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HELICOPTER FLOAT SCOOPS

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HELICOPTER FLOAT SCOOPS

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Executive Summary

Earlier review work on helicopter ditching concluded that there was a clear benefit to be obtained from fitting scoops to helicopter flotation equipment. The static and dynamic effect of the scoops on the helicopter motions seemed to improve the resistance to capsize performance of most helicopters by about 1 sea state number.

The present study was performed by BMT with the assistance of Westland Helicopters Limited (WHL) in order to consolidate the present state of the art regarding float scoops and specifically to estimate the cost implications of fitting scoops to a typical large transport helicopter.

An outline design for float scoops was conducted for the Agusta/Westland EH101 civil transport helicopter. The increased float forces resulting in the addition of float scoops were estimated, and these loads compared with design calculations for the original helicopter in order to establish the structural and cost implications for the helicopter structure, floats and the float fixings.

The work has again highlighted the need for a better understanding of the dynamic motions of a helicopter in steep (and perhaps breaking) waves. Lack of detailed understanding of the helicopter behaviour limits the precision of any estimates of the forces experienced by emergency floats, whether they include scoops or not.

BMT's estimates of the dynamic forces experienced by the floats with and without scoops indicated that the magnitude of these forces depends crucially on the zero-crossing period of the sea state selected for analysis, and depending on the selection of this period, might lead to forces larger or smaller than the simple static load assumptions currently used in the helicopter certification process.

In the cases studied, the addition of the scoops to the floats increased these forces by between 12% and 17%.

Using a conservative assumption of an increase in forces between 25% and 50%, it was estimated that the cost of the helicopter airframe might increase by about 1%, and the cost of the flotation bags themselves by 10%. This would be expected to increase the total cost of the helicopter by about 0·28%. The small weight penalty associated with the float scoops was estimated to lead to a possible reduction in payload revenue of about 0·25%.

Contents

1 INTRODUCTION

A key finding of earlier review work performed by BMT Offshore Limited (BMT) on helicopter ditching [1][1] was that there seemed to be a clear benefit from fitting scoops to helicopter emergency flotation equipment. On average it seemed to increase the severity of the sea-state at which capsize occurred by about 1 sea state number.

It was believed that the reason why float scoops had not been taken up by the industry might be the lack of published information on their benefit. Consequently the main aim of this short study was to prepare a document on float scoops that can be published in order to promulgate their benefits.

Whilst a number of model tests had been performed on helicopters fitted with flotation scoops [2] this work had not been pursued through to design. It was believed that the main reason why work on scoops was not continued was difficulty in estimating the additional forces introduced into the helicopter structure by the floats.

The present study was performed by BMT with the assistance of Westland Helicopters Limited (WHL) in order to consolidate the present state of the art regarding float scoops.

The objectives of the current study were therefore:

1.1 Objectives

- To confirm whether difficulties with estimation of float forces was the reason for lack of continuation with work on the design of float scoops.
- In collaboration with WHL, to perform a short design study for emergency float scoops. The main output of the study being an estimate of the cost of fitting scoops to a helicopter.
- To summarise the benefits and costs of float scoops in a report.

1.2 Method

An outline design for float scoops was conducted for a specific helicopter type. The increased float forces resulting in the addition of float scoops was estimated, and these loads compared with the original design calculations for the helicopter in order to establish the implications for the helicopter structure, floats and the float fixings.

2 CONCLUSIONS

2.1 It has been established that the reasons why float scoops have not been pursued by helicopter designers in general (and WHL in particular) are:

- Difficulties in estimating the additional flotation loads.
- Lack of demand for float scoops from customers and from certification bodies.

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1 References are listed in Section 8 on page 14.

2.2 Despite this, it has been established from model tests that the fitting of scoops to existing helicopter flotation equipment results in an improvement in the resistance to capsize of most helicopters by about 1 sea state number. (In the southern North Sea this might approximately halve the probability of capsize following any random ditching incident from 26% to 14%.)

2.3 A short design study on fitting scoops to a large modern civil transport helicopter, the Agusta/Westland EH101, has found that:

2.3.1 Dynamic vertical forces estimated on the floats in waves obtained using a simplified dynamic analysis are broadly consistent with the static force assumptions made in the design by WHL.

2.3.2 The estimation of the vertical dynamic forces in a more precise manner is hampered by uncertainties in the water particle velocities and accelerations in steep (possibly breaking) waves, and by difficulties in the non-linear responses of the helicopter to these waves. These difficulties could be at least partly removed if a non-linear simulation of the floating helicopter were to be developed.

2.3.3 The selection of a wave period for the dynamic analysis is crucially important to any dynamic analysis of the float forces. Because of the relatively short natural roll period of helicopters, a period should be selected which is towards the steeper end of realistic waves expected for the area of flight operations.

2.3.4 The main effect of the scoops will be to increase the dynamic vertical components of the loads experienced by the floats in waves.

2.3.5 In the cases studied, adding scoops to the main floats of the EH101 increased the vertical forces by between 12% and 17% depending on the wave period assumed.

2.4 Whilst no specific model tests have been performed for the float scoops assumed for the EH101 in this study, one can be fairly confident that the same benefits in terms of resistance to capsize would accrue for this type.

2.5 In order to safely cover the scoop force increases estimated, and to allow for possible changes in the size and design of scoops, it was decided to estimate costs for a range of increases in the float loads of between 25% and 50%.

2.6 Based on the above range of increase in the flotation loads, a short design study was performed on the float scoops and the modifications likely to be required to the airframe to accommodate them. This study found that the cost of the helicopter airframe was likely to increase by about 1%, and the cost of the flotation bags themselves by 10%. This is expected to be reflected in an increase in the total cost of the helicopter of about 0·28%.

2.7 There will also be some increase in the weight of the airframe as a result of the structural modifications and flotation system modifications. This was estimated to be in the region of 25kg, which might typically equate to a cost of about 0.25% in terms of lost payload revenue.

2.8 The increased helicopter capital and running costs identified above are relatively modest. The benefits of this investment will be felt in terms of a significantly reduced overall risk of capsize when forced to ditch in the sea.

3 BENEFITS OF FLOAT SCOOPS

Scoops or water pockets have been used on inflatable life rafts for many years. Once these scoops have deployed and filled with water, they add weight to the craft and improve its resistance to capsize.

In 1986 [2] BHC performed a series of wave tank tests on models of nine different helicopter types in order to investigate the effect of adding scoops to the emergency floats. Overall they noted that the addition of the scoops showed an improvement in the helicopter resistance to capsize in irregular waves for most of the helicopter types tested.

Appendix A reproduces some example results from [2]. Sketches are shown of the flotation units and scoops fitted to types S-61N, S76 and AS332L. Also shown are the static stability curves of the three helicopter types demonstrating the increase in the peak righting moment that results from fitting scoops, and the effect on wave height and steepness of the capsize threshold that is achieved in regular waves. Improvement in the irregular wave capsize threshold was in most cases about 1 sea-state number. However, the S-61N was an exception, showing virtually no change in performance in waves, even though the static stability curves showed a marked increase in peak righting moment. A tabular summary of the results of [2] is reproduced from [1] in Appendix B.

In reviewing this work, reference [1] noted that the stabilising effect of the scoops is probably due to a number of different static and dynamic physical effects; the improvement in static stability that the scoops produce (due to the weight of the water in the scoop being lifted out of the water), the additional dynamic roll inertia, and the additional roll damping that scoops produce. All these effects will play their part, but it is not clear which are the most important.

If one takes the example of a helicopter which just capsizes in sea state 4 without scoops but survives up to sea state 5 with scoops, then the probability of a capsize following a ditching in the southern North Sea would be significantly reduced. Sea state 4 is exceeded for 26% of the time throughout the year, whilst sea state 5 is exceeded for 14% of the time. The probability of capsize will therefore be reduced by about half from 26% to 14%.

4 HELICOPTER SELECTION AND FLOAT SCOOP DESIGN

4.1 Helicopter Selection

The helicopter type selected for this study was the civil version of the Agusta/Westland EH101. The reasons for selecting this helicopter were:

- It is an example of a large modern transport helicopter.
- EH101 is being certified according to current CAA ditching rules (as at 1991).
- Owing to the current certification process on EH101, WHL can access design calculations relatively easily.

4.2 Float Scoop Design

As no design existed for float scoops for the EH101, it was necessary to design some that were broadly consistent with those used in the BHC model tests [2] for the other helicopter types which demonstrated an improvement in resistance to capsize of about 1 sea state number.

An analysis of the float scoop sizes used in those model tests was performed and the volume of the scoops expressed as a percentage of the individual float volume and the total flotation volume (a number of the helicopter types did not have the scoops added to all their floats). It should be emphasised that this was not a precise analysis as information on float volumes and dimensions was not to-hand for all the helicopter types. However, the results of the analysis are summarised in the following table:

Float Scoop Volumes – BHC Work **44035sv1.ws**

(units are mm scaled from drawing)

Type	*Float Vol* mm^3	*Scoop Vol* mm^3	*Scoop Vol* %	*Fitted* %	*Est Tot* %
Bell 412	330,260	59,638	18%	66%	12%
Bell 214ST	1,925,168	203,198	11%	100%	11%
Bell 212	343,470	82,676	24%	100%	24%
BK 117	565,487	82,002	15%	50%	7%
W30-300	443,065	109,589	25%	50%	12%
W30-100	444,388	146,976	33%	100%	33%
S-61N	182,605	54,225	30%	100%	30%
S76	313,961	89,098	28%	100%	28%
AS 332L	317,050	80,151	25%	50%	13%
		Mean:	23%		19%
		Stdev:	7%		10%
		Min:	11%		7%
		Max:	33%		33%

It can be seen from the above that the scoops fitted for these experiments varied in volume from 11% to 33% of the volume of the float to which they were fitted, and in total varied from 7% to 33% of the total flotation volume. The mean value in each case was 23% and 19% respectively.

On the basis of the above, it was decided to design a main float scoop for the EH101 which amounted to 28% of the main float volume. This was achieved by arranging an EH101 main float scoop with a radius 1.5 times the float radius, running for the full length of the float, and subtending an 80° arc. Figure 1 shows the scoop arrangement selected for the study (dimensions in metres). Figure 2 shows the location of the floats on the EH101.

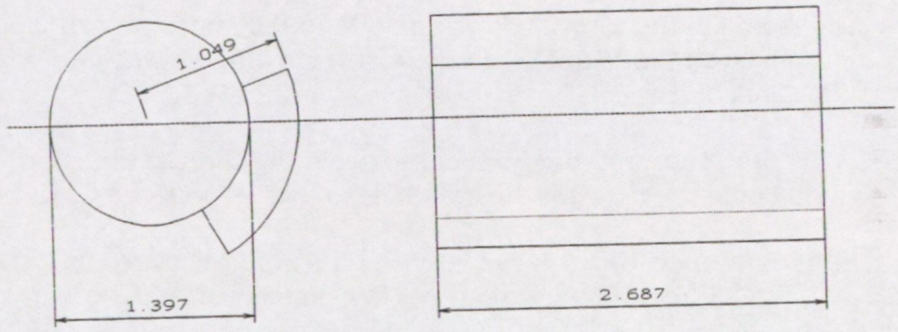

Figure 1 Scoops assumed for the EH101 main floats

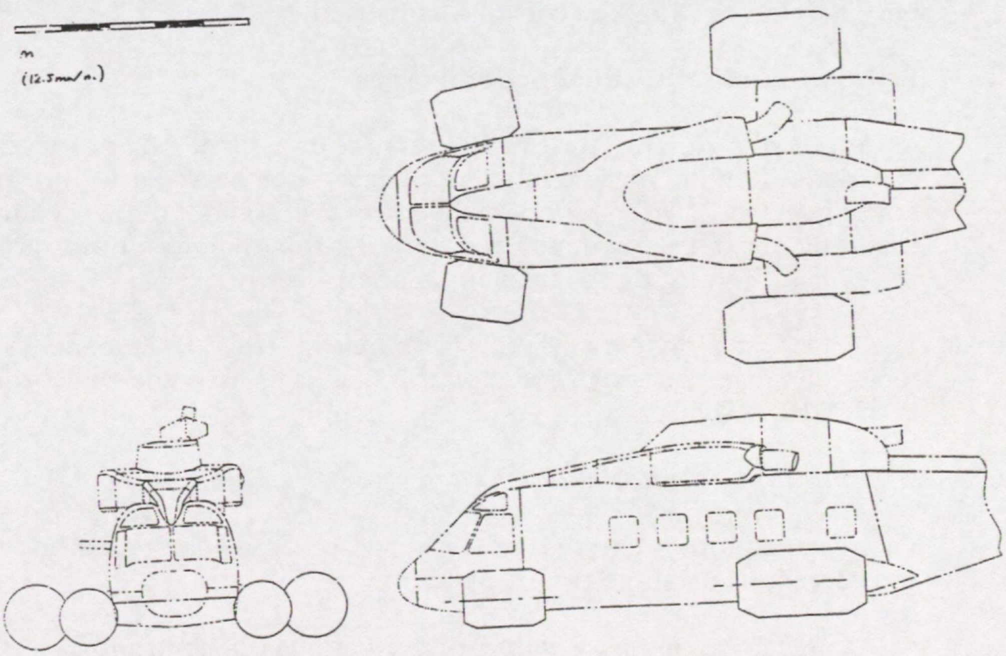

Figure 2 Float locations on EH101

5 FLOAT AND SCOOP LOADS

5.1 Existing Float Forces

The load cases considered for the emergency floats of the EH101 in its certification [3] basically consider the following conditions:

(i) drag in the fore-aft direction, due to the craft's forward speed, after the craft has ditched, but while it is still slowing down, and while the floats are inflating,

(ii) drag and pressure gradient loads in the fore-aft direction, after the craft has come to rest, with the craft head to waves, with the floats fully inflated,

(iii) buoyancy forces in the vertical direction, calculated as if the craft is at rest in still water, but with the floats fully immersed.

