March 1955 P/Models/60

STRUCTURAL INVESTIGATION OF A 3% t/c RATIO MULTI-SPAR PLASTIC MODEL FIN

W. Czerwinski A.P. Sentance

AVRO AIRCRAFT LIMITED

SECRET

BOX 4004
TERMINAL 'A'
TORONTO, ONT.

Engineering
1467/01/J

25th April, 1955

Mr. F.R. Thurston,
Director, Structures Laboratory,
Division of Mechanical Engineering,
National Aeronautical Establishment,
National Research Council,
Montreal Road,
OTTAWA, Ont.

Dear Mr. Thurston,

Please receive herewith two copies of Avro Aircraft Projects Office Report P/Models/46, dealing with structural investigation of a 3% t/c ratio Multi Spar Plastic Model Fin. These are for retention in your Structures Laboratory files.

The report deals with the first stage of a series of plastic model investigations, the progress of which we shall keep you informed from time to time.

The fair agreement shown in this report between deflections and strain distributions obtained by analysis of an idealised structure, and the deflections and strain distributions of the closely representative plastic model of the idealised structure, thoroughly justifies the use of model investigation.

Normally, a model will represent a close approximation to an actual structure, not an idealised one; and the analytical investigation will be performed on a close idealisation of the actual structure.

I feel that one of the valuable features of plastic model investigation, is the possibility of indicating how the structure shall be idealised for analytical investigation.

Our next model tests will be on a representative structure of the C-105.

If you should require further data on the above reports, please do not hesitate to make the request.

With best regards,
Yours truly,
For Avro Aircraft Limited

E.W.H. Thompson
E.W.H. Thompson
Chief Structures Engineer

EWHT:dmh

Serial No. JCF 597

A. V. ROE CANADA LIMITED
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TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT: C-105 REPORT NO P/MODELS/46

FILE NO: P/Models/46 NO. OF SHEETS:

TITLE:

STRUCTURAL INVESTIGATION OF A 3% t/c RATIO MULTI-SPAR PLASTIC MODEL FIN

PREPARED BY A.P. Sentance DATE Feb. 1955

CHECKED BY DATE

SUPERVISED BY W. Czerwinski DATE March 1955

APPROVED BY DATE

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SUMMARY

A multi-web fin structure on a foundation consisting of a portion of wing trailing edge and representing at a reduced scale a structure previously analyzed analytically was tested under several conditions of load to determine the strain distribution and deflected shape. Modifications were made to the structure during the test period in order to study their effects. The test is discussed herein and the conclusions reached that as well as verification of theoretical methods much additional information of very great interest can be gained in this manner. The data recorded under test have been analyzed and are shown to be in the main in close agreement with calculated values, however, several points possibly not dealt with particularly in a theoretical analysis are brought forth through observation of the experimental results.

INTRODUCTION

The theoretical analysis of stresses and deformations in complicated aeroplane structures represents a great deal of time consuming procedure. In order to reduce the time involved, simplifications are of necessity made to the actual structure with of course a corresponding reduction in the accuracy of the results. It is desirable therefore to check in some manner the degree of validity of these results and since full scale tests of structural parts and alternative designs are very costly and sometimes only completed after the prototype is ready, the building of reduced scale plastic models is one way of reducing the difficulties. The reliability of the underlying theories for stressing can be checked and useful information extracted, such as the performance of different types of structures and local stress concentrations, which are not always illustrated by the calculations.

The first of such tests had as its purpose the determination of the deflected shape of fin structure, the strains at selected points and the rotation at the root of the foundation beams making up the wing base structure, under simulated aerodynamic loading at subsonic speed. The influence of point loads applied at a free edge and at an internal point were also investigated. Testing being completed for the present on this structure, the full collection of experimental results are available in another volume of this report. Contained herein are the final results and interpretation of the same for the more interesting and relevant points.

Reference: (a) R.T. No. 08-226
(b) Memo datum 13th May 1954.
(c) Memo 3305/31/J - dated 16th July 1954.

C-105
PLASTIC MODELS

FIN (t/c = 3.0%)

A.P. Sentance February/55

APPARATUS

The structure was investigated experimentally by the Structural Test Department in set-ups shown pictorially in Figure 1 and in photographs of figures 2 and 3. An attempt was made to carry on the experiments in an enclosed area wherein temperature and humidity were, if not controlled, kept relatively constant through any one test run.

The Model

The model consisted of a six cell swept box with six ribs approximately perpendicular to the spars and top and bottom skins of tapered thickness. There was a narrow doubler on the skins in the root region. The main structural details are shown in Figure 4.

An eight cell trailing edge portion of wing of a constant taper in the chordwise direction only was used as a foundation beam. Structural details are shown in Figure 5.

Both the wing and base were manufactured of "Xylonite" material (cellulose nitrate), all cementing being done with a mixture of acetone and ketone. The fin to base connection was made by cementing along the entire chord length with the addition of bolts as shown in Figure 5 at the spar to wing beam joint positions.

The model was tested in three conditions, these being -

(a) as originally conceived and designed.

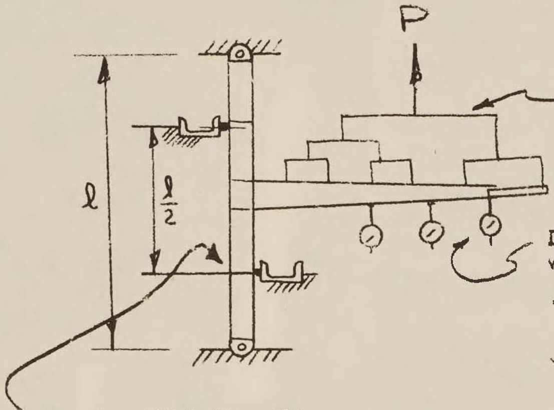
(b) with the addition of shear diaphragms in the fin-root wing intersection, See Figure 8.

(c) with V-struts installed on the lower wing surface, the extremities of which were fixed. See Figure 9 for typical installation.

Instrumentation

All deflections were measured with Ames or Federal dial gauges, with plunger springs removed, deflections being taken at main rib spar intersection points. One-half inch and one-quarter inch National Research Council strain gauges were used at selected positions and read through a Baldwin-Southark SR-4 unit. Gauge arrangement on the fin and foundation beam is given in Figures 6 and 7.

FIG. 1 PICTORIAL VIEWS OF TEST ARRANGEMENT



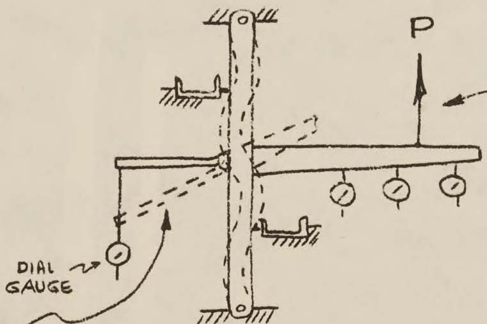
TYPE OF SET-UP UNDER DISTRIBUTED LOAD P

LOAD APPLIED THROUGH WIFFLE TREE ARRANGEMENT

DIAL GAUGES POSITIONED ON LOWER WING SURFACE AS FIG. 7.

STRAIN GAUGES POSITIONED AS ON FIG. 6 & 7.

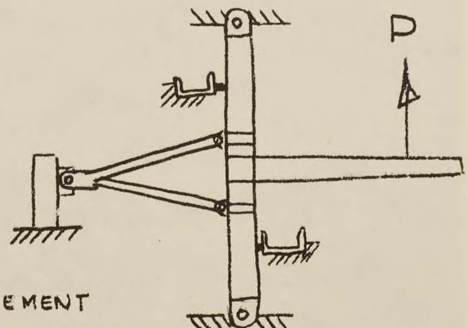
USE OF CHANNELS TO PRODUCE HALF WIDTH SUPPORT POINTS



TYPE OF SET-UP UNDER POINT LOAD P

LOAD APPLIED AT PREDETERMINED POINT.

ARRANGEMENT FOR MEASURING ROTATION OF ROOT INTERSECTION



V-STRUT ARRANGEMENT ON LOWER WING SURFACE SEE DWG 7-0802-0021 FOR DETAILS.

