AVIONS MARCEL DASSAULT-BREGUET AVIATION

WP/6

B. S. C. E.

17th Meeting WP N° 6

French Experimental Research Program on behaviour of Aramid Epoxy Composite Structures in Bird Impact

by

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S U M M A R Y

Considering the development in Aeronautics of Aramid Epoxy Composite structures and the scarcity of bird impacts test conducted in the past, the French S T P A has sponsored, in C.E.A.T., an experimental investigation on the behaviour of these structures in bird impact.

This paper presents the experimental research program started at C.E.A.T. and summarizes the first results achieved.

Necessary equipment for the lecture : an overhead projector.

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1. INTRODUCTION

The aircraft now in the design or prototype stage include an ever greater amount of structures in aramid-epoxy (KEVLAR*) composite material. See for example :

- in figure 1 the Falcon 900 of the Avions Marcel Dassault-Breguet Aviation company.
- in figure 1bis the Airbus 310 on which components in advanced composite structure have been fitted since its first flight (April 1st 1982).

Such materials serve as a substitute for the thin sheets of light aluminium alloys which are traditionally used to build metal formed components such as nose cones, leading edges, fillets, and yield a gain in weight and cost.

Generally, these structures are considered as secondary in comparison to the overall strength of the aircraft. However since they are used as fairings to cover equipment, part of systems, and the main structure itself, they are involved in the safety of the aircraft.

Thus is set the problem of the bird impact resistance of these KEVLAR composite structures.

The KEVLAR fabrics are known for their good qualities of strength in the ballistic shootings.

In France, in the field of aeronautics, an experimental research has been conducted on these fabrics to investigate the containment of blades or disk fragments in rotor burst of turbine engines.

In this case the projectile concerned was a solid body. On the contrary, in bird impact, the projectile is a soft body which behaves like a fluid at the considered impact velocities.

Considering the development in Aeronautics of KEVLAR composite structures and the scarcity of bird impact tests conducted in the past, the French S T P A has sponsored in C E A T an experimental investigation to know the behaviour of KEVLAR composite structures in a bird impact.

These structures are either multi-ply monolithic or multi-layer (sandwich) including honeycomb core.

In the second type of structure, each KEVLAR layer can consist of several plies of KEVLAR fabric.

* KEVLAR : Du Pont's registered trademark for its aramid fibre.

AMD-BA

DTM-6057/84
REFERENCE

2. PROBLEMS TO INVESTIGATE

The ballistic studies have established a relationship between the penetration velocity and the mass of the unit area of the KEVLAR shiel This formula has been adjusted to bird impact with consideration given to the following assumptions :

- The bird is a fluid flowing in thin trickles parallel to the sp
- The strength of the composite material is in direct proportion the normal component of the bird kinetic energy.

From these assumptions, the relationship found for the solid bodies be applied under a differential form. Its integration over the impacte surface then yields the equation between the kinetic energy of penetra and the mass of the unit area of the structure. (*)

This type of formula causes the following problems to be resolved :

a) Choice of KEVLAR

- KEVLAR 49 with a high rate (54%) of epoxy resin
- KEVLAR 29 with a low rate (23%) of damping resin

b) Effect of the mass of the unit area of the target on the kinetic of penetration : Monolithic structures, sandwich structures with honeyc

c) Effect of the style of fabric.

d) Effect of the bird mass and the obliquity of the shooting.

e) Effect of the curvature radius of the target surface (convex surf

Small radius : Leading edges

Large radius : radomes

(*) See Annex 1-2-3 Ballistic studies.

.../...

3. TYPE OF TEST SPECIMEN USED

The investigation of the behaviour of KEVLAR compos[illegible] covers [illegible] those type of structure existing or design[illegible] aircraft.

The following will be considered :

- Monolithic test specimens : representative of [illegible]
- Sandwich test specimens : with honeycomb core [illegible] the nose cones and leading edges.

The investigation of the influence of the different [illegible] such as bird mass - impact velocity - impact angle [illegible] will be conducted on a plane test specimen.

Figure 2 shows the monolithic specimen.

The arrow on the forward face of the specimen indi[illegible] of the warp of the first ply of fabric.

Figure 3 shows the sandwich specimen (plane).

The specimens having a radius of curvature will [illegible]

Figure 4 shows the specimen representative of the [illegible] (small radius).

Figure 5 shows the specimen representative of the [illegible]

4. TEST MEANS

Figure 6 is a general view of the test facility and air pressurized guns in CEAT.

The smooth bore gun of 150mm diameter will mainly be used.

The bird masses are :

1.8 kg for civil applications

0.9 kg for military applications

shootings with 3.6 kg birds in 300mm diameter gun are planned to check the test results on the specimens of leading edge types.

Two high speed cameras film the impact :

The first is set perpendicular to the bird path

The second is set at 45 degrees from this path and records pictures of the forward surface of the test specimen.

Strain an stress measurements are planned.

Two frames are supporting the test specimens :

Fig. 7 : for square plates (475 x 475 mm) in normal impact

Fig. 8 : inclinable support for oblique impacts ; and for this suppor[t]

Fig. 9 : adapter for curved specimens. (large radius of curvat[ure])

5. IMPACT TEST CONDITIONS

The program consider the three following impact conditions :

- Normal impact on monolithic and sandwich plane plates.
- Oblique impact on these plates and also on sandwich shells with a large radius of curvature.
- Impacts in which the bird trajectory crosses the central point of curvature of the test specimens with small radius (leading edges) and this trajectory remains perpendicular to the surface (effect of sweepback angle not investigated).
- For all these tests, the penetration kinetic energy will be defined and in the event of piercing the motion of the bird after penetration will be studied.

.../...

6. DEFINITION OF TEST SPECIMENS

The following tables give the definition and the number of the test specimens initially provided.

- Plane monolithic test specimens Table 1
- Sandwich test specimens with honeycomb core Table 2
- Cruved test specimens
  - 1 layer of honeycomb core Tables 3 and 4
  - 2 layers ofhoneycomb core Table 5

7. FIRST RESULTS OBTAINED

At the date of the preparation of this report (May 1984), the tests are not fully completed.

The first campain of testing concerns only the normal impact on monolithic plates. (square plates - length of side : 475mm).

Two styles of Kevlar 49 fabric were investigated : Satin 8 and Satin 4.
For each style the kinetic energy of penetration is directly proportional to the mass of the unit area of the dry fabric.

This disposition of plies has a significant influence on the strength of the plate.
The dispositionscalled isotropic are less resistant than the other ones.

Although the static strength of a Kevlar Fabric of Satin 4 style is greater than that of a Satin 8 style fabric,(only by some percentage), the latter, for a same mass of unit area of dry fabric, shows a greater ability to absorb the kinetic energy of the bird. This property is due to the mode of weaving.

The woven armour of a fabric of Satin 8 style is more deformable than that of a fabric of Satin 4 style. Therefore, the Satin 6 fabrics are used to build complicated shapes.

Finally, the most surprising peculiar characterisric, is the discontinuity between the kinetic energy of bird containment and the kinetic energy absorbed in the piercing.

For this phenomenon we are not able, at the present time, to provide a really satisfactory explanation.

I. BALLISTIC STUDIES :

SNPE FORMULA FOR THE IMPACT OF SOLID BODIES ON KEVLAR®

KINETIC ENERGY OF PENETRATION

$$1/2\ MV^2 = \alpha_1 A_D\ A_P + \alpha_2 A_D^2 \sqrt{A_P} \simeq \alpha_1 A_D\ A_P$$

A_D = MASS OF THE UNIT AREA OF THE TARGET

A_P = AREA OF THE PART OF THE PROJECTILE IN CONTACT WITH THE TARGET

α_1 AND α_2 : EXPERIMENTAL COEFFICIENTS

REMARK : α_2 IS VERY SMALL IN COMPARISON WITH α_1

EXAMPLE : FOR KEVLAR 29 WITH 23% IN WEIGHT OF NEPURANE® IN COMPATIBLE UNITS :

$$\alpha_1 = 313\ 117\ (M^2\ S^{-2})$$

$$\alpha_2 = 300\ \ (M^5\ S^{-2}\ KG^{-1})$$

® DU PONT'S REGISTERED TRADE MARK

2. TRANSFORMATION OF THIS FORMULA IN THE CASE OF A BIRD IMPACT ON A PLANE SURFACE OR ON A CONVEX SURFACE (REPLACED BY ITS TANGENT PLANE AT THE IMPACT POINT)

ASSUMPTIONS :

1°) THE PENETRATION IS DUE TO THE NORMAL COMPONENT OF THE BIRD KINETIC ENERGY : $1/2\ M\ V^2 \cos^2\alpha$

WHERE α IS THE ANGLE BETWEEN THE BIRD VELOCITY AND THE NORMAL TO THE SURFACE.

