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An Experimental Investigation into some of the Problems Associated with Stress Diffusion in the Vicinity of Chord-wise Cut-outs in the Wing, and a Comparison with Existing Theories.

-by-

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SUMMARY

Chord-wise openings in the skin between the spars of the wing are designed in some aircraft for undercarriage doors, bomb bay doors, and the wing fold joints of naval aircraft. Stress concentrations exist in the region of these cut-outs where the load is transferred from the stringers and skin into the concentrated load carrying members. Two theories have evolved to predict the resulting behaviour of the structure. The 'stringer sheet' theory predicts an infinite shear stress in the corners of the sheet; the 'finite stringer' theory predicts a high, finite shear stress in the corners, the magnitude of which increases with the number of stringers.

Tests were made on a large stringer-skin panel bounded by constant area edge members and subjected to concentrated, equal end loads. The dimensions of the panel were typical of modern practice; thick skin, multiple stringers, spar cross sectional area equal to panel area. In these tests variations were made in the lateral stiffness of the spar booms, the method of attachment of the end rib to the spar, and the loading between spar and sheet. The tests showed conclusively that the shear stresses are not only finite in the vicinity of the corner and considerably less than those predicted by either theory but in most cases the shear stress fell off toward zero.

The tests also brought out certain other aspects of this stress diffusion problem of which little has previously been known.

(1) Changing the method of attachment of the end rib to the spar had little effect upon the shear stresses in the corner.

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(2) In the tests in which the edge stiffener was attached to the spars, the transverse load applied to the spar by this member was considerable, and it may not safely be ignored in the design of the spar-to-rib attachment.

(3) Diffusion of the load into the sheet was considerably slower than predicted by either theory.

(4) At the initial joint between the spars and the sheet (termed in this report the 'corner') and under certain conditions of joining the spars and end rib, the sheet is actually putting additional end load into the spars instead of unloading them.

(5) Variation of the lateral stiffness of the spar booms appears in most cases to have little effect upon the stresses in the sheet. The tendency of the sheet to increase the boom load at the corner is more marked in the design with stiffer booms. The diffusion of load takes place slightly less rapidly from the stiffer booms.

(6) When the sheet was attached to the booms with two symmetrical rows of bolts, the loading by these rows was eccentric, tending to relieve the bending moment due to the lateral shears applied by the rib and sheet. Removal of the outboard row of bolts caused virtually no difference in the resulting behaviour of the panel.

(7) Large bending moments occur in the spar booms above the cut-out. The maximum stresses in the booms due to these moments are of the order of twenty to twenty-five per cent of the boom direct stress.

It is concluded that there are no infinite shear stresses in the corners of a cut-out. The shape of the spar boom cross-section and the geometrical relationships among the corner elements have important effects upon the behaviour of the structure. The choice of design is extremely complex, and there is at present insufficient knowledge about the problem to enable designers to choose an optimum design for any arbitrary set of conditions.

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SYMBOLS

2a	panel width
b	stringer spacing
e_{xx}	direct strain in the longitudinal direction
e_{yy}	direct strain in the lateral direction
e_{xy}	shear strain in longitudinal or lateral direction
f	stress
f_B	average tensile stress in boom
f_o	tensile stress in boom below the cut-out
f_r	stress measured in (end) rib
f_{xx}	direct stress in the longitudinal direction
f_{yy}	direct stress in the lateral direction
k	non-dimensional coefficient $\sqrt{Et_s/Gt}$
l	length of panel
q_{xy}	shear stress in longitudinal direction
t	thickness of sheet
t_s	thickness of stringer sheet $-(t + A_s/b)$
x	distance in longitudinal direction, measured from the lower right corner upward
y	distance in lateral direction, measured from the lower right corner inward
A_r	cross sectional area of (end) rib
A_s	cross sectional area of one stringer
E	Young's Modulus
F	boom cross sectional area
G	shear modulus $= E/(2 + 2\sigma)$
M	bending moment in boom
P	end load in boom $(F.f_B)$
R	bolt or rivet reaction
S	shear per inch $(t.q_{xy})$
T_2	loading per inch in lateral direction $(t.f_{yy})$
V	shear
α	non-dimensional coefficient $(a.t_s/F)$
σ	Poisson's ratio - assumed to be 0.30.

Introduction

Whenever openings are cut in stress carrying materials of an aircraft structure, the load normally carried by these materials must be transmitted around the opening by some system of concentrated load carrying members. The transfer of load into and out of these concentrated members is called stress diffusion. The subject of stress diffusion, particularly the build-up of stress in the corners of a panel adjacent to an opening, has been comprehensively treated by several authors.

Several aspects of this problem are of interest to the aircraft designer. First is the problem of producing a structurally efficient design, i.e., a combination of panel and booms which will diffuse the load from booms into the panel as quickly as possible, thereby making maximum practicable use of stringers and skin to carry the load and permitting the boom cross section to be decreased rapidly as the distance from the cut-out grows. The second problem is to design the corners of the cut-out in such a way that dangerously high shear stresses in the skin near the rivet line may be avoided. Third, the designer must ascertain that the connections between elements in the corner are safely able to transmit the loads required without shearing rivets, tearing skins, stretching rivet holes, or otherwise exceeding allowable stresses.

The major objective of this investigation was the determination of just what does occur in the corner, with a search for effects which may heretofore have been ignored or unknown. A large diffusion panel was constructed with constant area edge members and dimensions similar to those of modern design practice. Electrical resistance strain gauges were located on the skin, end rib, and spar boom around one of the corners. Tests were made to determine in detail the behaviour of the panel and the results of varying the boom lateral stiffness, the conditions of end rib support, and eccentricity of loading. One additional test was made on the panel with the end rib removed.

It was found that most of the present theories concerning stress diffusion are incorrect in the vicinity of the corners. The problem is an extremely complex one; there are many variables that have not been treated mathematically. Further investigation is required to determine more precisely the effect of these variables.

Review of Past Work on the Problem

Two general theoretical methods of solution of the problem of stress diffusion have been developed; the 'Finite Stringer' method in which the shear stress in the sheet changes in finite steps at the stringers; and the 'Stringer Sheet' method in which the stresses vary differentially across the plate. A variation of the second method, in which the panel is solved by a stress-function solution, has been used by a few recent authors.

'Finite Stringer' Theory:

The first work on the finite stringer theory was begun in 1937 with R. and M. 1780 by H.L. Cox, C.G. Conway, and H.E. Smith, (Reference 1). In this report three types of diffusing structures placed between a concentrated load and a diffused load, were considered. One of these types made use of the sheet to transfer the load by shear from one stringer to another. The basic assumptions made were that the sheet transmitted shear only (no direct loads), that the stringers carried all the end loads, and that at any transverse section the shear stress between adjacent stringers was constant.

In January 1938 W.J. Duncan published R. and M. 1825 (Reference 2) in which he extended somewhat the work of R. and M. 1780. It is noteworthy that the author foresaw the need for a different theoretical basis when, in paragraph 1, he wrote:

> 'But at any considerable distance from the end the sheet must evidently partake of the longitudinal strain of the stringers, and if the material is isotropic, the sheet must be in direct load. Hence, it appears that the equations can not be exactly applicable to structures having webs of isotropic material.'

Later in 1938 H.L. Cox presented R. and M. 1860 (Reference 3) in which the two previous reports were amplified and generalised to consider a complete monocoque shell with any number of stringers. He shows that the presence of a constant stress stringer divides the structure mathematically and reduces the complexity of the solution. In regard to the effectiveness of the sheet in carrying direct loads, Cox annunciated the fourth basic assumption of the finite stringer theory:

> 'In this case, by assuming a small width of sheet on either side of each stringer to act with, and in fact to form part of the stringer itself, the resistance of the remainder of the sheet webs to direct stresses may probably safely be neglected'.

He goes on to limit the applicability of this theory:

> 'On the other hand, if the sheet webs are unbuckled, their contribution to the direct load may be considerable, and the present method of analysis is probably not adequate to such cases'.

Cox considered his method to be applicable under conditions of heavy loading, heavy stringers, buckled sheet - and, one might add, probably a very thin sheet.

In R. and M. 2098, D. Williams, R.D. Starkey, and R.H. Taylor (Reference 4) reviewed the work of past contributors and enlarged upon the work of Cox and Duncan to obtain solutions for a box beam, using the theorem of minimum potential energy. These solutions include variations in such conditions as stringer area and spacing, sheet thickness, and spar flange area. The work done in this report is actually applied to the problem of shear lag, but the method could be applied as well to the problem of stress diffusion. The first mathematical treatment now known as the 'Stringer Sheet' theory was devised in this report. It will be discussed farther on.

H.L. Cox and J. Hadji-Argyris in R. and M. 1969 (Reference 5) gave a general method for the analysis of diffusion in a stiffened panel which varies in edge stress and dimensions along its length. The authors considered the problem of a flat plate between two concentrated edge members under various types of loading. They obtained expressions for the average stringer stress and the panel edge shear stress, valid for any number of stringers.

In R. and M. 2038 (Reference 6) Hadji-Argyris considers using the stringer sheet method but concludes that it is too inaccurate because of the infinite shear stress in the corner. He derives expressions for the edge shear stresses and the average stringer stress for a uniform parallel panel under concentrated symmetrical end loads.

In A.R.C. Report No. 9662 (Reference 7) Hadji-Argyris extends the work of R. and M. 2038 to solve the problem of antisymmetrical concentrated end loads.

'Stringer Sheet' Theory:

As previously stated, Williams, Starkey, and Taylor in R. and M. 2098 developed a method of mathematical treatment of the diffusion problem known as the 'Stringer Sheet' theory. In this method the following assumptions were made:

(1) The stringers and effective sheet are split up into an infinite number of small stringers of uniform thickness capable of carrying end load only. This is known as the stringer sheet.

(2) The ribs and effective sheet are split up into a uniform sheet capable of carrying only transverse loads.

(3) The actual sheet is fully effective in resisting shear.

(4) Lateral stresses and strains can be ignored.

The stringer sheet theory yields a Laplacian equation for the longitudinal displacement 'u' which can be solved in the usual manner. The stringer sheet solution of R. and M. 2098 was for the problem of shear lag only, although the Laplacian equation for the longitudinal displacement is applicable to the problem of any such flat plate.

In R. and M. 2618 (Reference 8) Fine and Hoskins solved the problem of chord-wise cut-outs in a flat sheet between two parallel spar booms, considering a finite length of sheet, cut laterally at each end. The solution for the edge stress gave infinite stress at the corners. The authors qualified this solution by assuming that rivet slip, local skin buckling, or plastic elongation would relieve the stresses to a finite quantity.

Stress Function Solution:

Much recent work has been done by E.H. Mansfield using a stress function solution. His first approach (Reference 9) was to find the stress function solution for a semi-infinite sheet subjected to a concentrated load at a distance from the free edge and normal to the edge. By matching sheet strain to the strain of a boom loading the sheet in the direction normal to the free edge, he was able to determine the sheet stresses for certain boom-to-sheet shear loadings and the sheet stresses for the case of an actual boom diffusing its load into a sheet. His solutions predicted that in the case of a lateral cut-out there would be infinite shear stress at the corner as long as there was any strain in the edge member.

In R.A.E. Report Structures 13 (Reference 10) Mansfield examines the problem of reducing the infinite shear stresses by constructing a rib boom at the cut-out and so attaching it to the corner that it is built into the spar boom. Such an attachment would obviously not rotate and would therefore cause the shear stress to be zero at the corner. It would also transmit immediately a portion of the boom load to the end of the panel, thereby somewhat hastening the process of diffusion.

In R.A.E. Report Structures 27 (Reference 11) Mansfield considers the problem of reducing the infinite shear stress at the corners of the cut-out. As a substitute for the transverse rib boom, he suggests an increase in the spar boom area near the corner to decrease the spar boom strain. In order to avoid the design of a spar boom of infinite cross section at the corner, Mansfield concludes that the spar boom area may remain finite while the rivets in the corner shall be just flexible enough to permit the required slip between sheet and boom. This requires the use of rivets of 'graded flexibility'.