Load case (i) above will be unaffected by the presence of scoops. Scoops will only be deployed once the craft has come to rest, and can be designed to ensure that they lie flat against the float while it is moving forwards.

The scoops will face upwards, and so will have relatively little effect on fore-aft loads, other than a small change in the presented area of the float. This effect will be small, and so load case (ii) will also be largely unaffected by the presence of scoops.

Load case (iii) is the only one likely to be affected by the addition of scoops. Dynamic loads are not considered in the WHL standard load case (iii), which assumes instead that there is enough conservatism already in calculating static buoyancy forces with the floats fully immersed.

5.2 Estimation of Additional Scoop Forces

As noted above, the action of the scoops will be to increase the forces experienced by the float attachment points in the vertical axis only. However, the forces generated by the scoops will be dynamic, and not directly comparable with the static buoyancy force assumed by WHL. It is therefore necessary to examine the dynamic forcing on the float and scoop.

The EH101 main float is a cylinder of nominally 1·4m diameter and 2·7m long. The totally immersed buoyancy force on this float is 41·4kN, and this is the force used in the WHL design.

5.2.1 *Dynamic forces on stationary float*

The dynamic forces exerted by a water wave on a submerged body are usually considered to arise from two components:

- a drag force (in phase with the wave particle velocity), and
- an inertial force (in phase with the water particle acceleration).

The limiting sea state mentioned in the British Civil Airworthiness Requirements (BCAR) [4] is sea state 6. The BCAR paper defines sea state 6 as a significant wave height of between 4m and 6m, and WHL in their float load estimates [3] have taken the upper limit significant wave height of 6m, which also according to [4] approximately corresponds to a maximum wave height of 9·6m.

If the float is taken to be stationary and fully immersed in a 9·6m regular wave with a period of T = 8s (i.e. a steepness of about 1/10), and if normal assumptions are made about the drag coefficient and inertia coefficient of the cylindrical float, then the magnitude of the two vertical force components can be shown to be[2]:

• drag force	27·0 kN
• inertial force	25·0 kN

Because the drag and inertial force components are 90° out of phase with each other, the resultant maximum dynamic force is given by the square root of the sum of the squares of these two numbers:

• total resultant dynamic force	36·8 kN

In order to arrive at the total maximum vertical force experienced by the float attachments, the static buoyancy force due to the immersion of the floats (i.e. the weight of the helicopter) must be added also. If it is assumed that the float is 50% immersed (approximating to the helicopter floating at or near its maximum weight), then this static force will be 20·7 kN which leads to a total maximum force of:

• total maximum vertical force	57·5 kN

5.2.2 *Dynamic forces on stationary scoop*

The main effect of adding the scoop to the float will be to increase the vertical projected area of the float and the total vertical drag force on the scoop.

For the scoop held stationary in the same wave considered above, the additional drag force due to the scoop is estimated to be:

• additional drag due to scoop	15·5 kN

If the inertial component remains the same as above, then the new total resultant dynamic force on the float and scoop is given by $[(15{\cdot}5 + 27)^2 + (25)^2]^{1/2}$:

• total resultant dynamic force	49·3 kN

and if the static buoyancy force is again added the total maximum vertical force becomes:

• total maximum vertical force	70·0 kN

This represents an increase of about 22% on the maximum force estimated in section 5.2.1 above.

However, these calculations using the effects of a *regular wave* acting on a *fixed* float represent a gross simplification of the reality. The following section therefore extends this simple analysis to deal with a helicopter responding with roll motions in irregular waves.

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2 Example calculations of the velocities and accelerations in the wave, and the resulting force components are given in Appendix C.

5.2.3 *Dynamic forces on a moving float*

In reality the float is not being held stationary in the waves. The helicopter responds with the waves, and to some extent tries to follow the water particle motions of the waves. If it follows the motions of the waves then the forces on the floats will be reduced. If, on the other hand, the motions get out of phase with the waves (as they will at the roll resonance wave period) then the forces on the floats will be larger.

In order to estimate the dynamic forces experienced by the moving float it is necessary to have a knowledge of the motions of the helicopter in the waves and, in order to properly take account of the effects of roll resonance, this should be for irregular waves.

An accurate theoretical assessment of the helicopter motions in realistic steep waves is hampered by the following uncertainties:

(i) Uncertainty in the wave particle velocities and accelerations in a steep (possibly breaking) irregular wave.

(ii) Non-linear motion responses of the helicopter to the waves.

(iii) Uncertainty of the drag coefficient and inertia coefficient experienced by the float and scoop when partly immersed in the water.

Of these, the first two are probably the more important, and a proposal [5] has been made for the development of a more detailed mathematical model to address this, but this work has not yet been commissioned.

A simplified and linearized assessment of the helicopter motions has therefore been utilised (using BMT's NMIWAVE program) to arrive at an estimate of the helicopter's roll motion, and consequently the relative motions between the float and the water particles in the wave.

A wave with a significant wave height of 5m was assumed. This is the mean of the range of wave heights suggested by [4], and based on the tank tests described in [2], also seems to be a reasonable design goal.

However, the selection of a suitable wave zero crossing period is also important because of the potentially resonant response of the helicopter in roll. Figure 3 shows the joint probability of significant wave height and zero crossing period at a location in the North Sea [6].

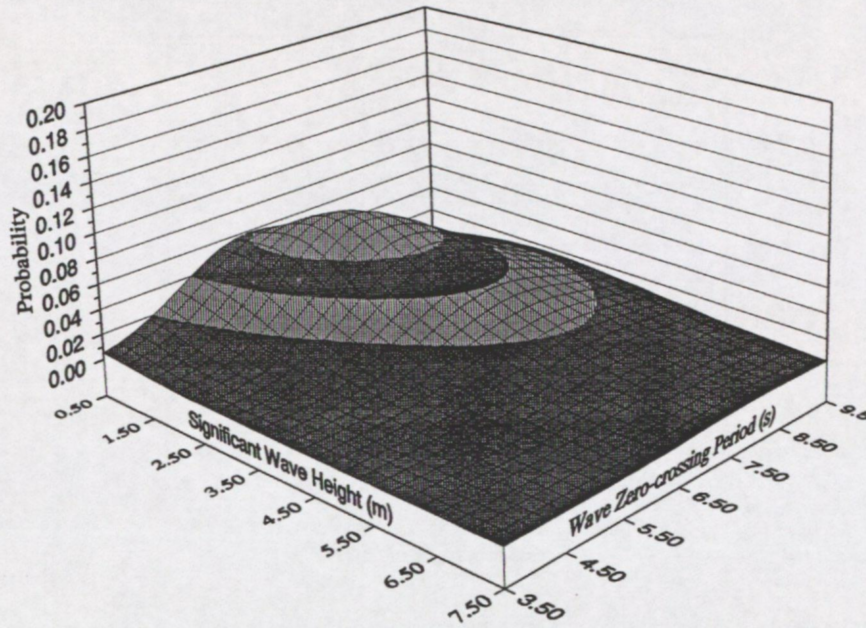


Figure 3 Joint probability of significant wave height and zero crossing period

It can be seen that any particular significant wave height can occur with a zero-crossing period over quite a range of values. And the steepness of the waves will be dependent on this period.

Figure 4 shows the distribution of periods for three different significant wave heights in the region of interest (i.e. selected sections from Figure 3). (It should be noted that these relationships are different for every ocean location, and so the data selected here can only be considered as indicative for the purposes of these float scoop force calculations.)

On the basis of the above, two periods were selected; T_z = 7s and T_z = 8s. The T_z=7s value roughly corresponds with the steepest waves that one might expect at this wave height, whilst the T_z = 8s value is a steepness which is more likely to be experienced in practice.

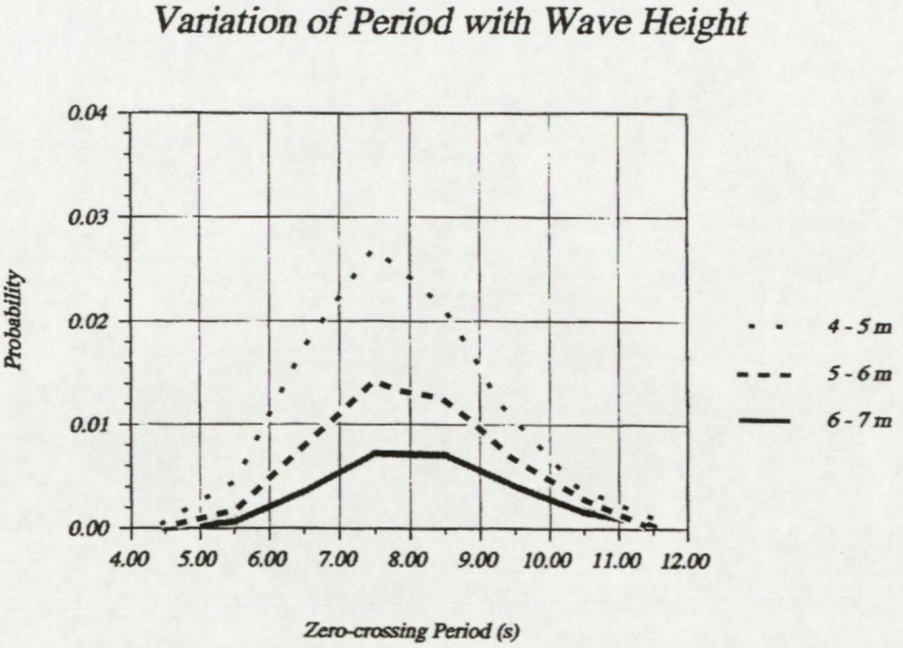


Figure 4 Variation of zero-crossing period with wave height

The most probable total maximum vertical forces experienced are summarised in the following table:

Vertical Float Loads		
	$T_z = 7s$	$T_z = 8s$
Float only	52·3 kN	39·6 kN
Float plus scoop	61·4 kN	44·3 kN
Percentage increase due to scoops	17·4%	11·9%

These forces include the drag and inertial components of the vertical dynamic load, and 50% of the static buoyancy force, and are the maximum values most likely to be experienced in a total exposure of 200 waves (i.e. about 20 minutes).

In view of the gross simplifications involved in the above calculations, it would be wrong to read too much into the differences between these values and the value of 41·1 kN assumed in WHL's static force estimates. The difference is not significant when taken in context with the inherent inaccuracies in the procedure used to estimate these dynamic loads. However, in relative terms it can be seen that the presence of the scoops adds between 12% and 17% to the total maximum vertical forces experienced by the float.

In view of the uncertainty in the estimation of these float load increases it was decided to conservatively carry forward a float load increase of between 25% and 50% to the remainder of the study for the estimation of the consequential airframe and running costs.

6 FLOAT SCOOP INSTALLATION COST ESTIMATION

The compilation of cost estimates for aircraft modifications is an arduous process and it is impossible to arrive at accurate figures without a considerable amount of preliminary design activity.

However, it has been estimated that the cost of the structural modifications required to the airframe to cope with the additional float loads, and to provide stowage space for the additional bulk of the floats, would not be particularly sensitive to the actual increase in those loads (be it 25% or 50%). The number of components would remain the same, and the manufacturing effort would be largely unchanged.

On this basis it has been estimated that the structural modifications might lead to an increase in the cost of the airframe of about 1%. This cost is likely to be much the same for a new design, or for the modification of an existing design.

The addition of the scoops to the floats is likely to increase the manufacturing cost of the floats themselves by about 10%. However, a retrofit of the scoop system to an existing helicopter would almost certainly require the complete replacement of the float units.

Given that the total additional airframe costs are about 1%, and given that the airframe represents about 28% of the total cost of the helicopter, it can be deduced that the scoops will add about 0·28% to the total capital cost of the helicopter.

The scoops system will also add weight to the helicopter, and all other things being equal, this additional weight will represent a loss of maximum payload capacity. It is estimated that the float scoop modifications will add about 25kg to the weight of the helicopter.

Estimates of seat revenue for a medium civil helicopter operating a typical route suggest that, if every flight was previously operated up to maximum weight, then the loss of revenue due to the additional weight of the scoops system would be in the region of 1%. However, it is probably that for most operators fewer than 25% of flights would be operated at maximum weight and therefore the true cost is likely to be less than 0·25%.

Overall the above cost and revenue variations seem very small, and would be easily swamped by other variations in helicopter types, routes and operational conditions.

7 DISCUSSION

The clear benefit of fitting scoops to the emergency floats of a helicopter is a general increase in the sea state at which capsize is likely to occur. This leads to a reduction in the capsize risk for any given random ditching incident. The actual level of reduction of risk depends on the helicopter type and on the weather climate in the operational area, but as an example, a helicopter whose capsize boundary is increased from sea state 4 to sea state 5 by the addition of scoops will have its probability of capsize approximately halved from 26% to 14% if it were operating in the southern North Sea area.

