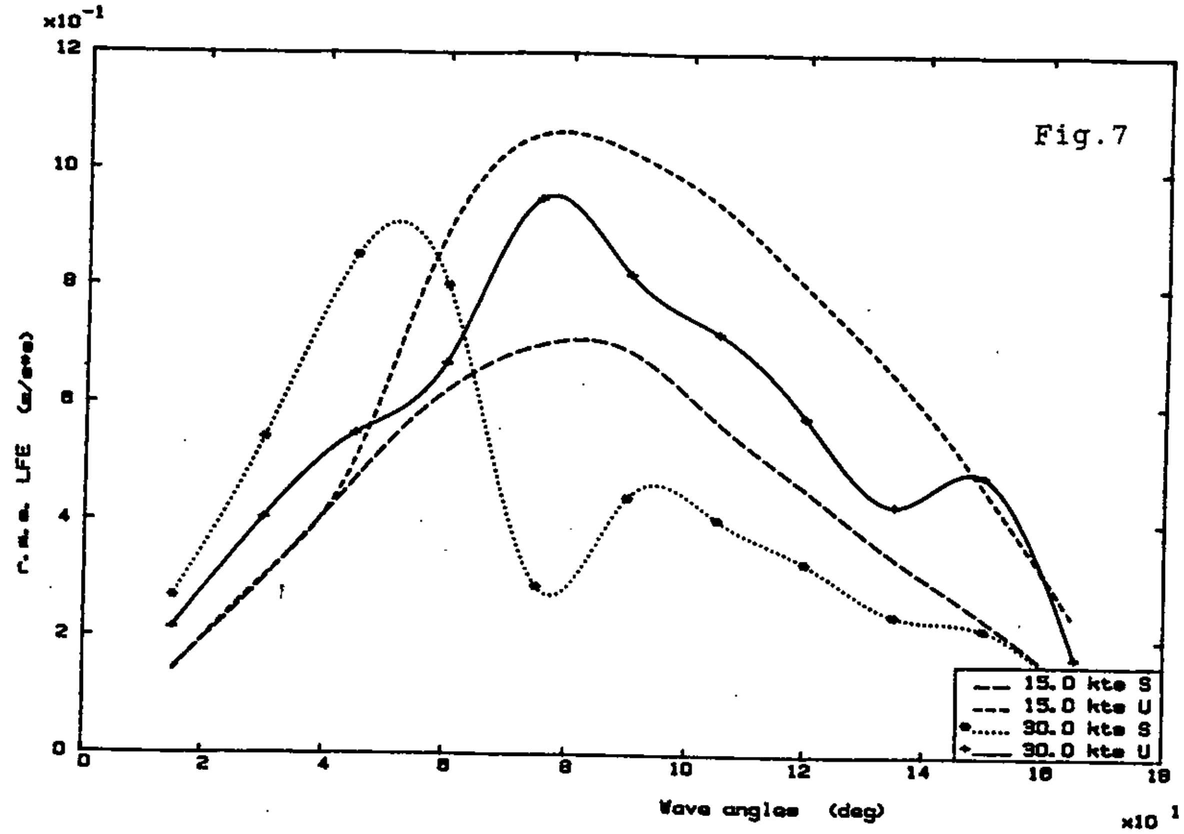
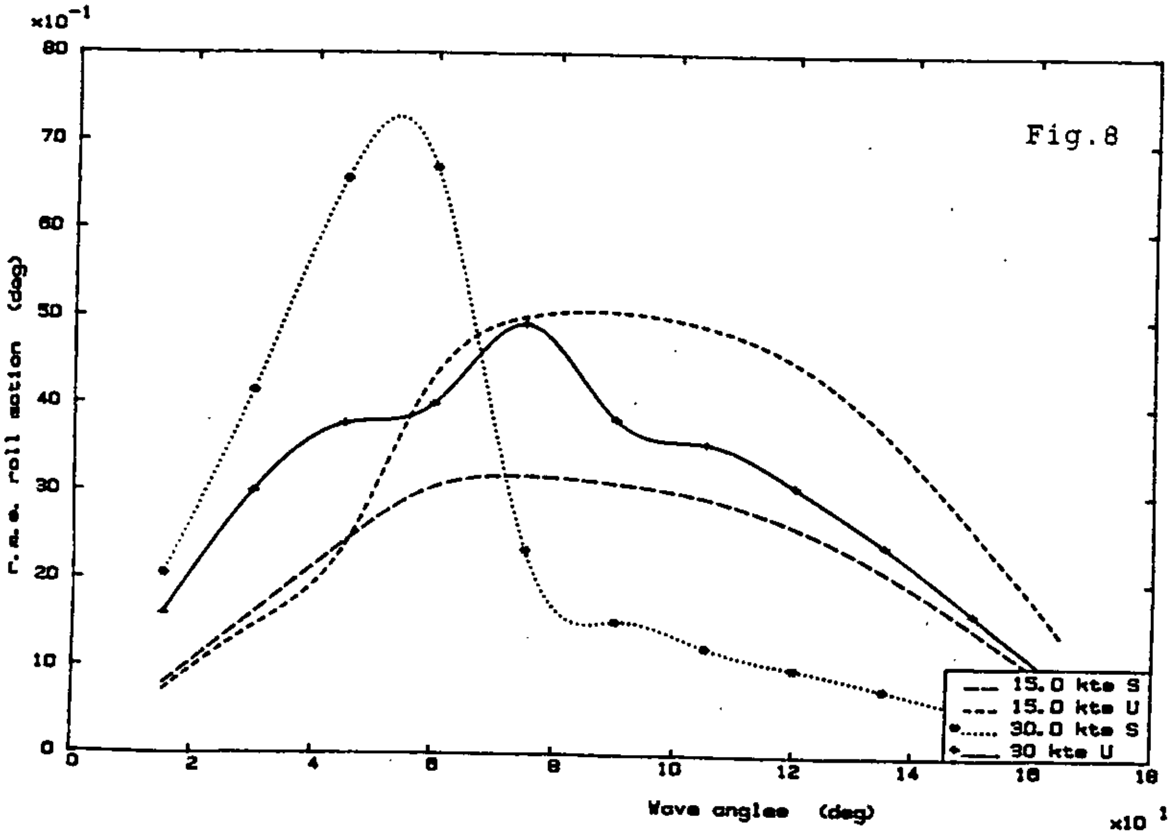


Rudder rate response with rudder stabilisation 5.5m 12.4sec Newship



LFE response with rudder stabilisation 5.5m 12.4sec Nk



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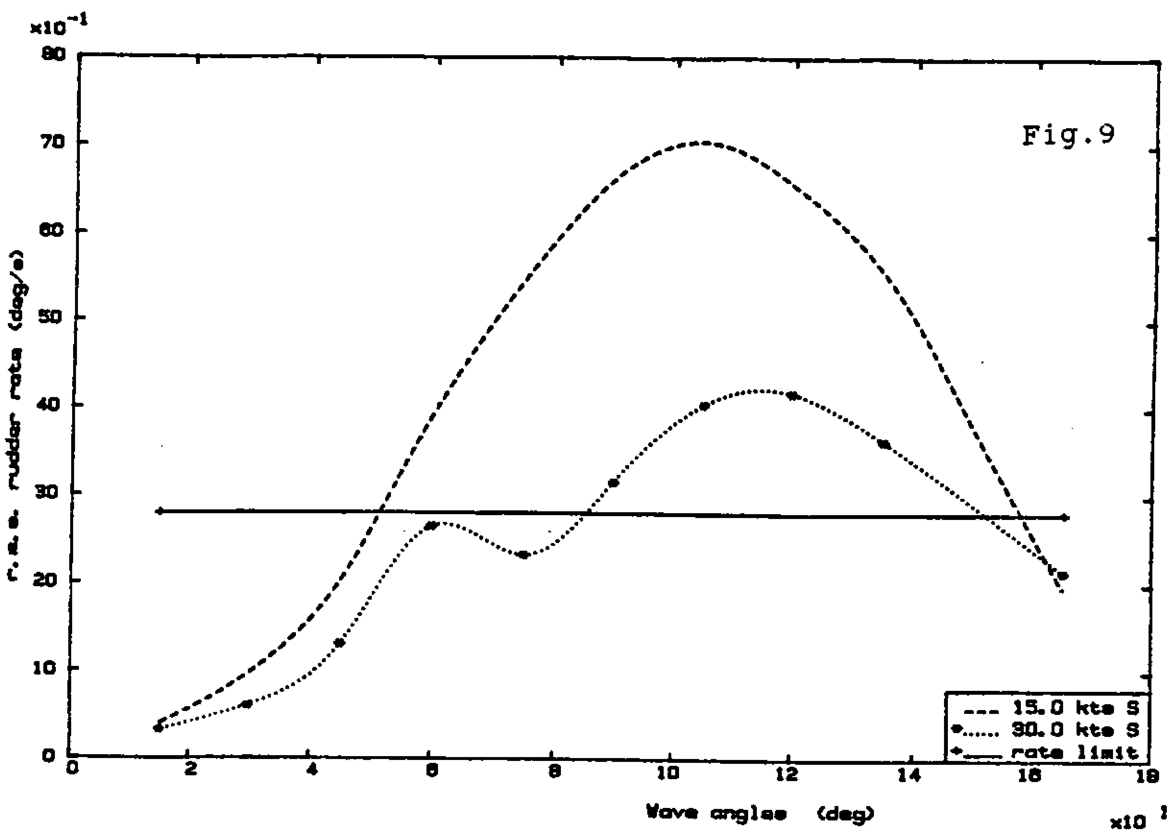

