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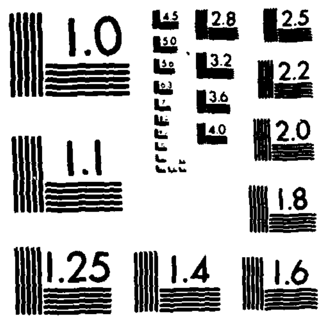

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DEPARTMENT OF DEFENCE

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MELBOURNE, VICTORIA

Structures Technical Memorandum 373

CALIBRATION OF CT-4A FATIGUE TEST ARTICLE - MARCH 1983

R.P. CAREY and D.G. FORD

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CALIBRATION OF CT-4A FATIGUE TEST ARTICLE - MARCH 1983

by

R.P. CAREY and D.G. FORD

SUMMARY

In preparation for fatigue testing, a strain gauged CT-4A fatigue test article has been calibrated by discrete static loadings. The strain/load data are analysed herein and strain sensitivities to various load parameters are reported.

The responses of some gauges have been compared with flight strains and ground calibrations.

POSTAL ADDRESS: Director, Aeronautical Research Laboratories,
P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

1. INTRODUCTION

Structures Division of ARL has been commissioned by the RAAF to fatigue test the CT-4A airframe A19-031A built for this purpose.

In preparation for fatigue testing, calibration loadings have been performed in a test rig to check that the strains in the airframe under the test loading system agree satisfactorily with strains measured during ground calibrations of the flight test aircraft A19-031.

This memo reports the gauge sensitivities under fatigue-rig loading and also reports work done to isolate the influence of basic load parameters - torque and bending moments.

2. PROCEDURE

Various discrete calibration loads were applied to the fatigue test article by the rig to be used for the fatigue test.

Symmetric wing loadings ($\leqslant$ 6.67 kN) were applied to each side by the hydraulic jack/whiffletree system. A symmetric tail plane loading ($\leqslant$ 0.334 kN) was applied to each side, and an asymmetric loading was also performed using dead weights ($\leqslant$ 0.545 kN) on the starboard side superimposed on the symmetric loading. A fin loading of 0.334 kN was applied in the starboard direction only. Further details are given in Table 1.

Strains were monitored with electric resistance strain gauges on the wing main spar (9C, 9T, 10C, 10T, 12C, 12T), front spar (21S, 22S), fin (33T), tail plane (37C, 37T, 38C), and fuselage longerons (51C, 52C, 53T, 54T). Precise descriptions of gauge stations are available from reference 1.

Linear regressions, strain against force, have been fitted and the results tabulated. Additional sensitivities have been derived by interpreting the slopes as responses to local moments. These results were compared with results from ground calibration of the flight test aircraft.

Further manipulation enabled the separation of sensitivities to fuselage bending moments and torque. Details of these analyses are given in Appendix A for the fatigue test article and Appendix B for the flight test aircraft ground calibration.

Some additional information on sensitivities of fuselage gauges to wing loading has been obtained from flight testing and has been included for comparison.

3. BASIC SENSITIVITY RESULTS

Two-parameter regressions were fitted to the available data so that an offset from the origin was permitted, but for brevity only the slopes have been included herein.

The sensitivities of gauges to calibration forces have been tabulated as follows:-

Table 2. Wing loading
Table 3. Symmetric tail loading
Table 4. Asymmetric tail loading
Table 6. Fin loading.

Additional sensitivities of empennage gauges to test rig bending moments are given as follows:-

Table 3. Symmetric tail loading
Table 5. Asymmetric tail loading
Table 6. Fin loading.

Factors to convert the base from root bending moments to local bending moments at gauge stations are also given with the latter tables. Fin and tail plane root positions are taken as stations 8.0 and 3.0 inches respectively.

4. FLIGHT TEST DATA

Additional data relating wing load and strains are available from flight test. These consist of strains recorded at eight wing load factors:- 1.0g, 3.7g, 0g, - 1.5g, 4.2g, 4.0g, - 1.5g, and 1.0g. Table 7 shows the results of linear regression analyses on these data. The data used were chosen to coincide with low empennage loads. The results in Table 7 can be compared with those in Table 2 for the fatigue test article.

5. SENSITIVITIES OF FUSELAGE GAUGES TO MOMENTS AND TORQUE

5.1 Response to Fuselage Vertical Bending

The response of the fuselage gauges to vertical bending moments has been calculated using data from various sources. For the fatigue test article calculations were based on two wing loadings and the tailplane loading and the slope of the pooled data obtained by the method shown in Appendix A. Table 9 shows the results.

Vertical bending sensitivity has also been determined for the flight test aircraft using data from ground calibration. No wind loading data were available so tail loading data were used as shown in Appendix B. The results are included in Table 12.

5.2 Response to Fuselage Torsion and Sideways Bending

By manipulation of responses by the fuselage gauges to various loadings, additional sensitivities have been extracted. Appendix A shows how sensitivities to fuselage torsion and sideways bending were obtained for the fatigue test article and Table 10 gives the values obtained. For the flight test aircraft it was necessary to assume sensitivities to torsion so that sideways bending sensitivity could be extracted. The assumed torsion sensitivities are contained in Table 11 and the sideways bending values are included in Table 12.

6. COMPARISON WITH GROUND CALIBRATION OF FLIGHT TEST AIRCRAFT A19-031

Table 13 shows the comparison between strain sensitivities measured on ground calibrations of the flight aircraft and the fatigue test airframe. Appropriate allowance has been made for the different positions of load applications to the empennage.

7. DISCUSSION AND CONCLUSIONS

1. Table 13 comparisons show that the sensitivities for the fatigue airframe calibration are reasonably consistent with those of the flight test aircraft A19-031, for the wing, fin and tailplane values.

2. On the fuselage of the test article there is good consistency in estimates of gauge sensitivity to sideways bending. This is despite the low responses of the gauges and the significant amount of computation required.

3. The derived sideways bending responses of gauges 53TE and 54TE on the flight test aircraft are of opposite sign to that expected
(T (Table 13). It is likely that the unavailability of genuine torque sensitivity values and differences in fuselage support close to these gauges has affected the calculations and it is assumed that the sideways bending responses for the flight test aircraft are not reliable.

4. One gauge 53TE shows much lower torque response than the other fuselage gauges on the fatigue test airframe. This suggests that there is a considerable error in the estimated torque sensitivities and that this value is especially suspect.

