[illegible]

NEW BIRD IMPACT TESTS PERFORMED AT CEAT

MM. DRUOR (CEAT) and J. BESSE (AMD-BA)

With the collaboration of MM. CLAMAGIRAND and DELMUR (AMD-BA)
MM. ROUSTAN and GAY (SNIAS)

1. FOREWORD

This report presents the bird impact tests on airframes carried out in France at CEAT since 1978.

These tests concern mainly two investigation programs sponsored by the French S.T.P.A :

- Investigation of bird impacts on metallic flat plates with or without stiffeners, which is the same as on airframes.
- Investigation of bird impacts on leading edges.

The presented results, illustrated by motion pictures of tests, are a continuation to the Working Papers number 26 and 37 published for the 13th BSCE in Bern and to the information given by the BIRA to the Working Group "structural testing" for the 14th BSCE in The Hague.

After a brief review of the present CEAT test installations, we will deal with the results of :

- the 4 lb bird impacts on AU4G1 (2024) plates inclined on the bird trajectory
- the 8 lb bird impacts on the leading edge of Airbus A 300 B tail plane.

Between these two series of tests, we will present a particularly interesting film about 4 lb bird impacts on the bubble of the forward observer of the Breguet-Atlantic airplane.

After each part of the film we will present a synthesis of the test results obtained.

.../...

2. BIRD IMPACT TEST INSTALLATIONS IN CEAT

The CEAT (Aeronautical test center in Toulouse) performs bird impact tests on aiframes by means of two compressed air guns.

The 150mm bore gun permits carrying out impact tests with birds of a mass not exceeding 4 lb (1,8 kg) at speeds up to 300 m/sec.

The 300mm bore gun is used for 8 lb bird impacts.

Each installation is equipped with a safety wall in order to stop the projecti But the flat surface of the wall perpendicular to the shooting axis allows the possible projectile deflection to be measured.

See fig. 1 150 mm gun

fig. 2 300 mm gun

The bird velocity is measured at the departure from the gun muzzle by a syste of photoelectric cells set on a one meter interval basis.

The bird is placed in a package making up the "shell".

The sizes of these packages are shown fig.3.

For these packages the materials are :

150 mm gun : Polystyrene foam

300 mm gun : Polyurethane foam

For the 4 lb bird and 150 mm gun the packages are standardized, whereas for the 8 lb birds, the packages are adjusted to the bird species used.

These packages are stripped from the bird before the bird impacts the target.

The shooting is filmed with a fast cinecamera (4000 frames per second).

An horizontally and vertically graduated blackboard faces the cinecamera at the oppositeside with regard to the gun axis.

This device associated with a time base either inside or outside the camera allows reconstitution of the trajectories after impact in order to determine the velocities and thus the kinetic energy characteristics of the test.

.../...

3. BIRD IMPAC[illegible]

3.1 Historic[illegible] the problem

The [illegible] impacts performed at CEAT on airframes of Mirage F1, Mercure, [illegible] conducted AMD-BA Company to propound a theory trying to explain [illegible] (see Working Paper n° 37 - 13th BSCE).

[illegible] as follows :

The [illegible] energy, normal to the impact surface, is the measurement of [illegible] observed.

[illegible] energy is proportional to the thickness of the skin [illegible] of the airframe web affected by the shock.

[illegible] destruction of structure and with the bird flesh going through [illegible] deflection of the bird trajectory can be evaluated by means of [illegible] shock mechanics theory.

The [illegible] experimental investigation for 4 lb bird impacts [illegible]

These [illegible] not stiffened, like the airframe, and their material is [illegible] 13) or TA6V (titanium alloy).

The [illegible] investigation is to verify the various points of AMD-BA [illegible]

[illegible] and AMD-BA, have defined flat panels of about [illegible] and with skin thicknesses from 1 to 4 mm.

These [illegible] stiffened by angle extrusion and Z-shaped beams set a right [illegible]

[illegible] spacing is 150mm.

The Z [illegible] spacing is 150mm or 300mm.