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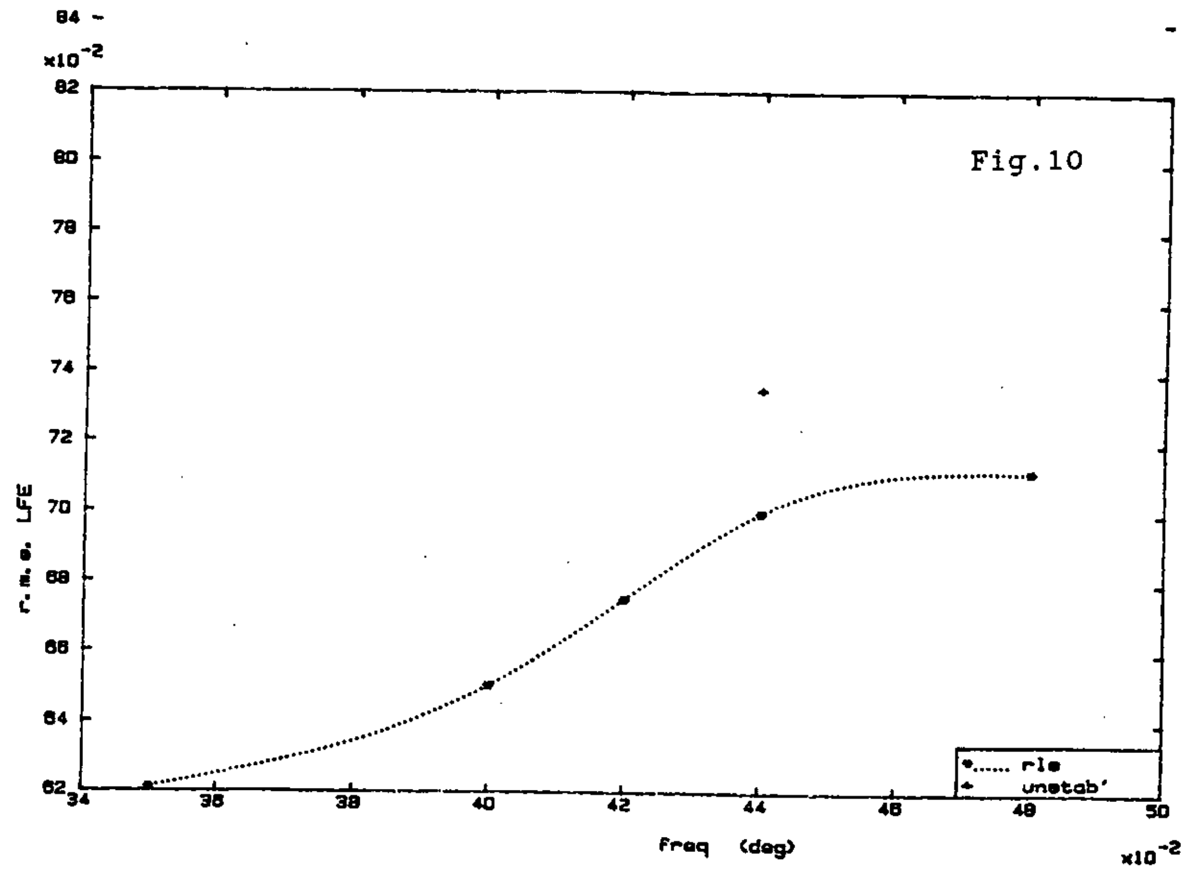
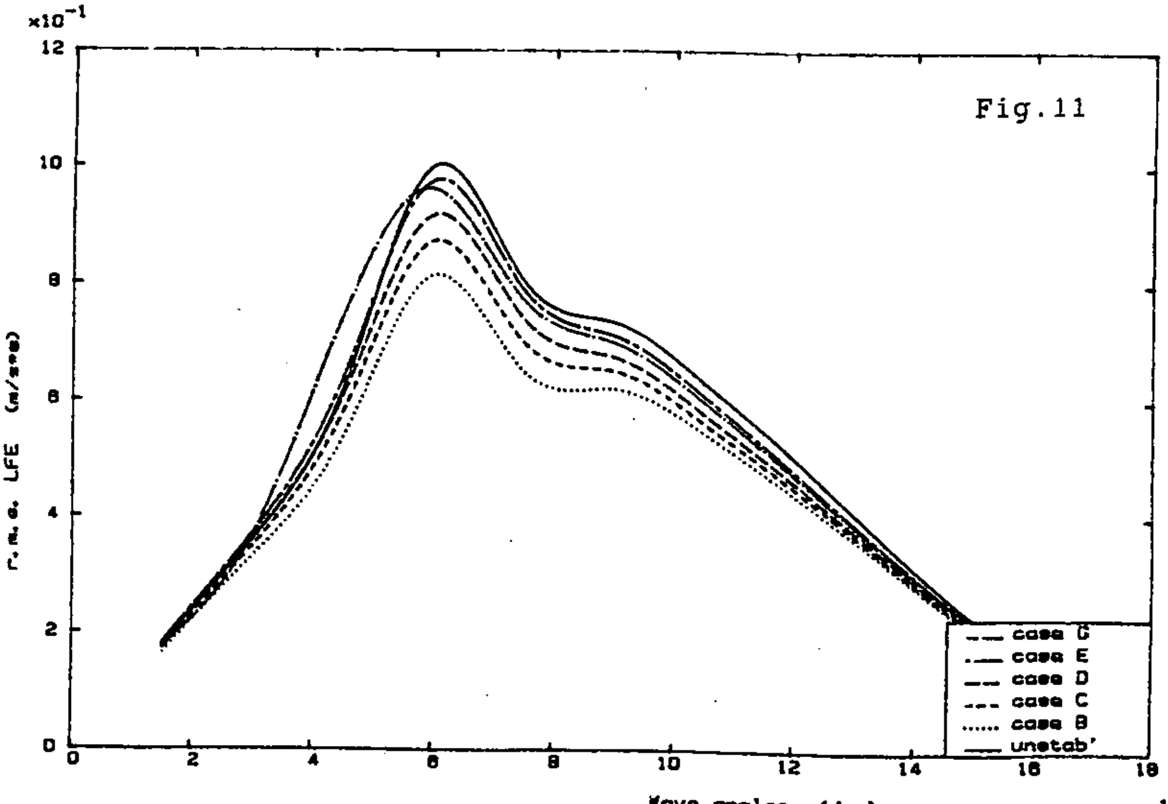
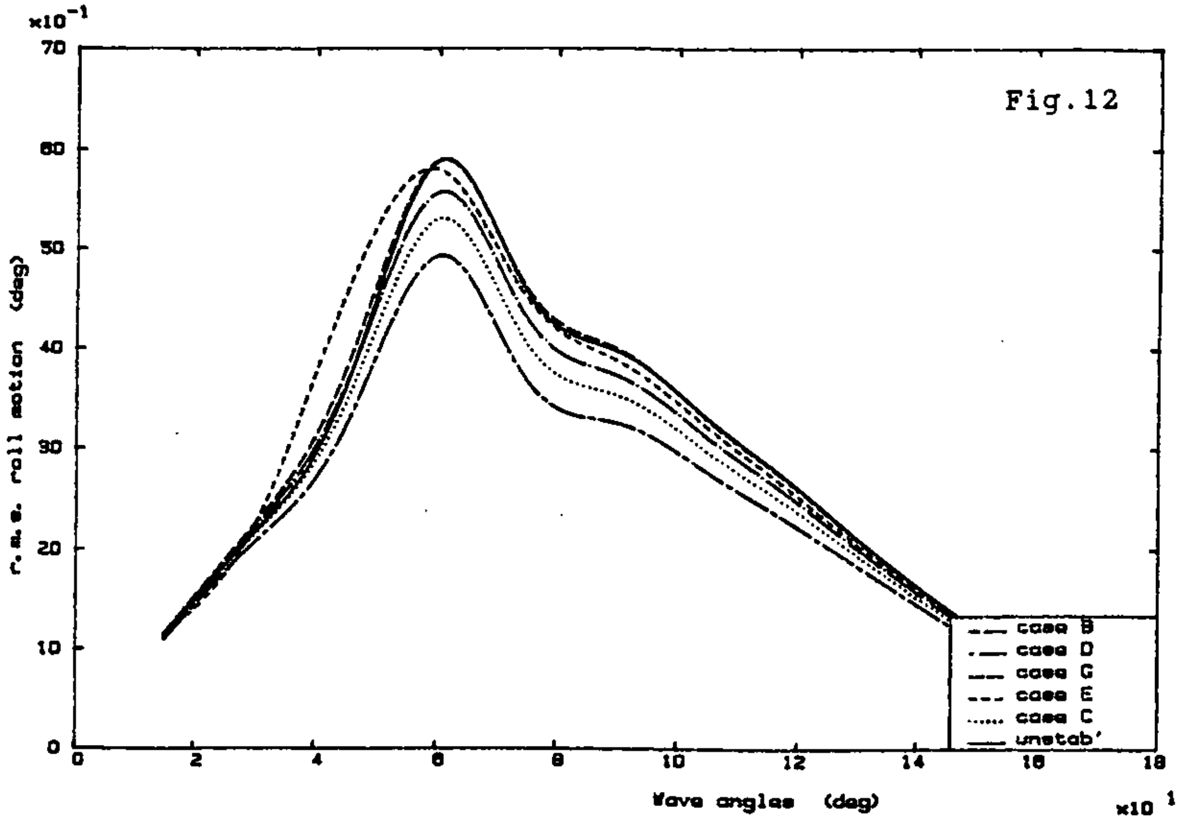


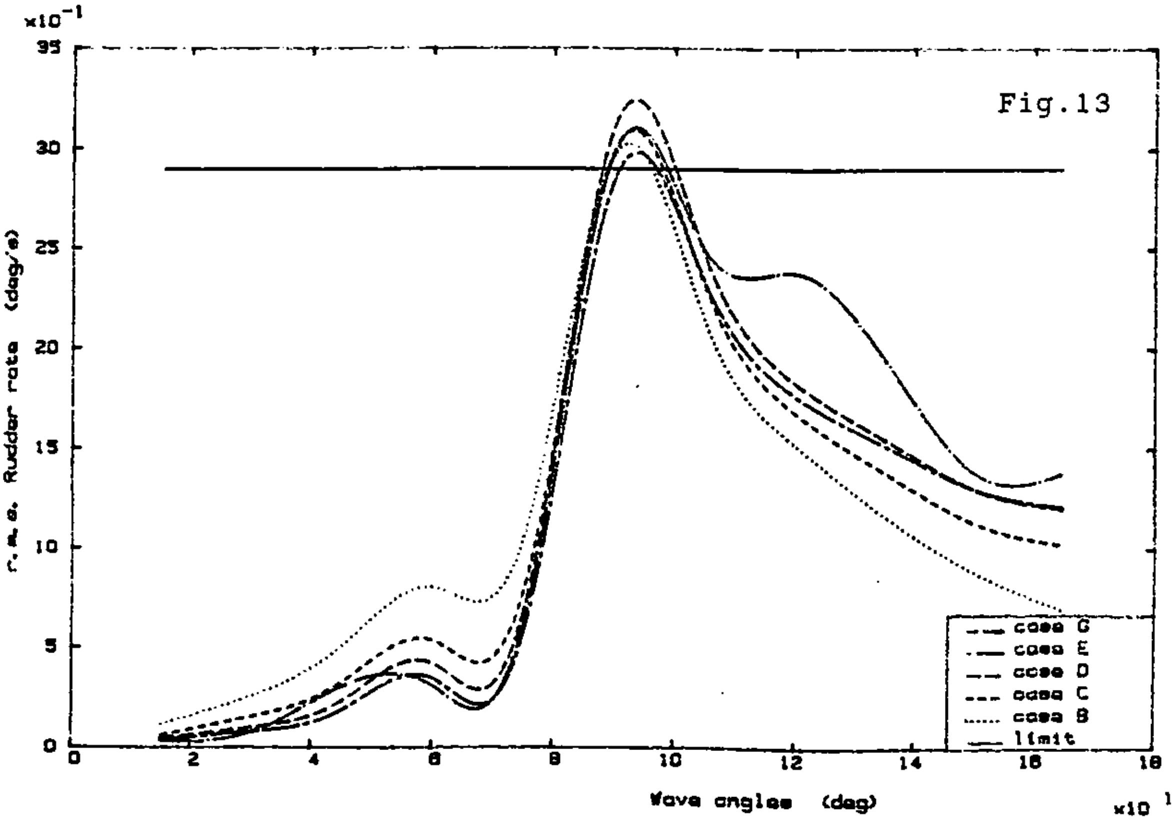
Tuning for RLS stabilisation 5.5m 12.4sec 20 kts Newship



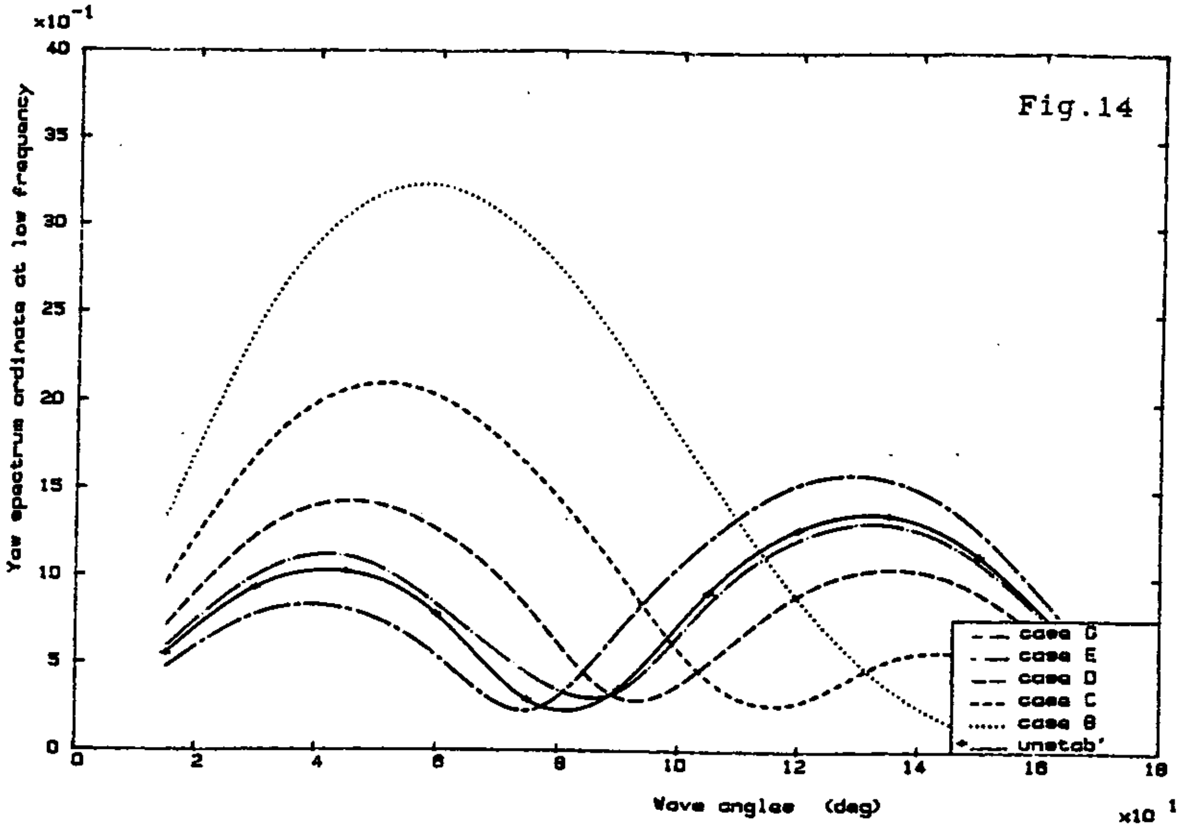
LFE response with RLS stabilisation 5.5m 12.4sec 20 kts Newship



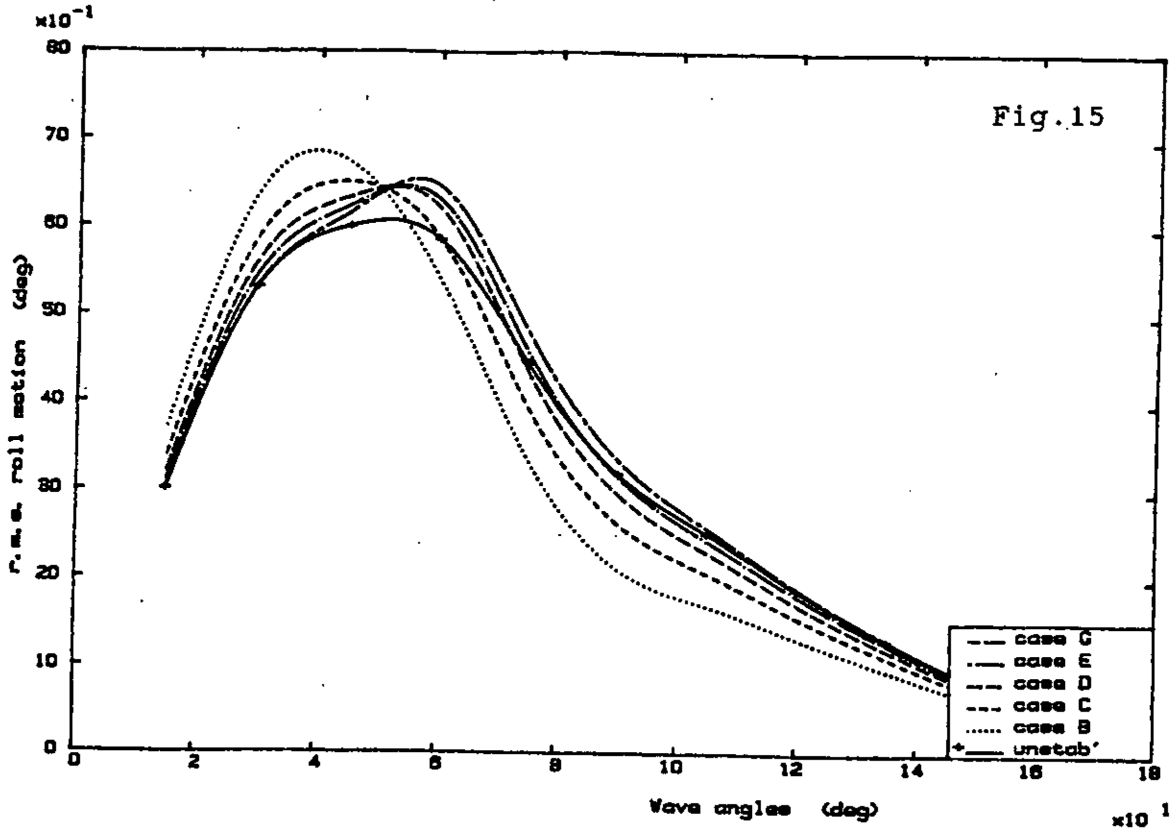
Roll response with RLS stabilisation 5.5m 12.4sec 20 kts Newship



