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CRANFIELD

STRUCTURAL PROPERTIES OF HIGH MODULUS ALUMINIUM ALLOY

by

D. HOWE and N. C. SOPER

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T H E   C O L L E G E   O F   A E R O N A U T I C S

C R A N F I E L D

An Experimental Investigation of the Structural Properties of High Modulus Aluminium Alloy

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D. Howe, D.C.Ae. and N.C. Soper, B.Sc., D.C.Ae.

SUMMARY

The purpose of this report is to give the results of an experimental investigation of the structural properties of high modulus aluminium alloy.

The tests carried out consisted of tension, compression, hardness, bending and compression panel investigations.

It was found that high modulus material is difficult to form and very prone to cracking on failure.

Thus although the material has a definite structural application, in view of the forming and cracking problems it is doubtful whether further development is worthwhile.

1.0 Introduction

In the structural design of certain high speed aircraft, it is found that the requirements for adequate stiffness, rather than strength, are the governing criteria. One of the ways by which this can be alleviated is to use a structural material having a high elastic modulus. Accordingly, with this in view, an aluminium alloy has been developed which has a Young's Modulus of approximately 12 x 10^6lb/sq.in., rather than the more customary 10 x 10^6lb/sq.in.

The purpose of this report is to describe an experimental investigation of the structural potentialities of this material. Originally the work was intended to cover two spheres. Firstly, an investigation of the general properties of the material, and its behaviour when used in compression panels. Secondly, to study it when used for the construction of a multi-web swept box beam. Unfortunately material for this latter part was not available, and so this aspect has not been covered.

2.0 Material

The material used was all supplied through the Royal Aircraft Establishment, and was in rolled sheets, five and a half feet by two and a half feet, of nominal 16 gauge. No specification code was given, and throughout this report it is referred to as "High E" material.

3.1 Control Tests

In order to establish the properties of the material in comparison with more commonly used aluminium alloy sheets, a series of control tests was carried out. Five separate cases were investigated, namely, D.T.D. 610; D.T.D. 546; D.T.D. 687 and High E, all in the condition as received, and High E after annealing and the subsequent heat treatment. This latter was as recommended by the R.A.E., and is given in Table 1.

A comparison of the tensile properties for each of these cases, both longitudinally and laterally with respect to the direction of roll, are given in Table 1. A standard 0.5 in. wide specimen having a 2.0 in. gauge length was used. The corresponding compression properties obtained from a 1.0 in. wide specimen are shown in Table 2.

Vickers Diamond Pyramid hardness tests gave the results shown in Table 3.

From these Tables it can be seen that the High E material has a strength comparable to D.T.D. 546, and an elastic modulus some 20% greater. It is inferior to D.T.D. 687 from the strength aspect, and its elongation is also very low.

3.2 Tangent Modulus

The reduced elastic modulus of a material at high values of stress is often more important than the initial value. The Tangent Moduli of the tested materials in both tension and compression are shown in Figs. 1 and 2. These indicate that D.T.D. 687 has a higher modulus for stresses above 35,000 to 40,000 lb/sq.in. Above this stress level, the High E behaves similarly to D.T.D. 546.

3.3 Bend Tests

Before constructing panels of High E material, it was necessary to investigate its forming properties. This was done by carrying out bend tests on 1.0 in. wide strips. The results are given in Table 4.

The difficulty in forming High E material, and its poor behaviour under these conditions - even when compared to D.T.D. 687 - are clearly shown by these results.

In addition, subsequent heat treatment was found to cause considerable distortion, which was very marked in the Zed section stringers used for the compression panels. Vertical quenching was used.

3.4 Panel Tests

Four panels were tested, the details of which are given in Fig.3. In all cases the skin was of High E material, but only in Panel 4 were the stringers also made of this material.

The main results are given in Table 5, while Figs.4 and 5 show the $f_a - f_e$ and $f_{Skin} - f_e$ curves respectively.

