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Report No.B.A.1568

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ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Tank tests on water rudders for float seaplanes

by

K.W. Clark, B.Sc. D.I.C.

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R.A.E. Reference: B.A./561.R/61
Item No. : 170/8/36.

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SUMMARY

Reasons for enquiry

To collect and consider the results obtained up to date.

Range of investigation

Yawing moments and rudder hinge moments were measured over a range of speed on a number of rudder and float combinations of 1/6, 1/7.5 and 1/3.75 scale with the floats towed along the tank without sideslip. These tests were extended for one set of floats and one speed to cover a range of angles of sideslip and also tests on a 1/30 scale model on a whirling arm. Here the model was towed along a circular path, the tests being mainly to investigate the technique of the method.

Conclusions

At a speed of 10 knots in the first set of tests the yawing moments are shown to depend predominantly on rudder area, and the hinge moments for rudders without balance to depend on aspect ratio. Extending these tests to cover a range of sideslip did not provide much new information but enabled calculations to be made of the rudder angles required for maintaining a straight course in a sidewind. The whirling arm method can give measurements of the turning circles obtainable with different rudder angles and on a larger scale could be extended to cover hinge moments.

2. Description of [illegible] floats and rudders.

The [illegible] used [illegible] was [illegible] powered by a Panther [illegible] engine [illegible] bladed metal airscrew. The float [illegible] of the "fine stern" floats [illegible] and shown in Fig.2 of the above report.

The rudders [illegible] are [illegible] Figs.1 to 5 and their [illegible] are given in Table 1.

Rudder No.1. (Fig.1).

At [illegible] of [illegible] and [illegible] protrudes [illegible] fitted with [illegible] float stern to [illegible] experience has shown that [illegible] stern [illegible] fitted with high [illegible] frequently [illegible] it is desirable [illegible].

Rudder No.2. (Fig.2).

Was evolved during [illegible] at reference 1 to give good control without requiring a [illegible] at the float stern.

Rudder No.3. (Fig.3).

Is a two-position rudder. It is hinged at 'A' and rotates under the moment of its own weight from a raised position to a low position. In flight, take off and landing the rudder is held in the raised position by a wire control which is released so that the rudder can fall to the lower position for taxying.

Rudder No.4. (Fig.4).

Is fitted with a trailing edge flap operated by lever 'B' and rod 'C' from a fixed hinge at 'D'. The relation between the rudder and flap angles is thus linear over the working range. The gearing between rudder and flap was

..........varied

varied by changing the length of the flap operating lever 'B'. The flap extended throughout the span of the rudder and the chord was 0.1 of the rudder chord.

<u>Rudder No.4a.</u>

This rudder is rudder No.4 without the flap.

<u>Rudder No.5.</u>

is a two-position rudder. It is similar to a rudder made by the Fairey Aviation Company which has been tested recently on a Seal fitted with large buoyancy floats. During the general handling tests of this seaplane (M.A.E.E. report F/128B, ref.2.) the rudder proved to be very effective. It was desired therefore that quantitative tests on this type of rudder should be made on a III.F. seaplane for comparison with the other rudders. The rudder is made of two parts; part 'E' is hinged and controlled in the normal manner and part 'F' is a disc hinged close to its edge at 'G'. A cable operated from the cockpit is attached to a quadrant fixed to the hinge pin. Thus, the disc can be raised for take off, landing and beaching and allowed to fall under its own weight for taxying.

Although some of the above rudders are only partially balanced experience has shown that even a small balance area may result in overbalance during landing.

3. <u>Scheme of Tests.</u>

The report at reference 1 shows that in straight taxying at constant speed the air rudder is almost as effective in turning the seaplane as the water rudders. In consequence small differences in the performance of water rudders cannot be measured accurately with the air rudder in operation. For these tests the air rudder was removed but the fin was retained.

............/The

The yawing moment of each pair of water rudders was determined over a small range of speeds from measurements of the rudder angle required to balance a drogue towed from the wing. The measurements were made during constant speed runs at selected engine speeds up and down a measured course. The resistance coefficient of the drogue used was known from measurements made during the tests reported at reference 1.

All the above tests were made in calm weather and when the wind direction was parallel with the course. For the measurements of hinge moment the rudder controls were separated; the pilot retained control of one rudder and the observer controlled the other. The post of the rudder under the observer's control was fitted with a large wheel and the control cables were fed direct to the observer's cockpit where the force applied to the cable was observed from a spring balance. Thus friction, which is very large in the III.F. water rudder control system was almost eliminated and the seaplane could be taxied on a straight course with the side force on one rudder balanced by that on the other.

In addition to the above measurements it was desired to determine the relative efficiencies of the rudders when working behind yawed floats such as occurs when taxying across wind and across tide. Owing to the difficulty of reducing the results of a series of such tests to a common value of the wind speed together with the inconvenience of waiting for any chosen standard wind speed it was more expedient to simulate these tests by making turns through 360°. The time to turn the seaplane through 360° was observed with each pair of rudders set over 20° for three values of the engine R.P.M.

The tests were made between March, 1934 and January, 1935.

…………/Reduction

4. Reduction of Results.

(a) Yawing moment.

Let R = drogue resistance.

θ = angle of drogue towing line to horizontal.

F = side force on each rudder.

d_1 = distance between C.G. and point of attachment of drogue towing line.

d_2 = distance between C.G. and the line joining the float sterns.

and V_W = water speed in ft/sec.

Then, neglecting the yawing moment of the air forces on the floats

$$R\cos\theta\, d_1 = 2Fd_2 \quad \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

now $F = k_F S_W \rho_W V_W^2$

and $R = k_R \rho_W S_d V_W^2$

so that

$$k_F = \frac{k_R S_d \cos\theta\, d_1}{2 S_W d_2} \quad \ldots \ldots \ldots \ldots (2)$$

and

$$k_F = a_1 \eta_W \quad \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

where k_F = cross water force coefficient of each water rudder.

k_R = drag coefficient of drogue.

S_d = frontal area of drogue.

S_W = area of water rudder in the water.

η_W = rudder angle

and a_1 is the slope of the $k_F \sim \eta_W$ curve.

(b) Hinge moment.

Let P = pull on rudder cable.

d_3 = radius of pulley.

Then H = Pd_3 = hinge moment.

and $k_H = \dfrac{H \text{ (per degree)}}{C_W \rho_W S_W V_W^2}$ = hinge moment coefficient per degree.

where C_W = mean rudder chord of submerged area.

The results of yawing and hinge moments over the useful range of speed are given in Figs.6 to 9. The yawing moments increase up to 8 knots where there is a falling off as the water level drops, and then rise to a peak value. For the raised rudders (except No.4) this peak occurs at about 15 knots where the rudders are buried in the splash. When this breaks clear the raised rudders are nearly out of the water so that the yawing moments show a sharp decline. The hinge moments follow the yawing moments, but remain high at speeds beyond the peak value of the yawing moments, as all the work is being done at the tips.

4.32. Scale effect.

Figs.8 and 9 show the results for rudders No.6 on the 1/7.5 scale pair of floats and on the 1/3.75 scale single float. The results are of the same order up to 15 knots, except that the hinge moments for the dropped rudders are smaller on the 1/3.75 scale. At 16 knots the results are different because the flow breaks clear of the sides of the after body of the large float at an earlier speed. It would seem likely that this was due to scale effect rather than the absence of the other float because when the hinge moments were measured on one of the pair of small floats, the 16 knot value was the same with the rudder either towards or away from the other float, i.e. the flow was unaffected by the other float. The attitudes were the same for both scales of float.