In R.A.E. Report Structures 31 (Reference 12) Mansfield considers a panel bounded by constant stress booms with a transverse beam at the edge of the cut-out. He solves the case of the pin-jointed edge beam as well as the built-in case, and shows that theoretically the shear stresses at the corner are finite for the pin-jointed beam, zero for the built-in beam, and infinite for the case of no beam.

Practical Consideration of the Problem

In attempting a practical approach to this problem of stress diffusion one should begin by exploring the limitations to the theoretical treatment, examining the assumptions, and considering effects that have been ignored or have resisted mathematical treatment.

In almost every theory of any sort there are some shortcomings in the assumptions which may or may not be of great importance. Certainly when one predicts such effects as infinite stresses, any flaws in the assumptions relating to this effect are of vital importance, and we must face up to the possibility of the resulting limitations to the theory.

In the 'finite stringer' theory the shortcomings of the theory were foreseen by its early developers and still exist in the latest reports. In addition, no account whatsoever is taken of lateral stresses or displacements. In a centre-loaded panel the lateral stresses and forces on the concentrated load carrying members may be safely neglected as self-cancelling, but not so in a panel bounded by concentrated booms. Yet in the Royal Aeronautical Society Data Sheet Structures 02.05.00 it is stated not only that one of the basic assumptions is that the lateral direct strains are zero, but that '.....in particular the exact condition of lateral restraint is relatively unimportant'.

In the 'stringer sheet' theory the assumption is inherent that the lateral displacement is zero or negligible at the spar boundaries. The ribs are assumed divided into a rib sheet, giving distributed forces of <u>just</u> the right amount to balance the usual equilibrium equation between shear and direct stresses. This, if true, is fortunate indeed. It is further assumed that the lateral displacement is constant at the edge so one must conclude that the spar boom has infinite stiffness in the plane of the sheet. On the other hand, it can be shown that theoretically the plate gives infinite curvature to the spar boom at the corner, so the boom must at the same time have zero stiffness.

In the method of solution by stress function Mansfield painstakingly derives a solution for a semi-infinite sheet with finite spaced concentrated booms. He then cuts the sheet either midway between booms or in the middle of each boom and states that the previous solution has not been effected, using the

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argument that '......... under the assumptions made in stringer sheet theory, stresses normal to these lines do not affect the solution', (Reference 9). Since he has already predicted an infinite lateral direct stress at the corner, it is a stretch of one's credulity to believe that this stress can be ignored.

There is no question that the stress-function solution for an unbounded plate is reasonable physically and correct mathematically, but most of the proper boundary conditions of this problem are not truly amenable to exact definition. One can not say that the lateral displacement along the booms is zero or that the lateral edge loading of the sheet along the booms is zero. The same is true of the longitudinal displacement at the edge, and, if a rib is attached, of the longitudinal loading. One boundary condition that seems certain is that the shear and longitudinal stresses are zero across the transverse (cut) edge if there is no end rib. In this case, theory can be made to predict that the shear stress along the longitudinal edge will rise to $2/\pi$ at the corner or it can predict infinite shear stress depending upon which theory is used. Both theories use a stress function solution. For the last word on boundary conditions, it should be mentioned that from the experimental evidence gained in this investigation, it is difficult to say positively that the sheet partakes of the same strain as the boom, even that portion of the sheet which is rigidly attached to the boom.

Even the concept of the corner itself defies an exact definition. The corner in an actual diffusion panel may be markedly different from the equivalent mathematical panel. First, the loads are actually applied in finite amounts by rivets or bolts of finite width, often in two or more lines of attachment. The edge of the panel must extend a finite distance beyond the last rivet connection and may be attached to an edge rib with several rows of rivets or bolts. So there are not two mathematical lines intersecting in a point to be defined the corner. We could define the corner as the intersection of the inboard rows of longitudinal and transverse connections, and that is the corner as used in this report. We are, however, still left with the consideration of the sheet outboard of the corner.

One further consideration is the method of applying loads to the sheet. In theory they are applied at points or in a line; in actuality they are distributed and limited to certain stresses in the area of application. It is difficult to believe that the action of the sheet will have any effect other than to reduce those stresses at increasing distances from the point of application.

Certain other effects have so far been ignored in the handling of the theories or else are not amenable to mathematical consideration within the problem. The lateral stiffness of the spar booms has already been mentioned. In addition there are

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such factors as the elasticity of the connections between sheet and booms, the possibility that a thick skin tends to support itself at the corner, eccentricity of loading, and shortening of the boom due to curvature.

It does seem that this problem of stress diffusion, although it can be treated with pure mathematics, is too complex to yield one exact solution to the whole problem. The necessary assumptions are too great, and the factors ignored are probably too important. While an approximately correct answer can be obtained over much of the panel, there is no resemblance at all between actual behaviour in the corner and the predictions of theories.

Experimental Equipment

In order to measure relatively close to the corners of the cut-out, a very large test specimen had to be chosen. In addition to large size, the test specimen was designed to have the following characteristics of the tension skin and booms of a typical two spar torsion box:

(1) Thick skin (14 gauge) of high strength alloy. (DTD546)

(2) Large number of closely spaced stringers. (20 stringers at 2-inch pitch).

(3) High ratio of skin-plus-stringer area to boom area. (Unity).

(4) High ratio of skin area to stringer area. (Over 2:1)

(5) Medium rib spacing.

Photographs of the test panel are shown in Figs. 1 and 2.

The following details should be noted:

(a) Length/width ratio is only about 9/8. This would be low for ordinary diffusion testing but is believed satisfactory for investigating the localised effects in the corners. See R. and M. 2618 (Ref. 8).

(b) Stringers are replaced by equivalent flat strips. Since the panel is tested in tension only, the effect of the stringer can be represented by its ability to carry tensile loads.

(c) Panel is symmetrical about its centre-line. This is a departure from ordinary designs but assures that eccentricity of loading out of the plane is minimised.

/(d) ...

(d) Large edge rib. It has relatively high lateral stiffness but rather low bending and shear stiffness in the plane of the plate. In a later test the edge rib was removed and the panel tested with the edge free.

(e) End rib attachment to booms can be varied to simulate built-in support (as shown) or single support, or the rib can be left free from support by the booms.

(f) Booms are bolted to the plate by two rows of bolts, equidistant from the centre-line of the booms. Bolting gives a poorer joint between booms and plate than riveting, but permits interchange of sets of booms of different properties. A later series of tests was performed with only the inboard row of bolts in use. (As shown in Fig. 2).

Location of electrical resistance strain gauges is shown in Fig. 2. A dial gauge was rigged to record relative lateral motion between the two booms. Its reading was so small, however - 0.0025 inches for a load of 34,000 pounds - that it was felt to be of little practical use.

Two sets of booms were tested, one a 3/8 inch slab, the other a tee section of about the same area, both three inches wide. They were not tapered. All parts of the test panel, except the bolts, were of light alloy.

Details of Panel

Length: 51 inches
Width (between centre-lines of booms): 45 inches
Width (between inboard rows of bolts): 42.3/4 inches
Boom area per side: Slab booms - 2.23 square inches
Tee booms - 2.17 square inches
Boom moment of inertia per side: Slab booms - 1.689 inches^4
Tee booms - 0.970 inches^4
Web (skin) thickness: 0.0813 inches
Stringer area: 0.0732 inches^2
Stringer spacing: 2.0 inches
End rib area: 0.684 square inches

Test Technique

Loading System

The desired aim in loading was to apply symmetrical loads to the two spar booms. Arrangement of the loading system can be seen from Figure 2. The purpose of the links between the steel

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channels and the connections to the booms was to minimise the introduction of spurious bending moments or side forces.

In order to ascertain that loads applied were equal and symmetrical, strain gauges were fixed on both booms below the edge of the panel, and tensile loads and bending moments determined. The position of the hydraulic jacks was varied laterally until the loading was as desired.

Tests

Ten tests were performed. In each the total load was varied in 4000 pound increments from 14,000 pounds to 34,000 pounds, readings of all strain gauges taken at each loading. The conditions of the panel for each test are described below:

Test 1. The Tee booms were bolted to the panel with both rows of bolts. The edge rib was given 'built-in' support at the spar booms.

Test 2. Same as Test 1 except that the edge rib was given 'simple' support at the spar booms.

Test 3. Same as Test 1 except that the edge rib was not attached to the spar booms.

Test 4. The Tee booms were removed and replaced by slab booms, connected with both rows of bolts. The edge rib was given 'built-in' support at the spar booms.

Test 5. Same as Test 4 except that the edge rib was given 'simple' support at the spar booms.

Test 6. Same as Test 4 except that the edge rib was not attached to the spar booms.

Test 7. Same as Test 4 except that the outboard row of bolts was removed.

Test 8. Same as Test 5 except that the outboard row of bolts was removed.

Test 9. Same as Test 6 except that the outboard row of bolts was removed.

Test 10. The edge rib was removed from the panel and the rivet holes in the rib enlarged. The edge of the panel was coated with a light grease and the rib was replaced and bolted on loosely with small bolts. This gave support to the edge of the panel against buckling in compression or shear but permitted no direct load to be transmitted between sheet and rib. In all other respects the test was the same as Test 9.

/General Remarks ...

General Remarks About Testing

It was found that bolted connections required a considerable amount of loading before transmitting forces in direct proportion to the applied loads. By starting the readings at a high loading (14,000 pounds) it was possible to get strains linear with load, and there was no trouble with pronounced nonlinearity in any of the readings.

A loading link was used to measure the applied load but did not turn out to be an unqualified success. It was very sensitive to changes in circuit current and moreover seemd to vary a bit from day to day. As a result, the average stress indicated by strain gauges on the booms below the edge of the panel was used as the basis for computations.

As mentioned previously, the loading system was adjusted to give symmetric loading. In actuality the strain gauges showed loads within one per cent of each other; the bending moments were usually both in the positive direction (shear outboard) but were rarely alike in magnitude. Since they represented shears of the order of ten pounds for a tensile load of ten thousand pounds, it was felt that exactitude here was not required.

In analysing the test results, Poisson's ratio effects were accounted for in determining direct stresses in the sheet. Poisson's ratio was assumed to be 0.30. Tests on control specimens showed that all elements had a modulus of elasticity within two per cent of 10.5×10^6 pounds per square inch, so in determining the results presented it was not necessary to use the modulus of elasticity, only to assume that it was the same for all elements.

Presentation of Test Results

A tabulation of the measured results of the ten tests is appended as Table II. For the skin, both strain measurements and relative stresses are indicated. For the end rib, strain, relative stress, and ratio of rib load to boom load. For the boom, average strain, relative stress, difference between inside and outside edge stresses, and that difference divided by the average stress in the boom at that location. By relative stress is meant the ratio of the particular stress to the average stress in the boom below the cut-out. It is felt to be best to reduce the stresses to non-dimensional figures in order for them to have the most significance and to compare one test with another or with theory.

Graphical illustration of the tests has been used, since this is considered to be the best available method of comparing the

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relative effects of the different variations (the boom and the end rib fixation).

Graphical results are presented in the appendix, arranged as listed in Table I, in groups in which one element is held constant while the other element is varied. Three sets of curves are presented for each group: one to show stresses along the longitudinal edge; one to show stresses along the lateral edge; and one to show the diffusion of load from the boom into the sheet. In addition there is a group to illustrate the comparison of a free edge with a stiffened edge and a group to compare typical results of this series of tests with the predictions of certain theories.

Stresses in the end rib are not shown in any of the graphs. It is felt that the stresses along the rib are of less importance than the rib loads, which must be taken out by the booms as shears. Both the rib and its stresses are relatively large, so these loads may be considerable. In the cases in which the rib is attached to the boom, the rib load enters the boom at one or three bolts and therefore makes up a proportion of the bolt reactions which may not be ignored.

Discussion of Test Results

It must be noted that the so-called 'edge stresses' were actually measured a finite distance away from the edges, both longitudinal and lateral. This distance is the sum of the overlap of the boom or rib beyond the line of bolts or rivets, plus the width of the strain gauges, and amounts to about two per cent of the effective panel width. It is believed that this is close enough to consider the results to be reliable quantitatively as well as qualitatively.

