C.P. No. 132
(13,946)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Tests on an Axial Compressor with Various Stator Blade Staggers

By

R. A. Jeffs, E. L. Hartley and P. Rooker.

LONDON : HER MAJESTY'S STATIONERY OFFICE
1953
THREE SHILLINGS NET

N.B. Please ignore 'RESTRICTED' classification which, by an oversight, has not been deleted.

C.P. No. 132.

Memorandum No. M.100.

September, 1950.

NATIONAL GAS TURBINE ESTABLISHMENT

Tests on an Axial Compressor with Various Stator Blade Staggers

- by -

R.A. Jeffs, E.L. Hartley and P. Rooker.

SUMMARY

This Memorandum presents the results of a series of low speed tests on 6 stages of a medium stagger free vortex design of axial compressor blading, in which the stagger of the stator blades was varied over a wide range while the rotor blade stagger remained at its design figure.

It is shown that efficiencies in excess of 35% were achieved over a range of stator blade stagger from -50° to $+10^\circ$, compared with the design figure of -25.4°.

This performance augurs well for the improvement of the performance of axial flow compressors away from their design point by the method of altering the stator blade stagger in some of the stages.

CONTENTS

ILLUSTRATIONS

1.0 Introduction

When an axial compressor is operated away from its design point, the matching between successive stages deteriorates owing to the incorrect flow areas and air angles at the new conditions, with consequent loss of performance. One method of reducing these ill effects is to alter the stagger of the stator blades in some of the rows in order that the blades may operate at more favourable incidences. It is therefore of interest to investigate the range over which the stator blade stagger may be altered without serious loss of efficiency.

Tests have therefore been carried out on a medium stagger free vortex design of blading, in which the overall characteristics of the compressor have been measured for each of a series of stator blade staggers, the rotor blades remaining fixed at their design stagger.

2.0 Test Procedure

The details of the blades tested are shown in Fig. 1. For all the tests, the rotor blade stagger was - 36.2°, while the stator stagger was changed from its design value of - 25.4°. Characteristics of pressure rise, temperature rise and isentropic efficiency were measured for stator blade staggers of - 55°, - 40°, - 25.4°, - 10°, + 5°, + 20° and + 30°.

All the tests have been carried out on the low speed experimental compressor[1] built up as shown in Fig. 2 with six stages of blading arranged with an axial clearance between successive blade rows of approximately 2/3 mean chord. The characteristics were all measured at 1,500 r.p.m. except that with a stator blade stagger of + 30°. This had, because of power limitations on the dynamometer, to be measured at 1,300 r.p.m.

The pressure rise recorded was the mean of a comb of 5 pitot tubes spaced across the annulus, the comb having been yawed to approximately the mean airstream direction for each stator blade stagger. The temperature rise was computed from the measurement of input power and mass flow.

For each value of the stator blade stagger, the air outlet angle from the inlet guide blades at mean diameter was arranged to be the same as the nominal air outlet angle from the stators. This involved resetting the existing inlet guide blades for the negative stagger settings, and the use of reset stator blades as inlet guide blades for the positive stagger settings.

The details of the blades tested are shown in Fig. 1. The design of these blades followed conventional lines, being of medium stagger free vortex type, with constant work done and axial velocity at all radii. Since the compressor annulus is untapered and the change in density through the compressor is small, the blades in all the stages are identical.

3.0 Discussion of Results

3.1 Overall Characteristics

The overall characteristics are shown plotted non-dimensionally in Figs. 3, 4 and 5 the most striking feature of these results is the very wide range of stator blade stagger over which the compressor operated at high efficiency.

There are two factors whose influence on these plotted results was not considered in the computation. Firstly, the torque reaction of the dynamometer which was used for calculating the compressor efficiency includes the bearing friction and skin friction on the ends of the compressor drum. These have been allowed for by assuming a constant mechanical efficiency. However, as the power absorbed varies over a wide range at constant rotational speed, as in these tests, the mechanical efficiency will certainly not remain constant. At the high negative staggers, the bearing losses etc.

consume a considerable proportion of the total input power, this proportion decreasing as the stagger is changed towards high positive values. An estimate has been made of the bearing losses and the maximum test efficiencies have been corrected for this to give a better picture of pure blading efficiency. This is represented by the dashed curve of Fig. 6.

The second influence is that of Reynolds number. Previous tests on this blading have shown that this parameter has a considerable effect on the blading efficiency and although these tests were conducted over a range of Reynolds numbers clear of the worst effects, there still appears to have been a noticeable effect. An estimate of the magnitude of this effect has been made on the assumption that the previously measured variation of maximum efficiency with the rotor blade Reynolds number[2] could be applied to these tests, using the mean of the rotor and stator blade Reynolds numbers, and the results have been corrected on this basis to a common Reynolds number of 0.65×10^5, this being the value at the design stator stagger.

The dotted curve of Fig. 6 shows the results fully corrected for these two variables and it may be seen that the apparent increase in efficiency between the design stagger and about - 5° has been accounted for by the corrections.

The wide range of stator stagger over which the efficiency remained about 85% can be seen to cover from - 50° to + 10°, while the maximum efficiency of 89.5% was achieved at the design setting of - 25.4°.

3.2 Rotor and Stator Incidences

The two-dimensional 'cascade' characteristics of the rotor and stator blades have been calculated by the method given by Carter in Ref. 3. From these characteristics, the mean incidences on to the rotor and stator rows have been estimated, assuming uniform flow.

The curves thus obtained were similar to those of Figs. 8 and 9 but the rotor incidences showed a peak value the severity of which appeared unjustified especially at the design value of the stator blade stagger. This peak disappeared if the assumed deviation at incidences greater than the optimum was reduced. The incidences plotted have therefore been calculated on the assumption that the increase in deviation at incidences greater than the optimum was 30% less than that given by Carter. Beyond the peak deflection of the cascade characteristics estimated in this way a constant value of deflection was assumed. These assumptions are illustrated in Fig. 7.

The rotor and stator incidences calculated in this manner are shown in Figs. 8 and 9 and the values attained at the surge points are plotted in Fig. 10. It will be noticed that at high negative staggers, the onset of surging appears to have been dictated by the incidence on to the rotor blades having reached its stalling value, irrespective of the stator incidence. At negative staggers lower than approximately - 30°, however, the rotor blades did not reach the stalling value and surging appears to have been controlled by the stator blades, although these estimated incidences suggest that the stator blades did not cause the compressor to surge until they had considerably exceeded the stalling incidence.

Another curve of interest which has been derived from these calculations is shown in Fig. 11. Here the rotor "work done" estimated from the compressor characteristics is plotted against mean rotor incidence, and it is shown that until rotor incidences of greater than + 2 are reached, all the various stator staggers yield the same curve. Beyond this there appears a variation which matches the variation in surging incidence of Fig. 10. The curve does show that, as a good approximation, over a very wide range of stator stagger and hence of inlet conditions to the rotor, the mean performance of the rotor based on simple considerations of uniform flow is independent of the stator stagger, and dependent only on the mean inlet conditions to the rotor.

4.0 Application to Matching Problems

The results of these tests suggest that varying the stagger of the stator blades in some or all of the rows of an axial flow compressor may be an effective method of achieving a considerable improvement in the performance of the machine away from the design point.

Thus in most gas turbine applications of axial compressors designed for high pressure ratios a serious trouble encountered at low fractions of the design speed is stalling of the first stages. These tests show that unstalled high efficiency flow can be maintained in these early stages by altering the stagger of the stator rows, while still retaining a reasonable stage pressure rise.