These [illegible] represent respectively the stringers and the frames of a [illegible]

.../...

The CEAT has built a variable slope support for the test panels and the 150mm gun installation has been completed by the safety wall.

This information was already supplied by STPA to the Working Group of the 14th BSCE.

Initially CEAT has built only AU4G1 panels.

A first impact test campaign took place last spring.

Before the film, we want to indicate that the oblique impact tests on stiffened panels, shown at the end of the film, are actually the first ones ever conducted.

These tests have given unexpected results.

They have led to improving the support in order to improve the joining of the panel with the support.

But in a parallel direction, an investigation has been carried out with square and unstiffened plates set perpendicularly to the shooting axis.

This arrangement eliminates the difficulties of kinetic energy distribution and permits the influence of the thickness and the size to be investigated.

The analysis of the results of these impacts tests will be explained after the film.

3.2 Test results onto plates perpendicular to shooting axis

Hence two types of unstiffened AU4G1 plates have been tested :

- small plates size : (380 x 380 mm)
  thicknesses : 1-2-3-4 mm
- large plates size : (896 x 896 mm)
  thicknesses : 1 and 2 mm

These sizes are the free bearing between the support edges.

21 shootings were performed : 17 on the small plates
4 on the large ones.

The range of the sweeped energy stretches from 3,000 to 22,700 Joules for the small plates and from 16,600 to 29,000 Joules for the large plates.

The analysis of bird impacts on airframes led to propound two Laws for the destroying normal energy (see W.P. n° 37 - 13th B S C E) and showed fig.n°4.

N°1 Law presented by the form

$$W_N = 1900\ e\ \frac{\ell}{136} \simeq 14\ e\ell$$

where W_N = penetration normal energy (Joules)

e = skin thickness (mm)

ℓ = smallest size (mm) of the plate

The factor $\frac{\ell}{136}$ indicates the reduction to make because the analysed tests concerned only structure webs with 136mm in their smallest size.

This n°1 Law applies far from strong beams.

Near the strong flanges n°2 Law had been propounded :

$$W_N = 3250\ e\ \frac{\ell}{136} \simeq 23{,}9\ e\ell$$

with the same notations as above.

As for the test results with plates perpendicular to shooting axis, two remarks can be made :

1°) The test results for the large plates and one shock on the smallest (shooting n°12 on 2mm thickness) are spotted, after reduction, on n°1 Law (see fig. 5).

2°) The test results on small plates appear after reduction to rather obey to n°2 Law : thus

- for the thicknesses of 1 and 2 mm

$$W_N = 4250 \; e \; \frac{\ell}{136} = 31{,}25 \; e\ell$$

- for the thicknesses of 3 and 4 mm

$$W_N = 4800 \; e \; \frac{\ell}{136} = 35{,}3 \; e\ell$$

(see fig. 6).

It seems that the results obtained depend on the attachment of the panel on the support for the small plates.

On the contrary, for the large plates, the effect of the attachment is not seen.

This can be explained by the fact that the large plates behave as if they were loaded in their centerpoint.

It is known by analogy with the bending beam theory, that in this case, the energy of deformation, even in plastic range is the same, the edges being supported or built-in.

We can principally say that these tests corroborate the proportionality of the bird impact breaking energy with the skin thickness and the size of the impacted surface [illegible].

We should note that at the present time n°2 Law has not an expression which tends to become stable.

This arises from the first evaluation of this law unfavorably established with the results of three impacts (see fig.6).

Yet at present time, no good explanation has been found, neither concerning the ratio of the coefficients of n°1 and n°2 Laws nor the variation of thirteen percent between the two groups of thicknesses for n°2 Law.

3.3 Development of test program

The experience gained during this test campaign led to forecast a modification of the test support in order to try to obtain a brittleness of the specimens by the isolation of the webs submitted to the bird impact.

In a parallel direction, finite-element calculations will be undertaken with the intention of verifying the boundary conditions and compare them with the conditions obtained in the airframe.