2°) THE BIRD IS REPRESENTED BY A CIRCULAR CYLINDER OF RADIUS R (R = 0,0675M FOR A 4 POUND BIRD).

THE AREA IN CONTACT WITH THE TARGET IS :

$$A_p = \frac{\pi R^2}{\cos\alpha}$$

3°) THE BIRD REMAINS IN THIS CYLINDRICAL FORM AND SIZE DURING THE PENETRATION.

THE FORMULA BECOMES :

$$1/2\ M\ V^2 \cos^2\alpha = \alpha_1 A_D \frac{\pi R^2}{\cos\alpha} + \alpha_2 A_D^2 \cdot R\sqrt{\frac{\pi}{\cos\alpha}} \simeq \alpha_1 A_D \cdot \frac{\pi R^2}{\cos\alpha}$$

FOR NORMAL IMPACT $\alpha = 0$

$$1/2\ M\ V^2 = \alpha_1 A_D \quad R^2 + \alpha_2 A_D^2 \quad R\sqrt{\pi} \simeq \alpha_1 A_D \pi R^2$$

WITH THE PREVIOUS REMARK CONCERNING α_1 AND α_2 AND THE VALUE ASSIGNED TO R, WE CAN WRITE FOR A NORMAL IMPACT OF A FOUR POUND BIRD :

$$1/2\ M\ V^2 = K \quad A_D$$

3. AIMS OF THE INVESTIGATIONS

1°) IN NORMAL IMPACT

TO VERIFY THE LINEARITY OF THE KINETIC ENERGY OF PENETRATION WITH RESPECT TO THE MASS OF THE UNIT AREA FOR

EITHER THE KEVLAR + RESIN TARGET

OR THE DRY KEVLAR ALONE

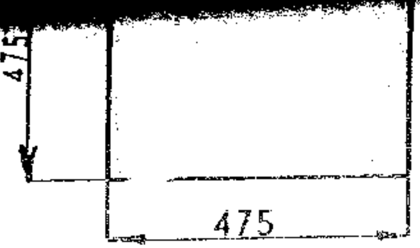
2°) IN OBLIQUE IMPACT

TO VERIFY THE INFLUENCE OF THE SHOOTING ANGLE.

THE THIRD PRECEDING ASSUMPTION LEAD TO A TERM IN $\cos^3\alpha$, WHEREAS FOR THE METALLIC PLATES AN INFLUENCE IN $\cos^2\alpha$ ONLY WAS FOUND.

3°) INFLUENCE OF THE SIZE OF THE TARGET

MONOLITHIC PLANE PLATES



Material	KEVLAR® 49				KEVLAR® 29	
Fabric	SATIN 8		SATIN 4		NATTE 2/2	
Style	DU PONT 181 NL . 5 . 2233		DU PONT 285 NL - 5.2234			
Supplier	BROCHIER INDUSTRIE		BROCHIER INDUSTRIE		STEVENS - GENIN	
Reference	788		914		[illegible] 311	
Resin	EPOXY 1452 (54.5 %)		EPOXY 1452 (54 %)		NEP JR ANE 5500 SPRE (23 %)	
Quantities	Number of Plies	Number of Specimens	Number of Plies	Number of Specimens	Number of Plies	Number of Specimens
Definition of Specimens	6	5	[illegible]	4	4	5
	8	5	8	4	[illegible]	5
	12	4	[illegible]	4	8	4
	16	4			11	4

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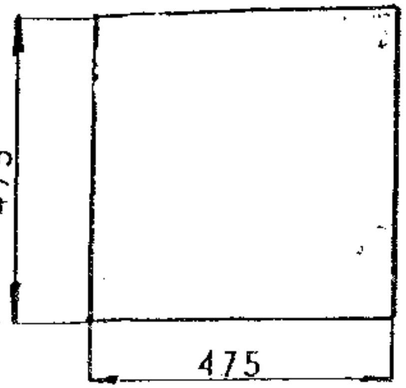
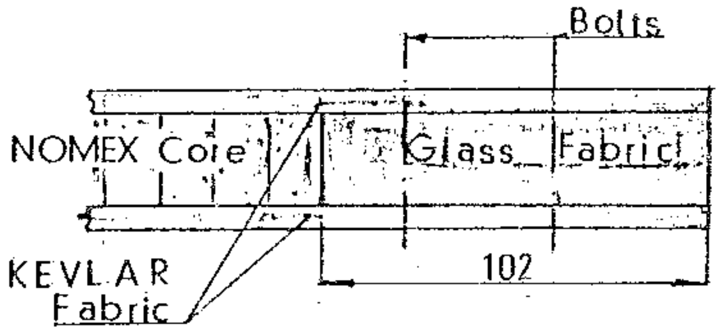
TABLE 2 PLANE PLATES SANDWICH WITH NOMEX® HONEYCOMB CORE

Material: KEVLAR® 49

Epoxy resin 1452 (54%)





Number of Honeycomb Layers	1				2		
Thickness of Honeycomb	7.5 mm NOMEX 3/16 4.5		20 mm NOMEX 3/16 4:5		2 layers t = 20mm each 3/16 4.5		
FABRIC	SATIN 8 DU PONT 181 NL-5.2233		SATIN 4 DU PONT 285 NL-5.2234.		SATIN 4 DU PONT 285. NL-5.2234		
Number of Plies of KEVLAR	3+3	4+4	4+4	6+6	3+3+3	4+4+4	5+5+5
Number of Specimens	4	4	4	4	4	4	4

SANDWICH CURVED SPECIMENS (ONE LAYER OF HONEYCOMB)

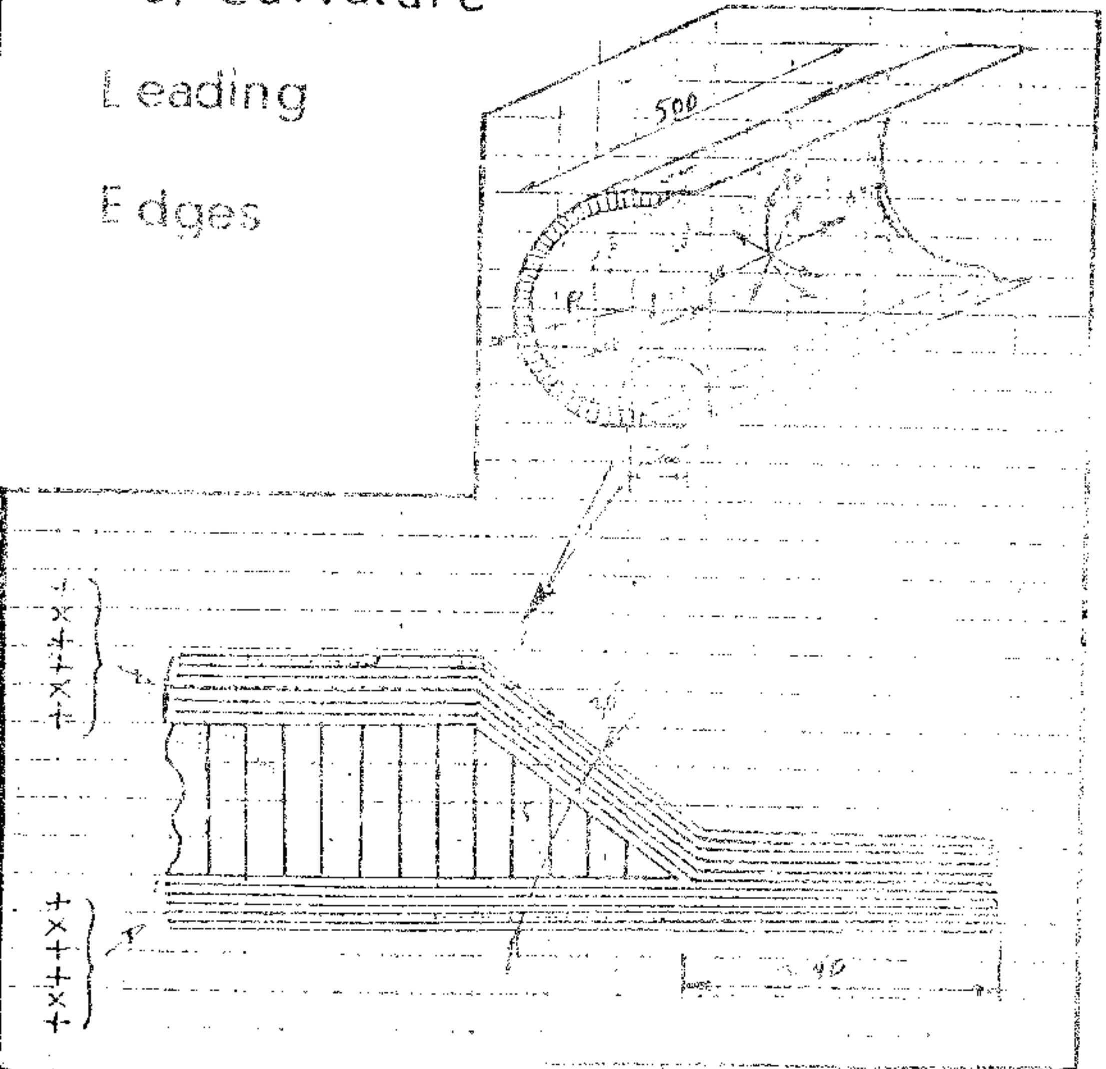
… CURVED SPECIMENS (ONE LAYER OF HONEYCOMB)

