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THE COLLEGE OF AERONAUTICS
CRANFIELD

ANALYSIS OF EXPERIMENTS ON SWEPT WING STRUCTURES

by

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Analysis of Experiments on Swept Wing Structures [*]

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SUMMARY

This report is concerned with the application of various theories to the solution of problems investigated experimentally, and in some cases theoretically, by others at the College of Aeronautics.

The following work is considered:-

A single cell swept wing with ribs normal to the spars, a strain energy solution, allowing for a flexible root rib and shear lag, being applied. The shear lag correction is found to be desirable.

A two cell swept wing, with ribs normal to the spars, again using a strain energy solution. The theory was found to be in good agreement with the experiment, and the root effects were found to be limited to approximately within one root chord length along the rear spar.

A two cell swept wing with ribs parallel to the line of flight, where oblique coordinate theory is used. The Z wise force theory overestimates the cross sectional variation of direct strain in a tapered box, and a pure couple theory gives better results in this case.

A single cell swept box, having oblique ribs, where oblique coordinate theory is found to give good results away from the root. At the root a correction for shear lag is found to be necessary.

A comparison of wings with ribs normal to the spars and parallel to the line of flight is made. It is concluded that the latter is at an advantage in most cases.

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[*] This investigation was made during the tenure by the author of a Clayton Fellowship awarded by the Institution of Mechanical Engineers.

LIST OF CONTENTS

1.00 INTRODUCTION

In the course of several years a series of investigations on the structural problems associated with swept back wings, have been made at the College of Aeronautics. This work has been mainly of an experimental nature, although in certain cases a theoretical analysis was also undertaken.

The purpose of the present report is to summarize the more important aspects of this work, to make theoretical analyses of the structures tested, and to present a comparison between the experimental and theoretical results.

The work covers specimens representative of both single and two cell wings having either ribs parallel to the line of flight, or normal to the mainspar. A comparison between the two types of rib configuration is also made.

2.00 DETAILS OF INVESTIGATIONS

This section is concerned with the actual comparisons made between the original experimental work, and the theoretical analyses.

2.01 Single Cell Swept Box with Ribs Normal to the Spars

The original work on this specimen is due to McClean(11) and details of the root of the wing considered are given in Fig.1. The specimen was a converted "Stirling" bomber tail-plane, the root being cut to give the required sweepback of $36\frac{1}{2}^{\circ}$ on the centreline. The root was built in.

Two loading cases have been considered, the bending of the wing by a normal force applied on the centreline at the tip, and torsion by a couple applied in the plane of the ribs.

A comparison has been made between the experimental results of McClean and the theoretical values given by the first order strain energy solutions due to the present author(6),

/ for both ......

for both the loading cases. The effect of the flexibility of the root rib is considered, and in addition for the normal force loading case, the second order theory of Ref.6 has been applied. In using the theories, the structure was idealised as shown in Fig.2, and the final results were assumed to be correct at the centroids of area of the actual boom skin combination, there being linear variation of stress between these points.

Figs. 3-8 show the resulting direct and shear stresses across a section three inches outboard of the root triangle, (Section A of Fig.1) and the variation of direct stresses in the spar booms.

2.02 Two Cell Swept Box with Ribs Normal to the Mainspar

The experimental results for this wing were obtained by McKay(10) whilst the present author made an initial theoretical investigation(5). Details of the specimen, which has a sweepback of 40° on the mainspar, are given in Fig.9. The model is tapered both in planform and in front elevation. The root is built in at the mainspar only, the front and rear connections being arranged to take vertical shear loads.

The experimental results for the root have been compared with the theoretical strain energy solution of Ref.6. Fig.10 shows the idealisation of the root structure. In interpreting the final results, the assumption made for the single cell case has again been used.

The direct stress variation in the spar booms, and the shears in the spar webs, across a section parallel to the root rib, due to loading by a normal force applied at the centreline at the tip, are given in Figs.11-14.

2.03 Two Cell Swept Box with Oblique Ribs

The structure of this box is shown in Fig.15. It is identical to that of Fig.9 except for the direction of the ribs, and the experimental results are again due to McKay(10).

In this analysis, only a section remote from the root is considered, the dimensions of the actual and idealised sections being given in Fig.16. Two loading cases have been analysed, a normal force placed alternately on the centreline, and the front spar, at the tip. These are referred to as Cases 1 and 2 respectively.

/ Ref. 5 ....

Ref.5 gives the theoretical solutions based on the pure couple theory in oblique coordinates of Ref.7, and some of these results have been extracted, and compared here with a more general oblique coordinate theory of Hemp(4), which makes an allowance for normal shear forces.

The direct (e_{xx}) and shear (e_{xY}) strains across the section, and the spar web shear strain (e_{xz}) are shown in Figs. 17-19. The notation of the stress resultants, strains and stresses used is shown in Figs. 21 and 22.

2.04 Single Cell Box with Oblique Ribs - Section Away from Root Effects

Fozard(2) and Noton(12) carried out most of the work on this box, and with the exception of the calculations associated with oblique coordinate theory, the results presented here have been extracted from Ref.12. The aim of the work was to compare the experimental results of tests on a single cell uniform swept box having oblique ribs, with the theories of Hemp(3), Mansfield(9) and Wittrick and Thompson(14)-(18).

Details of the specimen are shown in Fig.20, the angle of sweepback being 45°. The three loading cases used were:-

(1) Pure "bending" couple (M_A), applied about an axis normal to the centreline of the box, and equivalent to the couple M_1 of oblique theory.

(2) Pure "torsion" couple (T_A), applied about the centreline of the box, equivalent to the oblique coordinate theory couple L.

(3) Loading by a normal shear force applied on the centreline at the tip.

The notation is shown in Figs 21 and 22.

Figs.23-25 present a comparison of the experimental results and the theory of Hemp, for the direct and shear strains in the skins. Table 1 compares the stiffnesses and stresses of the various theories, with the experimental values, and also gives the theoretical values for the equivalent unswept box. Table 2 gives a comparison of the strains for the oblique coordinate theory and experiment.

/ In all ......

In all these results, the experimental and theoretical work was restricted to a section of the specimen away from the root effects.

2.05 Single Cell Box with Oblique Ribs - Root Effects

The specimen used for this work was the same as that discussed above, the root being built onto a heavy steel box. The experimental results are due to Noton(12), but no record of root deflections are available, and for the purposes of comparison with theory, a fixed root is assumed.

The same types of loading, as used previously, were applied, and the theoretical calculations are based on the approximate theory of Hemp(3). No allowance is made for second order effects, and the theory is applicable only to cases of loading by pure couples.

A comparison of the experimental and theoretical results for the direct (e_{xx}), and shear (e_{xY}), strains in the skins appears in Figs. 26 and 27.

2.06 Comparison of Wings having Ribs Normal to the Spars, and Parallel to the Line of Flight.

The results given in Table 1, for the theory of Hemp and the unswept box have been used to compare the stresses of the two types of rib configuration. The problem is also discussed in Ref. 5 and the relevant results have been extracted.

/ 3.00 ....

3.00 DISCUSSION

3.01 Single Cell Box with Ribs Normal to the Spars

The large build up of direct stress towards the rear spar of a sweptback wing, for loading by a normal shear force, is clearly shown in Fig.3. The experimental results show considerable discrepancy across the centres of the skin on upper and lower surfaces, and this was most probably due to imperfect root fixing conditions. It can be seen that the shear lag solution gives the best comparison to the average of the experimental results, whilst the effect of assuming the root rib to be rigid is that the load transference to the rear spar is greater.

In the case of loading by a torsion couple, Fig.4, the theoretical direct stresses are of the right order, although near the front booms the variation does not compare well. The flexible root rib theory again gives lower stresses in the rear spar, and better agreement with experiment.

All the three solutions give good comparison with the average shear stresses in the web and skins, resulting from normal shear force loading, Fig.5. The shear lag solution diverges most from the experimental web shears, but gives an indication of the chordwise variation in skin shears. The flexible rib theory predicts results for the spar webs, which are in closest agreement with the test values. This is also seen to be the case for torsion couple loading, Fig.6, and here, the agreement for the skin shears is very good.

The variation in the spar boom stresses for the normal shear force loading case, Fig.7, shows that whilst the flexible rib theory is an improvement on the rigid rib solution, a shear lag correction is necessary to obtain good comparison. For the torsion loading case, Fig.8, the theories, particularly that assuming rigid ribs, predict higher stresses at the root than are actually obtained in practice, but the tendencies are correct.

/ Figs. ....

Figs. 7 and 8 show that the root effects die away rapidly, and in fact become very small at a section corresponding to one root chord out along the rear spar.

3.02 Two Cell Box with Ribs Normal to the Mainspar

The variation of the direct stresses in the spar booms, for normal force loading, is shown in Figs. 11-13. It will be seen that there is, in general, good agreement between the strain energy theory and the experimentally derived points. There is a tendency, however, for the mainspar boom stresses to be higher than the theoretical prediction, and this is most probably explained by the method by which the experimental points were obtained. Strain gauges were placed on the booms, which as can be seen from Fig. 9, Sect. "X-X", doe not lie adjacent to the skin. A linear beam theory distribution was used to predict the skin stresses, which are shown in Fig. 12, and it is likely that this distribution was not maintained.

The spar web shear stresses given in Fig. 14 show good agreement on the mainspar, but the theory predicts a greater load transference to the rear spar, than was in fact obtained. The assumption of rigid ribs is the most probable explanation of this effect.

As in the case of the single cell wing having normal ribs, the root effects are seen to become small, at a section corresponding to one root chord out along the rear spar.

3.03 Two Cell Swept Box with Oblique Ribs

The direct strain, e_{xx}, variation across the section analysed appears in Fig. 17. In both load cases the Z wise force theory gives a fairly good, but rather high value, for the strain at the centreline. However, the actual variation across the section is very small compared with the theoretical value. The theoretical result for pure couple theory gives

/ much ....

much better agreement, and it is possible that the effect of the taper of the wing planform is to cancel the cross sectional variation. This effect has been noted in another series of tests, on a 60° swept back wing(7). The experimental results on the mainspar are high, for the reasons discussed in the above paragraph.

The corresponding variation in shear strain e_{xY}, is given in Fig. 18. Unfortunately only one experimental point is available for each cell, and this is not sufficient for a definite comparison of experiment and theory to be made. Nevertheless it would appear that while the agreement between the two is quite good, there is a tendency for the front cell shear strains to be overestimated, and the rear cell strains to be underestimated by the theory. These results would be compatible with a smaller cross sectional variation in the shear strain than is indicated by theory, possibly due to the tapered planform, and accounting for the lower variation in e_{xx} across the section.

The web shear strains, e_{xz}, are given in Fig. 19. Although the mainspar experimental results are in good agreement with theoretical results, the theory, in effect, underestimates the strain, as the idealisation of the section necessarily increases the shear depth of the web. The front and rear web shear strains are overestimated by the theory, an inverse effect of that in the mainspar.

3.04 Single Cell Box, with Oblique Ribs - Section away from the root.

The strain e_{xx} in the skin, for the various loading cases, is compared with oblique coordinate theory in Fig. 23 and Table 2. There is very good agreement for all cases, except that there is a general tendency for the theoretical value under Z wise force loading to be some 4% to 5% high. The same remarks can be applied to the variation in shear strain, e_{xY}, as shown in Fig. 24. The higher values of e_{xY} under Z wise force loading would account for the similar discrepancy in the direct strain, e_{xx}, variation.

/ Fig. 25 .....

Fig. 25 shows the comparison of theoretical and experimental values of the direct strain e_{YY}. There is insufficient evidence for a true comparison to be made, but there is agreement for loading by the couple T_A, and the results are of the correct order in the other cases. The theory assumes continuous distribution of the ribs, and as a result, the application to a finite rib spacing necessarily involves a diffusion problem along the spar booms which must materially effect e_{YY}.

Table 1 compares the experimental results with the values given by the various theories on this type of structure.

In the case of flexural stiffness, both Hemp's(3) and Mansfield's(9) theories underestimate the value while the theory of Wittrick and Thompson(14)-(18) overestimates it. Wittrick's solution gives a torsional stiffness which is some three times that measured in the test, and given by the other theories. Comparison of the stresses indicates that both Hemp's and Mansfield's theories, which allow for the flexibility of the ribs, yield results which are of the same order as the experimental values, and often in very good agreement with them. The rigid rib theory of Wittrick is, however, in error, except for the web shear stresses under loading by a torsional couple.

The foregoing remarks show that the allowance for rib flexibility is essential for this type of wing, and that the two theories of Hemp and Mansfield give good theoretical results, there being little to choose between them from this point of view. The theory of Hemp is more general as it can allow for normal shear forces, and camber.

3.05 Single Cell Box with Oblique Ribs - Root Effects

The direct strain, e_{xx}, comparisons are shown in Fig.26. the theoretical values are for pure couples only, and as the strains for loading by the torsional couple, T_A, are very small they have been omitted. The results show the accepted build up towards the rear spar, and the theoretical results for the

/ couple ......

couple M_A show quite good agreement with the experimental values in the rear half of the skin. There is some indication of shear lag effect, but the actual build up is not as much as might be expected, and it is possible that there was some warping of the root fixing box. A similar type of attachment has been used for a two cell box, by Pratt-Barlow(13) and measurements on this box indicated a certain amount of warping. The variation of shear strain is shown in Fig. 27. The theoretical values have the correct order on the centreline, but whereas the theoretical results decrease towards the rear spar, the experimental values increase. This result shows the need for an estimate of the shear lag effect, and possibly a theory of even higher order. The increase in shear strain towards the rear spar is similar to that for the box having normal ribs.

3.06 Comparison of Wings with Ribs Normal to the Spars, and Parallel to the Line of Flight

The results shown in Table 1, for the unswept box are used to make a comparison with the theory of Hemp, the two theories representing as they do the two possible rib configurations discussed here.

These results show that the flexural stiffness of the box with oblique ribs is some 4½% higher than its counterpart, whilst the torsional stiffness is 19% greater. It must be appreciated that the ribs used in this specimen were unusually heavy, but the results of Ref. 5, for a more representative wing show the same trends.

Comparison of the stresses shows that for the case of loading by the couple M_A, the stress $\bar{f}_1$ is some 7% less for the oblique rib configuration, but there are associated direct and shear stresses, $\bar{f}_2$ and $\bar{f}_s$, which do not appear in the case of normal ribs. These are small compared with $\bar{f}_1$ and will not materially increase the maximum principal stress.

/ The same ......

The same remarks apply for loading by torsion couple T_A, where the shear stress is down some 20%, and Z wise force where $\bar{f}_1$ is down 10% relative to the box with normal ribs. This indicates that the wing having ribs parallel to the line of flight will be both stronger and stiffer, than its counterpart with ribs normal to the spars.

As the oblique ribs are longer than the normal ribs, the wing with this configuration will be heavier, and for the wings discussed in §2.02 and §2.03 the increase is some 3%-4%. Apart from the ribs, these models were geometrically identical, and the increased strength of the wing with oblique ribs means in effect that it will be lighter for a given strength. Another factor of some importance is the buckling of parallelogram plates, which is more favourable than that of rectangular plates(1), and might possibly enable the rib pitch to be increased. The much higher torsional stiffness of the wing with ribs parallel to the line of flight is important as the torsional stiffness criterion is the critical design factor for the outer portions of many high speed wings.