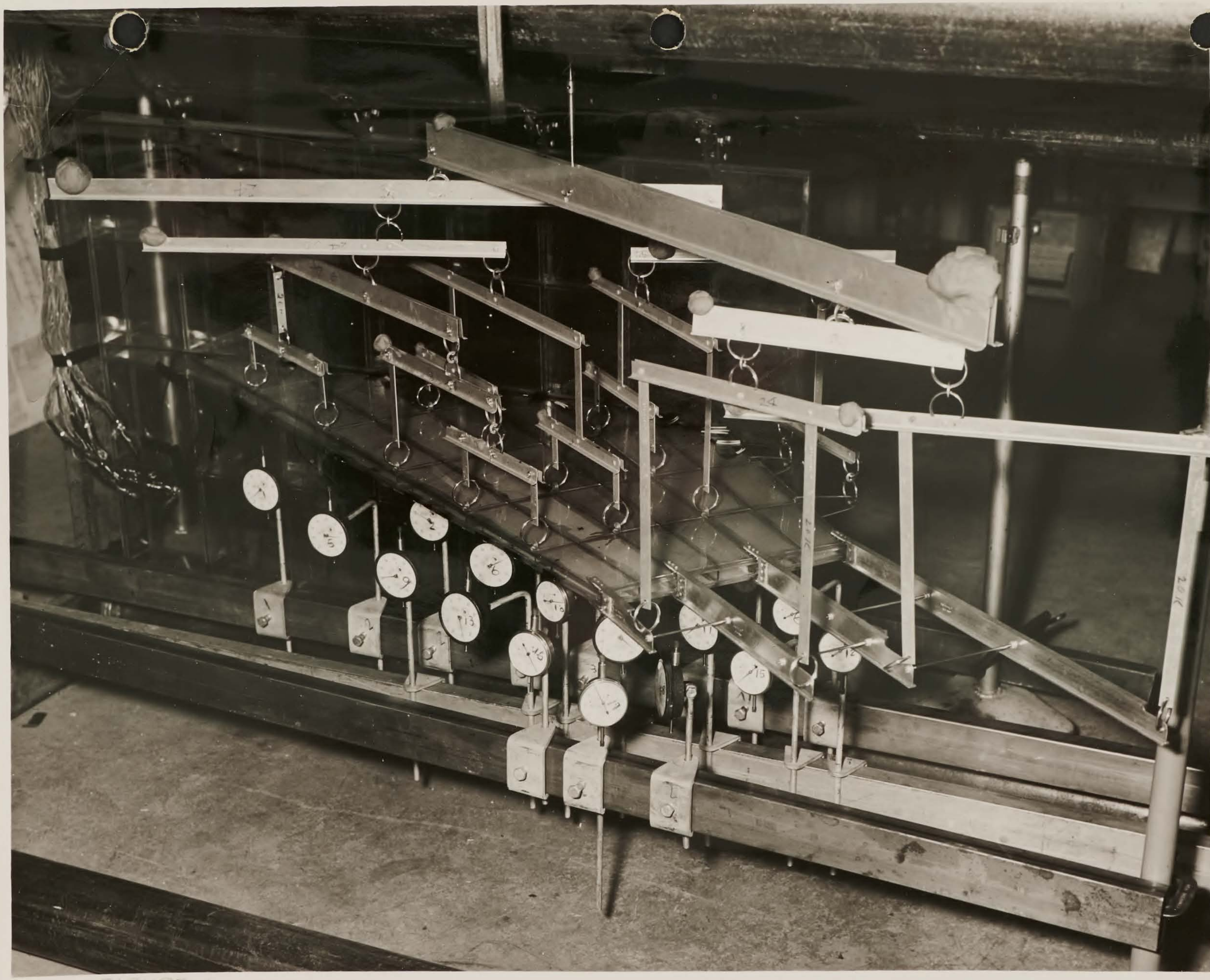


FIGURE 1

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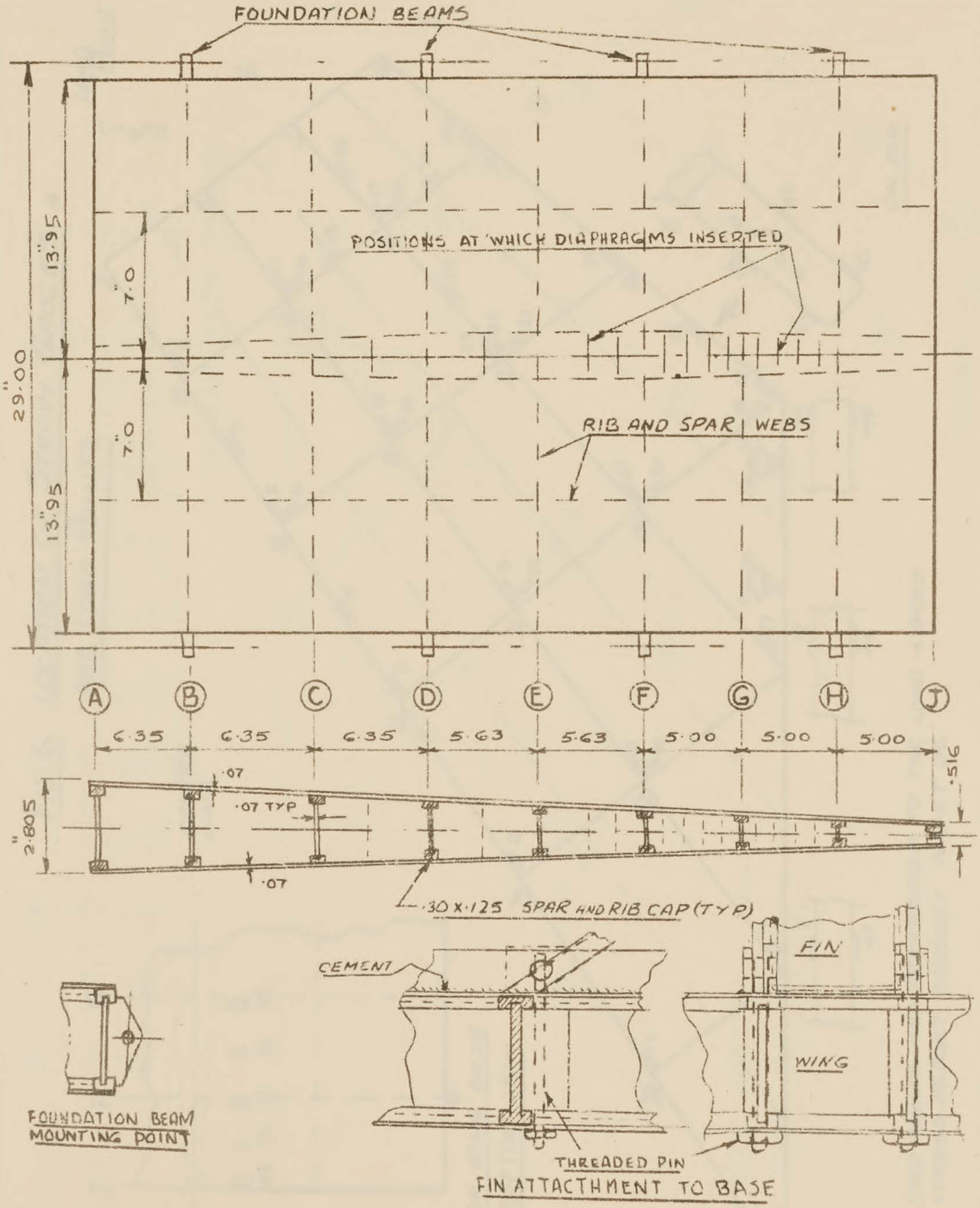

FIG. 5 STRUCTURAL DETAILS OF PLASTIC (XYLONITE) MODEL
WING PORTION SERVING AS FOUNDATION FOR FIN

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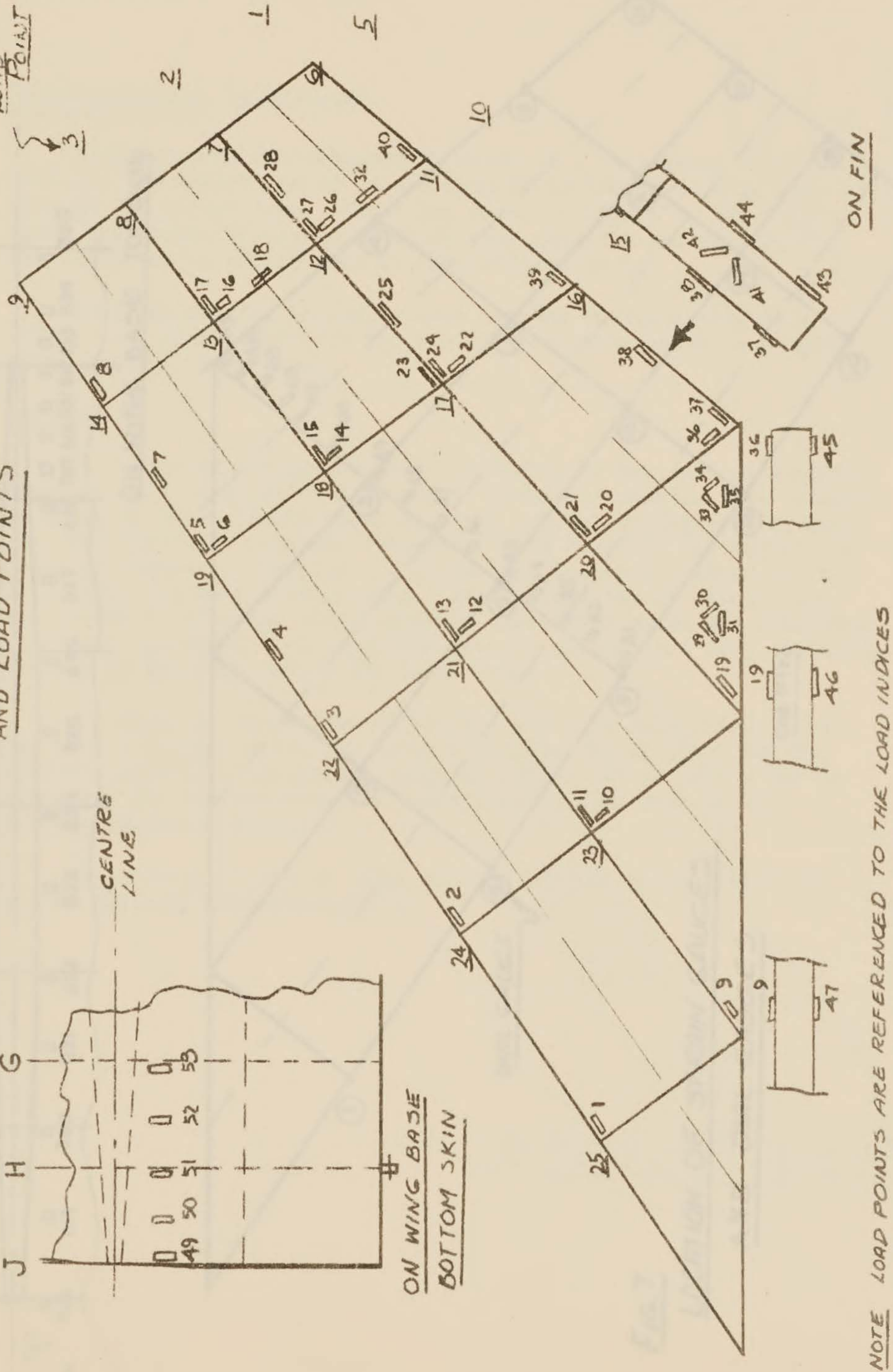

FIG. 6 LOCATION OF STRAIN GAUGES AND LOAD POINTS

NOTE: LOAD POINTS ARE REFERENCED TO THE LOAD INDICES STRESS REPORT 7/0510/1 SHEET 06.

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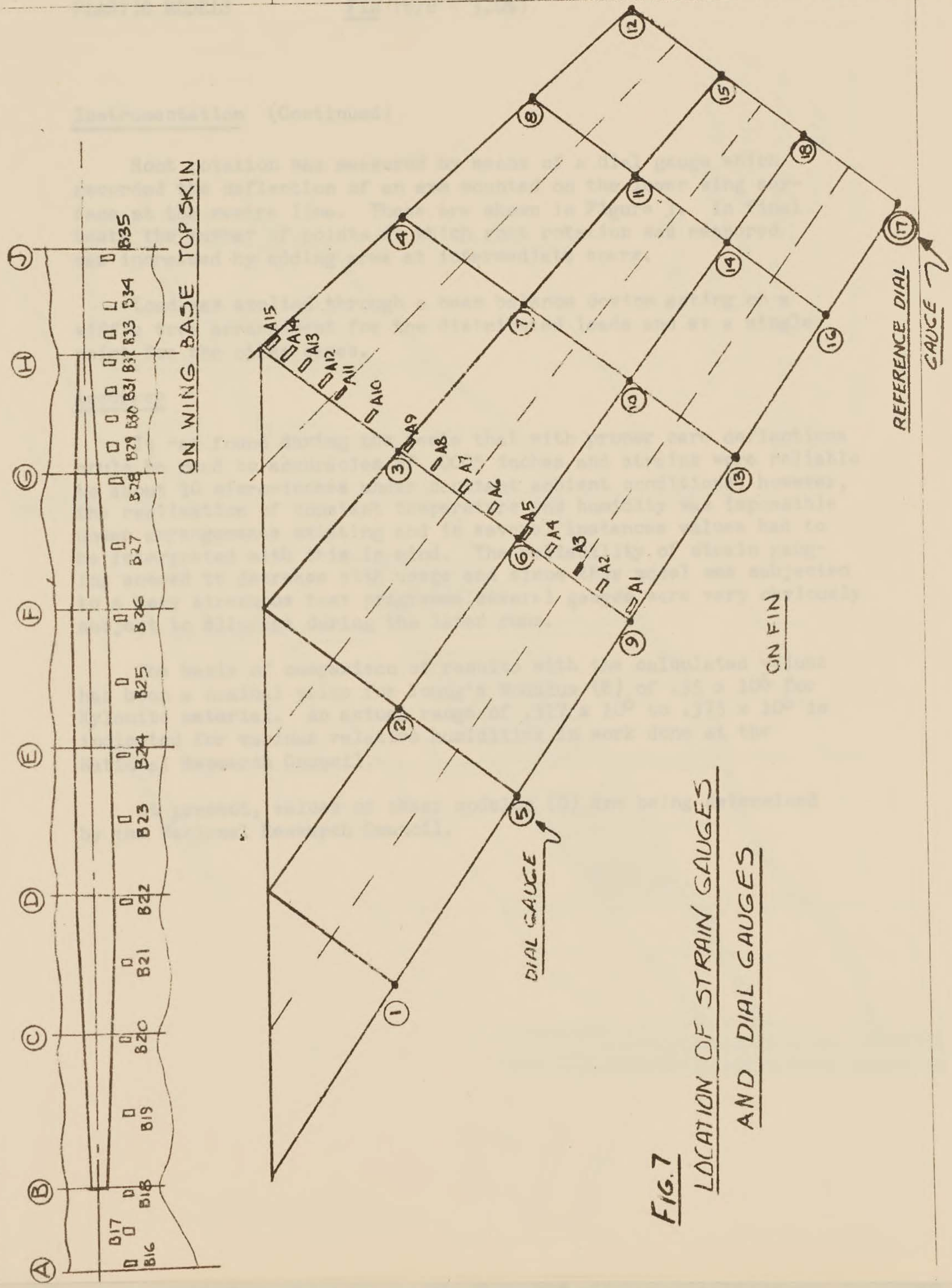


FIG. 7 LOCATION OF STRAIN GAUGES AND DIAL GAUGES

Instrumentation (Continued)

Root rotation was measured by means of a dial gauge which recorded the deflection of an arm mounted on the lower wing surface at the centre line. These are shown in Figure 3. In final tests the number of points at which root rotation was measured was increased by adding arms at intermediate spars.

Load was applied through a beam balance device acting on a wiffle tree arrangement for the distributed loads and at a single point for the other cases.

Accuracy

It was found during the tests that with proper care deflections could be read to accuracies of .0005 inches and strains were reliable to about 10 micro-inches under constant ambient conditions, however, the realization of constant temperature and humidity was impossible under arrangements existing and in several instances values had to be interpreted with this in mind. The reliability of strain gauging seemed to decrease with usage and since this model was subjected to a very strenuous test programme several gauges were very obviously subject to slippage during the later runs.

The basis of comparison of results with the calculated values has been a nominal value for Young's Modulus (E) of $.35 \times 10^6$ for Xylonite material. An actual range of $.317 \times 10^6$ to $.375 \times 10^6$ is indicated for various relative humidities in work done at the National Research Council.

At present, values of shear modulus (G) are being determined by the National Research Council.

