STRUCTURAL DESIGN AND TESTING RESULTS OF COMPOSITE LANDING GEAR COMPONENTS

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ABSTRACT

This paper is aimed at evaluating the advantages of constructing some landing gear parts from carbon fiber composite materials.

Even though fiber composite structures are more and more used in aviation and space applications, since the composite materials offer the advantages of high strength and stiffness at low weight, no composite structure is easy to find in a landing gear of an aircraft or helicopter. It is mainly due to the particular geometry of a landing gear and applied high concentrated loads.

The present paper describes the main concepts used to design, fabricate some C.F.R.P. landing gear components, giving evidence of results of tests performed.

The aim was to demonstrate the applicability of composite materials to landing structures with the objective to reduce weight in comparison to the equivalent metal parts.

1. INTRODUCTION

The items selected as a basis for this study were the transverse tube of A129 helicopter and the upper and lower arms of AMX nose landing gear drag brace. The existing metal parts are shown in fig. 1.

The primary programme objective was to investigate various aspects of design, technology for fabrication, related to C.F.R.P. landing gear components, saving the interfaces and geometry, to satisfy the replaceability requirements at the aim to obtain a weight reduction at acceptable manufacturing costs.

Structural tests were performed at the same conditions of the existing landing gear to verify the correspondance to the theorical work carried out.

2. SELECTION AND CHOICE OF MATERIALS

Particular attention has been payed to the right choice of the material to be used for each component also taking into account the experience of the prototypes producers.

The selection was made by first considering a large number of candidate materials, taking for good the theoretical properties indicated, while the final choice had to be based upon real values obtained from in-home tests performed according to ASTM specification for:

- Tensile
- Compression
- Flexure
- Shear (intralaminar)

and the values obtained were used as input data for software codes employed in design.

Although the material tests would lead to design with Fiberite T650/42/974 carbon fiber epoxy resin, supplying reasons led us to use for the prototype fabrication a carbon fiber epoxy resin ITALCOMPOSITI EA42/C15/VDH/IM400 characterized by lower mechanical properties.

The used design properties are shown in table 1.

3. DESIGN PROCEDURES

The design steps for the different components have all in commun the sequence of studying first the present metal solution, identifying the principal "missions" of the element in terms of load, stiffness, dimensions and weight, enucleating the basic requirements when changing the type of material, and then attempting first laminations and geometrical solutions to evaluate.

3.1 Description of conventional components

The components, we chose for our study, were:

- transverse tube of A129 helicopter
- upper and lower arms of AMX nose landing gear drag brace.

The reason of this choice was due to their not particular complicated geometry and current use made of this components on landing gear solutions.

3.1.1 Transverse tube

This component, installed in the fuselage, supports the two not retractable main landing gears. It is free to rotate through chromium plated surfaces in the helicopter attachments. The landing gear trailing arms, during the ground manoeuvrings and landings, rotate on chromium plated surfaces of transverse tube supports.

The transverse tube is in high strength steel 300M (MIL-S-8844). It is designed to withstand the bending moments and axial loads coming from critical crash conditions.

3.1.2 Drag brace

The brace consists essentially of the following two arms which fold to allow retraction and extension of the nose landing gear and react drag loads applied at the centre of the wheel:

a) 4340 steel upper arm
b) 7010 aluminium alloy lower arm.

The drag brace is a pin connected at both ends so that, subjected to axial loads only, it withstands a compression and tension strength in addition to a critical load of buckling.

3.2. Composite design aspects

Development work was performed for the considered components as follows:

3.2.1 Transverse tube

The composite transverse tube was designed to have a tubular lay up composed by layers with carbon fiber orientation $(\pm 45/0/\pm 30/\pm 45)_s$ and related thickness of $(.5/3/.5/.5)_s$ (in mm) for a total thickness of 9 mm.

The above lay up comes from considering the triaxial state of stress due to external loads and trying to maintain the flexural stiffness of the equivalent metal component.

The design constraint of respecting the actual helicopter interface obliged to maintain the outside diameter, 100 mm, and to increase the thickness, limiting the weight gain, fixed in 30% as technical goal.

In spite of the simple tubular geometry of the transverse tube, singularities exist in the following sections:

- attachments of the tube to helicopter
- attachments of the tube to the trailing arms
- attachments for mooring and lifting devices.

Taking into account the high concentrated loads in these points, in addition to the frictional effects due to the rotation of the trailing arms, the final design solution was to insert stainless metal bushings on the composite tube, after carrying out several tests on specimens only representative of the tube ends.

A finite element model was created to perform a complete analysis of the stress distribution, employing NASTRAN method on Univac computer.

Some layings were performed to verify stiffness and strength requirements taking into account the applicable technology.

A linear FE analysis consisting in:

- 795 nodes
- 829 shell type elements

was performed since it appeared sufficient for our purpose.

As regards the technology, it is important to note that presence of 0^ oriented fibers, obliged us to choose a fabrication process, which allowed the design lay up, therefore excluding the filament winding process.

Three fabricaton processes were taken into account:

. wrapping on metallic mandrel
. manual lay up on metallic mandrel
. pressure bag molding.

Basing on our drawings, suppliers, skilled in the above composite fabrication, were involved in constructing tubolar specimens with all the singularities they presented.

Test results, verification of piece quality, their reproducibility and price considerations put in evidence the advantages of wrapping process that was chosen.

This process, shown in fig. 2 , allows to lay up on a metallic mandrel the prescribed plies through subsequent automatic wrapping up.

The final layer was cured in autoclave after a previous compression.

Drawings and working process specifications were issued and four prototypes were fabricated. In fig. 3 is shown a complete composite transverse tube.

Stainless alloy 15-5 PH bushings were designed such to be bonded on composite transverse tube by structural adhesive, as shown in fig. 4.

3.2.2 Drag brace

Two design concepts were studied for the drag brace arms taking into account the geometry, strength and stiffness of the conventional items.

For both arms it was decided to design a composite structure composed by two parts, central and outside withstanding to compression and tensile loads respectively.

For the lower arm the central part consisted in a filament winding prismatic box on which four different composite flat platens, cured separately, were bonded together stainless alloy inserts by a structural adhesive.

The outside part consisted in a carbon fiber filament winding made and cured on central part directly.

Specific toolings and dies were designed to lay up the platens and to wind the outside part which presented the ends positioned at 90^ conforming to metal part geometry.

Two flat platens consisted of 53 plies oriented at $(0/\pm 45/0\text{-}90/\pm 45/0)_s$. The other two of 33 plies oriented at $(0/\pm 45/0\text{-}90)_s$.

Each layer was cut so as to allow the insertion of fiber glass bushings between the wound part and itself.