These remarks show that the wing with oblique ribs will be lighter, although in practice the actual gain will probably not exceed 2%. Even such an apparently small gain is of great importance when referred to the types of aircraft using swept wings.

The installation of equipment, such as power plants or guns, in wings may dictate the rib direction, and in these circumstances, it would almost certainly be parallel to the line of flight.

Although the outer portion of the wing having ribs normal to the spars is conventional from the point of view of structural design, the root causes a discontinuity in the structure, and consequent complication and increase of weight. The other wing has no major discontinuities, but the design is more difficult, in that the stress analysis does not follow the usual theory.

/ Manufacturing .....

Manufacturing problems are greater for the wing with oblique ribs, due to the rib direction which is difficult for initial jigging, and involves inaccessible acute angles at the rib-spar joints. Whether these points are allowed to outweigh the gain in weight mentioned above is a matter of conjecture. A compromise is possibly the best solution, with the main ribs oblique, and the nose and trailing edge ribs normal to the spars.

Aerodynamically there is little to choose between the two types, as the airflow across a swept wing is not straight but tends to move across the span towards the tips. The oblique rib may have an advantage in that it will tend to restrict section distortion of the wing in the direction of flight.

Taking all these considerations into account, the present author is of the opinion that in the majority of cases, the wing with ribs parallel to the line of flight is the better solution to the problem.

/ 4.00 ....

4.00 CONCLUSIONS

4.01 Single Cell Swept Box with Ribs Normal to the Spars

(1) The assumption of a rigid root rib results in an overestimate of the load transference to the rear spar.

(2) A shear lag theory is necessary to give good agreement with experiment.

(3) The root effects become small, at a section corresponding to one root chord out along the rear spar.

4.02 Two Cell Swept Box with Ribs Normal to the Mainspar

(1) The theory gives good results, but there is a slight tendency to exaggerate the load transfer to the rear spar.

4.03 Two Cell Swept Box with Oblique Ribs

(1) The Z wise force theory overestimates the cross section variation of strain in a tapered planform box, and pure couple theory gives better results for direct strains in these circumstances.

4.04 Single Cell Swept Box with Oblique Ribs - Section away from the root.

(1) The oblique coordinate theory of Hemp is in good agreement with test.

(2) The theory of Mansfield gives similar results to that of Hemp, although its scope is less.

(3) The rigid rib theory of Wittrick and Thompson is not satisfactory.

/ 4.05 .....

4.05 Single Cell Swept Box with Oblique Ribs - Root Effects

(1) The variation of direct strain predicted by theory is in fair agreement with experiment, but possible warping of the root prevented a true comparison being made.

(2) The shear strain variation requires a second order theory to predict it.

4.06 Comparison of Wings with Ribs Normal to the Spars, and Parallel to the Line of Flight

(1) The wing with oblique ribs is stronger and stiffer, for a given geometrical form.

(2) It is lighter for a given strength and stiffness, possibly some 2% gain being shown.

(3) The wing with ribs normal has less manufacturing problems.

(4) Aerodynamically there is little difference between the two.

(5) For most purposes the wing with ribs parallel to the line of flight is at an advantage.

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TABLE 1

SINGLE CELL - OBLIQUE RIBS

COMPARISON OF THEORY AND EXPERIMENT - NO ROOT EFFECTS

Stiffnesses and Stresses

THEORY		TEST	HEMP	MANSFIELD	WITTRICK	UNSWEPT BOX
Stiffnesses per Unit Length lb. in^2/rad.	Flexure x 10^{-6}	257	237	236	269	227
	Torsion x 10^{-6}	112	115	113	340	96
Stresses due to $M_A = 1$ lb/sq. in	$\bar{f}_1$	- .133	- .1306	- .117	- .107	- .143
	$\bar{f}_2$	+ .0058	+ .0067	+ .007	+ .023	0
	$\bar{f}_s$	+ .004	+ .0076	+ .007	+ .023	0
	f_{sw}	0	0	0	0	0
Stresses due to $T_A = 1$ lb/sq. in	$\bar{f}_1$	+ .0185	+ .0174	+ .021	+ .077	0
	$\bar{f}_2$	+ .0196	+ .0242	+ .021	+ .049	0
	$\bar{f}_s$	- .094	- .0872	- .090	- .034	- .108
	f_{sw}	- .224	- .245	- .246	- .243	- .250
Stresses due to $Z_1 = 1$ lb/sq. in	$\bar{f}_1$	-8.51+.047y	-9.26+.091y	-	-	-10.25-0.101y
	$\bar{f}_2$	1.96-.132y	.612+.018y	-	-	0
	$\bar{f}_s$	.36-.088y	.544-.083y	-	-	0
	f_{sw}	2.82	2.77	-	-	2.78

All Values are for Lower Skin

Z +ve

For Notation See Figs. 21 and 22

TABLE 2

SINGLE CELL - OBLIQUE RIBS

COMPARISON OF THEORY AND EXPERIMENT - NO ROOT EFFECTS

Strains

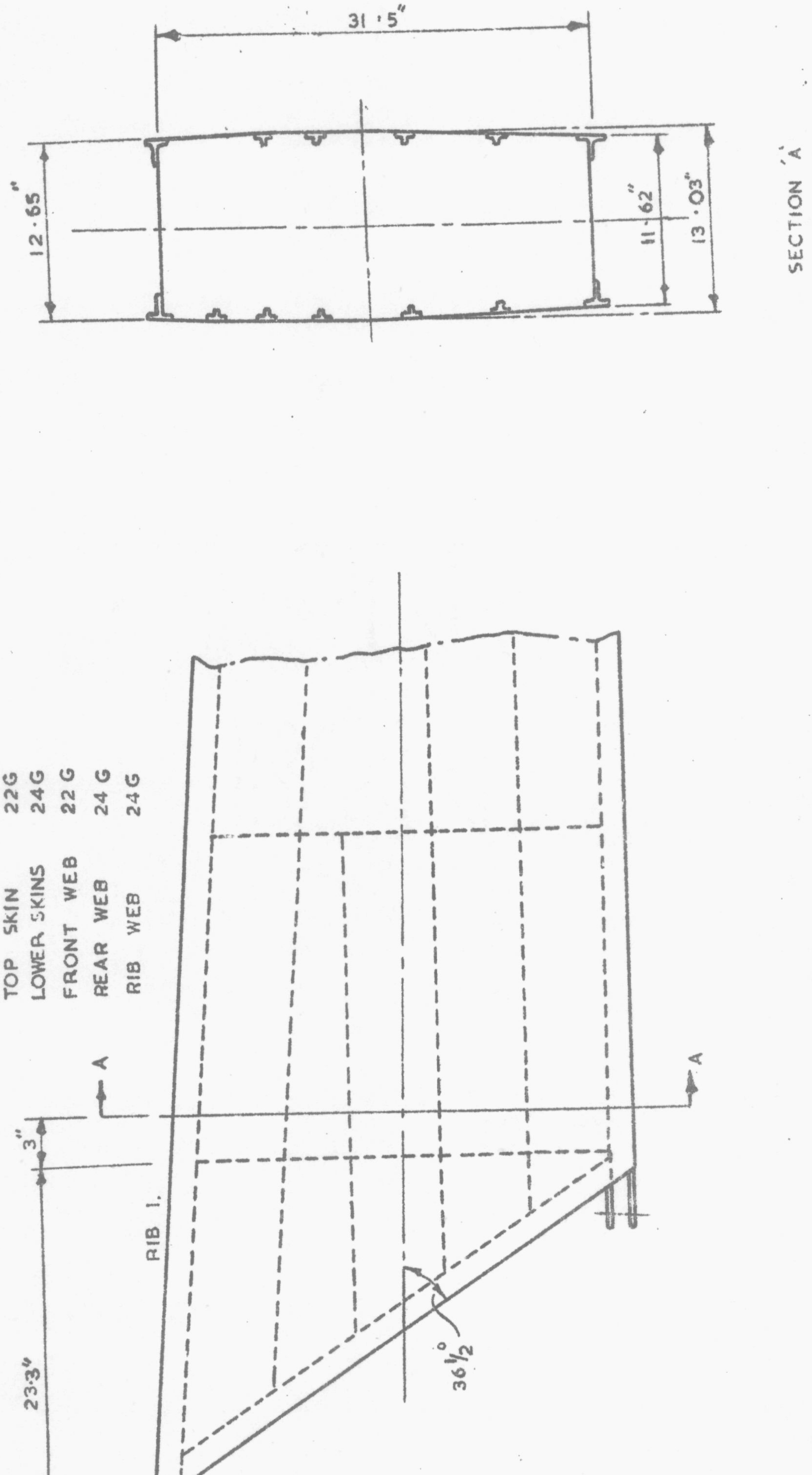
		TEST	HEMP
Strains due to $M_A = 1$ x 10^6	e_{xx}	- .0128	- .0126
	e_{yy}	-	- .00318
	e_{YY}	+ .0043	+ .00436
	e_{xY}	+ .001	+ .0019
Strains due to $T_A = 1$ x 10^6	e_{xx}	+ .0012	+ .001
	e_{yy}	-	- .00918
	e_{YY}	+ .0013	+ .0018
	e_{xY}	- .0235	- .0218
Strains due to $Z_1 = 1$ x 10^6	e_{xx}	- .865 + .0083y	- . 01 + .0082y
	e_{yy}	-	- .227 - .0063y
	e_{YY}	.43 - .014y	.326 - .001y
	e_{xY}	.09 - .022y	.136 - .0207y

All Values are for Lower Skin

Z +ve

For Notation See Figs. 21 and 22

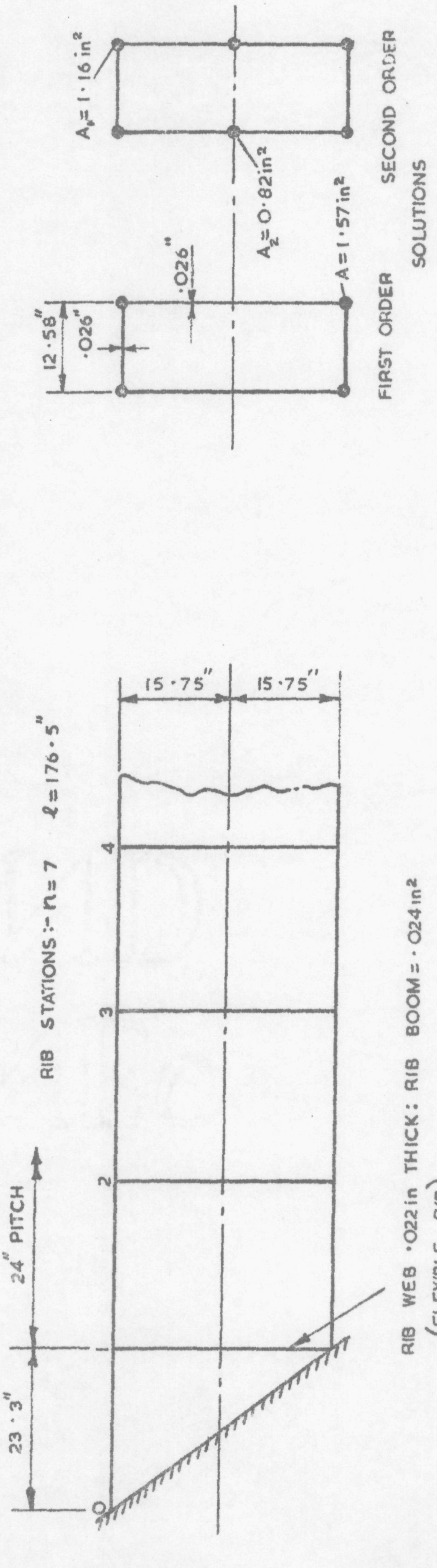
FIG. 1.



ROOT STRUCTURE OF WING -

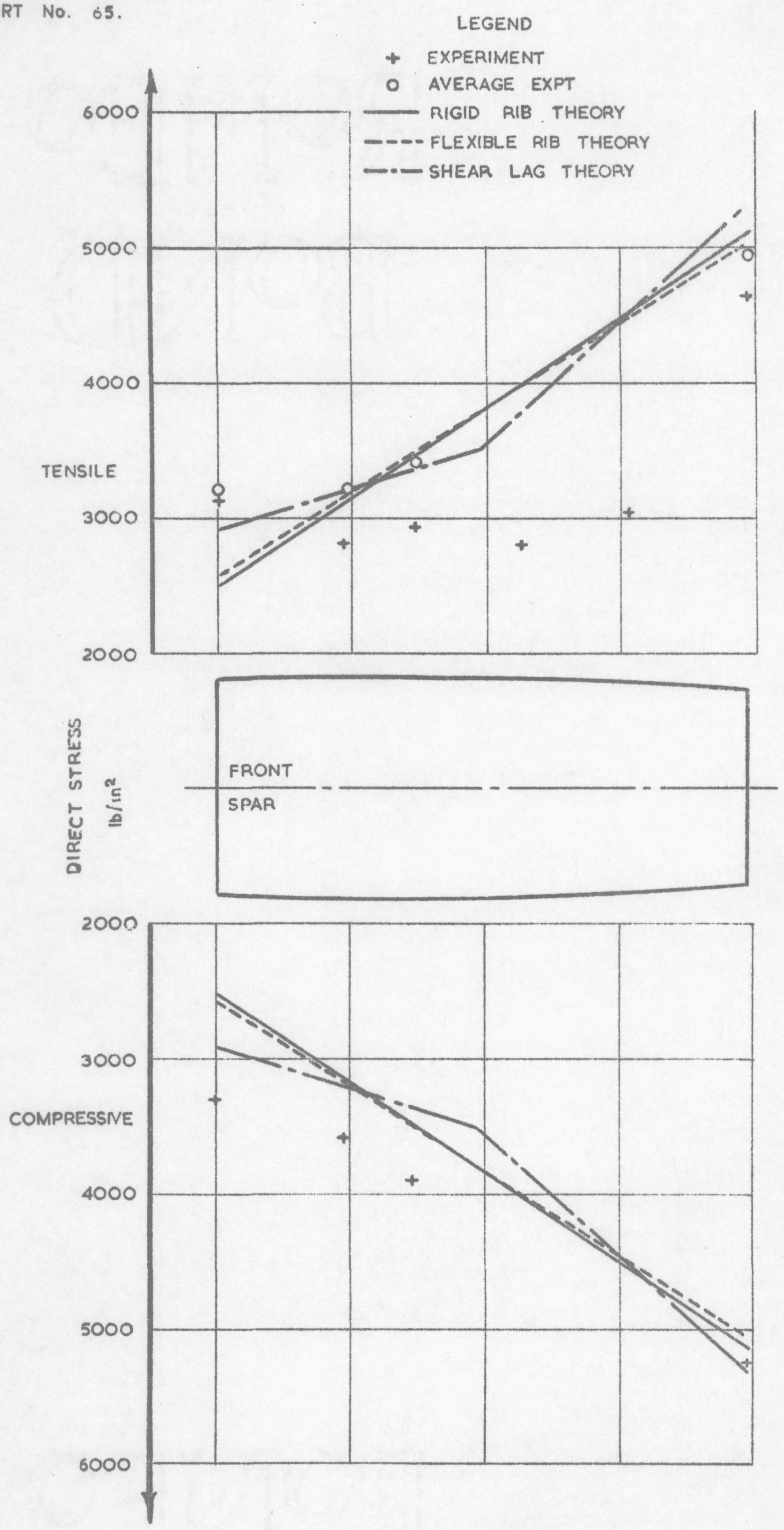
DIMENSIONS OF TEST SECTION -'A'. SINGLE CELL - NORMAL RIBS

FIG. 2.