The purpose of this work is to explain the test results already obtained on panels and to resume the investigation on the aims of the study as indicated in beginning of this section.

4. BIRD IMPACT TESTS ON THE BUBBLE NOSE OF THE BREGUET-ATLANTIC AIRPLANE

The film that will now be presented will remind impact test of 4lb birds on the forward nose of the Breguet-Atlantic airplane.

A view of test specimen is shown on fig.7.

This bubble has almost the shape of a spherical cap (Radius 1 m).

The material of this bubble is Plexiplus, produced by Rohm company (German Federal Republic) and worked by St-Gobain company.

This material is an acrylonitril product.

The bubble is obtained from a plate of 17,5mm thickness. The forming of this piece is achieved by suction and punching in temperature.

Therefore the thickness varies from 11,5 mm at the top to 14 mm at the borders.

The border is bonded to a Dacron and Orlon piece which is itself fastened by screws on the metallic airframe.

The film presents four impacts performed at the centre of bubble with birds having masses from 1,86 to 1,875 kg at a velocity of about 180 kt (92,6 m/s).

The bird velocities vary from 61 up to 120 m/s (velocity of the last shooting for the margin research).

The impact resistance of the bubble is a good example of the so called : "Bagging mode".

The high elongation characteristics of the material permits large deformations.

The bird is retained, stopped and then projected forward.

5. 8lb BIRD IMPACTS ON THE LEADING EDGE OF THE AIRBUS HORIZONTAL TAIL PLANE

5.1 Generalities

The illustration of the information given by French STPA to working group "structural testing" in 14th B S C E, will be presented by the next film concerning the 8lb bird impacts on the leading edge of the horizontal tail-plane of the Airbus A 300 B.

We remind that, at the request of STPA, five 8lb bird impacts have been carried out on this leading edge between October and November 1979.

The sweeped range of the velocity stretches from 54 to 186 m/s with the corresponding energies varying from 4,800 to 60,500 joules.

In this velocity sweeping, it has been tried to reach the limit velocity of penetration into the leading edge.

We point out that the birds used were ducks which masses varied from 3,3 to 3,6 kg.

The bird package for the 300mm gun is shown by figure 3.

5.2 Analysis of the results

The examination of the film show penetrations where the bird cut the skin of the leading edge along the path of the shooting.

These penetrations are like those observed formerly on the wing leading edge of the Mystere 20, but the damages are akin to those observed on CEAT leading edges.

Previously, in May 1974, the leading edge of the horizontal tail-plane of the Airbus had been submitted to three impacts of 4lb birds at velocities of 180-182 m/s.

The damages caused by the 8lb bird at a comparable velocity (186 m/s) are approximatly the same as those with a 4lb bird.

This fact was previously observed on the tail-plane of a much smaller airplane : the Falcon 10.

.../...

Consequently, we have applied to the impacts on the leading edge of the Airbus horizontal tail-plane, the principles of the analysis previously used for the CEAT leading edges as shown in figure [illegible].

For all impacts, the maximum diameter of the cylinder circumscribed about the bird (here 200mm) is lower than the leading edge height and all the matter of the bird flesh penetrates into the leading edge.

For the tested area, the intersections between the bird cylinder and the leading edge have similar dimensions for the various shootings (length : 1200mm - Area 320 sq.mm).

Impact n°5 can be considered to be the limit and this allows to give the maximum kinetic energy destroying the leading edge.

In looking at the damages of the fifth and the first shootings, it appears that the breaking energy per unit of surface W/S is located between 12.6 and 13.5 Joules per square millimeters.

For the damages of n°2 impact this energy is located between 12,9 and 14,2 Joules per square millimeters.

These values are included in the range where it was possible to locate the breaking energy obtained with the 4lb bird impact.

We can also bring these values closer to those found in the bird impact tests on the leading edge of :

- Falcon 10 tail-plane = 13.9 Joules/mm^2
- Mystere 20 wing = 14.7 Joules/mm^2
- CEAT simple leading edge = 12,5 to 13,3 Joules/mm^2
- CEAT leading edge with cleaver = 14,6 Joules/mm^2

At this stage of our analysis it seems that the energy values depend on the damage mode.