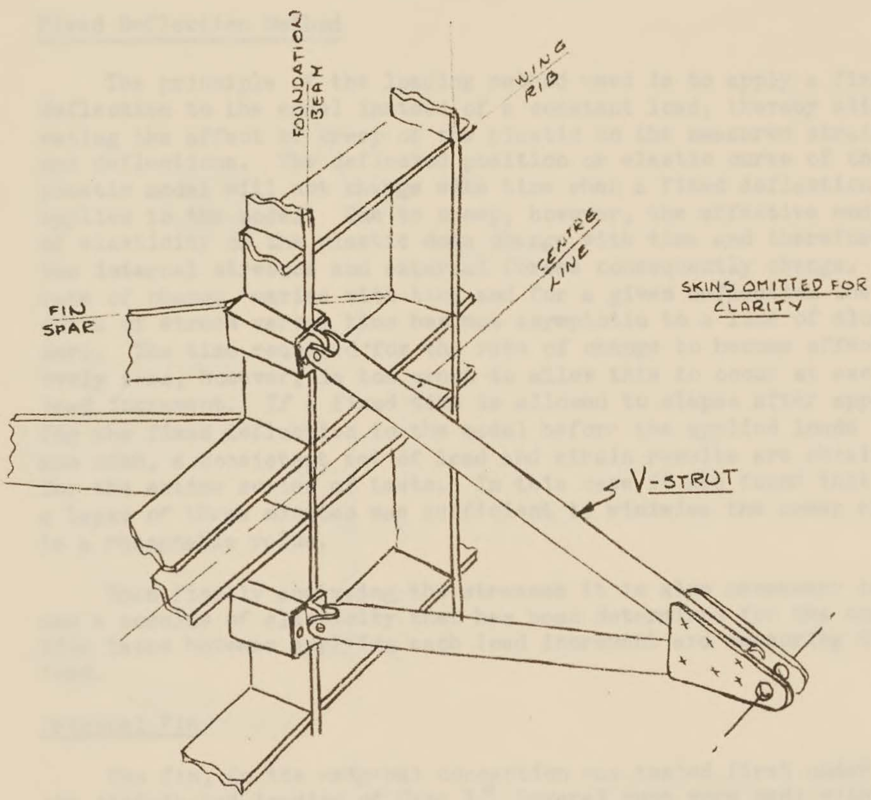


FIG. 9 TYPICAL V-STRUT ARRANGEMENT

TECHNICAL DEPARTMENT Aircraft

C-105
PLASTIC MODELS

FIN (t/c = 3.0%)

A.P. Sentance February/55

DESCRIPTION OF TESTS

Fixed Deflection Method

The principle of the loading method used is to apply a fixed deflection to the model instead of a constant load, thereby eliminating the effect of creep of the plastic on the measured strains and deflections. The deflected position or elastic curve of the plastic model will not change with time when a fixed deflection is applied to the model. Due to creep, however, the effective modulus of elasticity of the plastic does change with time and therefore the internal stresses and external forces consequently change. The rate of change, varies with time and for a given deflection the curve of stress versus time becomes asymptotic to a line of slope zero. The time required for the rate of change to become effectively zero, however, is too great to allow this to occur at each load increment. If a fixed time is allowed to elapse after applying the fixed deflection to the model before the applied loads are read, a consistent set of load and strain results are obtained for the entire series of tests. In this case it was found that a lapse of three minutes was sufficient to minimize the creep rate to a reasonable value.

When finally analyzing the stresses it is also necessary to use a modulus of elasticity that has been determined for the same time lapse between applying each load increment and measuring the load.

Original Fin

The fin, in its original conception was tested first under the distributed loading of Case I.* Several runs were made with wing foundation beams at the full width and half width support positions, (see fig. 1). Half width wing beam support positions were necessary for comparison with calculated values, which were done for a modified foundation beam stiffness determined by using an effective length equal to one-half the actual length. Tests were also carried out, for comparison purposes, on an arrangement giving effectively a stiff base. As shown in Figure 10, the fin was mounted directly to a large channel which was restrained at its ends.

Results from these runs (see discussion) prompted the addition of strain gauges on the lower wing skin in the trailing edge, centre line region - gauges 49 to 53 Figure 6.

*Loading Case I - Distributed loading simulating Aerodynamic loading at subsonic speed. See Appendix A, Sheet 37.

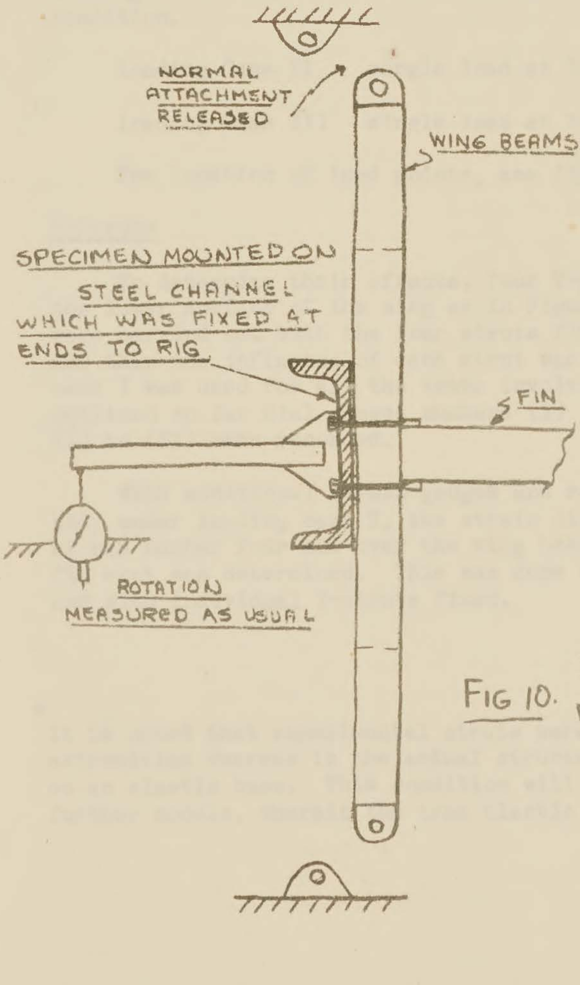


FIG 10. EXPERIMENTAL SET-UP FOR STIFF BASE BEAM

Shear Diaphragms Added

The strain distribution shown by the additional gauges indicated that the addition of shear diaphragms in the root box should be investigated. Diaphragms were added as in Figure 8 and repeat tests carried out on the modified structure under loading case I. Loading cases II and III were also investigated in this modified condition.

Loading Case II single load at load point 11

Loading Case III single load at load point 12.

For location of load points, see figure 6.

V-Struts

To determine their effects, four V-struts were mounted on the lower surface of the wing as in Figure 9. Several test runs were carried out with the four struts fixed at their lower ends* and then the influence of each strut was investigated. Loading case I was used for all the tests involving struts. In all tests outlined so far dial gauges numbers (1) to (22) and strain gauges (1) to (53) were recorded.

With additional strain gauges and root rotation positions and, under loading case I, the strain distribution over the fin at rib number four and over the wing beam upper skin near the fin root was determined. This was done with V-struts all fixed and with individual V-struts fixed.

* It is noted that experimental struts were fully fixed at their extremities whereas in the actual structure, they are supported on an elastic base. This condition will be investigated on further models, wherein the true elastic base will be simulated.

RESULTS AND DISCUSSION

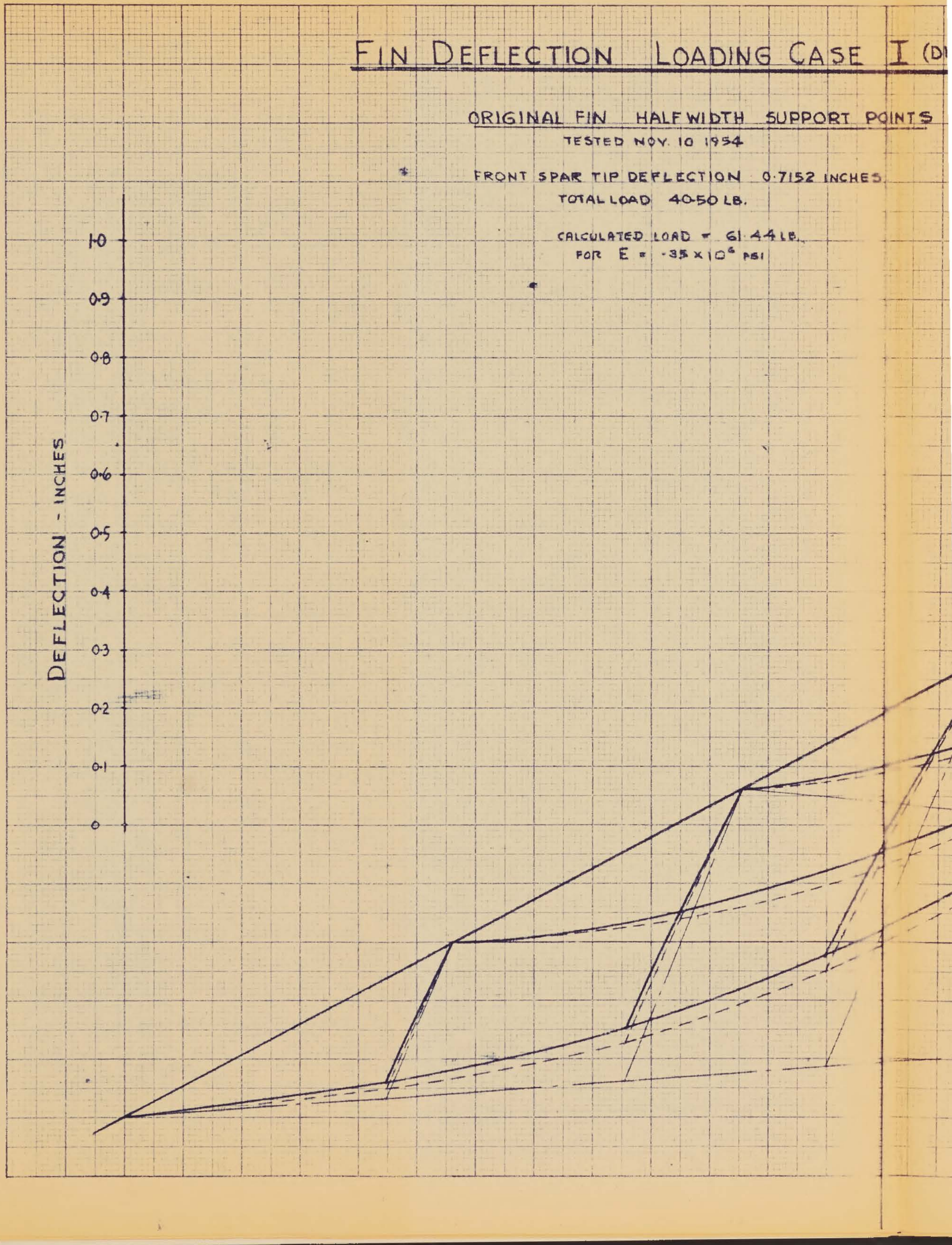
Calculated Values

Reference is made to Inter-Departmental Memorandum No. 3805/31/J "Test on C-105 Plastic Model for Strength Investigation" in which the theoretical deflections and strains for tests on the C-105 model fin structure are given. Excerpts from the above are given in Appendix A of this report in the form of charts of calculated values for deflections, strains and root rotations. Full reference as to derivation of the calculated values is given.

For comparison purposes calculated values of deflection and spanwise axial strains are presented on each graph of experimental results. Loading and deflection conditions for each set of calculated results are noted on the particular graph, for example, under loading case I, values for a "fixed deflection" at the reference point of 0.7152 inches and for a total applied load of 61.44 lbs. are shown. These two values are consistent with a value for modulus of elasticity of .35 x 10^6 p.s.i. for the plastic material and 10 x 10^6 for aluminum alloy of the full scale fin.

Experimental Values

Figures 12 and 13 show the deflected shape and sparwise axial strain distribution over the fin for the first test runs on the fin in original form. Tip deflection and measured load were as indicated. Immediate observations are that the experimental fin has far greater rotation at the root than calculated and that the distribution of this rotation is different than expected with a greater proportion occurring over the mid-chord region. With more root rotation than expected it follows that less of the applied deflection will occur under actual fin bending and this shows in the elastic curves of the spars, the curvature of the experimental line being less than calculated. Although strain measurements are of the same order as those expected in the root region, the fact that the amount of actual fin bending is less and that the applied load is only 66% of that predicted makes this seem illogical. Suspicions aroused by this situation are verified by a condition illustrated by curve "a" of Figure 14. This shows that the wing skin panels were carrying bending end load to a value of only 55% of that assumed in the fully effective condition assumed in the calculations. Assuming a similar situation existing in the fin skins near the root it can be concluded that strain gauge readings taken at spar positions were recording peak strains while the mean strain value over a panel (spar-skin-spar) would be but 55% of this value.