In an application of an axial compressor in which a low surging mass flow is not a major object of the design, even more advantage of the wide operating range might be taken. Thus, if the first stages could be allowed to operate at their optimum $^{V}a/_{U}$, later stages could probably be made to match by changing the stator blade stagger towards high positive values with consequent increase of work done at good efficiency.

In yet another application an axial compressor driven by a variable speed motor could be designed to operate efficiently at fixed pressure ratio over a wide flow range (of the order of 3 or 4 to 1). Alternatively, it might be arranged to cover a wide range of pressure ratio at one flow quantity.

5.0 Conclusions

The results of this series of tests show that the efficiency of an axial compressor stage is not adversely affected by altering the stagger of the stator blades over a wide range. Efficiencies of 85% and over have been recorded for changes in stator blade stagger over a range from - 50° to + 10°, with the maximum efficiency at the design stagger of - 25.4°.

This ability of the blades to operate at high efficiency shows that the matching, one with another, of the stages of an axial compressor may be improved by adjusting the stagger of the stator blades.

Estimated rotor and stator blade incidences indicate that the onset of surging may be controlled by the stalling of either the rotor or stator blades, although stalling appears to be more critical on the rotor blades than on the stator blades.

REFERENCES

No.	Author	Title etc.
1	R.A. Jeffs	Description of the low speed experimental compressor No. 106. Power Jets Report No. R.1198.
2	R.A. Jeffs	Preliminary note on the performance of blades designed to operate in a radially varying axial velocity distribution. N.G.T.E. Memorandum No. M.54. (A.R.C. 12,623)
3	A.D.S. Carter	The low speed performance of related aerofoils in cascade. N.G.T.E. Report No. R.55. (A.R.C. 12,883)

CIRCULATION

C.S.(A)
The Chief Scientist
D.G.T.D.(A)
P.D.S.R.(A)
D.E.R.D.
NA/DERD (Cdr. (E) G.J. Noble)
D.I.G.T. (Mr. R.H. Weir)
AD/Eng.R.
AD/Eng.RD.1.
AD/Eng.RD.2.
Mr. E. Clenence, Pats.1(c)
Secretary, G.T.C.C. Aerodynamics Sub-Cttee.
(Mr. D.V. Foster)
TPA3/TIB1C. 150 copies
A.R.C. (E.A. Sub-Cttee.) 50 copies
G.T.C.C. Aerodynamics Sub-Cttee. 25 copies

RAJ/EIH/PR/MEB/260/7/11/8.1.50.

APPENDIX I

Table of Blade Angles at Design Stagger

Rotor Blade

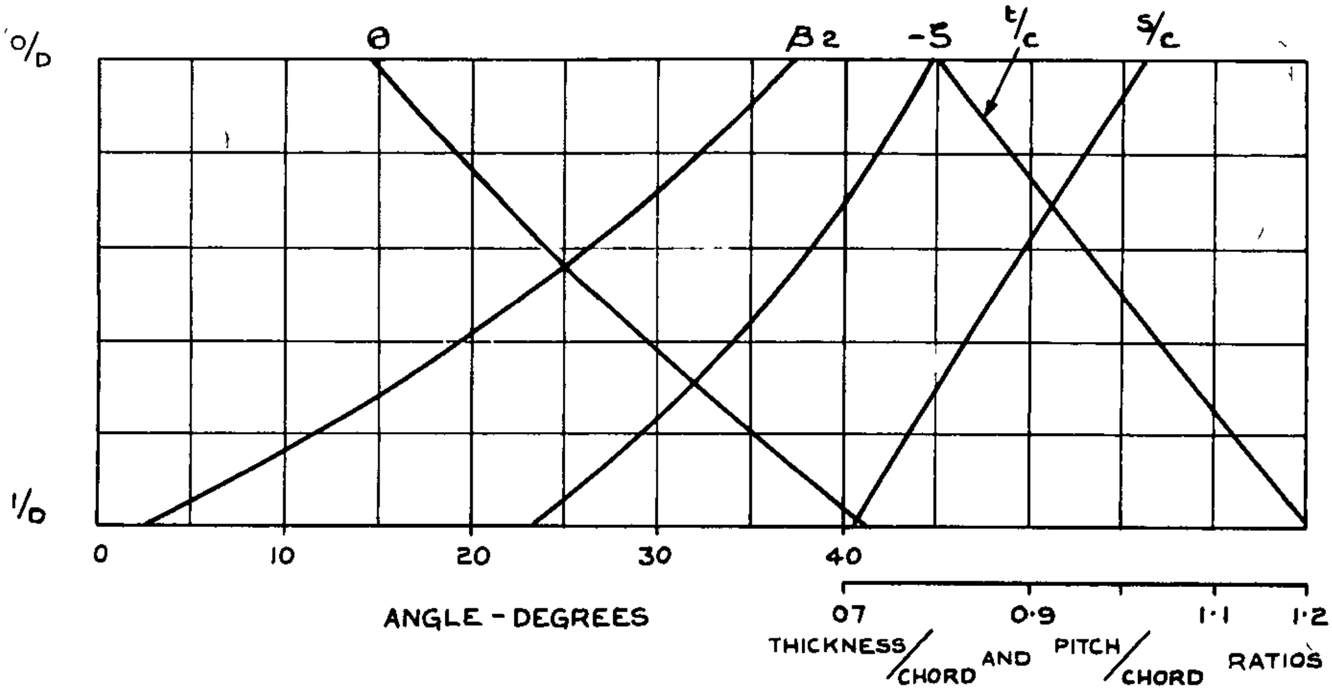
Radius r"	Camber	Stagger	Pitch/Chord Ratio S/C
7.5	41.0	-23.4	0.712
8.13	33.7	-30.5	0.787
8.15	26.5	-36.2	0.862
9.38	20.1	-41.0	0.942
10.0	14.9	-44.8	1.02