The cost of adding scoops to a helicopter will mainly consist of three elements:

- the additional cost of the float units themselves with the scoops added, and
- the cost of any modifications required to the helicopter structure in order to resist the additional forces transmitted by the scoops, and
- any revenue penalty associated with an increase in weight.

Certification calculations performed for the float forces by WHL consider both horizontal and vertical components of the float forces in order to check the strength of the floats and their attachment points to the airframe. It can generally be assumed that scoops could be designed such that the horizontal components of these float forces are not significantly changed. However, the vertical components of these forces will be changed by the addition of scoops, and indeed, it is these vertical force changes that give rise to the greater resistance to capsize of a helicopter fitted with them.

The vertical forces experienced by the floats (whether fitted with scoops or not) are difficult to estimate reliably. Currently the vertical forces on the floats themselves are estimated by WHL as the static buoyancy force experienced if the float is fully immersed. However, in reality the floats experience dynamic forces which are a function of wave drag loads, wave inertial loads, and drag and inertial components resulting from the motions of the helicopter as it responds the action of the waves. Such forces are difficult to estimate in steep (and perhaps breaking) waves, and where the float is only partly immersed. Better estimates of the forces could be made if there existed a non-linear computer simulation model of the floating helicopter, but to-date such a model has not been developed.

However, in the knowledge that the process is prone to significant inaccuracies, this project has made estimates of the dynamic float forces using a linearized motions analysis (BMT's NMIWAVE program). The forces were estimated in irregular waves for a 5m significant wave height which is in the region of the limiting sea state indicated by the BCAR [4] requirements. The results of the calculations emphasised the importance of the selection of a zero-crossing wave period because the two values chosen for the calculations showed very different vertical float forces.

The EH101 helicopter chosen for the current investigation has a natural roll period at around 3 seconds, and any waves occurring at these periods will lead to dynamic magnification of the roll motions and larger dynamic float forces. (This roll natural period is also presumably typical of other helicopters of this size.)

The steeper wave spectrum with a zero-crossing period at $T_z = 7s$ has significantly more energy near to the natural roll period than the $T_z = 8s$ case also used in the calculations. Particle velocities and accelerations near the water surface are also greater in the $T_z = 7s$ wave. Consequently the dynamic forces on the floats are higher for this case. The $T_z = 7s$ case estimated a total probable maximum vertical float force which was about 25% higher than the static buoyancy force assumed by WHL. The $T_z = 8s$ case, however, indicated forces closely agreeing with the static buoyancy assumption.

It must be emphasised that the accuracy of these dynamic force estimates is severely limited by the shortcomings identified above, and consequently it should not be assumed that the WHL statically based vertical design force is necessarily inadequate. The dynamic estimates do, however, clearly illustrate the importance of the wave period selected for any dynamic analysis.

In the North Sea a T_z = 8s might be commonly experienced accompanying a significant wave height of 5m. T_z = 7s would be a more unusual occurrence, and would be close to the steepest sea state that might be experienced at this height. However, if this steepest case results in the largest float forces it is arguable that it should be the basis of a dynamic forcing design process.

The total vertical forces have been estimated including both dynamic and static components. The dynamic component includes both drag forces (in phase with fluid velocities) and inertial components (in phase with fluid accelerations). The static component is equivalent to the part of the weight of the helicopter which is supported on the floats. For the purposes of these estimates it has been assumed that the main floats are 50% immersed (roughly equivalent to floating at maximum weight for the EH101).

The addition of the scoops resulted in the probable maximum vertical force on the floats increasing by 17% for the T_z = 7s case and by 12% for the T_z = 8s case. However, in order to be conservative in the remainder of the cost study, it was decided to use two vertical force increases of 25% and 50%.

The requirement to stow the larger floats, and the need to resist greater float forces in the helicopter structure lead to an estimated increase in the cost of the airframe of about 1%. This might be expected to lead to an increase in the total cost of the helicopter of about 0.28%.

The additional weight of the float system is estimated to be about 25kg. If all other design and operational parameters for the helicopter remain the same, this theoretically represents a reduction in the maximum payload that can be carried, which in turn represents a reduction in revenue earning capacity. An accurate estimate of this reduced earning capacity cannot be made without consideration of a particular route structure and operating profile. However, with various assumptions made here it has been conservatively estimated to be about 0·25% of revenue. It should be emphasised, however, that this weight increase is very small and is probably of the same order as weight differences between individual aircraft of the same type in a helicopter fleet.

Overall it must be said that the costs of installing scoops have been estimated in a conservative way, and nevertheless have been found to be very small.

The emergency flotation equipment of a helicopter is obviously only brought into use on the rare occasions when a major failure has already occurred leading to the ditching on the water, but the potential benefits from the scoops in reducing the likelihood of capsize occurring before the occupants can escape to the relative safety of the liferafts is an important tangible benefit.

8 REFERENCES

1 BMT Offshore Ltd., 'Review of helicopter ditching performance', Report on Project 44011/00 for the Civil Aviation Authority, Release 2, 7 July 1993 (Confidential to CAA).

2 BHC Report No. X/0/3257, April 1986, Study of Fitting Scoops to Emergency Floats (Confidential to CAA).

3 Letter from M L Overd of Westland Helicopters Limited, Ref E/MLO/VAB/3365 dated June 27th 1994.

4 Civil Aviation Authority, BCAR Paper No G779, 7th October 1985.

5 BMT Offshore Limited Proposal No Q/94099, 'Helicopter Stability Following Ditching – Section 2 – Numerical Model of Floating Helicopter', 4th November 1993 (Confidential to CAA).

6 PC Global Wave Statistics, BMT Fluid Mechanics Limited, 1987.

Appendix A Examples Results from BHC X/O/3257 (April 1986)

A1 GENERAL

Example results are presented in the following reproduced from Ref [2] for three of the nine helicopter types tested: S61N, S76 and AS332L.

In each case the following are shown:

- A sketch of the helicopter showing the location of the flotation units.
- A detailed sketch and/or photograph showing the scoops added to the flotation units.
- A static stability curve showing the increase in the peak roll righting moment which results from the addition of scoops.
- A graph showing the change in the regular wave height at which capsize occurs when the float scoops are added.

These results (and those for the other helicopter types not reproduced here) lead to the following main conclusions:

(a) All helicopters show a marked increase in static stability in terms of the peak righting moment when scoops are added.

(b) Most helicopters show an increase in the wave height at which capsize occurs, both in regular and irregular waves. The exception was the S-61N which showed no noticeable improvement in either type of wave.

A.2 SIKORSKY S-61N

(See overleaf)