For the leading edges cut by the bird in a direction parallel with the shooting axis (see upper part of figure 8) the value of 13 Joules/mm^2 seems to be suitable.

For a leading edge, on which the damage results from an initial bagging (see lower part of figure 8), the value of 12,5 Joules/mm^2 seems to be better.

.../...

5.3 Remarks on the formulae giving the limit velocity of penetration into the leading edges

A systematic experimental investigation upon bird impacts on leading edges permitted the CEAT to give a formula concerning the limit penetration velocity.

This formula is :

$$V_p = 56{,}7 \; e \; M^{-1/3} \cos \phi^{-2/3} \exp \frac{850}{r^2 + 30r + 1000}$$

with V_p = penetration velocity (m/s)

e = skin thickness (mm)

ϕ = leading edge sweep angle

M = bird weight in kg

r = leading edge radius

This formula is not very different from those propounded by the R A E (Technical Report 72056).

The R A E formula, with the same units and the same notation as above is as follows :

$$V_p = 50{,}4 \; e \; M^{-1/3} \cos \phi^{-2/3} \exp \frac{1234}{r^2 + 30r + 1000}$$

For the leading edge of the Airbus horizontal tail-plane we have :

sweep angle : ϕ = 38,5°

average skin thickness e = 1,17 mm

weight of the bird = 3,8 kg

Area where the radius is 65mm

CEAT formula gives V_p = 57,4 m/s

R A E formula gives V_p = 53,7 m/s

Area where the radius is 90mm

CEAT formula gives V_p = 53,8 m/s

R A E formule gives V_p = 49,4 m/s

But in the area where the radius is 65mm, the skin has not been pierced at the velocity of 65 m/s.

In the area where the radius is 90mm only the skin was damaged at the 90m/s velocity.

Consequently it seems that the propounded formulae are not applicable just as they are for the big bird impacts.

In fact the impact tests both in CEAT and in RAE were performed with birds of a maximum weight of 1,8 kg.

.../...

5.4 Conclusions

The analysis of the results of 8lb bird impacts on the Airbus horizontal tail-plane leading edge, gave the penetration energy values per unit of area, in the same range as the results previously obtained on the other airplanes.

Consequently we can give a good approximation of the breaking energy for the leading edges, with the expression :

$$W_N = 12.5\ e\ell$$

with

- W_N = breaking of penetration energy (Joules)
- e = skin thickness (mm)
- ℓ = length (mm) of the intersection between the leading edge and the bird cylinder.

This formula applies when we are sure that the whole flesh of the bird will be retained by the leading edge.

For the sharp leading edges for which only a part of the bird kinetic energy will be active, it will be necessary to determine the part of the bird mass acting on the leading edge (see W.P. n° 13th B S C E).

At that time the evaluation of the penetration energy is given by the formula

$$W_N = 14A$$

- W_N = Penetration energy (Joules)
- A = Area (sq.mm) of the section shown on upper part of figure 8.

-----

rizontal
of area,
rplanes.
ergy for
edge and
bird will
tic energy
mass
the formula
ure 8.

LEADING EDGES - PENETRATION ENERGY			
AIRPLANE	PART	BIRD MASS (kg)	PENETRATION ENERGY (Joules/mm^2)
AIRBUS A 300 B	Horizontal tail-plane Leading edges.	(shootings n°5 and 1) 3.6 shooting n°2 1.8	12.6 - 13.5 12.9 - 14.2 11.5 - 17.8
FALCON 10	Horizontal tail-plane Leading edge.	1.8 and 3.6	13.9
MYSTERE 20	Wing leading edge	1.8	14.2
CEAT simple leading edges		1.8	12.5 - 13.3
CEAT leading edges with cleaver		1.8	14.6
Value of energy propounded for the damages fig.8 upper part.			14
Value of energy propounded for the damages fig.8 lower part.			12.5