Stator Blade

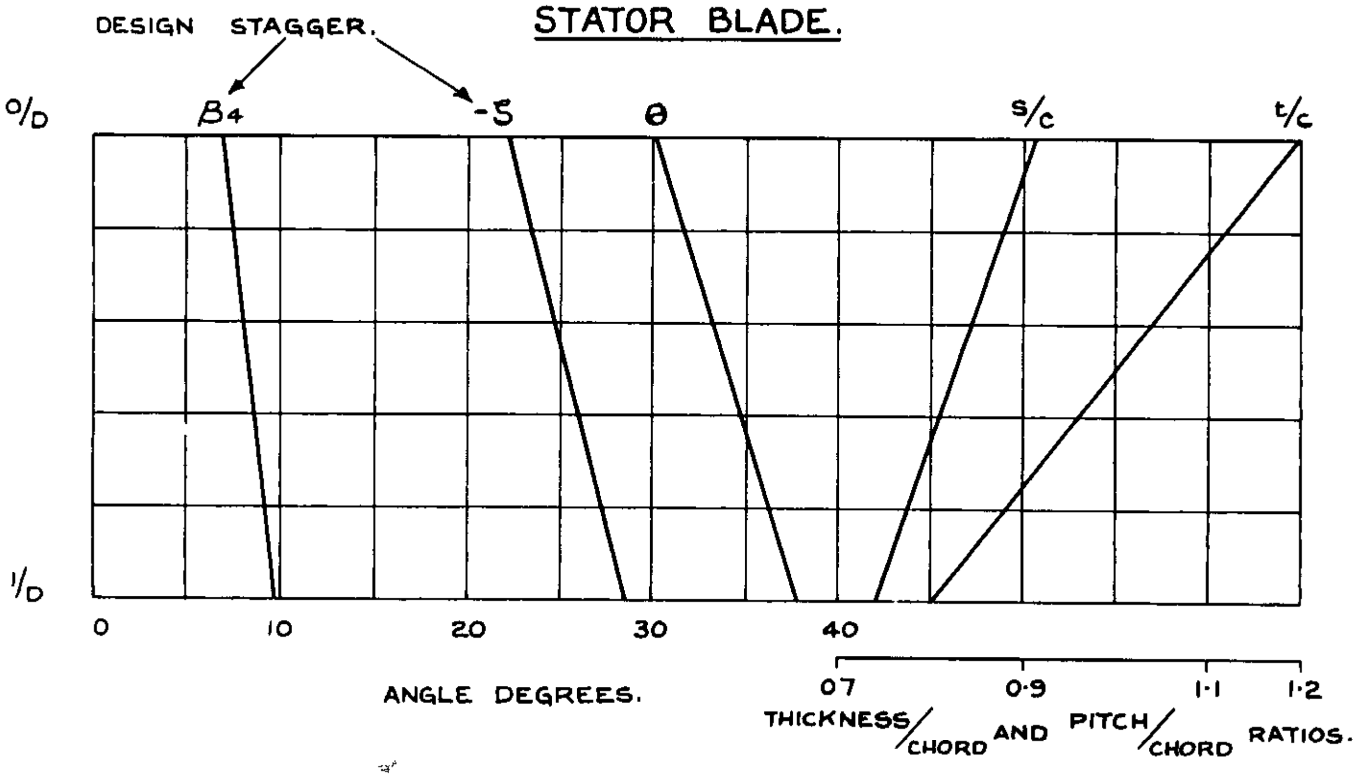
Radius r"	Camber	Stagger	Pitch/Chord Ratio S/C
7.5	37.7	-28.6	0.740
8.13	36.0	-27.0	0.788
8.75	34.0	-25.4	0.833
9.38	32.3	-23.8	0.876
10.0	30.6	-22.2	0.918

BLADE DETAILS. FIG. I.

ROTOR BLADE.



STATOR BLADE.



RANGE OF TESTS.

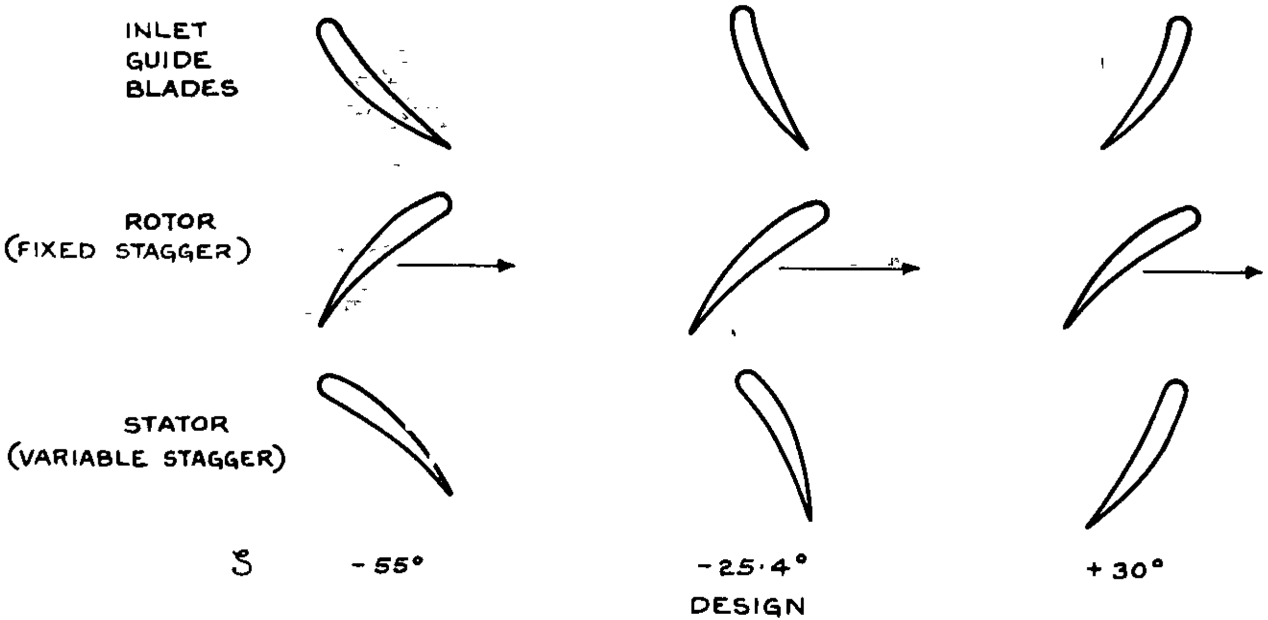
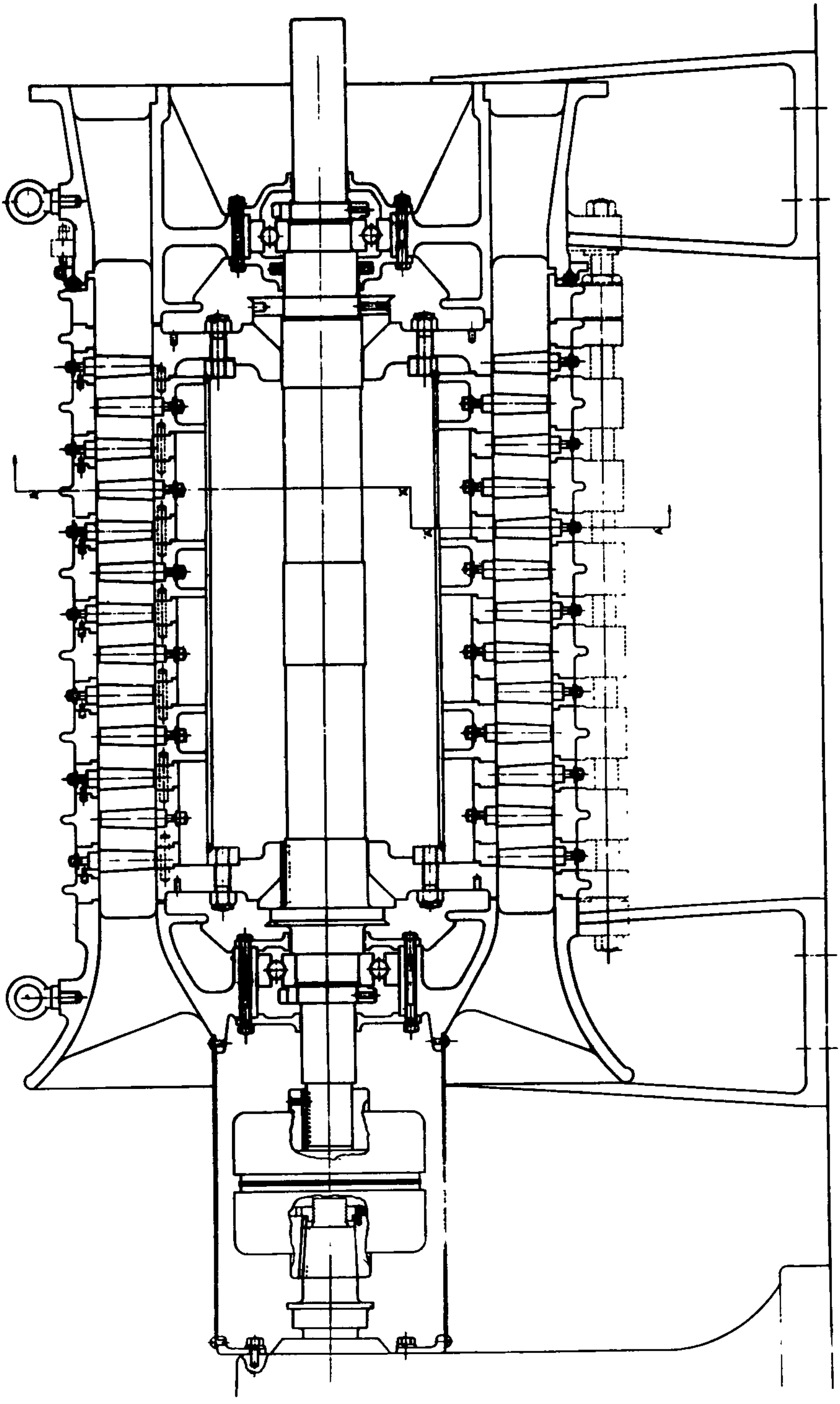


FIG. 2.