IDEALISED BOX (SPECIMEN FIG. 1.)

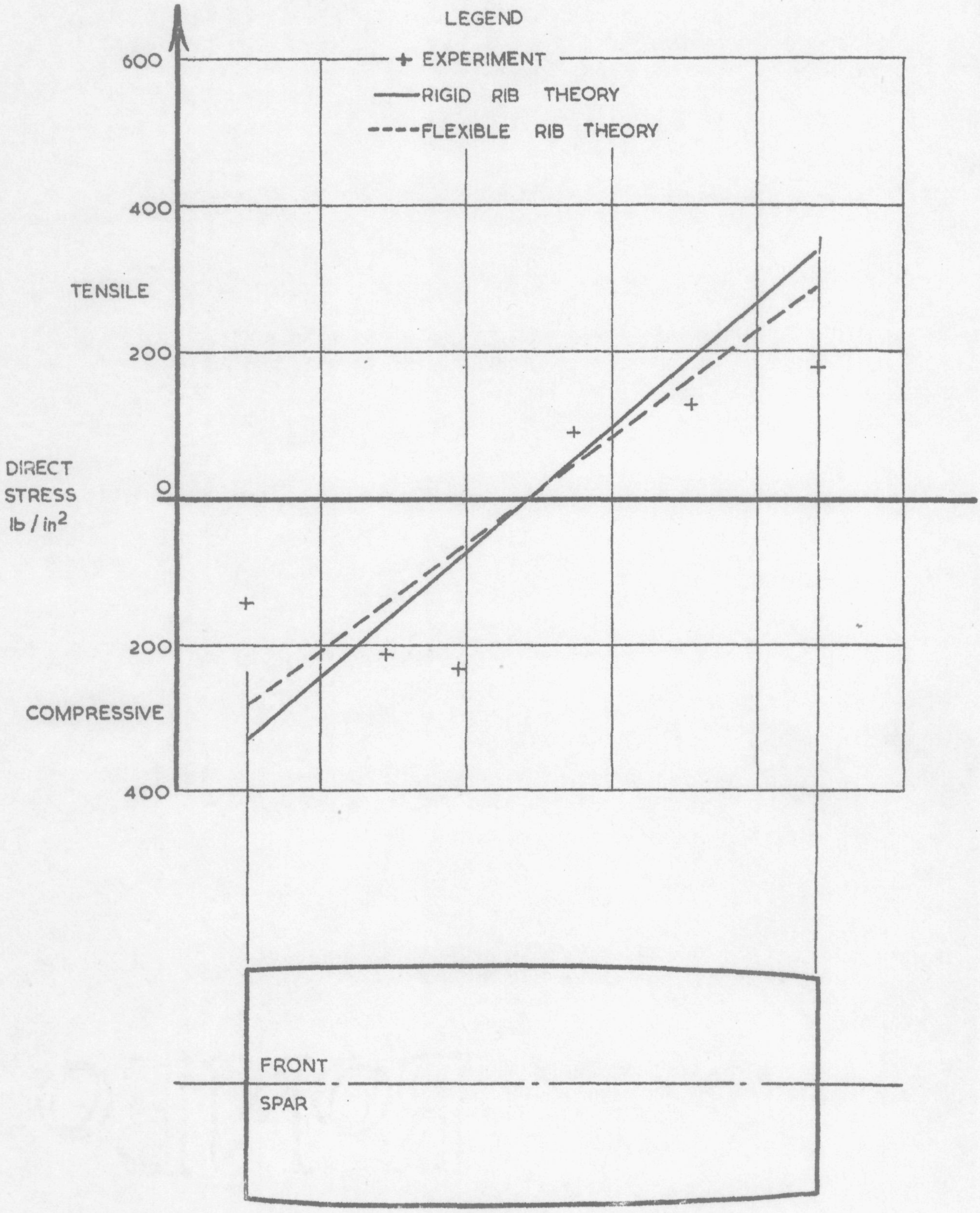
FIG. 3.



SINGLE CELL - RIBS NORMAL

DIRECT STRESS AT SECTION 'A' DUE TO Z WISE FORCE Z = 1000 lb

FIG. 4.

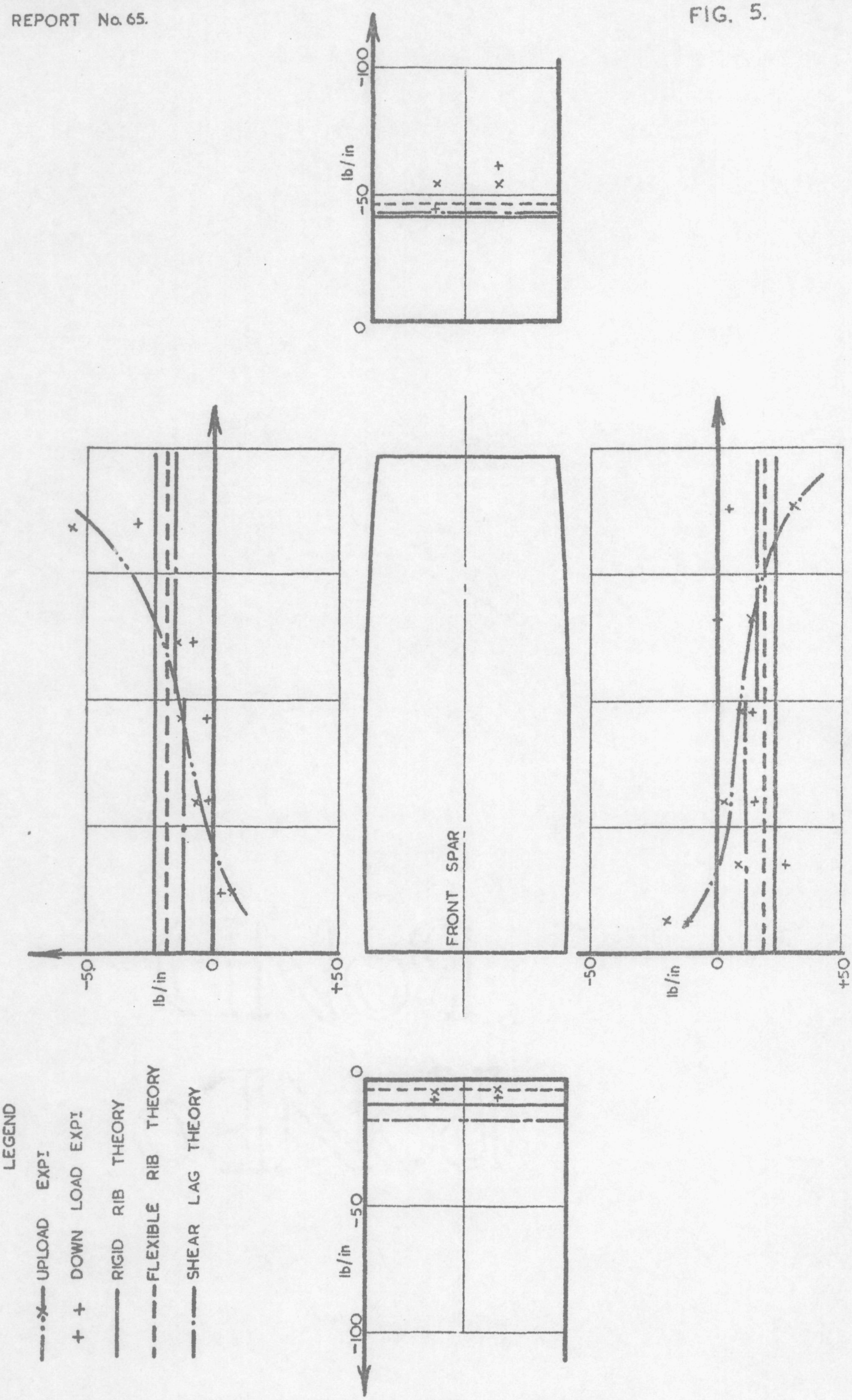


SINGLE CELL —— RIBS NORMAL

DIRECT STRESS AT SECTION 'A' DUE TO TORSION COUPLE L_i

$L_i = 22{,}000$ lb in

FIG. 5.

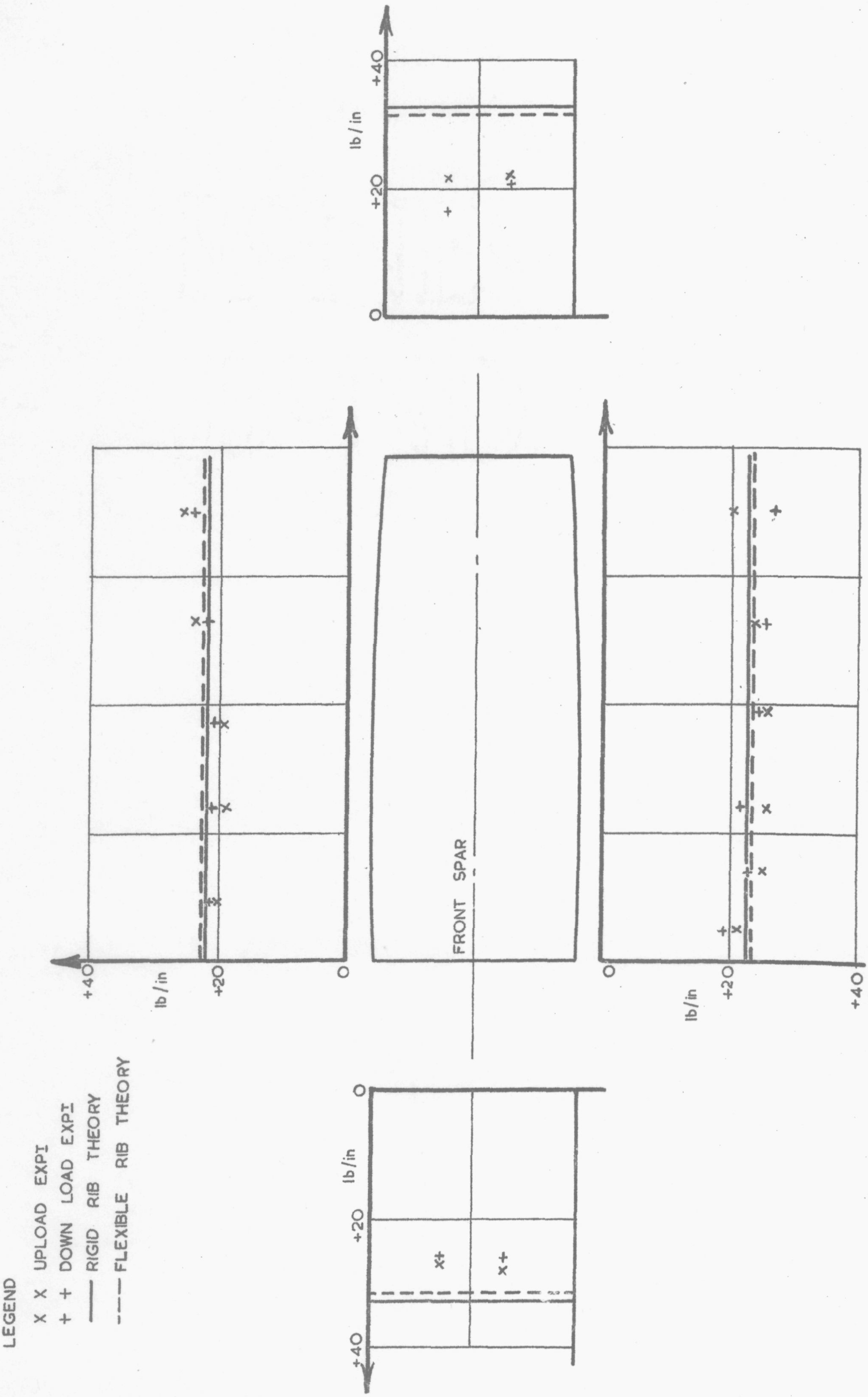


SINGLE CELL —— RIBS NORMAL

SHEAR FLOW AT SECTION 'A' DUE TO Z WISE FORCE

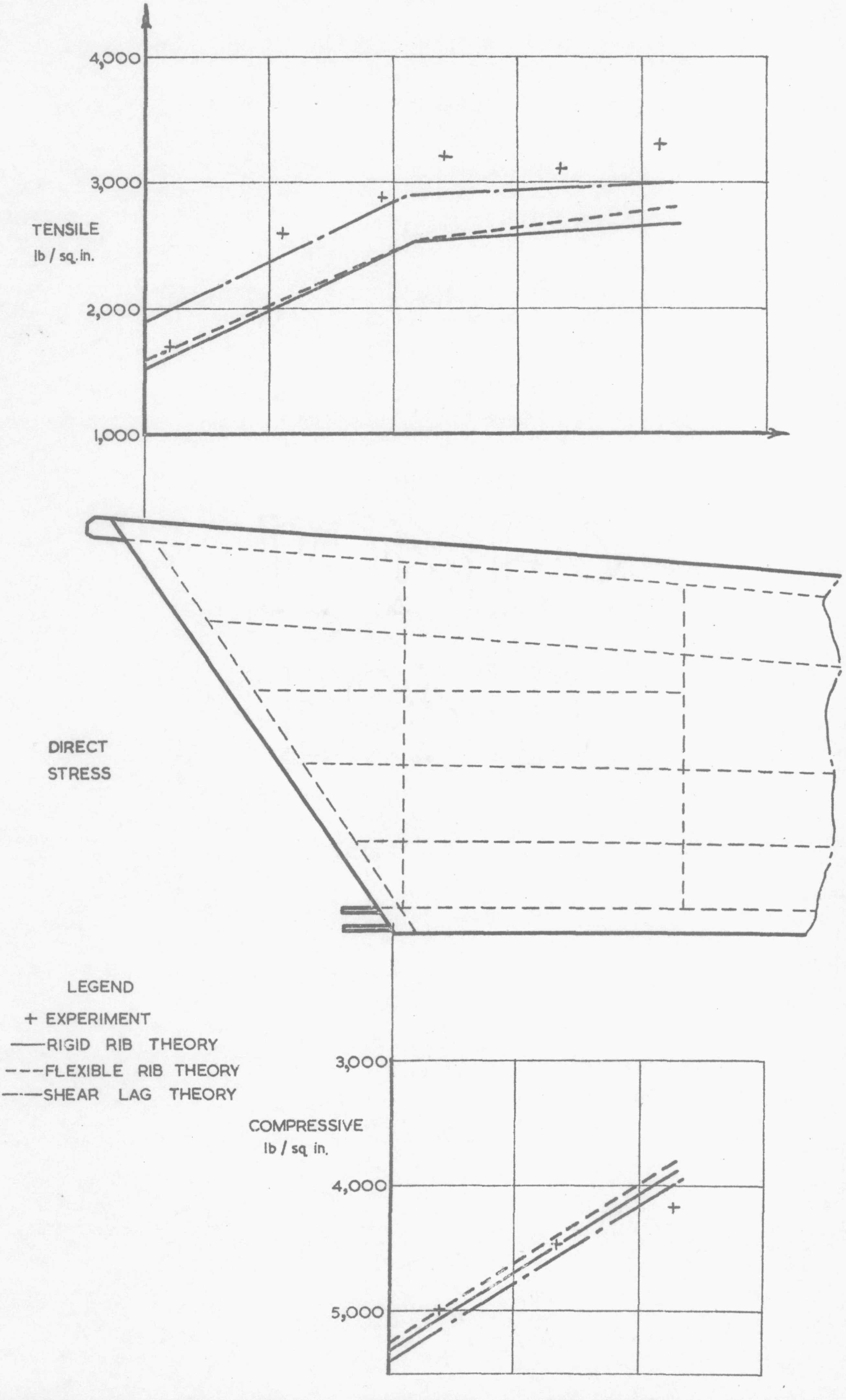
Z = 1,000 lb

FIG. 6.