4.33. Results at 10 knots

The relation between yawing moment and hinge moment at this speed and their values at different rudder angles are given in Fig.10. Similar curves for rectangular rudders are shown in Fig.11. The general trend is for short chord rudders to have a greater ratio of yawing moment to hinge moment.

The results are further analysed in Fig.12 where the results for 30° rudder have been based on actual rudder dimensions. The immersed dimensions have not been used as these are indefinite with the rudders swung over. The yawing moments for the raised rudders are shown in Fig.12A to be predominantly dependent on rudder area for those rudders tested. The partially and fully dropped rudders will lie on different lines roughly as indicated. As a greater proportion of their area is immersed they give a greater yawing moment per unit area. The hinge moments for a given yawing moment are given in Fig.12B. in terms of rudder aspect ratio, for the rudders without balance. The results lie satisfactorily on one curve.

4.4 Tests of rudders No.5 with sideslip

The results are given in Figs.13 to 16 for yawing moment, hinge moment and sideforce at one speed and at rudder angles of either sign. The change of yawing moment and sideforce with rudder angle is not much affected by sideslip. The hinge moments for the dropped rudders are appreciably reduced or increased according to how the incidence of the rudder is changed by the sideslip. The yawing moments in Fig.13 show the floats to be directionally unstable when sideslipped, which is understandable in view of the large immersed length ahead of the centre of gravity. The instability is less with rudders dropped due to their greater effective area. It is known that seaplanes when turning are stable directionally, i.e. the pilot holds the turn on, not off. Therefore no calculations of turning circles are possible from these tests, but these are discussed later and the condition of holding a straight course in a sidewind has been considered here as a means of comparing the rudders. It is not always a practical case as the seaplane is sideways on to the waves.

As it was known that the sideforce acting below the centre of gravity would cause the floats to roll slightly, a few measurements were made of the angle of roll the floats take-up. It was found that 10° of sideslip produced 3° of roll, which left the yawing moments unaffected for the dropped rudders and decreased them slightly when raised.

In making the calculations to find the rudder angle to maintain a straight course in a sidewind, assumptions have been made for the aerodynamic part of the calculations. The dimensions of the seaplane used with rudders No.6 were combined with generalised values for aerodynamic side force and yawing moments.[1,2] It was assumed that the air and water rudders moved through the same angle. The balance of the forces and moments involved is as follows. The weathercock stability of the seaplane turns it round into the wind and the floats increase this tendency due to their directional instability. The pilot counteracts this by moving the air and water rudders over until balance in yaw is achieved, and the sideslip through the water builds up until the water sideforce is equal and opposite to the aerodynamic sideforce. The sidewind that can be dealt with is shown in Fig.16, the diagram at the top of the figure shows the directions assumed. The superiority of the dropped rudder is again evidenced.

4.8. Whirling arm tests on rudders No.6.

A small whirling arm was made to fit across the tank with a view to examining the technique of testing rudders with the floats taking a circular path. As the width of the tank was 9 ft. the scale was restricted to 1/30. Tests were made at a speed corresponding to 10 knots full scale, the model being towed on a thread carried from the rotating arm. At each radius the rudder angle was adjusted so that the thread lay along the airscrew axis, i.e. the model was towed as if by the airscrew. The absence of the air rudder makes the turning circles larger than they would otherwise be.

A photograph of the model in Fig.17 shows it circling and towing small slips of wood to demonstrate the flow path. In the lower diagrams the model is shown in skeleton form with the slips of wood. Circular arcs show roughly the geometry of the turn and the sideslip at the C.G. The local sideslip changes sign along the float; so that the flow crosses the sterns at a considerable angle (about 20° in the left hand diagram), and much reduces the effective angle of the rudder. This change produces directional stability, i.e. if the rudder is centralised the turn straightens out.

In Fig.18 the results are given for rudders No.6. No great reliance may be placed on them owing to the small scale. They show however (a) that there is an advantage in using rudder angles up to 60° instead of the usual limit of 30° (b) that there is some advantage in moving the rudders differentially so that the outer rudder is at a smaller setting than the inner, in that the mean rudder angle required for a given turning circle is less than the angle required when both are at the same setting; on the other hand the minimum diameter obtainable is not so good, and (c) that in contra-distinction to the other tests the raised rudders are slightly more effective than the dropped rudders up to a rudder angle of about 40°.

In view of (c) the 1/30 scale floats were towed along the tank in a straight path and it was found here that the dropped rudders were the more effective. This shows that the comparison is dependent on the method of test and since the circling path bears a closer relation to their customary use full scale, the whirling arm method, on a model of reasonable size, should be the more reliable.

5. Comparisons with full scale.

The effectiveness of some of the rudders full scale is known from tests at the M.A.E.E., and these are differentiated in Fig.10. Rudder No.4 was inadequate and Nos.1, 2, 5 and 6 satisfactory. This is in agreement with the model tests in that No.4 has the minimum ratio of yawing moment to hinge moment. The dividing line between satisfactory and unsatisfactory rudders lies between rudders No.4 and No.6 (raised).

In the model tests No.6 (raised) appears to be rather inadequate, but it was considered so satisfactory full scale that the dropping mechanism was removed and all rudders of this type were fixed in the raised position. This suggests agreement with the whirling arm tests.

6. Notes on rudder design.

6.1. Raised rudders without balance.

Although the raised and dropped rudder comparisons appear subject to the method of test, it is probable that these rudders, all of one type, are comparable on the basis of Fig.12. The following notes on these rudders include values which are therefore comparable but not absolute, except momentarily as the rudders are moved over and before the turn has started.

Assuming rudder No.6 to have the limiting requirements, Fig.8 shows that the measured yawing moment at 10 knots for a rudder angle of 30° is 3000 lb.ft., and the measured hinge moment 125 lb.ft. The curve in Fig.12A shows that a yawing moment of 3000 lb.ft. is obtainable with a total rudder area of $8\frac{1}{2}$ sq.ft. For two rectangular rudders 19 ins. deep behind sterns of the same depth, the chord is $9\frac{1}{2}$ in., the aspect ratio is 2 and the hinge moment from Fig.12B. is 90 lb.ft. The rectangular rudder has therefore a smaller hinge moment than the shape of No.6, due to its smaller aspect ratio.

The method might be applied to different sizes of seaplane assuming the law of dynamical similarity. That is, with the turning circle proportional to linear scale or (all-up weight)$^{1}/3$, moments and control forces vary as (all-up weight)^{4}/3. With the pilot's strength a constant factor, a limit will be set to the size of seaplane he can manage without either balance or auxiliary power. The hinge moment figure of 90 lb.ft. would be raised to 125, the suggested limit, when the all-up weight was raised to 9500 lb. On the other hand, for a smaller seaplane the area could be increased at the expense of the aspect ratio. For instance, if the all-up weight were halved, i.e. 3750 lb., a hinge moment of 90 lb.ft. could be realised for an aspect ratio of 0.[illegible], so that the area and yawing moment would be more than double the dynamically similar amount of Fig.10A.

[illegible] Effect of rudder balance.