Stainless alloy inserts were designed to withstand to high shearing stresses. In fig. 5 it is shown a break down of lower arm design.

For the upper arm, the central part consisted in thick platen composed of 193 plies oriented at $(\pm 45/0/\pm 45/0/\pm 45/0\text{-}90/\pm 45/0/0/\pm 45/0)_s$ on which four flat platens, cured separately, were bonded together stainless alloy inserts by structural adhesive.

The outside part consisted in a carbon fiber filament winding made and cured on specific toolings.

A final assembly for the two parts and final cure were requested.

The insertion of fiber glass bushings was prescribed inside metallic inserts and flat platens.

In fig. 6 it is shown a break down of composite upper arm design.

For both arms were issued drawings and working process specifications.

A linear F.E. analysis was performed consisting in:
for lower arm: 314 nodes, 236 shell type elements, 56 truss elements, 80 beam type elements
for upper arm: 477 nodes, 407 shell type elements.

The manufacturing for both arms were subcontracted and four prototypes for the lower and the upper arms were fabricated.

In fig. 7 is shown the composite drag brace.

4. EXPERIMENTAL VALIDATION OF THE SOLUTIONS ADOPTED

Characteristics we required for composite elements were to reproduce as close as possible strength and stiffness behaviour of the traditional ones saving the interface configuration.

A series of tests were performed on the composite transverse tube and drag brace with the aim to evaluate their strength and stiffness behaviour when subjected to the most critical loads used for testing the metal components.

The composite components we tested, were manufactured by the Italian suppliers ITALCOMPOSITI and REGLASS.

4.1 Test description

4.1.1 Transverse tube

Static test was performed on the C.F.R.P. transverse tube applying the loads coming from the crash landing case and resulted most critical in testing of the traditional tube.

Two real trailing arms and two steel rods representative of the shock absorbers in a determined closure, were employed to create the same test conditions as the actual landing gear ones. Loads were introduced through two actuators acting on the axle of the trailing arms by means of two dummy wheels. A sketch of the test is shown in fig. 8.

Transverse tube was equipped by means of 12 strains and 7 displacement gauges; for some of these ones, position is shown in fig. 9. In order to make a comparison, we chose the same measurement points as those ones used for the traditional tube.

4.1.2 Drag brace

Static and fatigue tests were performed on the composite drag brace reproducing the most critical test cases used in testing of the traditional one.

The specimen was composed by: a C.F.R.P. upper brace, a C.F.R.P. lower brace and a metal unlock mechanism.

A specific rig was designed to test only the complete drag brace subjected to the axial loads coming from the ultimate test case conditions.

The tests were performed using a computer controlled test machine able to apply a static and/or cyclic load.

4.2 Test results evaluation

In order to verify the theoretical considerations done in the design phase aimed to obtain, for the C.F.R.P. components, similar stiffness and strength behaviour of the metal ones, we positioned the gauges such to have test results comparable to that available for the correspondent metal components.

4.2.1 Transverse tube

Use of carbon fiber in transverse tube manufacture allowed us to reach a weight gain of 31,5 % compared to that one of the metal tube.

Static test showed good performances of the composite tube when submitted to the design load; failure occurred at a load of 93% of ultimate crash load in correspondence of external attachment points as shown in fig. 10.

A sensible deviation can be noted at an examination of the comparison curves (fig. 11) of the gauges readings, relative to the tests on composite and metal tube, due to the effect of minor modulus of the material used in comparison to that considered during design and calculation.

4.2.2 Drag brace

Tests were performed on the composite drag brace using the load calculated on the metal one with the aim to evaluate the static and fatigue strength and investigate its critical points.

Static tests showed the total compliance of the composite specimen to the compression design load, while a rupture occurred in the lower eye end of the lower brace during the tension test at a load of 93,75 KN correspondent to the 78,2 % of the ultimate design load. Static test lay out and specimen rupture are shown in fig. 12 and 13.

No failures were evidentiated during the fatigue tests that consisted of a statistic sequence of the "mission types" shown in fig. 14; the total number of each mission performed is specified in table 3.

Use of composite as a basic material in manufacture of both lower and upper arms allow us to reach a complessive weight gain of 35,3% referred to that of the metal ones.

5 CONCLUSIONS

The results of this work indicate that landing gear components, normally employed in design solutions, may be constructed from composite material which results in weight savings and are structurally satisfactory.

The objective to design and fabricate the above composite elements starting from fixed geometries is achieved.

Transverse tube weight was reduced about 30% with a cost increment ratio of 1.5 to 1 as compared to conventional material.

Drag brace weight was reduced about 50% compared to steel part and 27% compared to aluminium alloy part with a cost increment ratio of 5 to 1 as compared to both conventional materials.

The advantages in terms of weight reduction and costs can be better than those ones obtained if the composite components are introduced from the beginning in the landing gear project.

TABLE 1 : COMPARISON BETWEEN MATERIALS

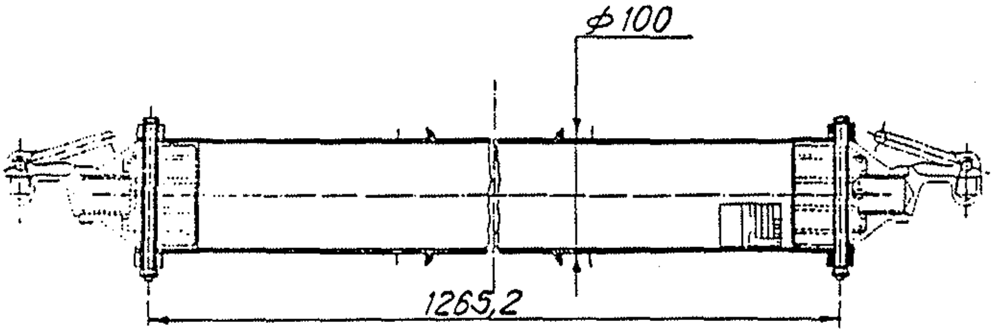
PROPERTY	EA42/C15 UDH/IM400	HY-E-T650-42/974	THEORETICAL VALVES
E_{11}	128.134	153.000	157.000
E_{22}	6.840	8.209	7.850
G_{12}	3.330	1.488	4.900