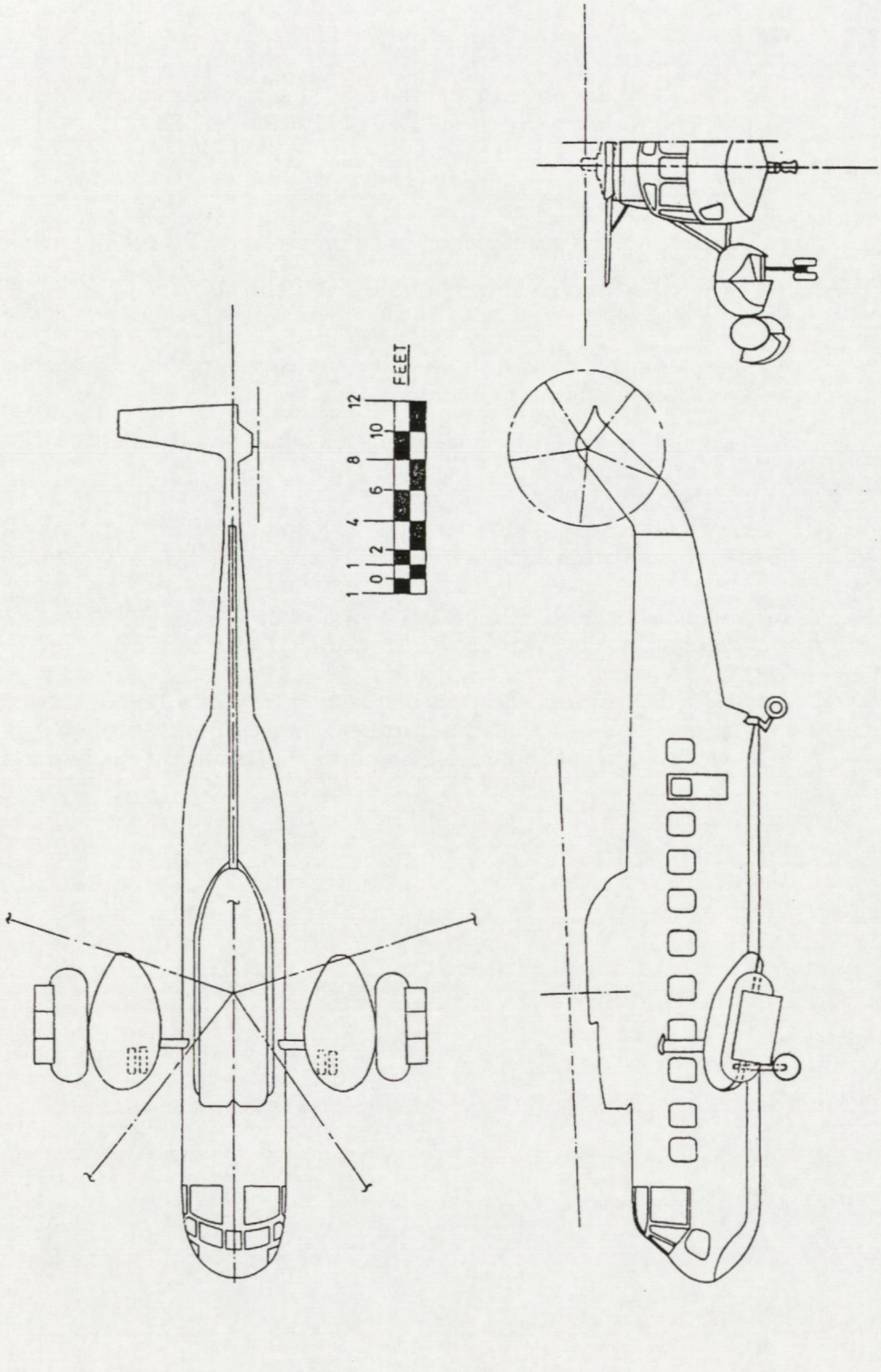


Figure 8/1 Sikorsky S-61N Helicopter

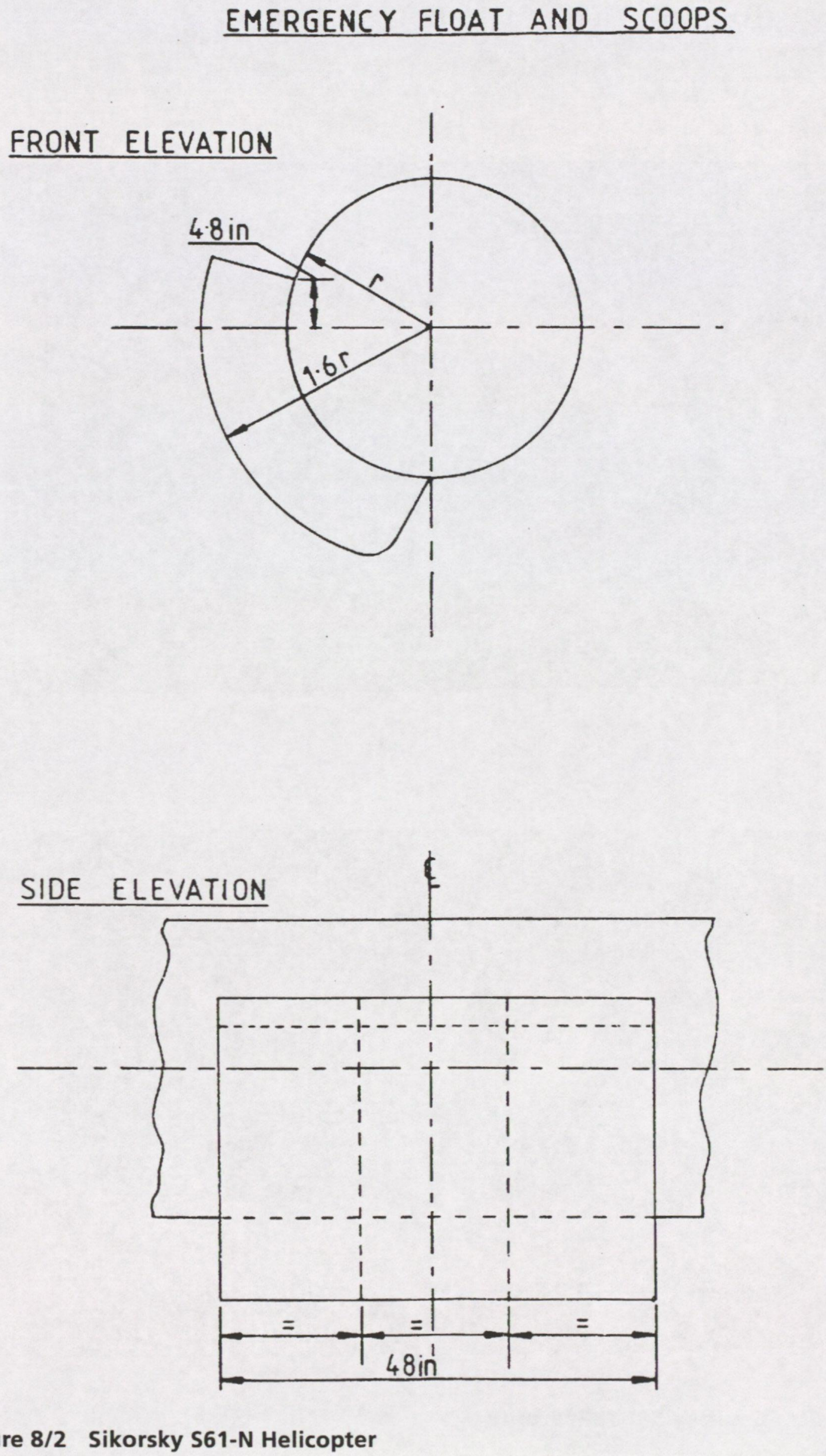
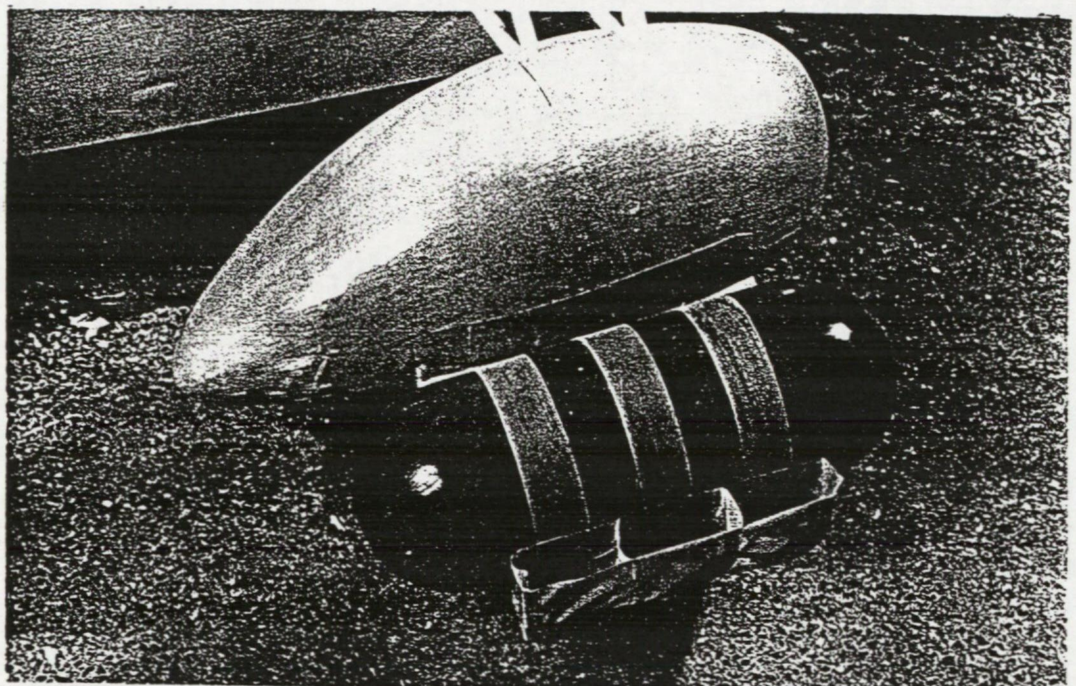