The hinge moments on a control surface may be lightened by setting back the hinge, provided that the amount is insufficient to overbalance the control at small angles. This was done successfully for rudder No.1 and the ratio of yawing moment to hinge moment in Fig.10 was doubled. A rudder angle of 2.5° was tested to make sure there was no overbalance. With this type of balance there is a slight danger of flotsam becoming wedged between the rudder and the float.

Rudders Nos.5 and 6 (dropped) are of the horn balanced type and both have greater ratios of yawing moment to hinge moment than average. It has been found that all-moving air rudders become fully balanced with only half the balance area of those rudders placed behind a fin. The same probably holds for water rudders.

Two practical points that arise with rudders like No.5 are that the dropped part moves between two plates and there is some likelihood of sand jamming the dropping mechanism, also that if the seaplane is landed with the rudders dropped so that the lower portion only is immersed, then this lower portion has an excessive proportion of balance. The rudder is then likely to be forced round and the lower portion bent up sideways.

7. Notes on methods of model tests.

Tests by towing the model along the tank with no sideslip have the advantage of simplicity and the use of existing apparatus. Extending these tests to cover a range of angles of sideslip considerably increases the amount of work involved without appreciably extending the usefulness of the results. The whirling arm method appears to be practical and has the advantage that the floats are tested under conditions most similar to their use in practice. A square shallow tank is shortly to become available and it is suggested that it might be used for whirling arm tests on models of the 1/7.5 scale size. The method would need extending to cover hinge moments.

References

No.	Author	Title
1.	Perring & Callen.	Moments and forces on a yawed model aeroplane. Report No.B.A.850, Feb.1930.
2.	Clark & Callen	Wind tunnel tests on the forces arising when aircraft are catapulted into side winds. Report No. B.A.972, July 1932.

Table 1

Actual full scale dimensions

Rudder No.	Scale of Model	All-up weight lb.	Length ft. F.P. to A.P.
1	1/7.5	7560	26.62
2	1/7.5	7560	27.1 (to hinge)
3	1/8	10400	28.91
4 & 5	1/7.5	5350	25.0
6	1/7.5 and 1/30	7600	26.5
6 and A. to E.	1/3.75	7600	26.5

Factors for conversion to uniform size of float

All the results and the dimensions given in Table 2 and Figs.1 and 2 have been converted by the following factors to a common all-up weight of 7500 lb.

Linear dimensions $\left\{\dfrac{7500}{\text{all-up weight}}\right\}^{1/3}$

Moments $\left\{\dfrac{7500}{\text{all-up weight}}\right\}^{4/3}$

Forces $\dfrac{7500}{\text{all-up weight}}$

Speeds $\left\{\dfrac{7500}{\text{all-up weight}}\right\}^{1/6}$

Table 2

Rudder dimensions

Feet full scale at common all-up weight of 7,500 lb.

Speed 10 knots where immersed

Rudder No.	Area of both rudders		Area balanced		Length C.G. to line joining hinges.
	Total sq.ft.	Immersed at 0° rudder	% when dry	% when immersed	
1/7.5 and 1/8 scale pairs of floats					
1	4.72	2.9	0	0	13.26
1 (hinge back 4½")	4.72	2.9	28	23	"
2	4.98	2.8	0	0	"
3	4.60	-	5	-	12.70
4	2.96	2.0	0	0	14.48
5	4.65	4.0	7	8	"
6 (raised)	2.13	1.8	0	0	12.94
6 (dropped)	2.13	2.1	12	12	"
1/3.75 scale single float					
6 (raised)	2.13	1.8	0	0	12.94
6 (dropped)	2.13	2.1	12	12	"
A (Fig.9)	1.46	0.9	0	0	"
B "	2.93	2.2	0	0	"
C "	3.90	3.1	0	0	"
D "	3.81	3.0	0	0	"
E "	4.68	3.9	0	0	"

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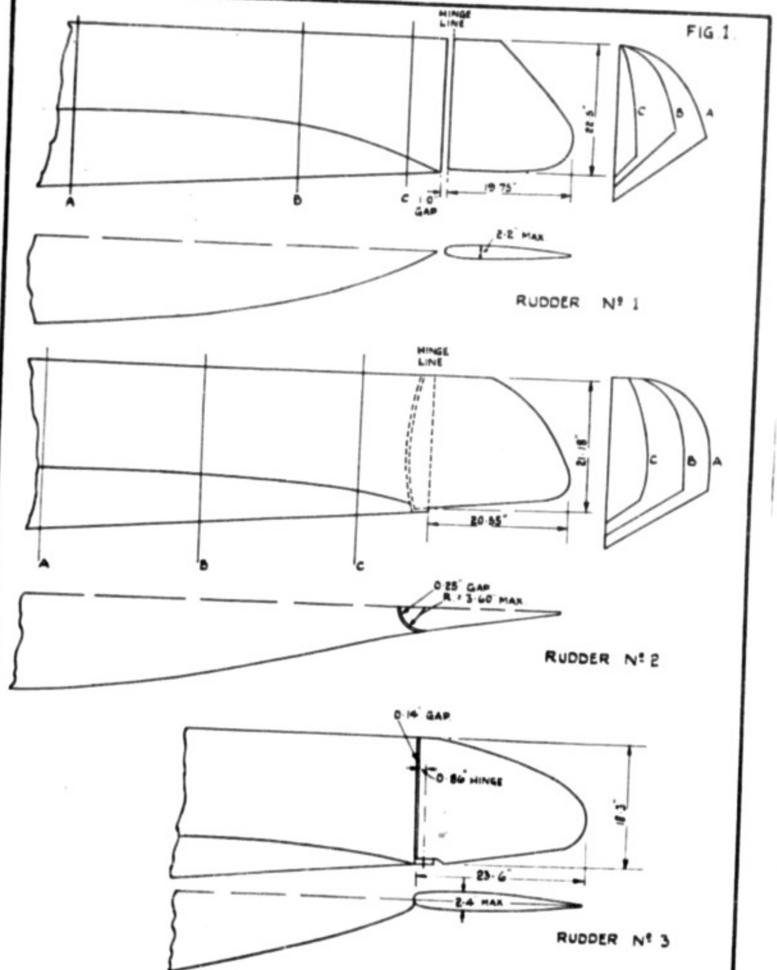
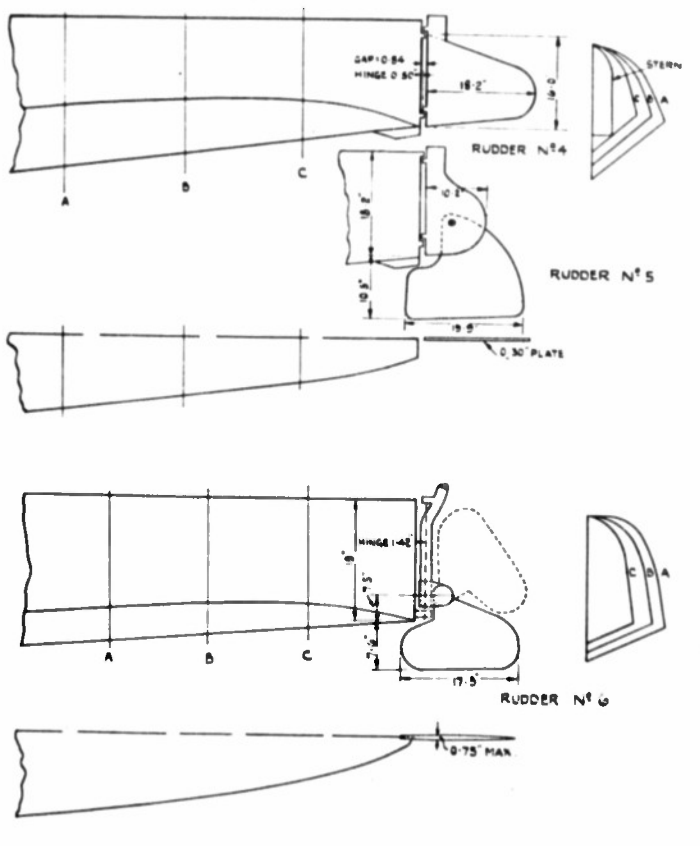