TABLE 2 : COMPARISON BETWEEN WEIGHTS

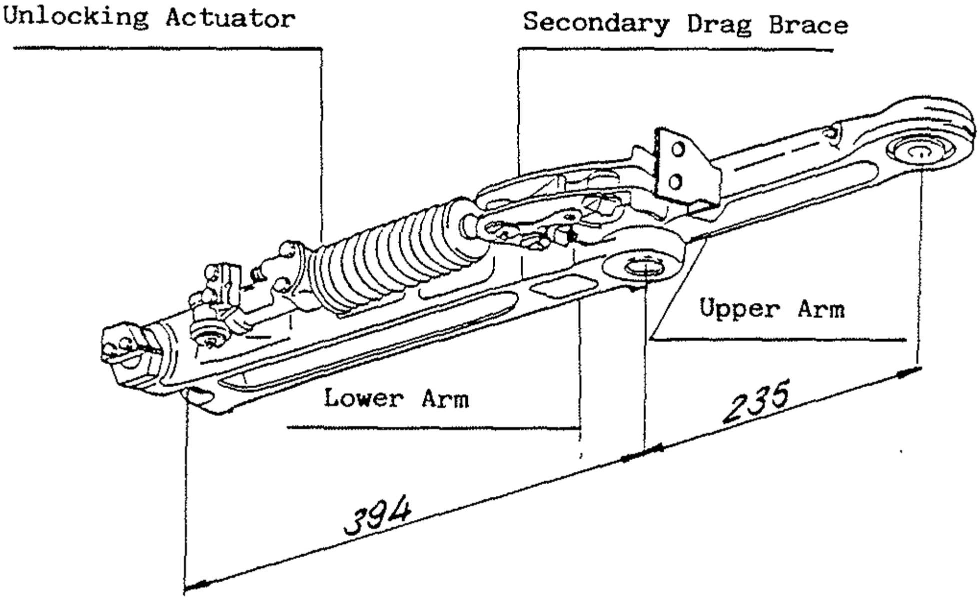
COMPONENT	WEIGHT (gr)		GAIN (%)
	TRADITIONAL	COMPOSITE	
Transverse Tube	10.500	7.190	31,5
Drag Brace: Upper Arm	1.520	742	51,1
Lower Arm	1.700	1.340	21,2

TABLE 3 : MISSION IN FATIGUE TEST

MISSION	NO. OF TEST CYCLES
Flight A	7.800
Flight B	7.800
Touch and go	4.000
Retraction / Extension	14.700