5. In general the gauge sensitivities to bending moment and torque exhibit considerable scatter for both the fatigue test and the flight test airframes. Future torques responses should be measured by calibrating with torsion applied directly.

8. REFERENCE

1. Carey, R.P. Group Calibration of a Strain-Gauged CT-4A Aircraft (1980). ARL Structures Technical Memorandum 349, October 1982.

APPENDIX A

A.1 RESPONSE OF FUSELAGE GAUGES ON FATIGUE TEST ARTICLE

By analysing the response of fuselage gauges to calibration loadings we establish in turn the sensitivities to vertical bending moment, torque, and side bending moment. These are required for the prediction of responses to general loadings.

The analysis is covered in detail hereafter, along with sample calculations for gauge 51CE.

A.2 LIST OF SYMBOLS

P = fin load (positive to starboard)

T_s, T_p = starboard, port tailplane loads (upwards positive)

W = wing lift force per side (upwards positive)

W_4 = reaction at aft tie-down, (upwards positive), shown in Figure 1

M_v = fuselage bending moment in vertical plane (positive for upward load at tail)

M_H = fuselage sideways bending moment (positive for fin load to starboard)

M_T = fuselage torque (positive for fin load to starboard)

h = moment arm of fin load developing fuselage torque, shown in Figure 2. This is relative to the mid-depth of the fuselage at the same station as the fin load.

l_H = moment arm for fin load inducing fuselage sideways bending moment (see Figure 1).

l_v = moment arm for tail loads inducing fuselage bending moments, (shown in Figure 1)

l_W = moment arm of furthest aft fuselage reaction point, (shown in Figure 1)

l_T = moment arm for difference of asymmetric tail loads producing fuselage torque (shown in Figure 2)

ε = strain at fuselage gauge

R = ratio of algebraic sum of tailplane loads to algebraic difference

K_V = sensitivity of gauge to fuselage vertical bending moment

K_H = sensitivity to fuselage sideways bending moment

K_T = sensitivity to fuselage torque

C_W = sensitivity to wing loading per side

C_T = sensitivity to total tail loading

C_A = sensitivity to algebraic excess of port side tail loading over starboard

C_F = sensitivity to fin loading.

A.3 RESPONSE TO FUSELAGE VERTICAL BENDING

Fuselage vertical bending is induced by wing loading and tail loading so that both types of loading can be used to estimate the sensitivity, as well as the flight test results.

Before combining the results from different tests they must be changed to compatible units so that the applied loads can be converted to fuselage bending moments. This is done in Sections A3.1 and A3.2 below. Section A3.3 discusses the separate slope estimates and their combination.

A.3.1 Fuselage Bending Moment Induced by Wing Loading

The vertical bending moments at the fuselage gauge stations are obtained in the following way. The aft reaction force is required and this can be determined from the geometry as -

$$W_4 = -0.459596\ W$$

Then referring to Figure 1, the bending moment induced by unit wing loading

$$M_v/W = -0.4596\ l_W \qquad ..(A1)$$

where l_W = 27.50 inches for 51CE and 52CE

= 20.0 inches for 53TE and 54TE.

A.3.2 Fuselage Bending Moment Induced by Tail Loading

For the tailplane loading the aft reaction is obtained from the geometry as

$$W_4 = -0.799908\ (T_p + T_s) \qquad ..(A2)$$

The bending moment induced by tail loading is (Figure 1) -

$$M_v = (T_p + T_s)\, l_v + W_4 l_W$$

or for unit tail load

$$M_v/(T_p + T_s) = l_v - 0.7999\, l_W \quad \text{lb.in/lb} \qquad ..(A3)$$

<u>Example</u>

For gauge 51CE, referring to Figure 1

$$l_v = 122.50 \text{ inches}$$

and $l_W = 27.50$ inches.

From (A3) the equivalent moment arm or sensitivity is therefore -

$$122.5 - 0.7999 \times 27.50 = 100.50 \text{ inches} \qquad ..(A4)$$

or twice this if the quoted tail load refers to just one side.

A.3.3 Pooling Sensitivity Estimates from Separate Tests

For estimating the strain sensitivity of a gauge to bending moment from several calibrations it is first necessary to discuss least squares fitting for one test.

Suppose we have a single set of strains denoted y_i ($i = 1$ to n) corresponding to the fixed variable x_i and the regression model -

$$y_i = m + bx_i + e_i \qquad ..(A5)$$

where

$$e_i \sim N(0, \sigma^2).$$

Then by least squares, which here is equivalent to maximum likelihood, the estimated slope

$$\hat{b} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) \Big/ \sum_{i=1}^{n} (x_i - \bar{x})^2 \qquad ..(A6)$$

When this is rewritten in the notation used in the data analysis programs this may be abbreviated to:-

$$\hat{b} = XPROD/SSX$$

For several tests or calibrations the terms on the right may be subscripted and in this notation the optimal slope estimate takes the form:-

$$\hat{b} = \sum_j XPROD_j \, / \sum_j SSX_j \qquad ..(A7)$$

for the tests j = 1, 2 etc.

Example for Gauge 51CE

Combined XPROD from two compatible wing loadings (per side)

$$XPROD_1 + XPROD_2 = -147400 - 145700$$

$$= -293100 \text{ microstrain lbf/side.}$$

Converting the load parameter to fuselage bending moment:-

$$\underline{XPROD} = -293100 \ (M_v/W)$$

$$= -293100 \ (-12.63889) \qquad \text{(see equation (A2))}$$

$$= \underline{3704500} \text{ microstrain lb in}$$

Similarly XPROD from tail loading is:-

$$XPROD = 4740 \text{ microstrain lbf/side}$$

and converting to bending moment:-

$$XPROD = 4740 \times 2M_v/(T_p + T_s)$$

$$= 4740 \times 201.0 \qquad \text{(see equation (A6))}$$

$$= \underline{953000} \text{ microstrain lb in.}$$

Then combining XPROD's from wing and tail loading

$$\text{Combined XPROD} = 3704500 + 953000$$

$$= 4.658 \times 10^6 \text{ microstrain lb in.} \qquad ..(A8)$$

Similarly looking at SSX the combined value from wing tests is:-

Combined SSX from wing test = 2889000 + 2371000 = 5.260×10^6 lbf^2

Wing SSX in terms of bending moments

$$= 5.260 \times 10^6 \, (M_v/W)^2$$

$$= 5.260 \times 10^6 \, (-12.63889)^2$$

$$= 840.3 \times 10^6 \, (lb.in)^2$$

The tail loading SSX in terms of bending moments

$$= 7235.6 \, (2M_v/(T_p + T_s)^2$$

$$= 7235.6 \, (201.0)^2$$

$$= 292.3 \times 10^6 \, (lb.in)^2$$

Combined SSX for wing and tail loadings

$$= 840.3 \times 10^6 + 292.3 \times 10^6$$

$$= 1132.6 \times 10^6 \, (lb.in)^2 \qquad ..(A9)$$

Now the combined sensitivity to fuselage bending is available:-

Pooled sensitivity to fuselage bending, K_v = XPROD/SSX

$$= 4.658 \times 10^6/1132.6 \times 10^6$$ reference (A8) and (A9)