In comparing the two booms, it must be pointed out that the slab booms are some three per cent greater in area than the tee sections. Making allowance for the material removed for bolt holes, the difference is less than two per cent. This, it is believed, has little effect upon the edge stresses but should be considered when comparing the diffusion of load from the booms.

Strains in the set of slab booms were measured in three places across the boom for each longitudinal location - on each edge and along the centre-line. In all positions except the first two above the corner there was close agreement between the strain in the centre and the average of the edge strains. In the readings of the first two groups above the corner the agreement was poor, and it was necessary to weigh each reading in order to arrive at a realistic average strain, taking into account the direct strains in the sheet along the two edges. The results

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so obtained should not be considered as being completely reliable.

Conclusions

1. The results presented, particularly the comparison of theory and test, show conclusively that the edge stresses in the corner are finite and in most cases drop off toward zero near the corner. These results represent a large, though localised, departure from the predictions of the theories considered. Little effect can be attributed to either spar stiffness or condition of end rib fixity.

The agreement with the finite stringer theory is fairly good as long as the longitudinal distance from the corner is greater than two-tenths of the semi-span and provided we make the reasonable assumption that the shear stress has decreased in the distance between the 'edge' and the strain gauges, (although this is contrary to one of the basic assumptions of the theory). It is possible that these predicted shear stresses could safely be used as an envelope around the maximum shear stresses that will actually occur in the sheet, applicable to within, say, two-tenths of the semi-span from the corner, at which point its magnitude would be the maximum encountered anywhere in the sheet. Further tests on sheets of different thickness would have to be carried out before this hypothesis could be accepted.

The correlation between the stringer sheet theory and the tests results is so poor that there is no basis on which to discuss the two further.

2. The diffusion of load seems to be a very complex problem, affected by many variables. Certainly the actual rate of load diffusion lags far behind the rate predicted by the theories.

Boom lateral stiffness appears to have some effect, particularly upon the phenomenon observed in certain tests in which the booms take additional load from the sheet at the first connections rather than transfer load into the sheet. Of the three tests using the flexible booms, this occurred once; in seven tests with the stiff booms it occurred five times. It was most marked in the tests with the end rib free and in the tests in which the loading was eccentric. Since tests on the Tee booms loaded eccentrically were not carried out, this is perhaps an unfair comparison, but from Figures 5, 8, and 11 it appears that the flexible booms do load the sheet much more rapidly in and near the corner.

The lag in the corner between the predicted and the actual load diffusion is probably related to the drop-off of edge shear stress. It is reasonable to conclude that since the sheet is not experiencing the shear strain predicted by theory the boom

/is not ...

is not loading the sheet as predicted.

Eccentricity of loading undoubtedly has some effect, as the load diffused in Tests 7, 8 and 9 was less than the load diffused in Tests 4, 5, and 6. Since the shear load bends the boom in the positive direction, the tensile loads bend it in the negative direction, and the whole panel probably behaves so as to minimise the total strain energy, it is possible that there is some optimum eccentricity, perhaps a function of radius of gyration and lateral shear stiffness, to give best load diffusion.

The presence of an end rib also speeds up load diffusion, even when it is not connected to the spar, as seen from Figure 25. The method of attachment of the rib to the spars makes a considerable difference in the load diffusion at the corner, although there is no significant difference eight or ten inches away. The effect of rib area has not been investigated except with a rib of zero area (no rib), in which case the diffusion was considerably slower.

It may be that the load diffusion predicted by the theories represents the maximum possible rate of load diffusion. From the results of the two theories, the finite stringer theory again appears to be much the more reasonable.

3. Contrary to the Royal Aeronautical Society Data Sheet Structures 02.05.00 on stress diffusion, the lateral loads in the end rib are of such magnitude that they can not safely be ignored. In these tests the end loads in the rib area are of the order of seven to nine per cent of the boom tensile loads. Since this is entering the boom as a concentrated load and, moreover, as a shear, it demands careful consideration both from the standpoint of the connection between the end stiffener and the spar and from the standpoint of designing the spar booms for maximum allowable stress. These lateral loads are higher in the tests with the flexible spar booms, (probably because they deflect more under bending). The effect of rib cross sectional area has not been investigated, but there is little doubt that a smaller rib will introduce smaller loads. In the test with a rib of zero cross section (no rib) the lateral stress in the skin was zero at the corner (no transverse load).

4. Large bending moments existed in the booms above the corner. These caused average additional tensile stresses of as much as twenty-five per cent of the average stress in the boom at that location. Localised additional stresses may be considerably greater. These additional stresses were highest for the flexible booms and they were higher when the boom was loaded eccentrically than when two rows of attachment were used. It is concluded that designers should increase the factor of safety for the spar booms in the first semi-span away from the corner in order to allow for these additional stresses.

5. Decreasing the end rib cross sectional area should produce the same qualitative effect as removing the rib. These effects

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should be as follows:

(a) Lower maximum shear stress. Shear stress drops off more markedly to zero at the corner.

(b) Higher compressive stresses in the rib and higher transverse compressive stresses in the skin across the cut edge.

(c) Lower direct stresses at the corner.

(d) Probably a lower transverse load applied to the boom.

(e) Less rapid diffusion of load from booms into the sheet.

(f) Slightly higher bending moments in the boom.

6. Some of the effects of increasing lateral stiffness of the booms may be predicted from the tests of the two booms. Not all of these are conclusive.

(a) Essentially no change in maximum shear stress. The drop off in shear begins farther up the booms when the stiffer booms are in use.

(b) Higher direct stresses in the corner. This was particularly marked in tests 6 and 9 in which the rib was not attached to the booms.

(c) The stresses in the rib are lower, and the transverse load applied by the rib is less.

(d) Less rapid diffusion of load from booms into the sheet.

(e) Lower stresses due to bending moment in the boom above the corner.

(f) Possibly more tendency for the stiffer boom to take additional load from the sheet at the corner, instead of applying load to the sheet.

7. All the effects of changing the condition of support of the end rib can not be predicted conclusively from the tests. The differences are sometimes small or even conflicting. There are some effects, however, and they are as follows:

(a) No marked difference in maximum shear stresses or the way in which the shear stresses drop off.

(b) Higher direct stresses in the corner when the rib was

/not attached ...

not attached. No significant difference between the built-in case and the simply supported case.

(c) No significant difference between rib stresses in built-in case and simply supported case. Slightly lower stresses all the way across the rib for the case of no support.

(d) A large proportion of the boom load was transferred directly to the sheet via the end rib when the rib was supported, except when the boom-to-sheet attachment was eccentric. This was more marked for the flexible booms. There was no consistent tendency for either condition to transfer the higher proportion of load.

(e) Bending moments in the boom are lowest for the cases of no rib attachment. There is little difference between the built-in and simply supported cases.

(f) The phenomenon of the boom increasing its end load at the first connection to the sheet occurred every time the rib was not connected to the boom. When the rib was supported by the boom this did not occur except when the loading was eccentric.

(g) Despite (d) and (f) above, there was, at a distance of a half semi-span above the corner, no difference in the amount of load diffused.

8. At the end of a cut-out, on the tension surface at least, a rigid stiffener must be employed to prevent buckling of the cut edge. It seems logical to attach that stiffener to the booms in order to take advantage of its capacity to relieve the booms immediately of a portion of their loads. In considering the support of the rib, there appears to be little to choose between built-in and simple support as far as transfer of load is concerned. It should be pointed out, however, that built-in support requires the application of a large bending moment between rib and boom as well as a longitudinal load. This in turn requires the means of applying that bending moment. Such means are almost certain to be very costly from the standpoint of weight, so it is possible that the use of a built-in rib will achieve no weight savings at all. A simply supported rib, on the other hand, requires the application of only a longitudinal load. By proper design it can be attached to the spar in such a way as to minimise the introduction of undesired bending moments.

9. Some of the conclusions that may be drawn from the results of this investigation are directly applicable to any diffusion design, but all the results must be considered in the light of the following limitations: the panel was symmetrical

/on both ...

on both sides of the skin; the tests were made on a flat plate, not a box section; and the edge members of the test panel were constant in area.

The assymmetry of the actual aircraft wing about the skin would add some bending moments out of the plane of the skin which would tend to buckle the skin or bend the spars. An actual structure is well braced by the spar webs against any such deformation of the flanges; the stringers would tend to relieve the moments in the skin as well as stiffen it; so it appears likely that the assymmetry of loading would have little effect.

A box section, being considerably stiffer out of the plane of the sheet and having, normally, a full plate rib at the cut-out to give lateral stiffness, might tend to raise the overall stiffness at the cut-out and hence increase the shear stresses in the corner and probably the rate of load diffusion. In the design in which only one surface is cut, as for undercarriage doors or bomb bay doors, the web would probably absorb a higher than usual proportion of the boom load and thus relieve the stresses in the corner. The total effect would probably be to raise the corner stresses somewhat, but it is not likely to be of more than secondary importance.

Constant area edge members are unlikely to arise in a practical wing design, so the results should be examined to see which would be changed markedly in a design of constant stress booms. The drop off of the shear stress toward zero in the corners is a localised effect and occurs even when the boom stress increases at the first connection to the sheet, therefore it would undoubtedly occur in a constant stress design. The maximum shear stress measured by test occurs well up the skin, usually between one and two tenths of a semi-span, so it is probable that in a constant stress design the maximum shear stress will be greater in magnitude and will occur farther from the corner. The diffusion of load will probably be slower than predicted by the theories for constant stress booms, the same as for constant area booms. The effects of boom stiffness, eccentricity of loading, end rib area, and end rib support are probably similar. The lateral loads in the end rib and the moments in the spar boom would still exist and would probably be higher because of the lower lateral stiffness of the booms at a distance away from the corner.

10. The problem of stress diffusion is extremely complex, and there are many variables that have marked effects upon the behaviour in the vicinity of this cut-out. There is insufficient quantitative knowledge about these variables to enable designers to obtain an optimum design for any arbitrary set of conditions.

The results of the tests performed lead to the conclusion that the theories are incapable of handling the problem in the

/corner ...

corner or of obtaining even qualitative indications. It is felt that some other means of solution, such as the relaxation of restraints, could well be attempted for a specific problem, but it is also believed that there should be further testing to obtain quantitative results that would be of value to designers.

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No.	Author(s)	Title, Etc.
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TABLE I

Arrangement of Presentation of Test Results

Group	Figures	Element Fixed	Element Varied	Tests
1	3-4-5	End Rib Support (Built-in)	Boom Stiffness	1-4-7
2	6-7-8	End Rib Support (Simple)	Boom Stiffness	2-5-8
3	9-10-11	End Rib Support (Free)	Boom Stiffness	3-6-9
4	12-13-14	Boom (Tee Booms)	End Rib Support	1-2-3
5	15-16-17	Boom (Slab Booms)	End Rib Support	4-5-6
6	18-19-20	Boom (Eccentric Loading)	End Rib Support	7-8-9
7	21-22-23	Illustrates Effect of Removing End Rib		3-6-10
8	24, 25	Comparison of load diffusion and longitudinal edge shear stresses by finite stringer theory (R.A.A. Data Sheets) and stringer sheet theory (Reference 8) with results of tests 6 (end rib free) and 10 (end rib removed).		
	26	Comparison of longitudinal edge shear stresses predicted by Reference 10 for built-in end rib with results of tests 1 and 4.		
	27	Comparison of longitudinal edge shear stresses predicted by Reference 12 for simply supported end rib with results of tests 2 and 5.		

/Table II ...