FIN DEFLECTION LOADING CASE I (D
ORIGINAL FIN HALF WIDTH SUPPORT POINTS
TESTED NOV. 10 1954
FRONT SPAR TIP DEFLECTION 0·7152 INCHES.
TOTAL LOAD 40·50 LB.
CALCULATED LOAD = 61·44 LB.
FOR E = ·35 x 10^6 PSI
DEFLECTION - INCHES
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0

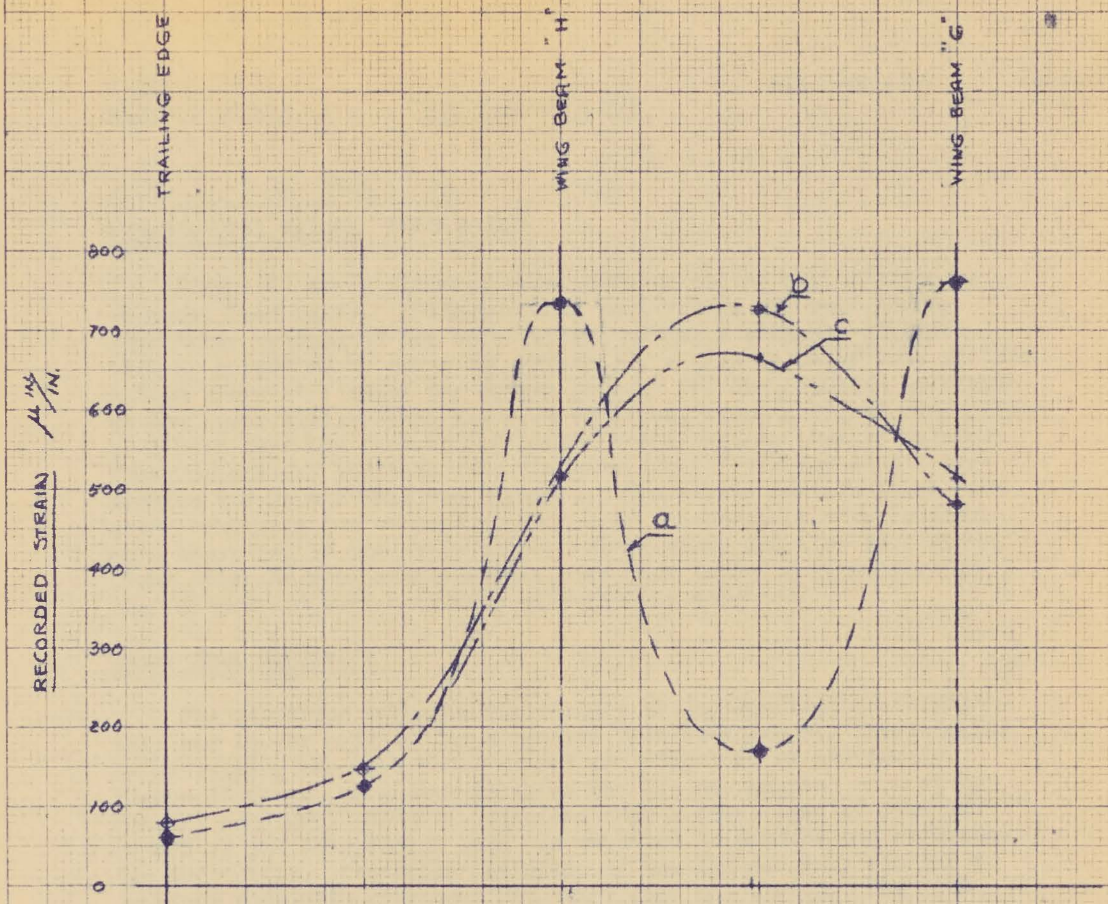


FIG. 14. STRAINS IN LOWER WING SKIN IN REGION OF FIN-WING INTERSECTION SHOWING INCREASE IN SKIN EFFECTIVENESS THROUGH ADDITION OF SHEAR DIAPHRAGMS IN ROOT BOX.

a ORIGINAL FIN CONCEPTION. (TOTAL LOAD 42.00 LB. DISTRIBUTED CASE I)

b & c SHEAR DIAPHRAGMS ADDED IN ROOT BOX. (TOTAL LOAD 49.00 LB DIST^{ED} CASE I)

b. FULL WIDTH SUPPORT BEAM;

c. HALF WIDTH " "

APPROXIMATE EFFICIENCY OF SKIN (NO DIAPHRAGMS) INDICATED BY CURVE a AS 55%.

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Experimental Values (Continued)

Figure 27 shows spanwise axial strains at the root plotted on an equal load basis. While recorded peak values are much higher than those calculated for such points, taking a probable distribution as suggested by curve "a" Figure 14, a mean value of this distribution shows strains of the proper order. The distribution of strain at the root, similarly to the root rotation, shows a higher proportion of strain over the forward and centre chord regions than calculated. These points all indicate that the behaviour of the fin-wing intersection box is not what was expected. The strain distributions have shown concentration of load at each spar intersection with considerable shear lag in the skins at the root region, and also have shown, along with the root rotation, that more load is being taken through the forward and centre chord positions than expected.

Stiff Base Condition

The suspicion that the discrepancy in load-deflection relationship was in the main due to excessive root-rotation was investigated by minimizing the root rotation and applying load as previously. Figure 10 shows the manner in which the fin was mounted on a steel channel for test. Results indicated that a total load of 53.5 lb. or 37% of the theoretical load was required to produce the reference tip deflection. The deflected shape of the fin was very similar to previous condition with less fin twist than calculated. The root rotation in this instance was the plot of torsional deflection of the channel beam under the torque applied by the fin loads. A plot of root rotation is shown in Figure 40 and indicates by the relationship with the calculated values that the higher rate of deflection to load recorded in previous runs was due to excessive root rotation. The root rotations are large even in this case which is an indication that the calculated values of rotation may be inaccurate as was suggested in previous work. (See Appendix A).

Strains recorded in the root region are shown in Figure 27. These show a redistribution due to the stiffening effect of the beam on the root box, the distribution now being similar to that calculated but numerical values higher due to "shear lag" in skins.

Effect of Shear Diaphragms

The addition of several shear diaphragms within the root box has the definite effect of correcting the distribution of root strains and by eliminating the majority of "shear lag" in the wing and fin skins in the root regions results in recorded strains which are in good agreement with those calculated. Figure 14, curves "b" and "c" show the immediate effect of the diaphragms on the distribution of bending end load strain in the wing skins. The skins having become virtually fully effective, the strain distribution now follows the

Effect of Shear Diaphragms (Continued)

expected type of distribution rather than peaking at spar positions. Deflected shape and strain distribution of the fin are given in Figures 15 and 16 and for reasonably good strain and deflection agreement it is seen that 80% of the calculated load is required. Root rotations being once more excessive could account for the lower load required to obtain "reference deflection". The distribution of root rotation, however, has definitely been corrected by the addition of diaphragms which indicates that the root box is now acting as a stiff torsion box and distributing the root restraint effects as theoretically determined.

A comparison of strains in the root region is shown in Figure 28, these being plotted on an equal load basis which minimizes the effect of the excessive root rotation experienced on test. The curves show recorded strains within six percent of those calculated which could indicate a small amount of shear lag still existing in the fin skins. This is substantiated by curves of figure 31 which shows the sparwise strain distribution over the whole ribwise length at rib number 4.

Twist of Fin

It is very noticeable in results that the experimental fin shows appreciably less twist than calculated deflections would indicate. As well, more chordwise bending occurs in the outboard ribs under loading case I on the experimental fin. The chordwise distortion is in the sense that the tension face goes concave and of course is due to the Poisson's ratio effect which has not been included in the theoretical analysis.

Reasons for the difference in fin twist are less immediately evident. An obvious factor, the difference in modulus of rigidity relationship to modulus of elasticity for model and full scale can have an effect in the opposite sense to that observed but only a very minor effect. Although it has been assumed that the ratio of G for the full scale aircraft to G for the model is the same as the ratio of E, the error implied even in the extreme case of pure shear is but

$$\left(\frac{1 + \mu_M}{1 + \mu_F} - 1\right) \times 100 = 7 \text{ percent}$$

for $\mu_M = .39$ and $\mu_F = .30$. An appreciable portion of the observed twist of a highly swept structure comes from bending along the flexural axis resulting in the trailing edge at any chord line deflecting further than the leading edge of the same chord. A greater stiffness in bending of the experimental fin could therefore account for some of the difference in twist. The greatest contributor, however, would be simply a greater torsional stiffness in the experimental fin than calculated.

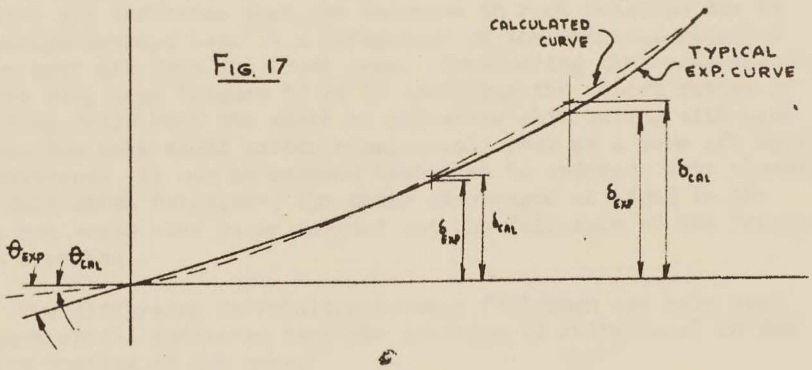
Twist of Fin (Continued)

A great deal of this effect could be due to the additional sparwise shear webs which were added to the model to make the skins between the main spars fully effective as assumed in the theoretical work. The calculations were done with spars 1, 3, 5 and 7 while spars 2, 4, and 6 are additional. See Figure 4.

In pure torsion on a typical outboard cross-section it can be shown that the torsional stiffness of a six cell box of these dimensions would be about 5 percent greater than that of a three cell box.

The deflection pictures show that the experimental fin has appreciably less curvature (greater stiffness) over the inboard region than the theoretical fin. While sufficient experimental or theoretical points are not available to show the exact difference, it is logical that for less root rotation yet greater deflections outboard, the theoretical analysis must imply greater bending curvature in the first few spanwise bays. Figure 17 shows the effect much exaggerated. This effect is more pronounced aft than forward.

Fig. 17



The additional spar webs as expected have but a slight effect on the flexural stiffness of the outboard fin. As the root region is approached and the flexural axis bends in to become more normal to the root chord, it is very probable that the additional spars have quite a part in integrating the "cross-bending" effect of the ribs into the overall bending stiffness of the section. Through virtue of their greater depth in this region, they will also contribute an increased amount to the sparwise stiffness.

Root Rotation

The indications thus far have been that experimental root rotations have been excessive although with the addition of shear diaphragms, the pattern of rotation was improved. Although, as has been pointed out, there is some risk in accuracy in calculating the root rotations, it is highly improbable that inaccuracy would account for the differences in root rotation observed. The basic reason would seem to be more probably the stiffness of the individual foundation beams. The assumption in calculation once more has been that a full half width of skin panel either side of the beam is effective in bending and this has been "lumped" as flange area at the beam position and the stiffness of the beam determined from this.

Two facts apparent from experimental results show that this is not necessarily so; Figure 14 indicates that the wing skin was not fully effective before the diaphragms were positioned in the root box and although the diaphragms made the wing skin in the region of the fin root effective, they would not cause it to continue fully effective over the full span. The difference in root rotation between the original fin and fin with diaphragms (Figure 40) indicates that the decrease in root rotation due to diaphragm becomes less as a percentage of the original rotation as we move aft from the front spar. Considering the cross-section of the wing base (figure 5) it is seen from the aspect ratios of the wing cells that the width of effective skin acting with each foundation beam would become considerably less as a more aft beam is selected. It can be assumed then that to approach more closely the calculated rotations, the shear diaphragms as added in the root box would have to be carried out the full span of the foundation beam box.

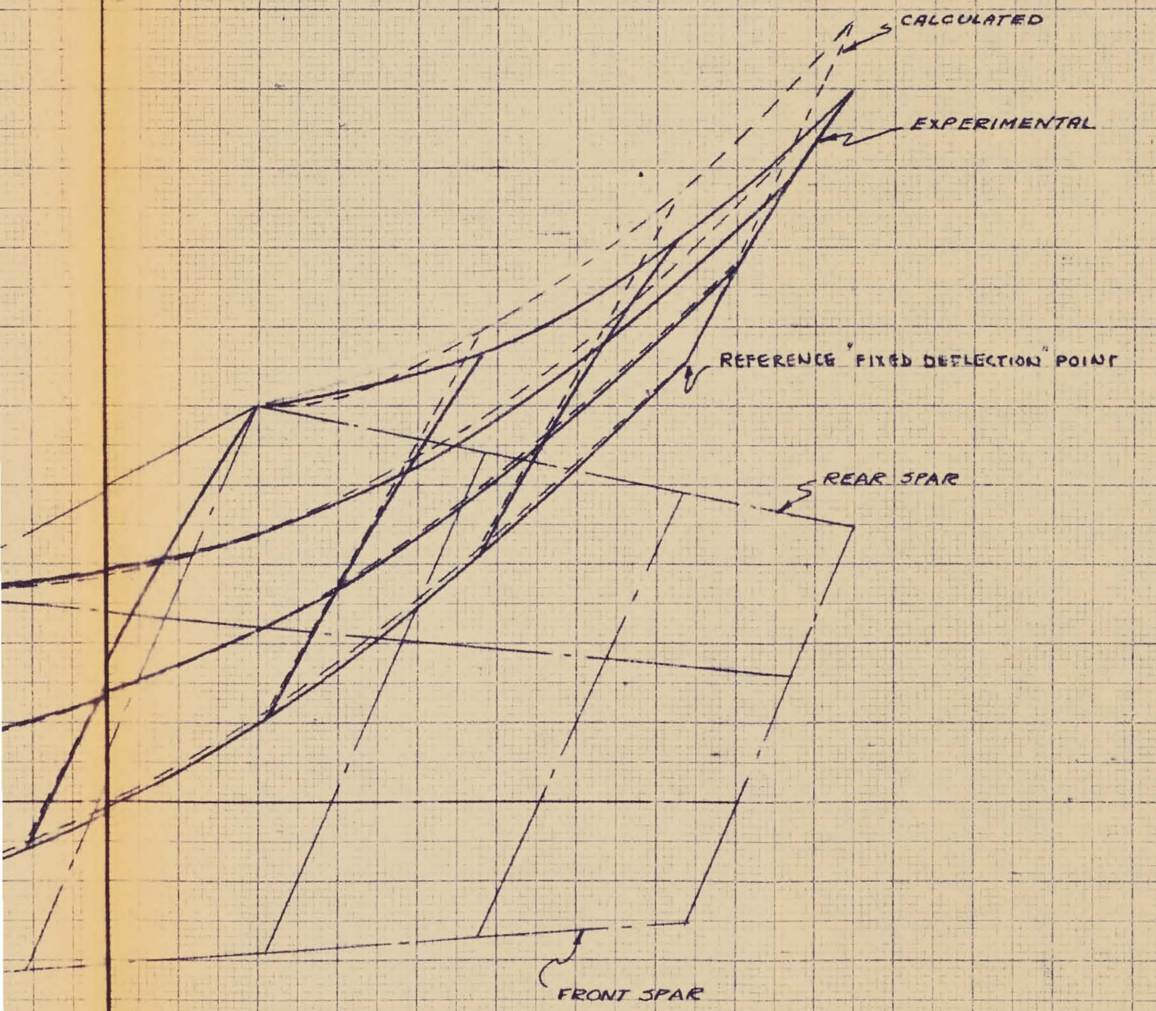
The difference in rotation between full span and half span support points indicates that the rotation is quite local to the centre portion of the span.