Limit penetration velocity

CEAT : $V_p = 56{,}7\ e\ M^{-1/3} \cos \Phi^{-2/3} \exp \dfrac{850}{r^2 + 30r + 1000}$

R.A.E $V_p = 50{,}4\ e\ M^{-1/3} \cos \Phi^{-2/3} \exp \dfrac{1234}{r^2 + 30r + 1000}$

V_p = penetration velocity (m/s)

e = skin thickness (mm)

Φ = leading edge sweep angle

M = bird weight (kg)

r = leading edge radius (mm)

For AIRBUS horizontal tail-plane :

$\Phi = 38°{,}5$ average skin thickness $e = 1{,}17$ mm

R (mm)	65	90
M (kg)	3.6	3.8
V_p CEAT	57.4 m/s	53.8 m/s
V_p R.A.E	53.7 m/s	49.4 m/s
$V_{experimental}$	69 m/s (no penetration)	90 m/s (skin only perforated] (velocity near limit)

N°1 Law (far from strong flanges)

$$W_N = 1900\ e\ \frac{\ell}{136} = 14\ e\ \ell$$

W_N = Penetration normal energy (Joules)

e = skin thickness (mm)

ℓ = smallest size of the plate (mm)

$\frac{\ell}{136}$ = reduction factor

N°2 Law (near the strong flanges)

First formula

$$W_N = 3250\ e\ \frac{\ell}{136} = 23.9\ e\ \ell$$

After the tests on the small plates :

thickness e = 1 and 2 mm

$$W_N = 4250\ e\ \frac{\ell}{136} = 31.25\ e\ \ell$$

thickness e = 3 and 4 mm

$$W_N = 4800\ e\ \frac{\ell}{136} = 35.3\ e\ \ell$$

1. [illegible]

2. [illegible]

3. [illegible]

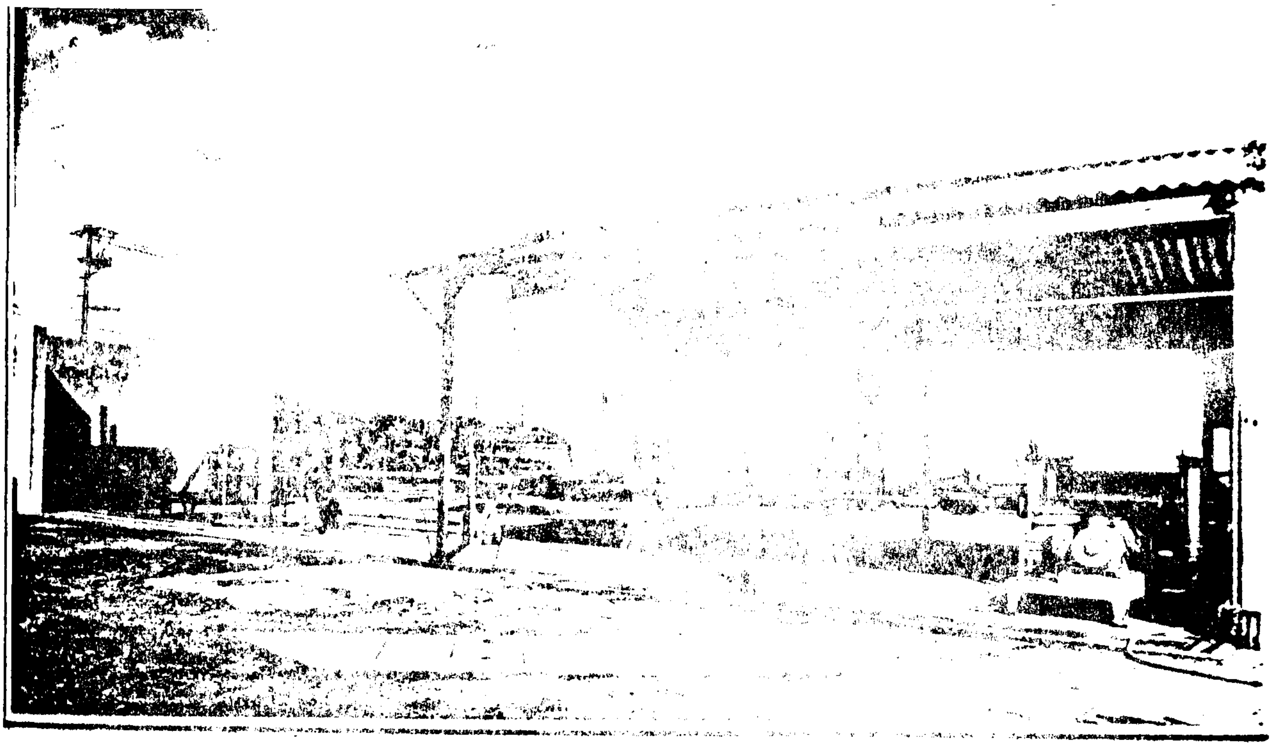
4. [illegible]