TABLE II

TEST DATA - DIFFUSION PANEL

SKIN STRESSES															
			Test 1						Test 2						
Gauge Group	x (ins)	y (ins)	$e_{xx}\cdot10^5$	$e_{yy}\cdot10^5$	$e_{xy}\cdot10^5$	f_{xx}/f_o	f_{yy}/f_o	q_{xy}/f_o	$e_{xx}\cdot10^5$	$e_{yy}\cdot10^5$	$e_{xy}\cdot10^5$	f_{xx}/f_o	f_{yy}/f_o	q_{xy}/f_o	Gauge Group
1	0.9	7.4	2.5	-8.9	14.2	0	-.228	.138	3.2	-7.4	15.6	.030	-.184	.157	1
2	0.9	5.4	3.5	-7.6	20.7	.034	-.184	.203	3.7	-6.7	20.4	.050	-.162	.204	2
3	0.9	3.4	6.0	-6.0	29.8	.119	-.119	.291	5.3	-5.5	31.0	.107	-.112	.311	3
4	0.9	0.8	13.1	-8.0	52.3	.300	-.114	.511	13.1	-7.4	49.9	.313	-.099	.500	4
5	2.75	0.8	13.8	-6.9	49.1	.330	-.077	.480	15.0	-3.4	44.0	.403	+.032	.443	5
6	4.72	0.8	15.6	-9.2	40.9	.359	-.126	.400	18.4	-8.7	40.9	.453	-.092	.410	6
7	8.67	0.8	19.6	-6.2	34.0	.495	-.007	.332	18.2	-3.7	31.5	.492	+.052	.316	7
8	2.75	3.40	3.8	-3.4	29.8	.077	-.065	.291	8.4	-3.0	26.8	.216	-.015	.269	8
			Test 3						Test 4						
1	0.9	7.4	1.6	-8.9	16.5	-.031	-.230	.148	3.2	-6.7	16.3	+.043	-.205	.208	1
2	0.9	5.4	4.5	-8.9	23.2	+.049	-.202	.210	4.4	-7.3	20.4	+.078	-.214	.258	2
3	0.9	3.4	+3.3	-9.9	34.6	+.007	-.242	.313	3.4	-10.1	24.1	.025	-.326	.301	3
4	0.9	0.8	-1.1	-5.3	52.4	-.073	-.153	.473	0.9	-3.0	25.9	0	-.096	.326	4
5	2.75	0.8	+8.7	-5.0	58.7	+.195	-.066	.530	3.7	+0.9	41.3	.153	+.071	.519	5
6	4.72	0.8	+15.1	-10.1	47.2	.330	-.153	.428	13.1	-6.2	39.9	.401	-.084	.500	6
7	8.67	0.8	21.1	-5.7	37.4	.525	+.016	.339	14.0	-3.2	26.4	.466	+.037	.333	7
8	2.75	3.4	2.3	-4.6	27.5	.024	-.016	.250	4.8	-4.4	20.6	.124	-.109	.258	8

TABLE II, Contd.

SKIN STRESSES															
			Test 5						Test 6						
Gauge Group	x (ins)	y (ins)	$e_{xx} \cdot 10^5$	$e_{yy} \cdot 10^5$	$e_{xy} \cdot 10^5$	f_{xx}/f_o	f_{yy}/f_o	q_{xy}/f_o	$e_{xx} \cdot 10^5$	$e_{yy} \cdot 10^5$	$e_{xy} \cdot 10^5$	f_{xx}/f_o	f_{yy}/f_o	q_{xy}/f_o	Gauge Group
1	0.9	7.4	2.3	-8.9	17.7	-.012	-.224	.170	2.3	-10.5	24.5	-.023	-.260	.228	1
2	0.9	5.4	3.9	-8.7	24.5	+.035	-.203	.234	5.5	-12.1	26.9	+.051	-.279	.251	2
3	0.9	3.4	4.1	-9.2	34.9	+.035	-.217	.333	+3.7	-15.8	31.0	-.028	-.391	.288	3
4	0.9	0.8	1.1	-6.6	45.0	-.024	-.170	.430	-13.1	-11.2	53.3	-.437	-.400	.495	4
5	2.75	0.8	7.3	-3.9	56.7	+.165	-.046	.541	+6.6	- 4.4	59.2	.140	-.064	.550	5
6	4.72	0.8	14.4	-8.7	49.3	.326	-.120	.470	12.6	- 8.7	54.0	.265	-.131	.502	6
7	8.67	0.8	19.7	-5.5	34.4	.520	+.012	.328	21.1	- 6.2	38.4	+.510	0	.357	7
8	2.75	3.4	2.5	-4.4	26.6	.033	-.099	.246	1.1	- 5.7	25.2	-.016	-.142	.234	8
			Test 7						Test 8						
1	0.9	7.4	2.3	-10.6	20.2	-.024	-.271	.195	3.4	- 8.7	20.0	.022	-.213	.194	1
2	0.9	5.4	3.7	-11.2	27.1	+.007	-.277	.259	4.4	- 9.4	25.7	+.043	-.223	.250	2
3	0.9	3.4	+4.8	-14.5	35.3	+.012	-.359	.337	1.1	-11.0	30.5	-.060	-.292	.295	3
4	0.9	0.8	-1.3	-6.2	38.8	-.088	-.180	.373	1.8	- 4.6	44.0	+.012	-.113	.427	4
5	2.75	0.8	+3.9	-4.6	55.8	+.069	-.093	.534	5.0	- 3.0	51.2	.096	-.041	.496	5
6	4.72	0.8	13.8	-10.3	51.2	.295	-.169	.493	14.9	- 8.7	51.6	.340	-.115	.501	6
7	8.67	0.8	19.5	-6.9	36.5	.477	-.024	.350	20.0	- 5.7	36.3	.506	+.007	.353	7
8	2.75	3.4	2.5	-7.8	26.9	.005	-.192	.259	3.9	- 6.2	27.5	.055	-.139	.266	8

TABLE II, Contd.

SKIN STRESSES															
			Test 9						Test 10						
Gauge Group	x (ins)	y (ins)	$e_{xx}.10^5$	$e_{yy}.10^5$	$e_{xy}.10^5$	f_{xx}/f_o	f_{yy}/f_o	q_{xy}/f_o	$e_{xx}.10^5$	$e_{yy}.10^5$	$e_{xy}.10^5$	f_{xx}/f_o	f_{yy}/f_o	q_{xy}/f_o	Gauge Group
1	0.9	7.4	2.5	-9.6	23.4	-.012	-.242	.225	+6.2	-17.9	4.8	+.035	-.580	.060	1
2	0.9	5.4	5.5	-11.0	27.1	+.059	-.256	.261	+3.9	-14.0	6.4	-.009	-.465	.082	2
3	0.9	3.4	+3.9	-14.7	32.8	-.014	-.370	.312	+4.4	-11.7	11.5	+.035	-.376	.147	3
4	0.9	0.8	-13.3	-7.3	54.1	-.425	-.308	.520	0	- 2.5	20.0	-.028	-.091	.254	4
5	2.75	0.8	+4.1	-5.3	52.1	+.069	-.111	.500	+6.9	- 3.7	31.6	+.210	-.056	.402	5
6	4.72	0.8	12.1	-8.0	51.5	.265	-.121	.494	+12.9	- 8.9	32.8	+.364	-.182	.417	6
7	8.67	0.8	20.4	-5.7	37.6	.510	-.012	.360	+16.5	- 5.5	25.7	+.536	-.019	.326	7
8	2.75	3.4	2.8	-7.6	26.4	.014	-.187	.254	+2.5	- 6.9	13.1	+.016	-.222	.166	8

TABLE II, Contd.

END RIB STRESSES									
			Test 1			Test 2			
Gauge No.	x (ins)	y (ins)	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R / F f_o$	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R / F f_o$	Gauge No.
25	-	21.4	-13.8	-.32	-.112	-13.3	-.35	-.110	25
26	-	11.4	-12.4	-.29	-.100	-11.7	-.31	-.096	26
27	-	7.4	-11.3	-.26	-.091	-11.7	-.31	-.096	27
28	-	5.4	-11.5	-.27	-.093	-11.3	-.30	-.093	28
29	-	3.4	-11.1	-.26	-.089	-10.6	-.28	-.087	29

SPAR BOOM STRESSES											
			Test 1				Test 2				
Gauge Group	x (ins)	y (ins)	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_R(psi) (DUE BM)	$\Delta f_B/f_B$	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	Gauge Group
30-41	-4.0	-	38.0	1.00	1000	+.244	38.2	1.00	1030	+.256	30
31-40	+0.8	-	36.4	.883	-2600	-.746	36.4	.950	-1230	-.322	31
32-39	2.8	-	32.6	.832	-1540	-.448	32.1	.840	-1380	-.408	32
33-38	4.6	-	31.3	.800	-1620	-.492	30.8	.805	-1640	-.507	33
34-37	8.4	-	29.6	.760	- 780	-.250	28.4	.742	- 800	-.268	34
35-36	12.4	-	27.1	.692	- 280	-.098	26.2	.688	- 320	-.116	35

TABLE II, Contd.

END RIB STRESSES

			Test 3			Test 4			
Gauge No.	x (ins)	y (ins)	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R/Ff_o$	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R/Ff_o$	Gauge No.
25	-	21.4	-12.7	-.29	-.098	-10.6	-.35	-.106	25
26	-	11.4	-11.3	-.26	-.087	- 9.0	-.29	-.090	26
27	-	7.4	- 9.9	-.23	-.076	- 7.6	-.25	-.076	27
28	-	5.4	- 9.7	-.23	-.075	- 7.1	-.23	-.071	28
29	-	3.4	- 6.9	-.16	-.053	- 5.1	-.17	-.051	29

SPAR BOOM STRESSES

			Test 3				Test 4				
Gauge Group	x (ins)	y (ins)	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	Gauge No.
30-41-50	-4.0	-	40.8	1.000	730	.170	30.7	1.000	190	.059	30
31-40-49	+0.8	-	41.5	1.014	+230	+.053	30.5	.992	+850	+.266	31
32-39-48	2.8	-	34.7	.849	-1210	-.331	28.5	.930	-190	-.063	32
33-38-47	4.6	-	33.0	.805	-1260	-.364	26.5	.864	-850	-.305	33
34-37-46	8.4	-	31.6	.772	-1080	-.325	23.6	.772	-650	-.262	34
35-36-45	12.4	-	28.4	.693	-480	-.166	21.8	.710	-390	-.162	35

TABLE II, Contd.

END RIB STRESSES

			Test 5			Test 6			
Gauge No.	x (ins)	y (ins)	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R/Ff_o$	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R/Ff_o$	Gauge No.
25	-	21.4	-13.4	-.33	-.101	-13.4	-.32	-.099	25
26	-	11.7	-12.2	-.30	-.093	-12.0	-.29	-.089	26
27	-	7.4	-10.6	-.26	-.080	-10.4	-.25	-.077	27
28	-	5.4	- 9.4	-.23	-.072	- 8.8	-.21	-.065	28
29	-	3.4	- 8.1	-.20	-.061	- 4.6	-.11	-.034	29

SPAR BOOM STRESSES

			Test 5				Test 6				
Gauge Group	x (ins)	y (ins)	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	
30-41-50	-4.0	-	40.5	1.000	320	.075	41.5	1.00	-	-	30
31-40-49	+0.8	-	38.1	.942	+530	+.132	42.0	1.014	+1010	+.228	31
32-39-48	2.8	-	36.2	.894	-560	-.147	39.2	.947	- 460	-.115	32
33-38-47	4.6	-	35.1	.870	-1160	-.315	36.8	.888	- 920	-.238	33
34-37-46	8.6	-	31.6	.782	- 610	-.183	32.5	.784	- 850	-.259	34
35-36-45	12.4	-	28.9	.713	- 680	-.224	29.5	.712	- 700	-.226	35

TABLE II, Contd.