Figure 8/2 Sikorsky S61-N Helicopter

VIEWS OF WATER SCOOPS



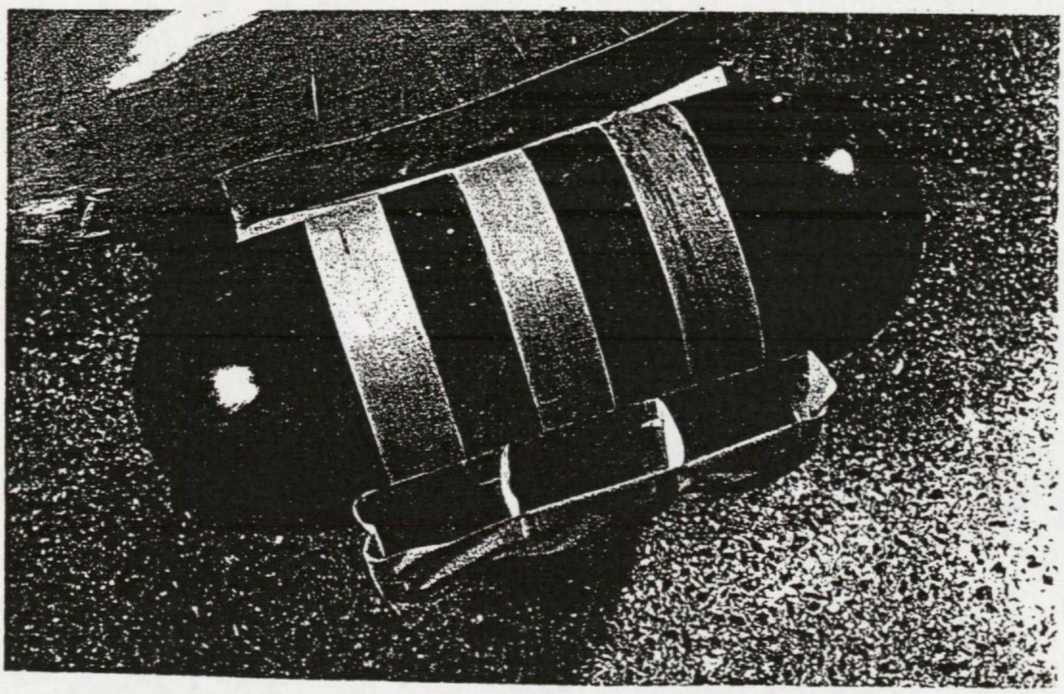


Figure 8/3 Sikorsky S61-N Helicopter

VARIATION OF RIGHTING MOMENT WITH ROLL ANGLE

SIKORSKY S-61N HELICOPTER TEST WEIGHT ~ 18000 lb

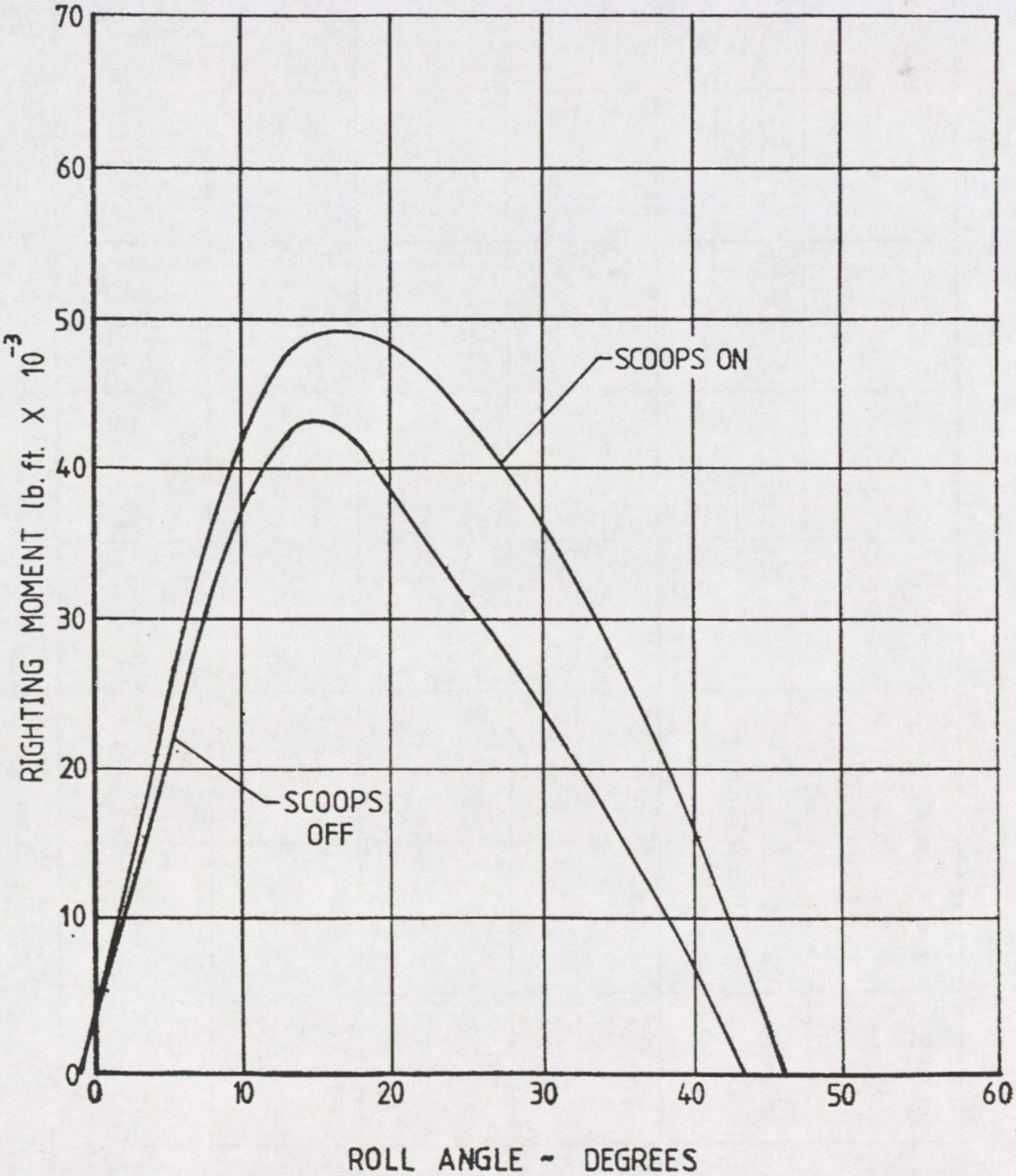


Figure 8/4 Sikorsky S61-N Helicopter

STABILITY WHEN FLOATING IN REGULAR WAVES