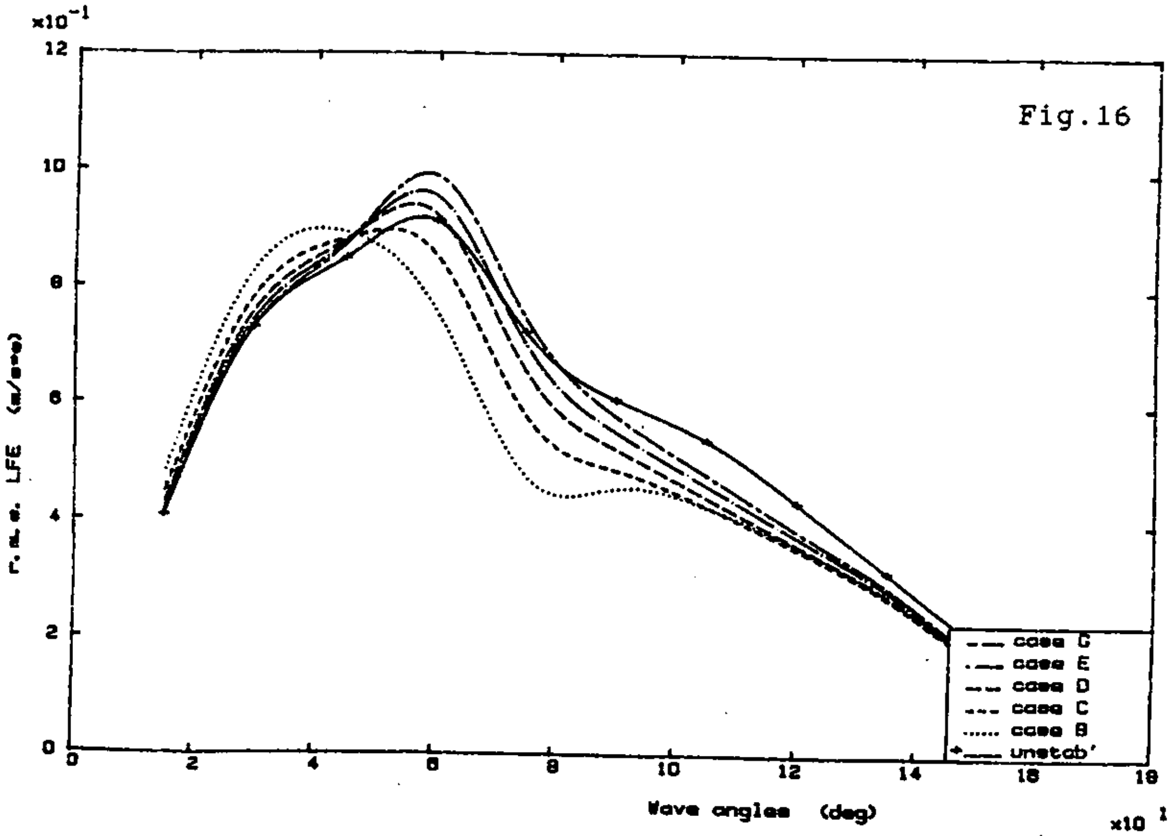
Rudder rate with RLS stabilisation 5.5m 12.4sec 20 kts Newship



Yaw response with RLS stabilisation 5.5m 12.4sec 20 kts Newship



Roll response with RLS stabilisation 5.5m 12.4sec 30 kts Newship



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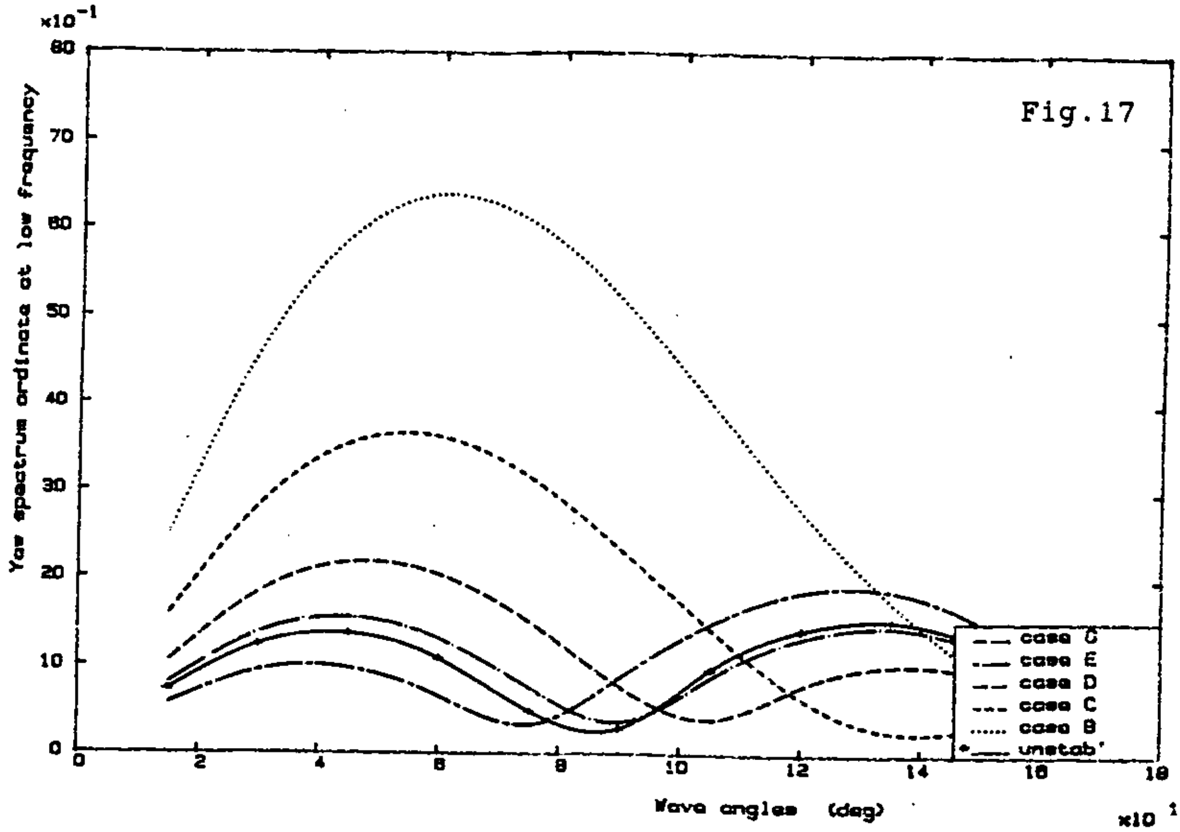

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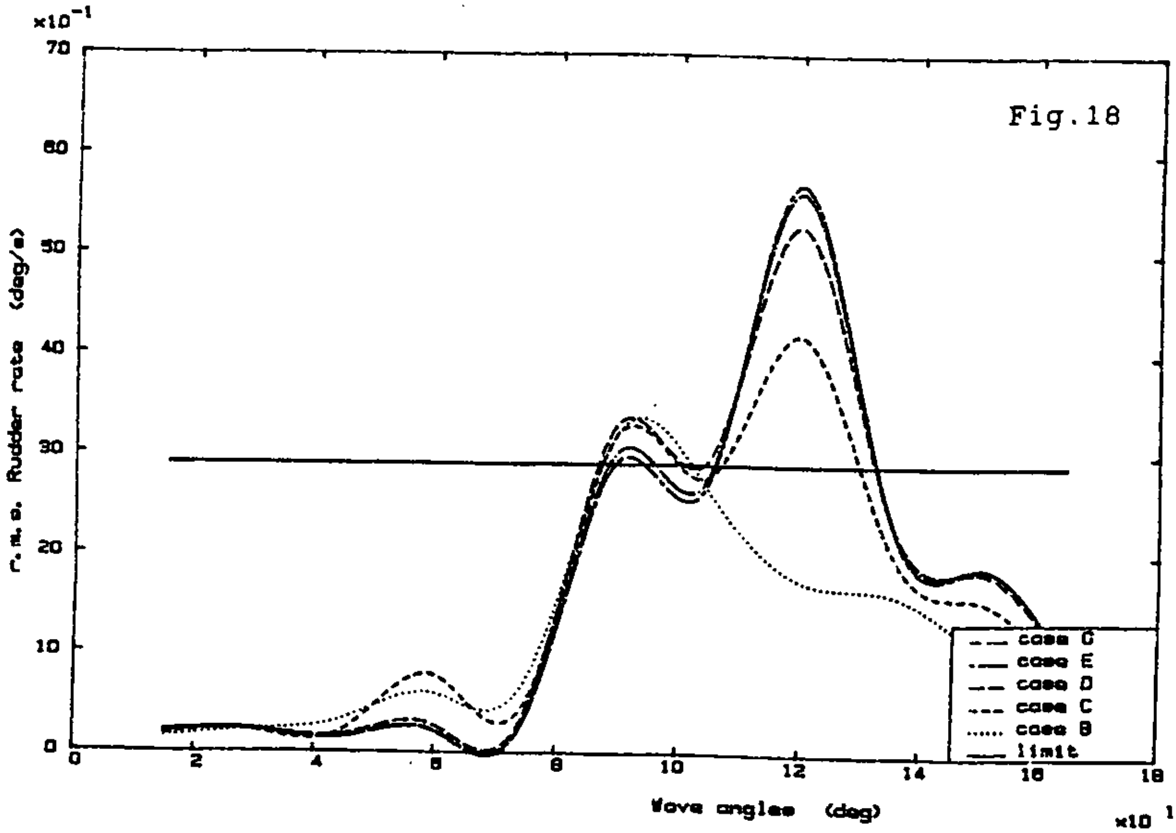

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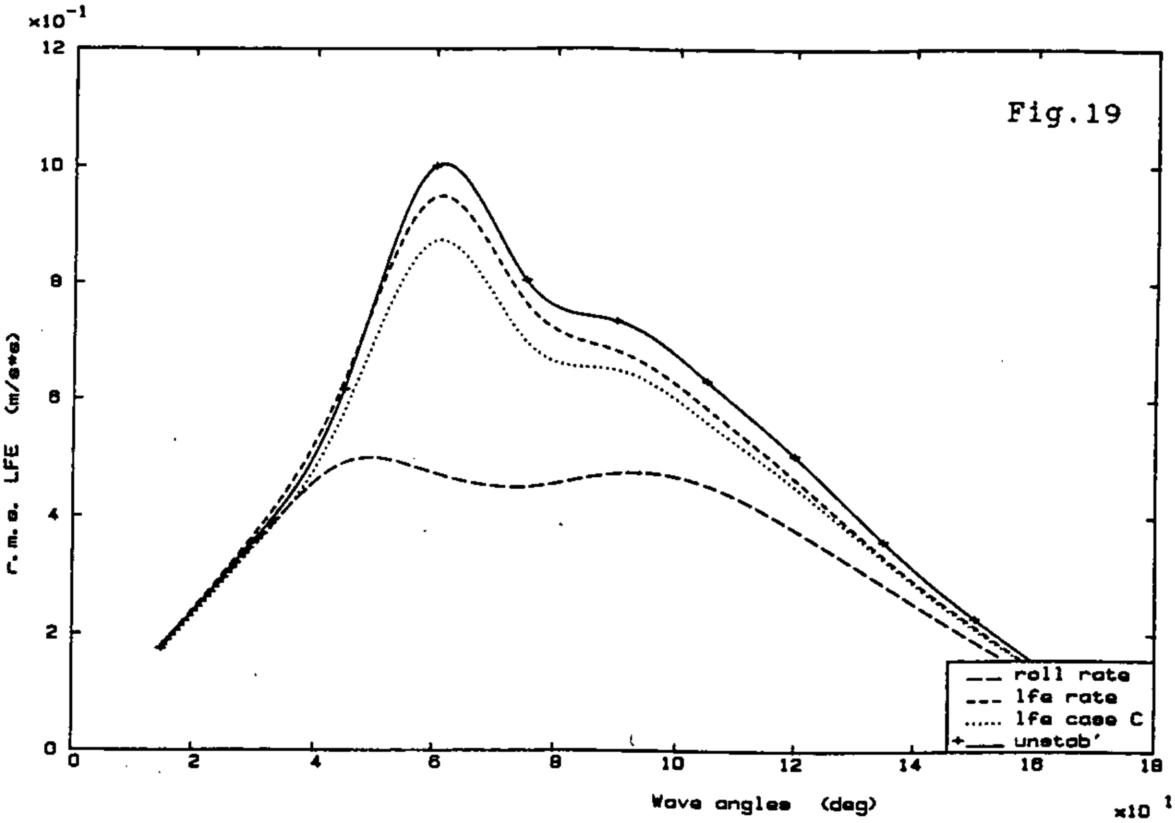