END RIB STRESSES

			Test 7			Test 8			
Gauge No.	x (ins)	y (ins)	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R/F f_o$	$e_R \div 10^{-5}$	f_R/f_o	$A_R f_R/F f_o$	Gauge No.
25	-	21.4	-13.8	-.34	-.105	-13.1	-.33	-.102	25
26	-	11.4	-12.2	-.30	-.093	-12.0	-.30	-.093	26
27	-	7.4	-10.6	-.26	-.081	- 9.7	-.24	-.075	27
28	-	5.4	- 9.2	-.23	-.070	- 8.8	-.22	-.068	28
29	-	3.4	- 6.7	-.17	-.051	- 6.7	-.17	-.052	29

SPAR BOOM STRESSES

			Test 7				Test 8				
Gauge Group	x (ins)	y (ins)	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	$e_{ave} \div 10^{-5}$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	Gauge Group
30-41-50	-4.0	-	40.1	1.000	340	.081	39.7	1.000	290	.070	30
31-40-49	+0.8	-	42.1	1.050	+460	+.104	44.3	1.114	+610	+.131	31
32-39-48	2.8	-	39.4	.982	-1060	-.256	40.1	1.008	-900	-.224	32
33-38-47	4.6	-	36.0	.900	-1520	-.402	35.7	.900	-1500	-.400	33
34-37-46	8.4	-	31.5	.787	- 820	-.248	31.5	.794	- 870	-.263	34
35-36-45	12.4	-	29.2	.728	- 630	-.205	29.0	.730	- 630	-.207	35

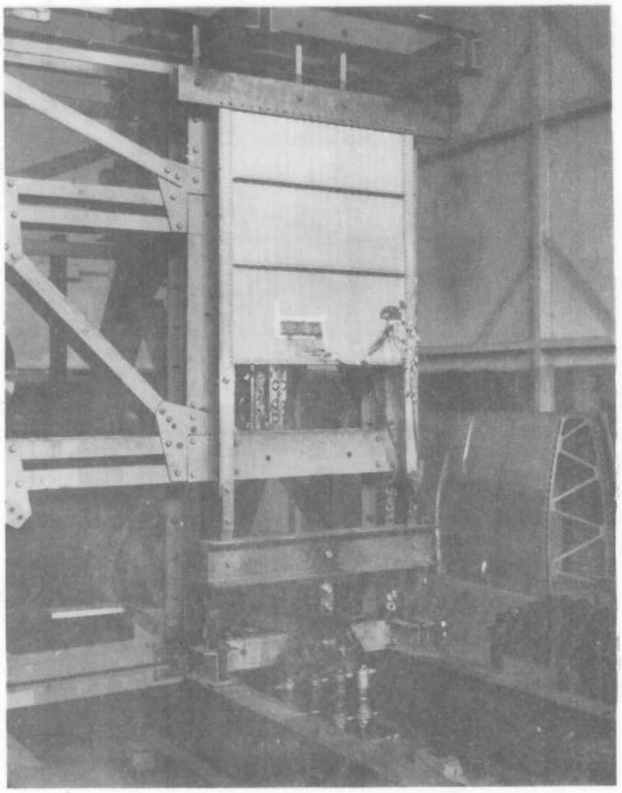
TABLE II, Contd.

END RIB STRESSES

			Test 9			Test 10			
Gauge No.	x (ins)	y (ins)	$e_R \cdot 10^5$	f_R/f_o	$A_R f_R/Ff_o$	$e_R \cdot 10^5$	f_R/f_o	$A_R f_R/Ff_o$	Gauge No.
25	-	21.4	-12.9	-.321	-.098				25
26	-	11.4	-11.5	-.287	-.088	NO END RIB			26
27	-	7.4	- 9.0	-.22	-.068				27
28	-	5.4	- 7.6	-.19	-.058				28
29	-	3.4	- 4.2	-.10	-.032				29

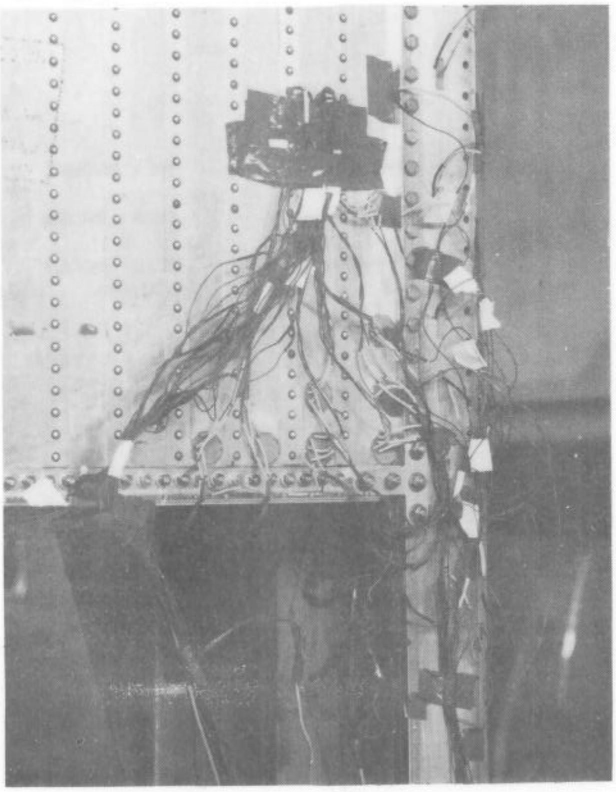
SPAR BOOM STRESSES

			Test 9				Test 10				
Gauge Group	x (ins)	y (ins)	$e_{ave} \cdot 10^5$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	$e_{ave} \cdot 10^5$	f_B/f_o	Δf_B(psi) (DUE BM)	$\Delta f_B/f_B$	Gauge Group
30-41-50	-4.0	-	40.2	1.000	-	-	30.4	1.000	560	.176	30
31-40-49	+0.8	-	40.8	1.017	+1110	+.259	31.5	1.040	+1060	+.320	31
32-39-38	2.8	-	38.3	.952	- 600	-.149	29.5	.972	-220	-.071	32
33-38-47	4.6	-	35.8	.890	-1600	-.425	28.1	.925	-1140	-.386	33
34-37-46	8.4	-	32.2	.803	-1060	-.312	25.6	.842	- 870	-.323	34
35-36-45	12.4	-	29.3	.730	- 680	-.220	23.3	.768	- 720	-.294	35



GENERAL ARRANGEMENT OF TEST PANEL

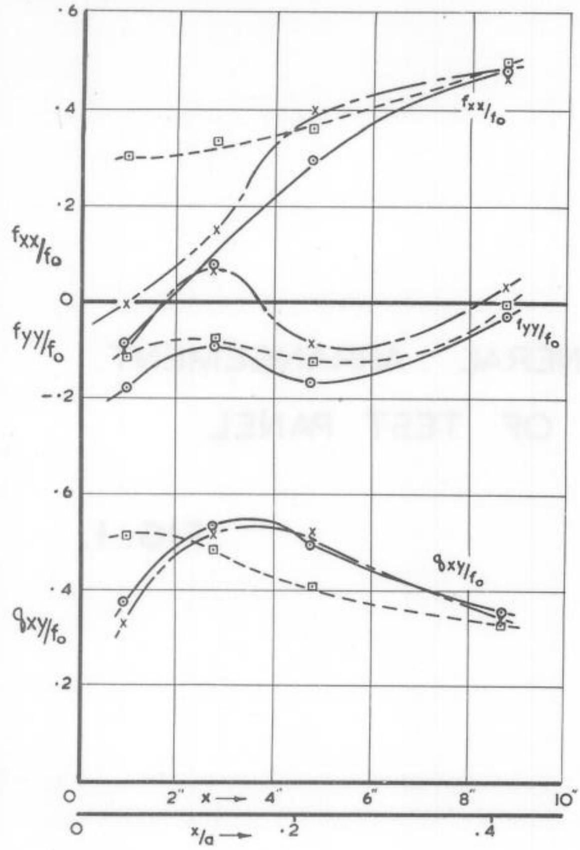
FIG. 1.



DETAILS OF CORNER

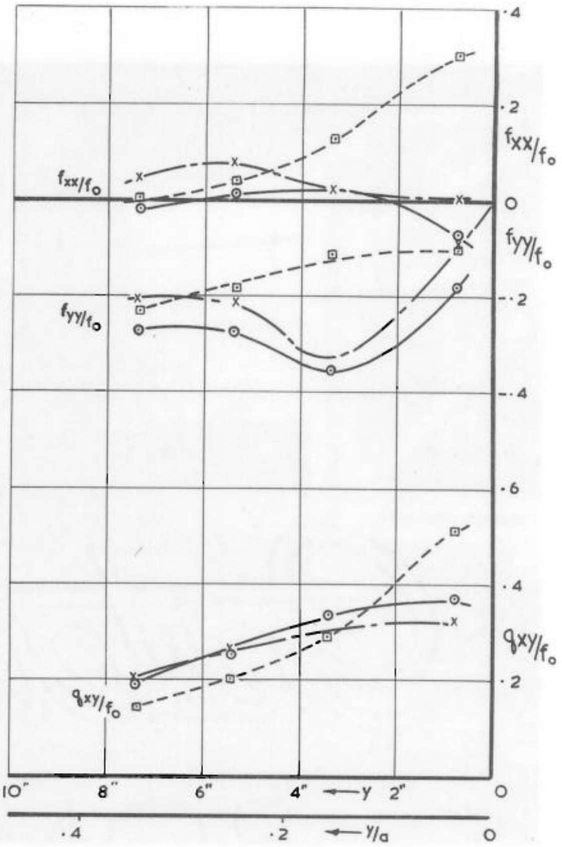
FIG. 2.

FIGS. 3, 4 & 5.



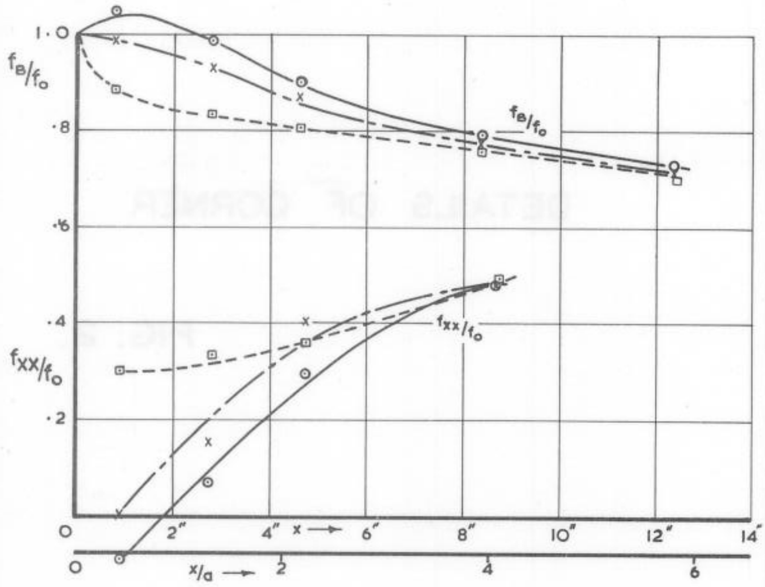
LONGITUDINAL EDGE STRESSES
END RIB BUILT—IN.

FIG. 3.



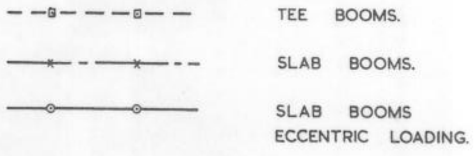
LATERAL EDGE STRESSES
END RIB BUILT—IN.

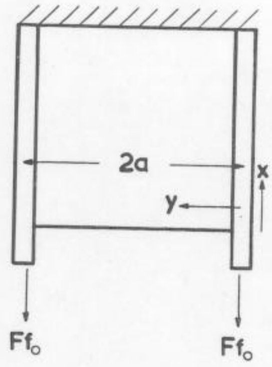
FIG. 4.

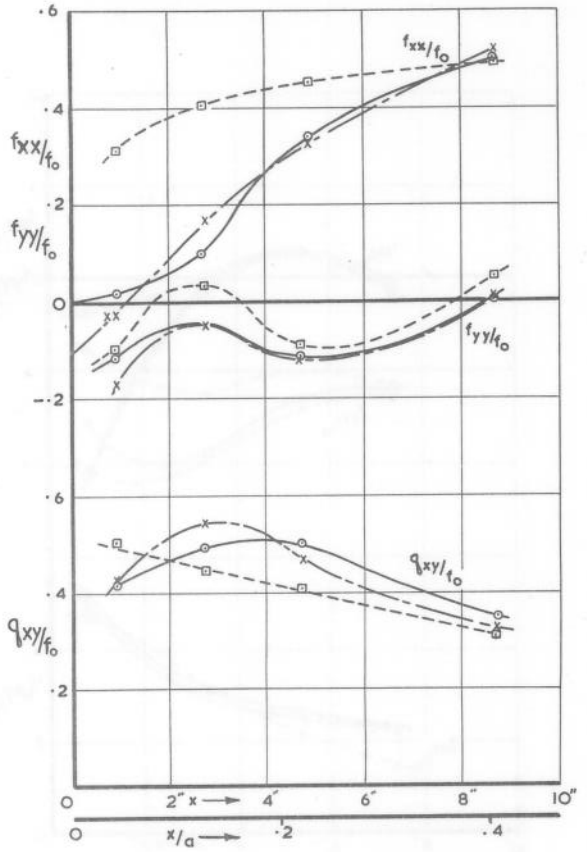


LOAD DIFFUSION END RIB BUILT — IN.