ASSEMBLY OF 6 STAGE COMPRESSOR.

PRESSURE RISE CHARACTERISTICS.

MEAN VALUE FOR 6 STAGES AT 1500 R.P.M
VARIOUS STATOR STAGGERS

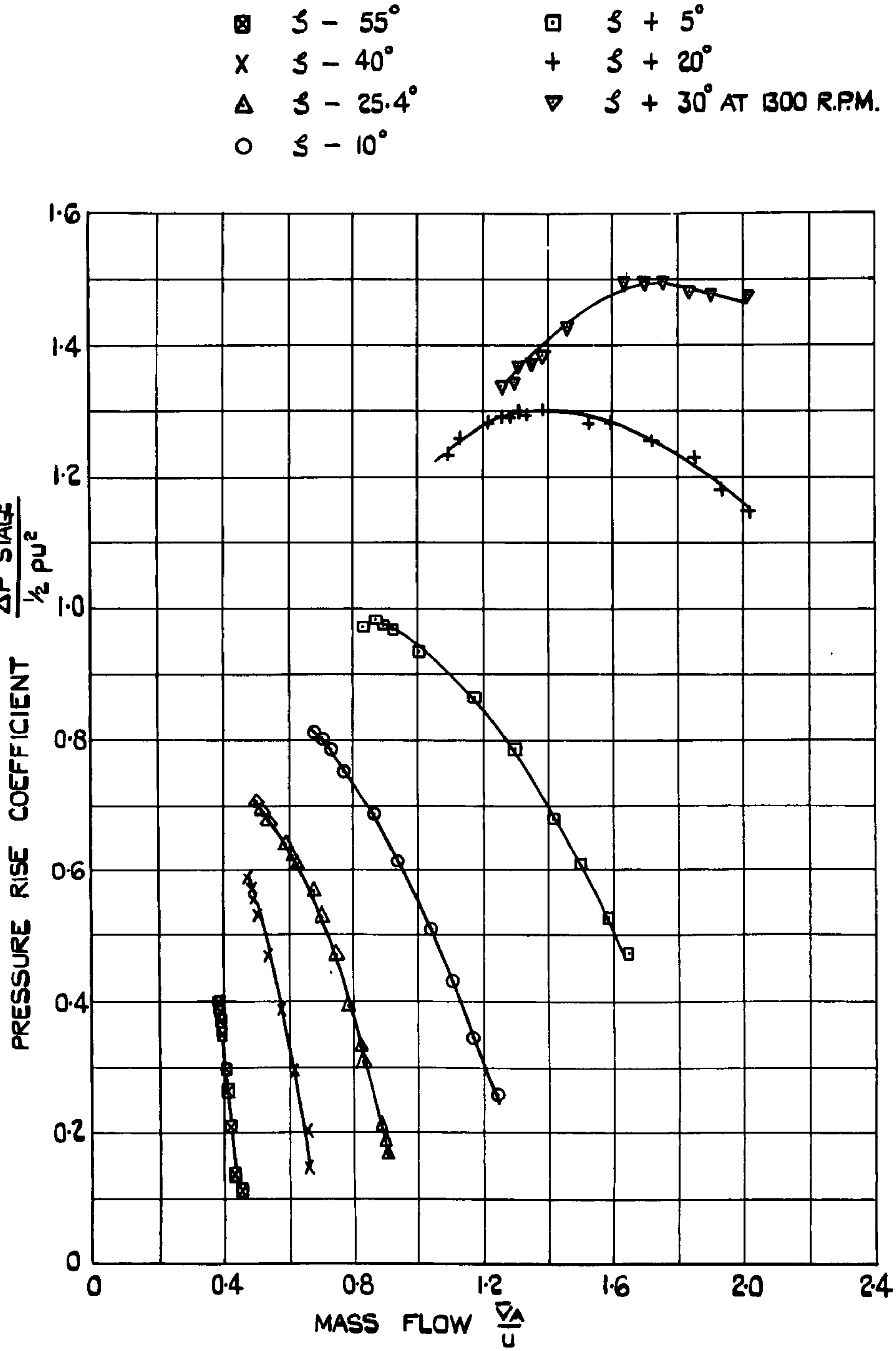


FIG. 4.

EFFICIENCY CHARACTERISTICS.