a) CONVENTIONAL A129 TRANSVERSE TUBE



b) CONVENTIONAL AMX NOSE LANDING GEAR DRAG BRACE

FIG. 1

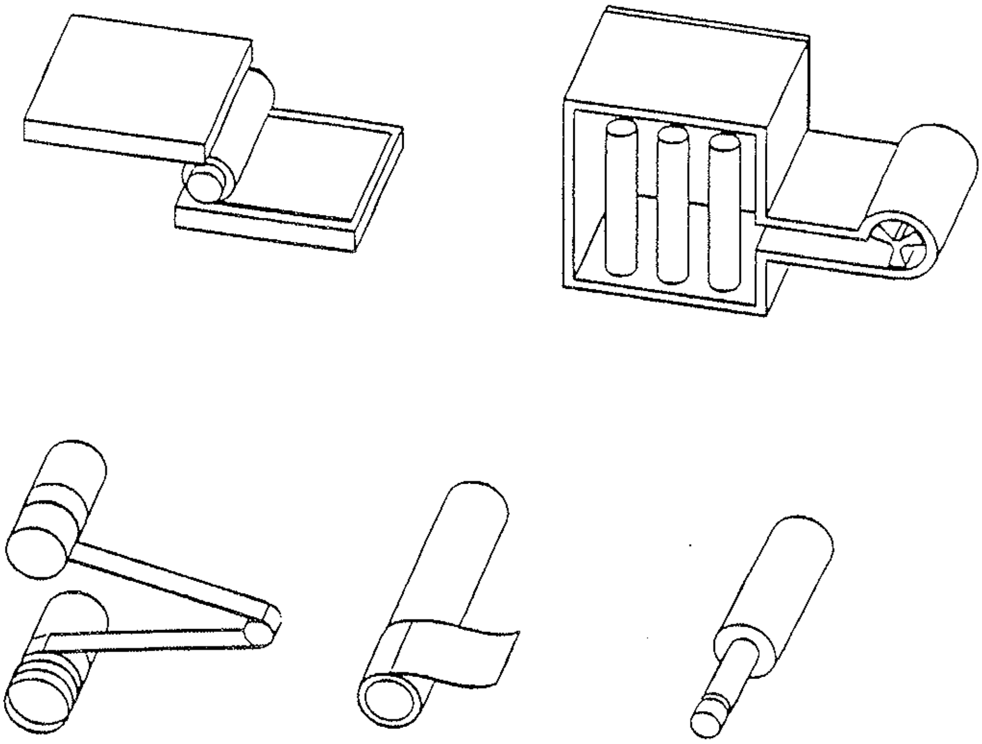


FIG. 2 : WRAPPING PROCESS FOR TRANSVERSE TUBE

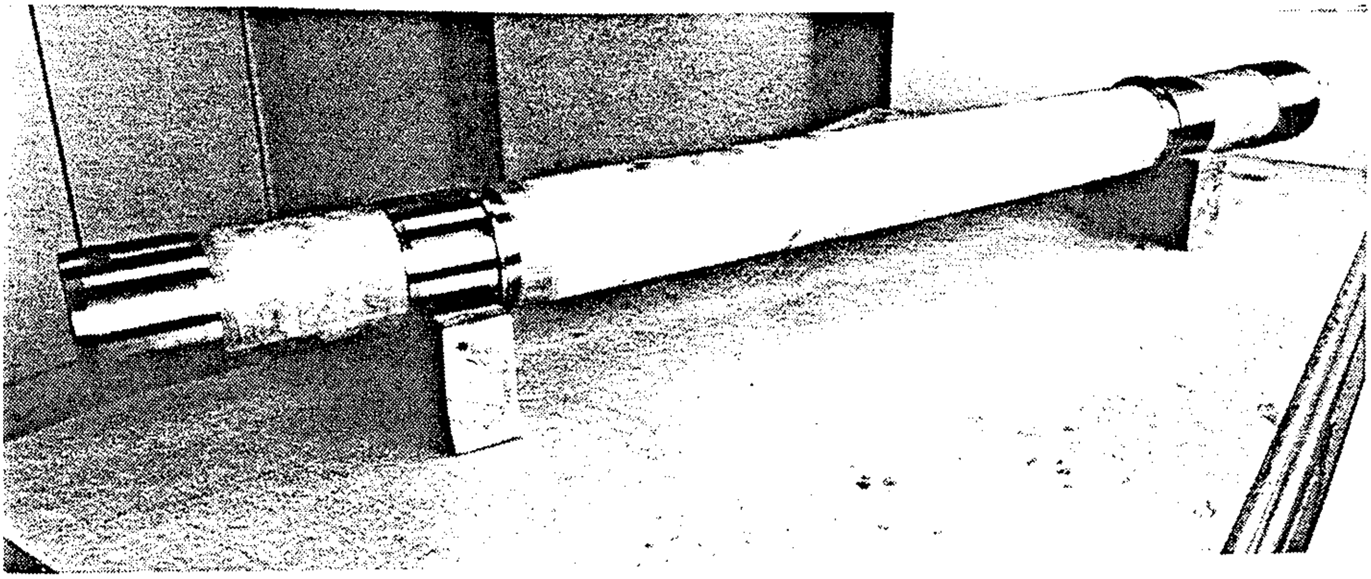


FIG. 3 : COMPOSITE TRANSVERSE TUBE