5. [illegible]

5. [illegible]

7. [illegible] cupole of the Breguet-Atlantic airpl[illegible]

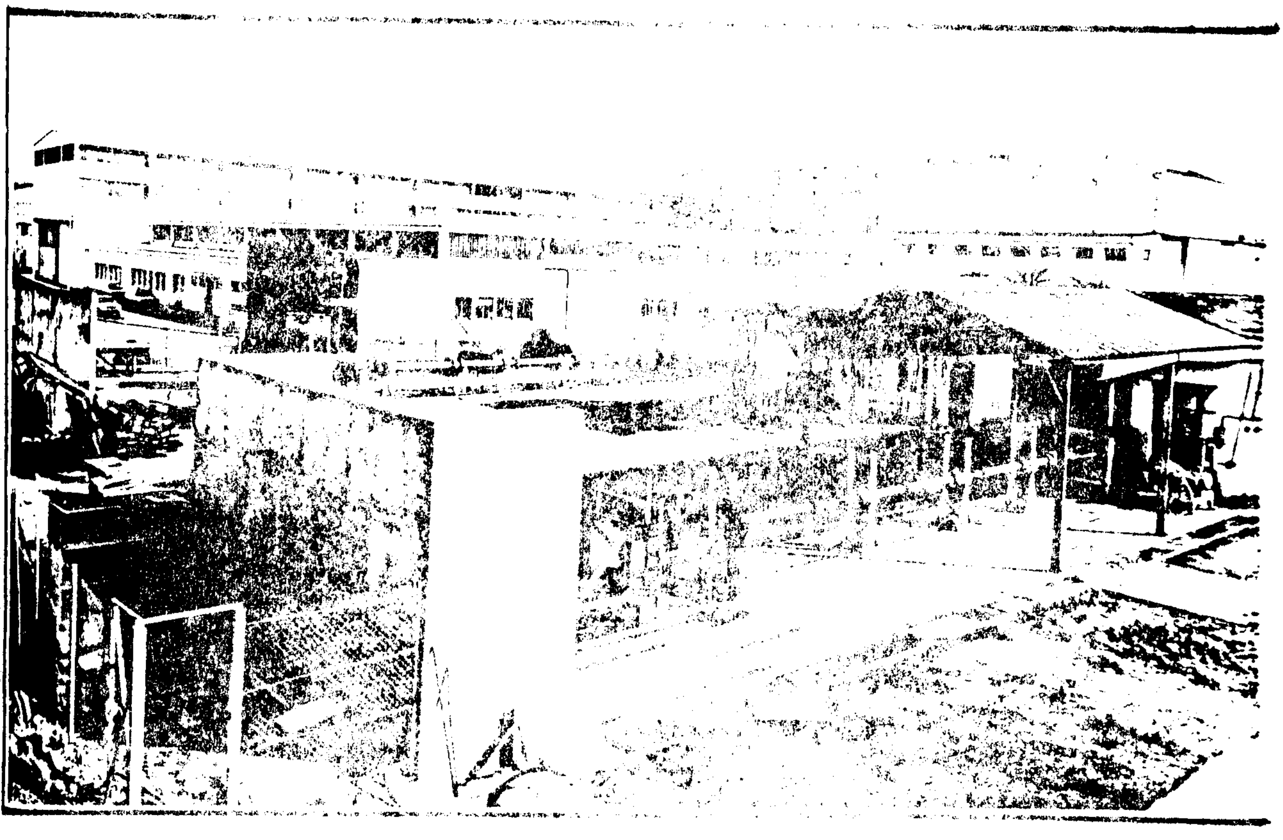
8. [illegible]