In the first three panels slight skin buckling was observed at about 26,000 lb. load. This did not develop or affect the load-extension curve. It was probably due to the skin accommodating slight strain incompatibility between the stringer rivets.

From the point of view of ultimate load, or buckling stress, there is very little to choose between the panels, but the results do indicate that the use of High E stringers tends to increase the buckling coefficient, K, an effect also obtained by increasing stringer area as in Panel 1.

A theoretical comparison for Panels 3 and 4, based on the tangent to the Euler curve, is seen to give a fairly good prediction of failing stress. In this calculation it was assumed that the short strut buckling stress was equivalent to the material ultimate tensile stress, and from previous test results that the effective length of the panel was 0.6 actual.

Panel 3 was found to have a crack in the skin after buckling. This crack began at a rivet hole on an edge stringer and continued to the edge of the skin. Fig.6 shows Panel 4 after failure. The considerable cracks in the stringers can be seen. There was also a skin crack similar to that found in Panel 3. It is understood that stringer cracking has previously occurred in D.T.D. 687 stringers, but the bend test results indicate how much more prone to this type of failure is High E material.

The implication is that High E material can only be used in flat or slightly curved sheets and, due to the probability of skin cracking, that the design must be such as to exclude the possibility of buckling until the ultimate, rather than proof, load is exceeded.

4.0 Conclusions

1) Due to probability of cracking, High E material is not suitable for formed sections, and can only be used in sheets having small curvatures.

2) High E panels must be designed such that buckling occurs above the ultimate load.

3) D.T.D. 687 has a higher tangent modulus for stresses above 35,000 lb/sq.in.

4) As the reduction in panel thickness for a given buckling stress resulting from the use of High E material is only 10%, a gain will only result in marginal cases of gauge thickness.

5) The use of High E material is restricted to non buckling structures where the ultimate stress level is below 35,000 lb/sq.in, and stiffness is the dominant factor.

6) In view of the foregoing conclusions, it is a matter of conjecture as to whether there is any point in further developing this material.

TABLE 1 - Tensile Properties

Material Specification	E. lb/sq.in x 10^6		0.1% proof stress lb/sq.in		0.2% proof stress lb/sq.in		Ultimate Stress lb/sq.in		% Elongation on 2.0 in.G.L.	
	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.
D.T.D. 610 (As received)	9.0	9.04	36,800	44,000	39,500	45,000	61,250	62,200	21.5	23.5
D.T.D. 546 (As received)	9.45	9.0	53,700	48,500	55,000	50,200	62,600	61,500	14.5	13.0
D.T.D. 687 (As received)	9.44	9.33	69.000	67,300	71,700	69,500	78,800	76,700	11.0	8.5
High E (As received	11.8	11.6	55,500	48,700	57,100	51,200	61,000	61,700	1.5	2.0
High E * (Heat treated)	12.0	12.0	48,800	48,400	51,600	51,200	61,500	59,400	6.0	2.5

* Heat treatment:- Annealed - 400°C for 1 hour and quench
Solution treated - 510°C for 1 hour and quench
Aged immediately - 155°C for 24 hours

TABLE 2 - Compressive Properties

Material Specification	E. lb/sq. in x 10^6		0.1% Proof Stress lb/sq. in.		0.2% Proof Stress lb/sq. in.	
	Long.	Lat.	Long.	Lat.	Long.	Lat.
D.T.D. 610 (As received)	9.83	9.83	34,900	39,400	37,800	42,400
D.T.D. 546 (As received)	9.33	10.0	50,900	52,000	53,000	53,200
D.T.D. 687 (As received)	10.1	10.5	72,900	72,300	75,800	75,500
High E (As received	12.6	12.2	49,700	55,800	54,200	59,000
High E * (Heat treated)	11.9	11.5	51,100	51,200	54,500	54,800

* Heat treatment:- See Table 1.