$$= .004113 \text{ microstrain/lb.in} \qquad ..(A10)$$

A.4 SENSITIVITY TO FUSELAGE TORQUE

Asymmetric tail loading affects the fuselage gauges in two ways - through fuselage vertical bending and through torque. The sensitivity to bending, K_v, is known from paragraph A.3 so the torque sensitivity, K_T, is now determinable.

Sensitivity to asymmetric loading difference = strain per unit load induced by vertical bending + strain per unit load caused by torque.

i.e.

$$C_A = d\varepsilon/d(T_p - T_s)$$

$$= \frac{\partial\varepsilon}{\partial M_v} \cdot \frac{dM_v}{d(T_p + T_s)} \cdot \frac{d(T_p + T_s)}{d(T_p - T_s)} + \frac{\partial\varepsilon}{\partial M_T} \cdot \frac{dM_T}{d(T_p - T_s)}$$

$$= K_v \left(\frac{M_v}{T_p + T_s}\right) . \; R + K_T . \, l_T \qquad ..(A11)$$

K_T is now the only unknown in (A11)

<u>Example</u>

$R = 0.25$

$l_T = 36.0$ (see Figure 2)

$C_A = .0545$ microstrain/lbf

$K_V = .004113$ microstrain/lb.in (refer (A10))

$M_v \;/\; (T_p + T_s) = 100.5$ inch (refer (A5))

so that:-

$$.0545 = .004113 \times 100.5 \times 0.25 + K_T \times 36.0.$$

Then torque sensitivity -

$$K_T = (.0545 - .10334)/36.0$$

$$= -.001357 \text{ microstrain/lb.in} \qquad ..(A12)$$

A.5 SENSITIVITY TO FUSELAGE SIDEWAYS BENDING

Fin loading affects the fuselage gauges through sideways bending of the fuselage and by torque. The torque influence can be evaluated as in the previous paragraph so that sensitivity to sideways bending can be determined.

Response to fin loading, C_F,

= strain per unit load caused by torque + strain per unit load caused by sideways bending.

i.e.

$$C_F = \frac{\partial \varepsilon}{\partial M_T} \cdot \frac{dM_T}{dP} + \frac{d\varepsilon}{dM_H} \cdot \frac{dM_H}{dP}$$

$$= K_T \cdot h + K_H \cdot l_H \qquad ..(A13)$$

from which sensitivity to sideways bending moment, K_H is found.

Example

C_F = .225 microstrain/lbf (see Table 6)

K_T = -.001357 microstrain/lb.in (see Equation (A12))

h = 31.21 inch (see Figure 2)

l_H = 100.1 inch (see Figure 1)

$\therefore$ 0.225 = (-.001357) x 31.21 + K_H x 100.1

and sensitivity to sideways bending,

K_H = (.225 + .004235)/100.1

= .002674 microstrain/lb.in.

APPENDIX B

RESPONSE OF FUSELAGE GAUGES ON THE FLIGHT TEST AIRCRAFT

The data available from the flight test aircraft are not sufficient to isolate all of the effects separated for the fatigue test article. To overcome the deficiency values for fuselage torque sensitivity have been taken from the fatigue test article and modified by averaging the magnitudes of symmetrically placed pairs. The values as measured and modified are included in Table 11.

B.1 BENDING MOMENTS FROM UNIT FORCES

Referring to Figures 3 and 4 the following bending moments and torques are derivable:

To obtain fuselage sideways moment, reactions are assumed at the vertical reaction stations.

The aft sideways reaction per unit fin load

$$= -\frac{236.5 - 44.1}{135.4 - 44.1} = -\frac{192.4}{91.3} \approx -2.1073.$$

The fuselage sideways moment per unit fin load to starboard for gauges 51CE, 52CE

$$= 1.0(236.5 - 125.5) - 2.1073(135.4 - 125.5)$$

$$= 90.1 \text{ lb.in/lbf (ie. inch).}$$

Fuselage sideways moment per unit fin load for gauges 53TE, 54TE

$$= 1 \times (236.5 - 133) - 2.1073\ (135.4 - 133)$$

$$= 98.4 \text{ inch.}$$

Fuselage torque per unit fin load = 47.5 - (-4.8) = 52.3 inch.

Fuselage aft reaction per unit tailplane load

$$= -\frac{251.0 - 44.09}{135.4 - 44.09} = -2.266 \text{ lbf/lbf.}$$

Fuselage vertical moment per unit tailplane total load (for gauges 51CE, 52CE)

$$= 1.(251-125.5) - 2.266(135.4-125.5)$$

$$= 103.1 \text{ inch.}$$

Fuselage vertical moment per unit tailplane total load (for gauges 53TE, 54TE)

$$= 1.(251-133) - 2.266(135.4-133)$$

$$= 112.6 \text{ inch.}$$

Fuselage aft reaction per unit wing load

$$= -\frac{85.5 - 44.1}{135.4 - 44.1}$$

$$= -0.483.$$

Fuselage vertical moment per unit wing load (for gauges 51CE, 52CE)

$$= -.483(135.4 - 125.5)$$

$$= -4.782 \text{ inch.}$$

Fuselage vertical moment per unit wing load (for gauges 53TE, 54TE)

$$= -.483(135.4-133)$$

$$= -1.1592 \text{ lb.in/lbf.}$$

B.2 SENSITIVITY TO FUSELAGE VERTICAL BENDING

Sensitivity to tailplane loading (Table 11) is readily modified to bending sensitivity using moments found in A.2.1 as in the following example for gauge 51CE. Sensitivity to tailplane vertical bending

$$= \frac{\text{Sensitivity to tailplane loading}}{\text{Moment per unit load}}$$

$$= .2046/103.1 \approx .001984 \text{ microstrain/lb.in.}$$

The values obtained for all gauges are given in Table 12.