WATER RUDDERS 1 TO 3

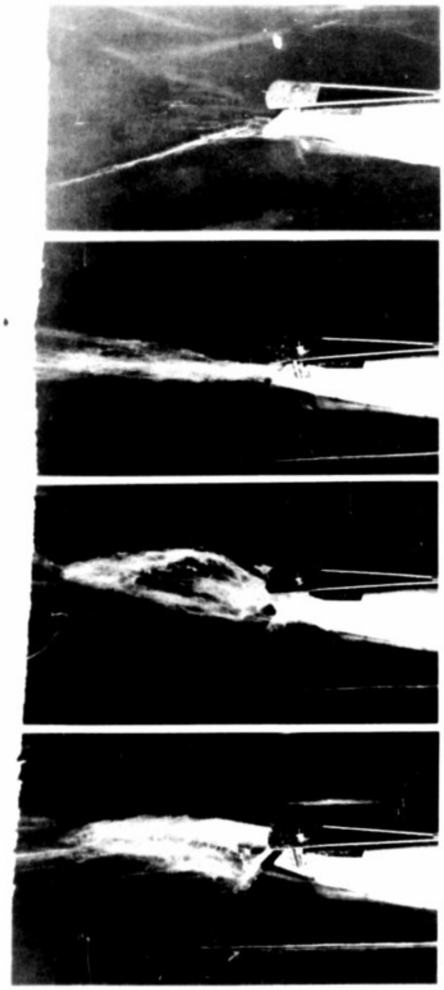
FIG 2



WATER RUDDERS 4TO6

3

19



SPEED [illegible]
RUDDER 0°

SPEED 13 KNOTS
RUDDER 0°

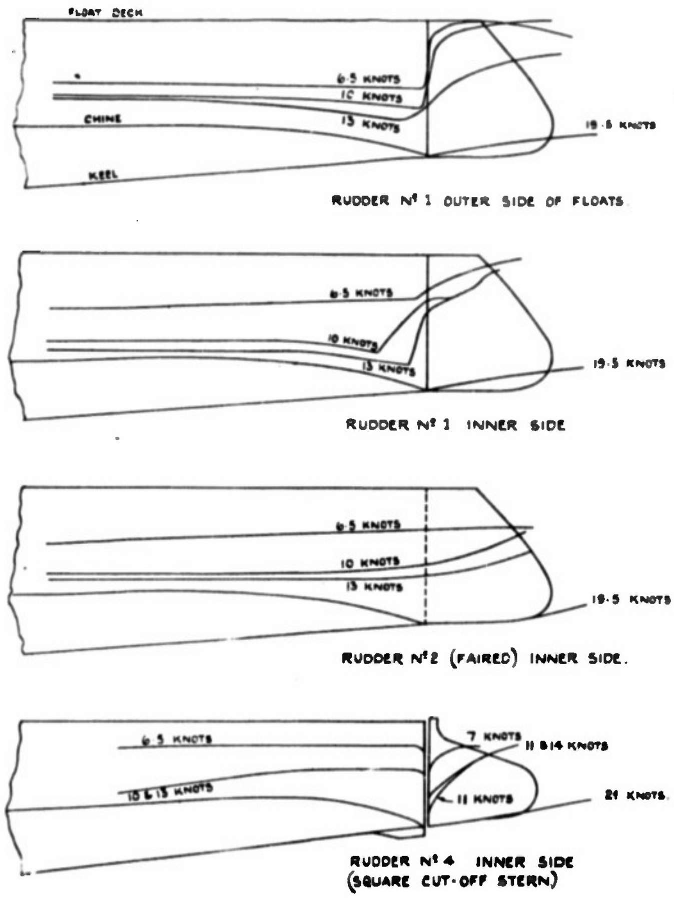
SPEED 13 KNOTS
RUDDER −20°

SPEED 13 KNOTS
RUDDER + 20°

FLOW OVER WATER RUDDER N°1

8874.S.

FIG. 4

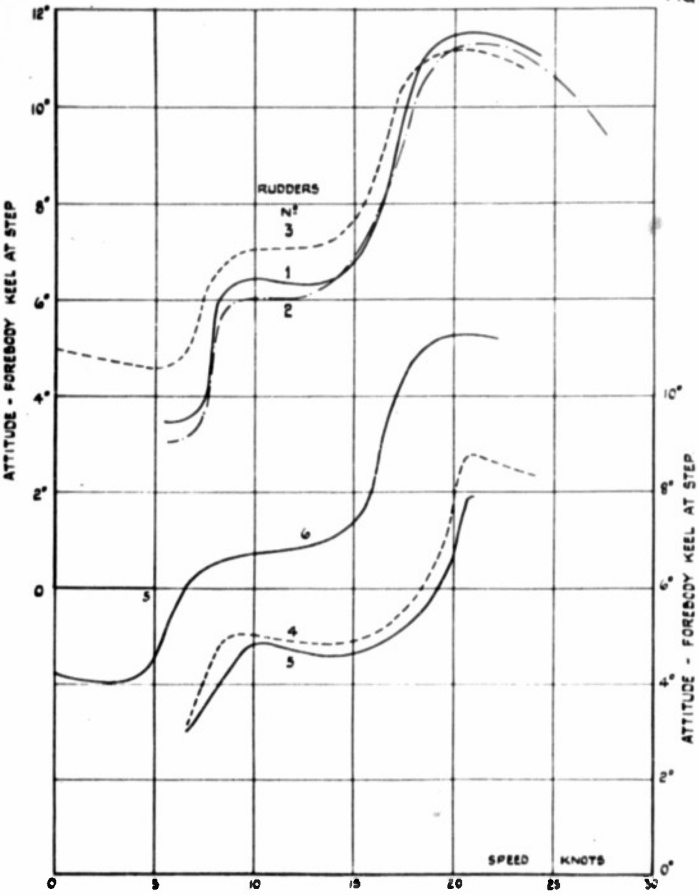


WATER LEVELS ON THE RUDDERS AT 0° RUDDER.

88 / 5. S.

20

FIG. 5



ABOVE ATTITUDES ARE FOR RUDDER ANGLE = 0° AND FLOATS FREE TO TRIM FOR OTHER RUDDER ANGLES THE DRAG REDUCES THE ATTITUDE E.G. RUDDER Nº 4 30° RUDDER 10 KNOTS $\Delta\alpha = -0{\cdot}3°$ 20 KNOTS $\Delta\alpha = -3°$

FLOAT ATTITUDE AGAINST SPEED.