OADING CASE I (DISTRIBUTED)

OOT BO
NTS
54

N 0-71?2 INCHES
D LB.

FIGURE 15



Sentance 3/5/55

Sparwise Axial Strain

Loading Case # I

Total load - 49.0 lb
Deflection at dial gauge # 17 - 0.7152 in
Date of test - Dec 7/54

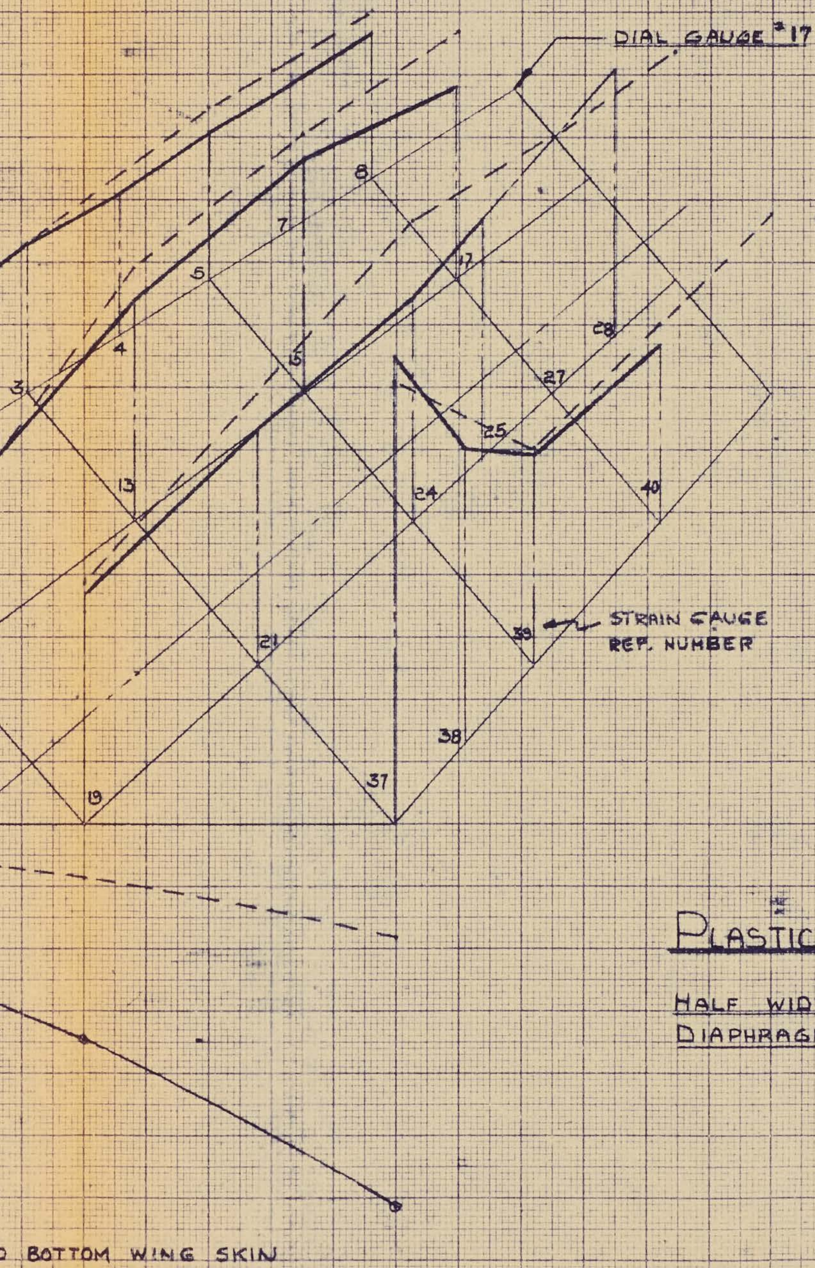


FIG. 16.

- - - - CALCULATED
——— EXPERIMENTAL

Plastic Model Fin

Half width wing beam
Diaphragms in root box

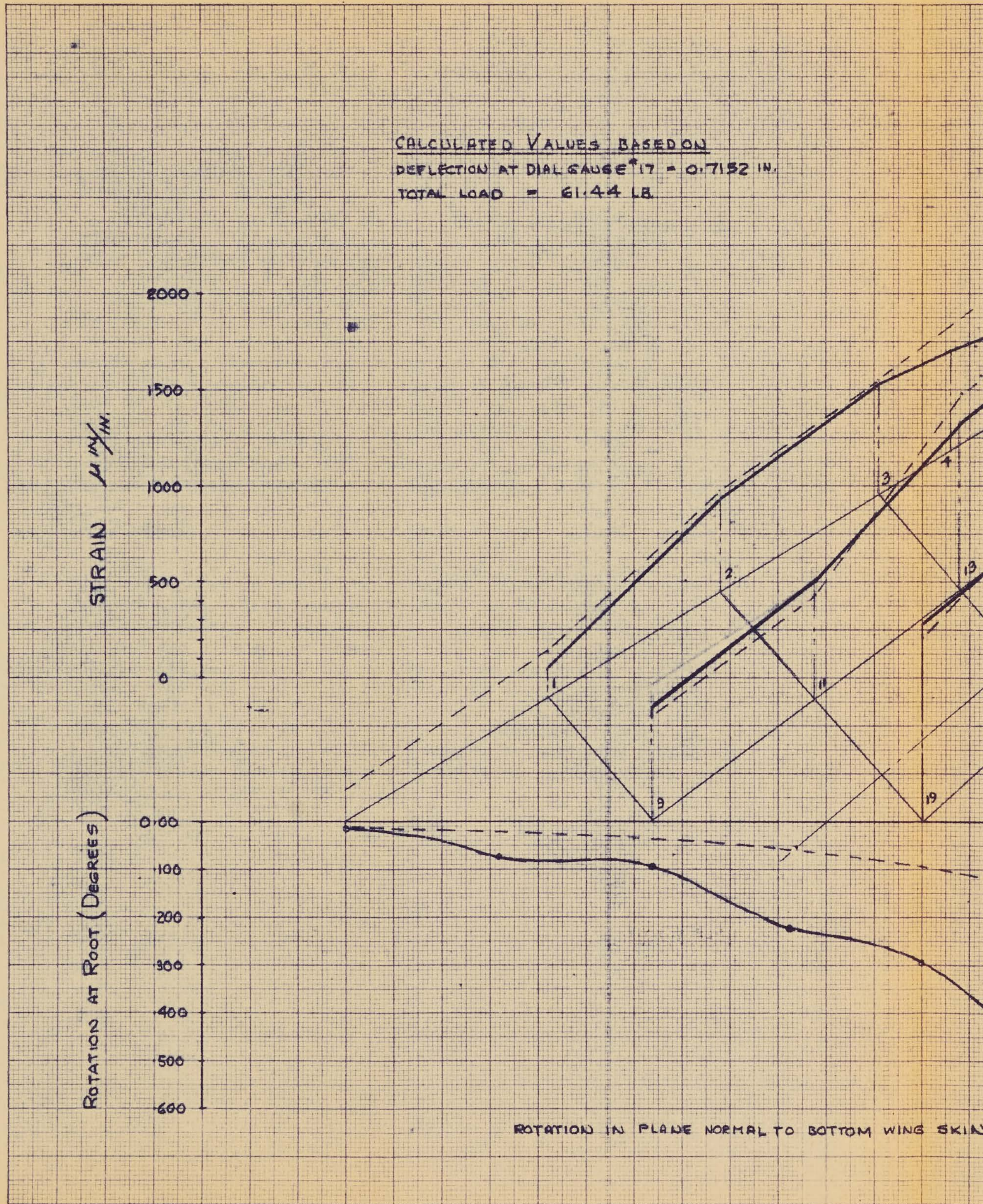
1/6/55

V-Struts

The addition of V-struts has very little, if any, effect on the deflected shape and strain pattern in the fin, the effects being confined locally to the strut positions themselves. Figure 22 shows the strain distribution and root rotation for all struts fixed and it is seen from the root rotation that a considerable local twist occurs between each strut position. This effect is shown graphically in Figure 30 wherein the influence of each individual strut is compared with the no strut rotation. It is seen that for equal tip deflections each strut has the effect of reducing slightly the whole rotation and locally reducing it by 30-40 per cent at the strut position. The rotation as a whole, however, is still appreciably more than that calculated for a no strut condition and therefore to compare root strains once more they are plotted on an equal load basis in Figures 28 and 29. Figure 28 showing a comparison of all-struts with no-struts which represents about a 21% increase in strain above the calculated values for no-struts and about 15% over the recorded no-strut values. The effect at each strut position of fixing one strut only is shown in Figure 29.

The sparwise strain distribution just outboard of rib No. 4 is shown in Figure 31. Under various struts fixed conditions there was no indication in the forward portion of the rib of any real differences in strain, the variations in each case having no order about them and being the normal experimental scatter. A typical distribution is plotted for comparison with calculated values. Near the trailing edge an attempt is made to differentiate between the various cases but the only definite point made is that for "all struts" and "strut H only" a higher value of strain is recorded, than for other conditions. Rather than a gradual increase in strain from spar 5 to spar 7 as indicated in the calculations the strains remain fairly constant until beyond rib 6 and peak suddenly at the rear spar. Values of strain at the leading edge are higher, the overall indication being a behaviour in accordance with normal bending theory except for the high concentration over a small region at the trailing edge. A slight shear lag effect is noticeable over the skin panels.

Figure 32 shows the sparwise strain distribution over the wing upper surface plotted along a chordwise line adjacent to the fin root. The "no struts connected" curve shows the expected distribution with a peak near the rear spar decreasing regularly to almost zero or a small negative value at the forward end. Due to magnitude of strains in the region forward of spar B, the accuracy in this region is very doubtful, and a very erratic behaviour was recorded. Definite reversals of stress were recorded, however, in the no struts connected case, at the forward end.



CALCULATED VALUES BASED ON
DEFLECTION AT DIAL GAUGE #17 = 0.7152 IN.
TOTAL LOAD = 61.44 LB.
STRAIN μ IN/IN.
2000
1500
1000
500
0
ROTATION AT ROOT (DEGREES)
0.00
.100
.200
.300
.400
.500
.600
ROTATION IN PLANE NORMAL TO BOTTOM WING SKIN

SPARWISE AXIAL STRAIN   LOADING CASE I

TOTAL LOAD   49·75 LB.
DEFLECTION AT DIAL GAUGE #17   0·7152 IN.
DATE OF TEST   DEC. 21, 1954.
JAN. 18, 1955.

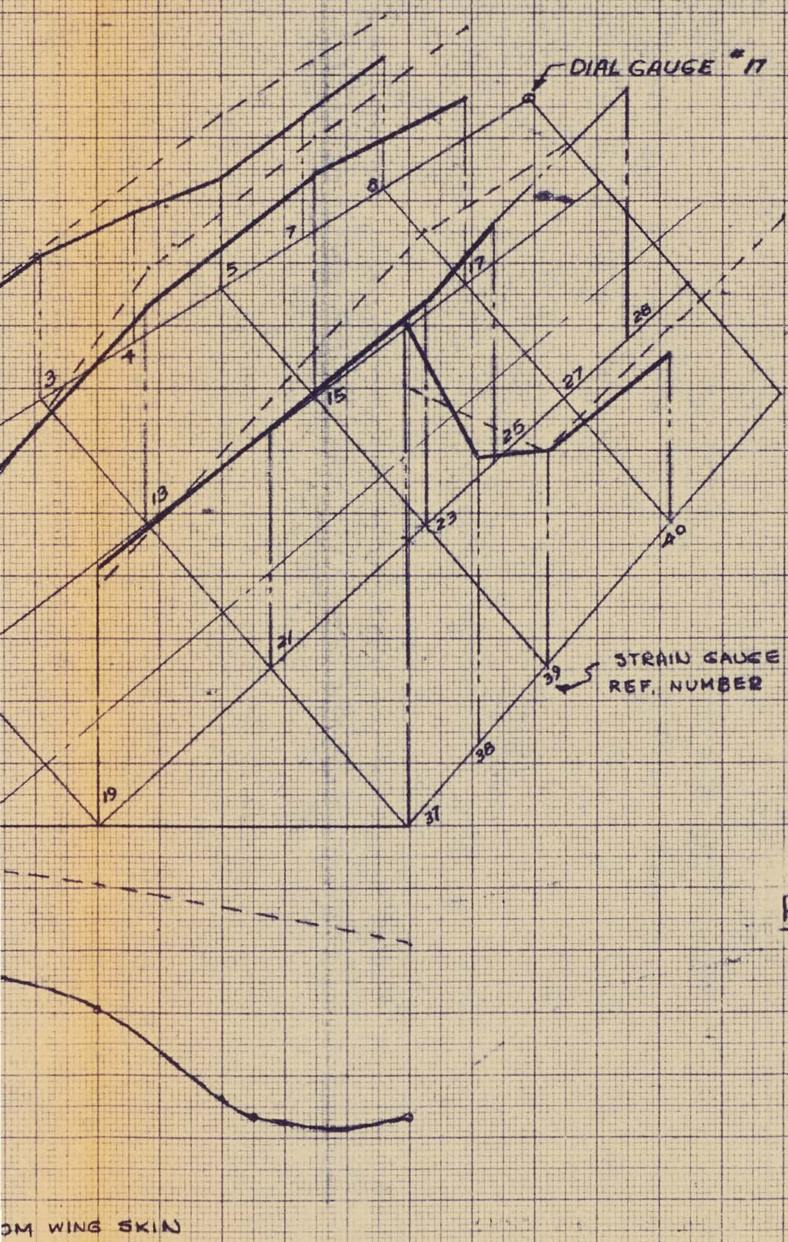


FIG. 22.