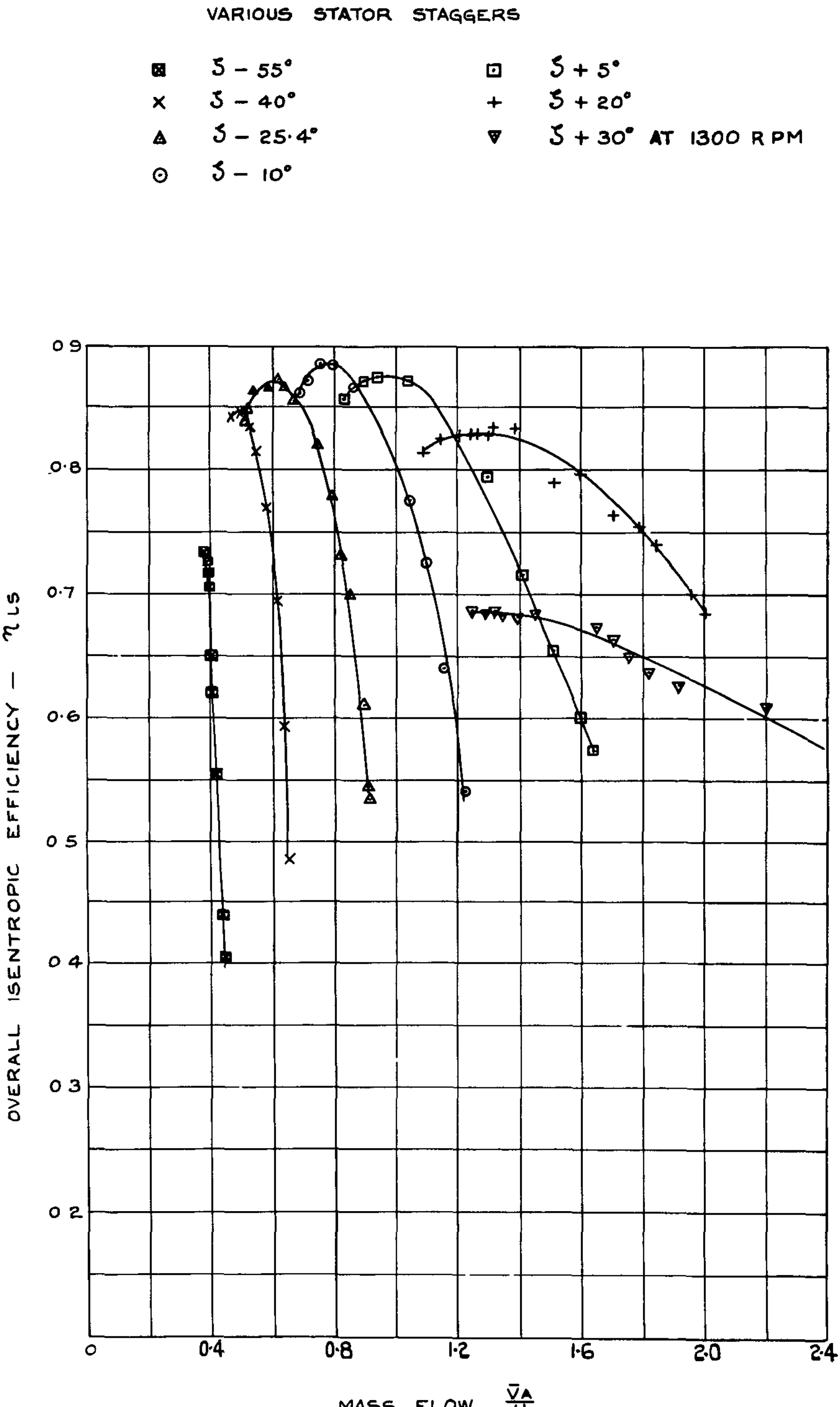


FIG. 5.

TEMPERATURE RISE CHARACTERISTICS.

MEAN VALUE FOR 6 STAGES AT 1500 R P M

VARIOUS STATOR STAGGERS

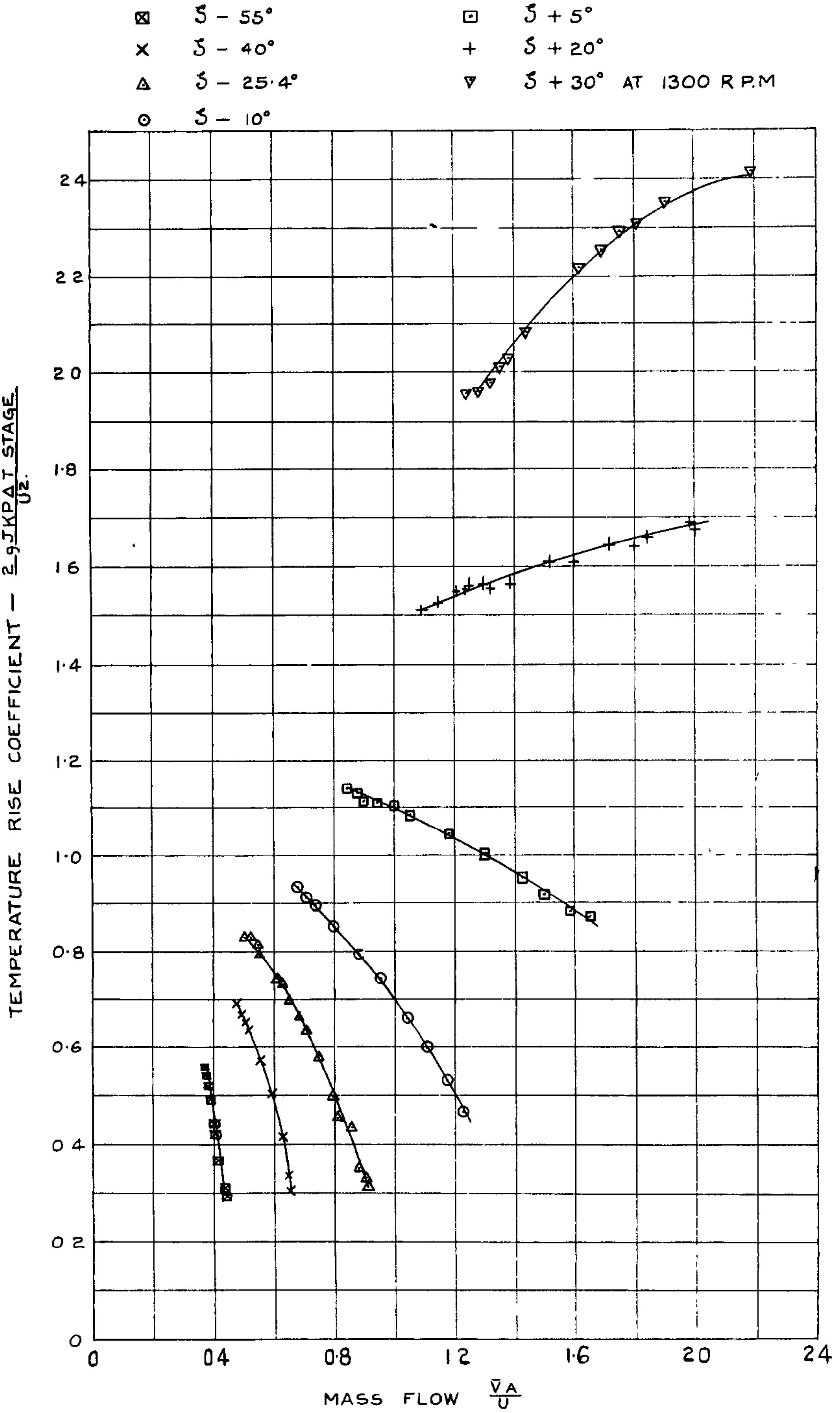


FIG. 6.

MAXIMUM ISENTROPIC EFFICIENCY.