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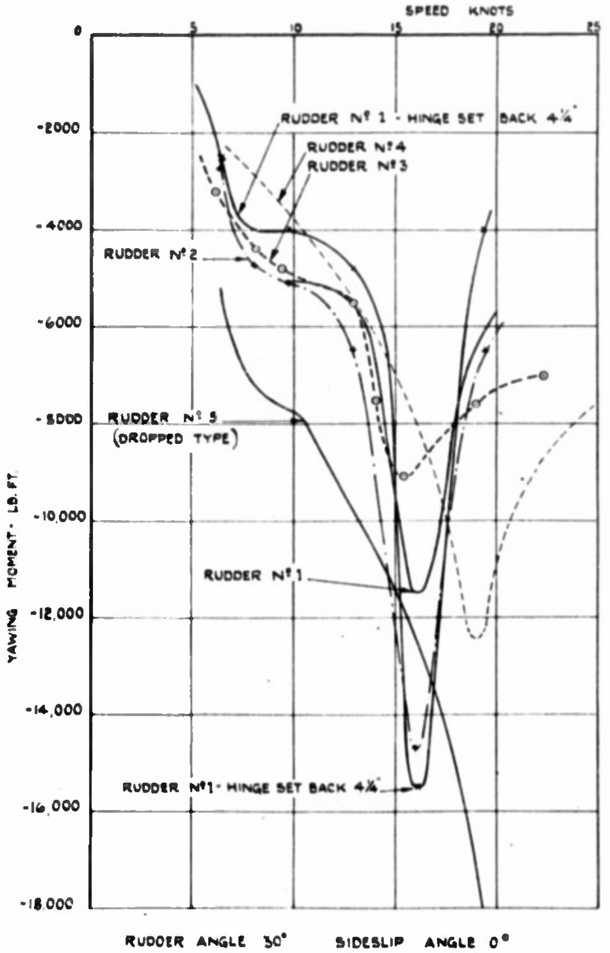
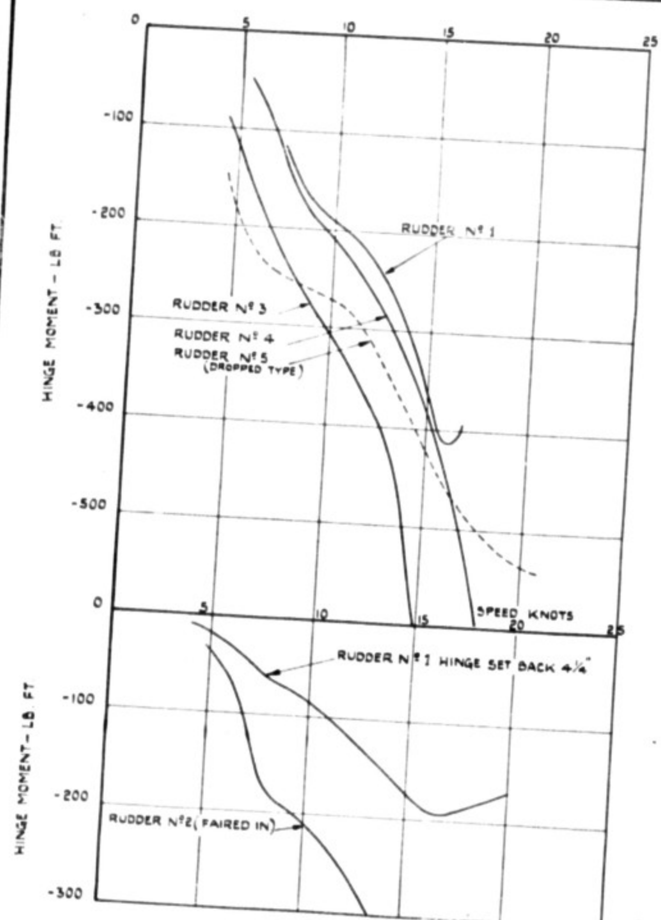
21

FIG 6.



YAWING MOMENTS FOR VARIOUS WATER RUDDERS.

FIG. 7.

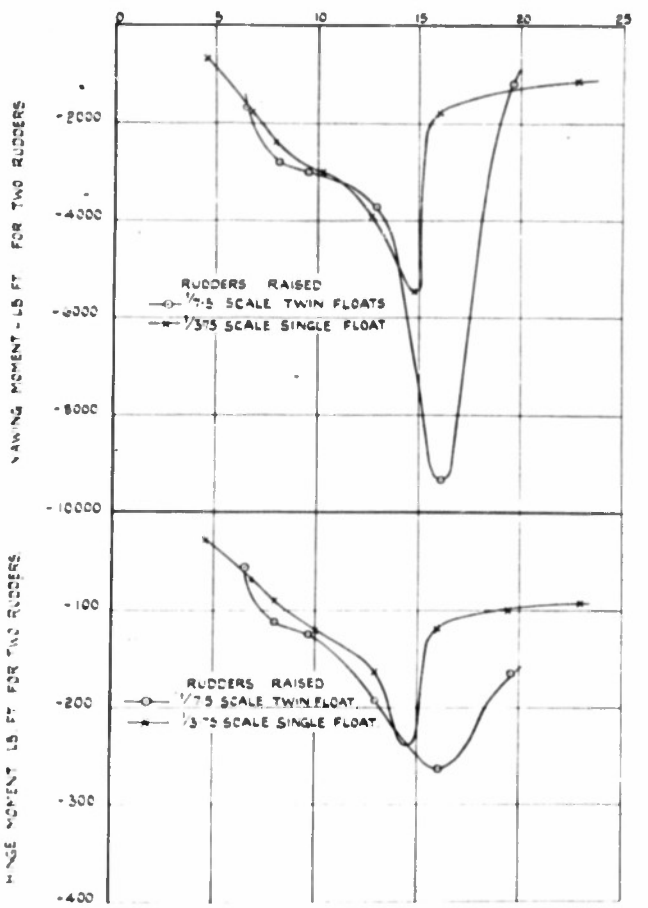


RUDDER ANGLE 30° SIDESLIP ANGLE 0° MOMENTS FOR TWO RUDDERS.

HINGE MOMENTS FOR VARIOUS WATER RUDDERS.

8878.S.

FIG 8

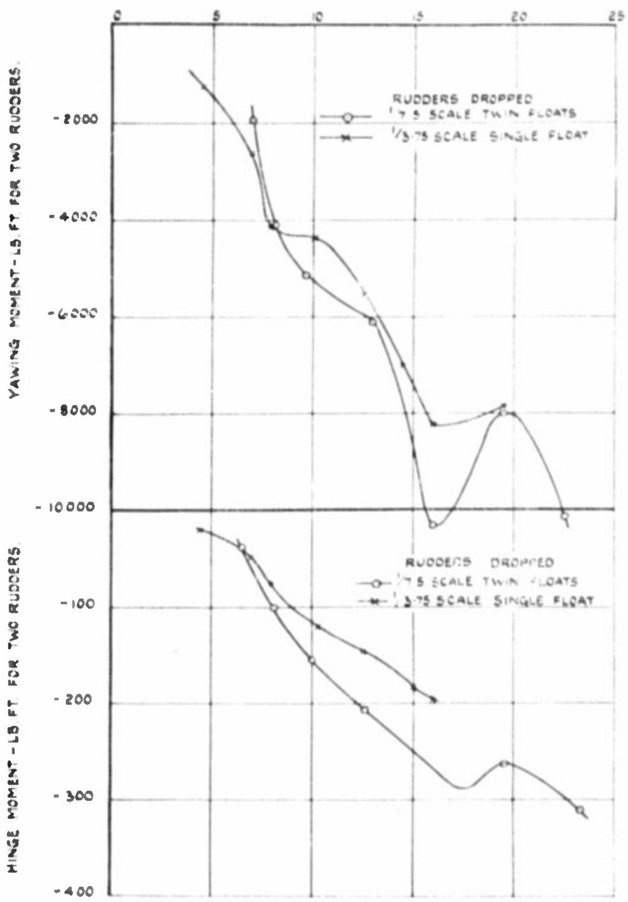


RUDDERS Nº 6 (RAISED) AT 30 DEG.