– – – – CALCULATED (NO STRUTS)
——— EXPERIMENTAL

PLASTIC MODEL FIN

HALF WIDTH WING BEAM
DIAPHRAGMS IN ROOT BOX
V-STRUTS ON BASE

1/5/55
Sentance

V-Struts (Continued)

Due to the positioning of strain gauges an interesting phenomenon was observed when each of the V-struts was made effective which illustrates the very local effect of the struts. It can be seen in Figures 32 and 33 that at each fixed strut location, a complete reversal of strain of fairly high value was recorded. The strain gauge concerned being very close to the intersection point of strut and wing, the reversal could only be due to the application of a normal load to the very thin stiffened plate (which the wing actually is) and which is already in a state of tension over the upper skin in this region. Local islands of compression stress form at each strut attachment point as that strut is made effective by fixing its lower end. These concentrations indicate a reversal of stress of a value at least as high as the normal tension stress existing in the skin!

Point Loads

Figures 34 to 36 show the effects of loads applied at a free edge and at an internal point and the comparison with calculated values. Calculated deflections and root rotations are given for the same 'fixed deflection' as was applied experimentally whereas strains are plotted for the load which was applied experimentally, enabling the strains to be compared on an equal basis without the distorting effect of the excessive root rotation. Strain pattern for both cases is in good agreement although numerically, case II is much better, with both cases indicating a higher peak strain at the root rib trailing edge than predicted. The deflection shows as in previous cases the evidence of greater stiffness in the experimental fin.

Plastic Model Fin (3% t/c)

Loading Case I

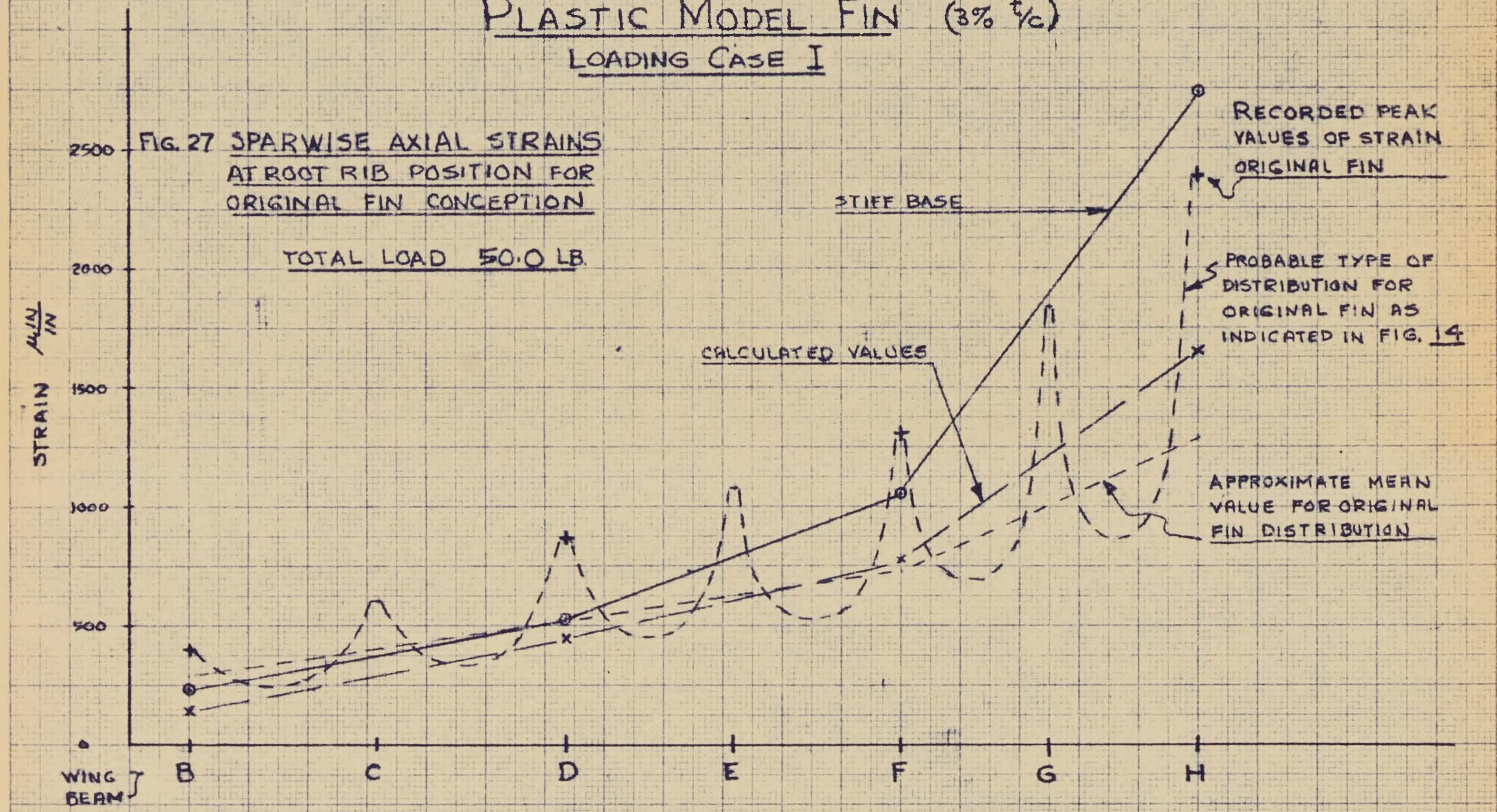


FIG. 27 SPARWISE AXIAL STRAINS AT ROOT RIB POSITION FOR ORIGINAL FIN CONCEPTION

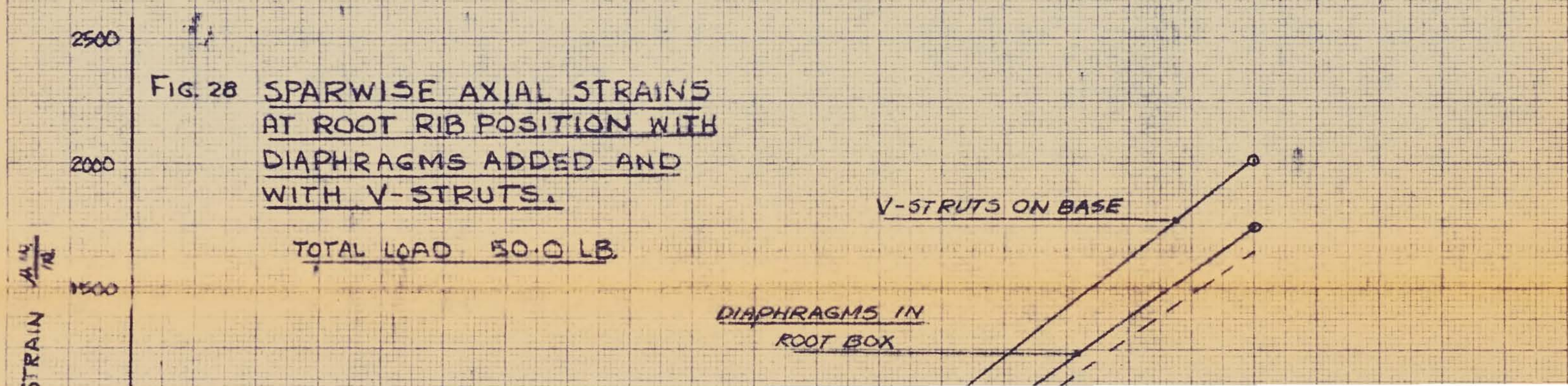
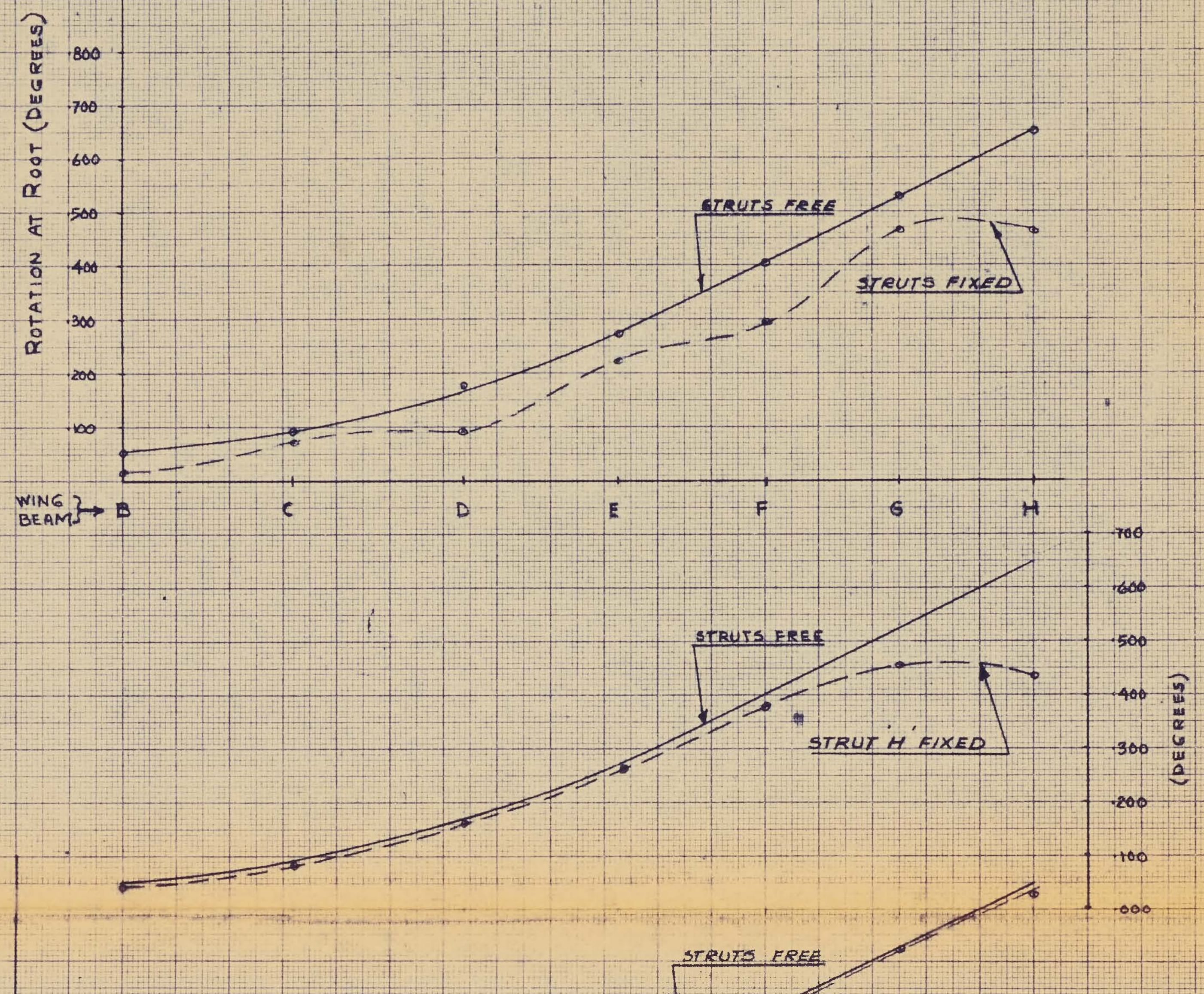
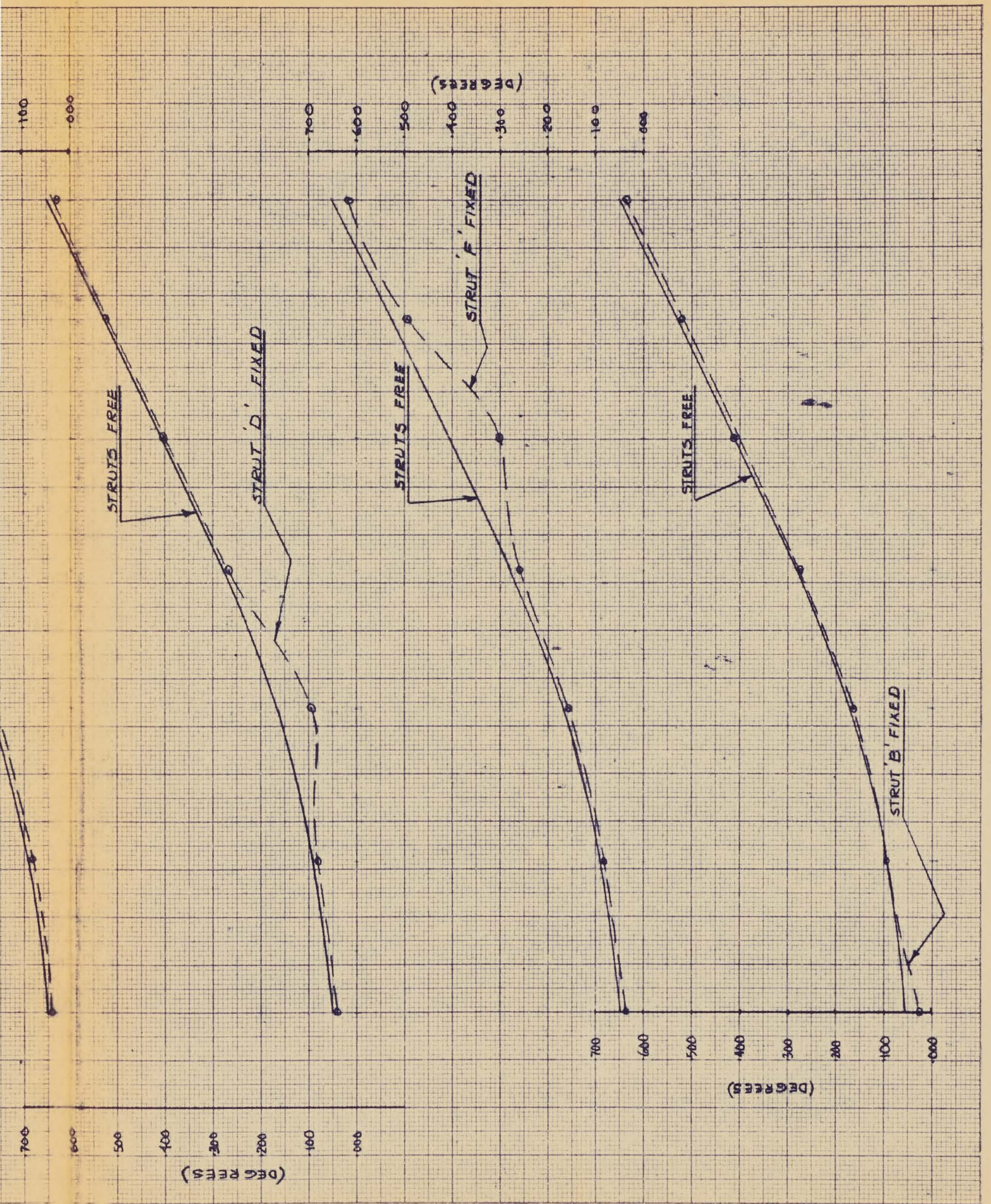