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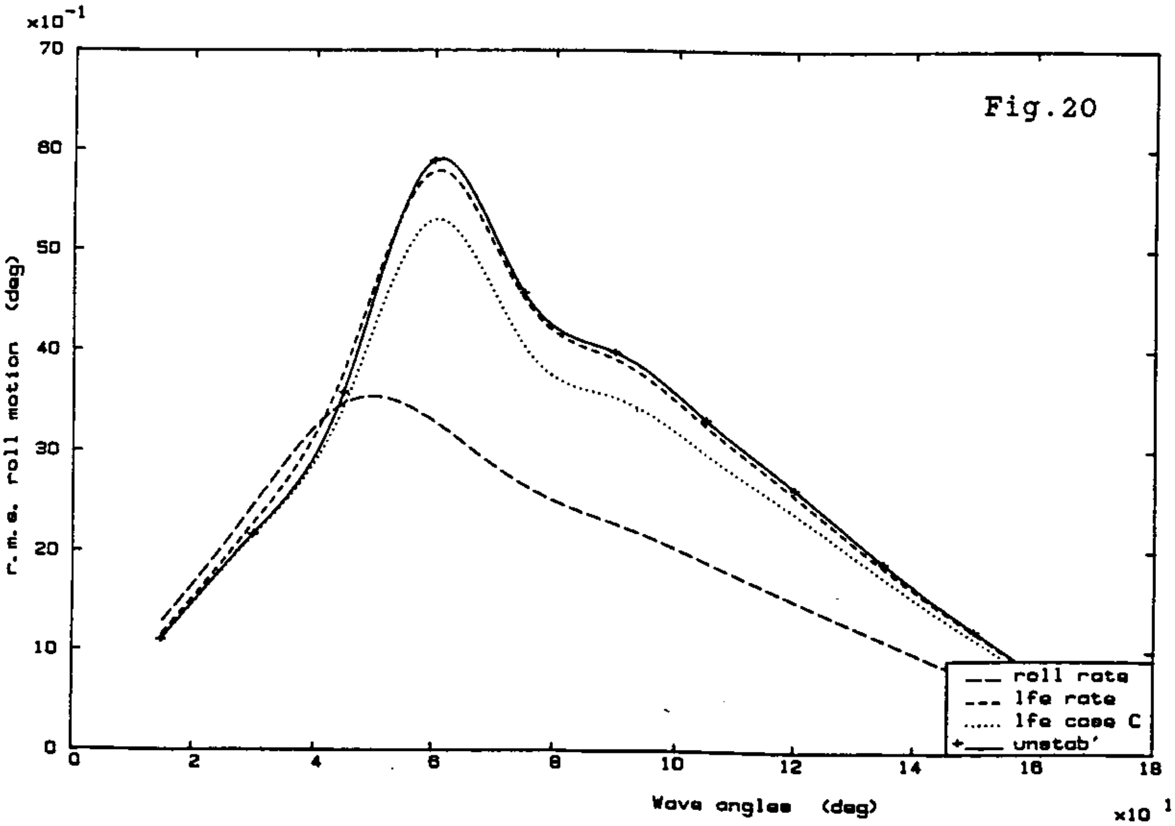

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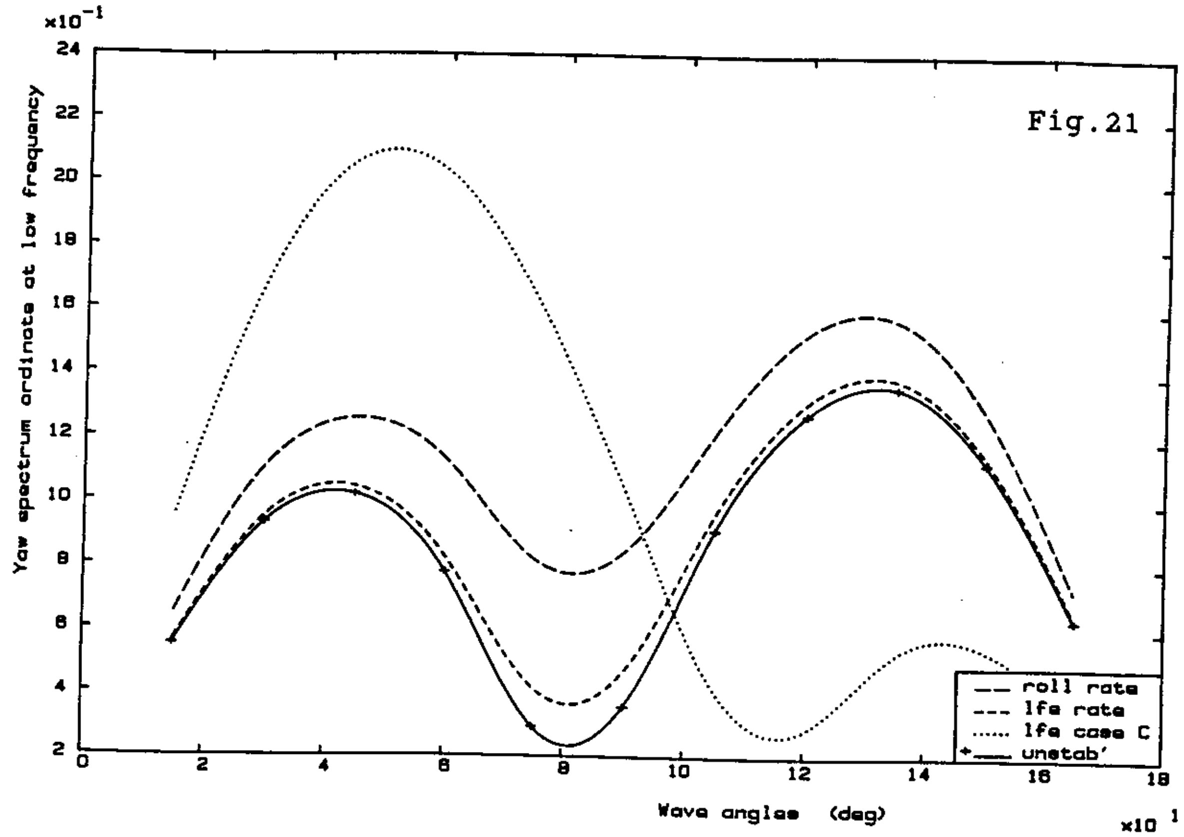

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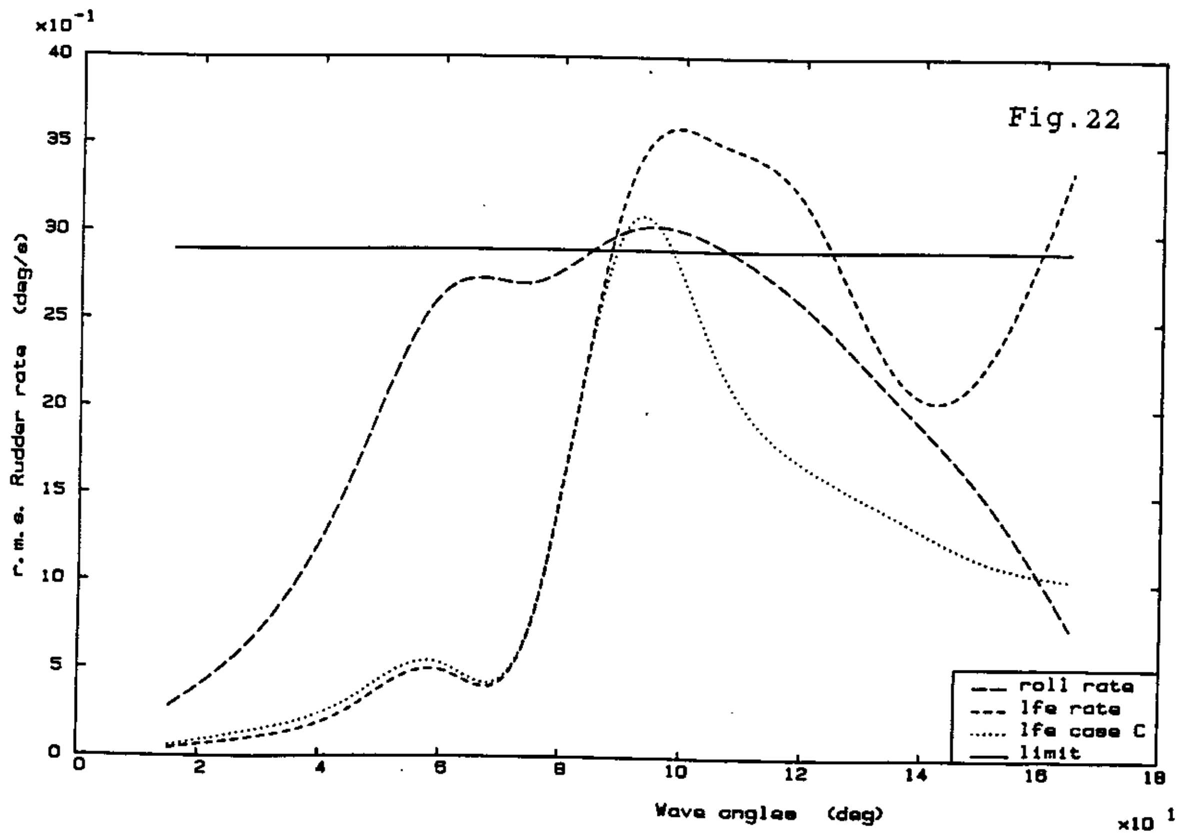
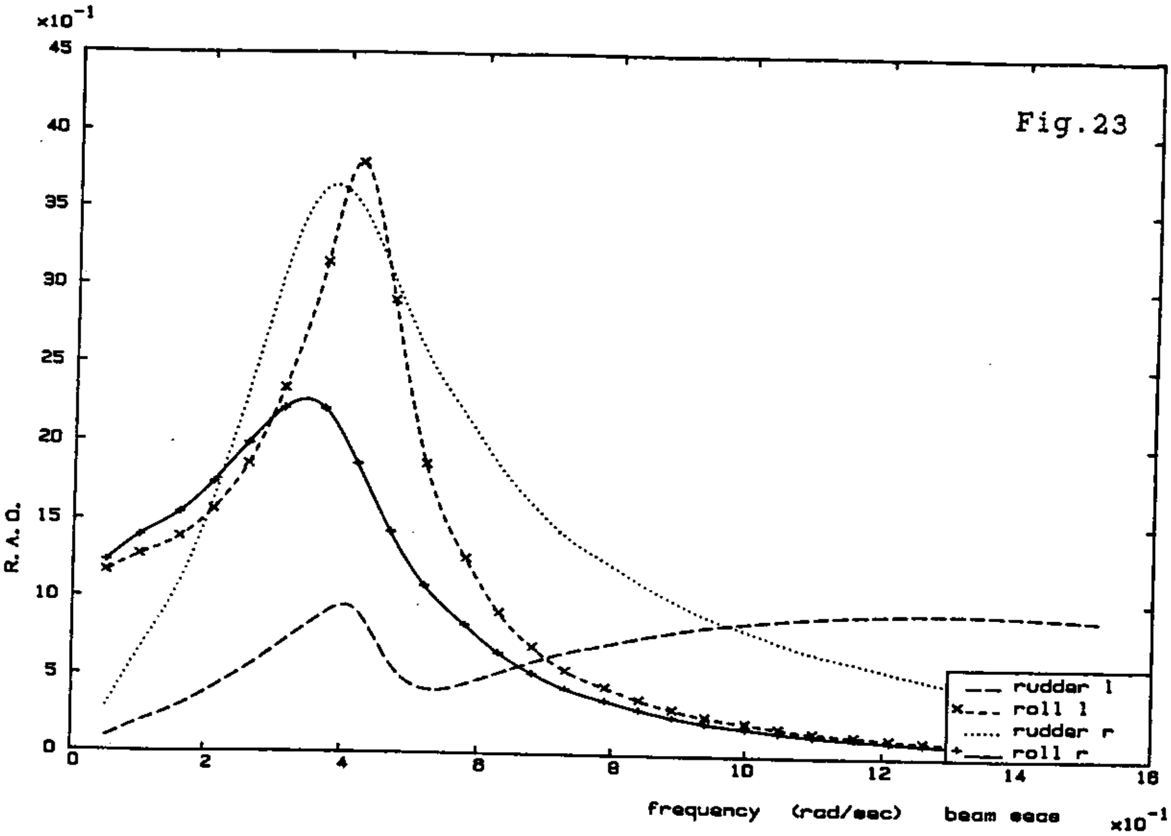
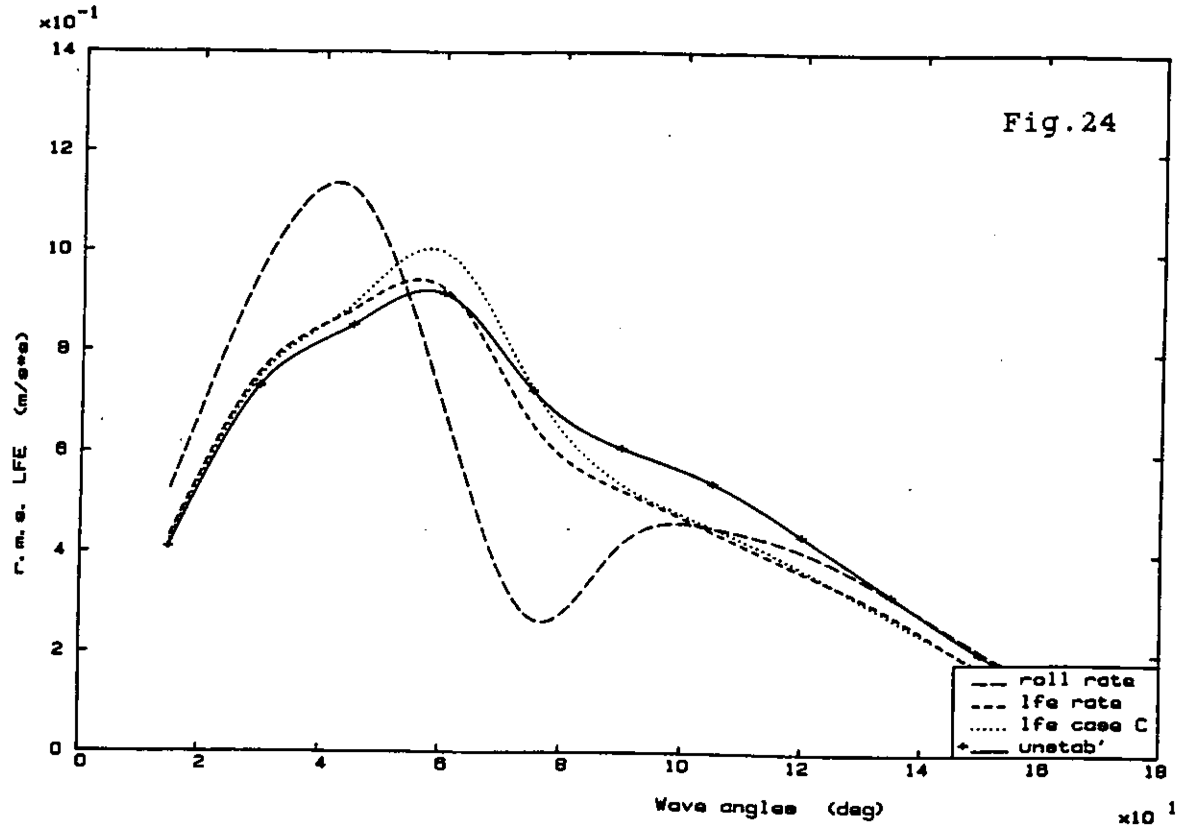