TABLE 3 - Hardness

Material Specification	Hardness No. ≠	
D.T.D. 610 (As received)	138	Vickers Pyramid - 20kg
D.T.D. 546 (As received)	154	
D.T.D. 687 (As received)	194	
High E (As received)	159	
High E * (Heat treated)	178	

* Heat treatment - See Table 1.

≠ Mean of large number of readings taken on edge of material

TABLE 4 - Bend Tests

	Material Specification	Failure Angle - Degrees ※				
		Bend Radius to centre line				
		5.5T	3.0T	2.0T	1.5T	1.0t
Annealed	D.T.D. 610	-	-	-	-	-
	D.T.D. 546	-	-	-	-	-
	D.T.D. 687	-	-	-	-	-
	High E	-	-	75° ≠	68° ≠	55°
As received	D.T.D. 610	-	-	-	-	-
	D.T.D. 546	-	-	60°	54°	48°
	D.T.D. 687	-	-	65°	45°	43°
	High E	31°	28°	25°	23°	23°

※ Mean of four specimens of 1.0 in. width

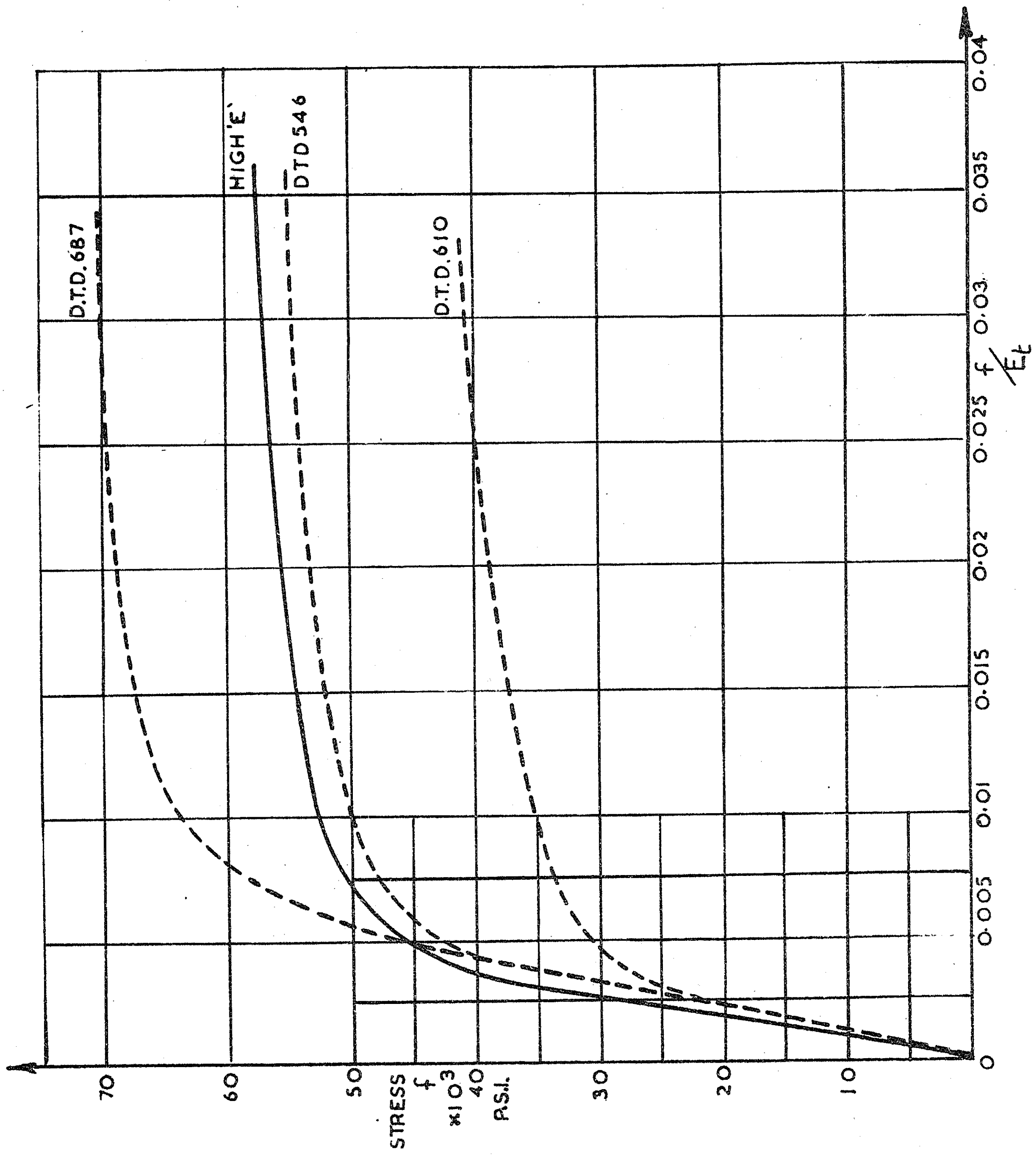
≠ Mean of three fractured specimens

TABLE 5 - Panel Tests

Panel	Stresses lb/sq.in.					Ultimate Load lbs	K
	Buckling Edge*	Buckling Skin	Failing Edge	Failing Skin	Theoretical Failing ≠		
1	22,100	31,700	23,700	35,000	-	44,600	4.9
2	21,700	28,500	33,400	32,900	-	46,400	4.2
3	21,400	30,200	30,800	33,400	36,000	45,600	4.5
4	28,200	31,400	36,000	34,200	36,500	48,800	4.85

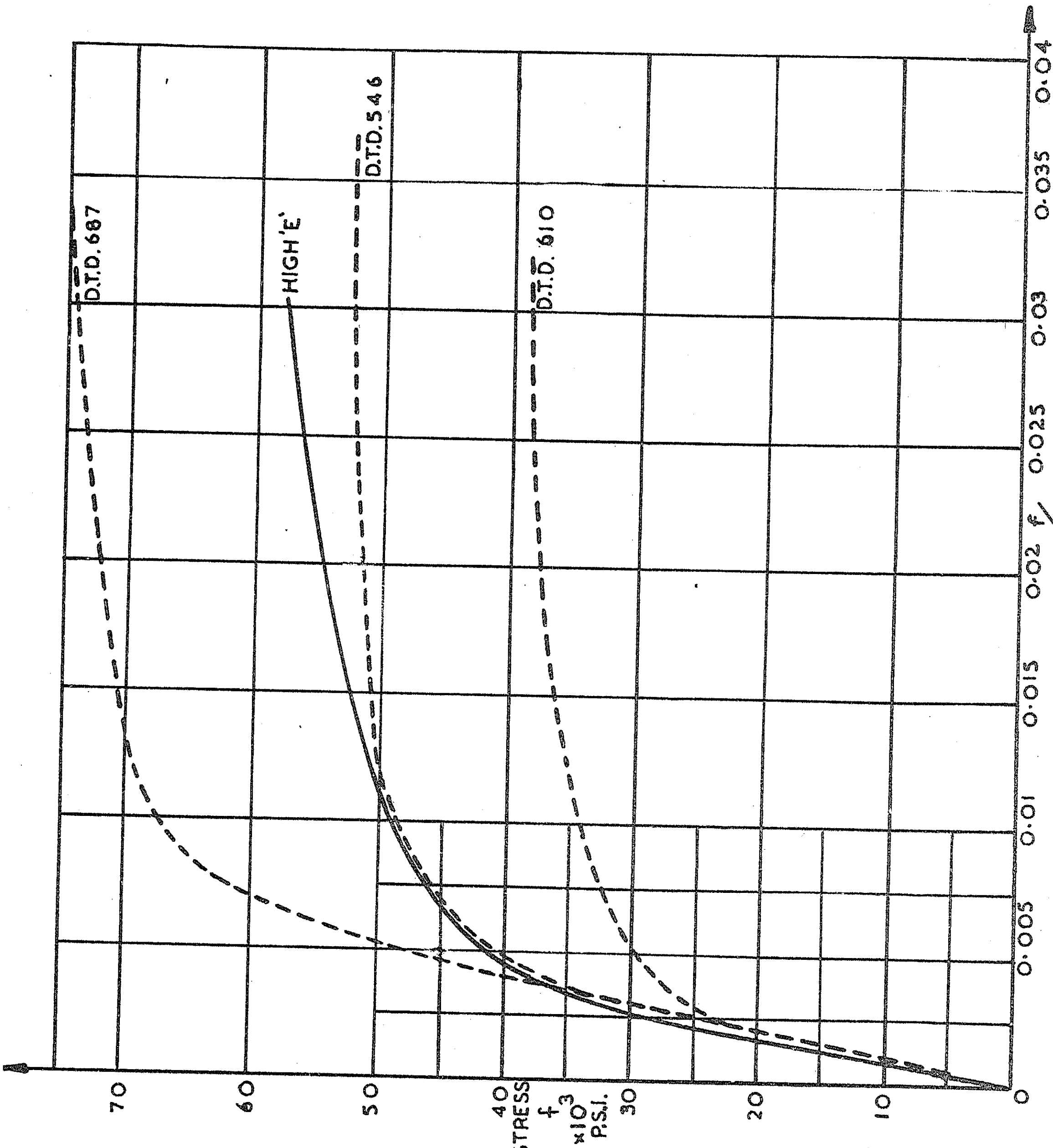
* Slight skin buckling observed in Panels 1,2 and 3 at approximately 26,000 lb. load.

