ELEVENTH EUROPEAN ROTORCRAFT FORUM

Paper No. 32

A SIGNIFICANT IMPROVEMENT TO THE LOW SPEED YAW CONTROL OF THE SEA KING USING A TAIL BOOM STRAKE

Alan Brocklehurst

Aerodynamics Department
Westland Helicopters

September 10-13, 1985
London, England

THE CITY UNIVERSITY, LONDON, EC1V OHB, ENGLAND

Eleventh European Rotorcraft Forum, London, September 1985

A SIGNIFICANT IMPROVEMENT TO THE LOW SPEED YAW CONTROL OF THE SEA KING USING A TAIL BOOM STRAKE

by

Alan Brocklehurst
Aerodynamics Department - Westland Helicopters

SUMMARY

The addition of a simple strake along the tail boom of the Sea King has produced a significant improvement in the helicopter's low speed yaw control.

The yawing moment generated by the vector sum of the main rotor downwash and the sideways flight velocity over the tail boom, acts against the direction of the tail rotor thrust. This leads to a yaw control problem when hovering in 10 knot winds from starboard.

The computer model of the tail boom yawing moment uses an approximation to measured main rotor wake velocities and a synthesis of the two-dimensional bluff body characteristics for application to any helicopter. Wind tunnel tests of the Sea King fuselage have been used to determine the tail boom side-force coefficient. The results of the theoretical model are confirmed by flight test data which show that adverse boom forces in the critical flight regime can be eliminated by means of the strake.

The Sea King can now be flown in starboard winds of up to 30 kts at high all-up-weight.

An optimum shape for the tail boom is suggested and confirmed to have the desired characteristics by recent wind tunnel tests.

Means of promoting flow separation on helicopter tail booms is the subject of pending patent applications of Westland.

INTRODUCTION

Most helicopters exhibit some degree of difficulty with yaw control in low speed flight. These problems are largely due to aerodynamic interactions between the main rotor, tail rotor, fuselage, and fin. The severity of these interactions varies with the helicopter's fundamental aerodynamic design parameters and geometrical configuration. When problems occur, or become critical through growth in weight, the cost of making the necessary configuration changes may be prohibitively high and penalties must therefore be accepted in performance.

The Sea King is no exception to the rule, and whilst it is designed for shipborne use, limitations are encountered in winds from the starboard quarter at high all-up-weight. A particular problem is encountered at speeds as low as 10 knots.

In the mid 70's flight tests demonstrated improvements in tail rotor performance using a modern aerofoil section, optimised for tail rotor applications. These tests proved the cambered aerofoil to be successful, but also highlighted a problem in understanding the true breakdown of the thrust required by the tail rotor. Shaft thrust implied from measurements of coning, and estimates of net thrust from engine and tail rotor torque, did not tie-up, even when the effect of fin blockage was taken into account. The tests indicated that the additional requirement in tail rotor thrust was in the region of 300 lbf. As confidence in the methods of calculating fin blockage grew with continued refinements to the methods through comparison with test data, it became apparent that there had to be an additional mechanism at work.

Main rotor induced velocity and sidewind over the aft fuselage and tail boom was studied as a source of the adverse moment. A computer model was developed using strip theory to calculate the aerodynamic forces and moments.

WIND TUNNEL TESTS

A brief wind tunnel study was undertaken in December 1976 to see if a tail boom could develop yawing moments of a magnitude suggested by the flight tests. The results showed that not only could large moments be generated, but they could also be eliminated by the use of a strake over the incidence range of interest. Flow visualisation using wool tufts showed that the strake caused the previously attached flow over the tail boom to separate, as illustrated on Fig. 1.

In the wind tunnel tests, the 1/7th scale Sea King fuselage without fin was mounted on its side with the rotor head facing into wind to simulate the flow direction resulting from the vector sum of the main rotor downwash and sideways flight velocity. Positive pitching of the model on the wind tunnel balance, therefore, gave an incidence angle representative of a right sideways flight condition.

The first part of the tests investigated the influence of Reynolds number and roughness. The effect of Reynolds number on the flow about non-circular cylinders is discussed by Polhamus, Ref. 1. It is essential that the Reynolds number is high enough to eliminate any possibility of sub-critical flow. Tests were done at three tunnel speeds as shown on Fig. 2. At the lower speed some hysteresis was observed. This became much less marked at higher speeds. A speed of 114 ft/s, giving a Reynolds number of 538400 based on mean tailboom depth was used for all other tests.