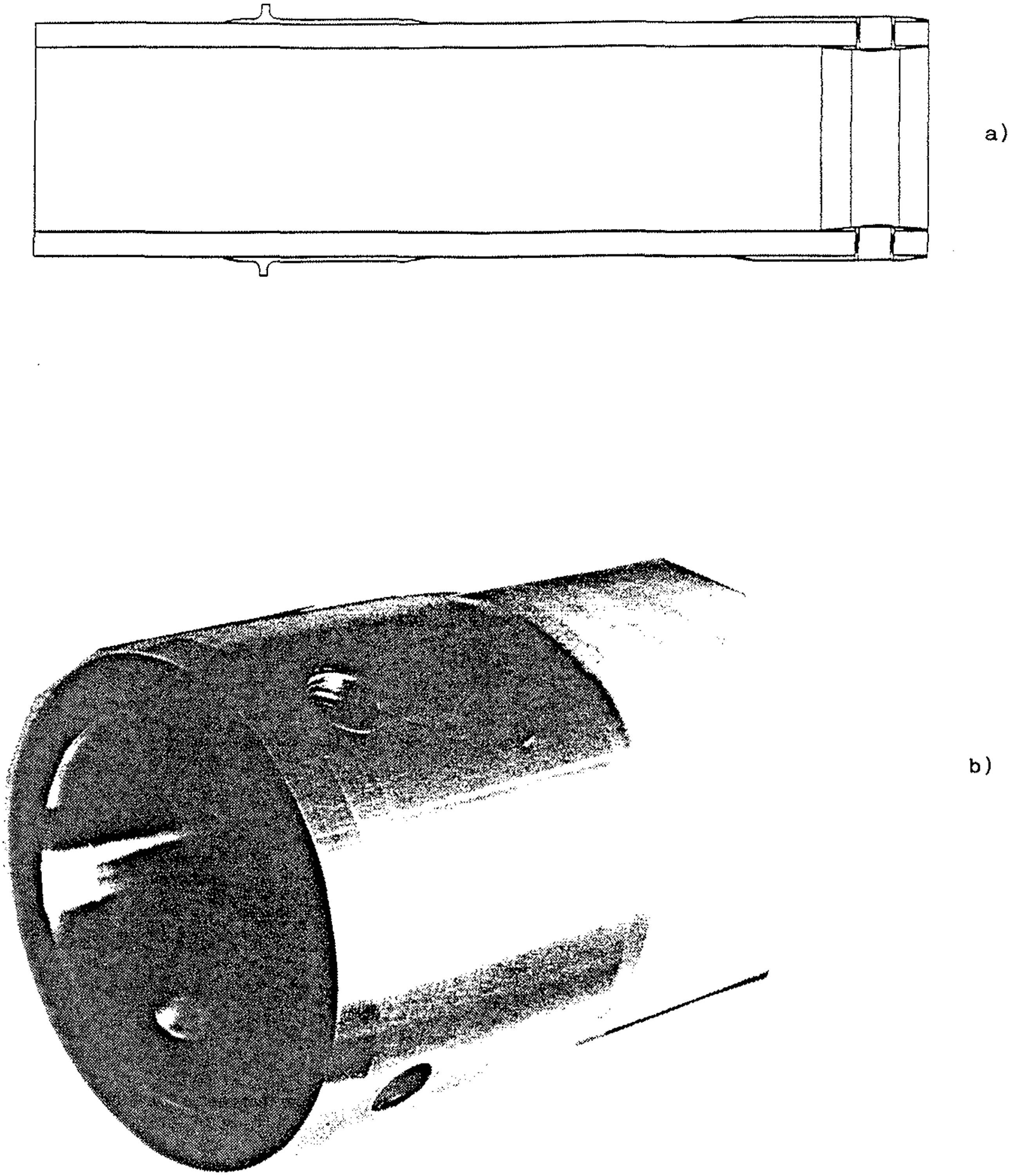


FIG. 4 : DETAILS OF STAINLESS ALLOY BUSHINGS ON COMPOSITE TRANSVERSE TUBE

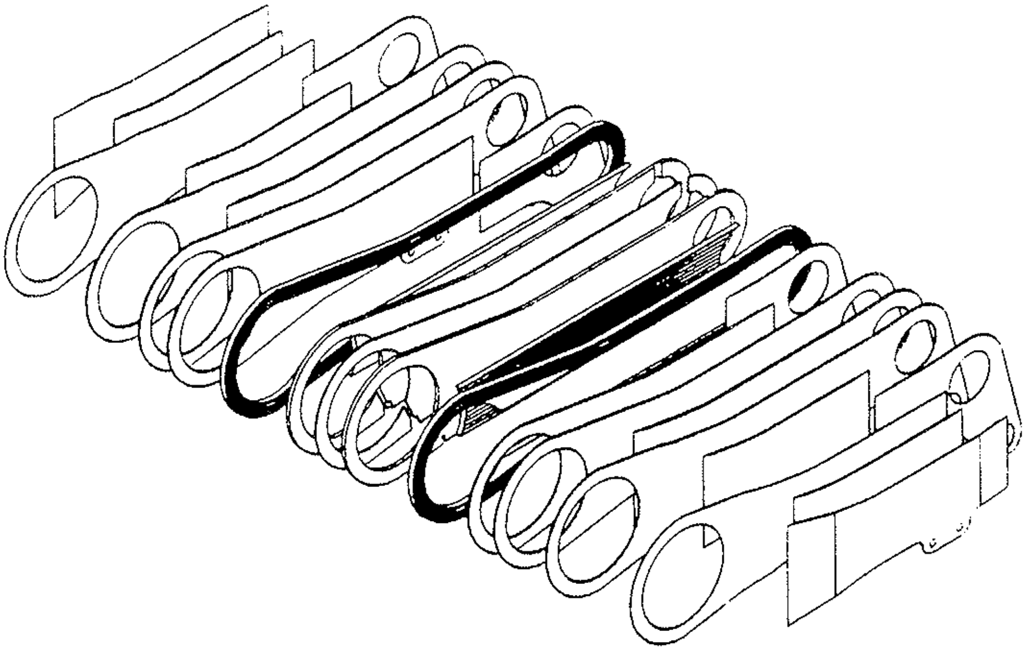


FIG. 6 : BREAK DOWN OF COMPOSITE UPPER ARM DESIGN

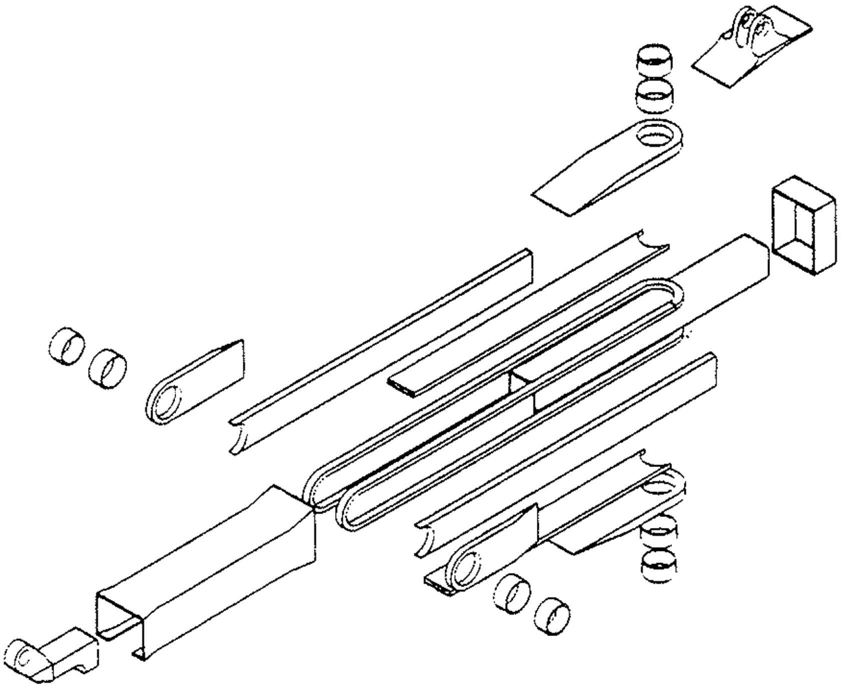