≠ Based on tangent to Euler curve. Short strut stress equivalent to Ultimate Tensile Stress. Effective length 0.6



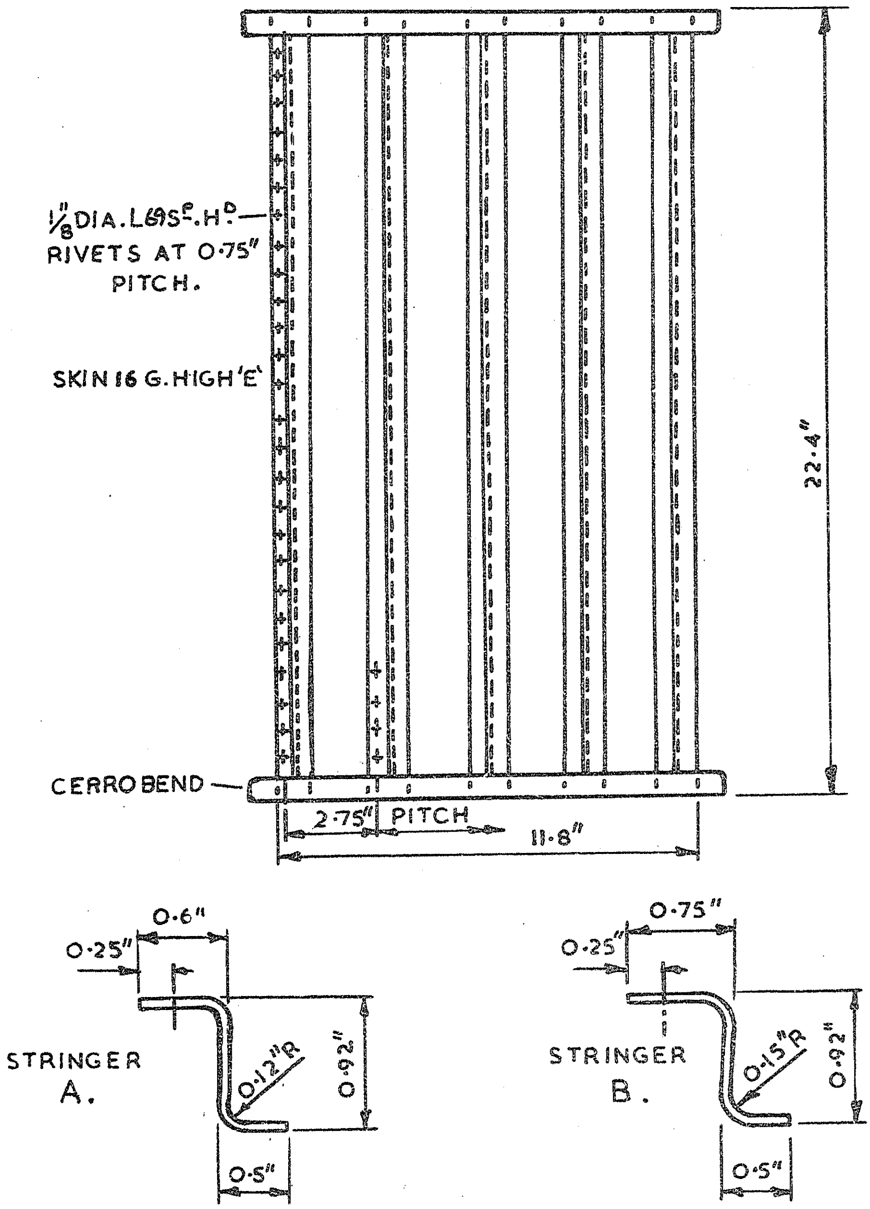