The yawing moment is given in terms of equivalent tail rotor thrust. Positive values represent an adverse moment which must be overcome by the tail rotor. The results are presented for a uniform velocity of 60 ft/s, representing a first approximation to the weighted mean flow induced by the main rotor.

The results for the clean fuselage, small strake and large strake are shown on Fig. 3. The small strake was only sufficient to promote separation above incidence angles of 10 degrees. However, the larger strake extended the range of separated flow to lower angles thereby eliminating the adverse yawing moment in hover and low speed right sideways flight.

COMPUTER MODEL

Over the last few years, a general tail rotor performance program has been built up at Westland to model the tail rotor in its interactional environment. The program comprises a collection of subroutines, each covering a particular aspect of the problem.

A strip analysis technique is used to calculate the yawing moment generated by the airflow over the tail boom. In the case of the Sea King the tail boom is notably large and deep, as shown on Fig. 4. The main rotor wake is treated as a skewed cylinder which is swept across the fuselage according to the induced velocity and relative wind. Figure 4 also shows how the effective length of the fuselage immersed in the wake varies according to the wind azimuth. The portion of the tail boom outside the main rotor wake is subjected only to the wind velocity components. The distribution of main rotor induced flow is assumed triangular within the cylindrical wake model in order to approximate the real wake.

To maintain generality, the mathematical model uses non-dimensional force coefficients appropriate to the tailboom cross-section in question. For the Sea King these coefficients were first derived from the wind tunnel results by running the computer model for a uniform flow over the fuselage. The computer model may be used to study the effect of the tail boom forces on the thrust required by the tail rotor. Figure 5, shows a typical breakdown of the tail rotor thrust requirement in right sideways flight and illustrates the cause of the 10 knot handling problem. The adverse force produced by the tail boom and the effect of the strake can be clearly seen. These results are also amplified by the effect of fin blockage which is dependent upon both tail rotor thrust and inflow velocity. Note that this effect gives rise to a natural limit to the low speed flight envelope at higher sideways speeds.

FLIGHT TESTS

The strake consists of a strip of angled aluminium, attached to the upper port shoulder of the aft cabin and tail boom. The strake was designed, fitted and flight tested within a three day period in June 1982, during the Falklands crisis. Flights took place on a day with clear skies and steady breeze.

The Sea King was first flown with the strake fitted at a normalised weight of over 22000 lb, significantly higher than its normal operating weight.

The pilot reported that no yaw control problems were encountered, and could not detect any significant difference between this configuration and a standard Sea King at light weight. It was only when the strake was removed and the aircraft flown again under the same conditions that the pilot realised the benefit. The helicopter without the strake was unable to hold heading when attempting to fly faster than 10 knots to starboard. In fact, the existing 10 knot operating envelope for the aircraft was confirmed at 20500 lb, S.L. ISA. The strake therefore provides a benefit of at least 1500 lb for a weight penalty of only 5 lb.

Figure 6 shows the measured tail rotor pitch in right sideways flight. It can be seen that the use of the strake improves controlability in the critical 10-15 knot region and enables yaw control to be maintained to speeds as high as 30 knots. Handling improvements were also experienced in the forward and rear quartering flight sectors. Even in areas where the improvements were apparently small, the enhancement in yaw control was found to be very useful.

Some vibration due to main rotor wake impingement on the fuselage is always present near hover. Changes in vibration were not significant. In cruising flight no penalties were discovered. This was later checked against further wind tunnel and flight tests. No changes were noted in left sideways flight.

A power saving in sideways flight, Fig. 7, had been expected, since the tail rotor would normally be operating deeply into stall when flying at 10-15 knots to starboard without the strake. The power saving in this region was found to be in excess of 80 hp, most of this was attributable to the reduction in tail rotor profile power.

A residual bulge remains in the curves of total power against sideways speed. This feature is possibly due to interactions between the main and tail rotor, or perhaps due to the low speed edgewise power characteristics of the main rotor itself, as suggested by Sheridan and Smith, Ref. 2.

The flight test data has also been cross-plotted in the form of tail rotor pitch contours, Fig. 8, which shows a significant expansion of the low speed flight envelope.

APPLICATION OF STRAKE

The simplicity of the strake means that it can be readily fitted to existing helicopters.

Subsequently, much flying has been done with the strake fitted to various versions of the Sea King always with a significant improvement to the low speed handling and yaw control.