SINGLE CELL—RIBS NORMAL
SHEAR FLOW AT SECI 'A' DUE TO TORSION COUPLE L_2
$L_2 = 22{,}000$ lb in

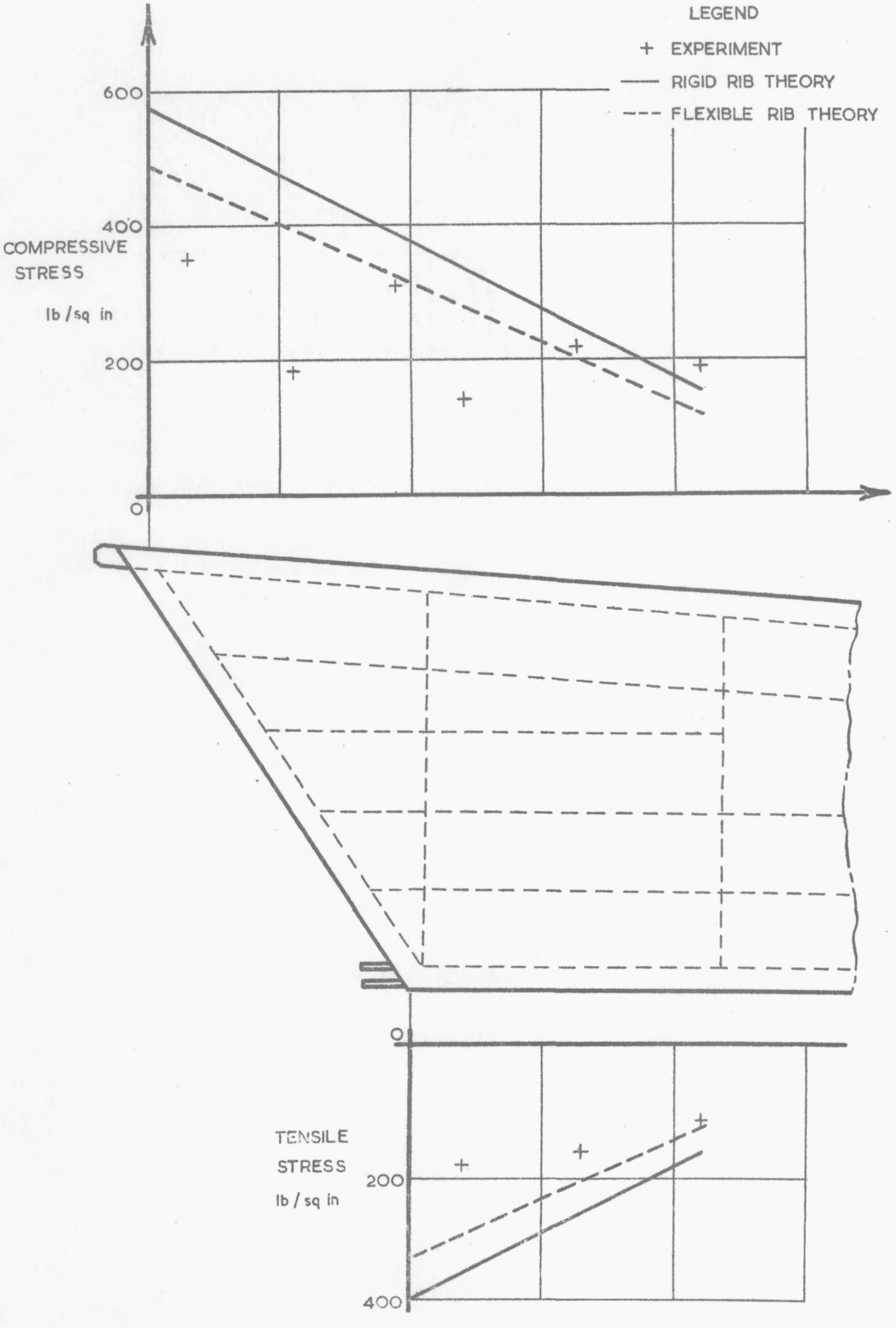
FIG. 7.



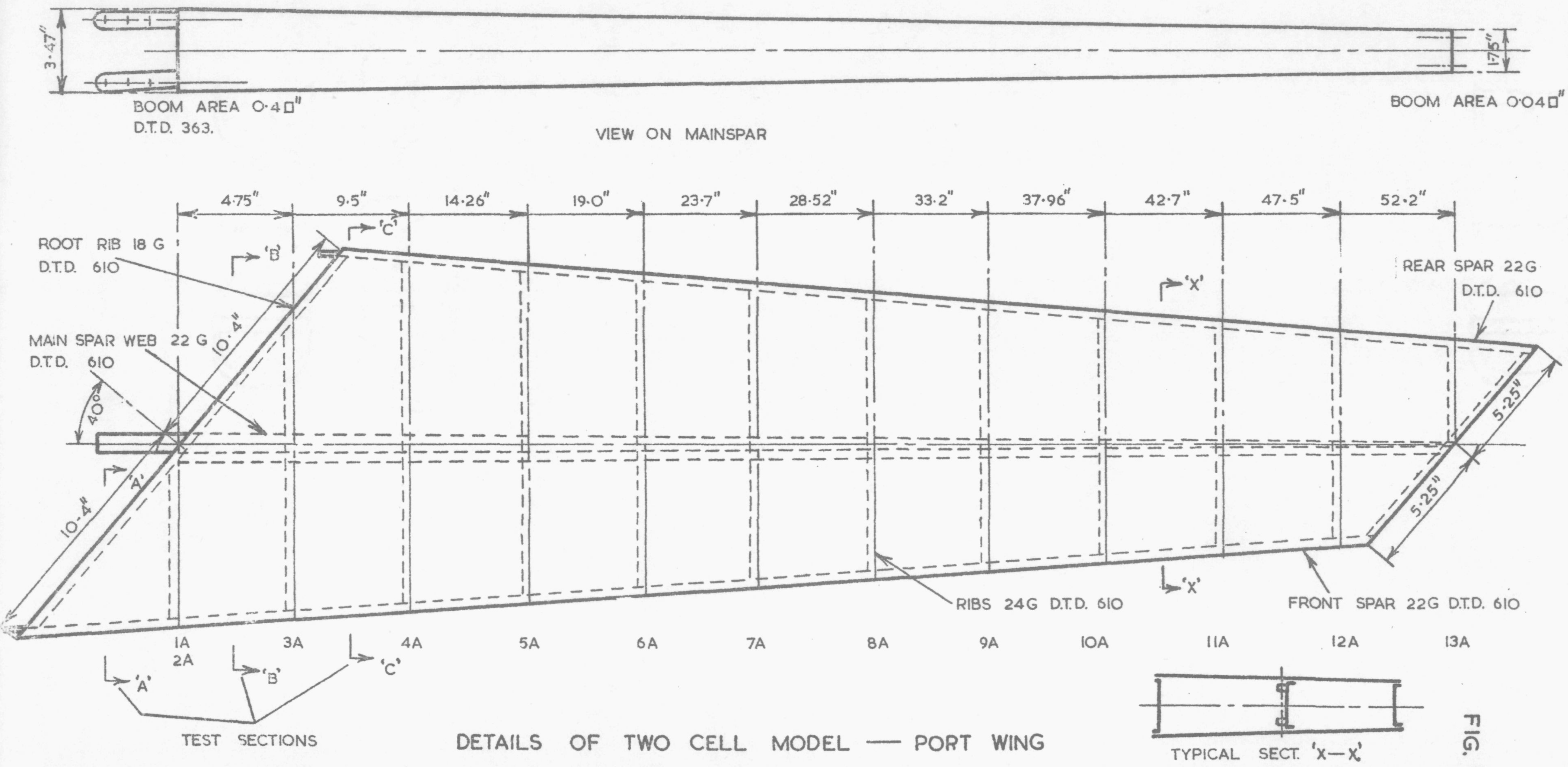
SINGLE CELL — RIBS NORMAL. VARIATION IN SPAR BOOM STRESSES.

DUE TO Z WISE FORCE = 1,000 lb.

FIG. 8.



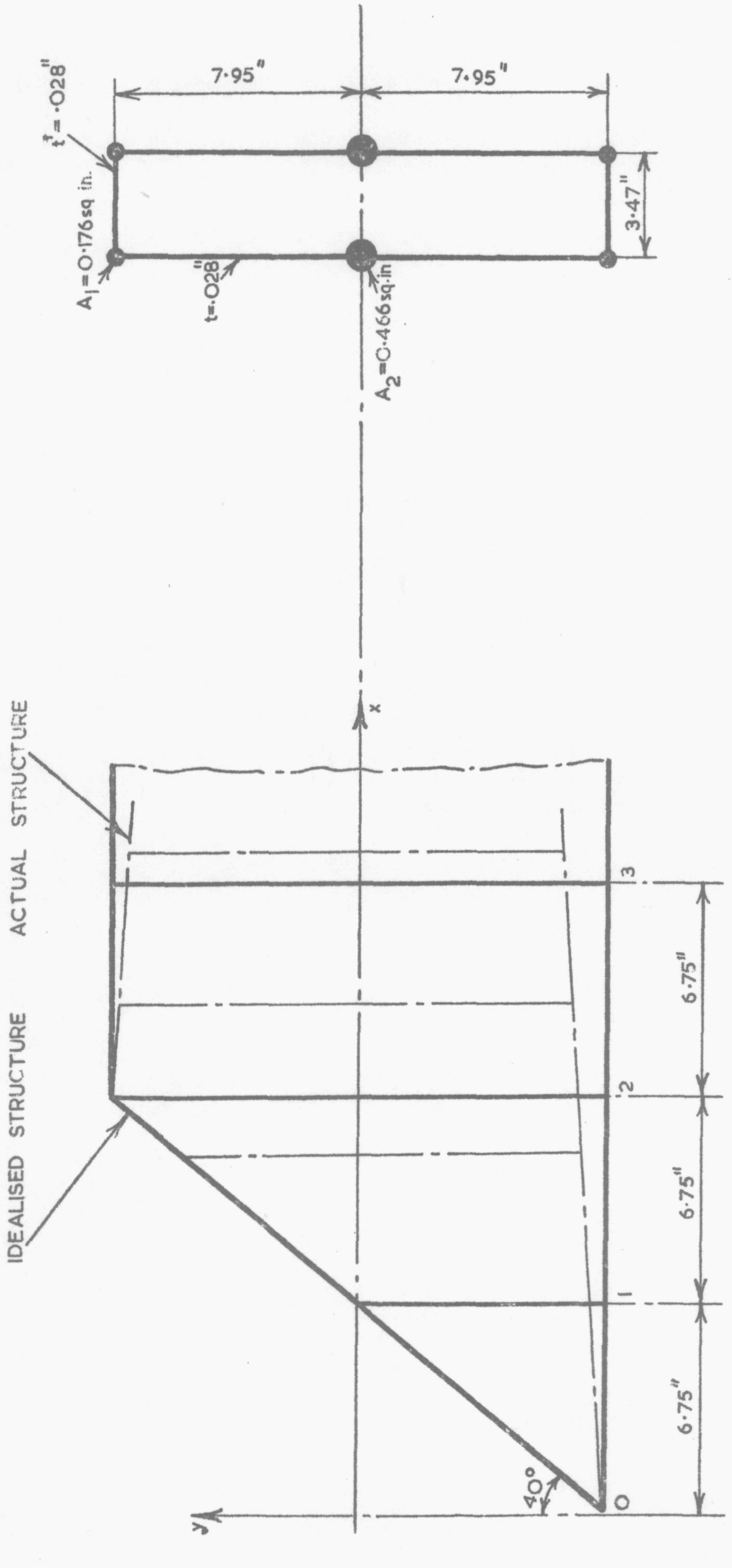
SINGLE CELL — RIBS NORMAL. VARIATION IN SPAR BOOM STRESSES DUE TO TORSION COUPLE = 22,000 lb in.



DETAILS OF TWO CELL MODEL — PORT WING

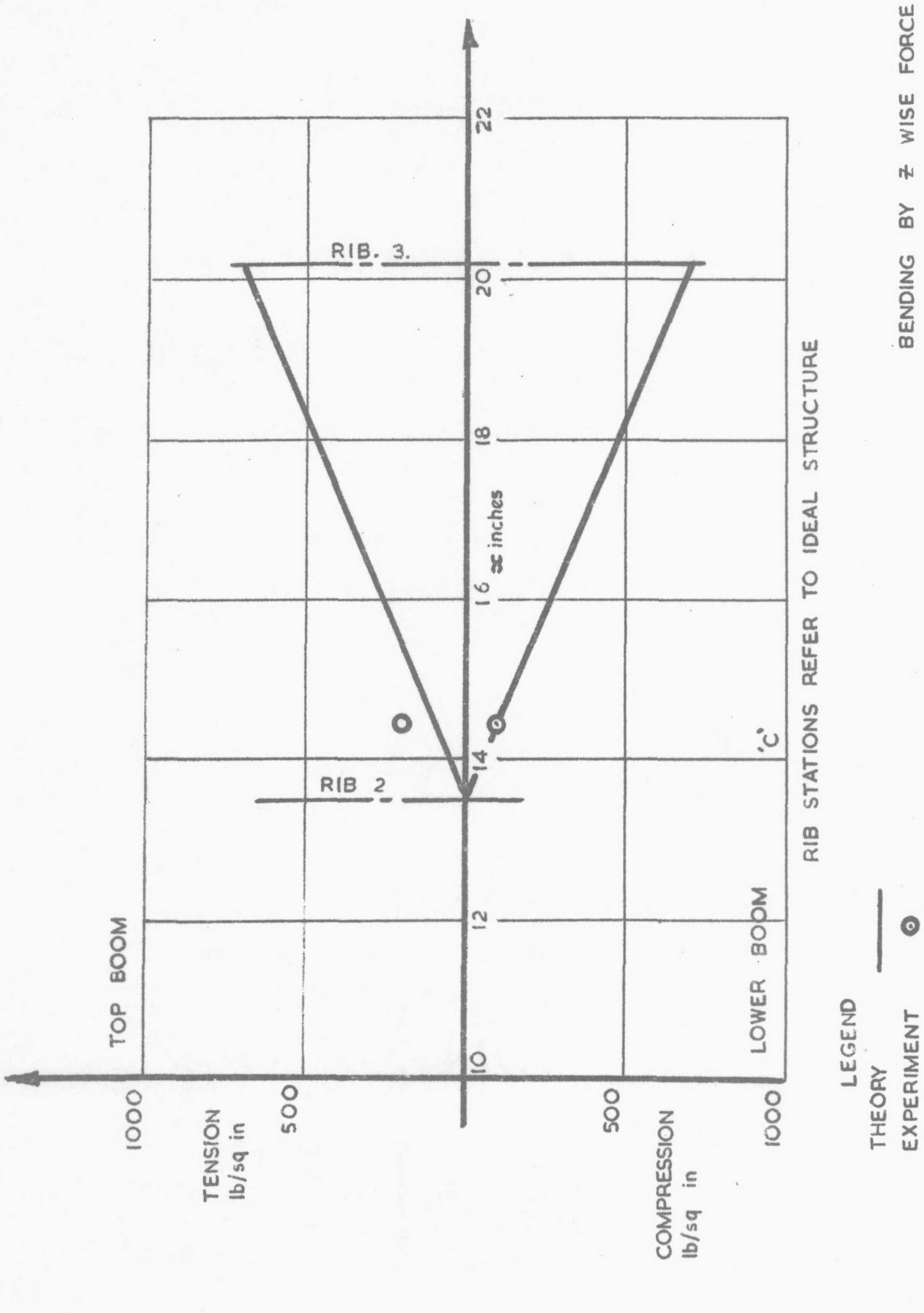
FIG. 9.