6 STAGES 1500 R.P.M.

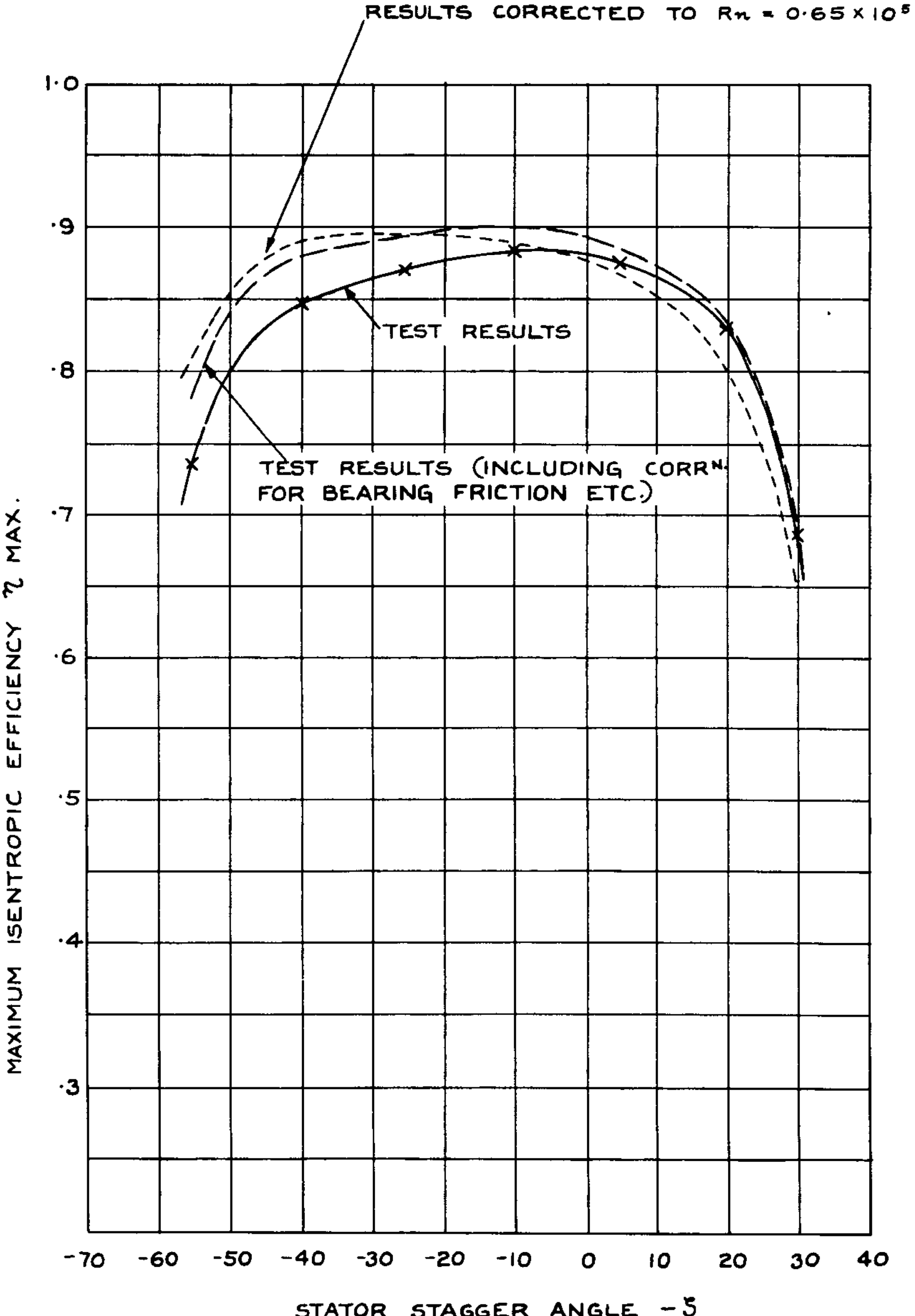


FIG. 7.

ASSUMED DEFLECTION CURVE FOR INCIDENCE CALCULATIONS.

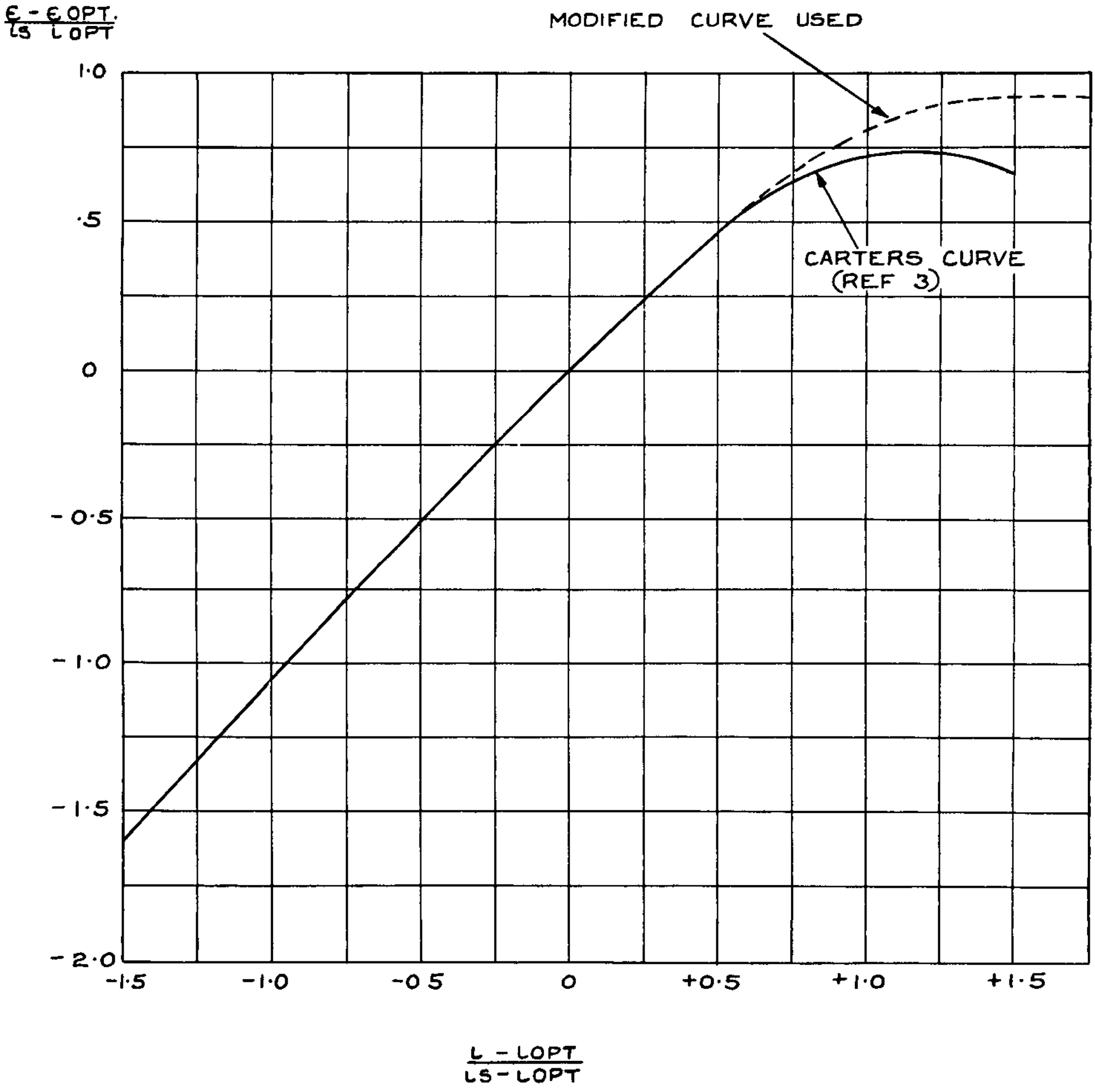


FIG. 8.

MEAN ROTOR INCIDENCE VARIATION.

MEAN VALUE FOR 6 STAGES AT 1500 R.P.M

VARIOUS STATOR STAGGERS

⊠	$\zeta - 55°$	⊡	$\zeta + 5°$
×	$\zeta - 40°$	+	$\zeta + 20°$
▲	$\zeta - 25{\cdot}4°$	▽	$\zeta + 30°$ AT 1300 R.P.M.
⊙	$\zeta - 10°$		