FIG. 5 : BREAK DOWN OF COMPOSITE LOWER ARM DESIGN

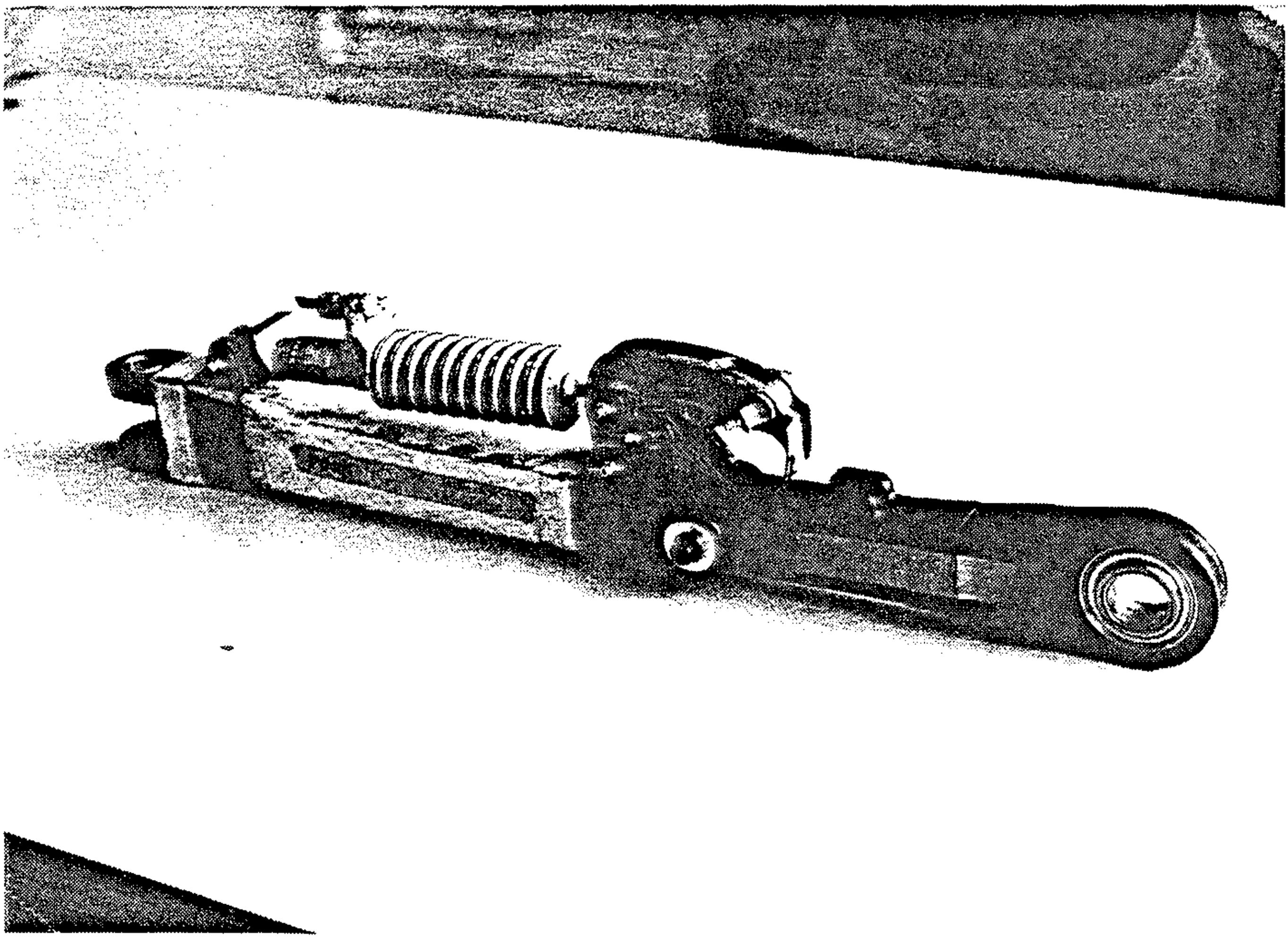


FIG. 7 : COMPOSITE DRAG BRACE

TRANSVERSE TUBE

STATIC TEST LAY OUT

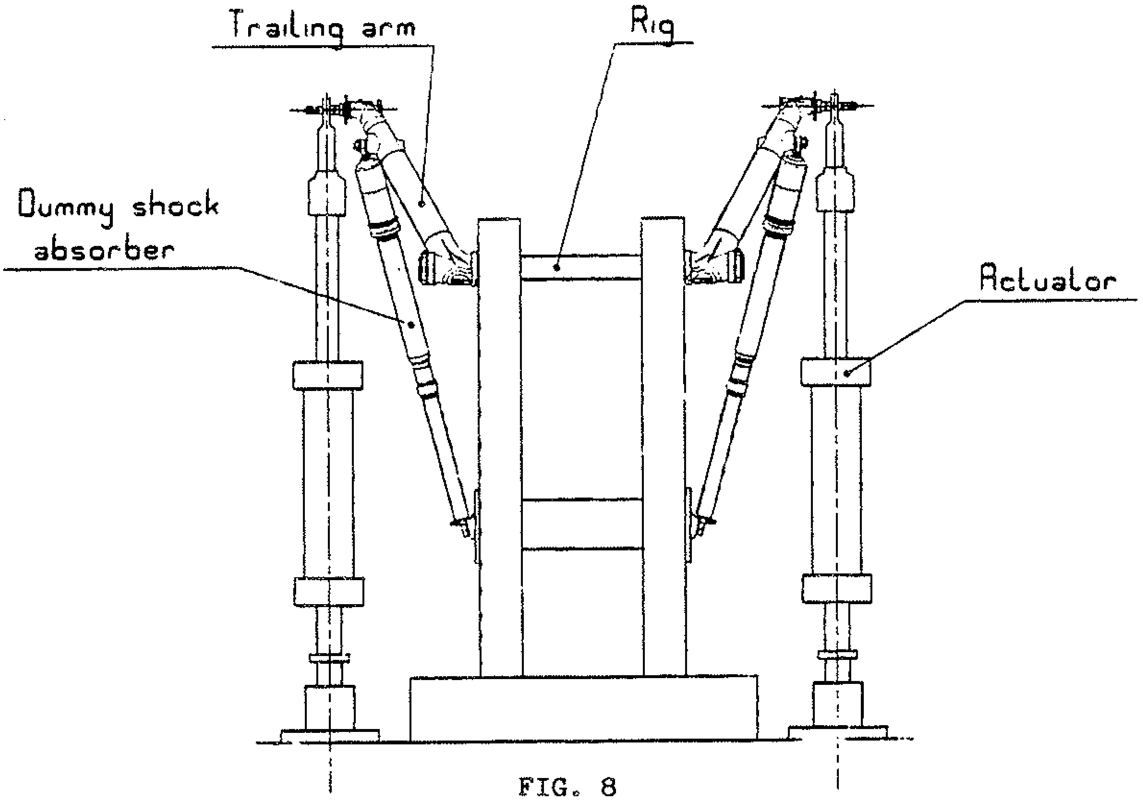
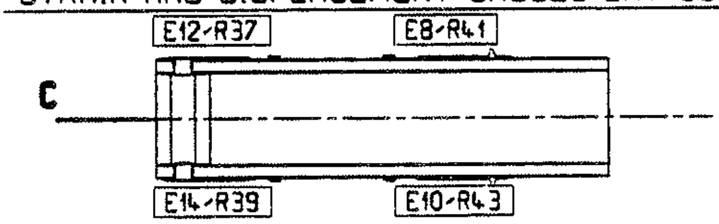