FIG. 10.



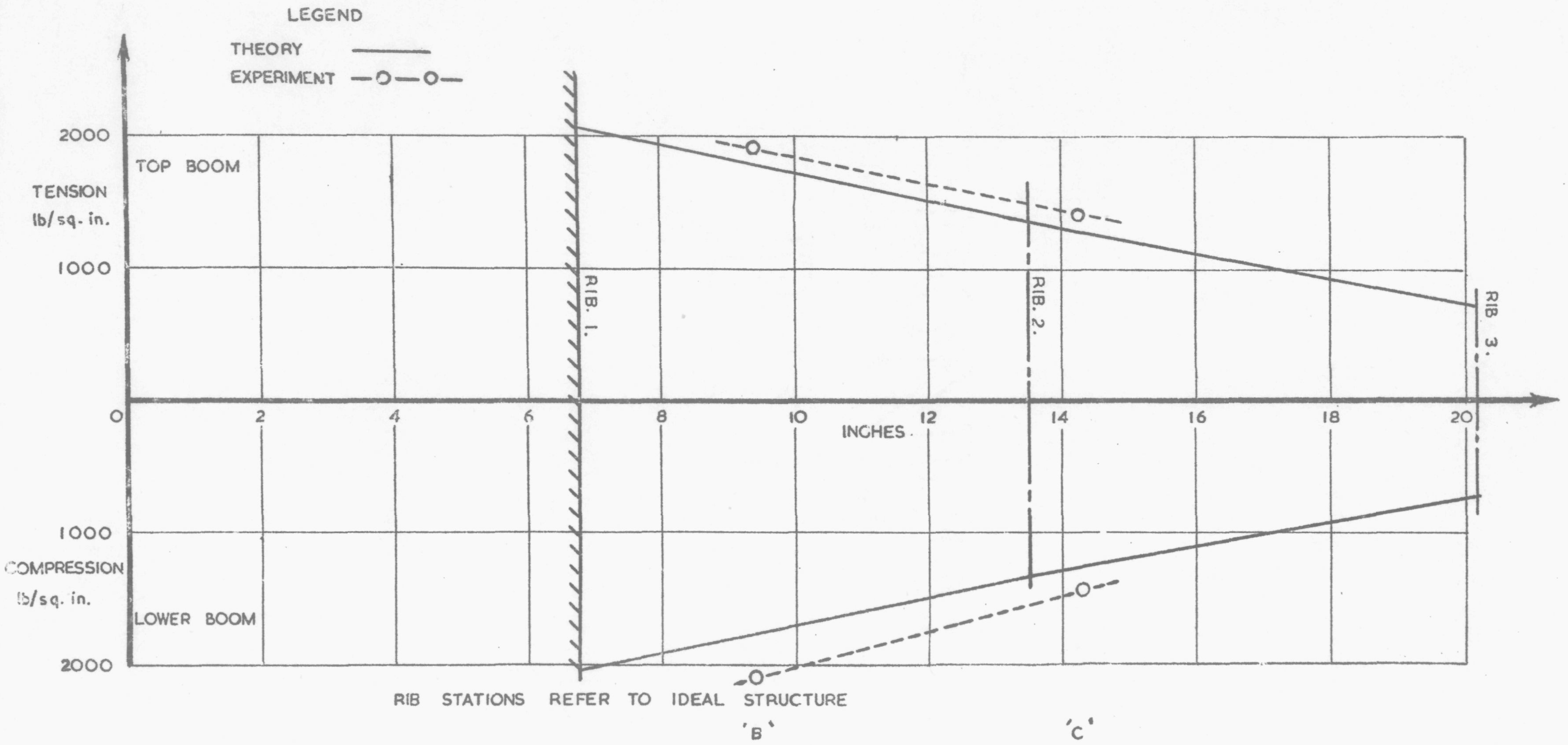
TWO CELL WING — PORT WING IDEALISED STRUCTURE AT ROOT.

FIG. 11.



TWO CELL SPECIMEN - PORT WING

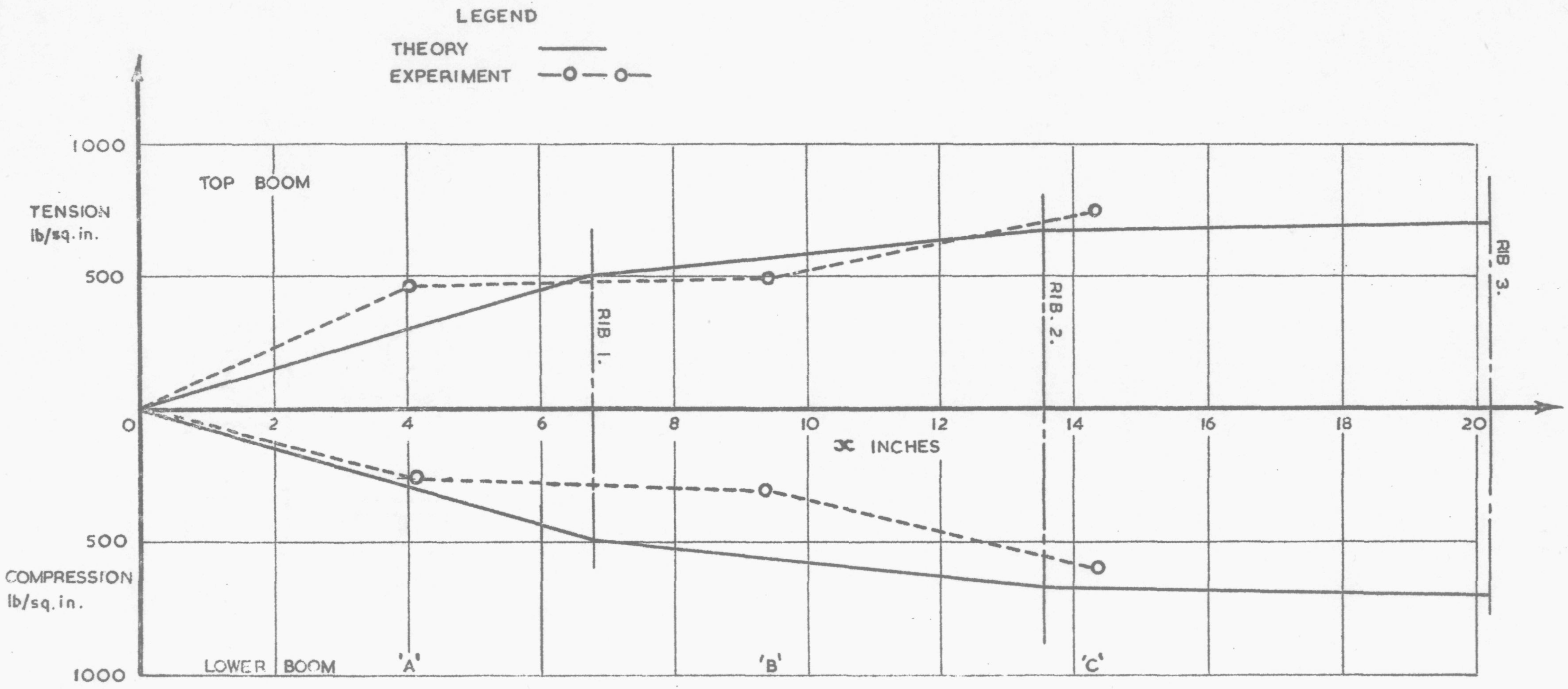
REAR SPAR BOOM STRESSES AT ROOT



BENDING BY Z WISE FORCE

TWO CELL SPECIMEN-PORT WING MAIN SPAR BOOM STRESSES AT ROOT

FIG. 12.



RIB STATIONS REFER TO IDEAL STRUCTURE

BENDING BY z WISE FORCE

FIG. 13.

TWO CELL SPECIMEN – PORT WING FRONT SPAR BOOM STRESSES AT ROOT

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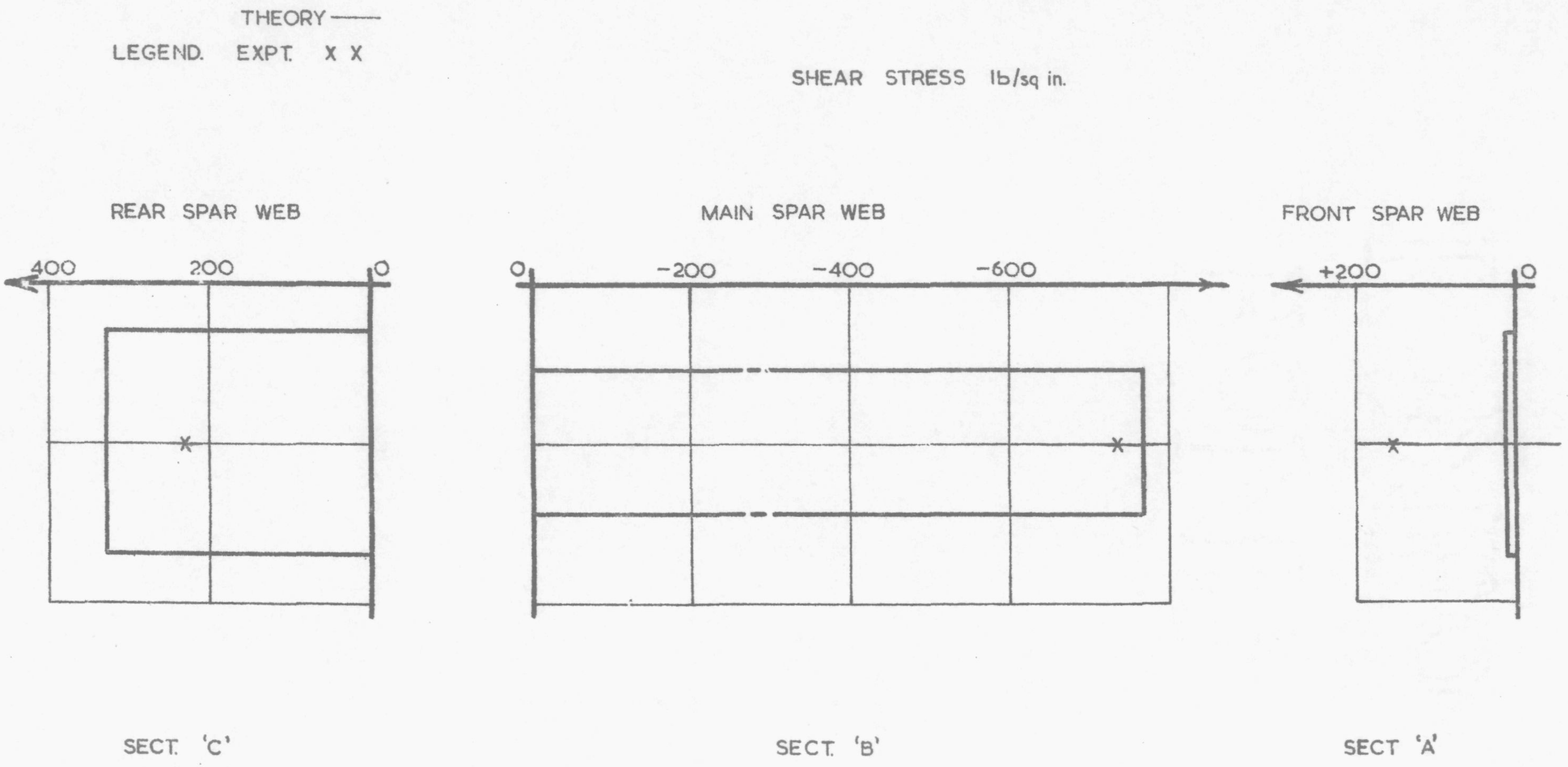
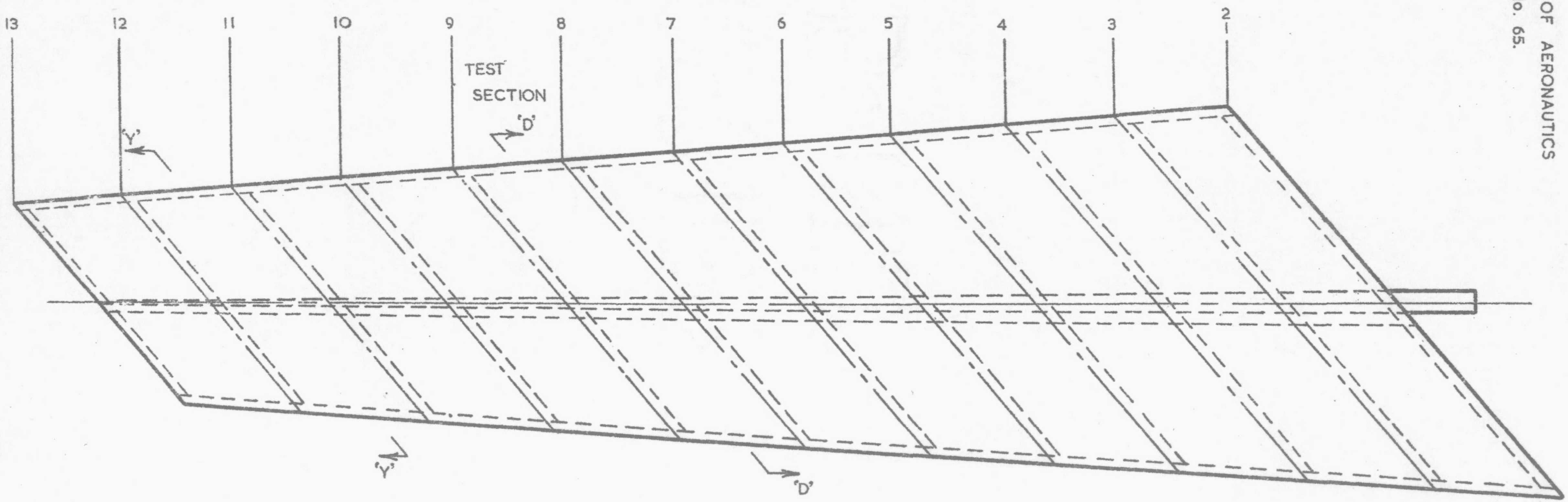


BENDING BY Z WISE FORCE

FIG. 14.