B.3 SENSITIVITY TO FUSELAGE SIDEWAYS BENDING

Fin loading influences the fuselage gauges in two ways - firstly by inducing torque on the fuselage and secondly through sideways bending. The influence of torque on gauge 51CE is found thus for a unit fin load:-

Torque = 52.3 lb.in (see paragraph B.1)

Strain due to torque = Torque x Sensitivity to Torque

= 52.3 (-.001163*)

= -.0608 microstrain/lbf.

* Obtained from Table 11.

Total strain = .1770 microstrain/lbf (see Table 11)

Net strain attributable to sideways bending

= .1779-(-.0608) microstrain/lbf

= .2387 microstrain/lbf.

Sideways Bending Moment = 90.1 lb.in.

Hence sensitivity to sideways bending moment is -

$$= \frac{.2387}{90.1} \text{ microstrain/lb.in}$$

= .002649 microstrain/lb.in.

The values for all gauges are included in TAble 12.

TABLE 1. FATIGUE TEST ARTICLE AIRFRAME CALIBRATION LOADINGS, MARCH 1983

TYPE OF CALIBRATION	TEST DATE	LOAD RANGE (NOMINAL	NO. OF SETS	STEPS	REMARKS
WING BENDING	17 MAR	0.0 to 6.67 kN (1500 lbf)	1	1.11 kN	FIRST ZERO LOAD POINT DISCARDED.
	18 MAR	0.0 to 6.67 kN (PER SIDE)	1	1.11 kN	
TAIL PLANE SYMMETRIC UP LOAD	18 MAR	0.334 kN (75 lbf) PER SIDE	1	0.056 kN	
ASYMMETRIC TAILPLANE	21 MAR	0.0334 kN (75 lbf) UPWARDS ON PORT SIDE & .200 kN (45 lbf) DOWNWARDS ON STARBOARD SIDE	1	.056 kN PORT .034 kN STARBOARD	DEAD WEIGHT ON STARBOARD TAIL TO .534 kN MAX., MODIFYING SYMMETRIC JACK LOADS OF .334 kN.
FIN	21 MAR	0.334 kN (75 lbf)	1	.056 kN	DISCARDED.
	22 MAR	0.334 kN (75 lbf) TO STARBOARD	1	.056 kN	YAW RESTAINT BAR DISCONNECTED

TABLE 2. WING LOADING CALIBRATION ON FATIGUE TEST AIRFRAME

Fitted Strain/Load Sensitivities

GAUGE	STRAIN ($X10^{-6}$)/LOAD FACTOR (G's)			STRAIN/FORCE (lbf)/SIDE	STRAIN/FORCE (N)/SIDE
	17 MAR	18 MAR	17, 18 MAR, AVERAGE	17, 18 MAR, AVERAGE	17, 18 MAR, AVERAGE
9CE	-261	-258	-259.5	-.389	-.0875
9TE	179	182	180.5	.270	.0607
10CE	-253	-253	-253	-.379	-.0852
10TE	192	194	193	.289	.0650
12CE	-346	-345	-345.5	-.518	-.1165
12TE	264.5	264.5	264.5	.396	.0890
21SE	- 25.85	- 25.78	- 25.82	-.0387	-.00870
22SE	- 37.21	- 36.74	- 36.98	-.0554	-.0125
33TE	.35	.36	.355	$.5x10^{-3}$	$1.1x10^{-4}$
37CE	- .83	.10	- .36	$-.6x10^{-3}$	$-1.3x10^{-4}$
37TE	.94	.08	.51	$.6x10^{-3}$	$1.3x10^{-4}$
38CE	.12	1.01	.56	$.8x10^{-3}$	$1.8x10^{-4}$
51CE	- 41.08	- 34.07	- 37.58	-.0563	-.0127
52CE	- 25.58	- 25.99	- 25.79	-.0386	-.0087
53TE	22.38	22.24	22.31	.0334	.0075
54TE	26.19	33.87	30.03	.0450	.0101

TABLE 3. *SYMMETRIC TAIL LOADING CALIBRATION ON FATIGUE TEST AIRFRAME*

Fitted Strain/Load Sensitivities

Test Date: 18 March 1983

GAUGE	STRAIN ($X10^{-6}$) PER LOAD (LBF) PER SIDE	STRAIN ($X10^{-6}$) PER LOAD (N) PER SIDE	STRAIN ($X10^{-6}$) PER TAILPLANE ROOT BENDING MOMENT (lb.in) (ARM = 33.0")	STRAIN ($X10^{-6}$) PER TAILPLANE ROOT BENDING MOMENT (N.m) (ARM = .838 m)
33TE	$-.601 \times 10^{-3}$	$-.135 \times 10^{-3}$	-1.82×10^{-5}	-1.61×10^{-4}
37CE	-1.60	-.360	$-.0485^{+}$	-.430
37TE	1.56	.351	$.0473^{+}$	.419
38CE	-1.62	-.364	$-.0491^{+}$	.435
51CE	.655	.147	N/APPLICABLE	N/APPLICABLE
52CE	.427	.096	"	"
53TE	- .737	-.166	"	"
54TE	-1.11	-.250	"	"

+ FOR CONVERSION TO STRAIN PER LOCAL BENDING MOMENT MULTIPLY BY 1.179 (ARM = 28.0")

TABLE 4. ASYMMETRIC TAIL LOADING CALIBRATION ON FATIGUE TEST AIRFRAME

Fitted Strain/Load Sensitivities

Test Date 21 March 1983

GAUGES	STRAIN ($X10^{-6}$) PER FORCE INDICATED BELOW							
	UP LOAD ON PORT SIDE		DOWN LOAD ON STARBOARD SIDE		NET LOAD ON TAIL		LOAD DIFFERENCE ON TAIL	
	(lbf)	(N)	(lbf)	(N)	(lbf)	(N)	(lbf)	(N)
33TE	$-.454X10^{-3}$	$-.102X10^{-3}$	$.757X10^{-3}$	$.170X10^{-3}$	$1.135X10^{-3}$	$.255X10^{-3}$	$.2838X10^{-3}$	$.064X10^{-3}$
37CE PORT	-1.71	-.384	*	*	*	*	*	*
37TE PORT	1.71	.384	*	*	*	*	*	*
38CE STAR-BOARD.	*	*	-1.64	-.369	*	*	*	*
51CE	*	*	*	*	.218	.0490	.0545	.0123
52CE	*	*	*	*	.4225	.0950	.10563	.0237
53TE	*	*	*	*	-.3375	-.0759	-.08438	-.0190
54TE	*	*	*	*	-.7825	-.1759	-.19563	-.0439

* THESE VALUES ARE NOT RELEVANT - E.G. INFLUENCE OF PORT TAIL LOAD ON STARBOARD GAUGES WHEN STARBOARD LOADING IS ALSO APPLIED.