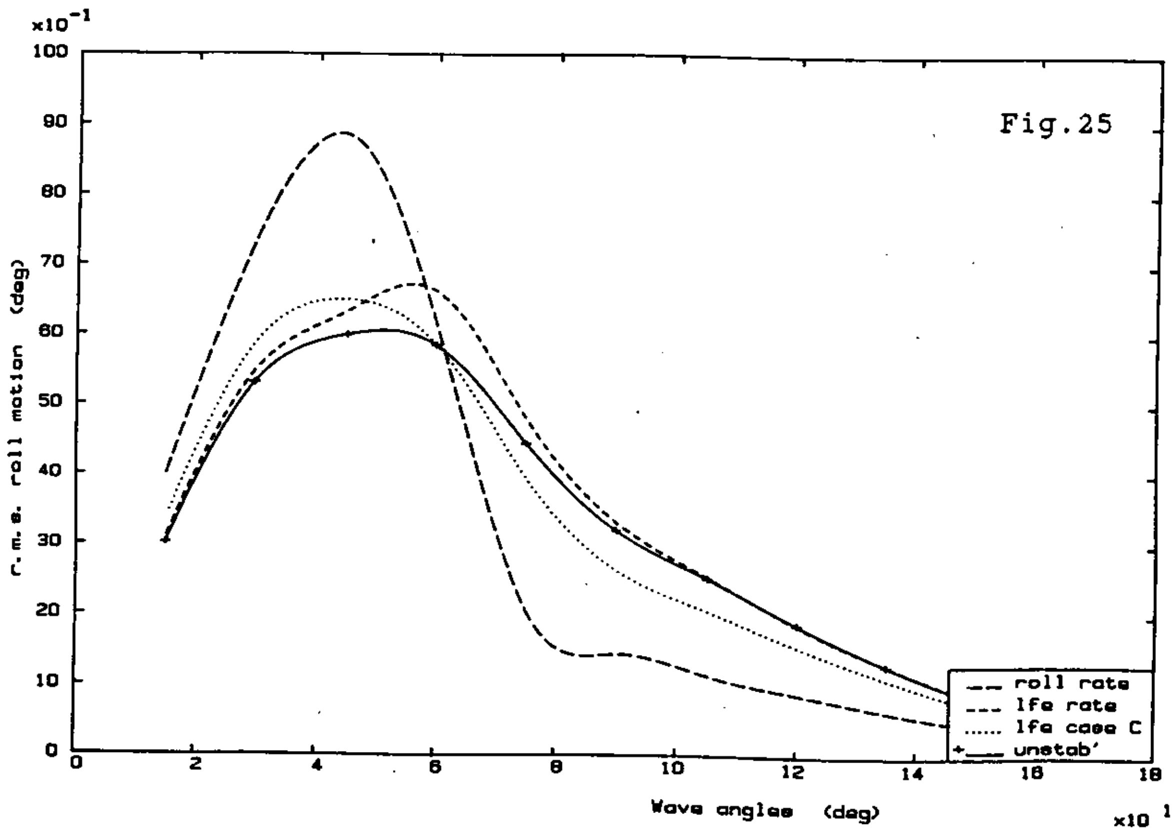
Rudder rate with RLS stabilisation 5.5m 12.4sec 20 kts Newship



Response spectrum with RLS stabilisation 5.5m 12.4sec 20 kts Newship



LFE response with RLS stabilisation 5.5m 12.4sec 30 kts Newship



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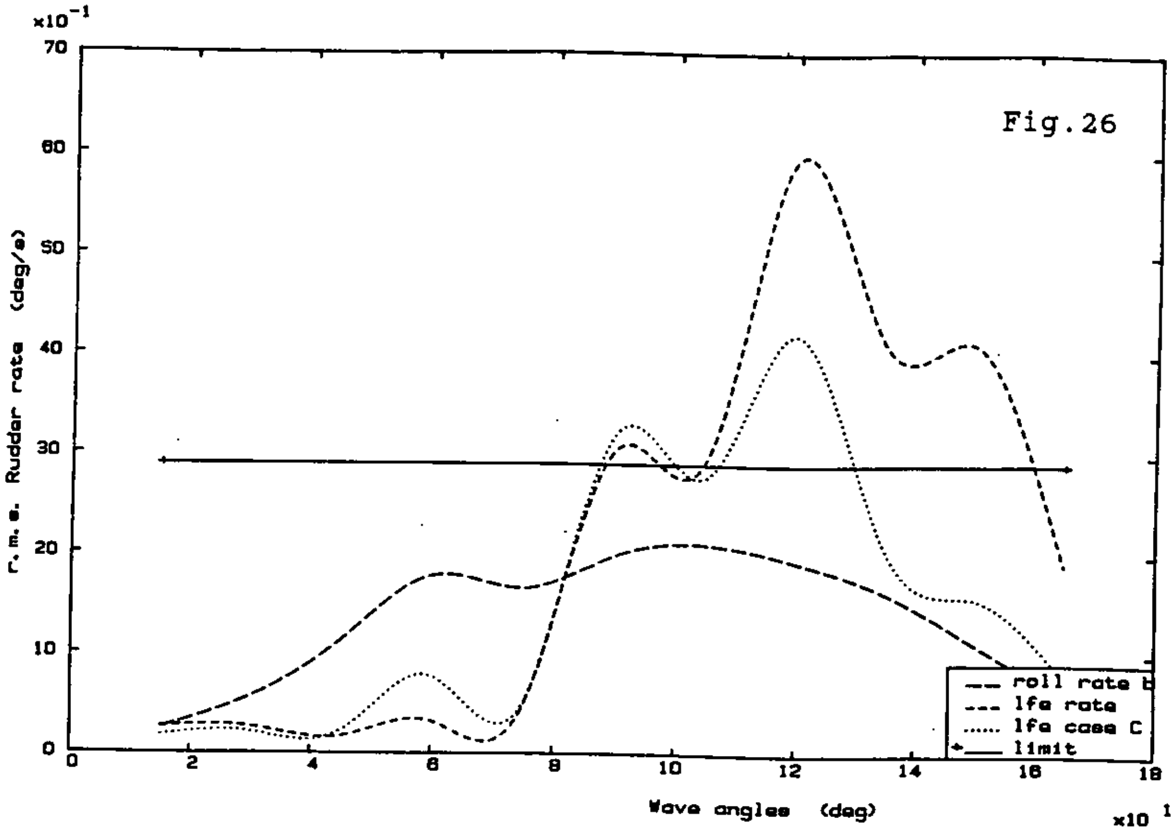
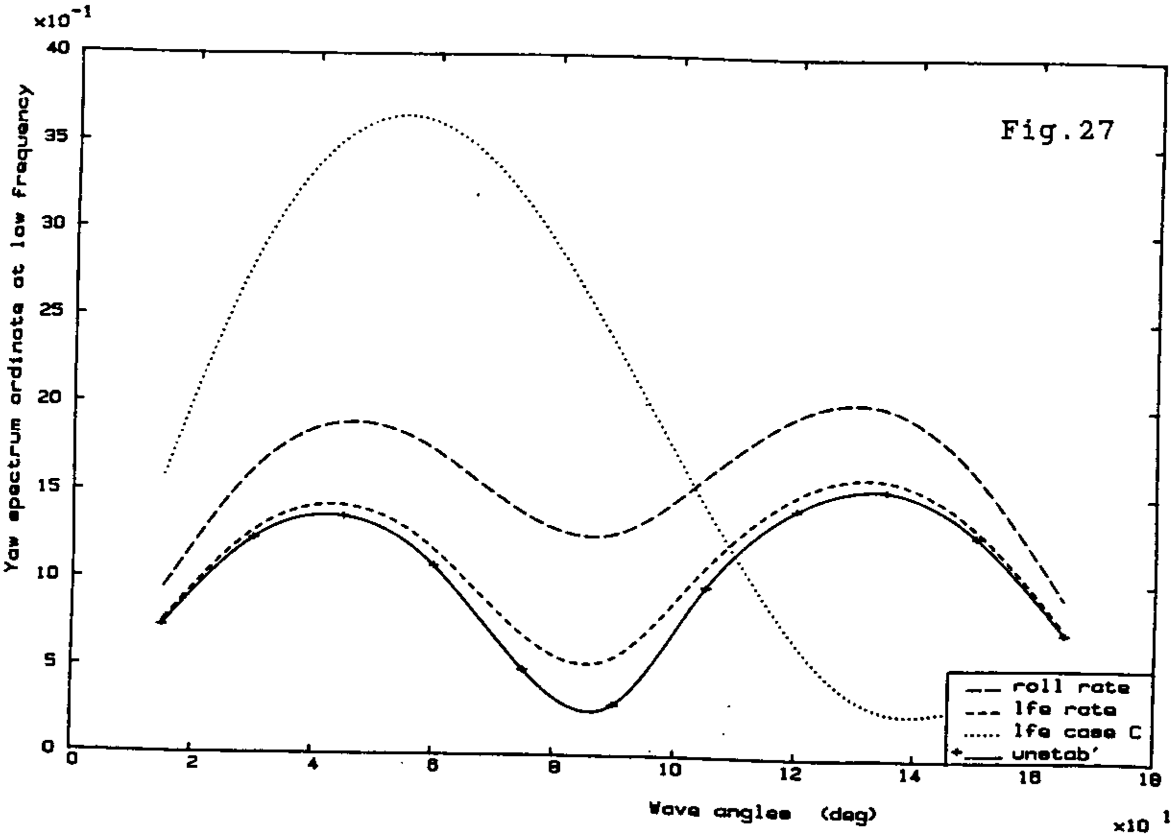


Rudder rate with RLS stabilisation 5.5m 12.4sec 30 kts Newship



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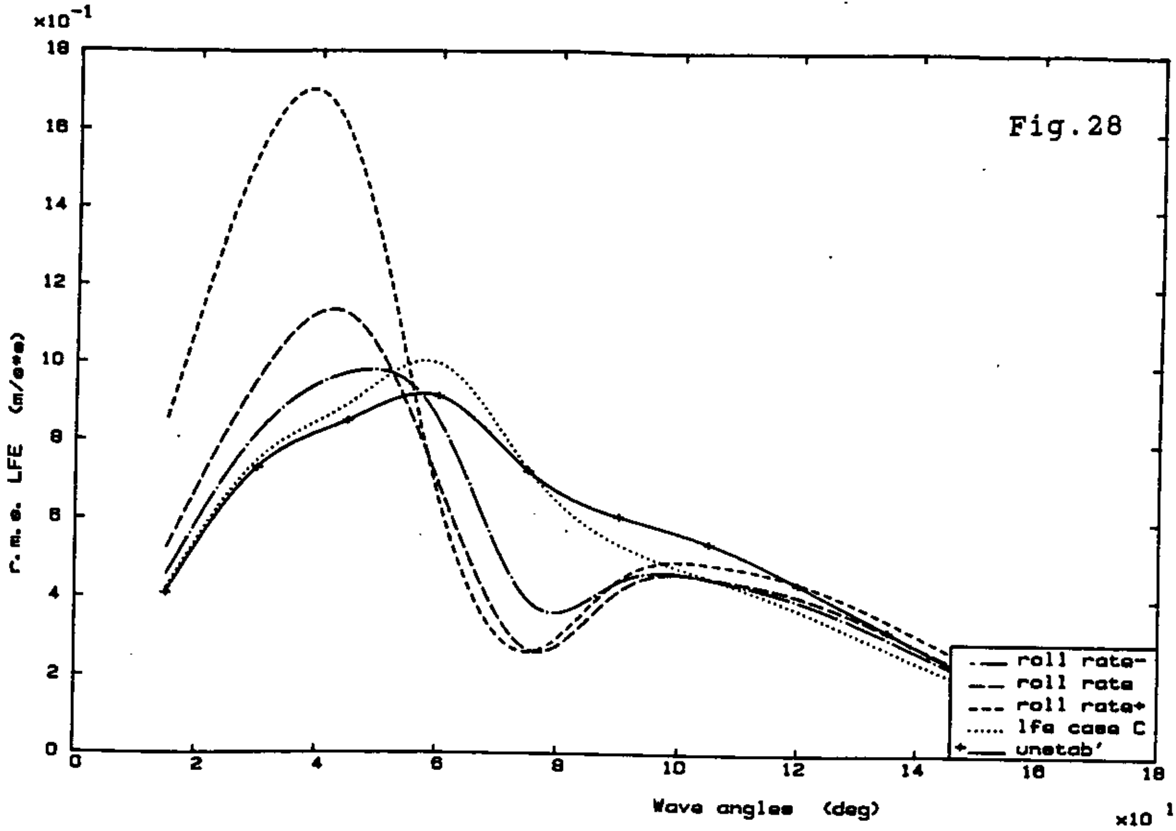