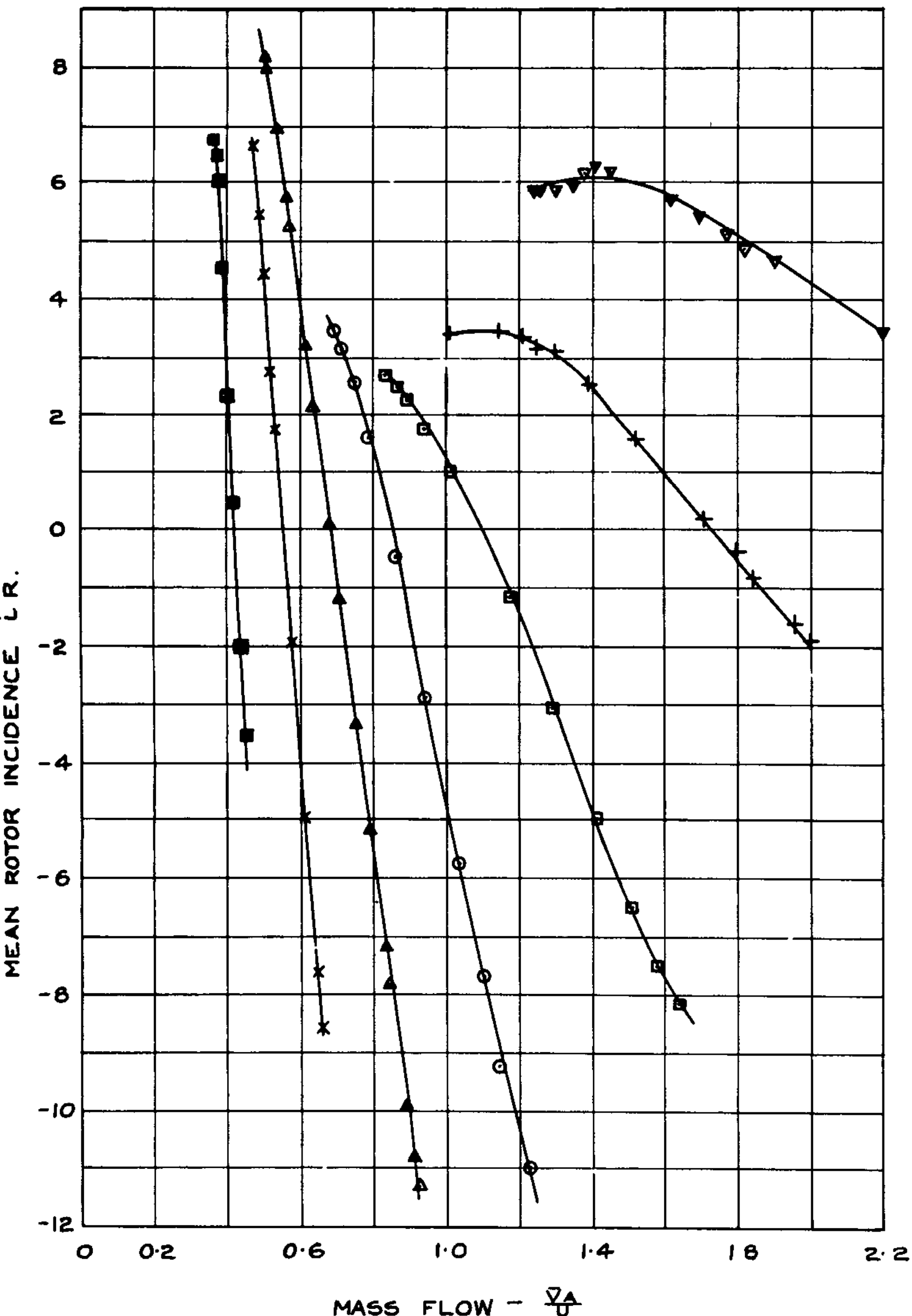


FIG. 9.

MEAN STATOR INCIDENCE VARIATION.

MEAN VALUE FOR 6 STAGES AT 1500 R.P.M

VARIOUS STATOR STAGGERS

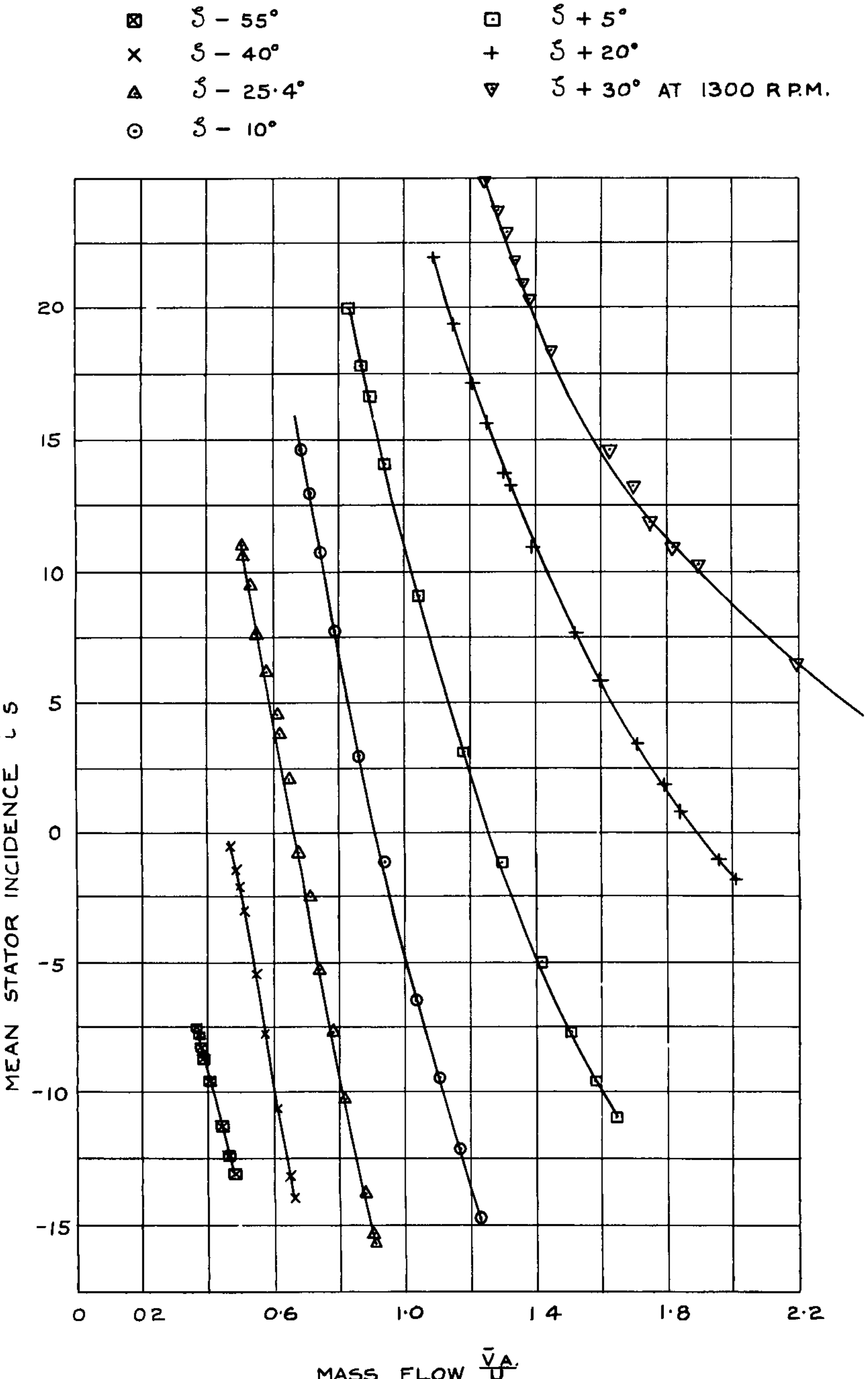


FIG. 10.

MAXIMUM ROTOR AND STATOR INCIDENCE.