TABLE 5. ASYMMETRIC TAIL LOADING CALIBRATION ON FATIGUE TEST AIRFRAME

Fitted Strain/Root Bending Moment Sensitivities

Test Date 21 March 1983

GAUGE	STRAIN PER ROOT BENDING MOMENT (Ib.in) (arm=33.0")	STRAIN PER ROOT BENDING MOMENT (N.m) (arm=0.838m)
37CE PORT	-0.0518+	-0.458+
37TE PORT	-0.0518+	-0.458+
38CE STARBOARD	-0.0497+	-0.440+

+ FOR SENSITIVITY TO LOCAL BENDING MOMENT AT GAUGES 37BE, 38BE MULTIPLY BY 1.179 (arm = 28")

TABLE 6. FIN LOADING CALIBRATION ON FATIGUE TEST AIRFRAME

Fitted Strain/Load Sensitivities

Test Date: 22 March 1983

GAUGE	STRAIN ($X10^{-6}$) PER LOAD (lbf)	STRAIN ($X10^{-6}$) PER LOAD (N)	STRAIN ($X10^{-6}$) PER FIN ROOT BENDING MOMENT (lb.in) (ARM = 18.41")	STRAIN ($X10^{-6}$) PER FIN ROOT BENDING MOMENT (N.m) (ARM = .467 m)
33TE	1.27	.286	.0690+	.611
37CE	- .020	-.0045	-.00109	-.00966
37TE	.042	.0094	.00228	.0202
38CE	.037	.0083	.00201	.0178
51CE	.225	.0506	N/APPLICABLE	N/APPLICABLE
52CE	- .211	-.0474	"	"
53TE	.167	.0375	"	"
54TE	- .221	-.0497	"	"

\+ STRAIN PER LOCAL BENDING MOMENT AT 33TE = 0.0843 X 10^{-6}/lb.in
(ARM - 15.07 INCH) = 0.747 X 10^{-6}/N.m

TABLE 7. FLIGHT TEST - FUSELAGE GAUGE SENSITIVITIES TO WING LOAD FACTOR

GAUGE	STRAIN ($X10^{-6}$) PER LOAD FACTOR	STRAIN ($X10^{-6}$) PER WING LOAD PER SIDE (16f)	STRAIN ($X10^{-6}$) PER WING LOAD PER SIDE (N)
51CE	-31.291	-.046842	-.01053
52CE	-27.733	-.041516	-.00933
53TE	32.863	.049196	.01106
54TE	35.057	.05248	.001180

NOTE: THE DATA WERE OBTAINED FROM CT-4A FLIGHT TRIALS:
FLIGHT 013, FILE 6, 30 APRIL 1980.

TABLE 8. MOMENT ARMS FOR BENDING MOMENTS AND TORQUES

SYMBOL	FORCE	MOMENT PRODUCED	STRAIN GAUGES	MOMENT ARM - METRE (INCH VALUES IN BRACKETS)	
				FATIGUE TEST ARTICLE	FLIGHT TEST AIRCRAFT GROUND CALIBRATION
l_V	TAILPLANE LIFT	VERTICAL BENDING ON FUSELAGE	51CE, 52CE	3.109 (122.5)	3.189 (125.5)
			53TE, 54TE	2.919 (115.0)	2.998 (118.0)
l_W	AFT FUSELAGE REACTION	VERTICAL BENDING ON FUSELAGE	51CE, 52CE	.698 (27.5)	.252 (9.9)
			53TE, 54TE	.508 (20.0)	.061 (2.4)
l_T	DIFFERENCE IN TAILPLANE LIFT BETWEEN SIDES	FUSELAGE TORQUE	51CE, 52CE 53TE, 54TE	.914 (36.0)	1.576 (62.03)
l_H	FIN FORCE	FUSELAGE SIDEWAYS BENDING	51CE, 52CE	2.541 (100.1)	2.820 (111.0)
			53TE, 54TE	2.350 (92.6)	2.630 (103.5)
h	FIN FORCE	FUSELAGE TORQUE	51CE, 52CE 53TE, 54TE	.792 (31.21)	1.329 (52.3)

CONT......

TABLE 8. (CONT.)

SYMBOL	FORCE	MOMENT PRODUCED	STRAIN GAUGES	MOMENT ARM - METRE (INCH VALUES IN BRACKETS)	
				FATIGUE TEST ARTICLE	FLIGHT TEST AIRCRAFT GROUND CALIBRATION
$\frac{M_V}{(T_p + T_s)}$ *	EFFECTIVE LENGTH APPLICABLE TO TOTAL TAIL LIFT	VERTICAL BENDING ON FUSELAGE	51CE, 52CE	2.551 (100.5)	2.619 (103.1)
			53TE, 54TE	2.513 (99.0)	2.861 (112.6)
M_V/W *	EFFECTIVE LENGTH APPLICABLE TO WING LIFT/SIDE	VERTICAL BENDING ON FUSELAGE	51CE, 52CE	-.321 (-12.639)	-.121 (-4.782)
			53TE, 54TE	-.233 (-9.192)	-.029 (-1.159)
M_H/P *	EFFECTIVE LENGTH APPLICABLE TO FIN LOAD	SIDEWAYS BENDING ON FUSELAGE	51CE, 52CE	2.541 (100.1)	2.289 (90.1)
			53TE, 54TE	2.350 (92.6)	2.500 (98.4)

* DERIVATIONS ARE GIVEN IN APPENDICES A AND B.