FABRIC : KEVLAR® 49 Satin 8 Ref 788 (Brochier Ind

RESIN Epoxy 1452 (54 %)

HONEYCOMB HEXCEL NYLON HRH 10 / F 505.0

Small Radius of Curvature Leading Edges



NUMBER OF SPECIMENS

R (mm)	NUMBER OF KEVLAR PLIES	
	6+4	4+4
100	2	Eventually
200	[illegible]	2
300	2	Eventually

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TABLE 4

SANDWICH CURVED SPECIMENS (ONE LAYER OF HONEYCOMB)

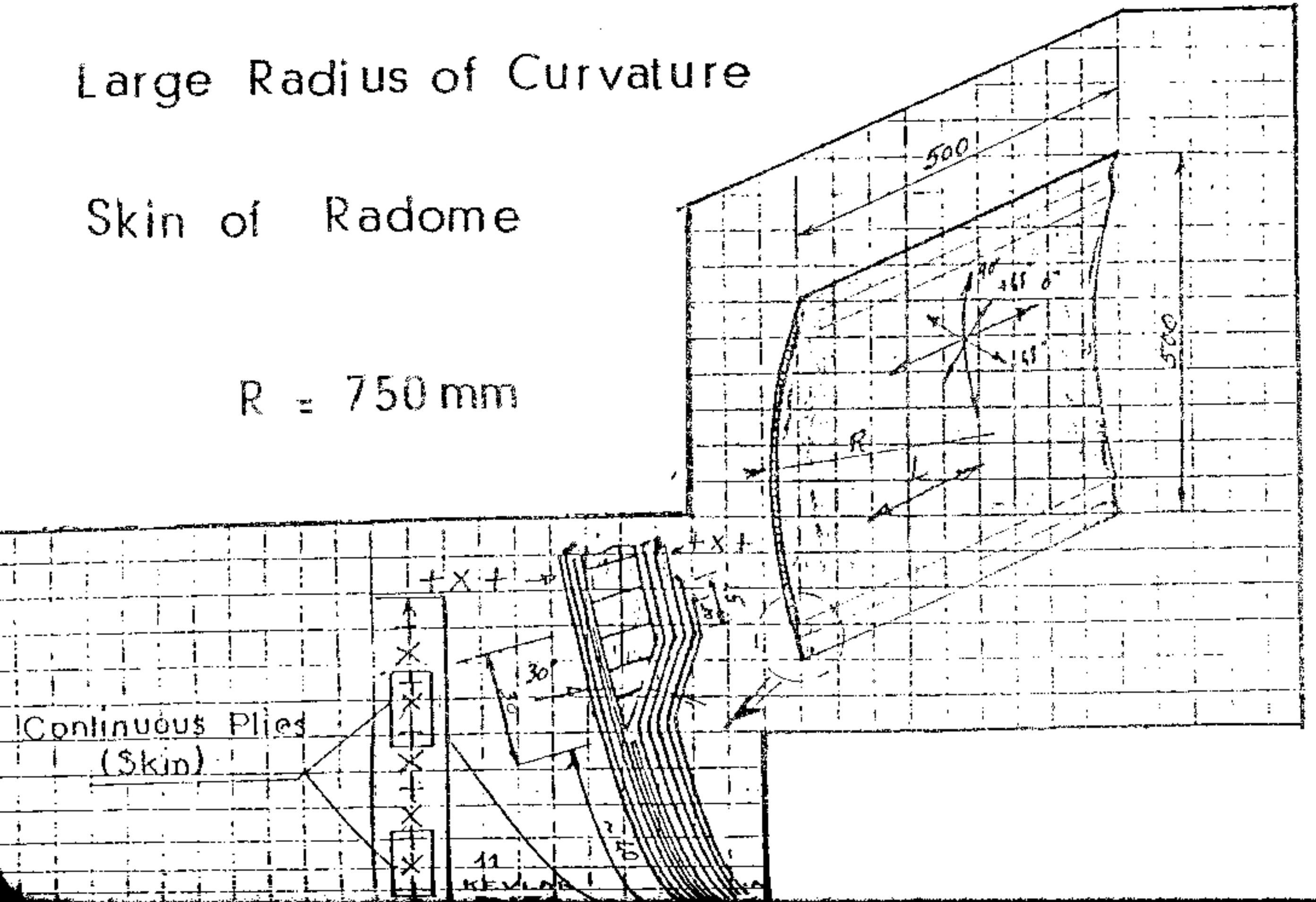
FABRIC KEVLAR® 49 Satin 8 Ref 788 (Brochier Ind.)
RESIN Epoxy 1452 (54 %)
HONEYCOMB HEXCEL GLASS NP 1/16 - 6.0

Thickness 7.7 mm

Large Radius of Curvature

Skin of Radome

R = 750 mm



NUMBER OF KEVLAR PLIES : 3+3

NUMBER OF SPECIMENS : 2

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TABLE 5

SANDWICH CURVED SPECIMENS (TWO LAYERS OF HONEYCOMB)

Test Specimens Planned But Not Yet Entirely Defined

Fabric : KEVLAR® 49 Satin 4 BROCHIER Ref : 914

Honeycomb : NOMEX® 2 Layers Thickness : 20 mm

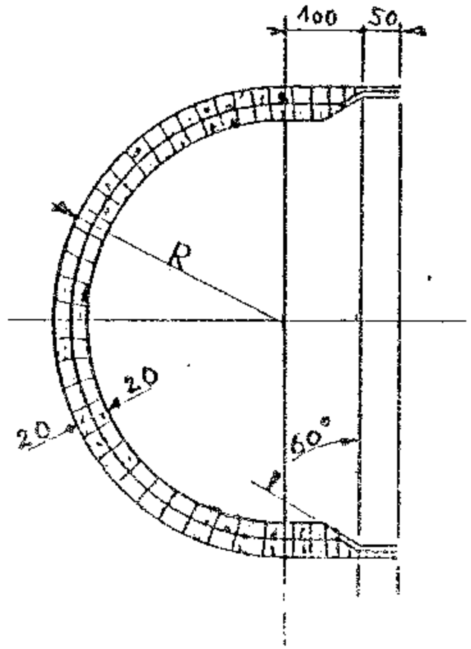
Radius of Curvature : 100 ; 200 ; 300 mm

Number of Fabric Plies : 4+4+4 & 5+5+5 (For the 3.6 kg Bird)