SIKORSKY S-61N HELICOPTER

TEST WEIGHT ~ 18000 lb

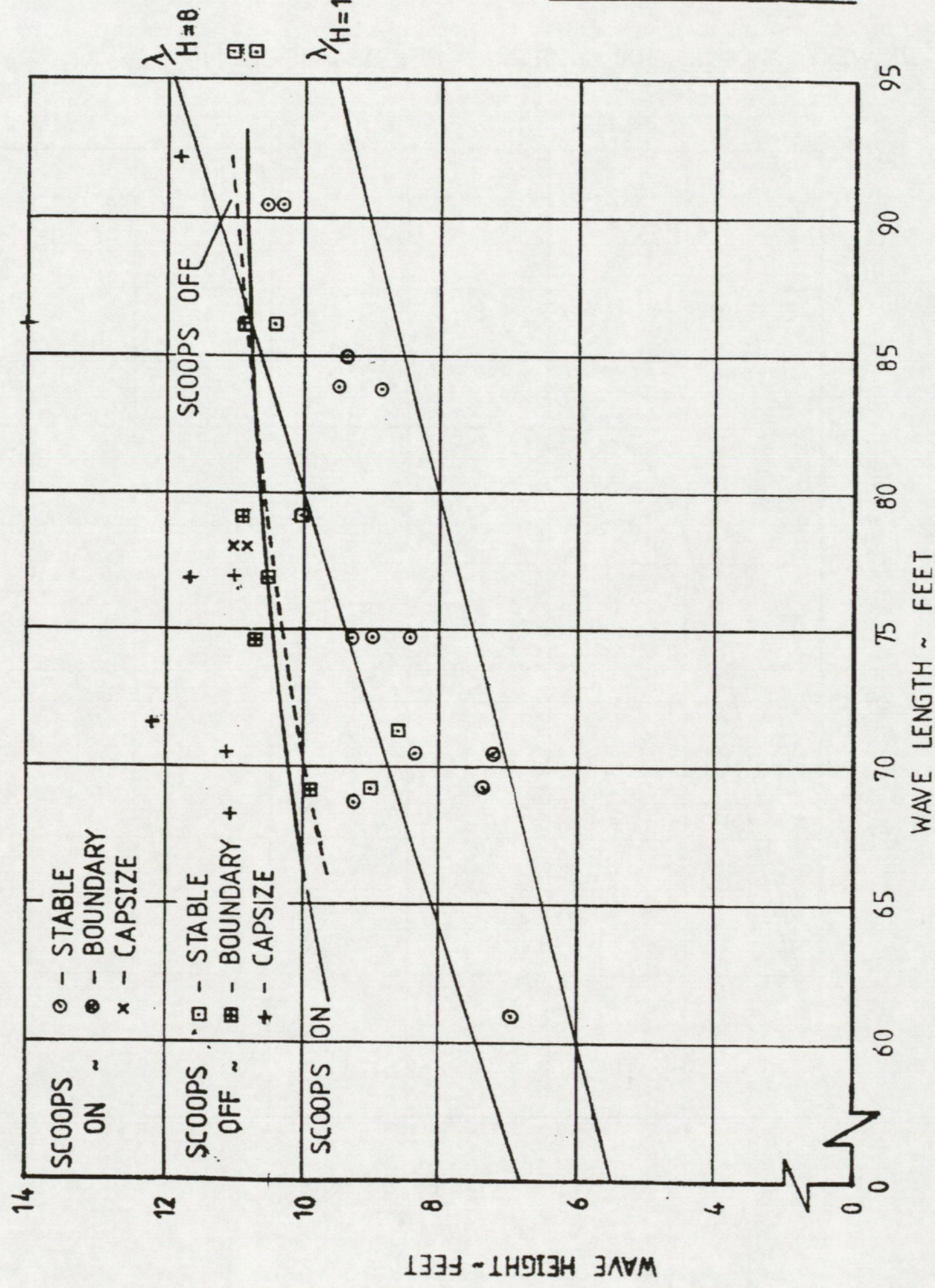


Figure 8/5 Sikorsky S61-N Helicopter

A.3 Sikorsky S76

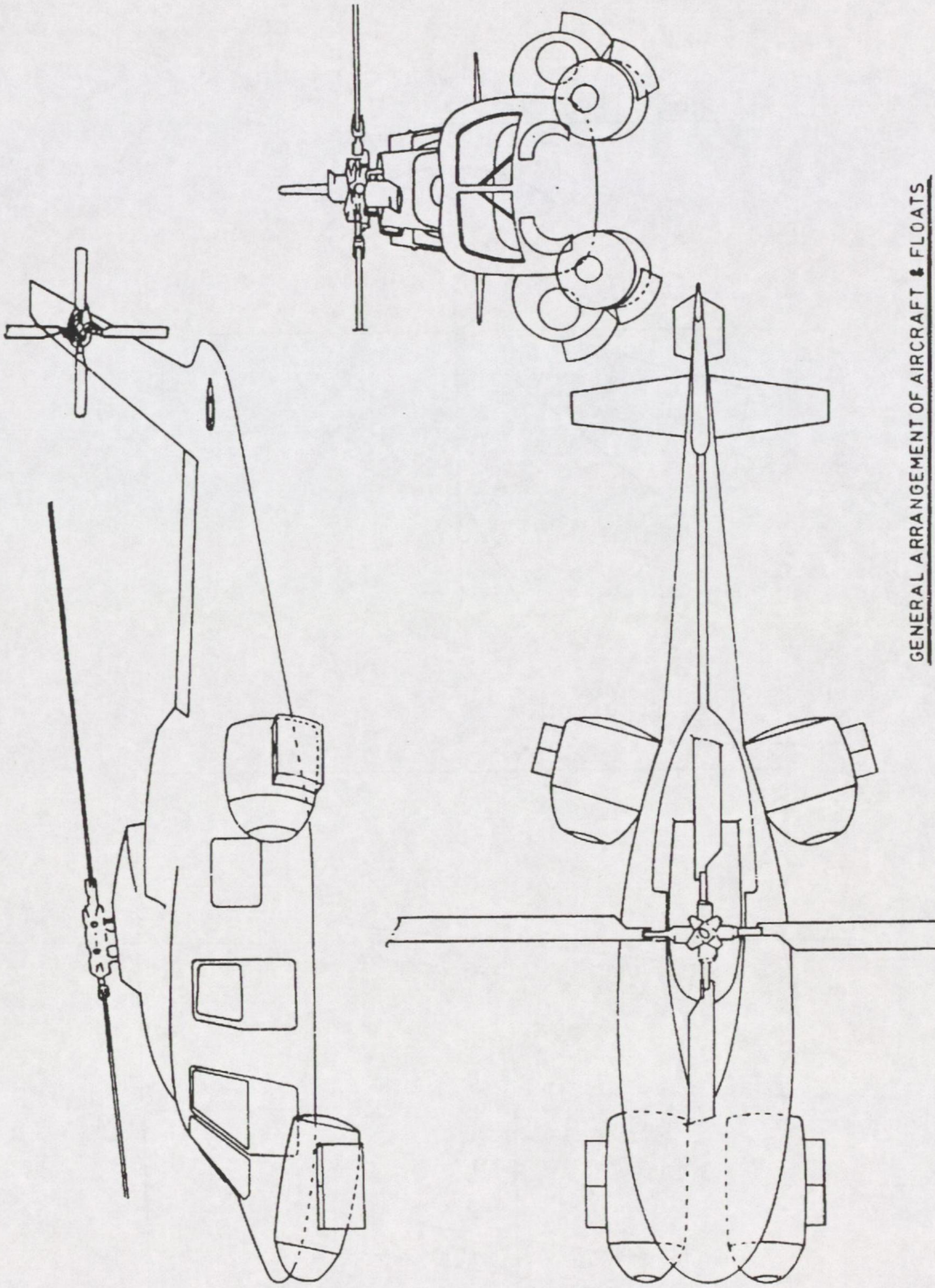


Figure 8/15 Sikorsky S76

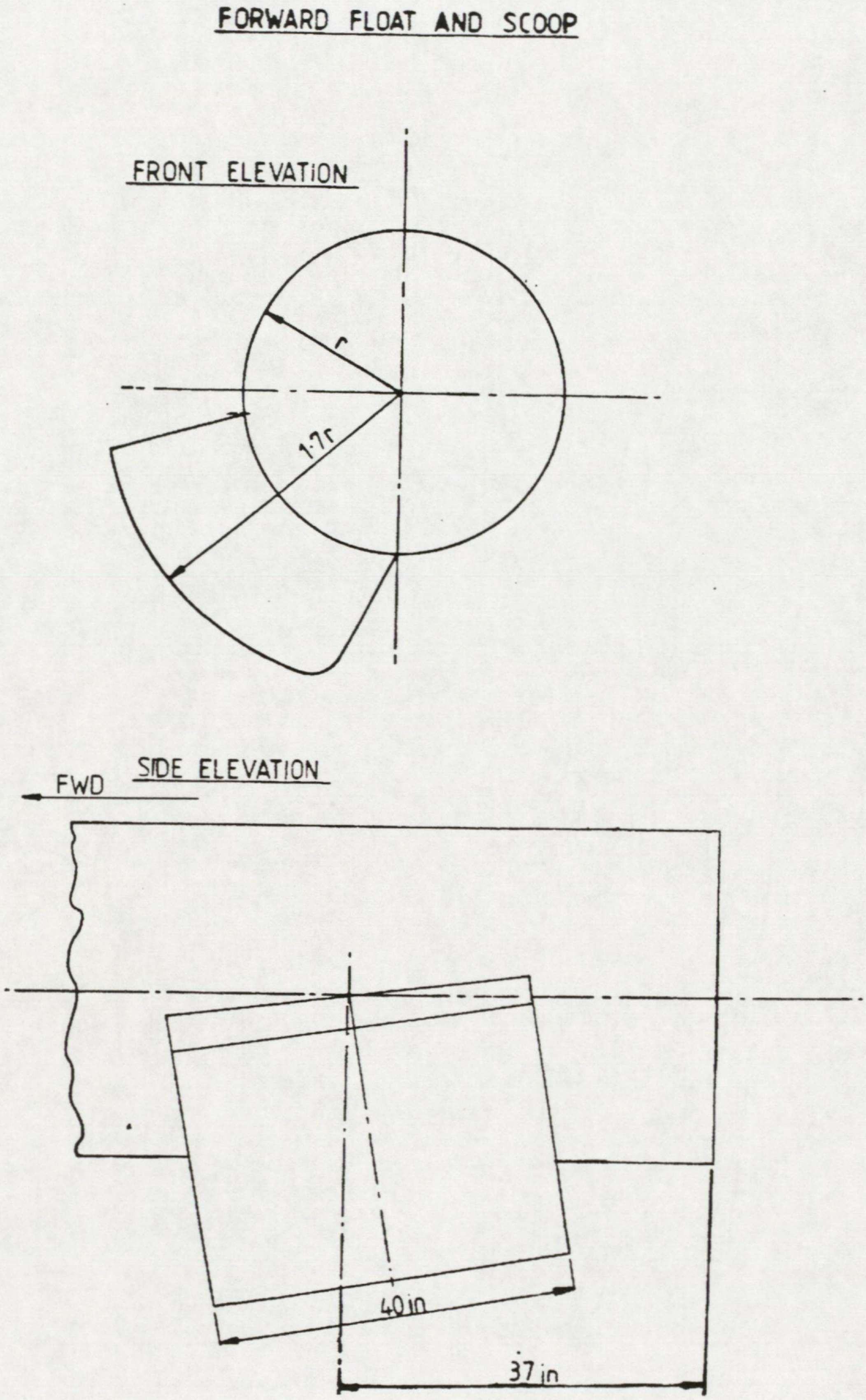


Figure 8/16 Sikorsky S76

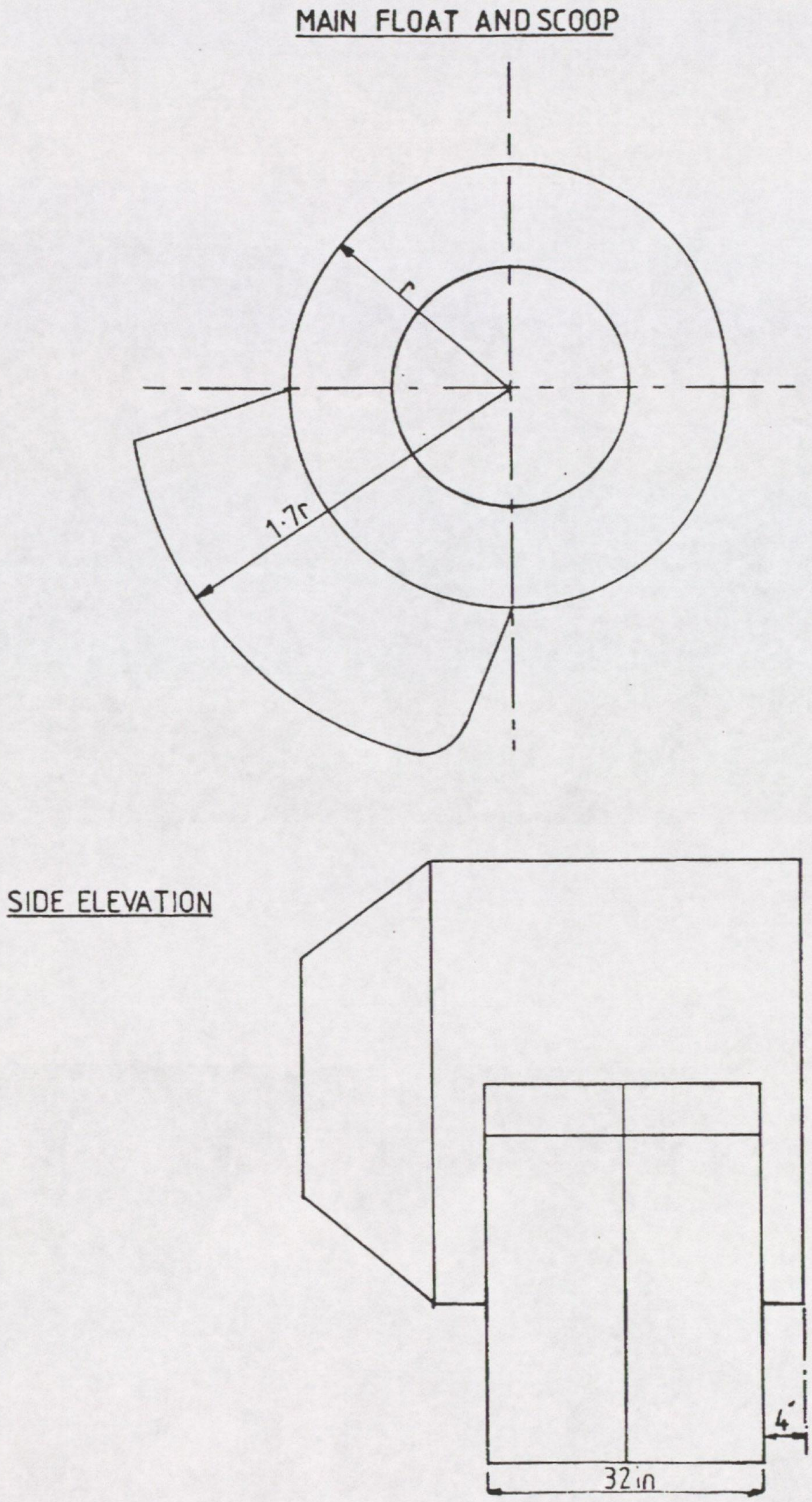
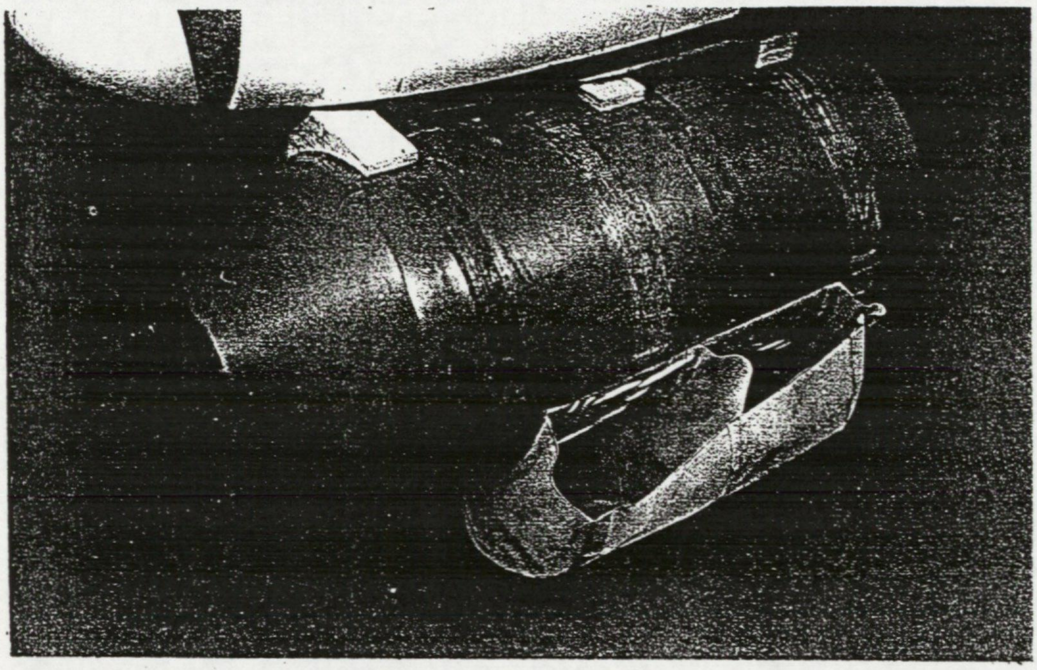