TABLE 9. RESPONSE OF FUSELAGE GAUGES TO FUSELAGE BENDING MOMENT IN THE VERTICAL PLANE

(FATIGUE TEST ARTICLE LOADINGS MARCH 1983)

GAUGES	STRAIN ($X10^{-6}$) PER FUSELAGE BENDING MOMENT (N.m) (STRAIN ($X10^{-6}$) PER IN.LB SHOWN IN BRACKETS)		
	SYMMETRIC TAILPLANE LOADING	WING LOADING	COMBINATION OF DATA FROM TAILPLANE AND WING LOADINGS
51CE	.02883 (.003258)	.03902 (.004409)	.03640 (.004113)
52CE	.01880 (.002124)	.02702 (.003053)	.02490 (.002813)
53TE	-.03294 (-.003722)	-.03215 (-.003633)	-.03244 (-.003666)
54TE	-.04961 (.005606)	-.04380 (-.004949)	-.04608 (-.005207)

TABLE 10. RESPONSE OF FUSELAGE GAUGES TO FUSELAGE TORQUE AND FUSELAGE SIDE BENDING

(FATIGUE AIRFRAME - MARCH 1983)

GAUGE	STRAIN SENSITIVITY TO FUSELAGE TORSION		STRAIN SENSITIVITY TO FUSELAGE SIDEWAYS BENDING MOMENT AT GAUGE	
	STRAIN ($X10^{-6}$) PER LB.IN	STRAIN ($X10^{-6}$) PER N.m	STRAIN ($X10^{-6}$) PER LB.IN	STRAIN ($X10^{-6}$) PER N.m
51CE	-.001357	-.01201	.002674	.02366
52CE	.0009709	.008592	-.002411	-.02134
53TE	.0001764	.001561	.001744	.01543
54TE	-.001854	-.01641	-.001762	-.01559

TABLE 11. FUSELAGE GAUGE RESPONSES USED IN ANALYSIS FOR GROUND CALIBRATION OF FLIGHT TEST AIRCRAFT

SENSITIVITY TO	UNIT	FUSELAGE GAUGE NO				REFERENCE
		51CE	52CE	53TE	54TE	
TAILPLANE LOAD/SIDE	MICROSTRAIN PER N	.092	.124	-.157	-.145	TABLE 11 REFERENCE 1
	MICROSTRAIN PER lbf	.2046	.2758	-.3492	-.3225	
FIN LOAD	MICROSTRAIN PER N	.040	-.051	-.016	.019	TABLE 14 REFERENCE 1
	MICROSTRAIN PER lbf	.1779	-.2268	-.0712	.0845	
FUSELAGE TORQUE (VALUES FROM FATIGUE RIG)	MICROSTRAIN PER N.m	(-.01201)	(.00859)	(.00156)	(-.01641)	TABLE 10
MODIFIED VALUES ASSUMED FOR FLIGHT TEST AIRCRAFT	"	-.01030	.01030	.00899	-.00899	
	MICROSTRAIN PER lb.in	-.001163	.001163	.001015	-.001015	

TABLE 12. FUSELAGE GAUGE RESPONSE TO VERTICAL AND SIDEWAYS BENDING

(GROUND CALIBRATION OF FLIGHT TEST AIRCRAFT - AUGUST 1980)

GAUGES	STRAIN SENSITIVITY TO:-			
	FUSELAGE VERTICAL BENDING INDUCED BY TAILPLANE LOAD		FUSELAGE SIDEWAYS BENDING	
	STRAIN ($X10^{-6}$) PER LB.IN	STRAIN ($X10^{-6}$) PER N.m	STRAIN ($X10^{-6}$) PER LB.IN	STRAIN ($X10^{-6}$) PER N.m
51CE	.00198	.0176	.00265	.0235
52CE	.00268	.0237	-.00319	-.0283
53TE	-.00310	-.0275	-.00126	-.0112
54TE	-.00286	-.0254	.00140	.0124

TABLE 13. COMPARISON OF FATIGUE AIRFRAME CALIBRATIONS WITH FLIGHT AIRCRAFT CALIBRATIONS

FATIGUE AIRFRAME CALIBRATION - MARCH 1983			FLIGHT TEST AIRCRAFT GROUND CALIBRATION - AUGUST 1980[1]		REFERENCE
GAUGE	STRAIN/LOAD (UNITS SHOWN)		GAUGE	STRAIN/LOAD	
WING LOADING			(UNITS: STRAIN ($X10^{-6}$)/LOAD FACTOR)		
9C	-260	220	9BE	227	TABLE 20
9T	181	AVERAGE			REF. 1
					(SEE NOTE 2)
10C	-253	223	10BE	220	
10T	193	AVERAGE			
12C	-346		12 TOP	365 (1 ARM ONLY)	TABLE 25
12T	265		12 BOTTOM	-247	REF. 1
					(SEE NOTE 2)
21S	-25.8		21S	-28.9	TABLE 20
22S	-37.0		22S	-61.1	REF. 1
					(SEE NOTE 2)
TAIL LOADING			(UNITS: STRAIN ($X10^{-6}$)/LOCAL BENDING MOMENT (N.m))		
37CE	.521[3]	UPLOAD ONLY	37BE	.528[4] DOWN LOAD	
TE				.566[4] UP	TABLE 22
38CE	-.516[3]		38BE	.526[4] DOWN LOAD	REF. 1
				.542[4] UP	

.../cont.

TABLE 13. (CONT.)