Length of Specimen : 500 to 700 mm

Number of Specimens : 3 For Each Radius of Curvature

& For Each Number of Kevlar Plies



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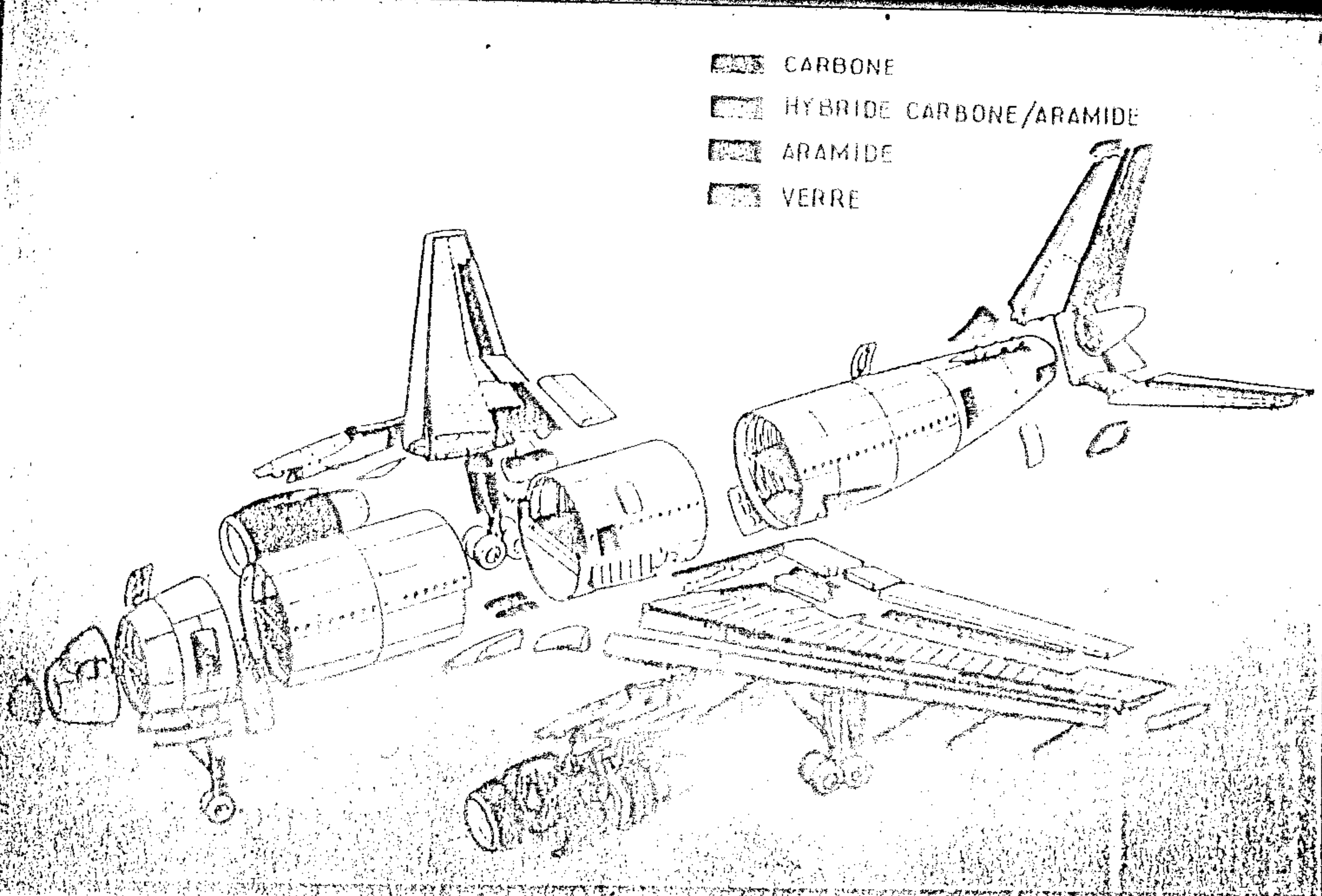
STRUCTURES COMPOSITES


CARBONE
HYBRIDE CARBONE/ARAMIDE
ARAMIDE
VERRE

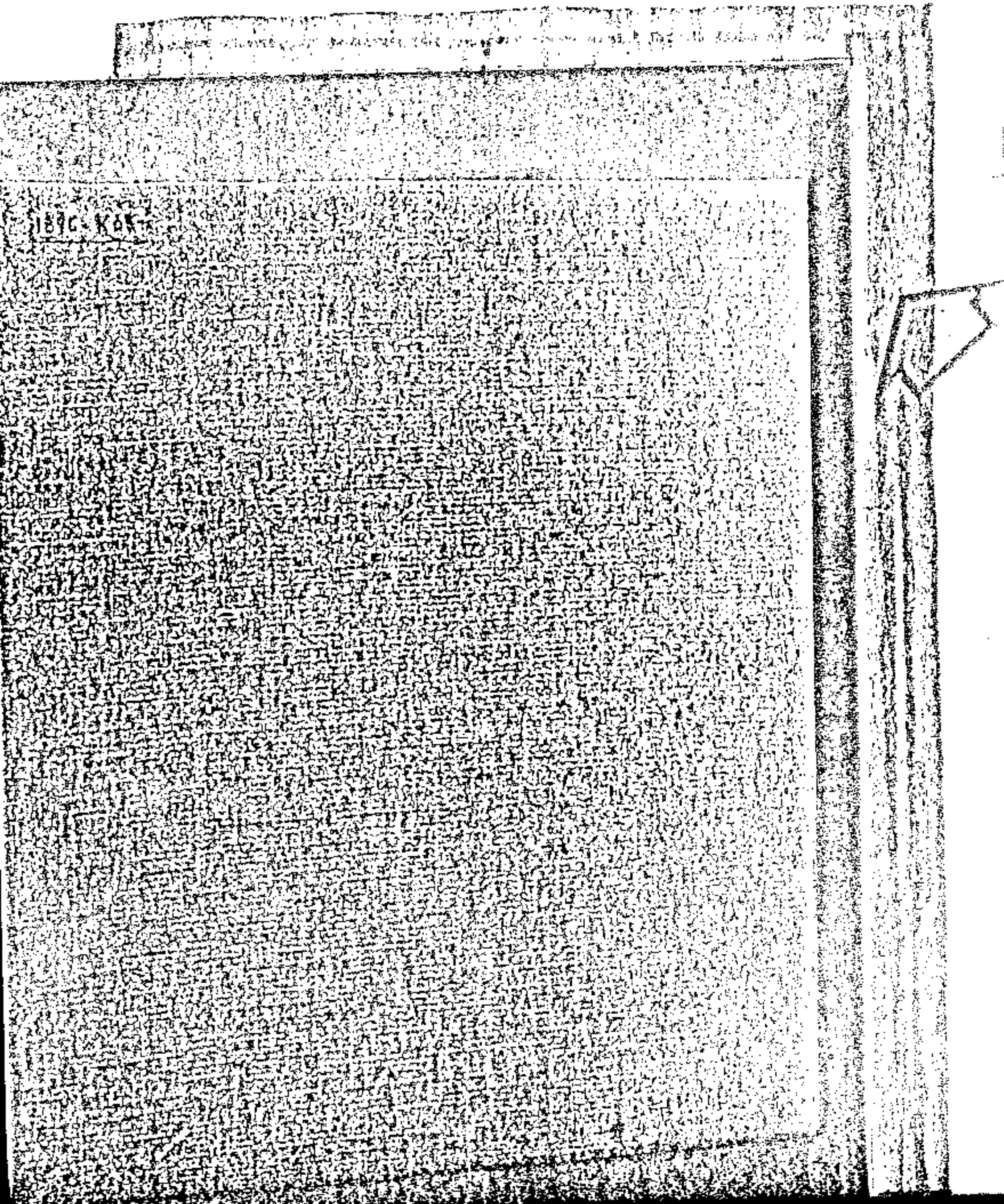


Figure 2 :

MONOLITHIC PLANE SPECIMEN

The arrow on the forward face indicates the direction of the warp of the first ply of fabric