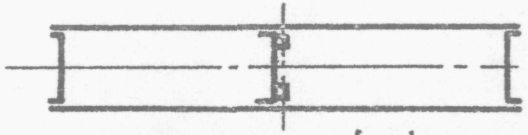
TWO CELL MODEL — PORT WING.
SHEAR STRESSES IN SPAR WEBS AT ROOT.

RIB SPACING ON MAIN SPAR AS FOR PORT WING.



ALL OTHER DETAILS AS PORT WING

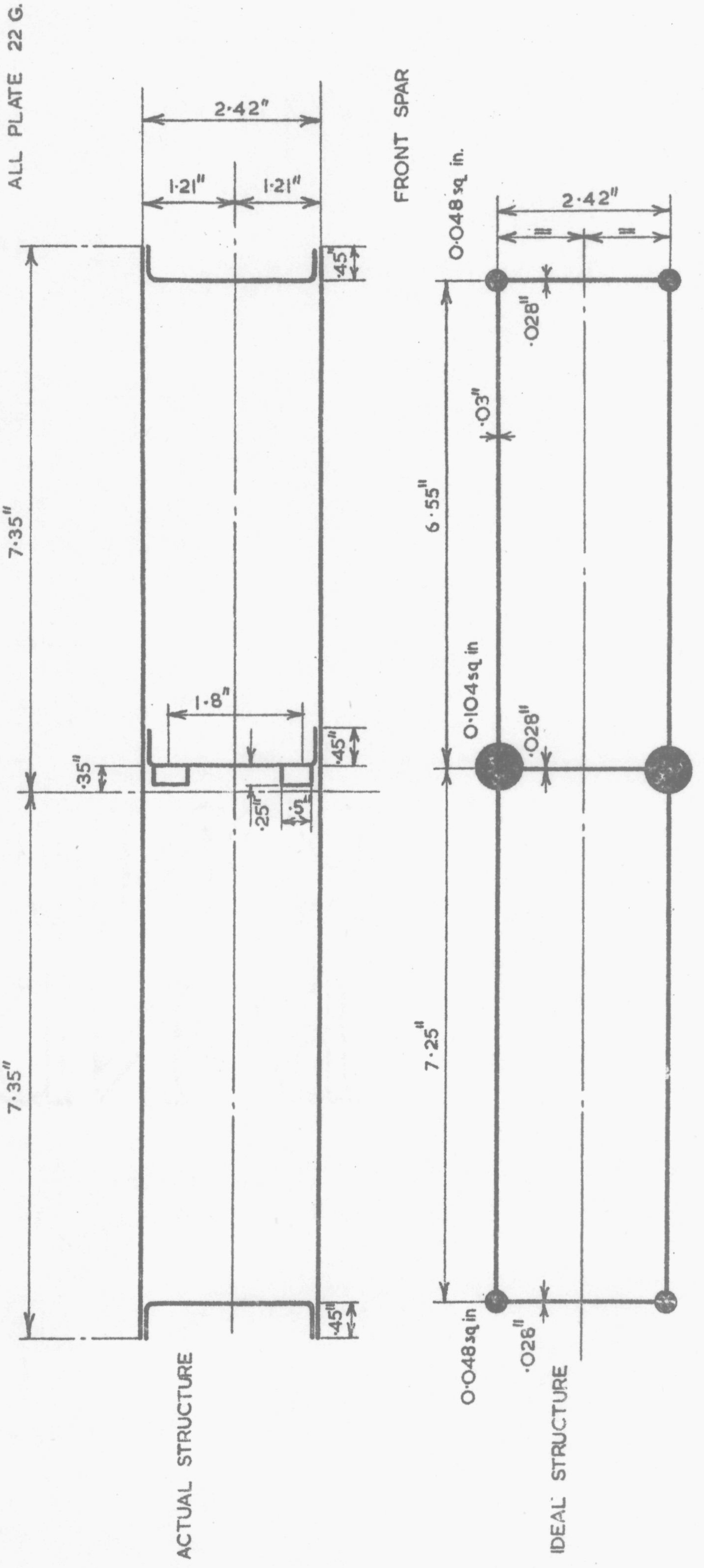
DETAILS OF TWO CELL MODEL — STARBOARD WING.



TYPICAL SECTION 'Y-Y'

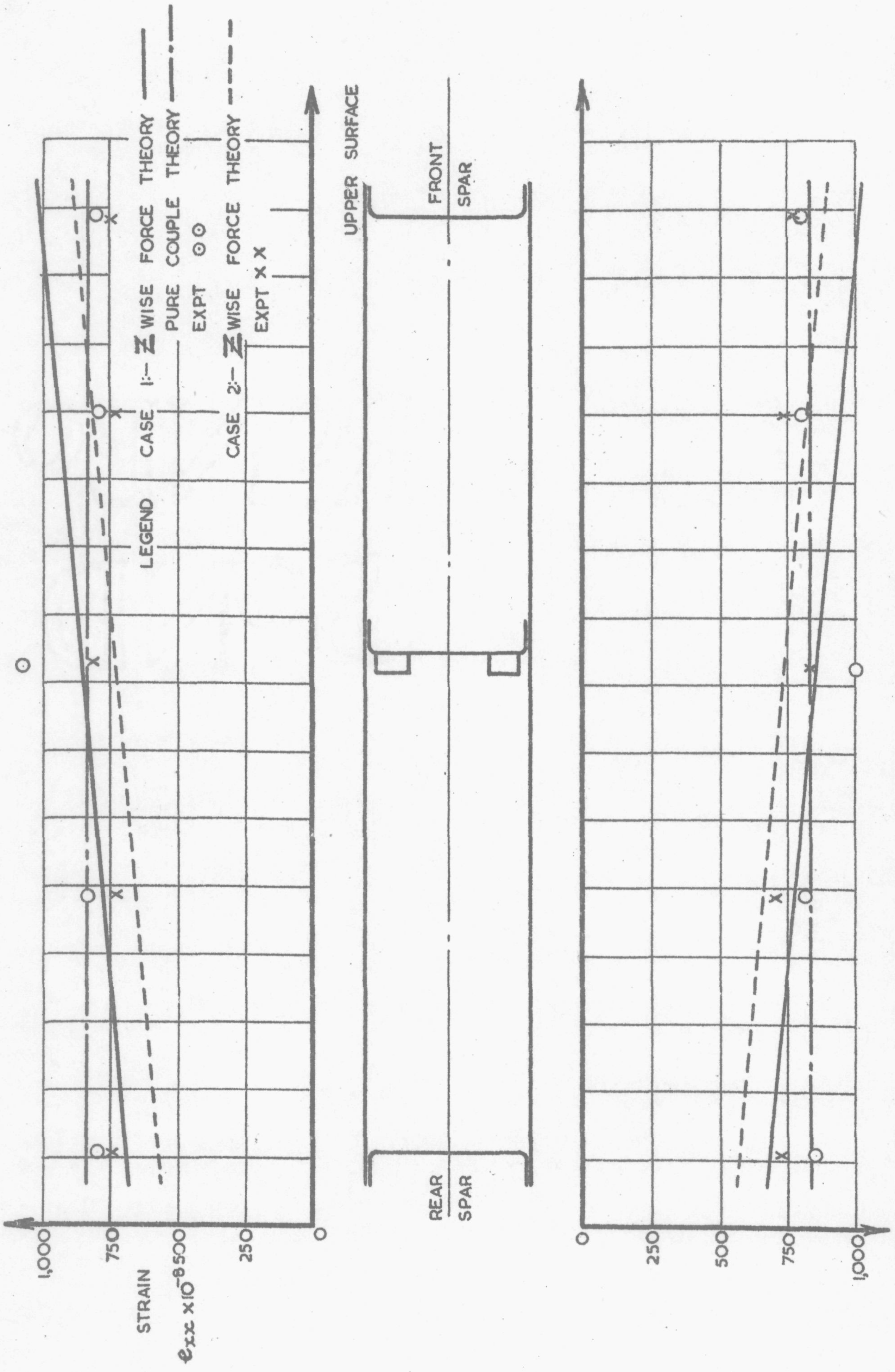
FIG. 15.

FIG. 16.



TWO CELL MODEL — STARBOARD WING. SECTION 'D' — RIBS 8–9.

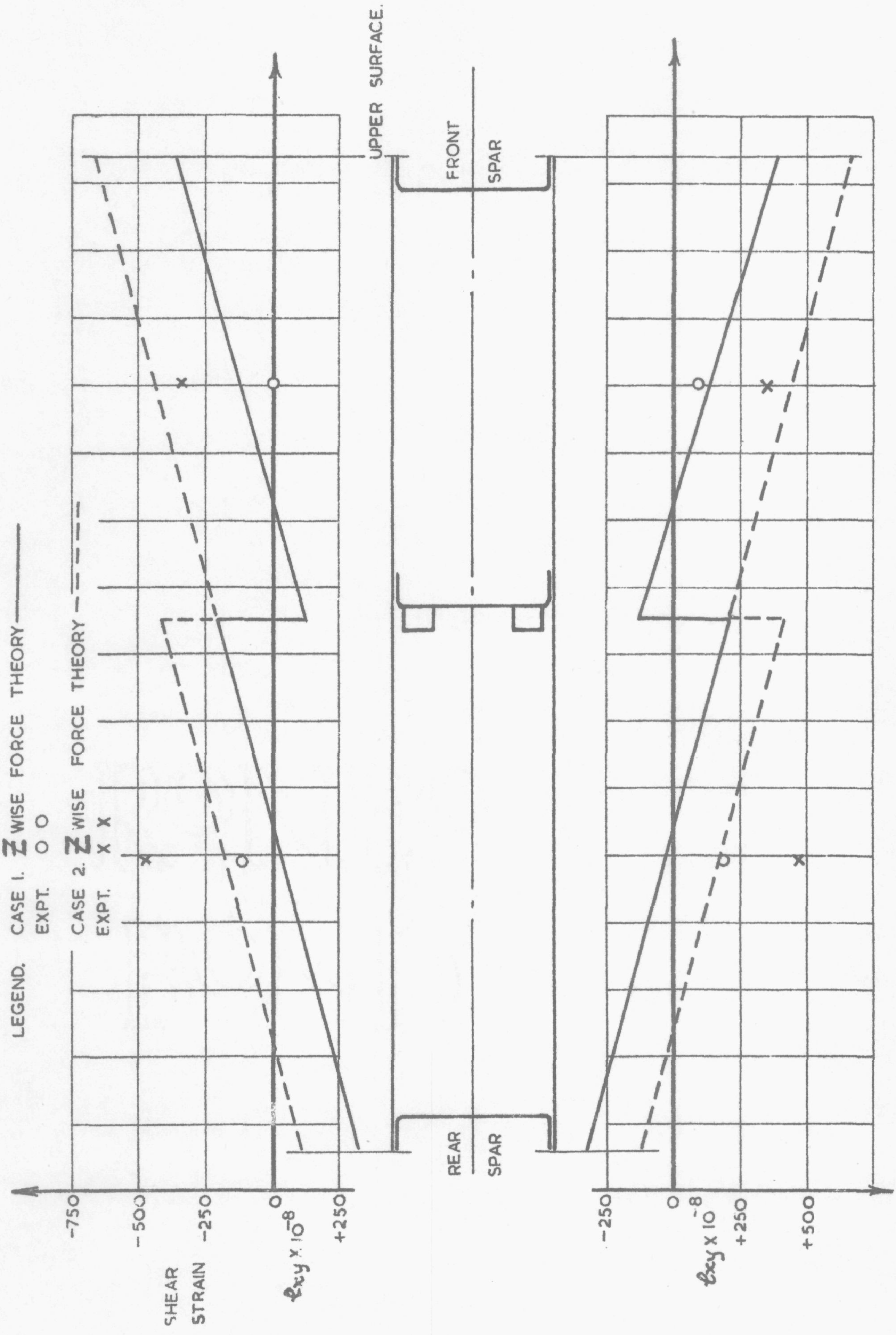
FIG. 17



TWO CELL MODEL——STARBOARD WING—SECT 'D'

DIRECT STRAINS ACROSS SECTION

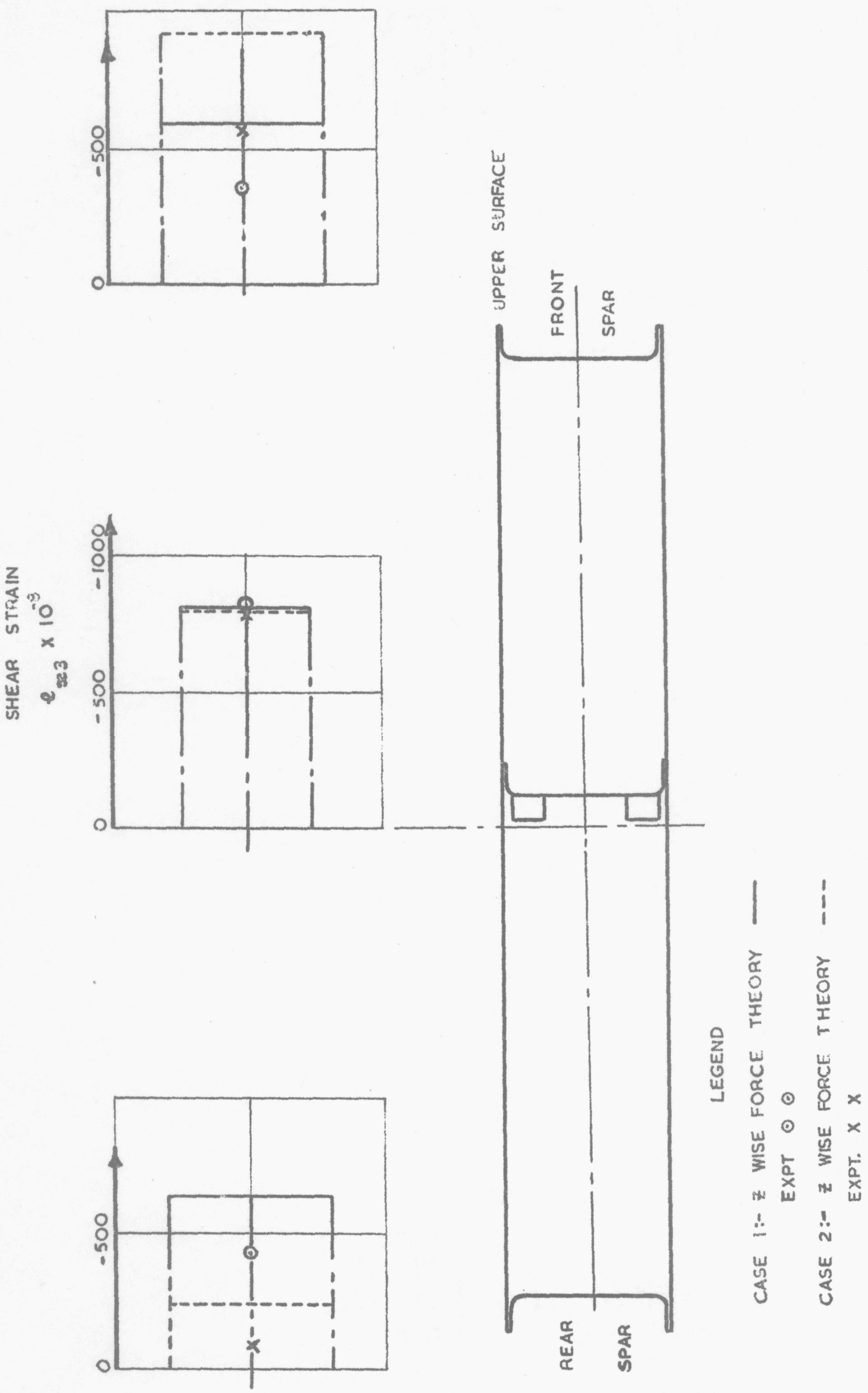
FIG. 18.