Westland's experience of the strake fitted to other helicopters with smaller near circular tail booms is to provide a benefit through a reduction in pilot workload. Pedal margins are improved and maintained to higher wind speeds. It appears that the strake reduces fluctuating aerodynamic loads on the tail boom, perhaps by fixing the separation points.

A flight investigation of strakes on the tail boom of a OH-58A has been reported by Smith, Leonard and Kelley, Ref. 3. The results on this helicopter, again with a small circular cross-section tail boom, with a drive shaft on top but no cover, showed very similar characteristics to those described above.

It is clear that the major benefit of the strake is obtained on helicopters with large, deep tail booms at low speed. Nevertheless, the strake produces a favourable effect when the tailboom is small.

TAIL BOOM CROSS-SECTION

The addition of a strake transforms the effective aerodynamic shape of the tail boom. The prevention of the adverse force by a separated flow process might be expected to produce a penalty in the download.

Wind tunnel data for the Sea King, Fig. 9, shows that the download only increases when the strake is actually causing flow separation to eliminate the sideload. The penalty in hover, near zero angle of attack, is minimal. The download for the flow angles appropriate to low speed right sideways flight increases, but this penalty is small compared to the improvements in yaw control and consequent saving in tail rotor power.

However, the Sea King tail boom, even with the strake fitted, is far from ideal. The large side area means that adverse yawing moments become significant at higher sideways speeds. The Sea King's low speed envelope, is therefore limited to about 30 knots. A modern, highly agile helicopter may have to meet design requirements for a 50 knot sidewind. A better shape for the tail boom is therefore required.

The first step towards a more suitable aerodynamic shape is to reduce the depth. As the depth of the section is reduced the presence of the drive shaft cover becomes more significant. A basically square shape may be desired to blend with the fuselage cabin and to provide tailplane mountings or fold hinges.

Subsequent to the flight tests on the Sea King, some work by Wilson and Kelley, Ref. 4, described some wind tunnel tests on tail booms of modern helicopters. The tests covered the UH-1, UH-60 and AH-64 helicopter tail booms both with and without a spoiler. The data shows that near square sectioned shapes can still produce a large sideforce coefficient. The data contains some interesting features in that these particular bluff bodies when clean, in addition to strong sideforce, may exhibit near zero download at incidences close to 35 degrees. When fitted with a spoiler, the sideforce characteristic is shifted to higher incidence angles which eliminates the low speed problems and the download is seen to increase over a fairly wide incidence range.

Test data for several bluff bodies of varying cross-section is also given by Polhamus as shown on Fig. 10. The two square sections, one with sharp corners, the other with rounded corners, have markedly different characteristics. The former actually reverses the sideforce at low incidence, but generates a high sideforce at moderate incidence. The square section with rounded corners retains its lifting properties at low incidence, and has low drag at high incidence. A section which combines the best features of these two shapes would provide a good solution for helicopter tail booms.

Fortunately, the data includes a shape with the desired characteristics, in the form of an inverted triangle with rounded corners. It can be seen from the data that the sideforce coefficient is negative or near zero in the incidence range appropriate to low speed sideways flight. At higher incidence the sideforce coefficient does not become large.

To maintain this desired characteristic with a tail drive shaft cover fitted it is necessary to reduce the radius of the upper corners to fix the separation points. These edges function in a similar manner to the strake by preventing attached flow on the tail boom when under the influence of the main rotor downwash. The lower half of the cross-section should have large corner radii to eliminate any Kutta condition being established which might encourage the generation of sideways lift.

The aerodynamically tailored, nominally square shape for a helicopter tail boom also retains a smooth external surface for good torsional stiffness and the lowest possible drag in cruising flight.

An example of this type of shape, inclusive of a drive shaft cover, has recently been wind tunnel tested and the results are shown on Fig. 11. The sideforce and download characteristics are confirmed to be as desired. This cross-section is, therefore, recommended for future helicopter tail booms.

CONCLUSIONS

Adverse yawing moments generated by the flow over the tail boom in low speed flight may be eliminated by the strake.

Use of a strake on the Sea King has resulted in a significant improvement in yaw control and lower torques in right sideways flight. When tail rotor control power is a limiting factor the maximum all-up-weight may be increased by at least 1500 lb.

Existing helicopters, such as the Sea King, with large, deep tail booms, benefit most from the use of the strake.