FIG. 5.

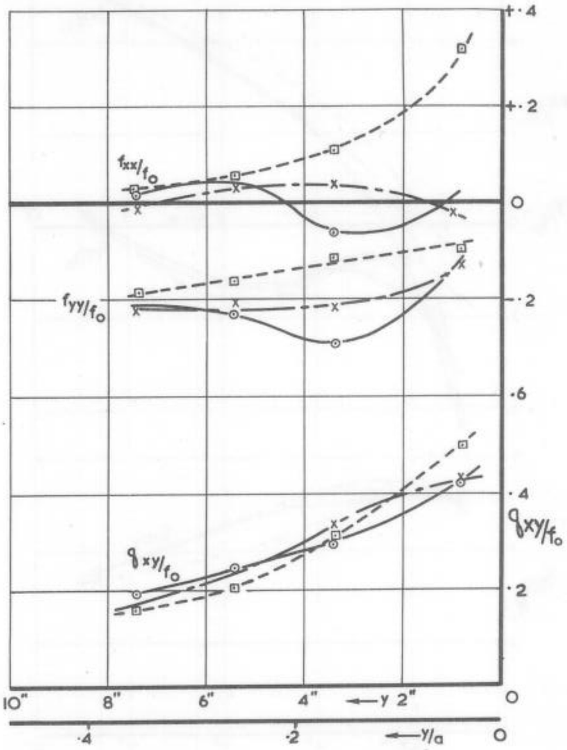






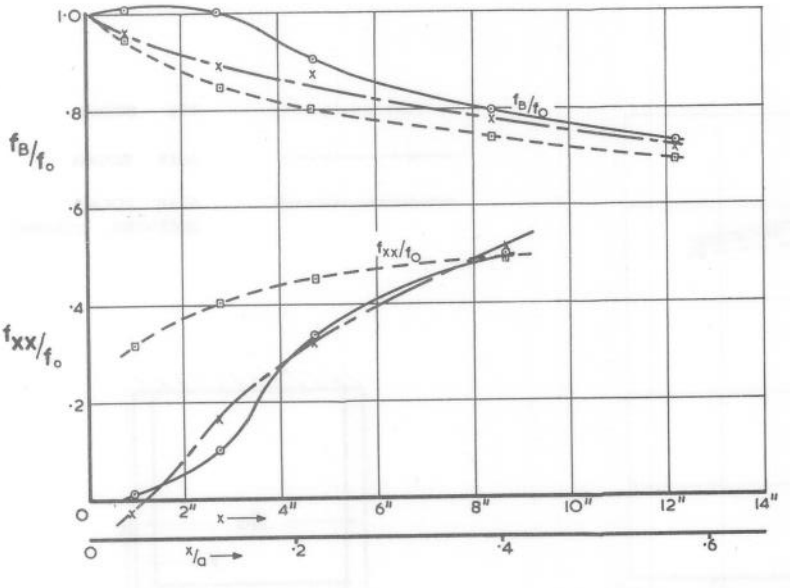
LONGITUDINAL EDGE STRESSES
END RIB SIMPLY SUPPORTED

FIG. 6.



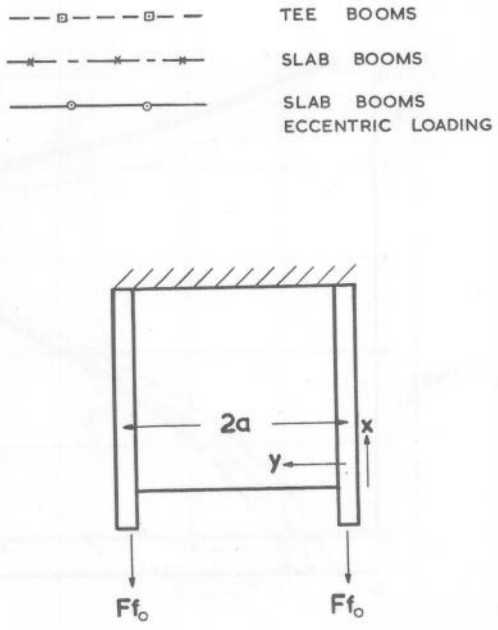
LATERAL EDGE STRESSES
END RIB SIMPLY SUPPORTED

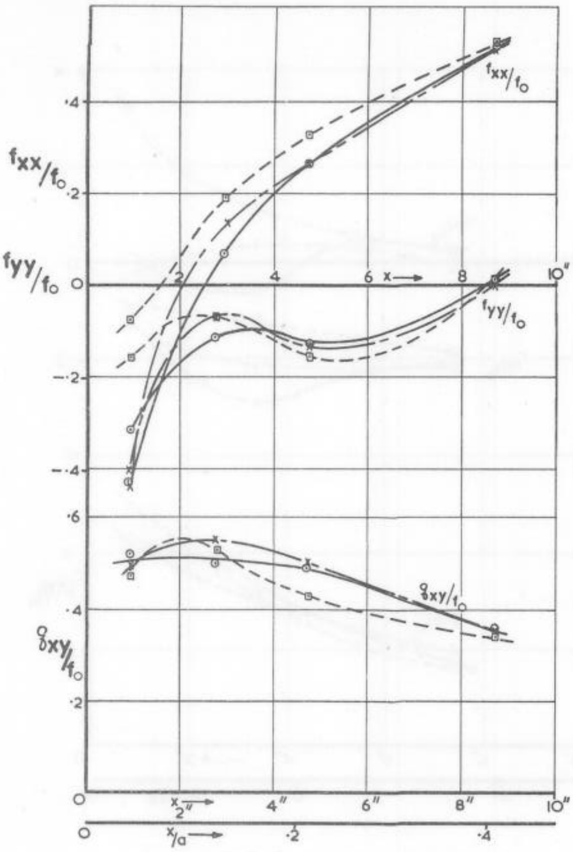
FIG. 7.



LOAD DIFFUSION END RIB SIMPLY SUPPORTED

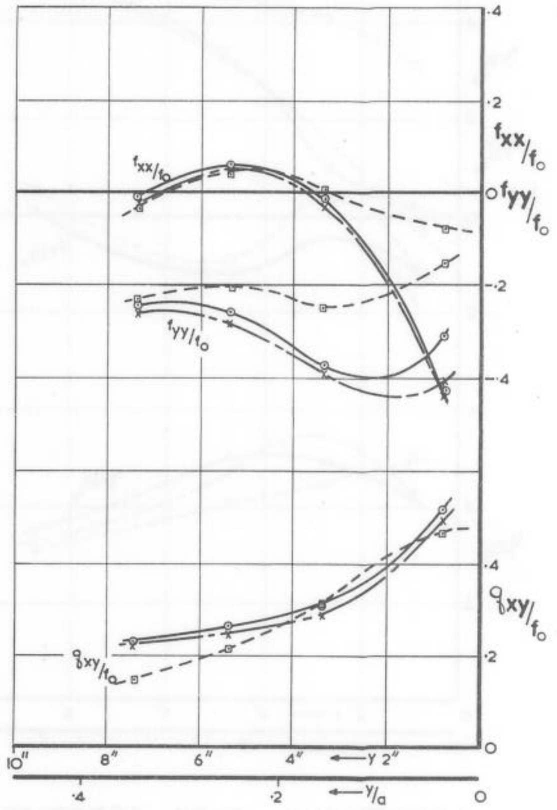
FIG. 8.





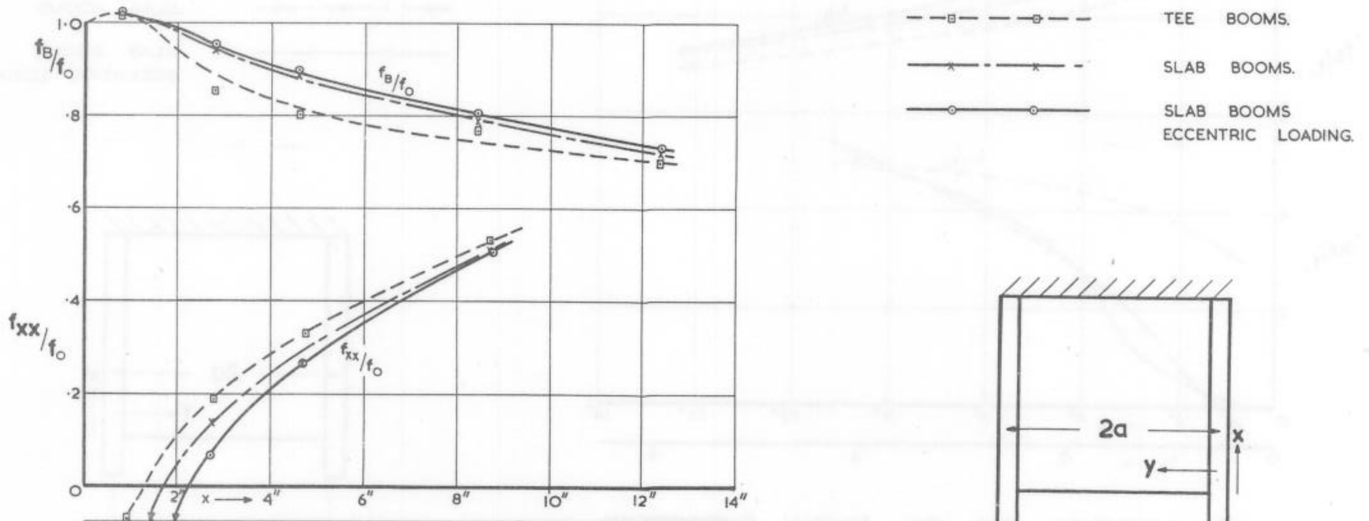
LONGITUDINAL EDGE STRESSES
END RIB FREE.

FIG. 9.



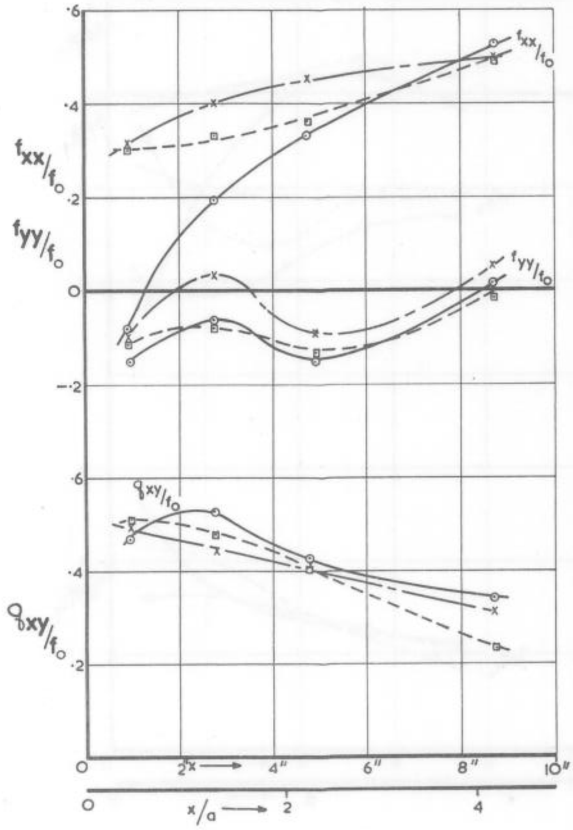
LATERAL EDGE STRESSES
END RIB FREE.

FIG. 10.