Figure 8/17 Sikorsky S76

VIEWS OF WATER SCOOPS

FORWARD FLOATS



MAIN FLOATS

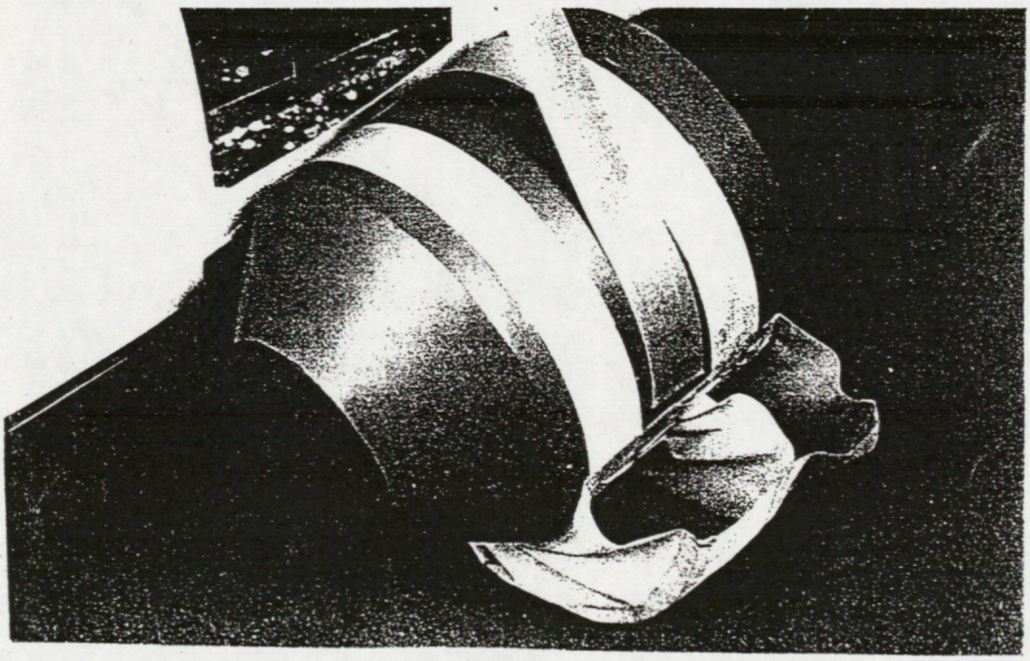


Figure 8/18 Sikorsky S76

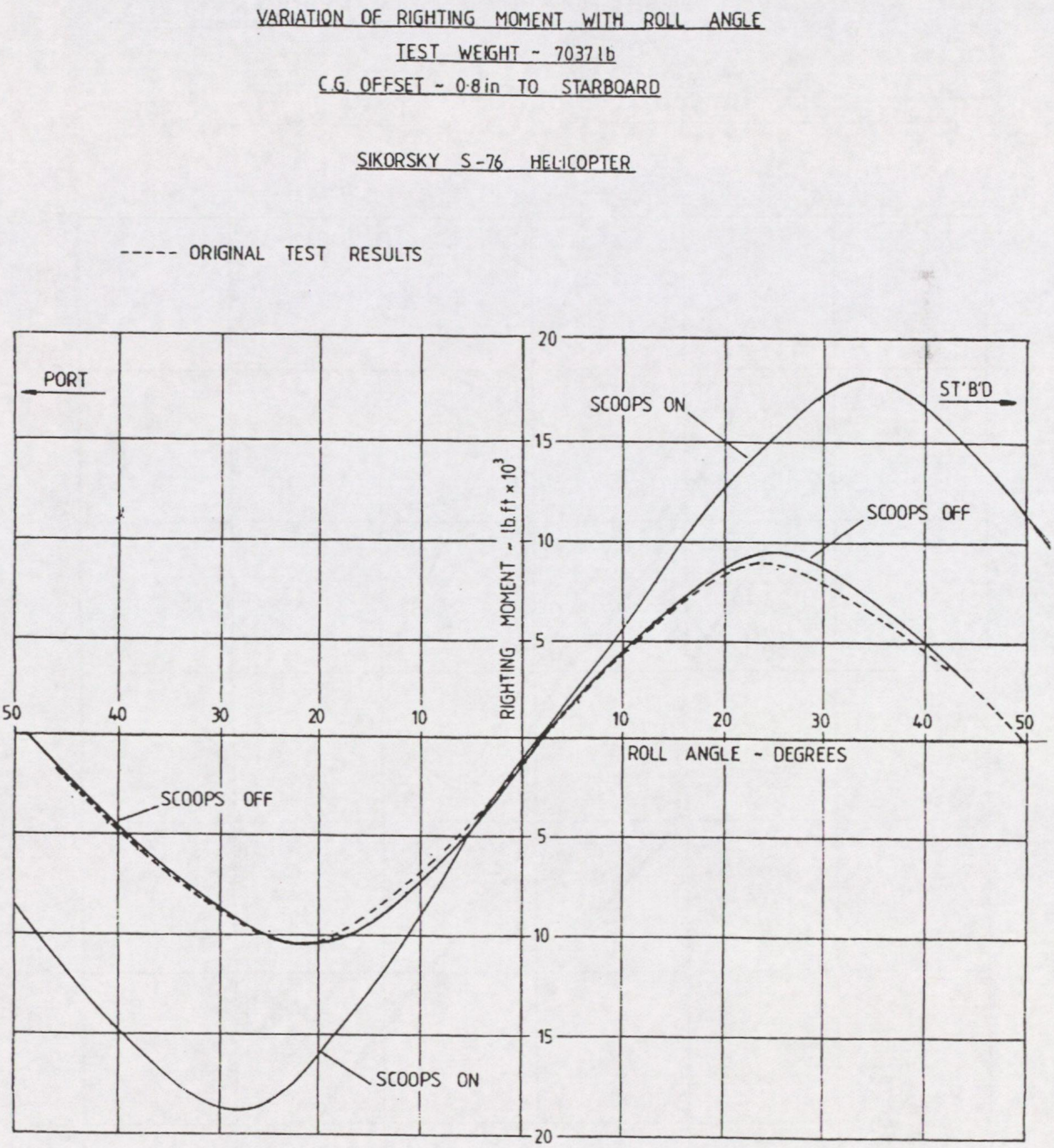


Figure 8/19 Sikorsky S76

STABILITY WHEN FLOATING IN REGULAR WAVES

SIKORSKY S-76 HELICOPTER

TEST WEIGHT ~ 7037 lb

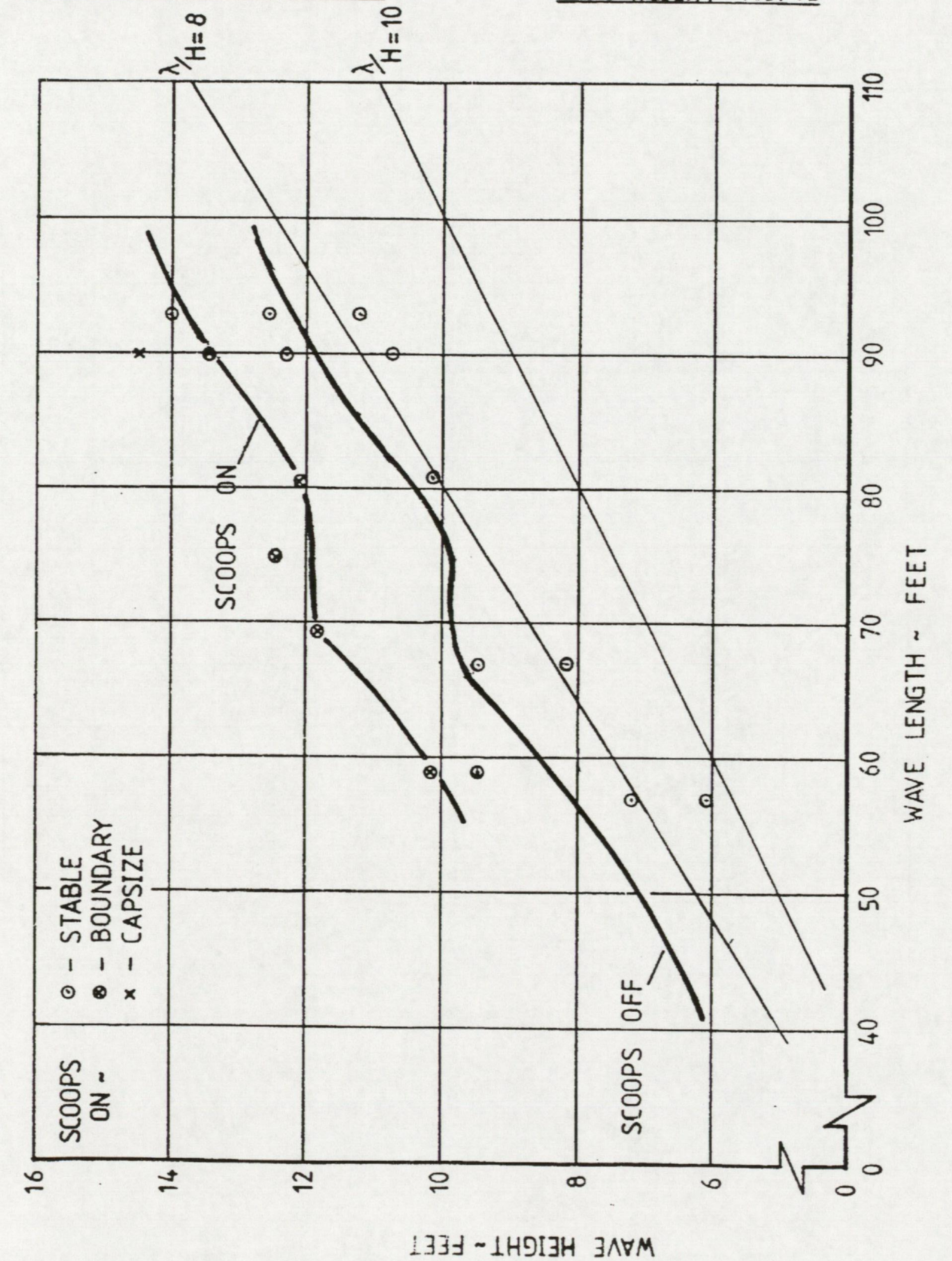


Figure 8/20 Sikorsky S76

A.4 AS-332L Super Puma

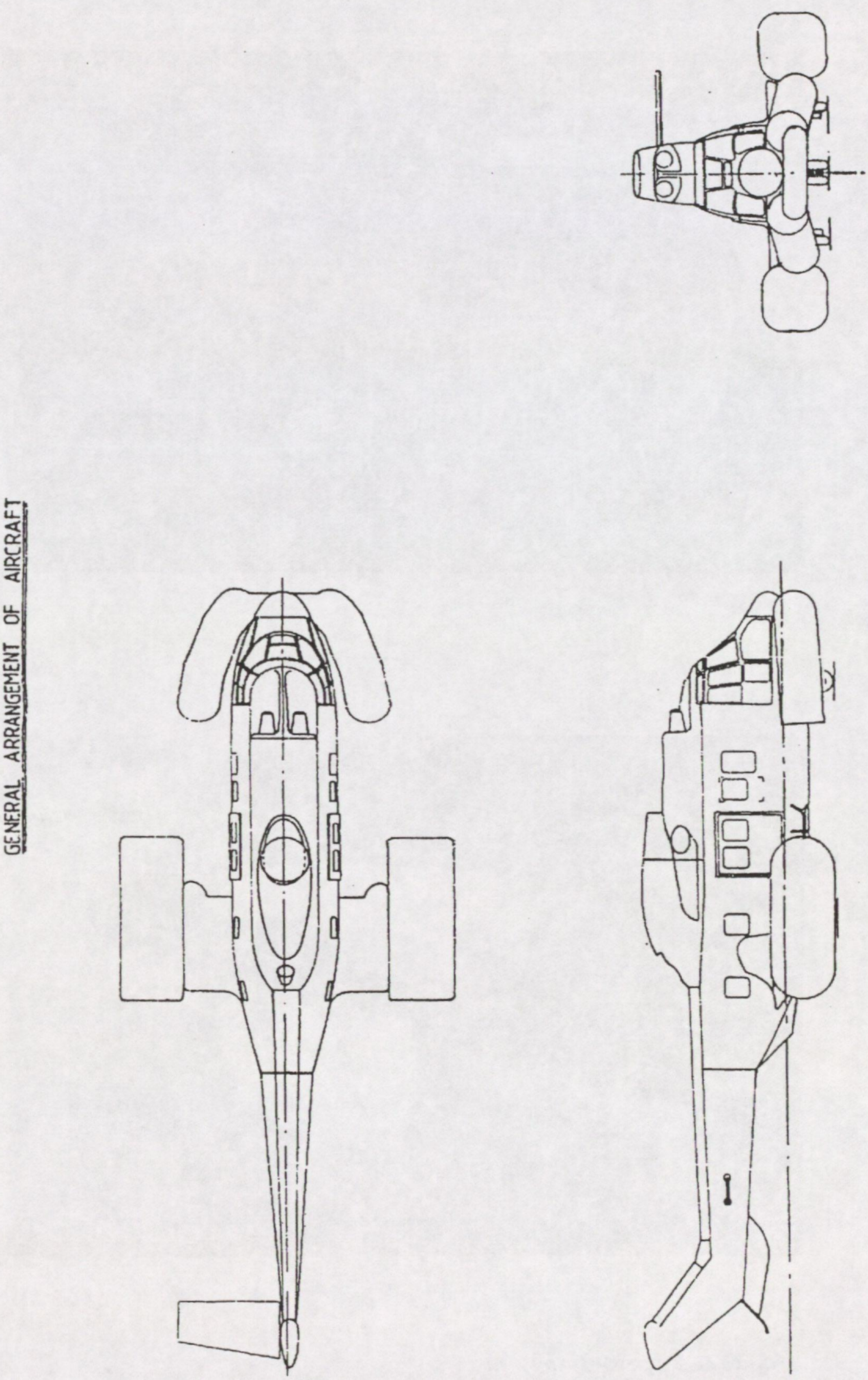
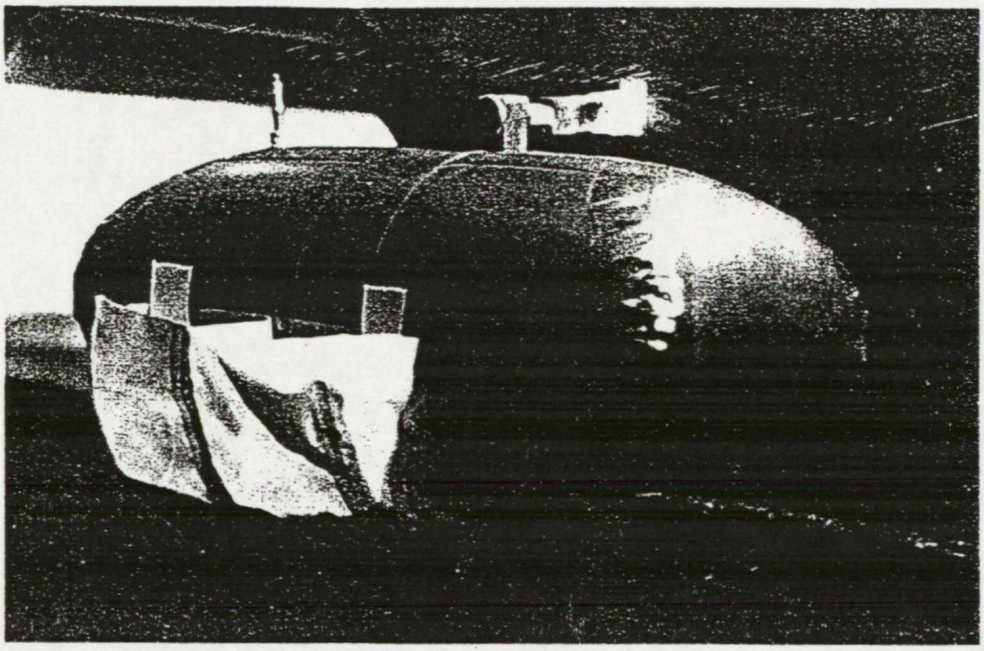