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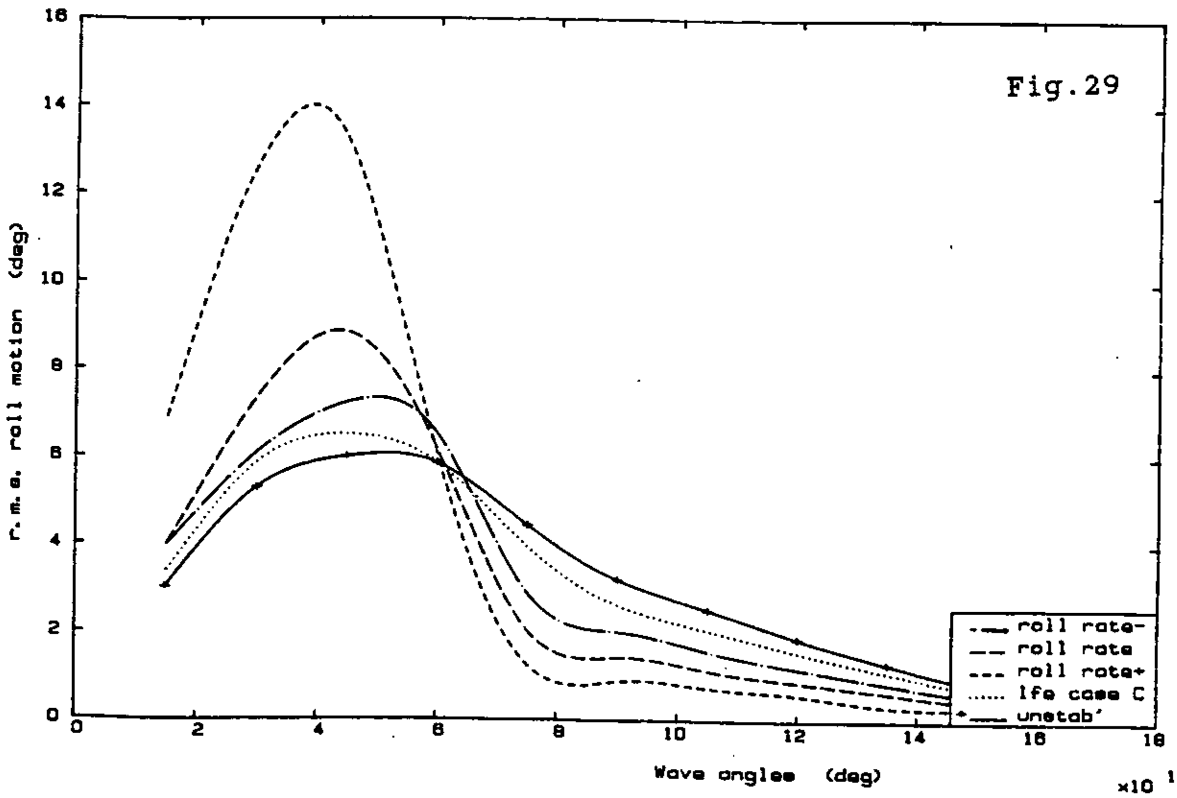

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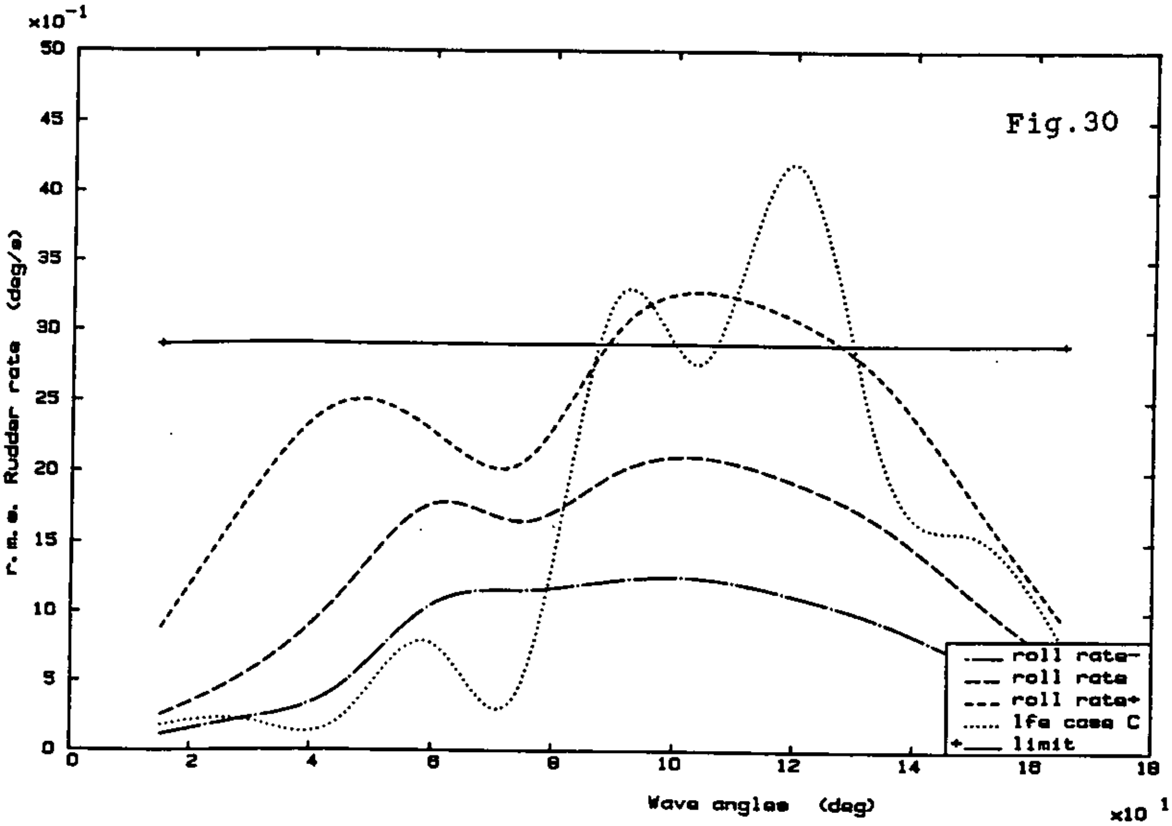
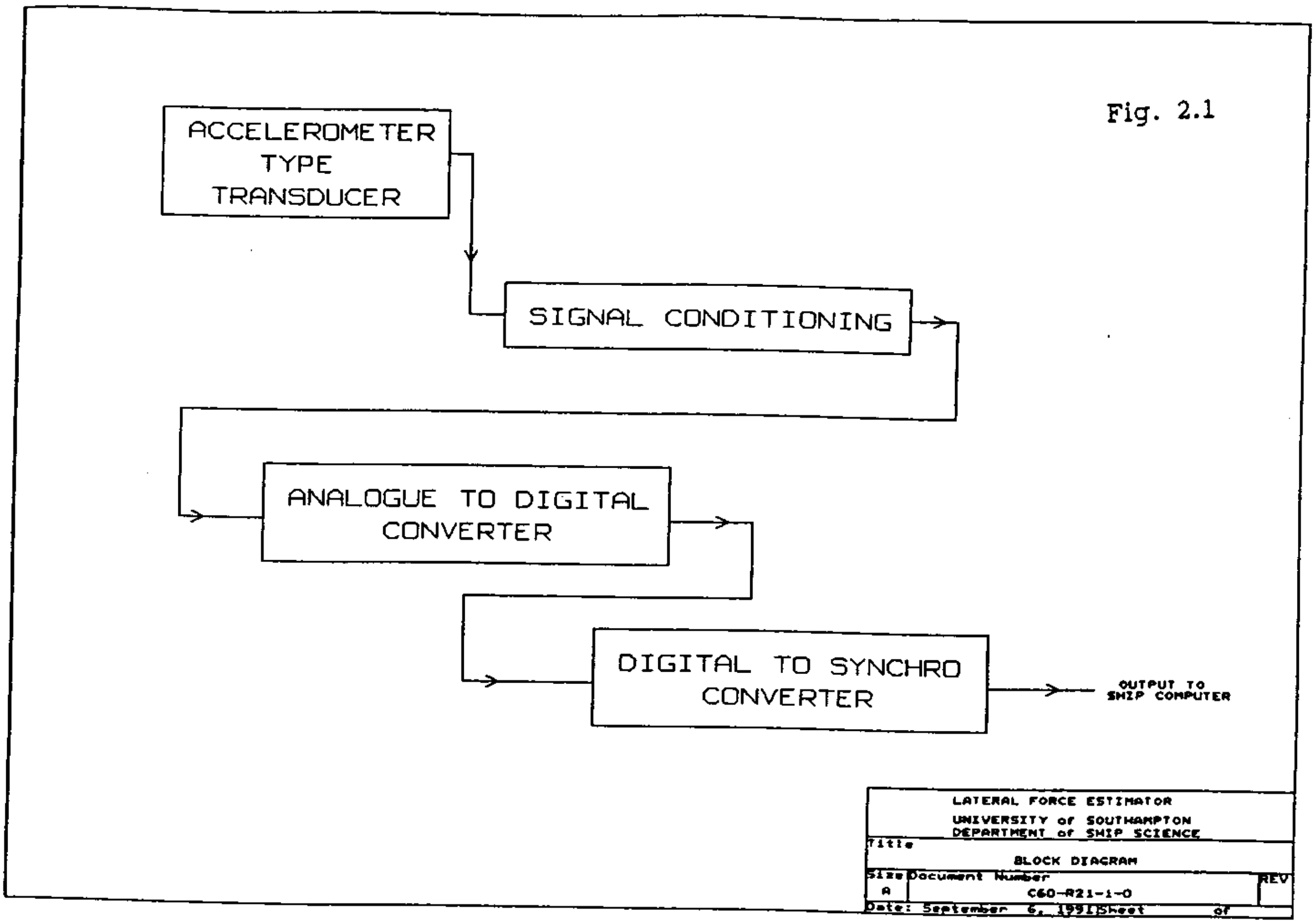