RESULTS FOR TWO SIZES OF MODEL.

8879 S.

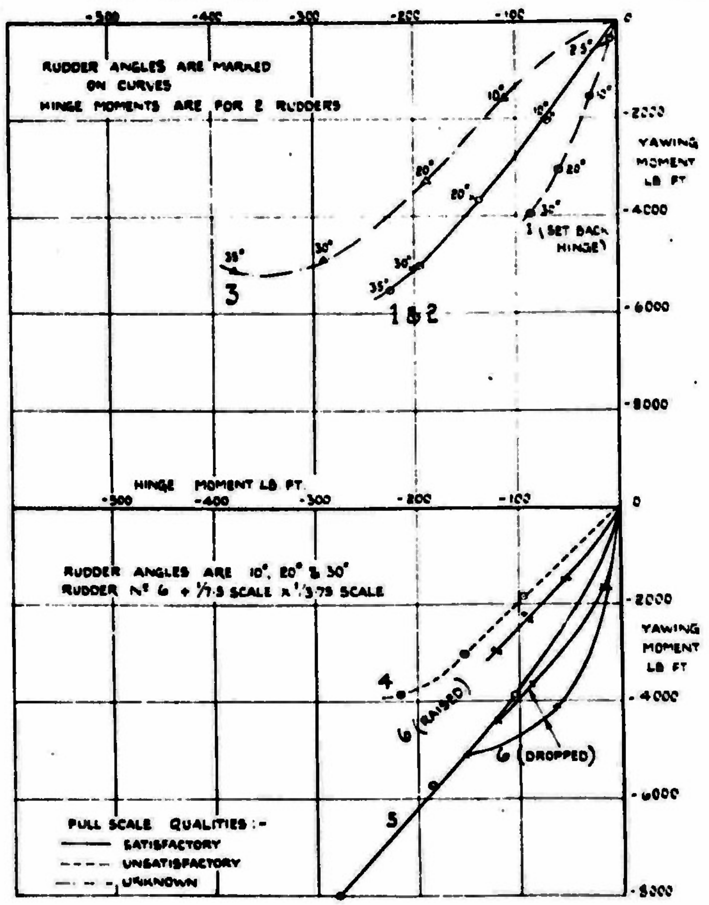
FIG 9



RUDDERS Nº 6 (DROPPED) AT 30 DEG.

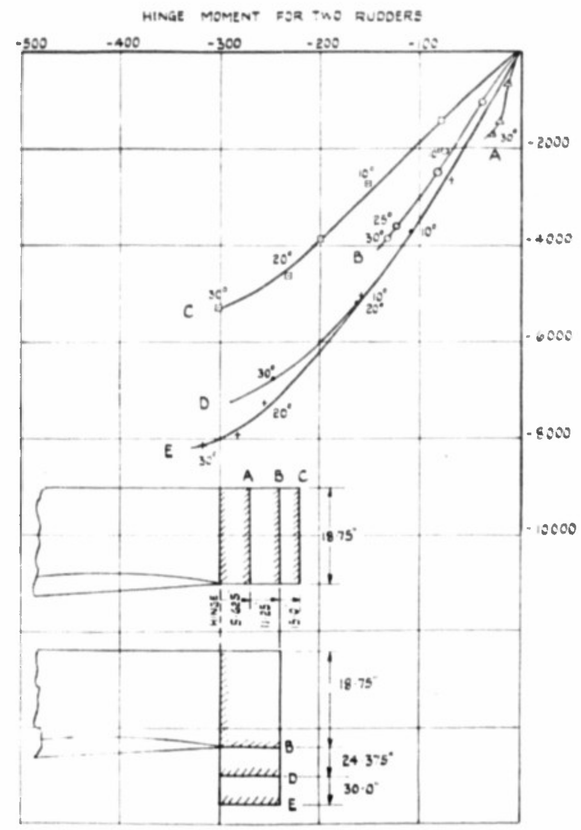
RESULTS FOR TWO SIZES OF MODEL.

FIG 10.



COMPARISON OF RUDDERS AT 10 KNOTS.

FIG.11



RESULTS FOR 1/3·75 SCALE FLOAT OF LINES USED FOR RUDDERS Nº 6. NO FULL SCALE TESTS MADE ON THESE RUDDERS

RECTANGULAR RUDDERS AT 10 KNOTS.

FIG 12

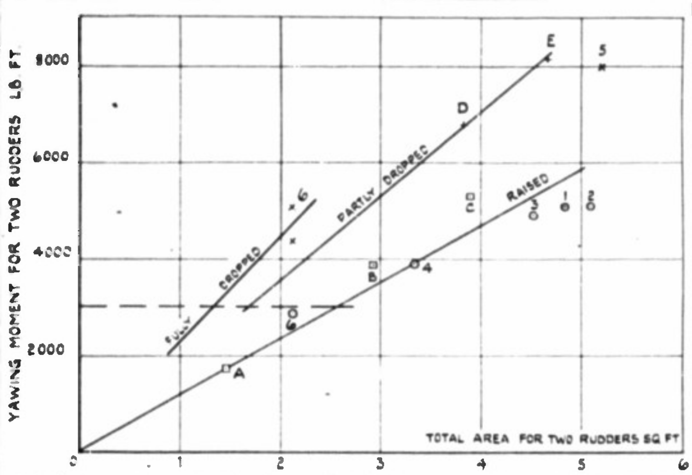


FIG 12 A. YAWING MOMENT AT -30° RUDDER ANGLE AT 10 KNOTS, NO SIDESLIP

RUDDER AREA = AREA × $\frac{L}{12.94}$ WHERE L = LENGTH C.G TO HINGE LINE.