Figure 9/1 AS-332L Super Puma

VIEWS OF SCOOPS



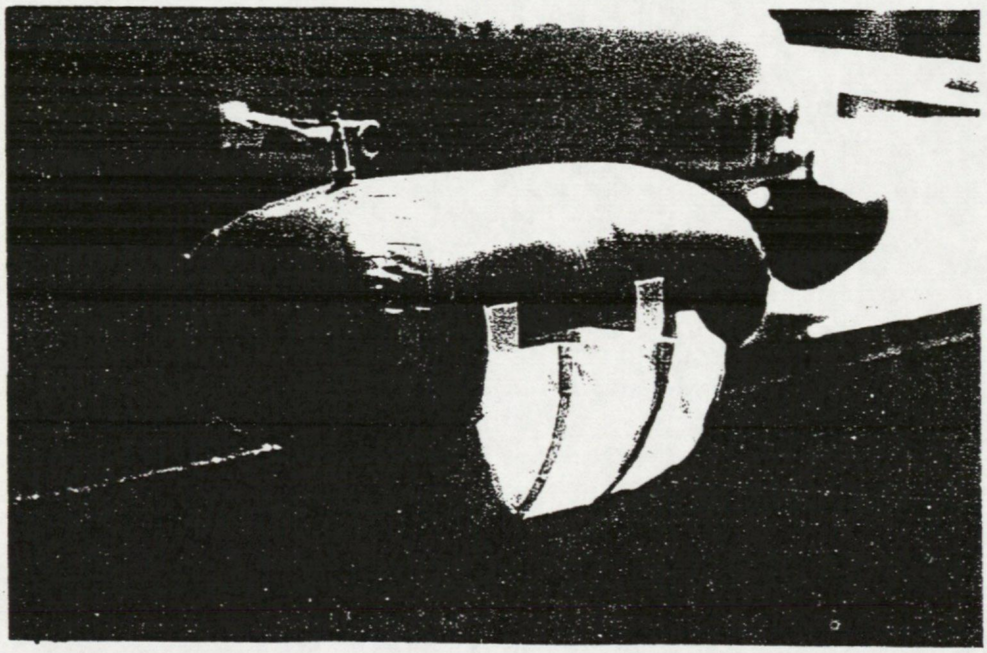


Figure 9/3   AS-332L Super Puma

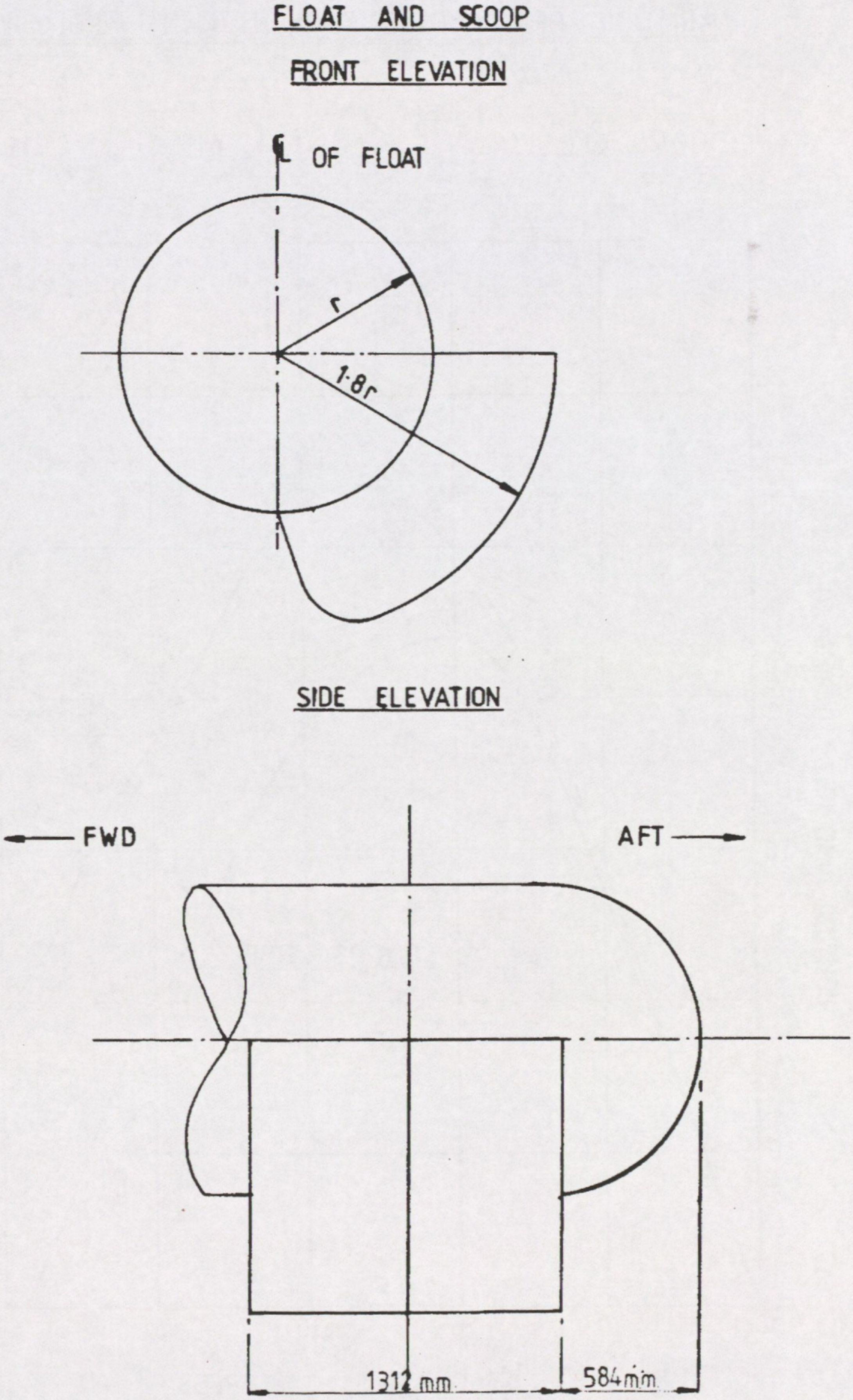


Figure 9/4 AS-332L Super Puma

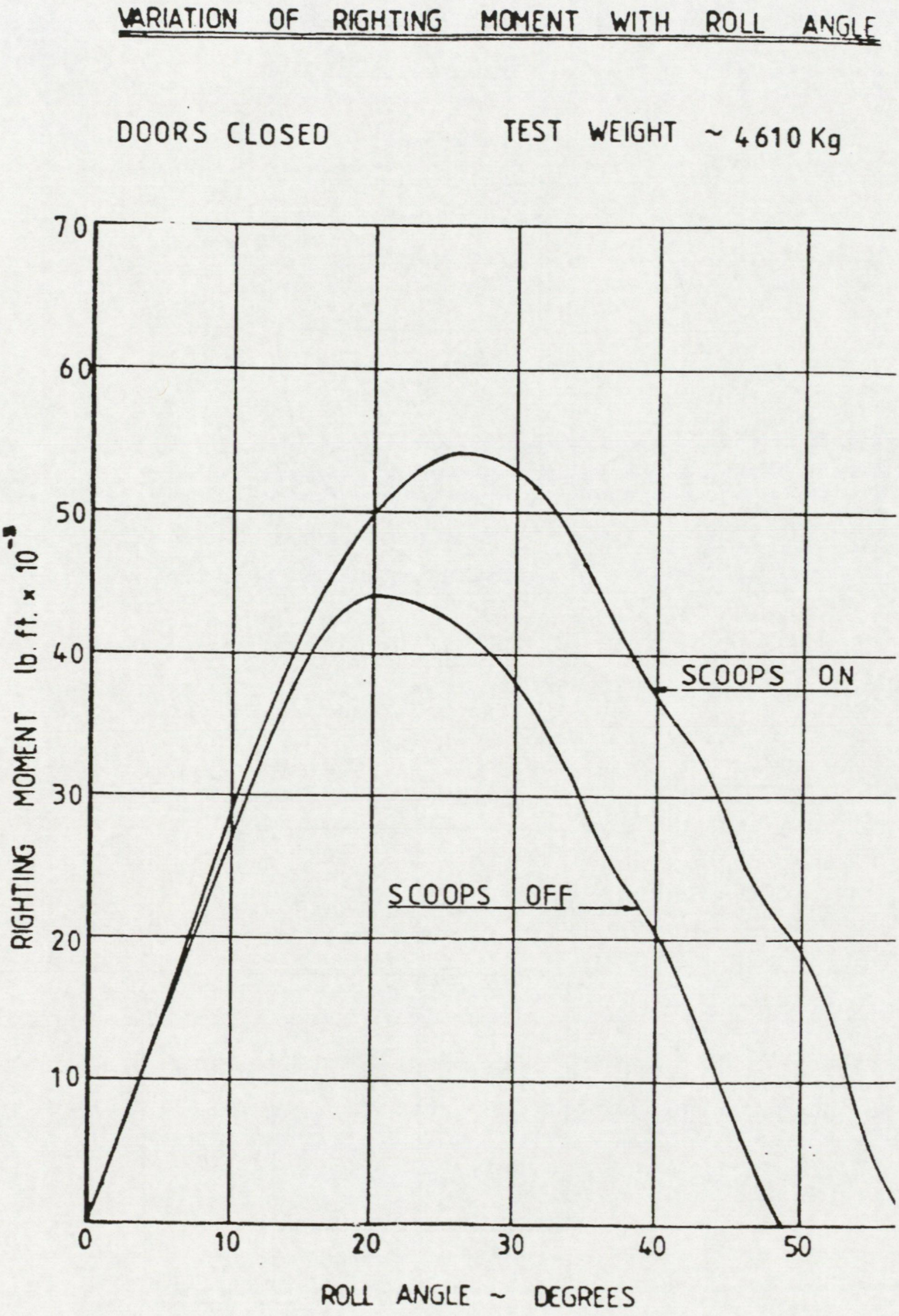


Figure 9/5 AS-332L Super Puma

STABILITY WHEN FLOATING IN REGULAR WAVES

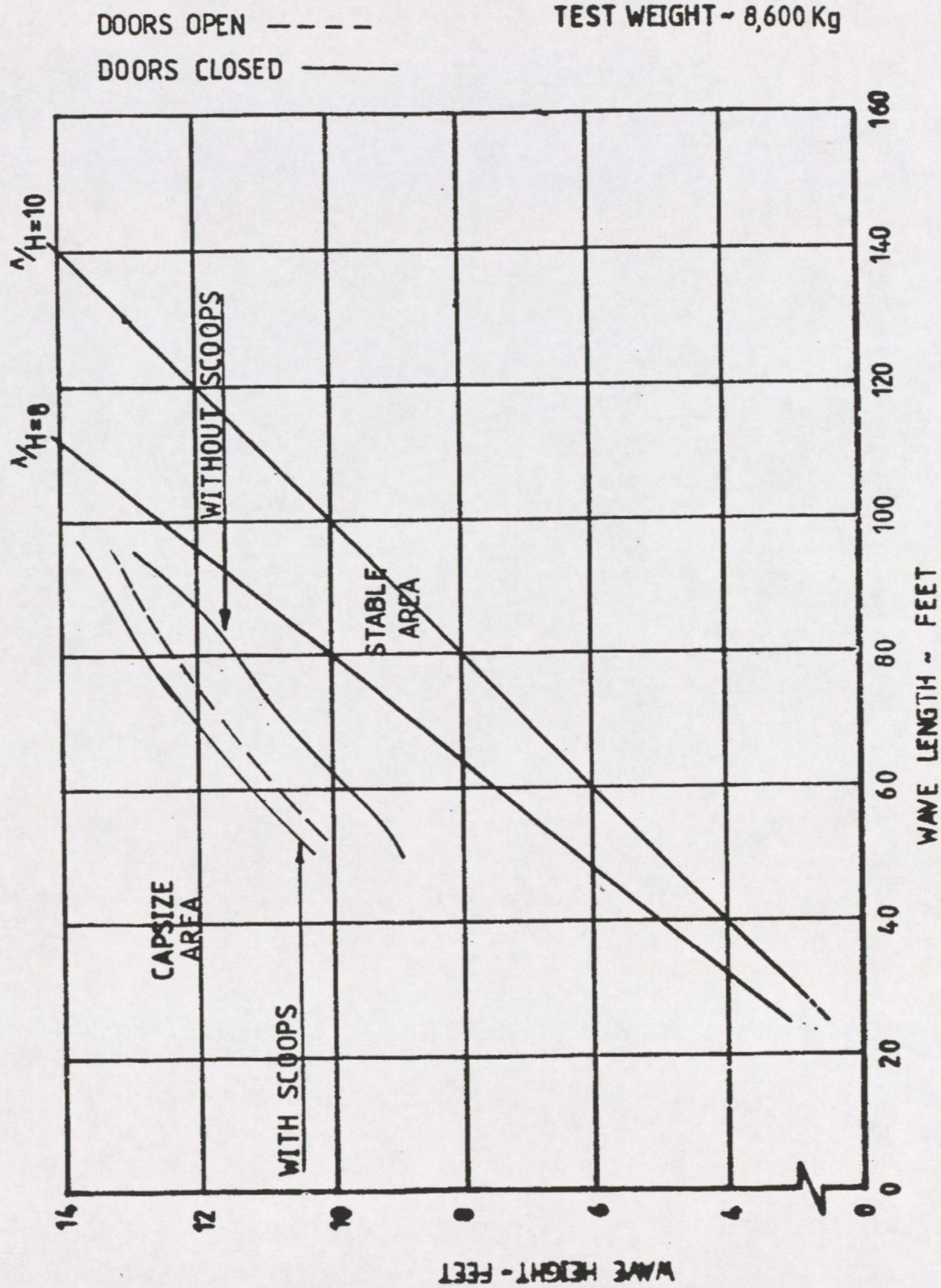


Figure 9/10 AS-332L Super Puma

Appendix B Summary of BHC Report X/O/3257 (April 1986)

Summary of Contents of BHC Report X/0/3257 (April 1986)

Helicopter Type	*Weights*	*Float Position Variant*	*Computer Models*	*Regular Wave Tests*	*Irregular Wave Tests. Sstte. H1/3/Tp*	*Comments*
B-412	3476 kg 5227 kg	Scoops fitted to main and rear floats.		Various	**1:10 scale:** S4 2·40m/6·5s S5 3·58m/6·80s **1:28 scale:** S5 2·80m/7·47s S5 3·94m/9·43s S6 4·40m/9·17s S7 6·06m/11·21s (with and without wind)	Both 1:10 and 1:28 scale models used. Concluded that scoops cause marginal improvement of limiting steepness of regular wave before capsize (from about 1:8.5 to 1:8). Improvement of about 1 sea-state in irregular waves. But note the wide range of conditions called Sea-state 5.
B-214ST	4184 kg 6500 kg (static tests only) 7955 kg	Scoops fitted to outside of main floats.		Various	**1:10 scale:** S4 2·40m/6·54s S5 3·58m/6·80s **1:26 scale:** S5 2·85m/7·19s S5 3·79m/9·08s S6 4·41m/9·09s S7 6·35m/11·60s	Both 1:10 and 1:26 scale models used. At 1:10 scoops improved regular wave boundary from 1:7.5 to 1:8.5. Larger model seemed less stable (in larger waves) and showed less difference. General improvement with scoops in irregular waves (not clear that results from the two models consistent though). NOTE two very different 'sea-state 5's referred to in the text for 1:26 scale model.
B-212	3636 kg 4545 kg 5091 kg (static tests only)	Scoops fitted outside each float.		Various	S4 ?? S5 3·58m/ ?? (with and without wind)	1:10 scale physical model. General improvement in stability with the addition of scoops. (Some tendency to adopt a more head to wave direction with scoops?) Removal of the doors reduced stability slightly.
BK-117	1700 kg 2800 kg	Scoops fitted to fwd floats only.		Various	S4 2·17m/6·62s S5 2·79m/6·08s (with and without wind)	1:8 scale physical model. Marked increase in dynamic stability in regular waves at the lighter weight. Little difference at the heavier weight. In irregular waves improved about 1 sea-state at both weights.

Summary of Contents of BHC Report X/0/3257 (April 1986)

Helicopter Type	*Weights*	*Float Position Variant*	*Computer Models*	*Regular Wave Tests*	*Irregular Wave Tests. Sstte. H1/3/Tp*	*Comments*
W30-300	7273 kg	Scoops fitted to rear floats only. Also tests with one float compartment deflated.		Various	S4 2·40m/6·54s S5 3·58m/6·80s (with and without wind)	1:10 scale physical model. Scoops increase stability in regular waves. Marginal improvement in irregular waves. Effect of scoops much more marked with the doors open and one float compartment deflated.
W30-100/-/200	4432 kg 5818 kg	Scoops fitted on both fwd and rear floats.		Various	S4 2·40m/ ?? S5 3·58m/ ?? (still air only)	1:10 scale physical model. Clear improvement with scoops in regular waves. Increase of about 1 sea-state in irregular waves.
S-61N	8182 kg	Scoops fitted to floats. Also tests with one float removed.		Various	S4 2·17m/6·62s S5 2·79m/6·08s (still air only)	1:8 scale physical model. Very little effect caused by the floats although static stability was increased.
S-76	3199 kg	Scoops fitted to all floats.		Various	S4 2·17m/6·62s S5 2·79m/6·08s (with and without wind)	1:8 scale physical model. Scoops improve behaviour in regular wave considerably (roll motion said to have been 'damped'). Helicopter also less vulnerable in breaking irregular waves. Improved about 1 sea-state. Scoops had little effect on weather cocking behaviour.
AS-332L	4610 kg 8600 kg	Scoops fitted to main floats.			S4 2·17m/6·62m S5 2·79m/6·08s	1:8 scale physical model. Significant improvement in stability boundary in regular waves. Also improvement in irregular waves. Improvement in weathervaning.

Appendix C Calculation of Drag and Inertia Forces

C.1 Wave Particle Velocities and Accelerations

The fluid dynamic forces exerted by a water wave on a submerged body are usually considered to arise from two components:

- a drag force (in phase with the wave particle velocity), and
- an inertial force (in phase with the water particle acceleration).

The instantaneous elevation of a regular (Airy) wave with a height (peak to trough) of H and a period T is given by:

$$\zeta = \frac{H}{2} \sin \omega t$$

where:

ω = angular velocity in radians = $2\pi/T$
t = time

Differentiating this, the instantaneous velocity and acceleration of the water particles at the surface are given by:

$$u = \dot{\zeta} = \frac{H}{2} \omega \cos \omega t$$

$$a = \ddot{\zeta} = \frac{H}{2} \omega^2 \sin \omega t$$

Thus the maximum velocity at the surface of a wave is given by $H\omega/2$ and the maximum acceleration by $H\omega^2/2$.

In the example regular wave considered in section 5.2.1 where H = 9·6m and T = 8s;

Maximum velocity = 9·6/2 $2\pi/8$	= 3·77 m/s
Maximum acceleration = 9·6/2 $(2\pi/8)^2$	= 2·96 m/s/s

It can be seen from the above equations that the velocity in the wave is a *cos* function and the acceleration in the wave is a *sin* function. Consequently the maximum values do not occur at the same time, but 90° out of phase.

C.2 Drag and Inertia Forces

Drag force and inertia force are described in terms of a drag and inertia coefficient as follows:

$$C_d = \frac{D}{1/2\,\rho\, u^2 A}$$

where:

C_d = Drag Coefficient
D = Drag force
ρ = Density of water (1025 kg/m^3 for sea water)
u = Water particle velocity
A = Projected area

$$C_m = \frac{I}{\rho V a}$$

where:

C_m = Mass Coefficient
I = Inertia force
V = Immersed volume
a = Water particle acceleration

If we are considering a helicopter emergency float which has a diameter of 1.397m and a length of 2·687m, then the horizontal projected area and the volume are respectively:

$A = 1{\cdot}397 \times 2{\cdot}687 =$ $3{\cdot}75\ m^2$
$V = 2{\cdot}687 \times \pi \times 1{\cdot}397^2 / 4 =$ $4{\cdot}12\ m^3$

For a cylindrical body such as the float the drag coefficient and the inertia coefficient are normally taken to be:

$C_d = 1{\cdot}0$
$C_m = 2{\cdot}0$

These coefficients are for a fully immersed cylinder. In the case of the helicopter float it is only partially immersed (about 50%). There is no established reliable information about drag and inertia coefficients for partially immersed cylinders, and so we shall assumed that the forces are the same as if it were fully immersed. Consequently we shall use the full volume and full projected area to produce the drag and inertia forces exerted on the cylinder held stationary in the waves as follows:

$D = 1{\cdot}0 \times 0{\cdot}5 \times 1025 \times 3{\cdot}77^2 \times 3{\cdot}75 =$ 27·32 kN

$I = 2{\cdot}0 \times 1025 \times 2{\cdot}96 \times 4{\cdot}12 =$ 25·00 kN

As noted in the previous section the maximum velocity in the wave occurs at a time 90° out of phase with the maximum acceleration. Therefore the maximum drag force will occur 90° out of phase with the maximum inertia force. Consequently the maximum value of the resultant force that will be experienced as a result of both components is given by the square root of the sum of the squares:

$F = (27^2 + 25^2)^{0.5} =$ 36·80 kN

C.3 Additional drag due to scoop

The actual additional drag due to the scoop is quite complex, depending on the shape of the scoop, and the velocity of the (accelerated) flow around the float and other 'interference' effects. However we can make an approximate estimate for this drag in a similar manner to the above if we have a drag coefficient for it. This time it is assumed that the drag coefficient for the scoop alone is similar to that for a semi-circular channel with its concave face to the flow. For this case Hoerner (Fluid Dynamic Drag, chapter III, section 7, figure 33, p. 3-17) gives $C_d = 2{\cdot}3$.

The horizontal projected area of the scoop (from Fig [2]) is approximately:

$(1{\cdot}043 - 1{\cdot}397/2) \times 2{\cdot}687 =$ 0·925 m^2

and the drag force on the scoop is:

$D_S = 2{\cdot}3 \times 0{\cdot}5 \times 1025 \times 3{\cdot}77^2 \times 0{\cdot}925 =$ 15·5 kN

Thus the total drag force on the float and scoop is:

$15{\cdot}5 + 27{\cdot}0 =$ 42·5 kN

and the new resultant dynamic force is

$F = (42{\cdot}5^2 + 25^2)^{0.5} =$ 49·3 kN