Figure 3 : SANDWICH PLANE SPECIMEN

One layer of honeycomb

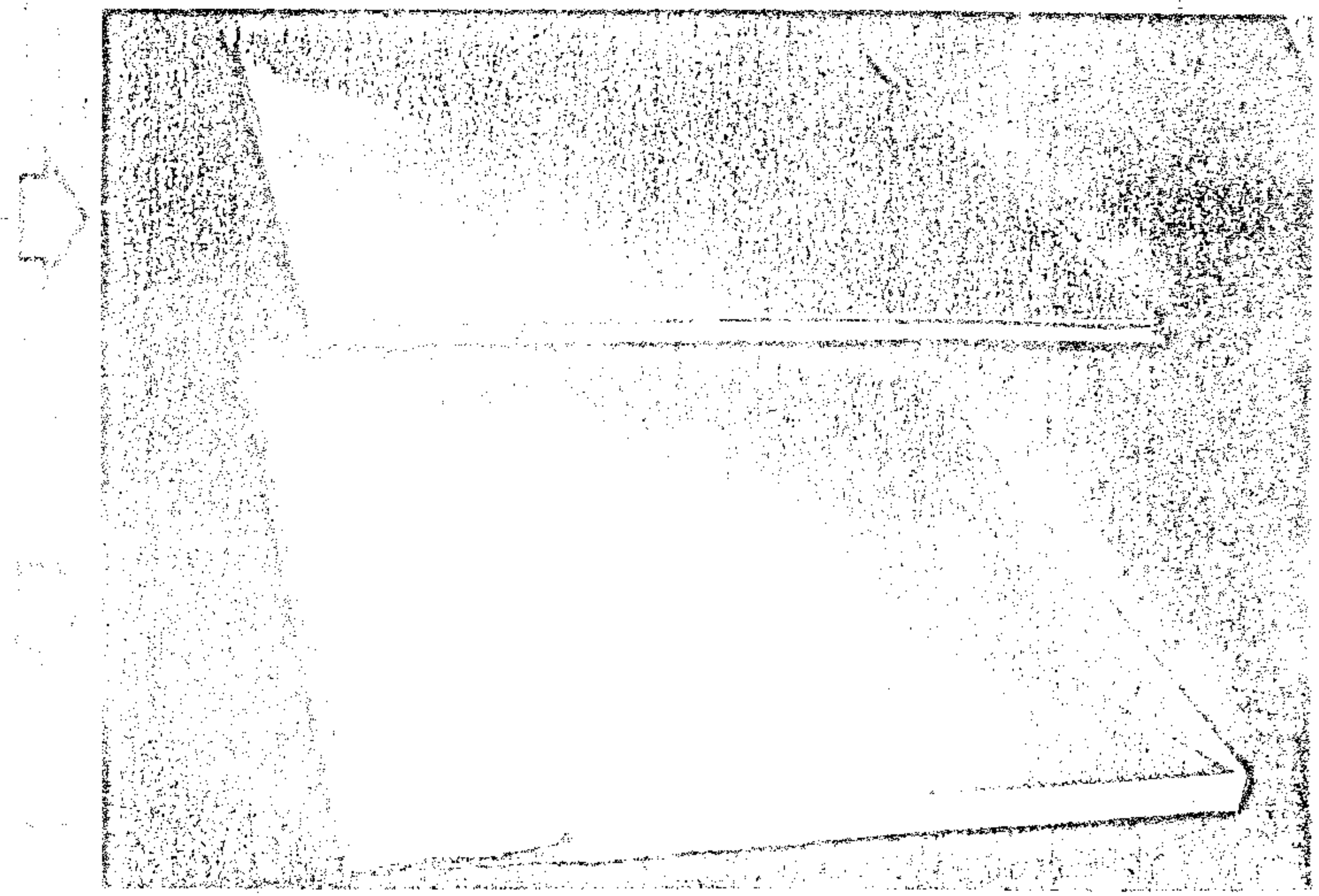


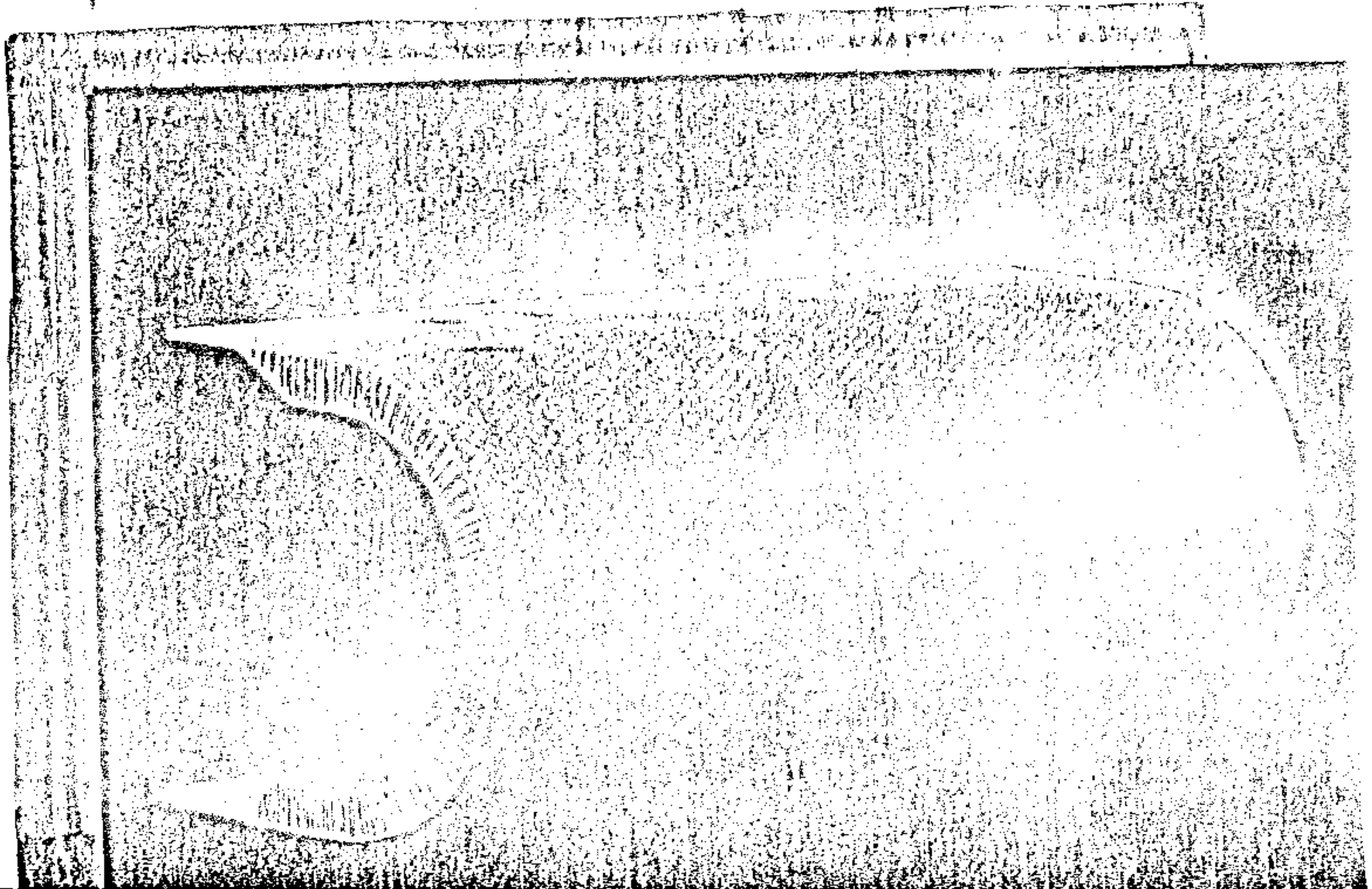
Figure 4 : SANDWICH CURVED SPECIMEN

One layer of honeycomb