The weight penalty and drag in forward flight are minimal. Download penalties are small and occur mainly when the strake is working to alleviate the handling difficulty in sideways flight.

An aerodynamically tailored tail boom section has been proposed. The design is based on a nomimally square section with small upper corner radii and large lower corner radii. Wind tunnel tests have shown that this geometry eliminates the sideforce problem and minimises the download penalty.

REFERENCES

1) E. C. Polhamus, Effect of Flow Incidence and Reynolds Number on Low Speed Aerodynamic Characteristics of Several Non-circular Cylinders with Applications to Directional Stability and Spinning. NACA Technical Report R-29, 1957.

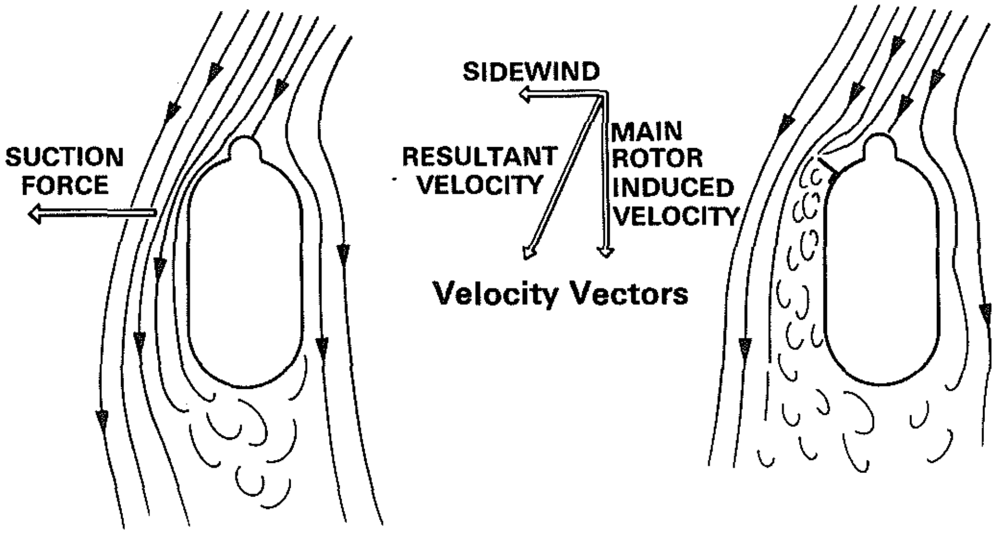
2) P. F. Sheridan and R. P. Smith, Interactional Aerodynamics - A New Challenge to Helicopter Technology. 35th Annual National Forum AHS, May 1979.

3) R. P. Smith, et al., Limited Flight Investigation of Strakes Mounted on a Helicopter Tail Boom. US Army/AHS International Conference on Rotorcraft Basic Research, February 1985.

4) J. C. Wilson and H. L. Kelley, Measured Aerodynamic Forces on Three Typical Helicopter Tail Boom Cross Sections. Tech. Note, Journ. AHS, October 1983.