TANGENT MODULUS CURVES
TENSION

FIG. 1



TANGENT MODULUS CURVES
COMPRESSION

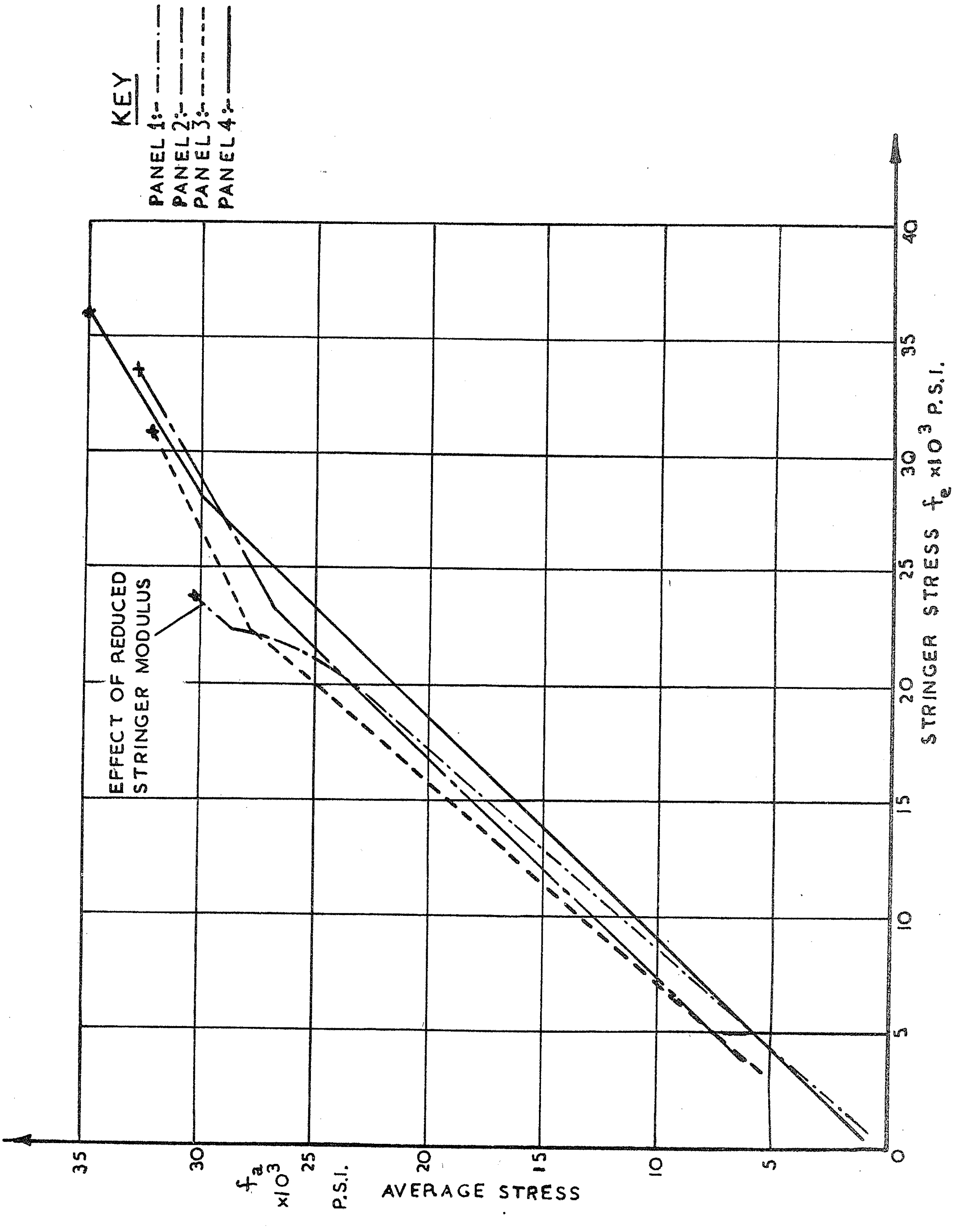
FIG. 2.