FIG. 28 SPARWISE AXIAL STRAINS AT ROOT RIB POSITION WITH DIAPHRAGMS ADDED AND WITH V-STRUTS.

FIG. 30 INFLUENCE OF V-STRUTS ON ROTATION OF ROOT

ALL VALUES FOR TIP DEFLECTION OF 0·7152 IN.





Sentance
3/3/55

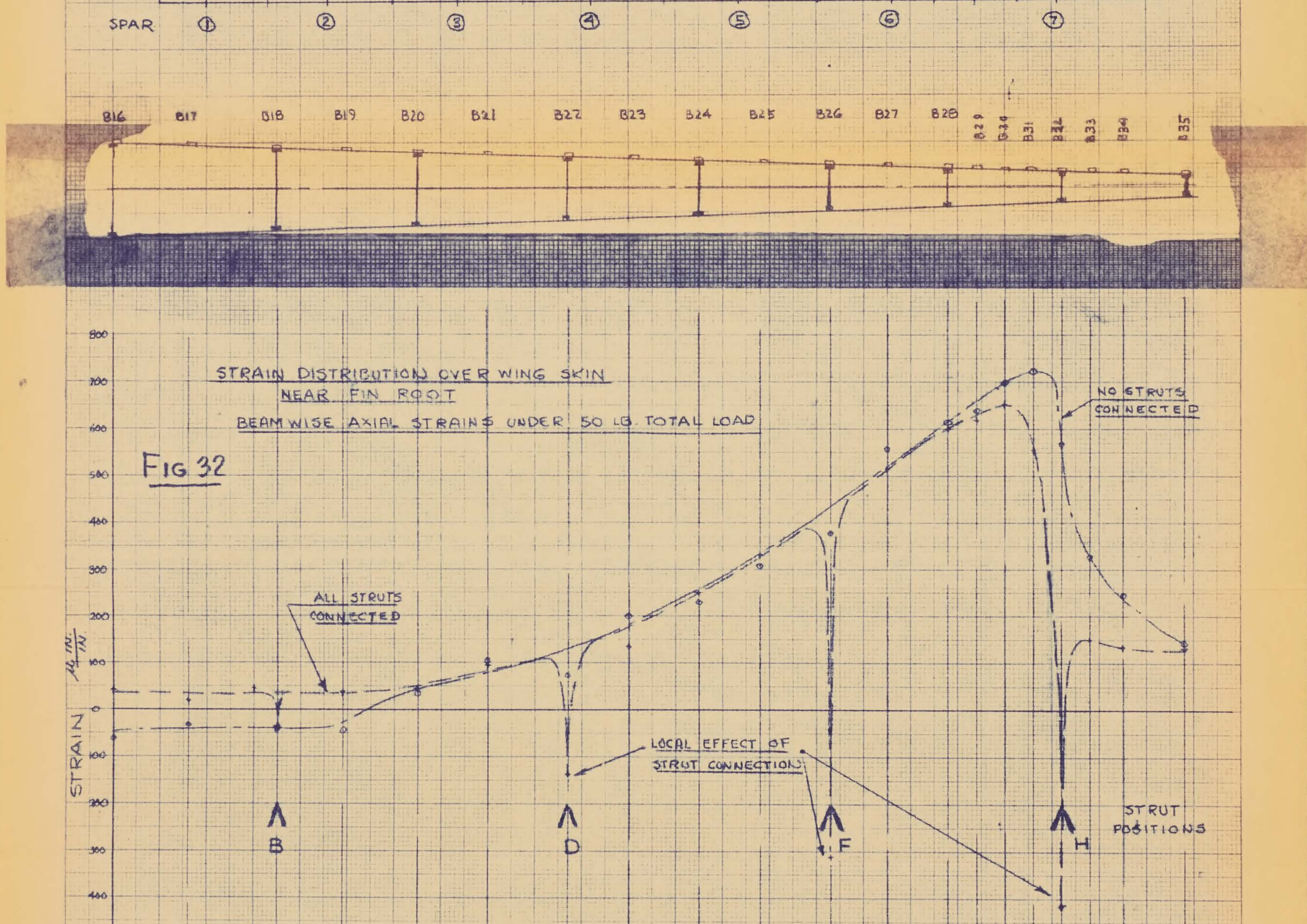

SPAR ① ② ③ ④ ⑤ ⑥ ⑦
B16 B17 B18 B19 B20 B21 B22 B23 B24 B25 B26 B27 B28 B29 B30 B31 B32 B33 B34 B35
STRAIN DISTRIBUTION OVER WING SKIN
NEAR FIN ROOT
BEAMWISE AXIAL STRAINS UNDER 50 LB. TOTAL LOAD
NO STRUTS CONNECTED
ALL STRUTS CONNECTED
LOCAL EFFECT OF STRUT CONNECTION
STRAIN μ IN./IN.
STRUT POSITIONS
B
D
F
H

FIG 32

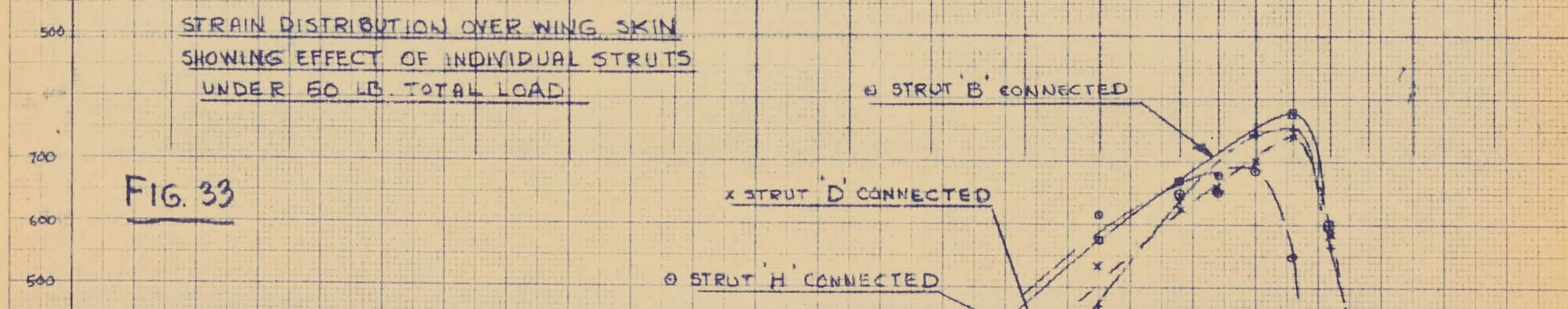

STRAIN DISTRIBUTION OVER WING SKIN
SHOWING EFFECT OF INDIVIDUAL STRUTS
UNDER 50 LB. TOTAL LOAD
STRUT 'B' CONNECTED
x STRUT 'D' CONNECTED
STRUT 'H' CONNECTED

FIG. 33

FIG. 34 LOADING CASE II

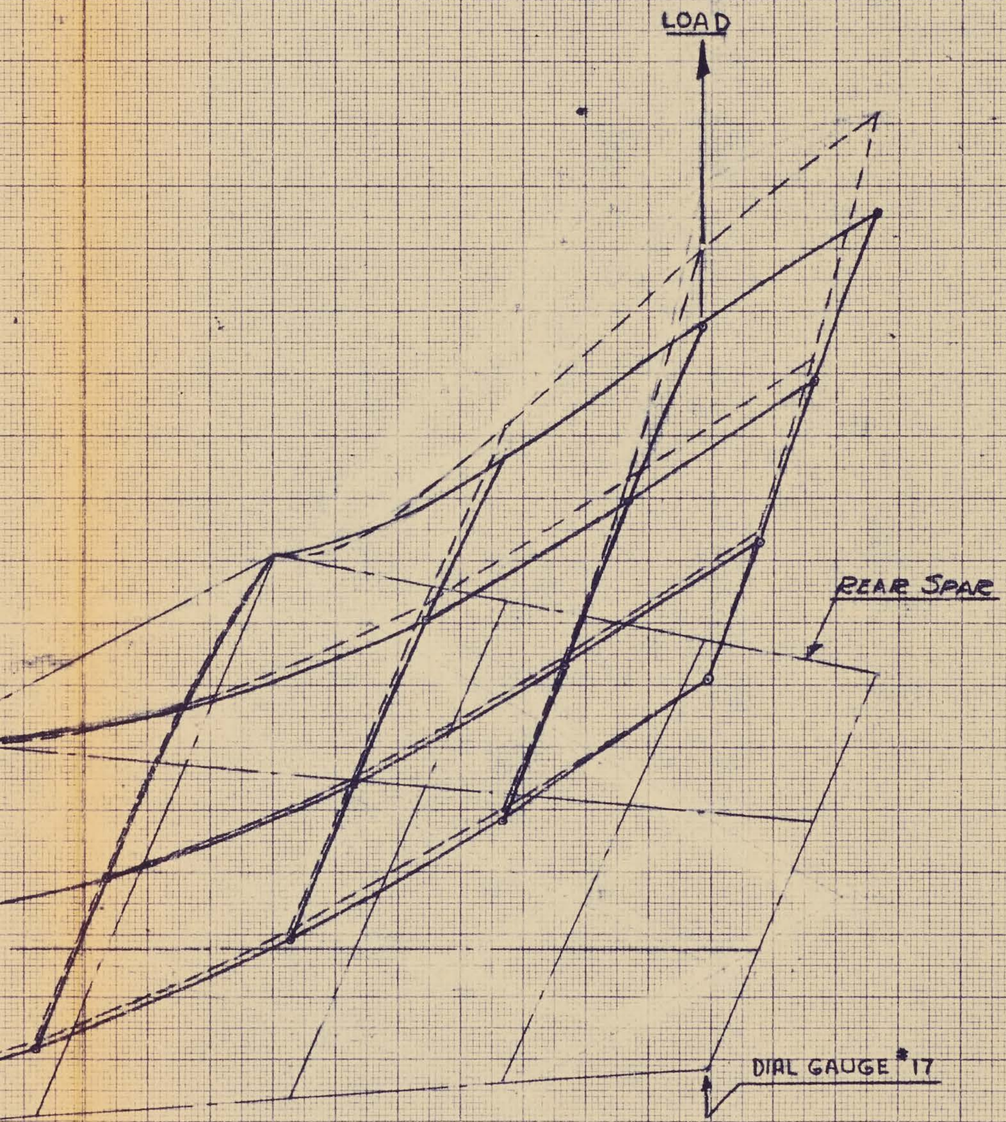
LOAD APPLIED AT LOAD POINT 11

TOTAL LOAD 14.5 LB.