Representative of the leading edges

SMALL RADIUS

CURVATURE



One layer of honeycomb

Representative of the skin of nose cones

Large radius

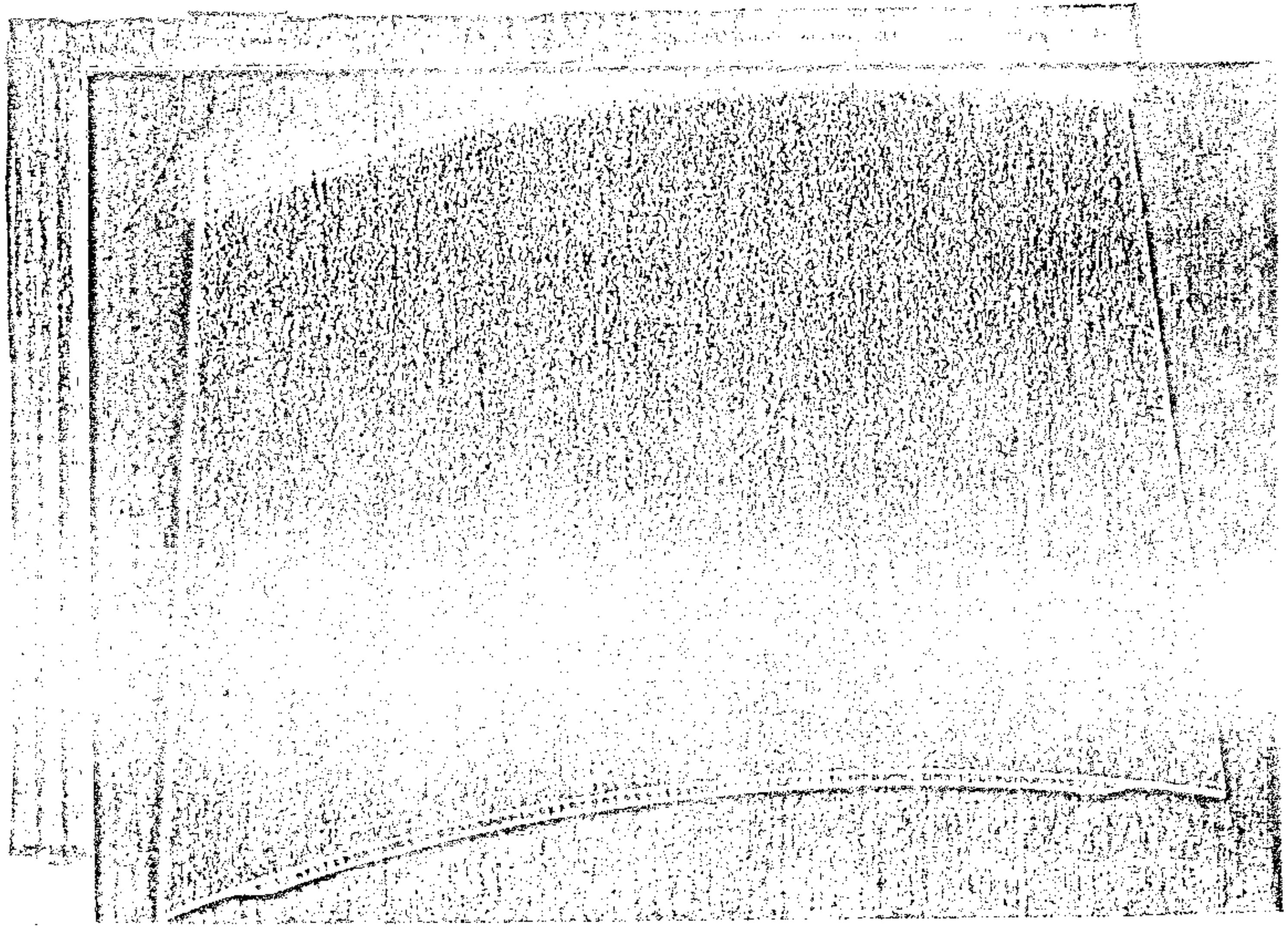
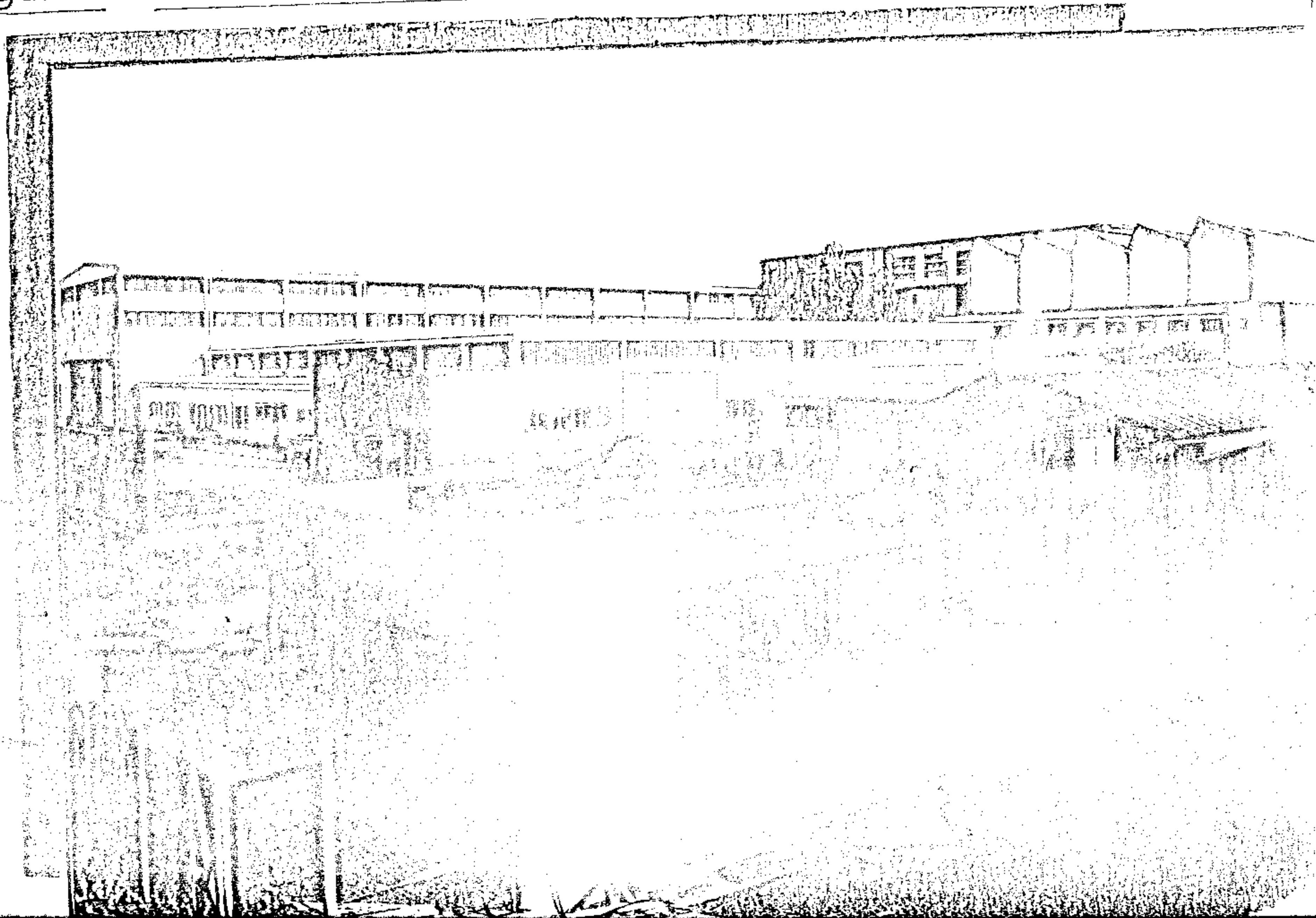