PANEL:- 1) STRINGER A. 14 G. D.T.D. 610
2) STRINGER A. 16 G. D.T.D. 546
3) STRINGER B. 16 G. D.T.D. 546
4) STRINGER B. 16 G. HIGH 'E'

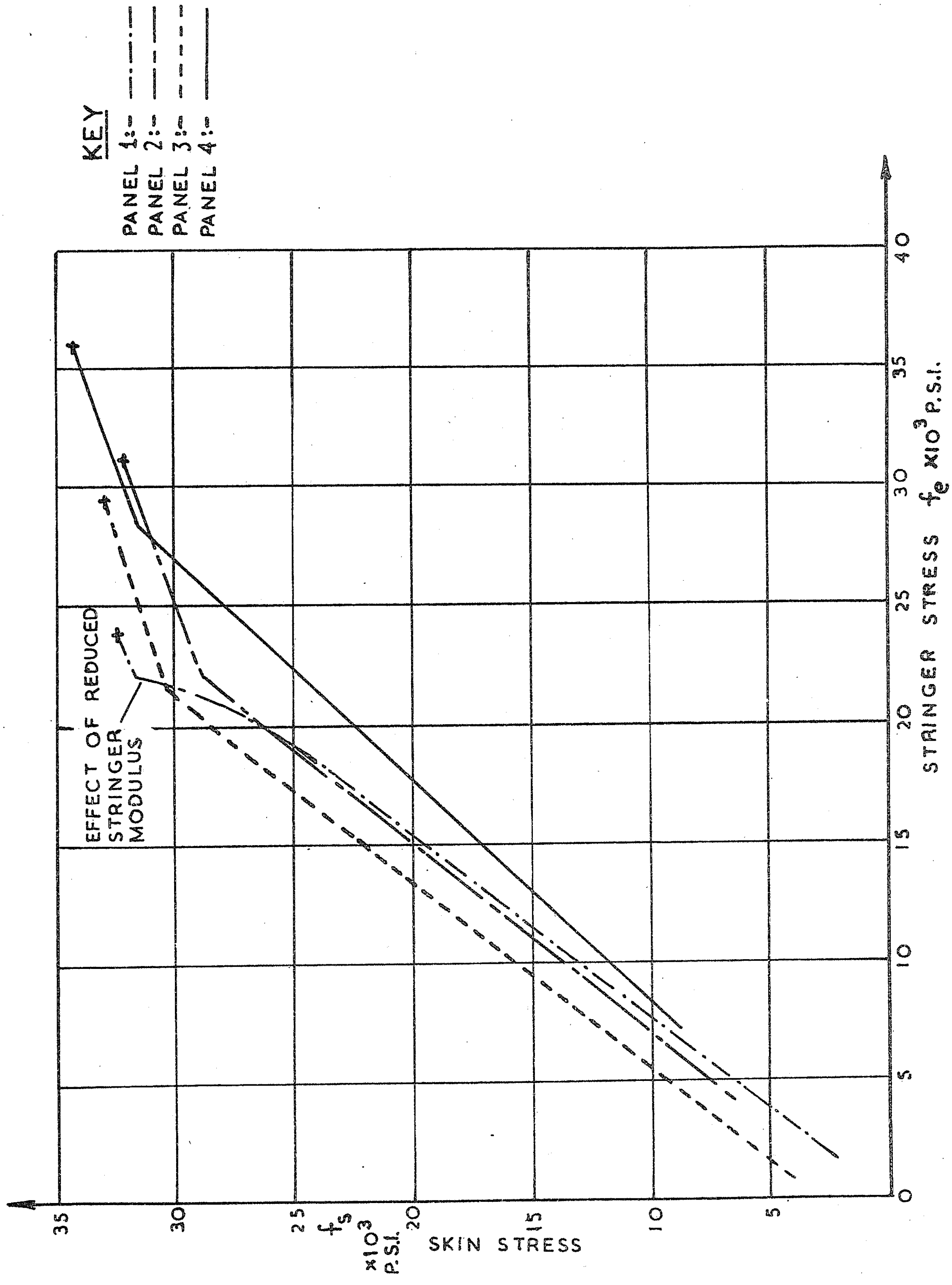