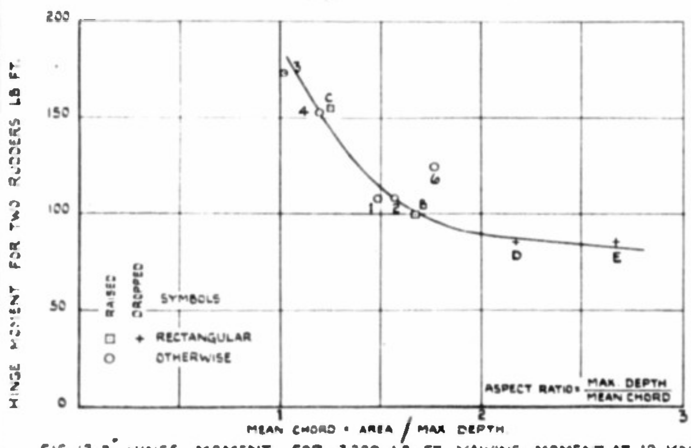
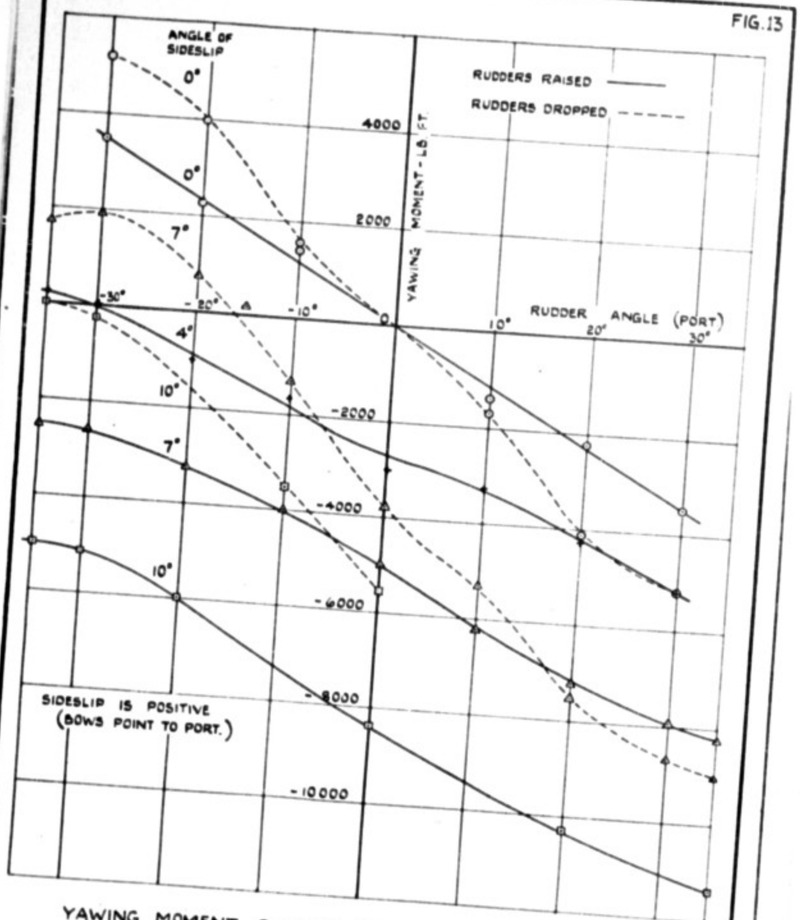


FIG 12 B. HINGE MOMENT FOR 3000 LB FT YAWING MOMENT AT 10 KNOTS. RESULTS ARE GIVEN ONLY FOR RUDDERS WITH NO BALANCE AND NO SIDESLIP.

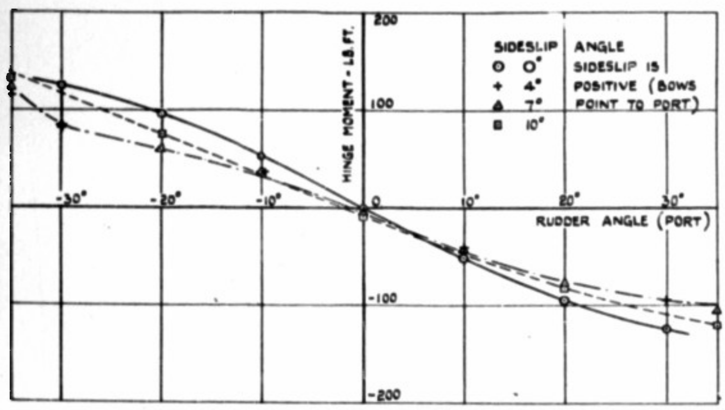
FIG. 13



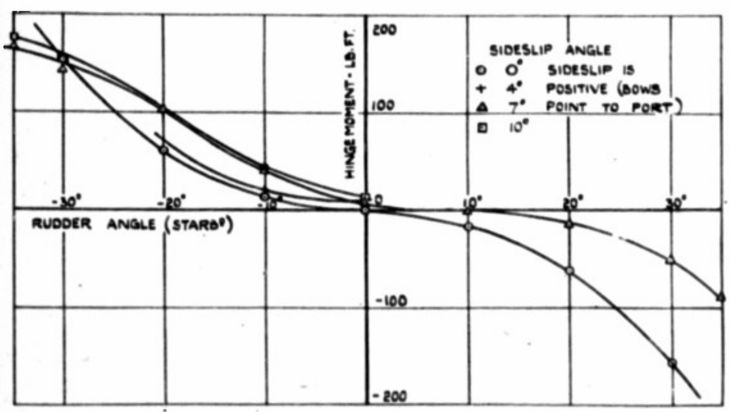
YAWING MOMENT CURVES FOR TWO POSITIONS OF RUDDERS Nº 6 AT 10 KNOTS.

8884.S

FIG.14.

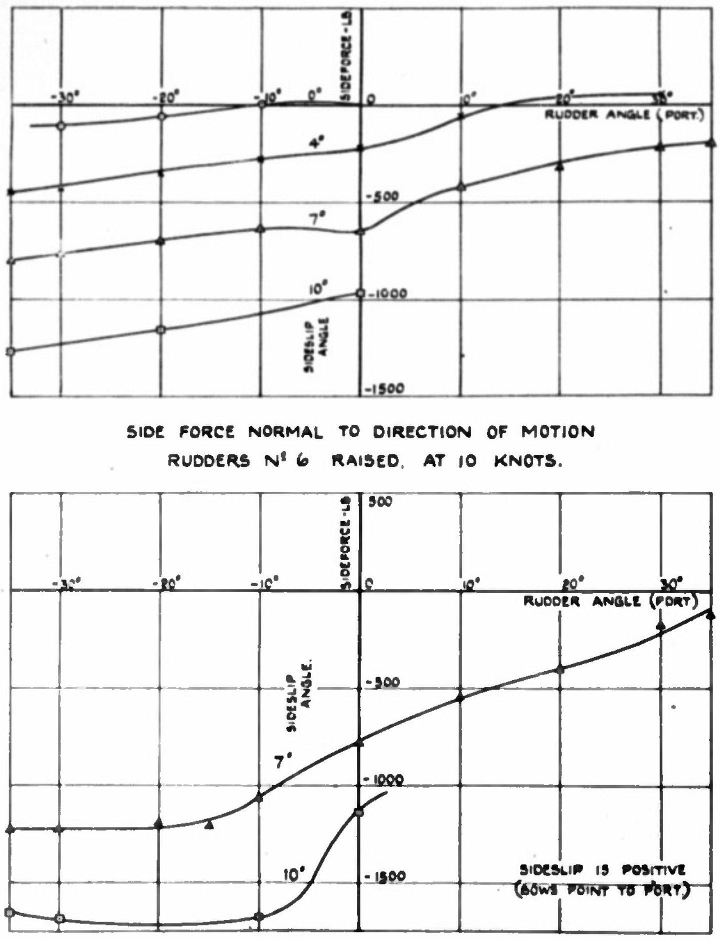


HINGE MOMENT CURVES FOR RUDDERS N° 6 RAISED AT 10 KNOTS.



HINGE MOMENT CURVES FOR RUDDER N° 6 DROPPED AT 10 KNOTS.