Figure 1

DIAGRAMS SHOWING FLOW MECHANISM AROUND TAIL BOOM
WITH AND WITHOUT STRAKE



Tail Boom Without Strake **Tail Boom With Strake**

Figure 2
SEA KING FUSELAGE WIND TUNNEL DATA
INVESTIGATION OF
REYNOLDS NUMBER EFFECTS

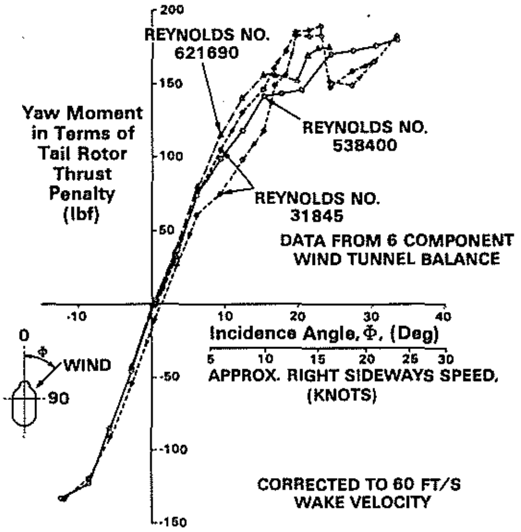


Figure 3
SEA KING FUSELAGE WIND TUNNEL DATA