PANEL DETAILS

FIG. 3



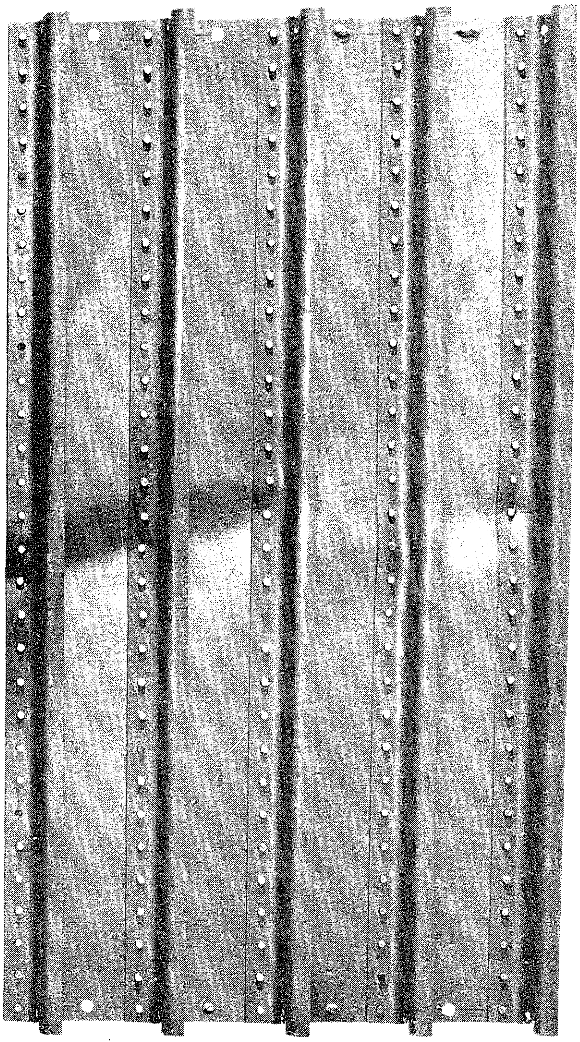
PANELS STRINGER-AVERAGE STRESSES

FIG.4.



PANELS STRINGER-SKIN STRESSES

FIG. 5



PANEL NO.4 AFTER FAILURE

FIG.6