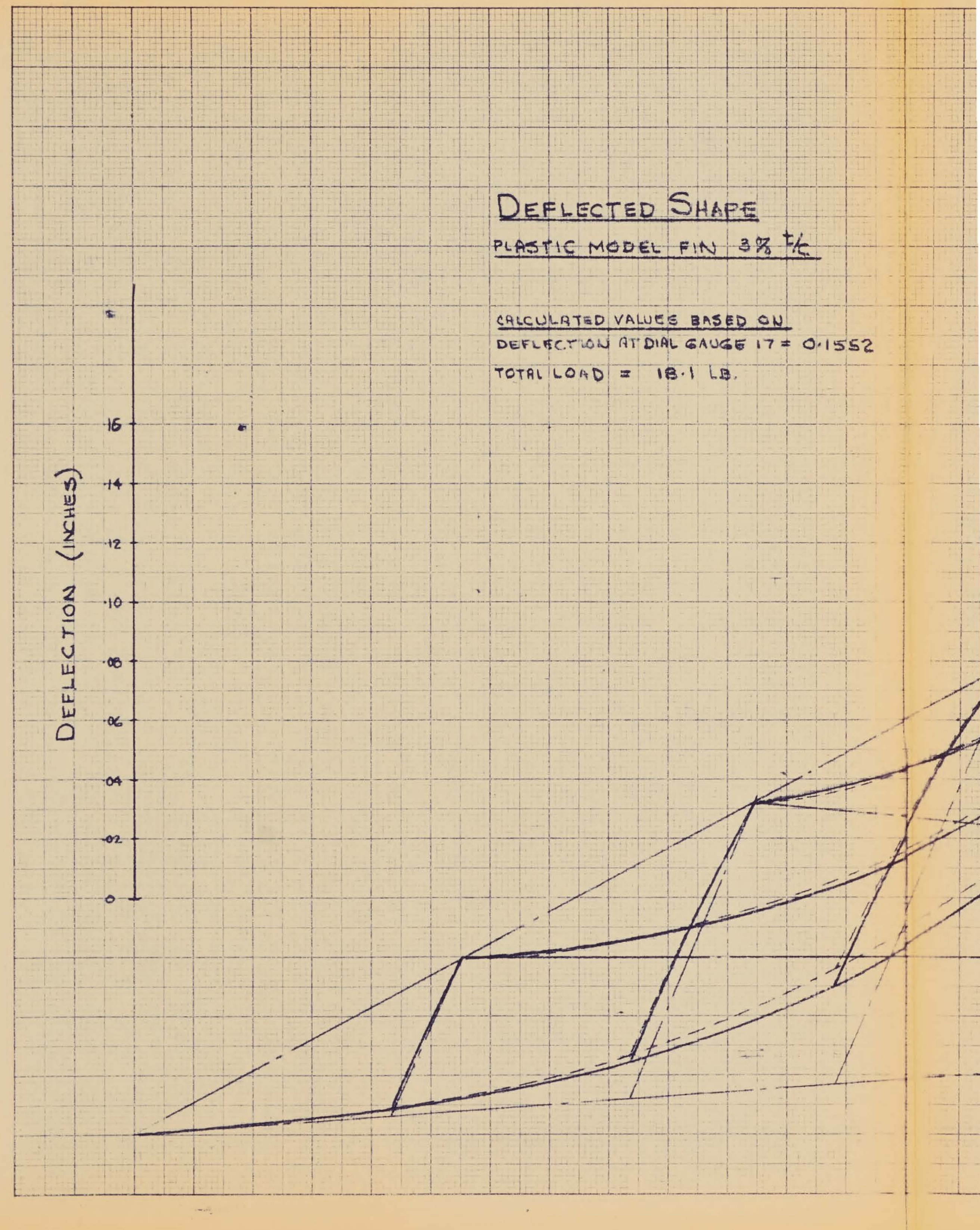
DATE OF TEST DEC. 9/54

HALF WIDTH WING BEAM
DIAPHRAGMS IN BASE

DEFLECTION DIAL GAUGE #17 = 0.1256



Santanna
3/5/55



DEFLECTED SHAPE
PLASTIC MODEL FIN 3% t/c
CALCULATED VALUES BASED ON
DEFLECTION AT DIAL GAUGE 17 = 0·1552
TOTAL LOAD = 18·1 LB.
DEFLECTION (INCHES)
·16
·14
·12
·10
·08
·06
·04
·02
0

CONCLUSIONS

A multiweb fin structure mounted on a base simulating a portion of wing, has been tested under several conditions and with progressive modifications incorporated as the test proceeded. Conclusions reached as a result of observations of these tests are as follows:-

1. The method involved is a satisfactory means of simulating a set of loading conditions on a structure and experimentally determining the deflected shape and strain pattern. The accuracy is completely dependent on the care taken throughout the design, manufacture and testing of the model and if dimensional relationships, joint rigidities and the test set-up are good, extremely accurate results are available. The "fixed deflection" method guarantees good deflection relationships while strain-load-deflection agreement is very sensitive to atmoshperic conditions and to treatment of strain gauges. It is felt that greater consistency of values can be obtained when greater control over ambient conditions is possible. The usefulness of quantitative results will also be much enlarged when more comprehensive data on variation of Xylonite mechanical properties with temperature and humidity are obtained.

2. Shear diaphragms in the root box of the model were very important to develop the proper load distribution over the root region. Without diaphragms concentrations result at spar positions and considerable shear lag develops in both the fin and wing skin panels. The diaphragms integrate the root box into a complete chordwise structure transferring load along its entire length rather than allowing the spars to act virtually independently.

3. With diaphragms, the experimental results verify quite well the calculated values of strain pattern when the effect of excessive root rotation is eliminated by comparison on an equal load basis. Strains in the rib 4 region indicate a small amount of shear lag existing in the fin skins and possibly a sharper peak at the rear spar due to root restraint effect than expected.

4. The V-struts have a very pronounced local effect causing some 20% increase in sparwise axial strain at the spar positions where struts are fixed. The root box is seen to twist locally in between each strut position as is shown by the root rotation recorded (Figure 40). The balance of the fin away from the strut locality behaves in the same manner as the no-strut condition indicating further the extremely local effects of the struts. A very concentrated reversal of strain occurs at each strut connection point where the axial load from the strut is applied as a normal load to the thin wing structure. The indication is that this reversal could be a serious condition as the value of the recorded reversal of strain was greater than the normal strain existing in that region and the strain recorded was not necessarily the peak value.

C-105
PLASTIC MODELS FIN (t/c = 3.0%) A.P. Sentance February/55

Conclusions (Continued)

5. The point load cases show agreement of strain pattern in the instance of a load applied on the rear spar, however, a higher peak strain occurs at the root rib trailing edge than calculated. The case of an internal load while showing fair agreement along the spar to which the load was applied indicated higher strains at other spar positions, as well as a slightly higher root rib trailing edge strain.

6. The deflected shape of the fin generally showed less twist than theoretically implied. It is shown that this is due to a greater torsional stiffness of the model and possibly a greater bending stiffness in the root region as is indicated by less curvature of the model fin elastic curve in this area. Ribwise distortion due to Poisson's ratio effect is evident in the model deflection.

7. Root rotation in all cases was excessive for the model fin. This is probably due to the ineffectiveness of wing base skins in contributing to the stiffness of the foundation beams in bending, particularly towards the aft end where due to the thin section, the aspect ratio of a cross-sectional cell becomes extremely high. It is felt that additional spanwise shear webs, say, continuations of the diaphragms installed in the root box would be necessary to reduce the root rotation to those values expected.

C-105
PLASTIC MODELS

FIN (t/c = 3.0%)

A.P. Sentance February/55

APPENDIX A

Calculated Loadings and Deflection

Tables of loads and deflection taken from Inter-Departmental Memorandum No. 3805/31/J "Test on C-105 Plastic Model for Strength Investigation" are presented below. Deflections are determined by using the Z_{ab} (deflection) matrix provided by the Stress Office and using the relevant structural parameters for the reduction to the model.

Load Point	LOADING CASE I		LOADING CASE II		LOADING CASE III	
	LOAD	DEFLN.	LOAD	DEFLN.	LOAD	DEFLN.
1	35.5 in.lb.		0		0	
2	108.0 in.lb.		0		0	
3	88.0 in.lb.		0		0	
4	19.0 in.lb.		0		0	
5	1.25 in.lb.		0		0	
6	1.75 lb.	.6388	0	.1797	0	.1582
7	9.65 lb.	.6639	0	.1480	0	.1595
8	7.90 lb.	.6842	0	.1326	0	.1536
9	5.10 lb.	.7152	0	.1256	0	.1552
10	3.05 in.lb.		0		0	
11	1.07 lb.	.3785	18.10 lb.	.1249	0	.1043
12	.93 lb.	.4253	0	.1043	18.10 lb.	.1134
13	.99 lb.	.4587	0	.0930	0	.1123
14	4.02 lb.	.4933	0	.0879	0	.1153
15	2.45 in.lb.		0		0	
16	1.21 lb.	.1521	0	.0556	0	.0454
17	1.23 lb.	.2229	0	.0577	0	.0636
18	1.34 lb.	.2668	0	.0542	0	.0692
19	4.78 lb.	.3040	0	.0525	0	.0746
20	1.52 lb.	.0777	0	.0203	0	.0231
21	1.68 lb.	.1250	0	.0234	0	.0334
22	5.31 lb.	.1599	0	.0244	0	.0393
23	1.91 lb.	.0397	0	.0059	0	.0108
24	5.63 lb.	.0642	0	.0074	0	.0145
25	5.42 lb.	.0170	0	.0010	0	.0029
Total Load	61.44 lb.		18.10 lb.		18.10 lb.	

AVRO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

P/MODELS/46

38

C-105
PLASTIC MODELS

FIN (t/c = 3.0%)

A.P. Sentance

February/55

Strains

The calculated strains for cases considered are given below. The matrix used in the calculation of these strains is given in Stress Office Report 7/0510/1. The numbering code refers to strain gauge position. Strains are for total load indicated.

STRAIN GAUGE	LOADING CASE I	II	III	STRAIN GAUGE	LOADING CASE I	II	III
1	214	38	70	23)	1230	252	258
2	501	110	138	24)			
3	600	132	134	25			
4				26			
5		122	112	27		-10	-26
6				28			
7				29			
8		30	36	30			
9	554	102	210	31			
10	130	0	24	32			
11	566	146	130	33			
12	-30	-32	-82	34			
13	1014	250	258	35			
14			-28	36	138	-240	32
15				37	2026	754	626
16			2	38			
17				39	906	186	160
18				40			
19	966	374	254	41			
20	104	2	-22	42			
21	1080	250	296	43	2026	754	626
22				44			
				TOTAL LOAD	61.44 Lb.	18.10 Lb.	18.10 Lb.

Strains - Micro-Inches per Inch

Rotations at Root

The rotations at the root (foundation beams), are less clearly defined and can be approximated theoretically by at least three different approaches. Two of these approaches involve first the calculation of the foundation beam stresses, and then the reduction of these stresses to moments. The rotation is then obtained by either using the notion of a concentrated moment acting on a beam, or two equal and opposite forces separated by the appropriate fin thickness at the root. A third method is to note that the ribs seem to be subject to very little deformation, hence, the rotation of those ribs connected to the foundation beams will give approximately the rotation of the respective beams. A comparison of the results using all of these methods is given below.

BEAM	METHOD	LOADING CASE		
		I	II	III
H	i	.212	.082	.062
	ii	.181	.069	.056
	iii	.206	.083	.061
F	i	.109	.020	.035
	ii	.087	.016	.028
	iii	.105	.016	.028
D	i	.042	.003	.0075
	ii	.032	.002	.0055
	iii	.045	.003	.0075
B	i	.010	.0001	.0005
	ii	.009	.00005	.0003
	iii			

i = Concentrated Moment
ii = Discreet Forces
iii = Rotation of Rib (Slide Rule Computation only).

In general, it is not considered that the above values for root rotation are necessarily accurate, in that they were derived as noted from foundation beam stresses presented in Stress Report 7/0510/1 from which the following remarks are taken.

Rotations at Root (Continued)

"The result of the analysis of the present paper points out conclusively that the representation of the conditions at the root by means of unconnected foundation beams is not accurate and can be misleading in some cases. The correct method of treating the supporting structure is in providing torsion members between beams." This would imply new redundant quantities in the analysis and it is explained that, "no exact boundary condition should be considered unless a more rigorous analysis is extended over a part of the supporting structure."

Therefore, the approximate boundary conditions used produce values of foundation beam stresses "the indiscriminate use of which is not recommended".