CANCELLATION OF YAWING
MOMENT BY USE OF STRAKE

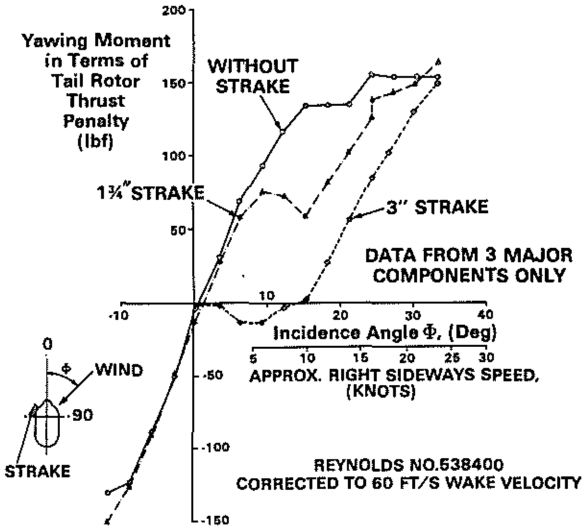


Figure 4
FUSELAGE AND WAKE GEOMETRY
FOR COMPUTER MODEL

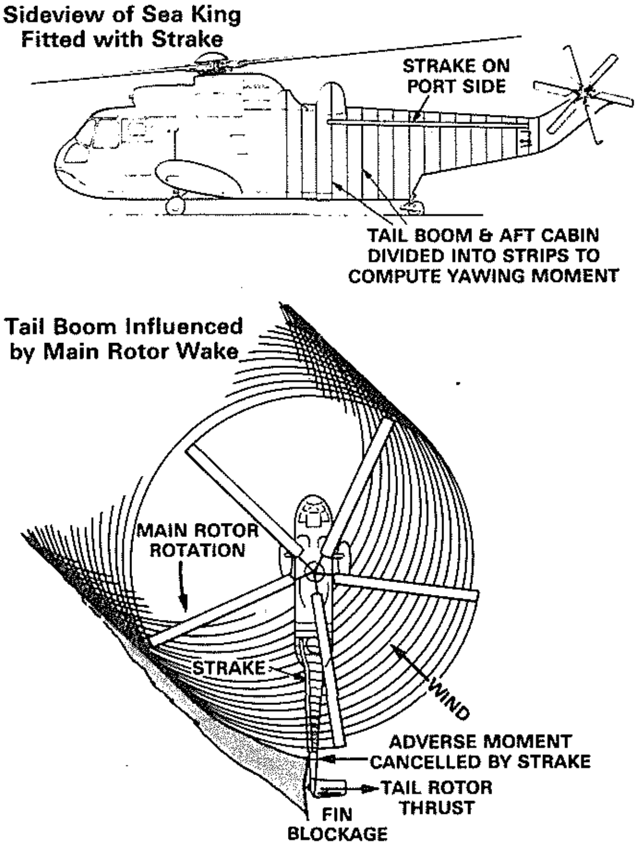


Figure 5
BREAKDOWN OF SEA KING
TAIL ROTOR THRUST

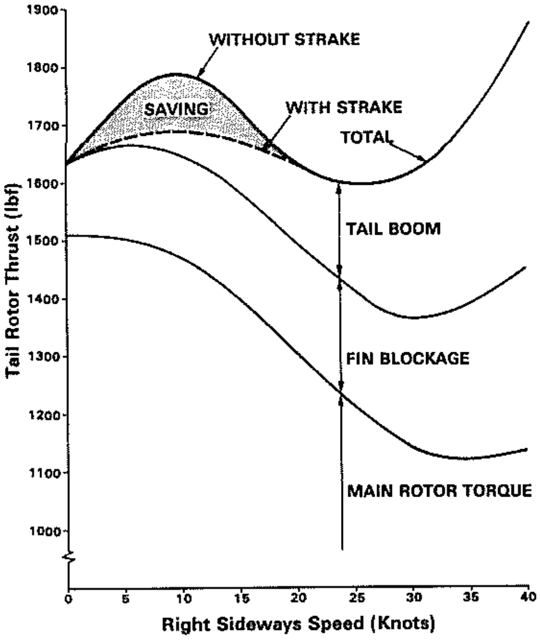


Figure 6
SEA KING TAIL ROTOR PITCH