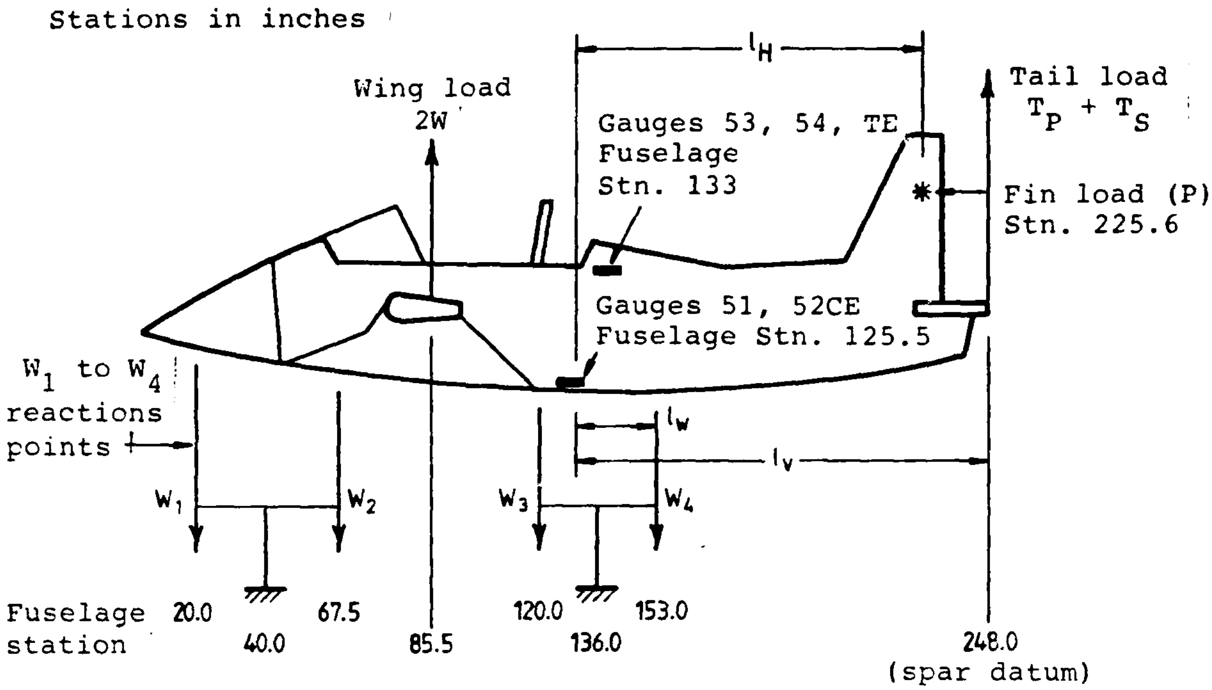
FATIGUE AIRFRAME CALIBRATION - MARCH 1983			FLIGHT TEST AIRCRAFT GROUND CALIBRATION - AUGUST 1980[1]		REFERENCE
GAUGE	STRAIN/LOAD (UNITS SHOWN)		GAUGE	STRAIN/LOAD	
FIN LOADING		(UNITS: STRAIN ($X10^{-6}$)/LOCAL BENDING MOMENT (N.m))			
33TE	.747[2]	(STARBOARD DIRECTION)	33TE	.783[5] (STARBOARD DIRECTION) .809[5] (PORT DIRECTION)	TABLE 14 REF. 1
SENSITIVITY TO FUSELAGE VERTICAL BENDING MOMENT (UNITS: STRAIN ($X10^{-6}$)/lb.in)					
51CE	.00411		51CE	.00198	TABLES 9 AND 12
52CE	.00281		52CE	.00268	
53TE	-.00367		53TE	-.00310	
54TE	-.00521		54TE	-.00286	
SENSITIVITY TO FUSELAGE SIDEWAYS BENDING MOMENT (UNITS: STRAIN ($X10^{-6}$/lb.in)					
51CE	.00267		51CE	.00265	TABLES 10 AND 12
52CE	-.00241		52CE	-.00319	
53TE	.00174		53TE	-.00126	
54TE	-.00176		54TE	.00140	
SENSITIVITY TO FUSELAGE TORQUE (UNITS: STRAIN ($X10^{-6}$)/lb.in)					
51CE	-.00136		NOT AVAILABLE		TABLE 10
52CE	.00097		" "		
53TE	.00018		" "		
54TE	-.00185		" "		

.../cont.

TABLE 13 (CONT.)

NOTES:

1. THE TAILPLANE VALUES ALSO INCLUDED TESTS ON ANOTHER TAILPLANE PERFORMED IN AUGUST 1980.
2. A LOAD OF 2.923 kN PER UNIT LOAD FACTOR IS ASSUMED.
3. AVERAGING SYMMETRIC AND ASYMMETRIC LOADINGS.
4. MOMENT ARM OF CALIBRATION LOAD = 1.373 m.
5. MOMENT ARM OF LOAD = 0.918 m.



Note 1. l_w and l_v are depicted as for gauges 51, 52CE

2. Fin spar datum 233.6 inches

FIG. 1. LOADS INDUCING FUSELAGE VERTICAL BENDING IN FATIGUE RIG.

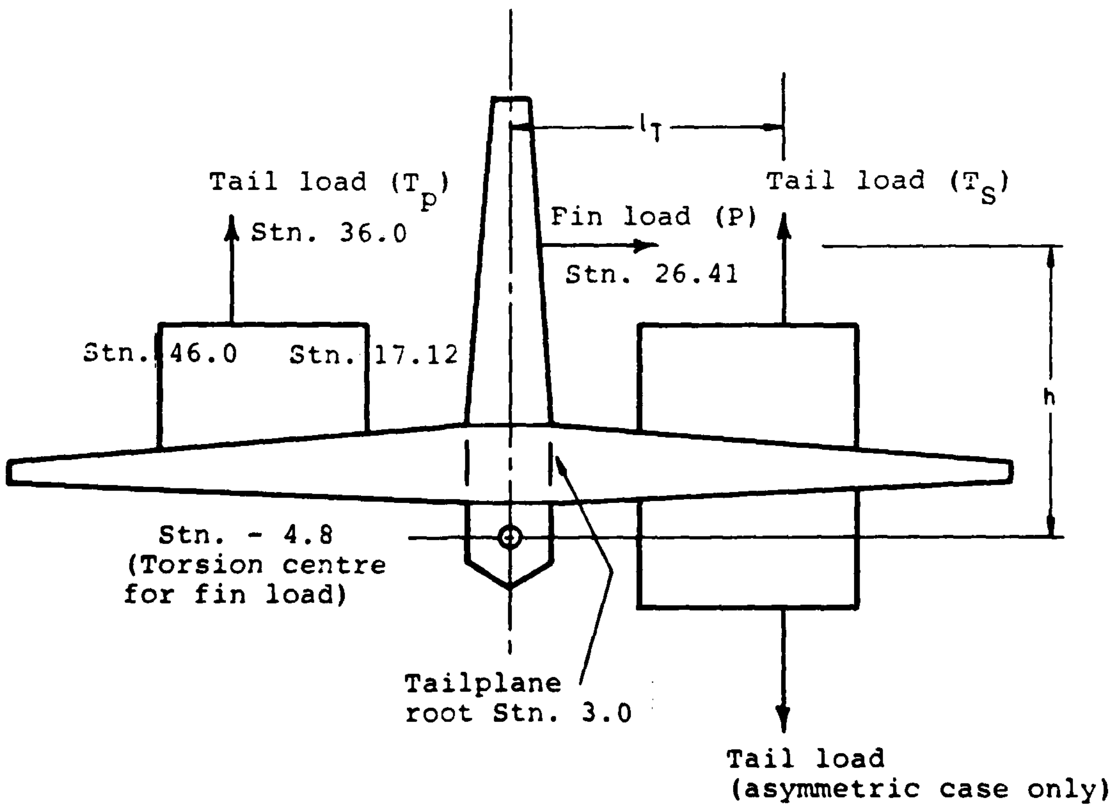


FIG. 2 - EMPENNAGE FATIGUE RIG LOADING.