FIG. 8

STRAIN AND DISPLACEMENT GAUGES LAY OUT



GAUGES	ON CARBON	ON STEEL
STRAIN	E 8	R 41
	E 10	R 43
	E 12	R 37
	E 14	R 39
DISPLACEMENT	Cx, Cy, Cz	Cx, Cy, Cz

FIG. 9

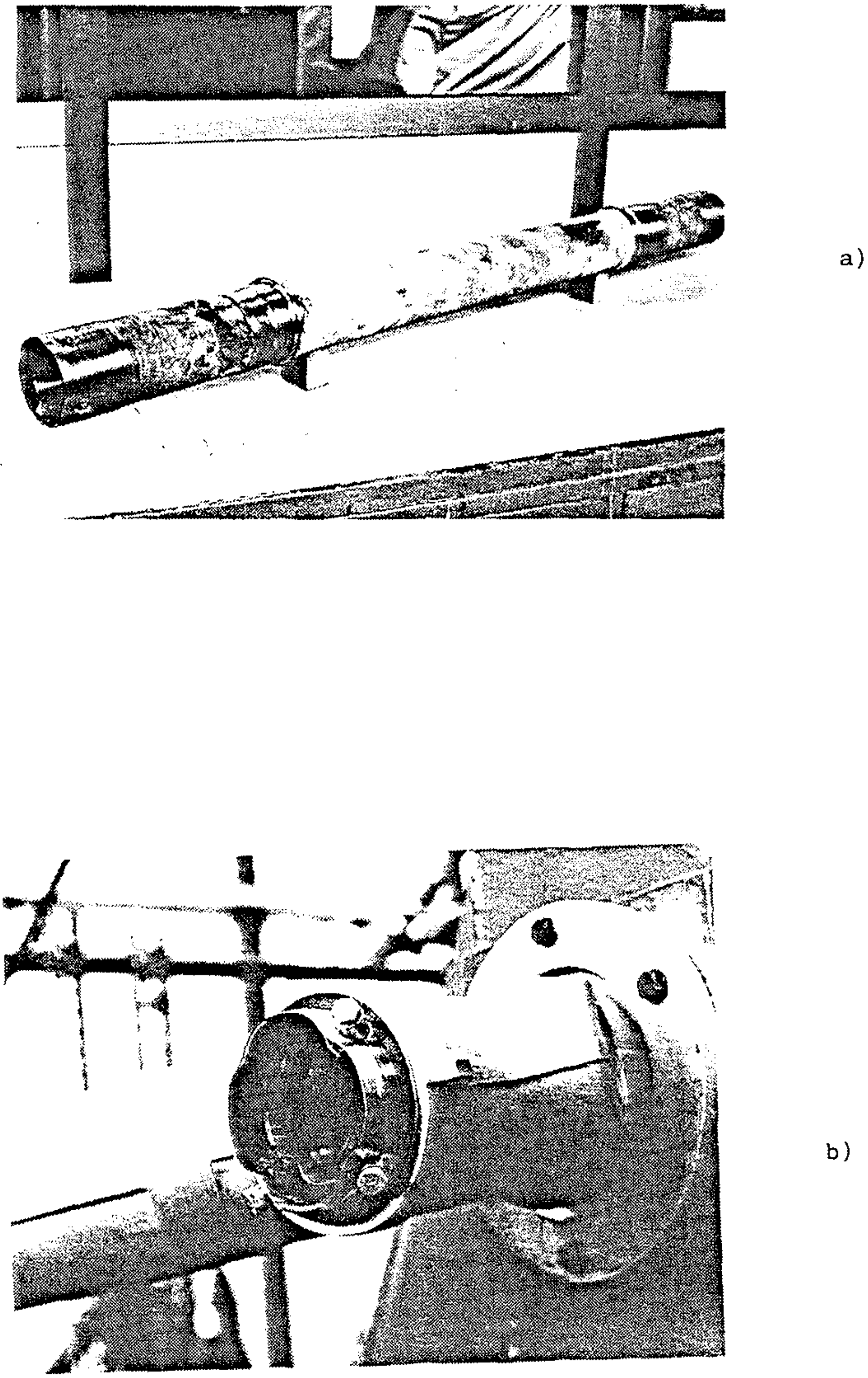
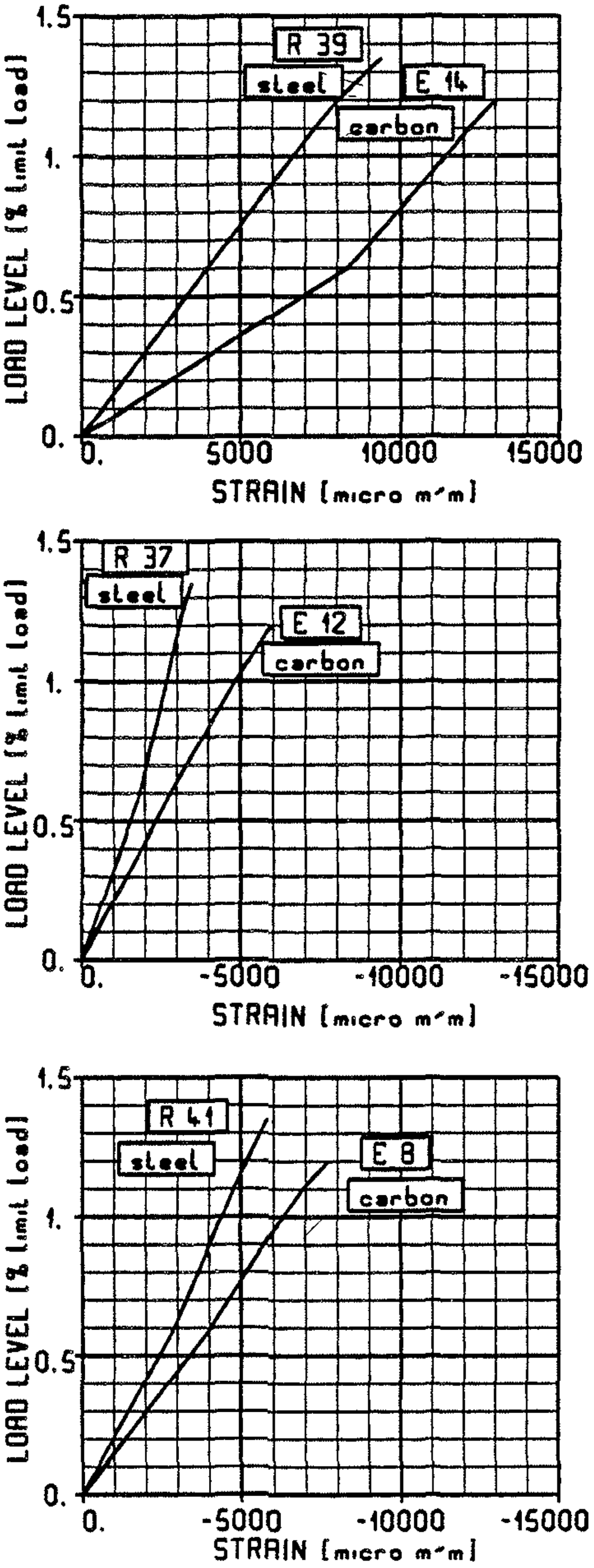