TWO CELL MODEL —— STARBOARD WING SECTION 'D'.

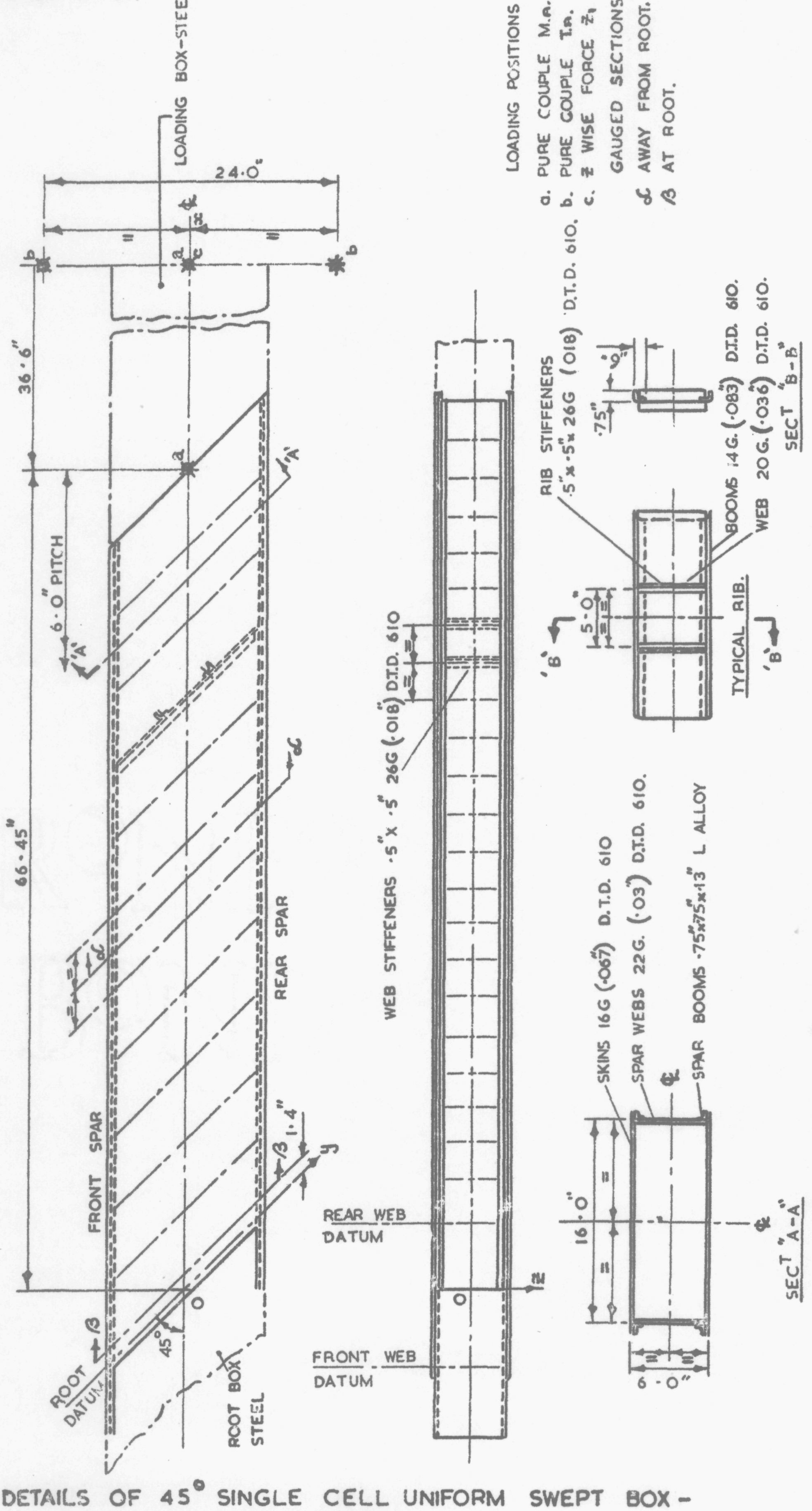
SHEAR STRAINS ACROSS SECTION

FIG. 19.



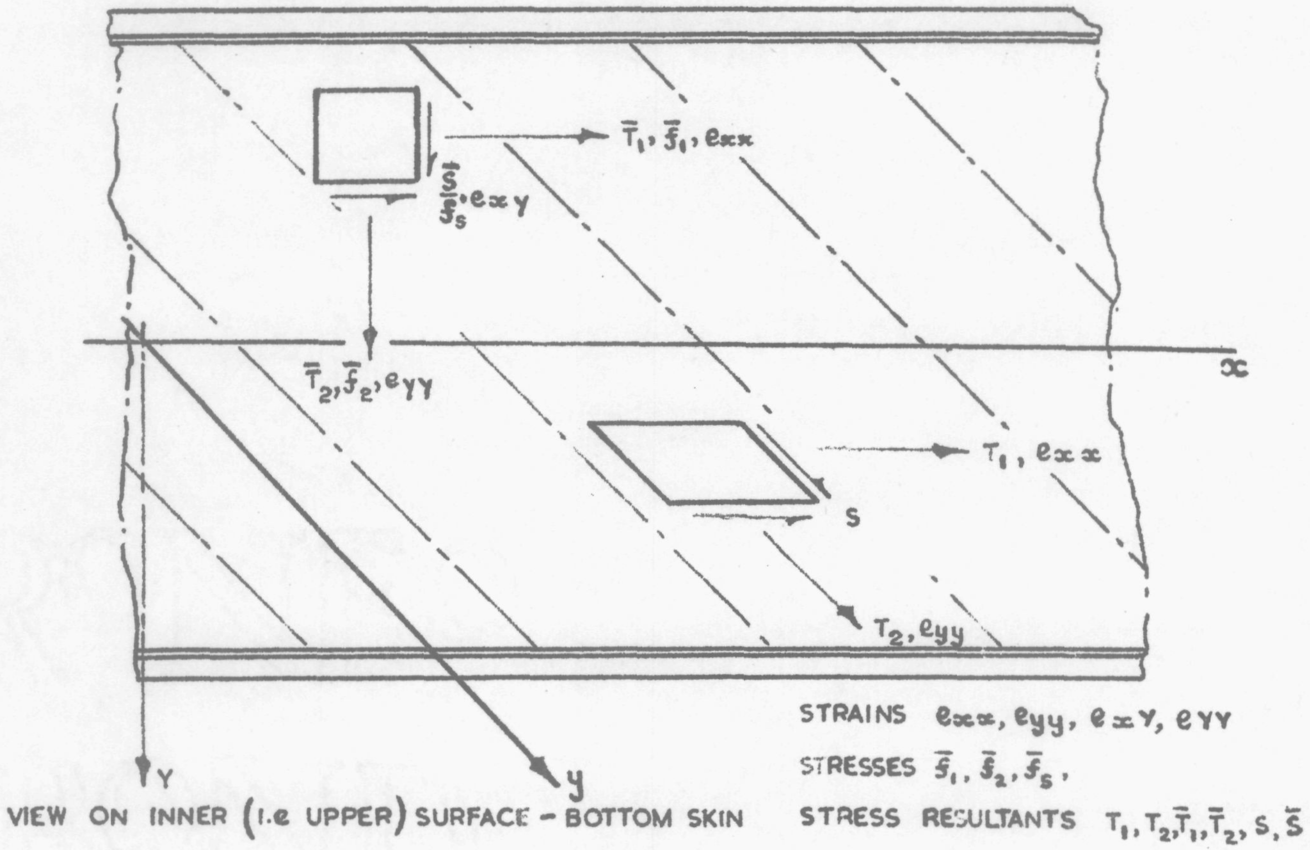
TWO CELL MODEL STARBOARD WING-SECT. 'D'

SHEAR STRAIN IN WEBS



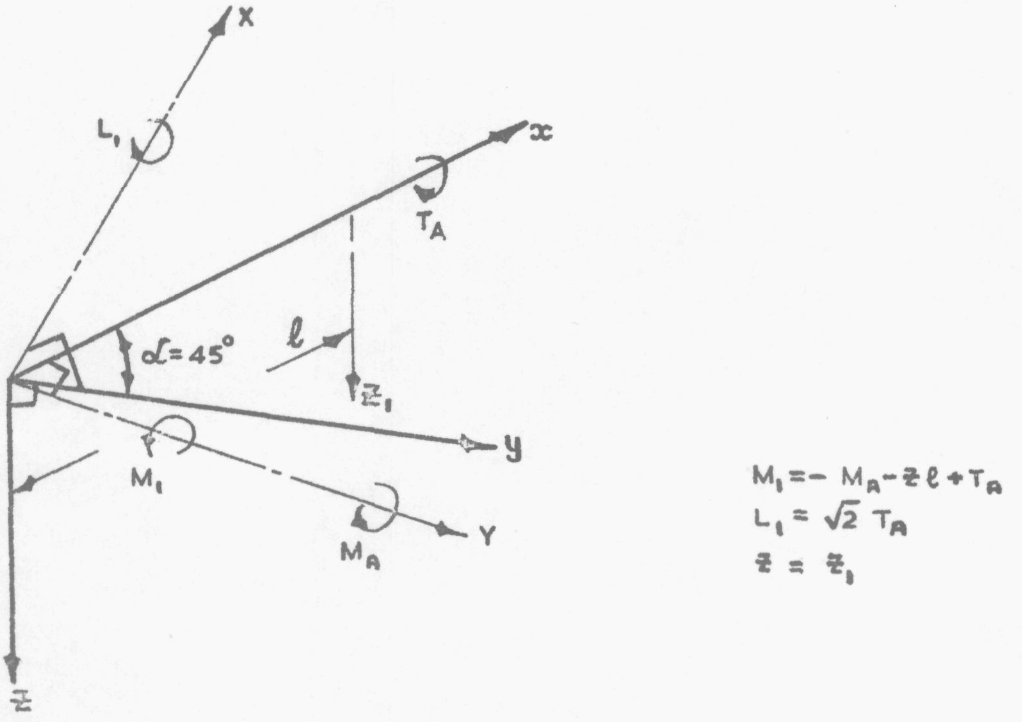
DETAILS OF 45° SINGLE CELL UNIFORM SWEPT BOX - OBLIQUE RIBS.

FIG. 21.



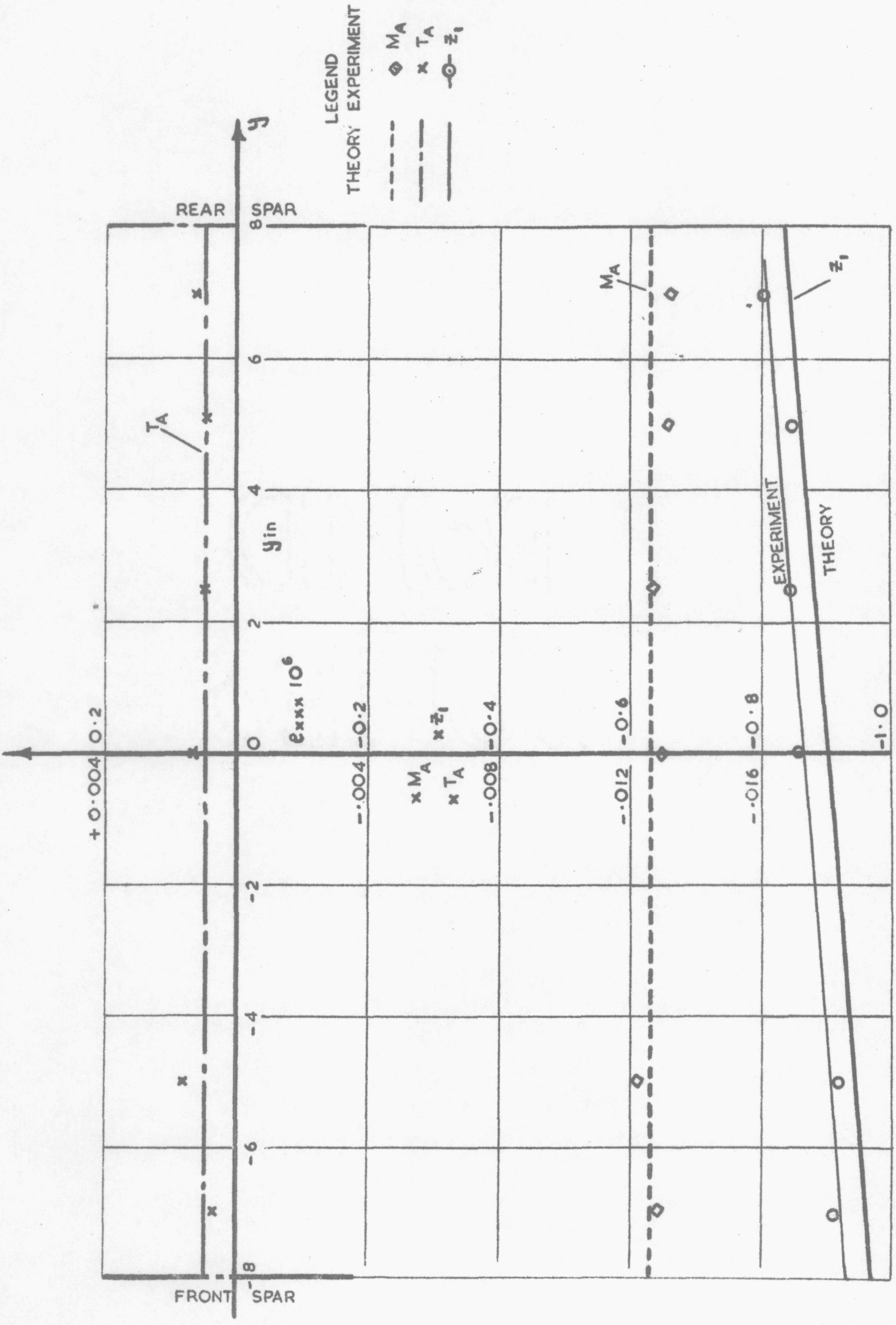
STRESS AND STRAIN SYSTEMS

FIG. 22.