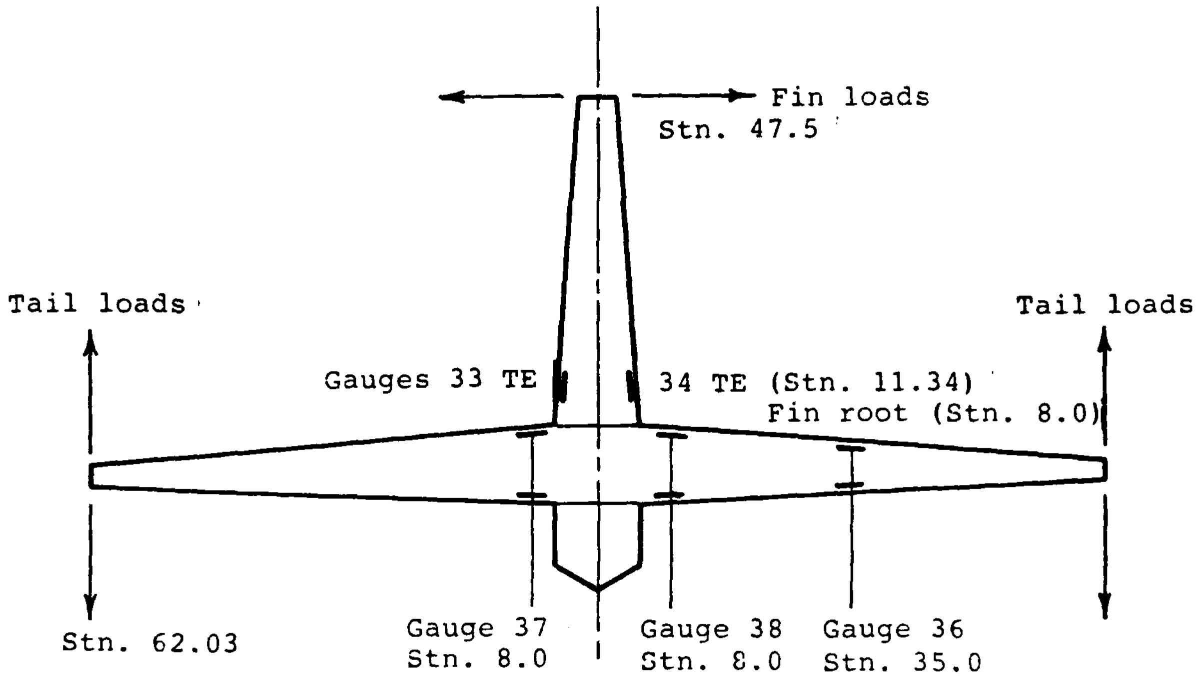


FIG. 3 - EMPENNAGE GROUND CALIBRATION LOADING AND GAUGE POSITIONS.

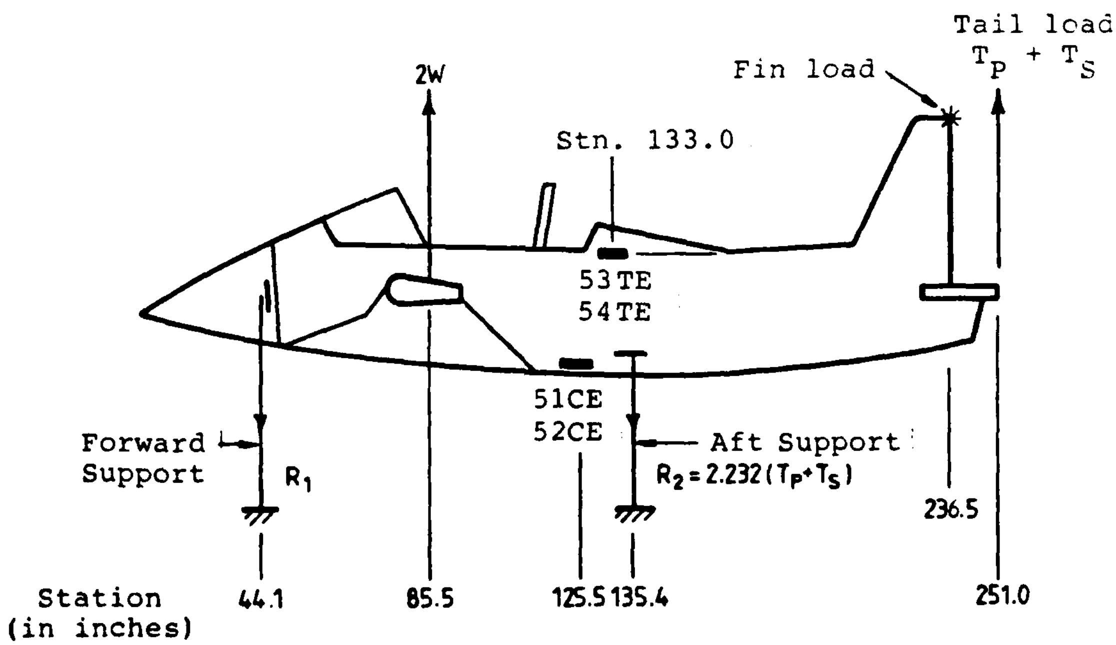


FIG. 4 - POSITIONS OF FORCES - GROUND CALIBRATION

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14. Descriptors

Calibration
Strain measurement
Airframes
Loads (forces)
CT-4A Aircraft

15. COSATI Group

0103
1402

16. Abstract

In preparation for fatigue testing, a strain gauged CT-4A fatigue test article has been calibrated by discrete static loadings. The strain/load data are analysed herein and strain sensitivities to various load parameters are reported.

The responses of some gauges have been compared with flight strains and ground calibrations.

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