FIG. 10 : FAILED COMPOSITE TRANSVERSE TUBE



TRANSVERSE TUBE
STRAIN GAUGES RESULTS ON STEEL AND CARBON

FIG. 11

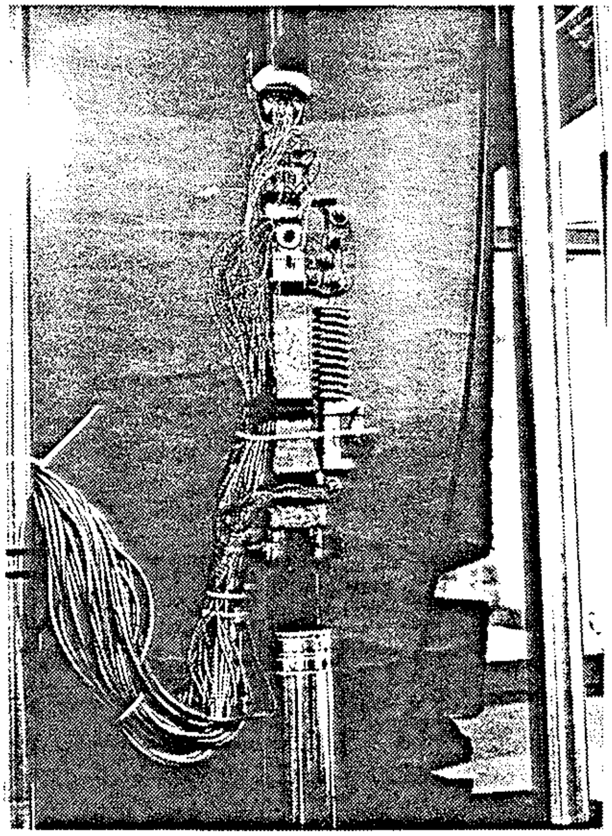


FIG. 12 : COMPOSITE DRAG BRACE TEST LAY OUT

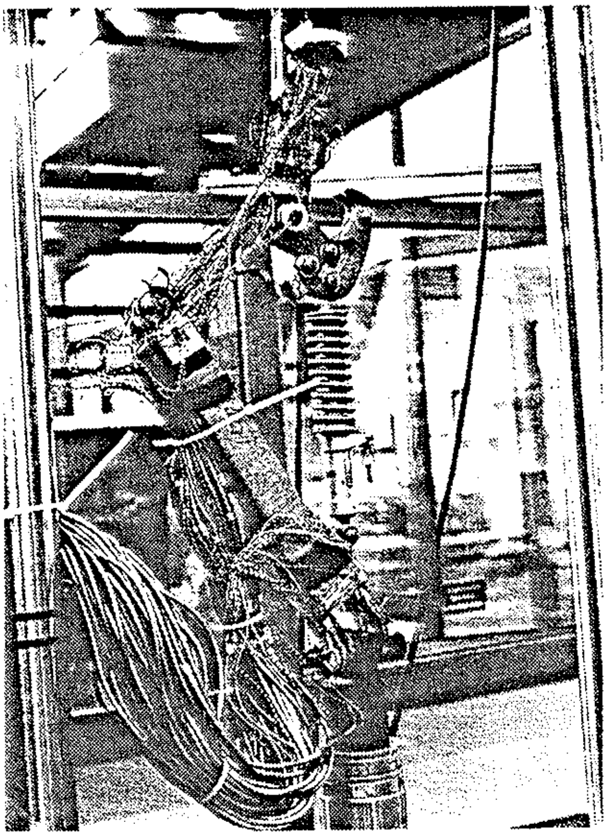
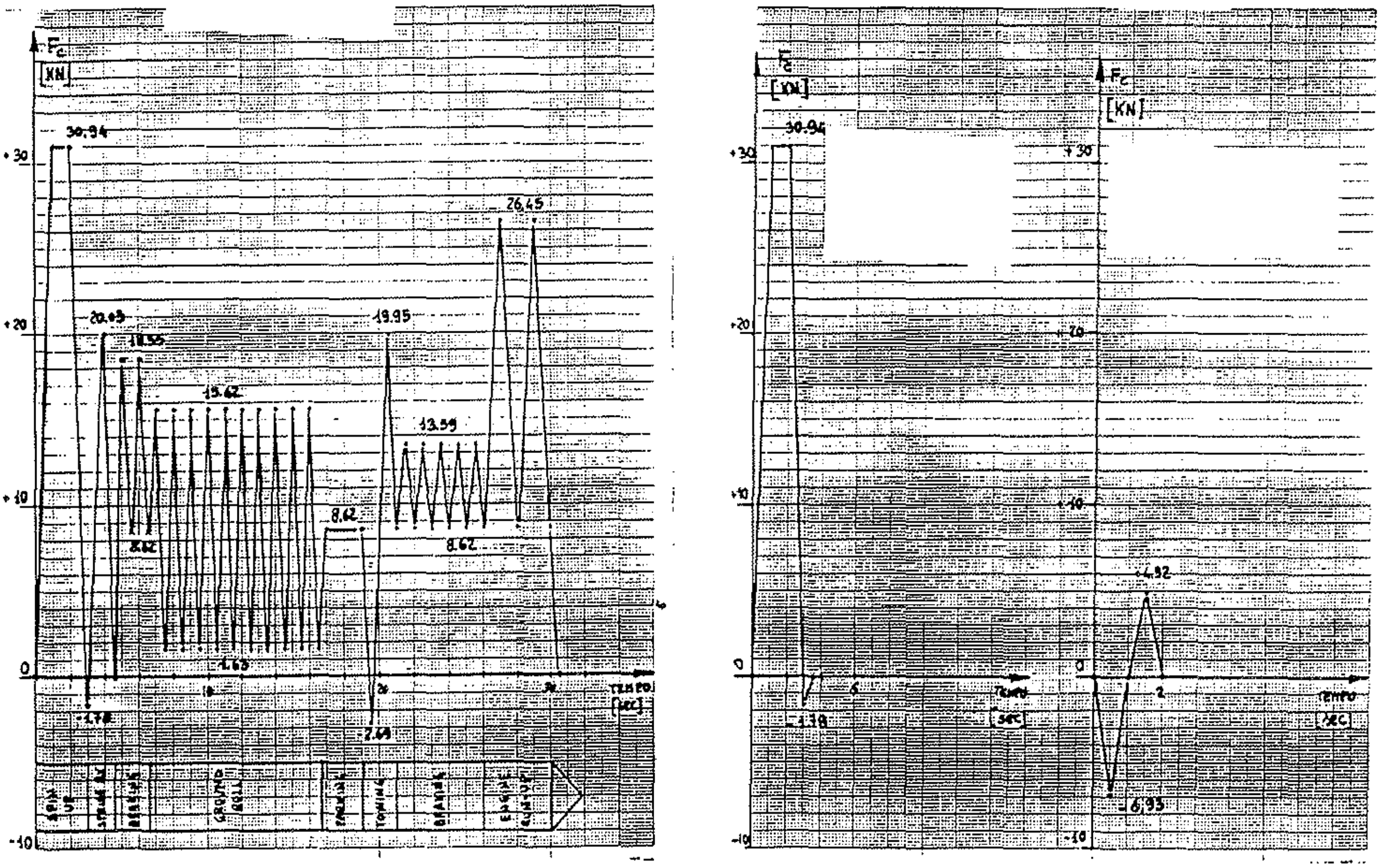
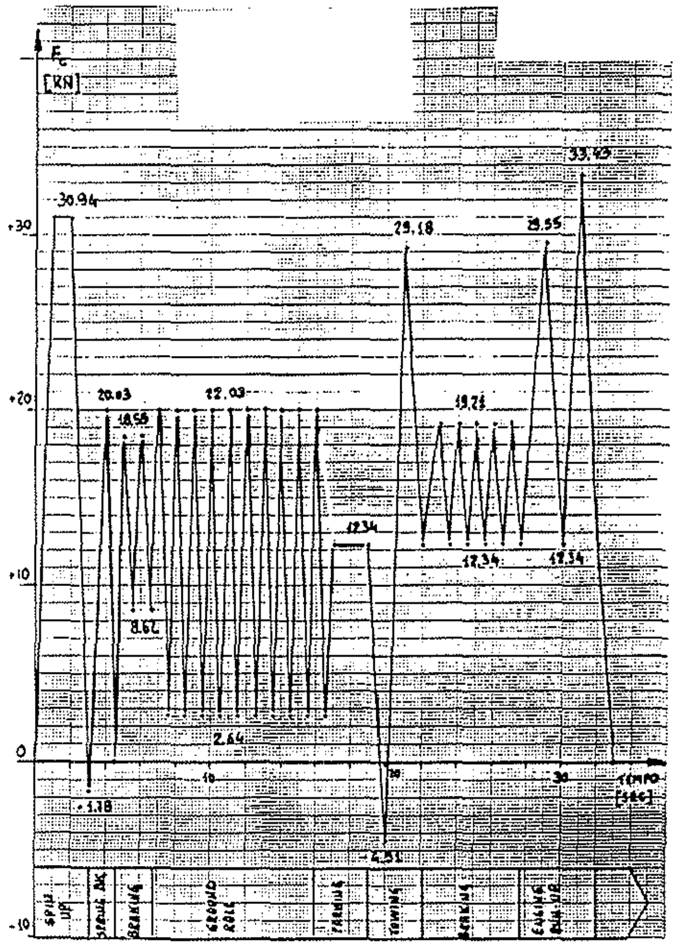


FIG. 13: COMPOSITE DRAG BRACE RUPTURE



a) Flight "A"

b) "Touch and go" and "Gear down"



c) Flight "B"

FIG. 14 : FATIGUE SPECTRA