Rudder rate with RLS stabilisation 5.5m 12.4sec 30 kts Newship

Fig. 2.1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DIGITAL TO SYNCHRO CONVERTER
OUTPUT TO SHIP COMPUTER
LATERAL FORCE ESTIMATOR
UNIVERSITY of SOUTHAMPTON
DEPARTMENT of SHIP SCIENCE
Title
BLOCK DIAGRAM
Size A
Document Number
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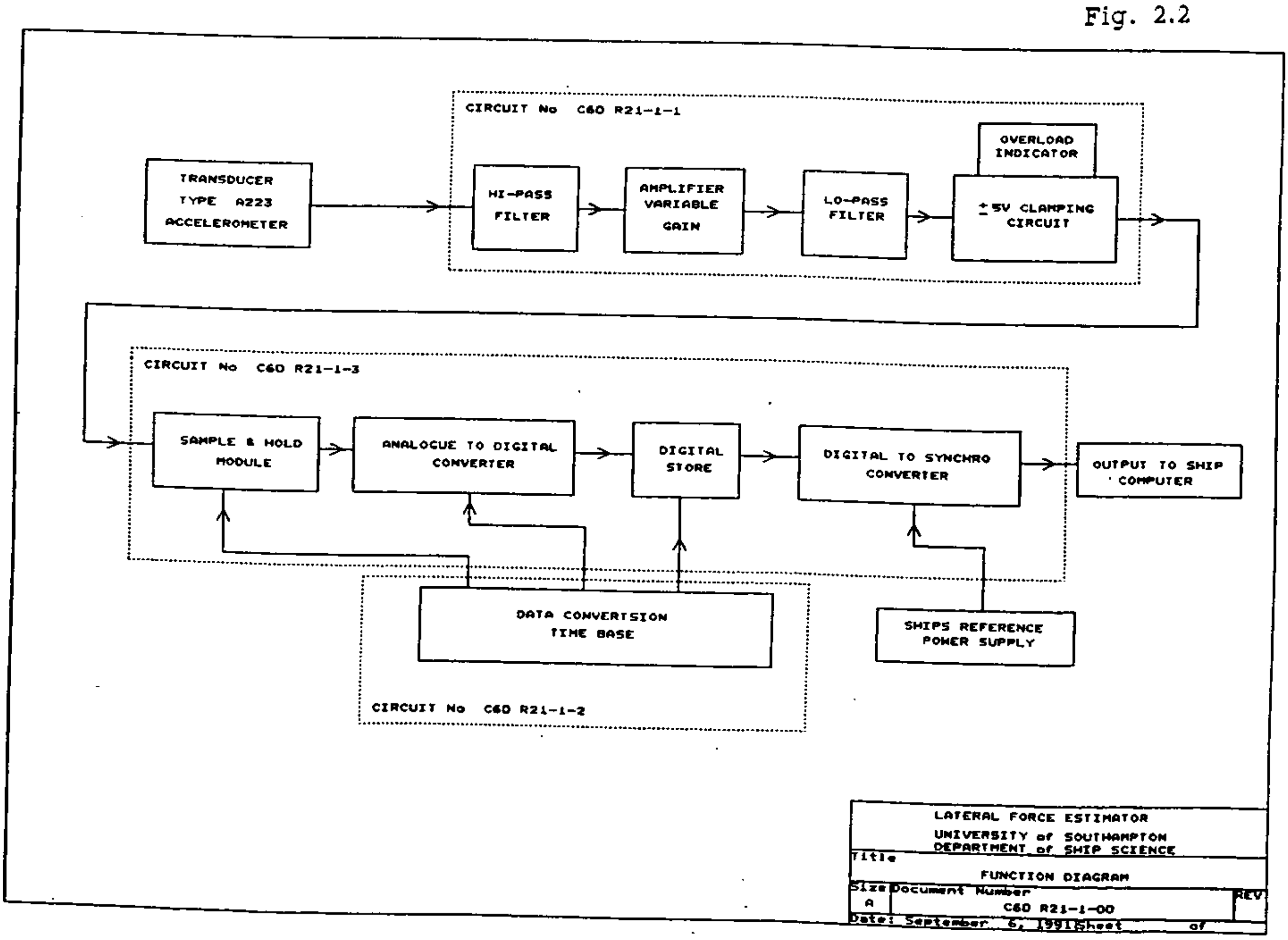
REV
Date: September 6, 1991
Sheet of

Fig. 2.2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LO-PASS FILTER
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± 5V CLAMPING CIRCUIT
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SAMPLE & HOLD MODULE
ANALOGUE TO DIGITAL CONVERTER
DIGITAL STORE
DIGITAL TO SYNCHRO CONVERTER
OUTPUT TO SHIP COMPUTER
DATA CONVERTSION TIME BASE
SHIPS REFERENCE POWER SUPPLY
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LATERAL FORCE ESTIMATOR
UNIVERSITY of SOUTHAMPTON
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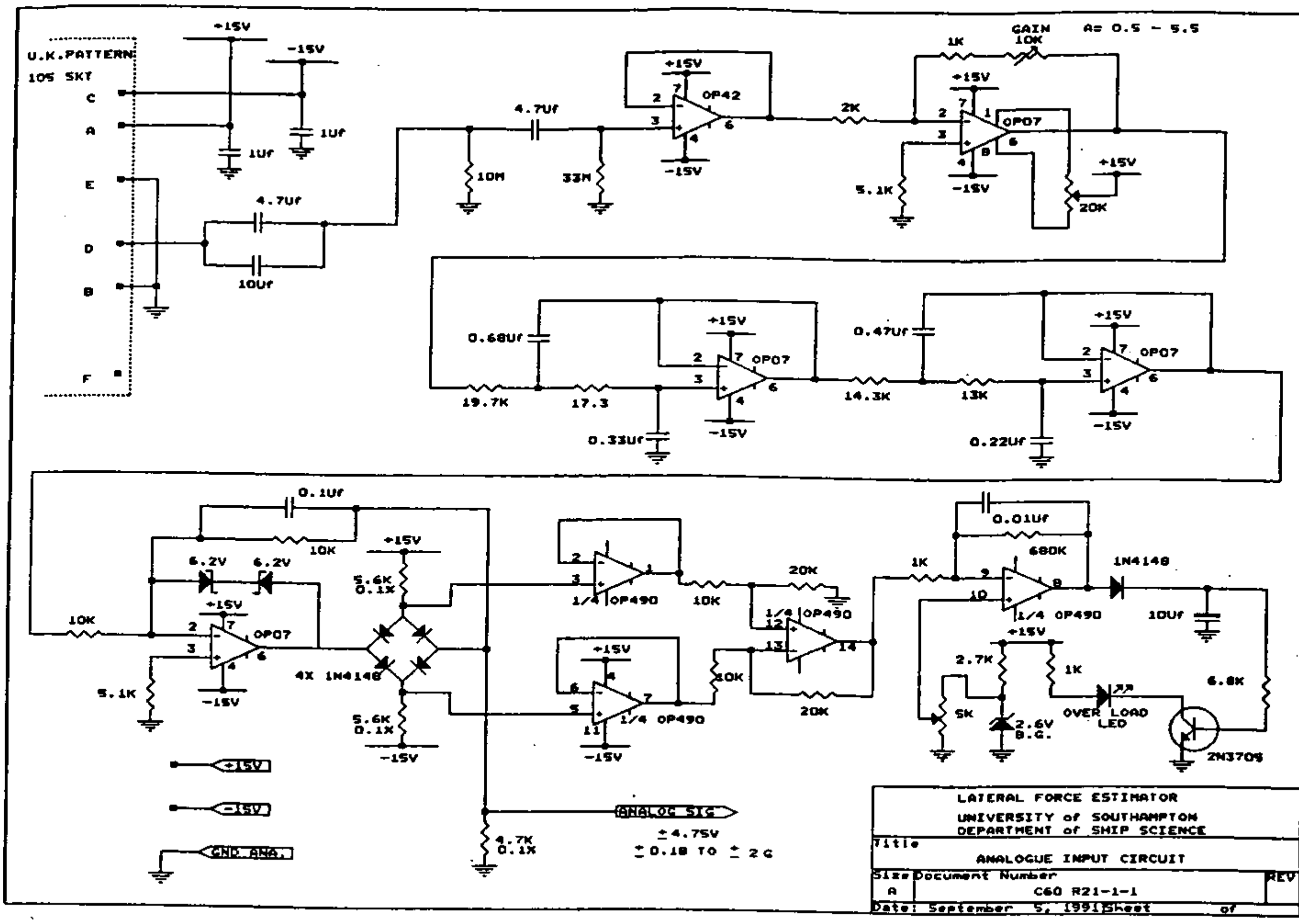
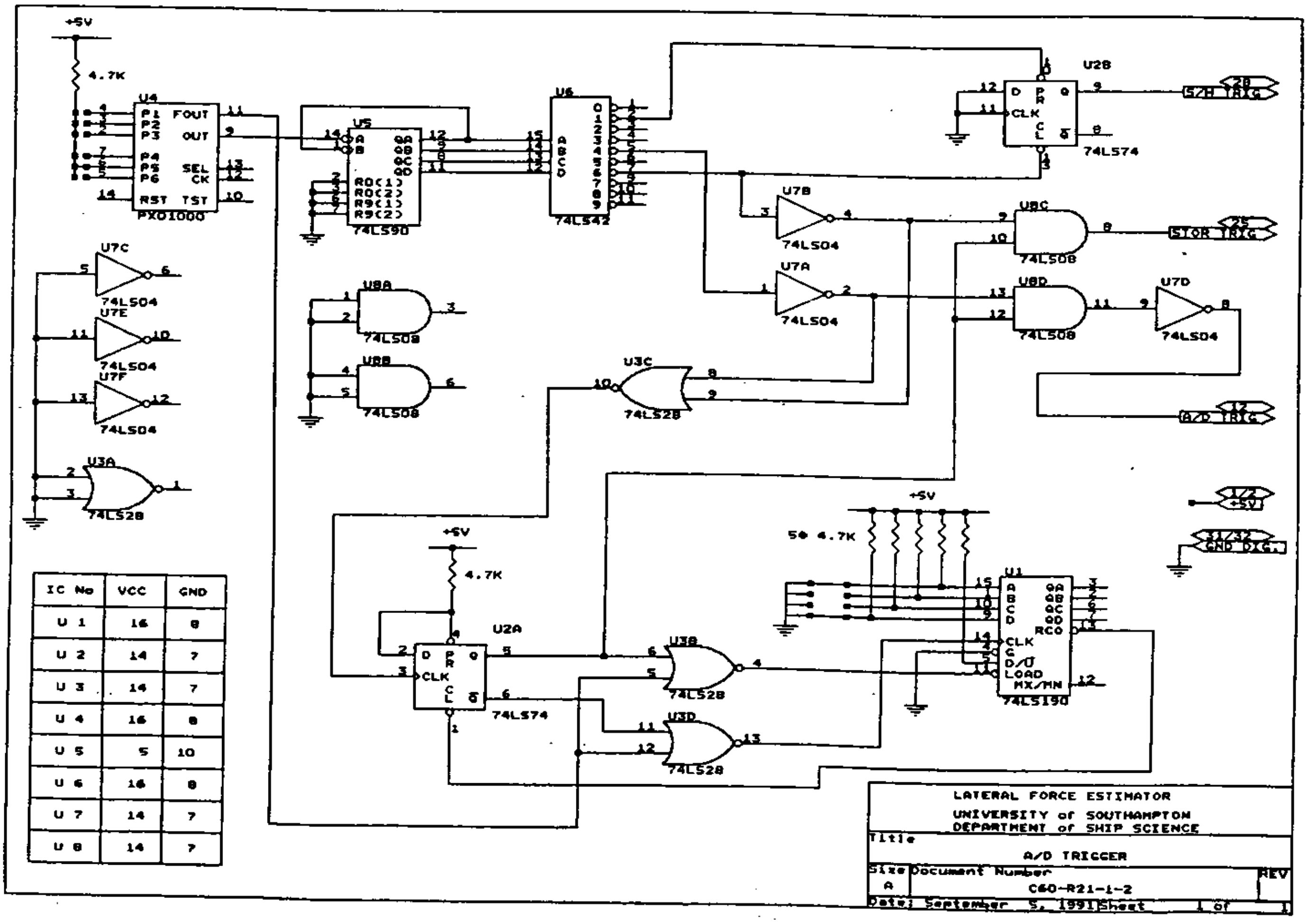