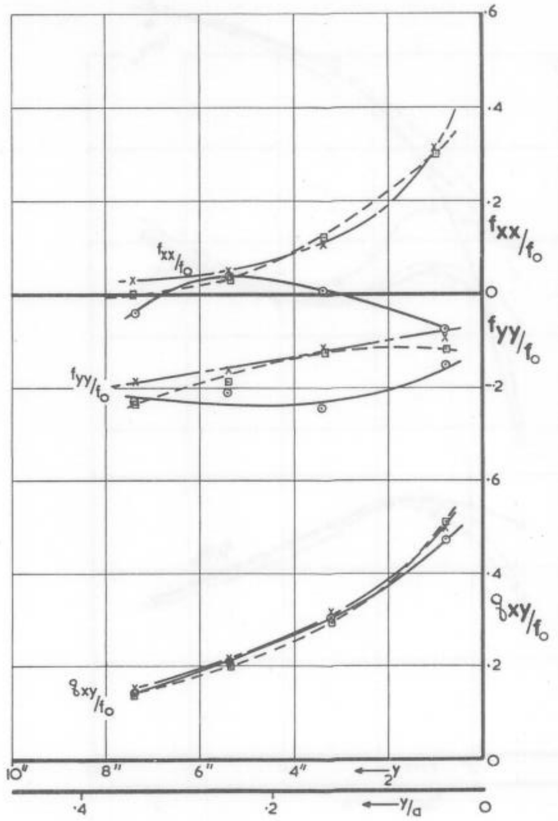
LOAD DIFFUSION END RIB FREE.

FIG. 11.



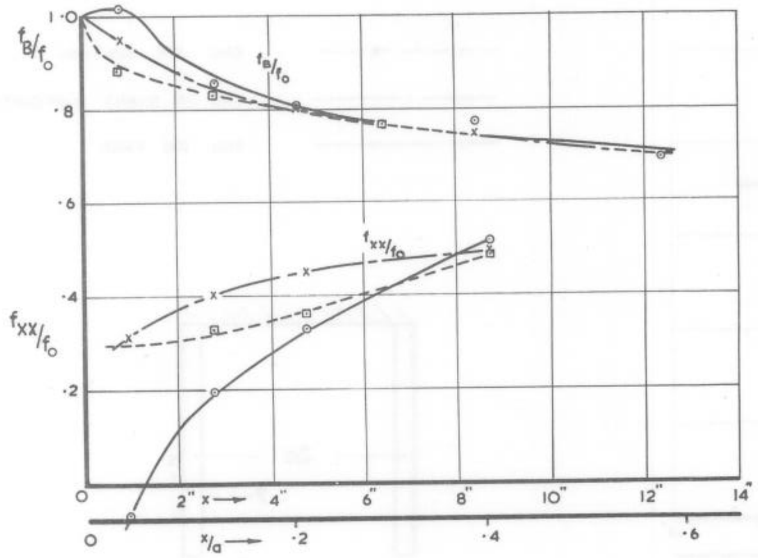
LONGITUDINAL EDGE STRESSES
TEE BOOMS

FIG. 12.



LATERAL EDGE STRESSES
TEE BOOMS

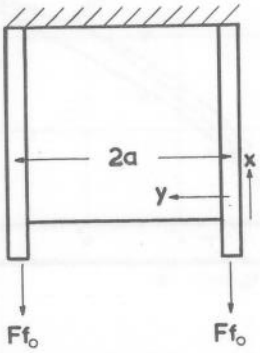
FIG. 13.



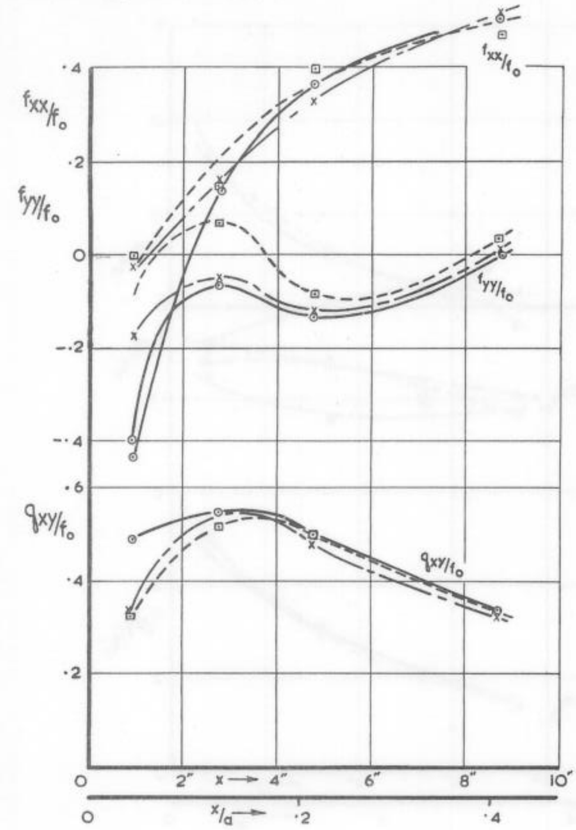
LOAD DIFFUSION
TEE BOOMS

FIG. 14.

- - ⊡ - - ⊡ - - END RIB BUILT-IN
–·×–·×–·× END RIB SIMPLY SUPPORTED
—⊙——⊙— END RIB FREE

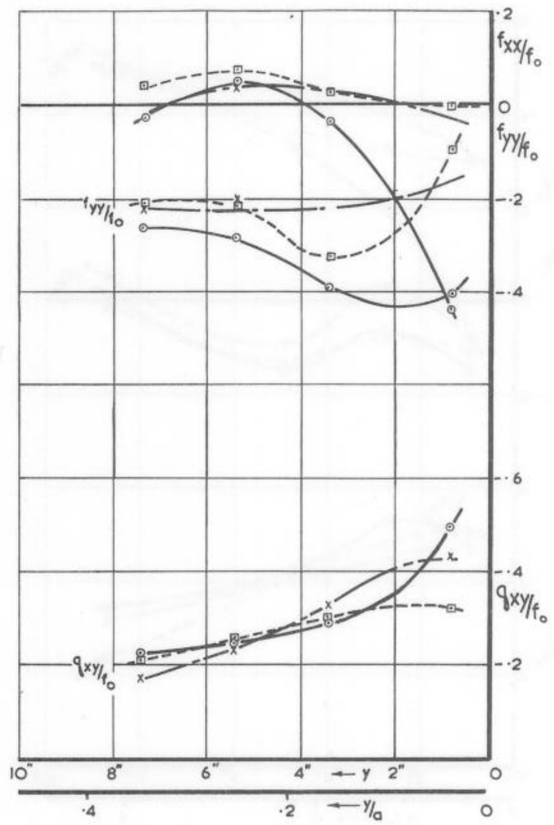


FIGS. 15, 16 & 17.



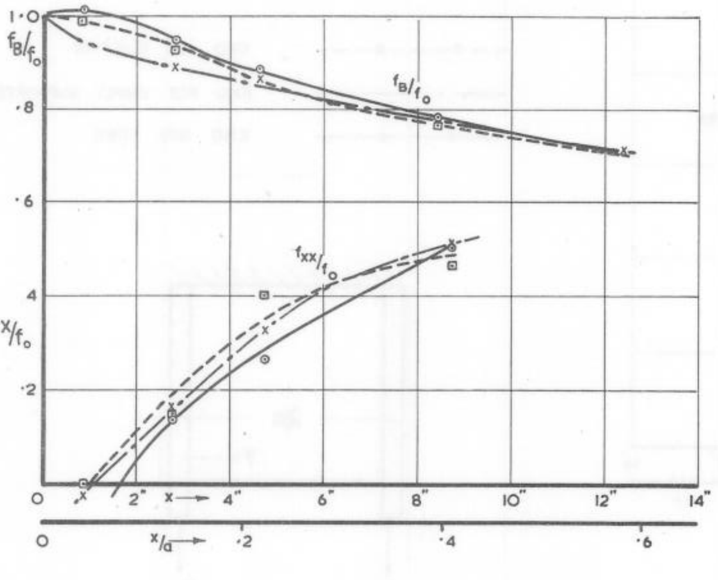
LONGITUDINAL EDGE STRESSES
SLAB BOOMS.

FIG. 15.



LATERAL EDGE STRESSES
SLAB BOOMS

FIG. 16.



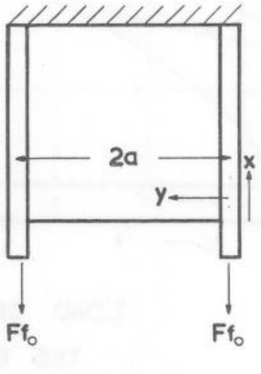
LOAD DIFFUSION SLAB BOOMS.

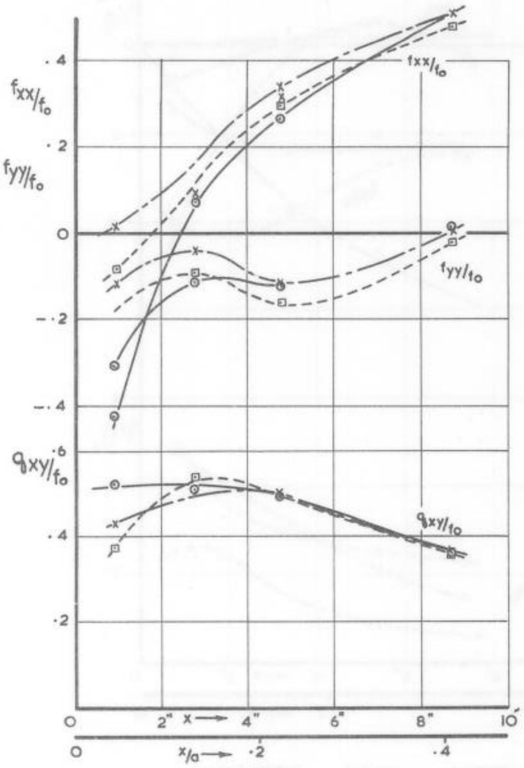
FIG. 17.

– – ⊡ – – – ⊡ – – END RIB BUILT-IN.

—×—·—×— END RIB SIMPLY SUPPORTED.

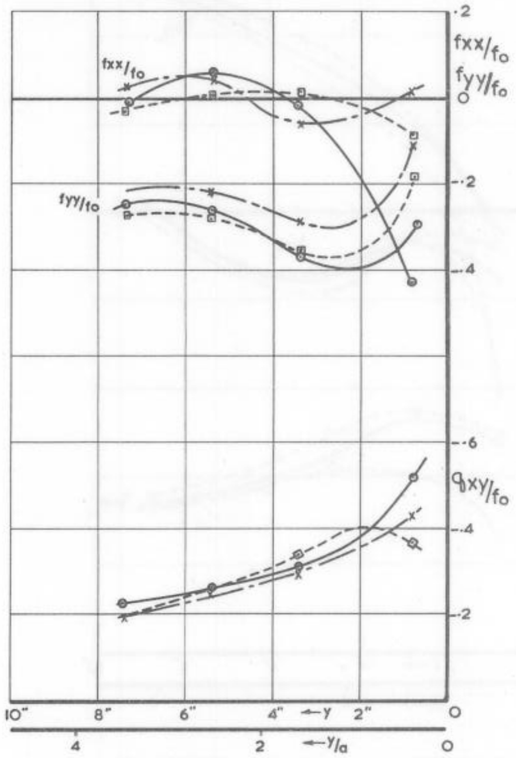
—⊙———⊙— END RIB FREE.





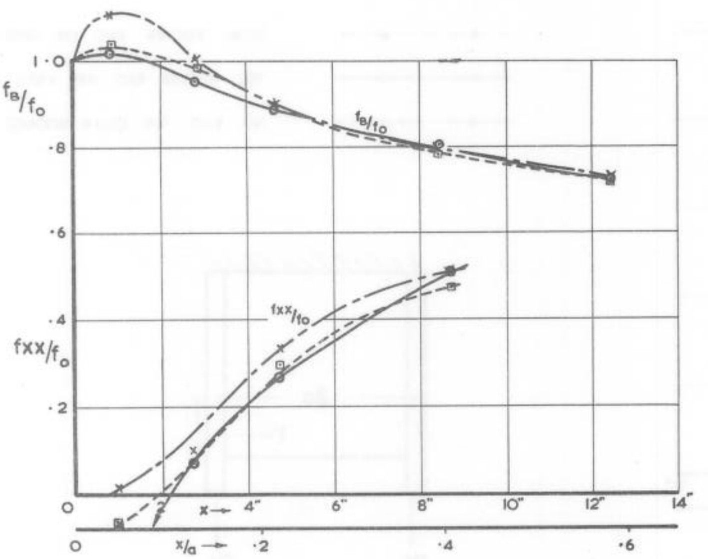
LONGITUDINAL EDGE STRESSES
ECCENTRIC LOADING (SLAB BOOMS)

FIG. 18.