FIG.15

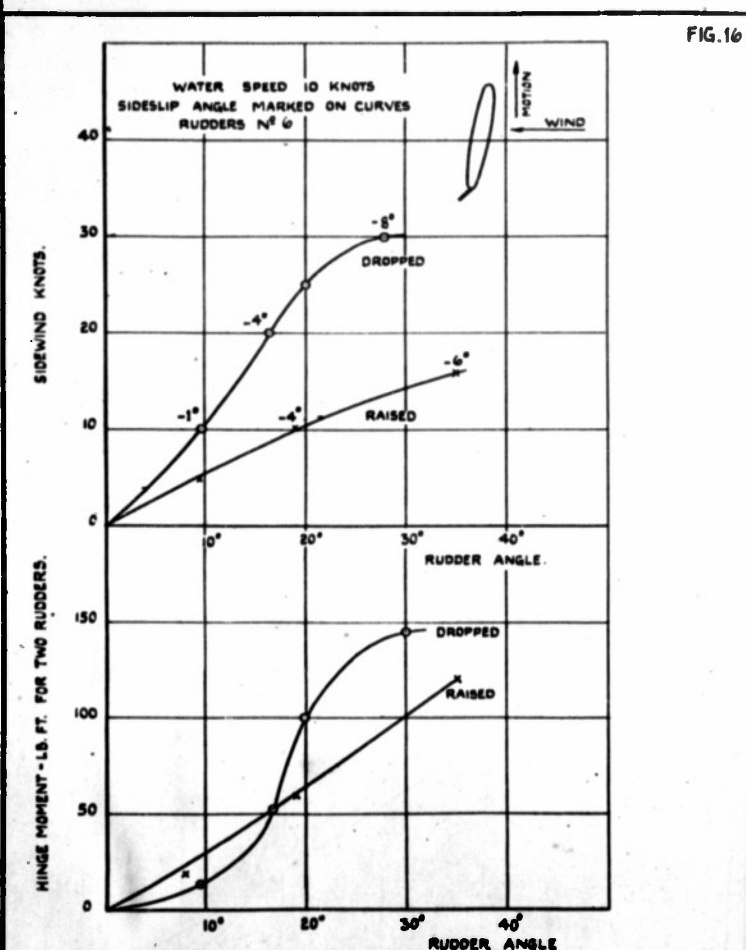


SIDE FORCE NORMAL TO DIRECTION OF MOTION
RUDDERS Nº 6 RAISED, AT 10 KNOTS.

SIDE FORCE NORMAL TO DIRECTION OF MOTION
RUDDERS Nº 6 DROPPED, AT 10 KNOTS.

8886.S.

31



RUDDER ANGLE FOR KEEPING STRAIGHT COURSE IN A SIDEWIND.

FIG. 17

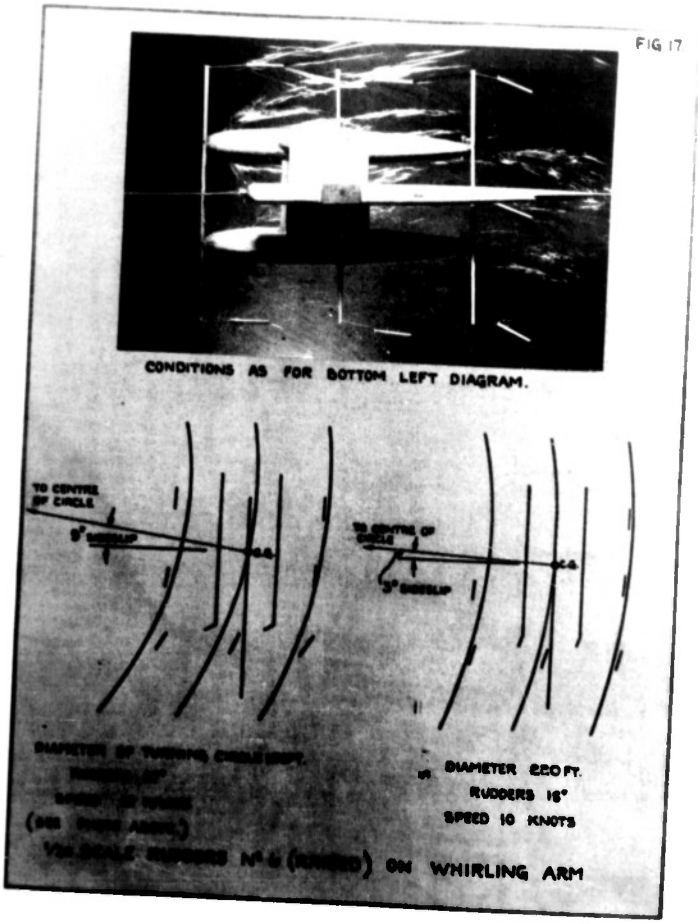
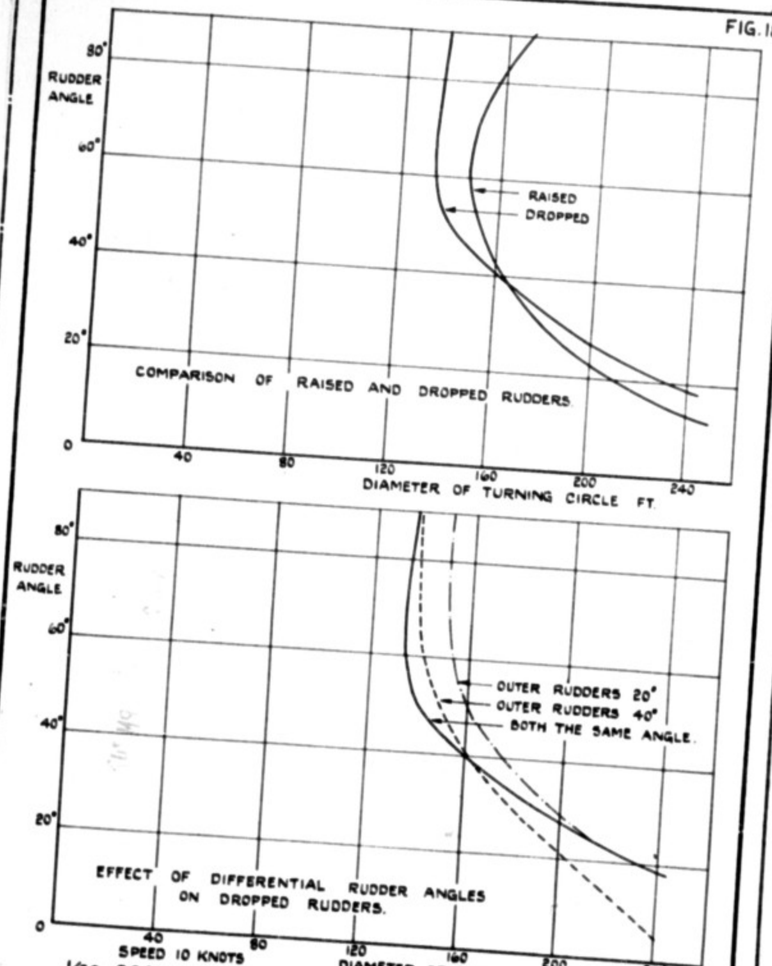


FIG 17
CONDITIONS AS FOR BOTTOM LEFT DIAGRAM.
TO CENTRE OF CIRCLE
9° SIDESLIP
TO CENTRE OF CIRCLE
3° SIDESLIP
DIAMETER 220 FT.
SPEED 10 KNOTS
ON WHIRLING ARM

8887.S.

33

FIG. 18.



1/30 SCALE RUDDERS Nº 6 ON WHIRLING ARM.

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9060

TITLE: Tank Tests on Water Rudders for Float Seaplanes	ATI- 9060
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P 13/10

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