IN LOW SPEED FLIGHT
STARBOARD WINDS

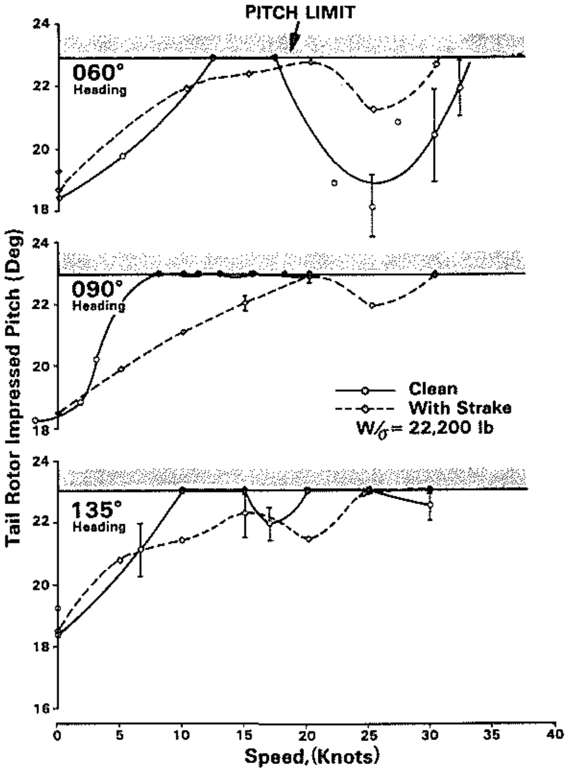


Figure 7
SEA KING TOTAL POWER
IN LOW SPEED FLIGHT
STARBOARD WINDS

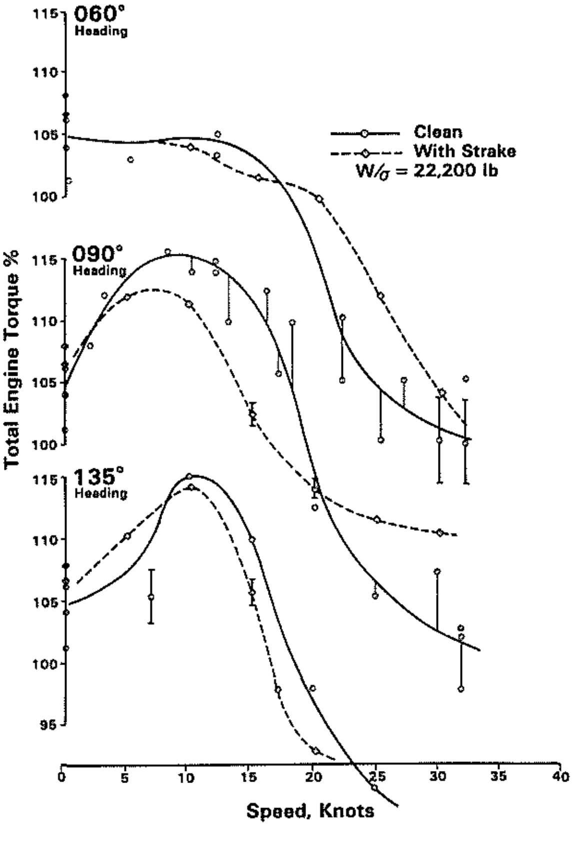


Figure 8

SEA KING TAIL ROTOR PITCH CONTOURS

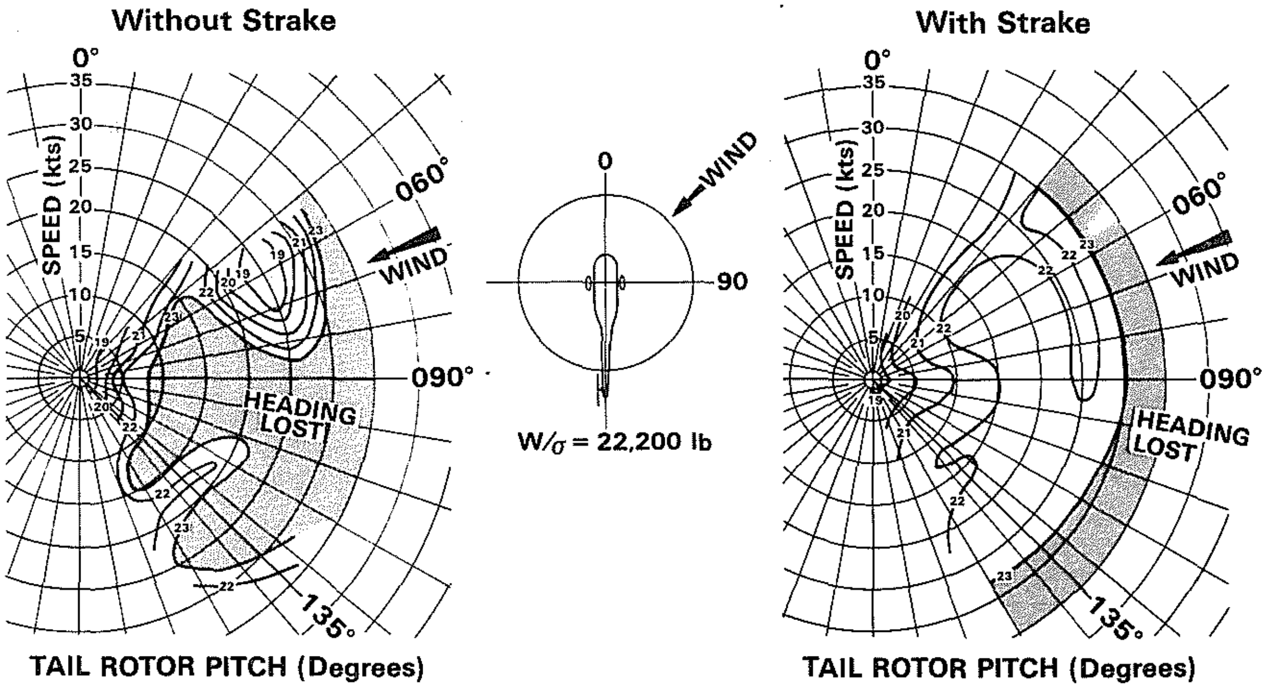


Figure 9