LATERAL EDGE STRESSES
ECCENTRIC LOADING (SLAB BOOMS)

FIG. 19.



LOAD DIFFUSION
ECCENTRIC LOADING (SLAB BOOMS)

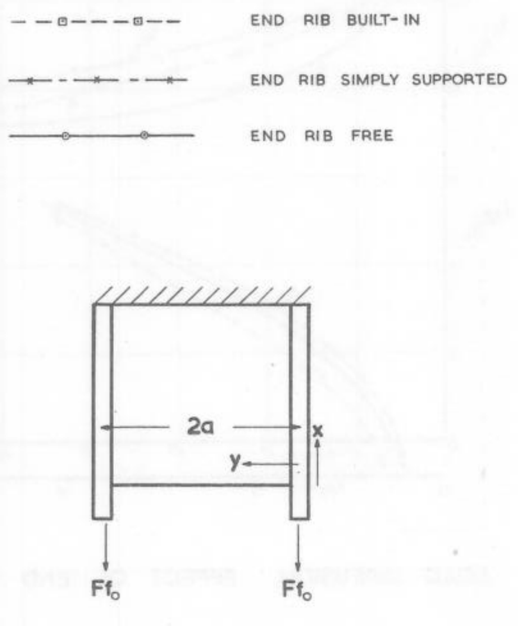
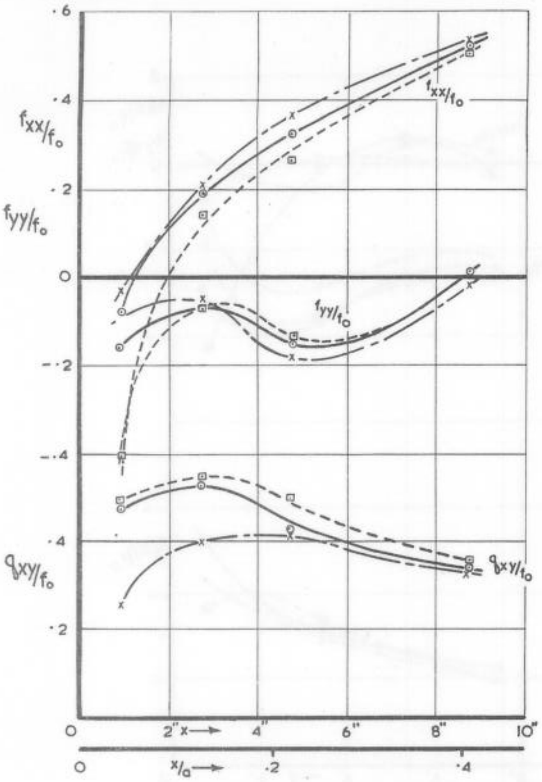


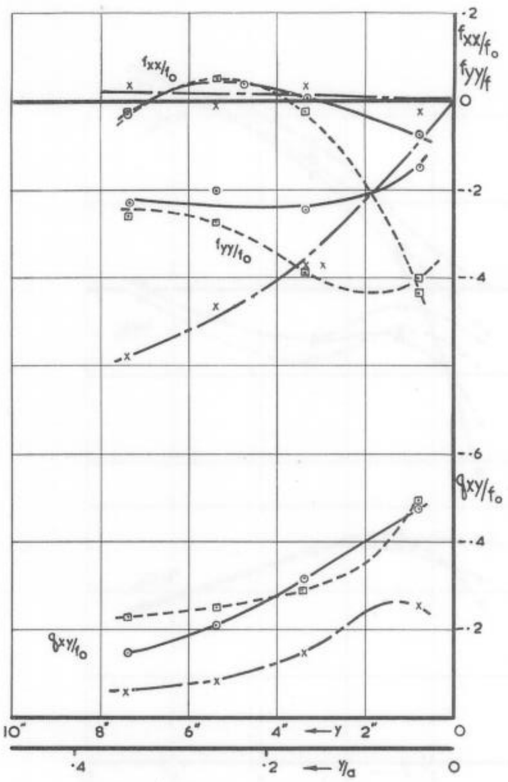
FIG. 20.

FIGS. 21, 22 & 23.



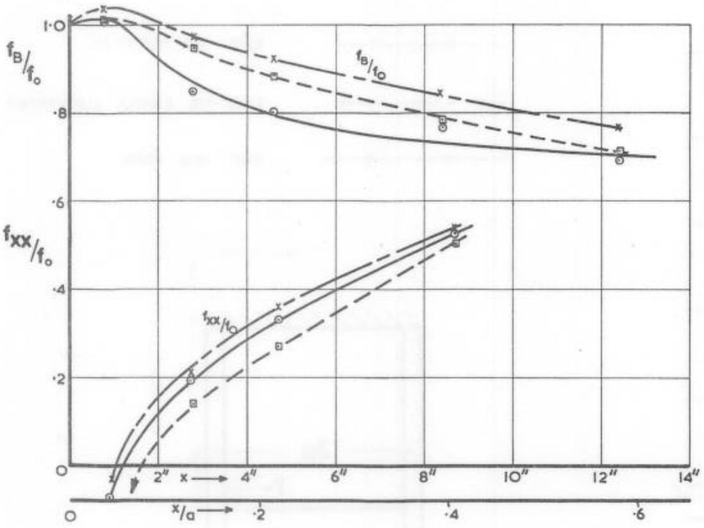
LONGITUDINAL EDGE STRESSES
EFFECT OF END RIB REMOVAL.

FIG. 21.



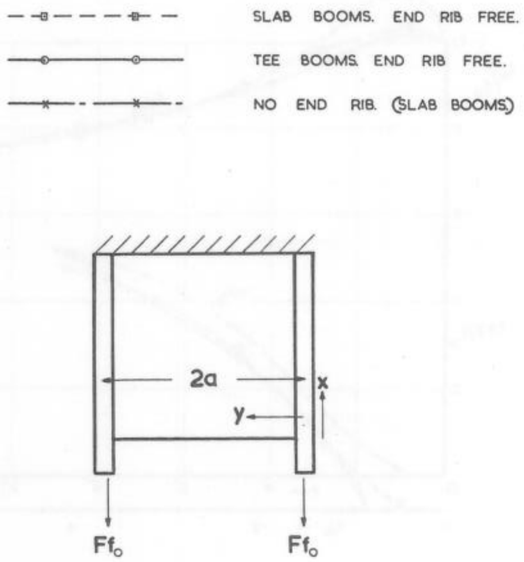
LATERAL EDGE STRESSES
EFFECT OF END RIB REMOVAL.

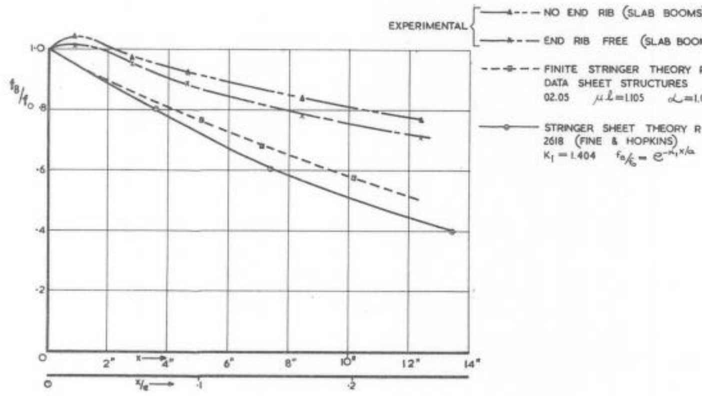
FIG. 22.



LOAD DIFFUSION EFFECT OF END RIB REMOVAL.

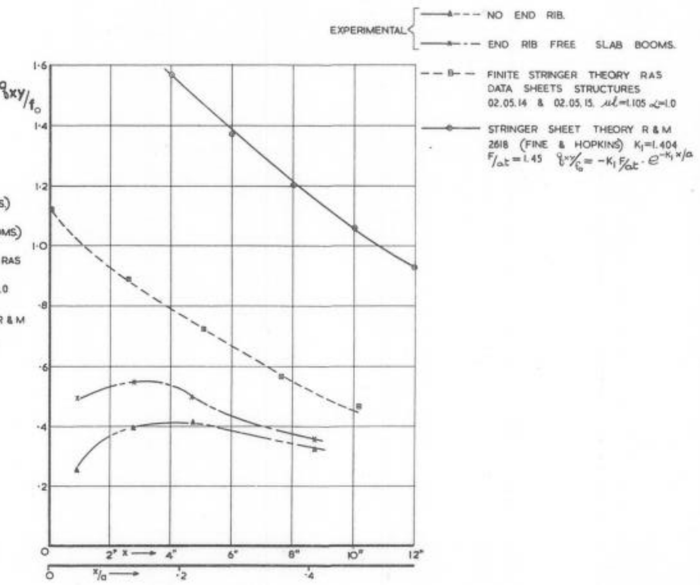
FIG. 23.





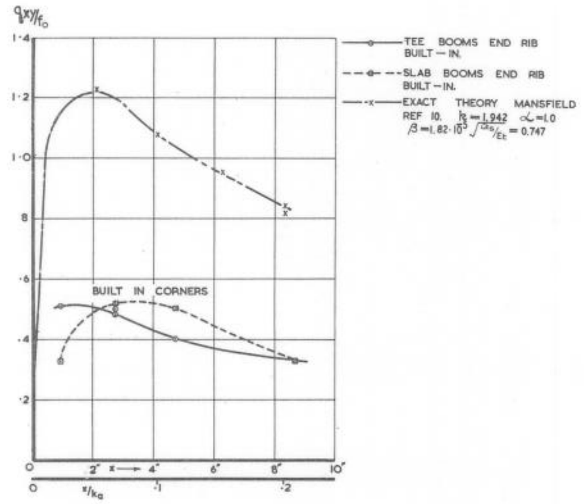
LOAD DIFFUSION COMPARISON OF THEORY WITH EXPERIMENT

FIG. 24.



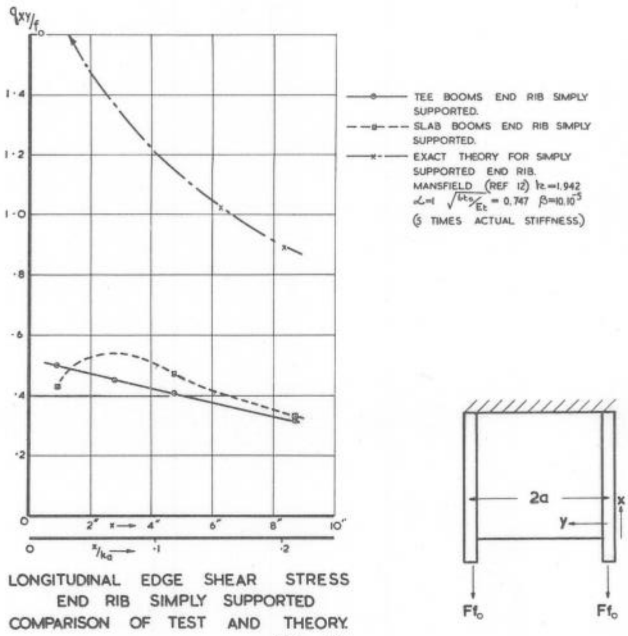
LONGITUDINAL EDGE SHEAR STRESS COMPARISON OF THEORY WITH EXPERIMENT.

FIG. 25.



LONGITUDINAL SHEAR STRESSES COMPARISON OF TEST AND THEORY

FIG. 26.



LONGITUDINAL EDGE SHEAR STRESS END RIB SIMPLY SUPPORTED COMPARISON OF TEST AND THEORY.

FIG. 27.