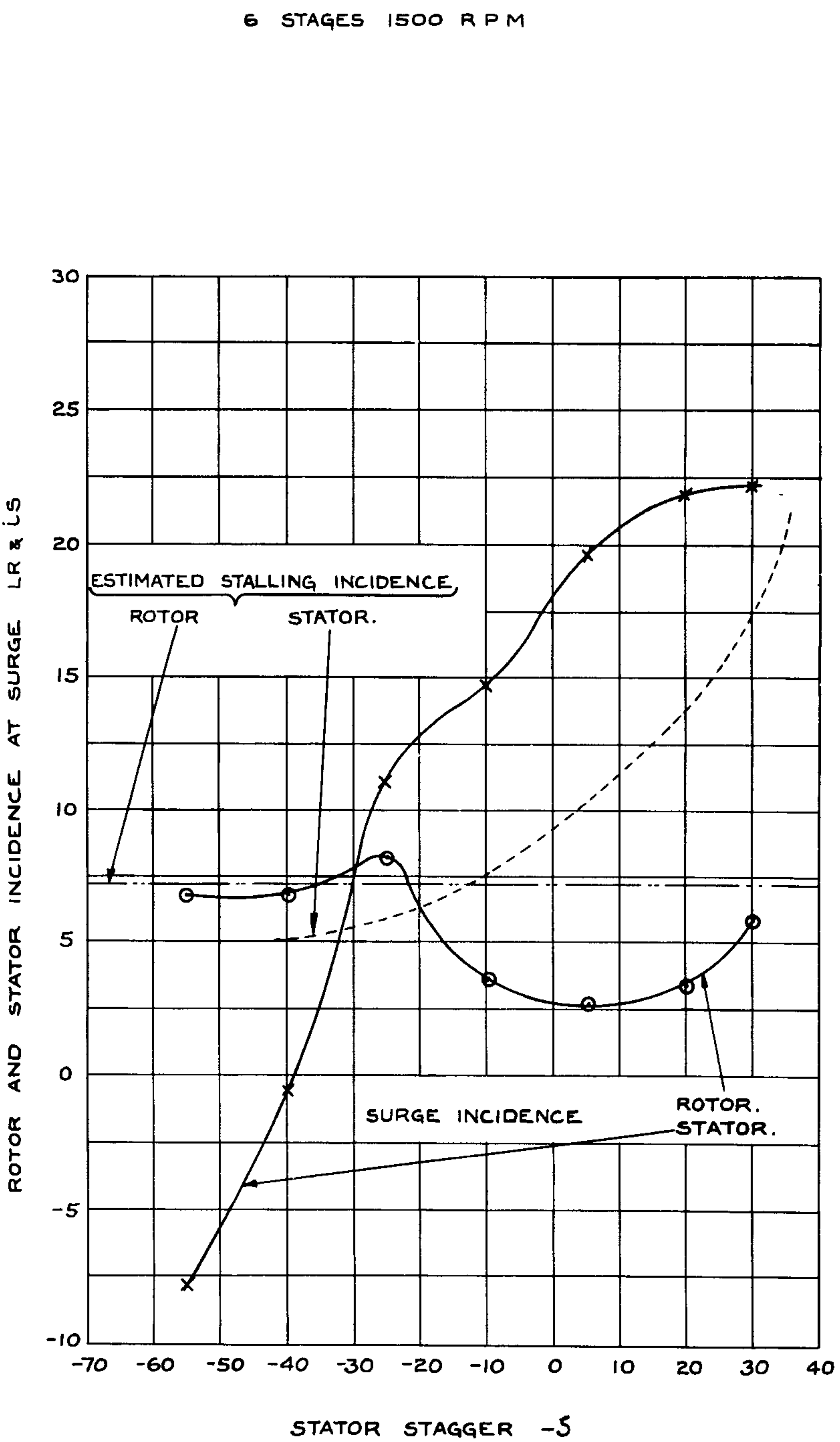
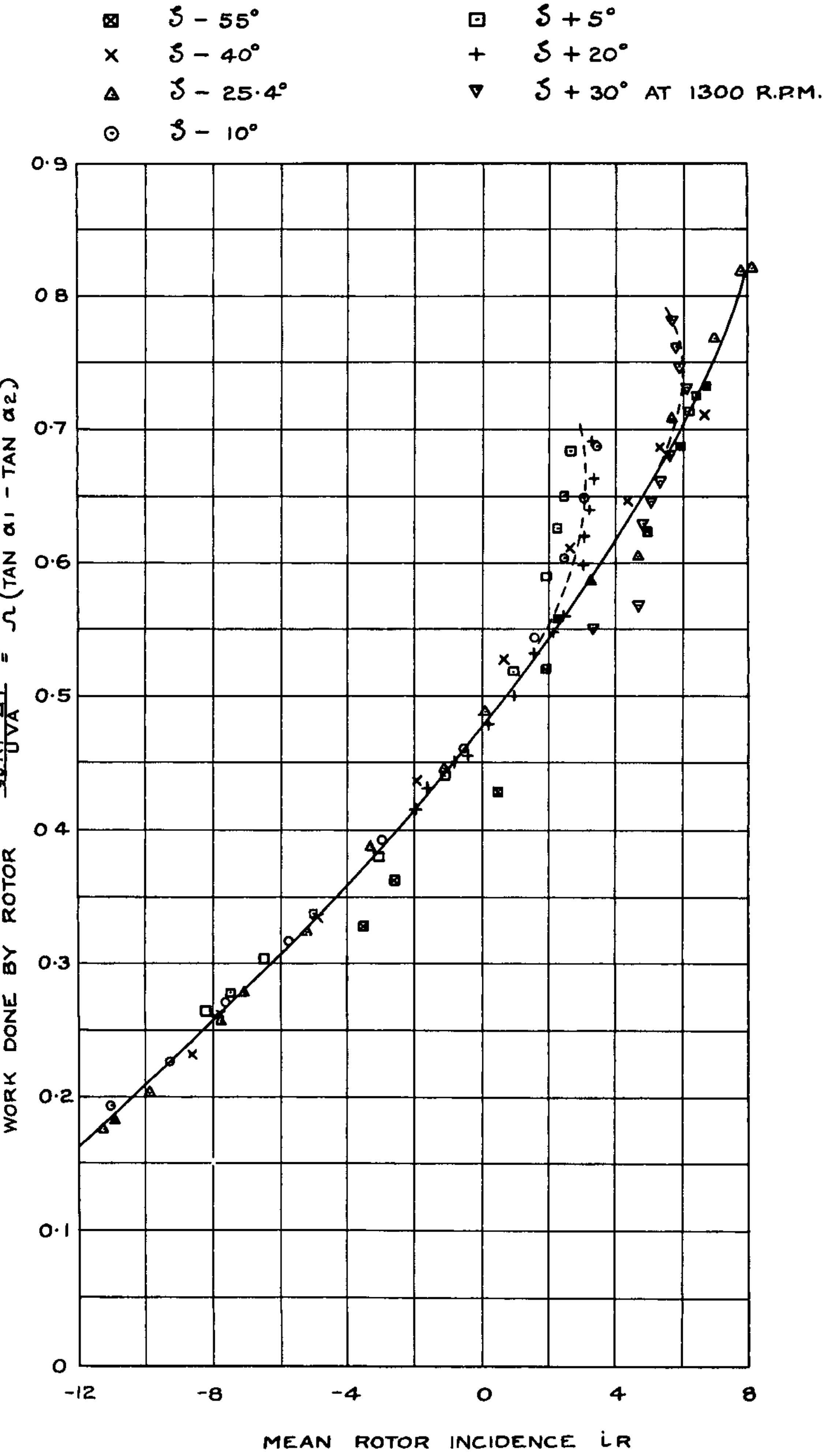


FIG 11.

WORK DONE BY ROTOR.

MEAN VALUE FOR 6 STAGES AT 1500 R.P.M

VARIOUS STATOR STAGGERS



C.P. No. 132
(13,946)
A.R.C. Technical Report

PRINTED AND PUBLISHED BY HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, LONDON, W.C.2 423 Oxford Street, LONDON, W 1
P.O. Box 569, LONDON, S.E.1
13a Castle Street, EDINBURGH, 2 1 St. Andrew's Crescent, CARDIFF
39 King Street, MANCHESTER, 2 Tower Lane, BRISTOL, 1
2 Edmund Street, BIRMINGHAM, 3 80 Chichester Street, BELFAST
or from any Bookseller

1953

Price 3s 0d net

PRINTED IN GREAT BRITAIN

S.O. Code No. 23-9007-32