WIND TUNNEL DATA FOR SEA KING
COMPARISON OF FUSELAGE DOWNLOAD WITH AND WITHOUT STRAKE

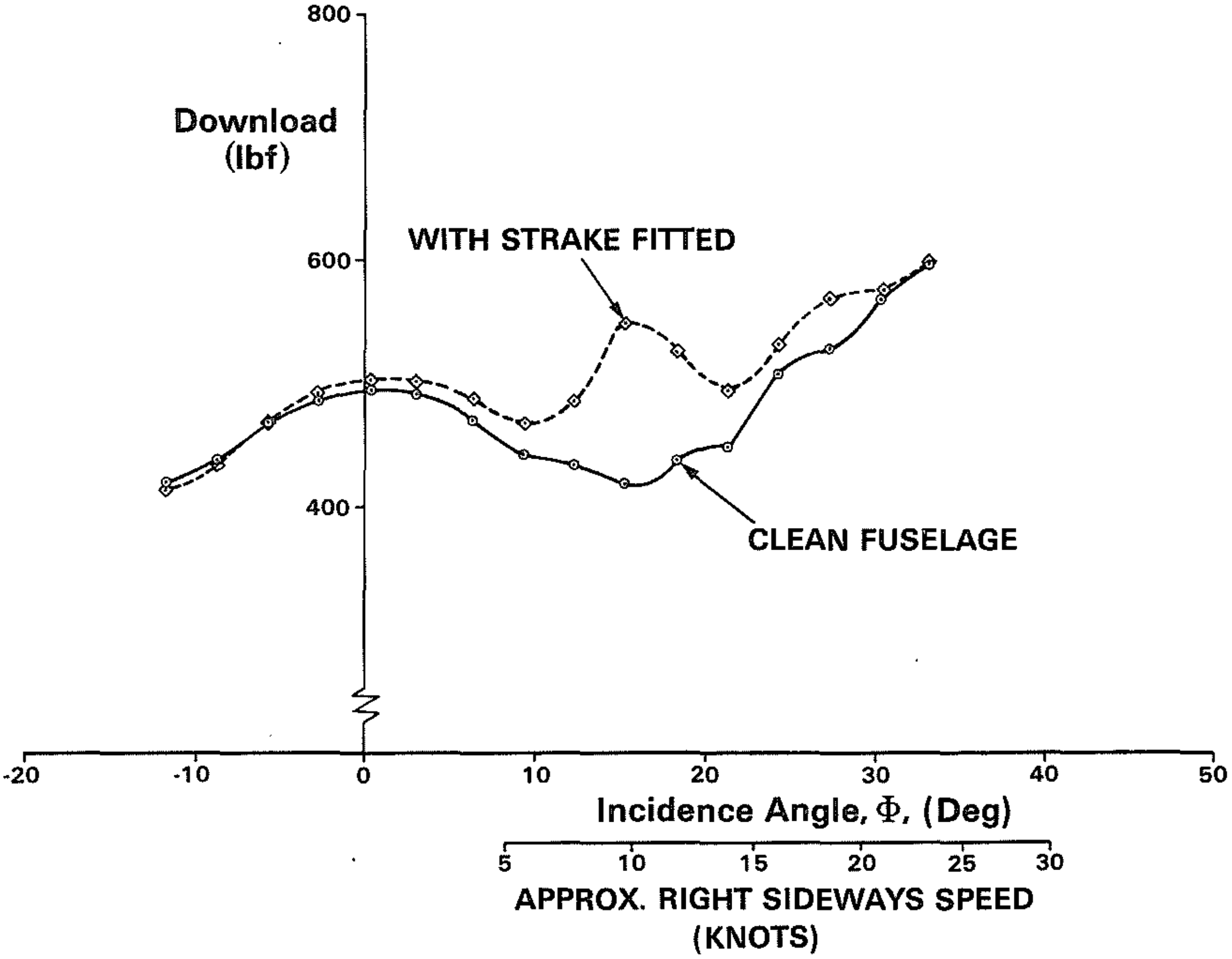


Figure 10

SIDEFORCE CHARACTERISTICS OF BLUFF CYLINDERS
AT A REYNOLDS NUMBER OF ONE MILLION

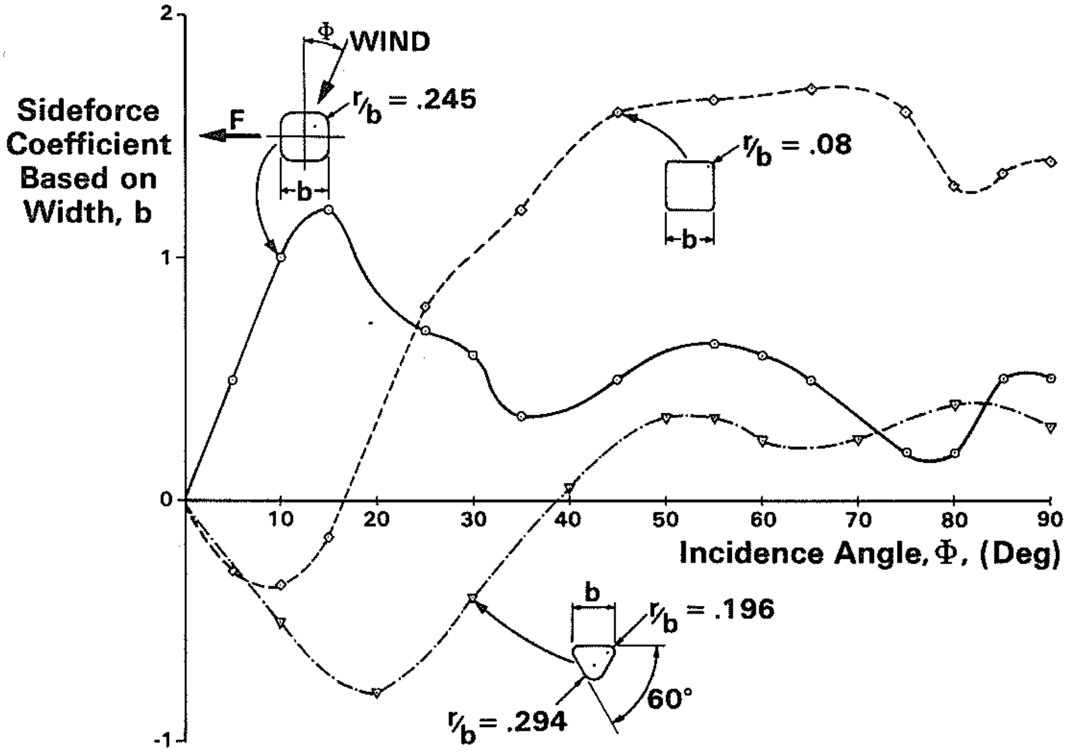


Figure 11

WIND TUNNEL TEST RESULTS ON TAIL BOOM SECTIONS