Figure 6 : C.E.A.T IMPACT TEST FACILITY

AIR

PRESSURIZED

GUNS



FRAME FOR SQUARE PLATES

IN NORMAL IMPACT

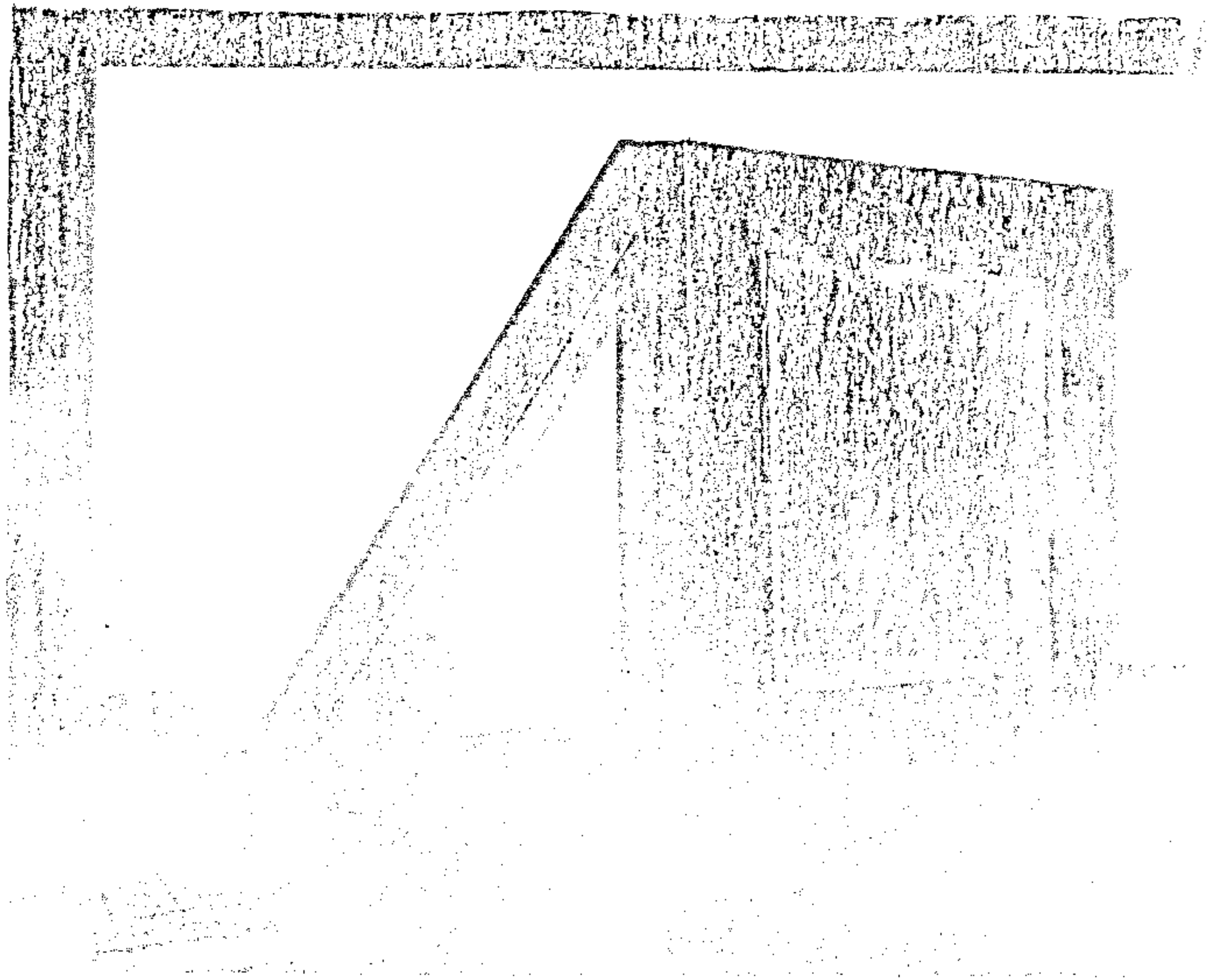
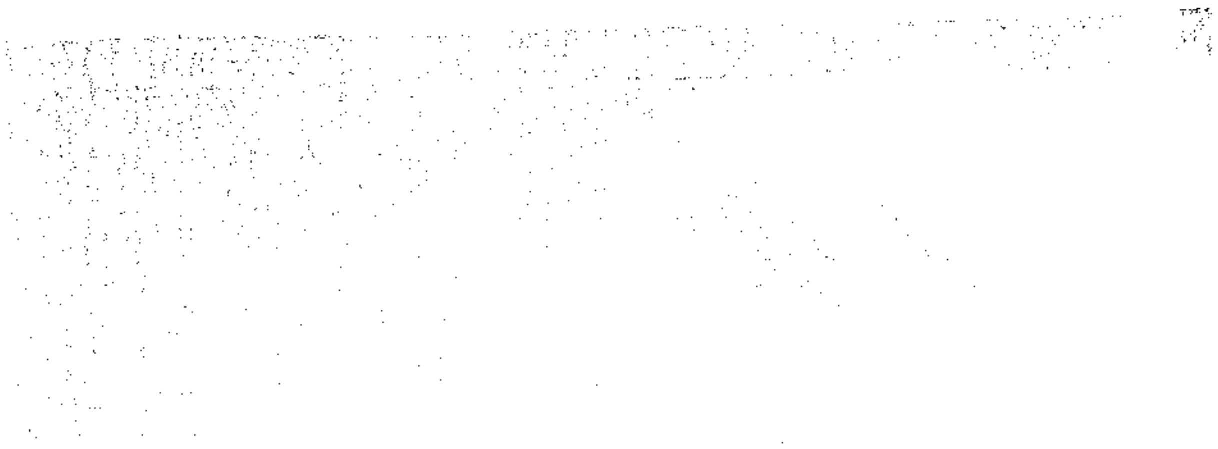
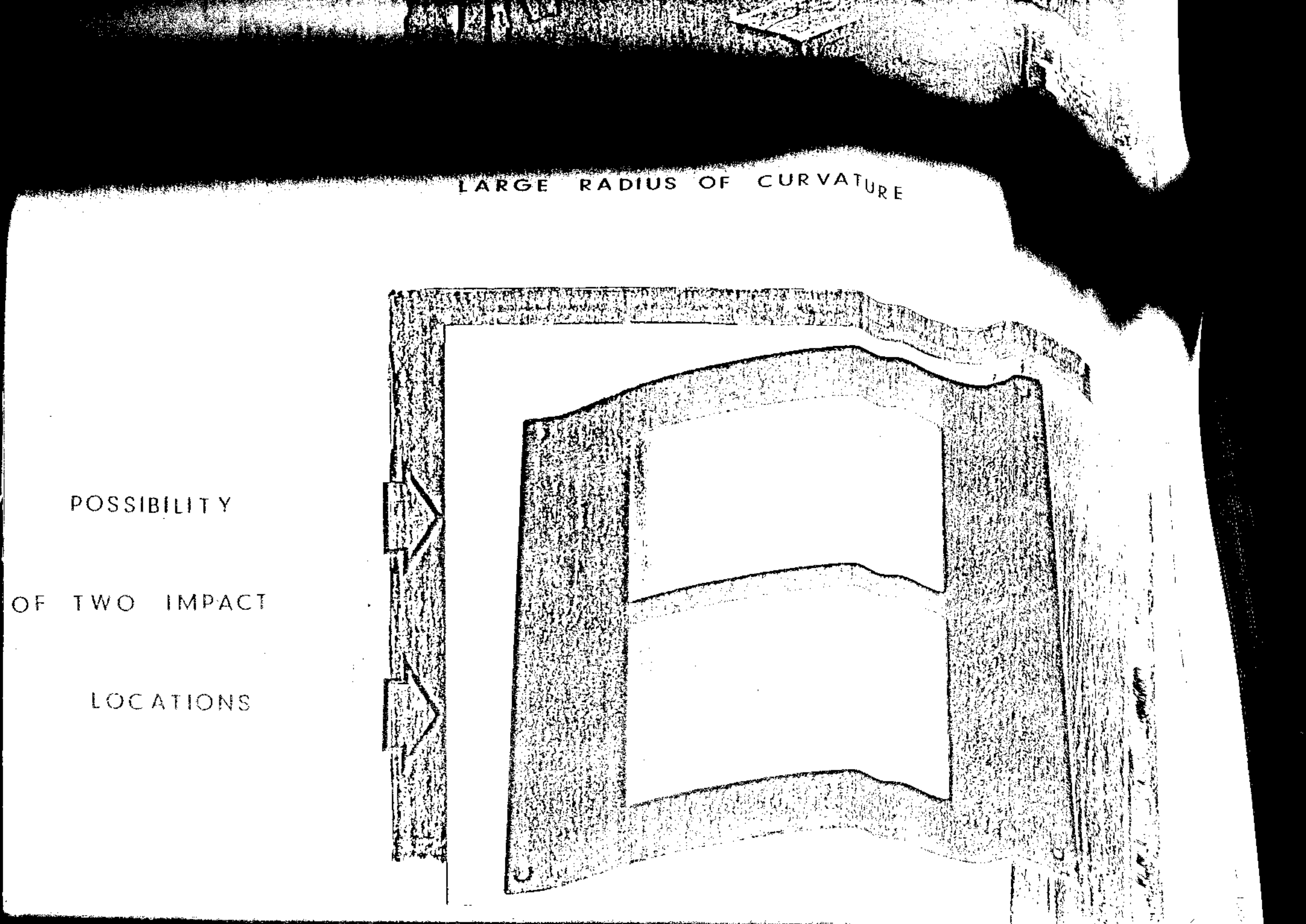