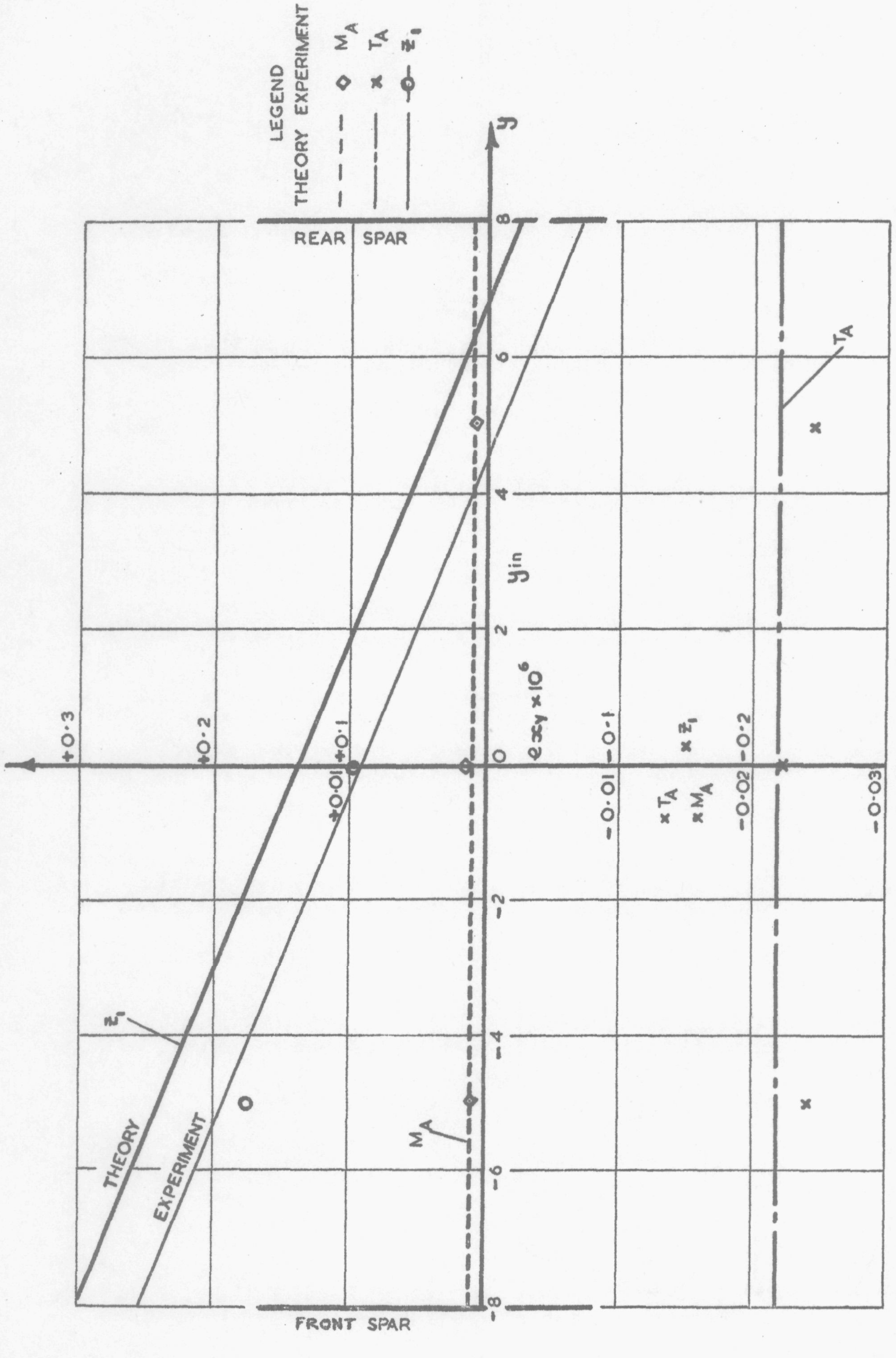
APPLIED LOADS AND AXIS SYSTEM

FIG. 23.



SINGLE CELL-OBLIQUE RIBS

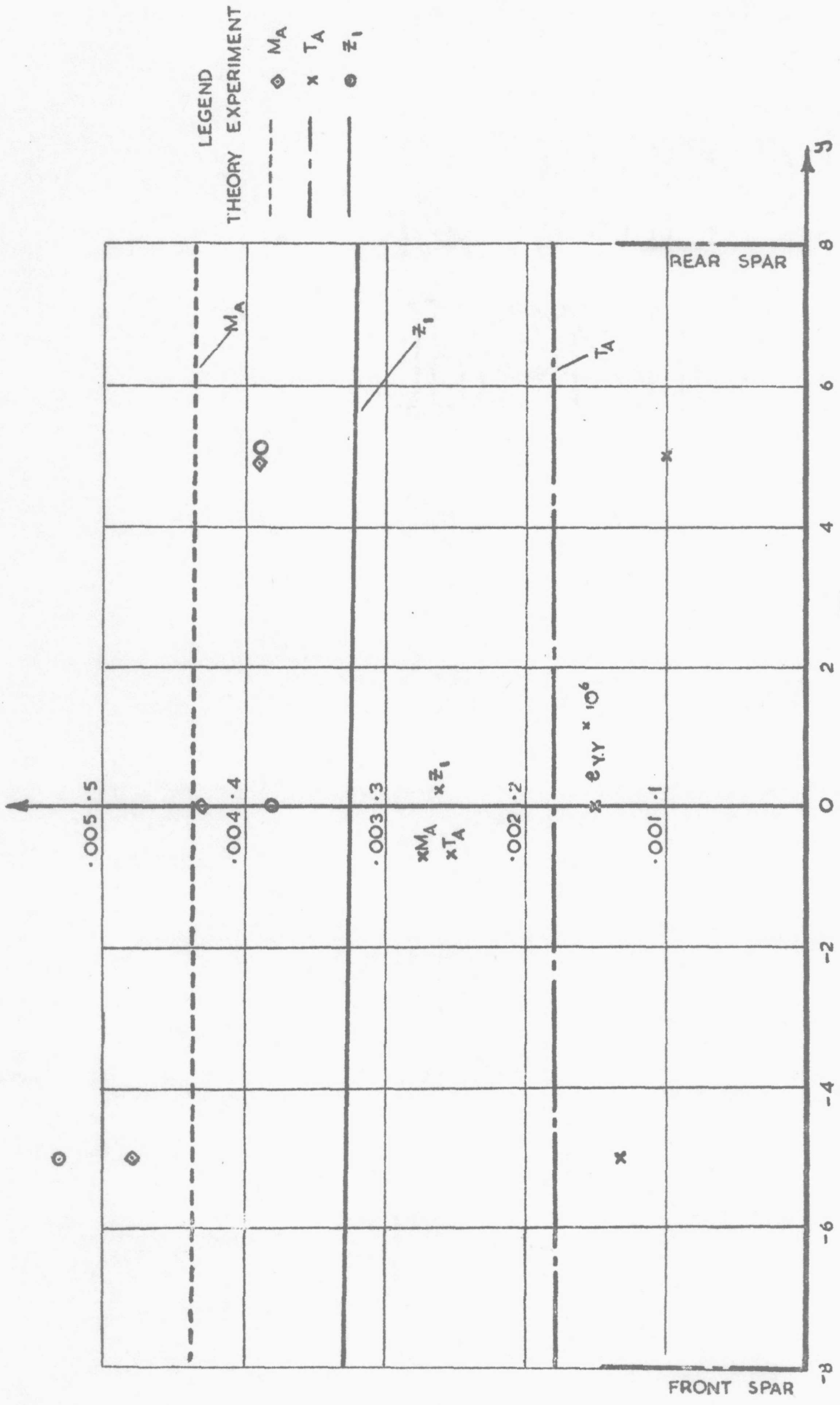
VARIATION OF e_{xx} ACROSS BOTTOM SKIN - x = CONST. SECT. α



SINGLE CELL - OBLIQUE RIBS

VARIATION OF e_{xy} ACROSS BOTTOM SKIN - x = CONST SECT ℄

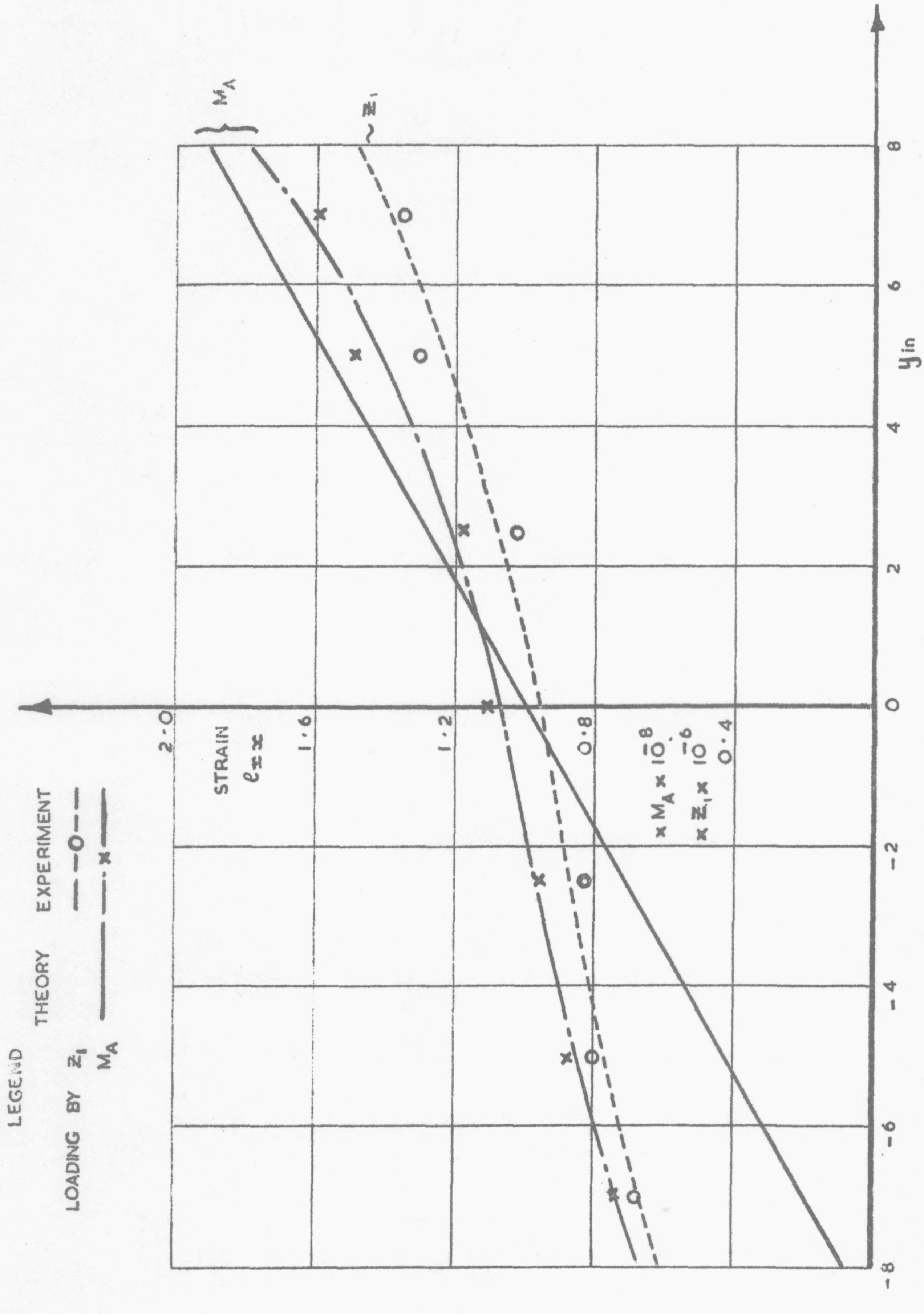
FIG. 25.



SINGLE CELL OBLIQUE RIBS

(VARIATION OF e_{YY} ACROSS BOTTOM SKIN
- x CONST. SECT. $\mathscr{L}$)

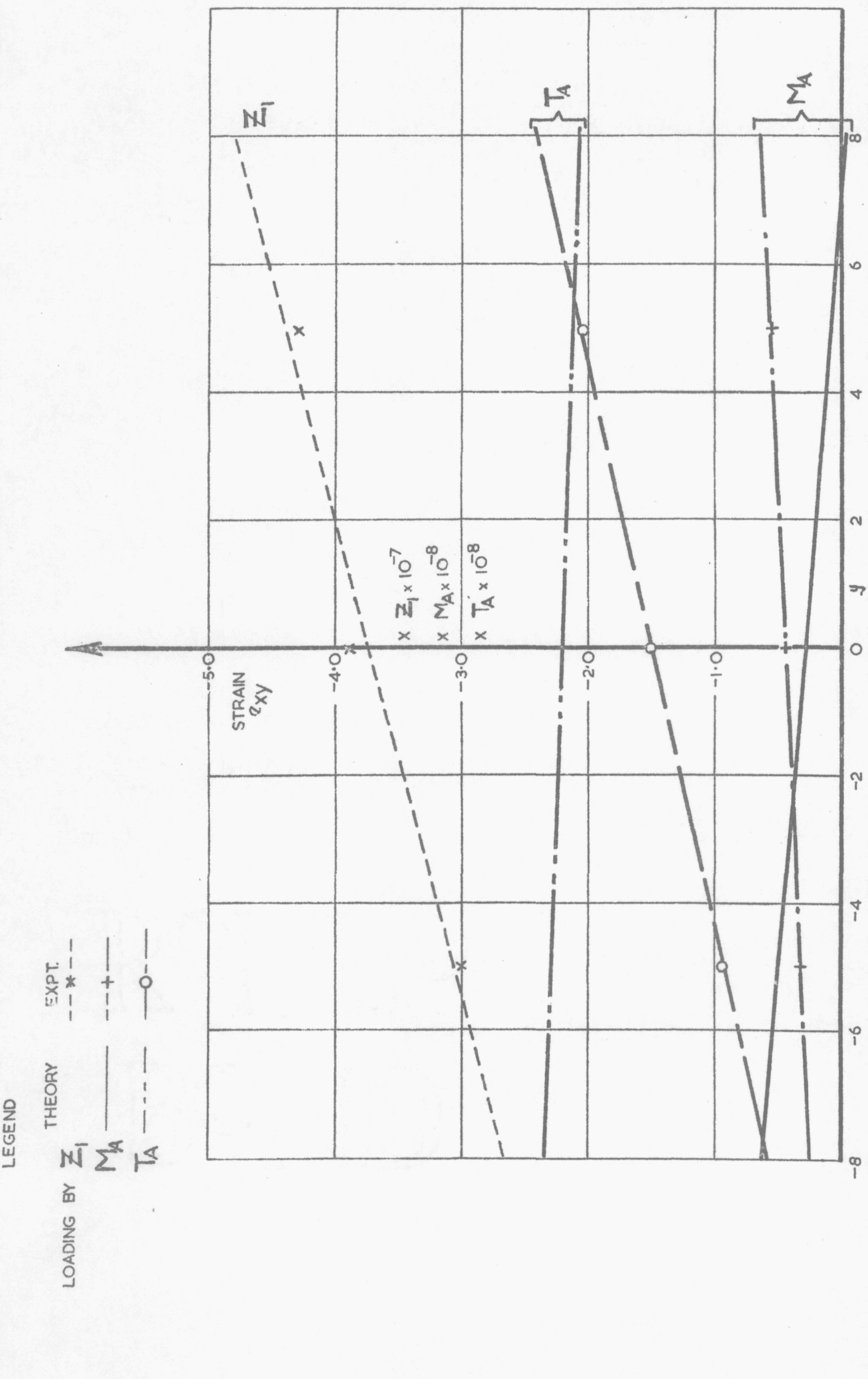
FIG. 26.



SINGLE CELL—OBLIQUE RIBS

STRAIN e_{xx} AT ROOT SECTION β

FIG. 27.



SINGLE CELL—OBLIQUE RIBS. STRAIN e_{xy} AT ROOT SECTION β.