Fig. 2.3

Fig. 2.4



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U 3	14	7
U 4	16	8
U 5	5	10
U 6	16	8
U 7	14	7
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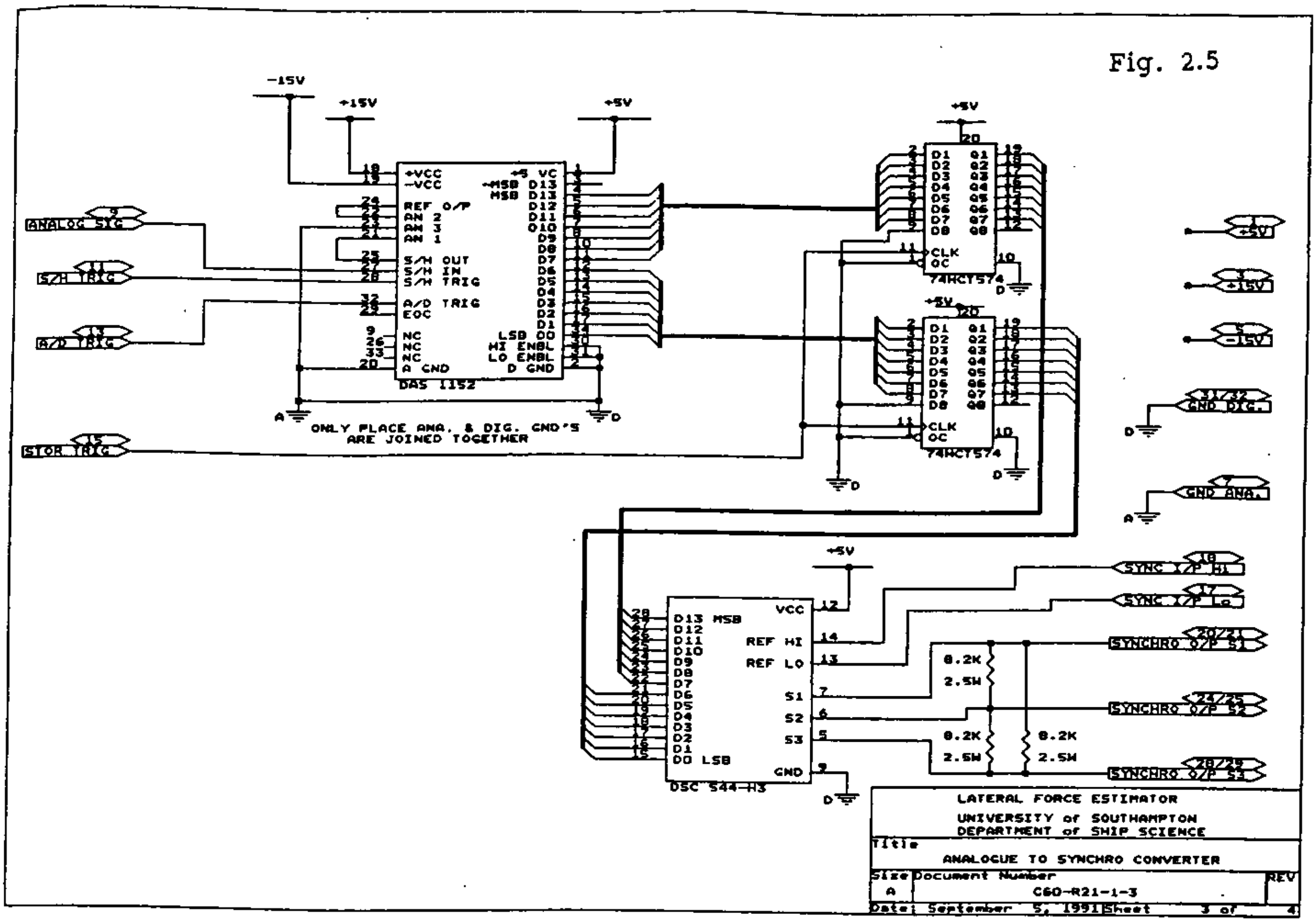
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+15V
+5V
DAS 1152
ANALOG SIG
S/H TRIG
A/D TRIG
STOR TRIG
ONLY PLACE ANA. & DIG. GND'S ARE JOINED TOGETHER
74HCT574
74HCT574
DSC 544-H3
SYNC I/P Hi
SYNC I/P Lo
SYNCHRO O/P S1
SYNCHRO O/P S2
SYNCHRO O/P S3
8.2K 2.5W
GND DIG.
GND ANA.
LATERAL FORCE ESTIMATOR
UNIVERSITY of SOUTHAMPTON
DEPARTMENT of SHIP SCIENCE
Title
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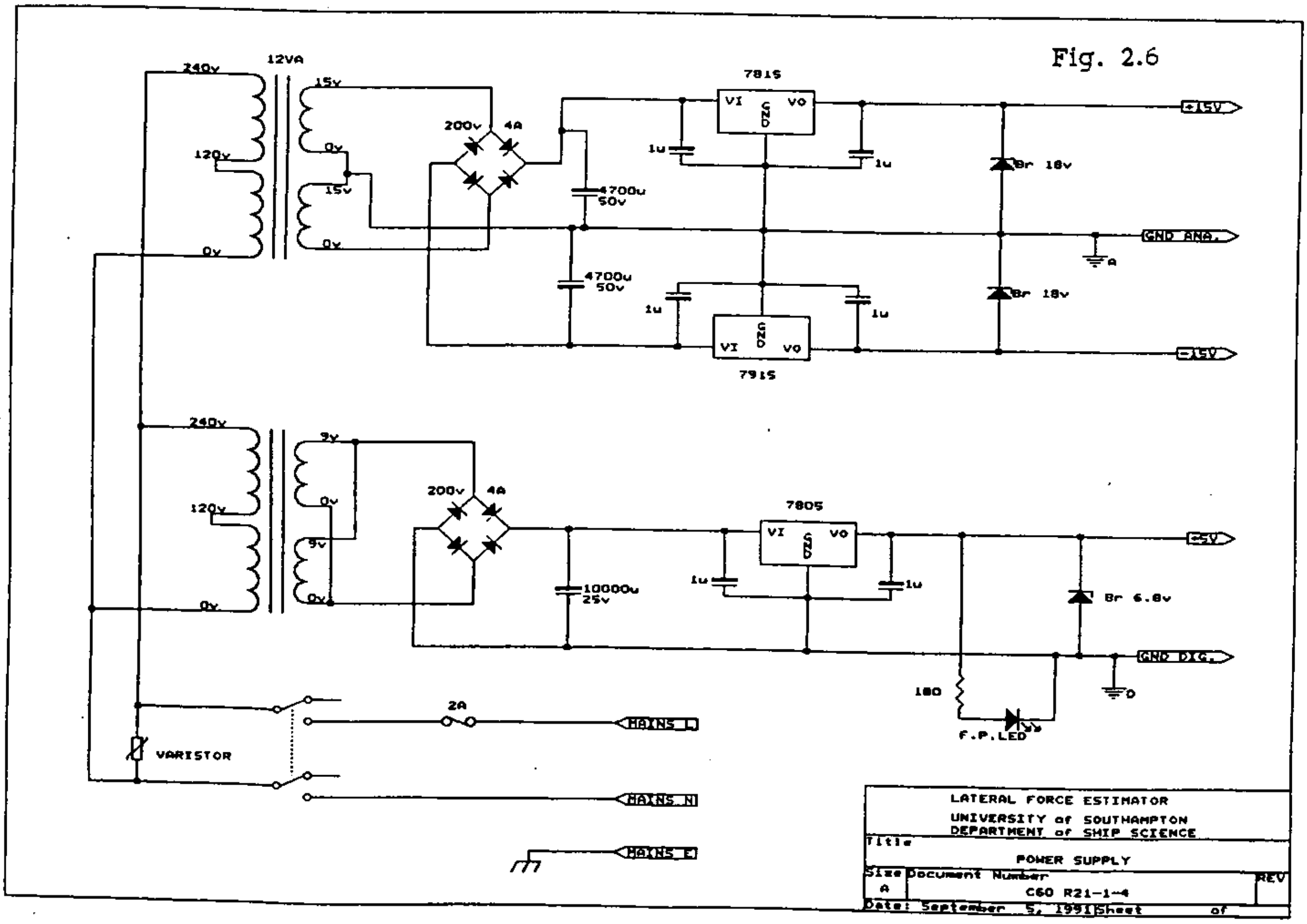
Size A
Document Number C60-R21-1-3
REV
Date: September 5, 1991 Sheet 3 of 4

Fig. 2.5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1u
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7915
-15V
9v
7805
10000u 25v
Br 6.8v
+5V
GND DIG.
180
F.P.LED
2A
VARISTOR
MAINS L
MAINS N
MAINS E
LATERAL FORCE ESTIMATOR
UNIVERSITY of SOUTHAMPTON
DEPARTMENT of SHIP SCIENCE
Title
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Size A
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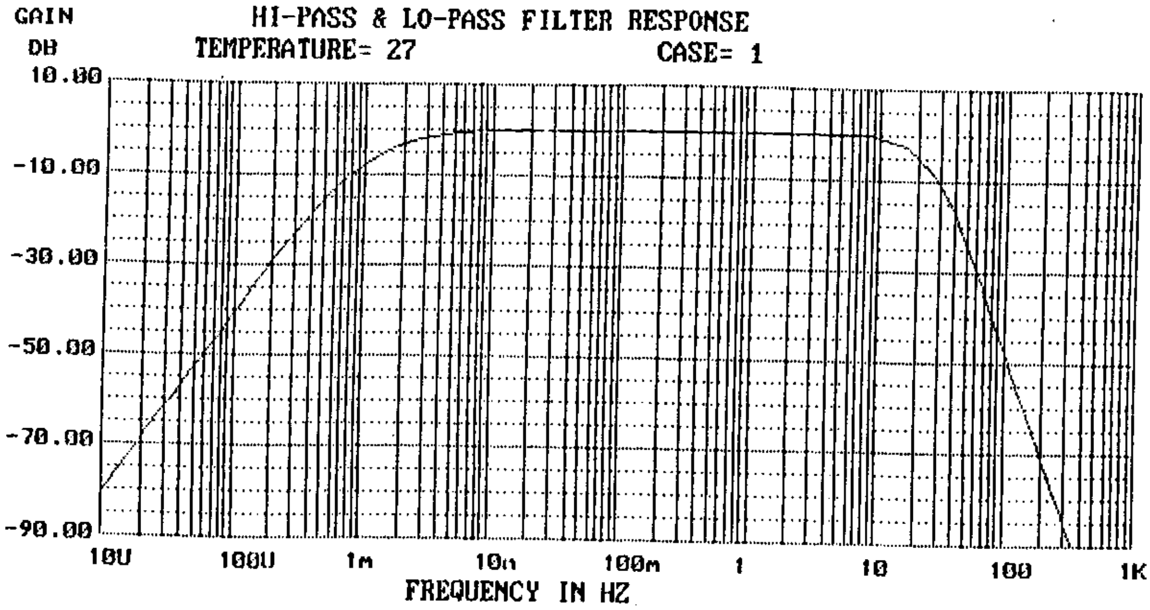
REV
Date: September 5, 1991 Sheet of

Fig. 2.6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-70.00
-90.00
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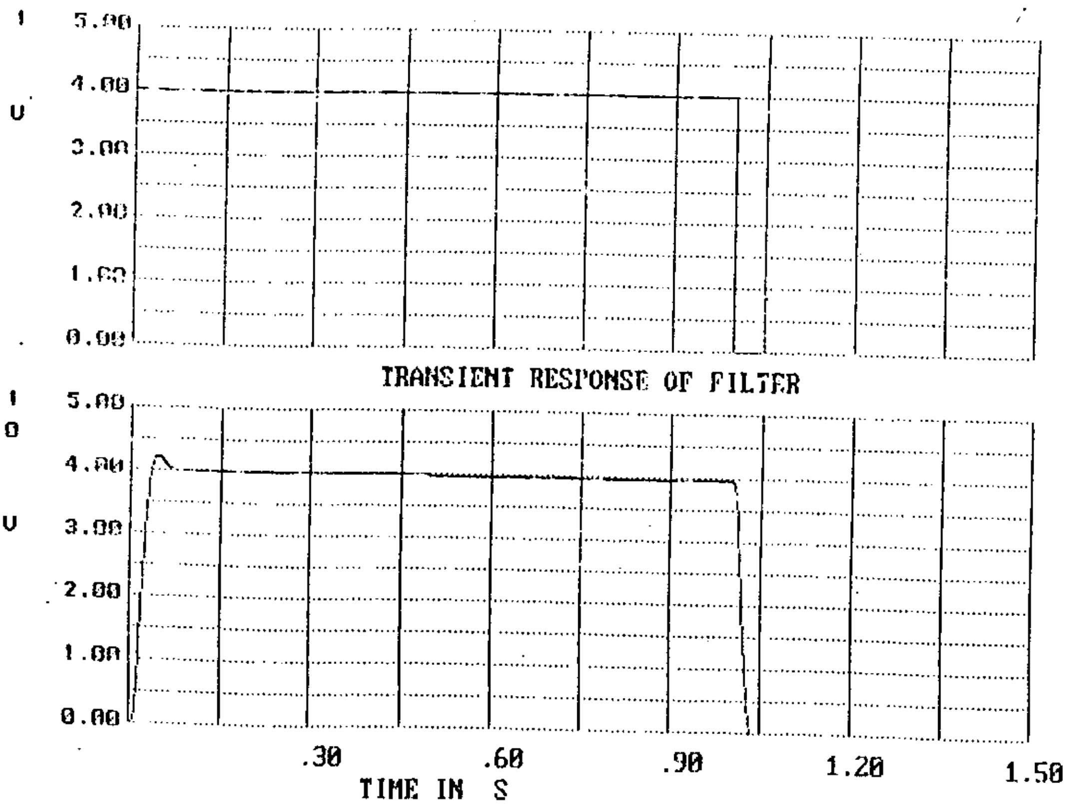
100U
1m
10m
100m
1
10
100
1K
FREQUENCY IN HZ

fig. 2.7

Fig. 2.8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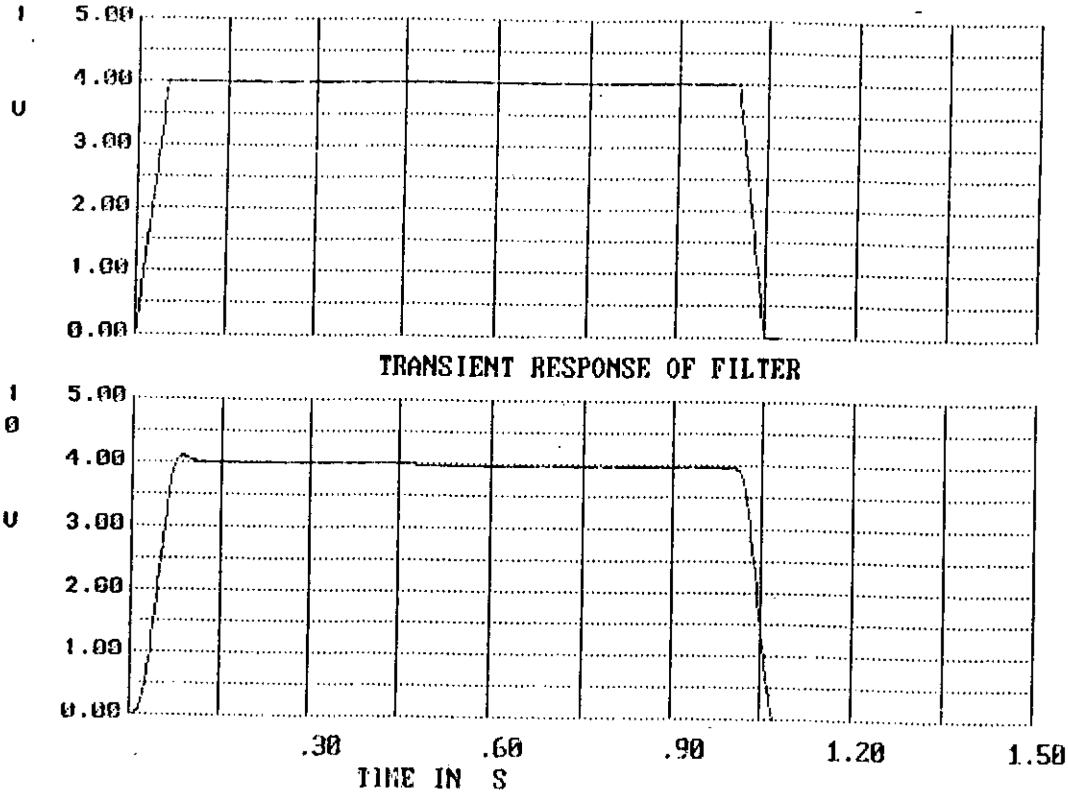
TIME IN S

fig. 2.9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3.00
2.00
1.00
0.00
.30
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.90
1.20
1.50
TIME IN S