Figure 8 INCLINABLE SUPPORT

FOR OBLIQUE IMPACTS



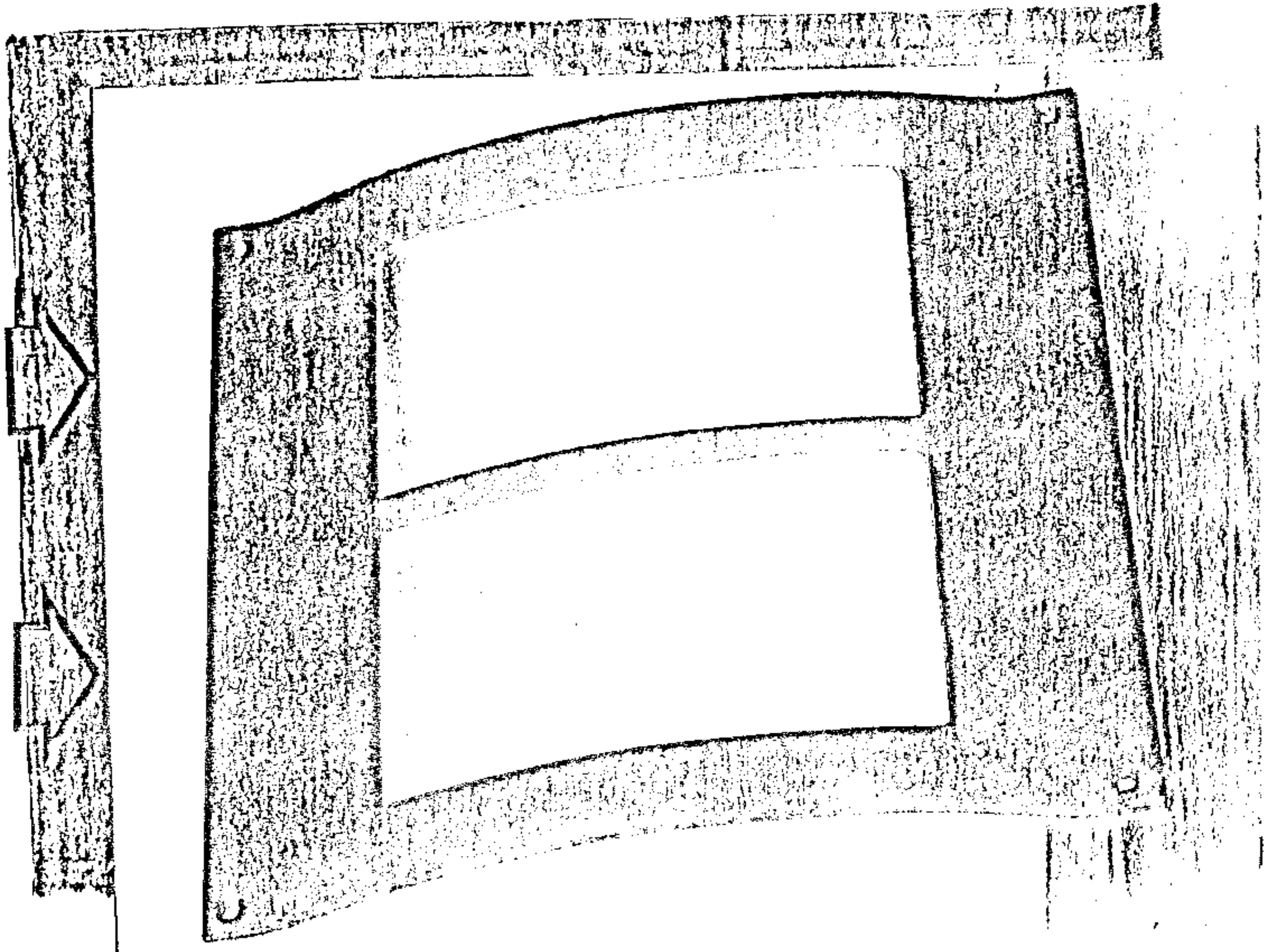

LARGE RADIUS OF CURVATURE
POSSIBILITY
OF TWO IMPACT
LOCATIONS

LARGE RADIUS OF CURVATURE

POSSIBILITY

OF TWO IMPACT

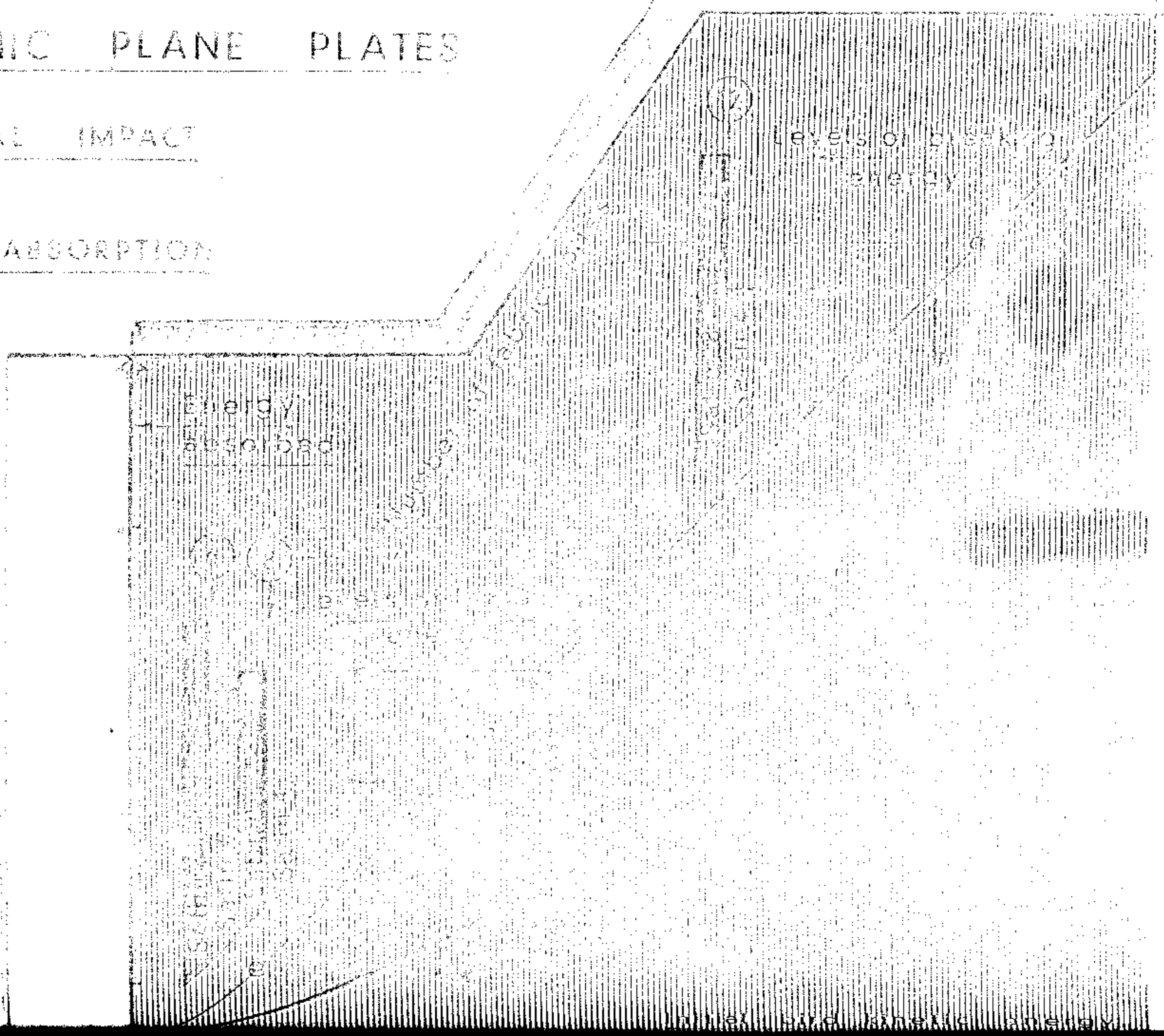
LOCATIONS



MONOLITHIC PLANE PLATES

NORMAL IMPACT

ENERGY ABSORPTION



MONOLITHIC PLANE PLATES

KEVLAR® 49 SATIN 4

NORMAL IMPACT