[illegible] BORE GUN

Figure 2

[illegible] view of the [illegible]



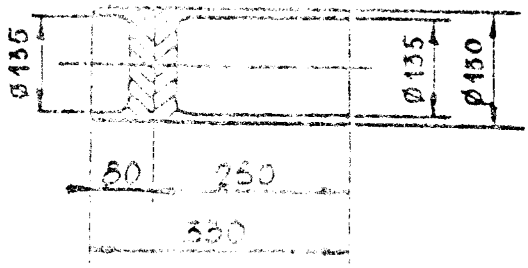
tic airplane

BIRD PACKAGES

Package for
150mm gun

Mass of package :

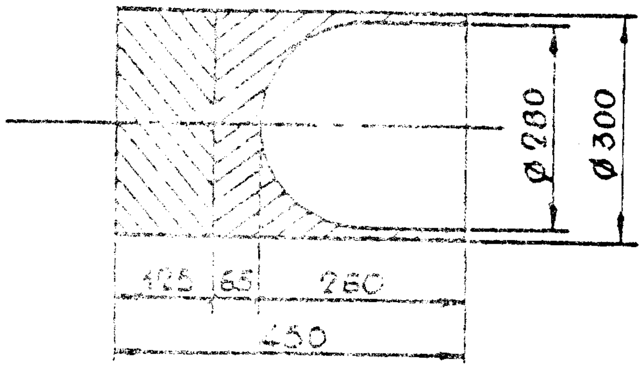
180g ± 15g



Package for
300mm gun

Mass of package : 850g

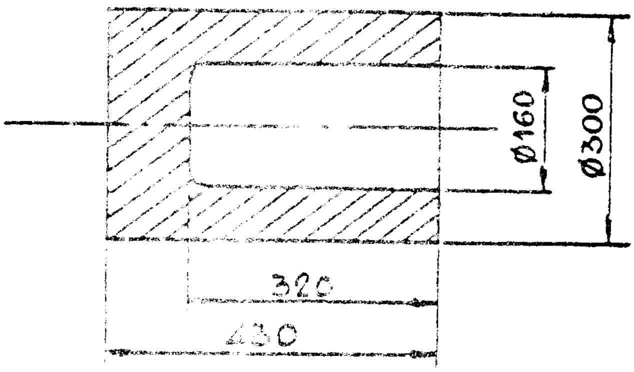
Bird : Turkey



Package for
300mm gun

Mass of package : 800g

Bird : big chicken



Package for
300mm gun

Mass of package :

1,[illegible] to 1,5 kg

Bird : duck

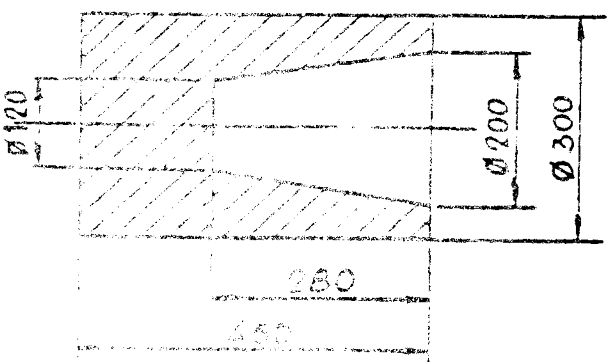
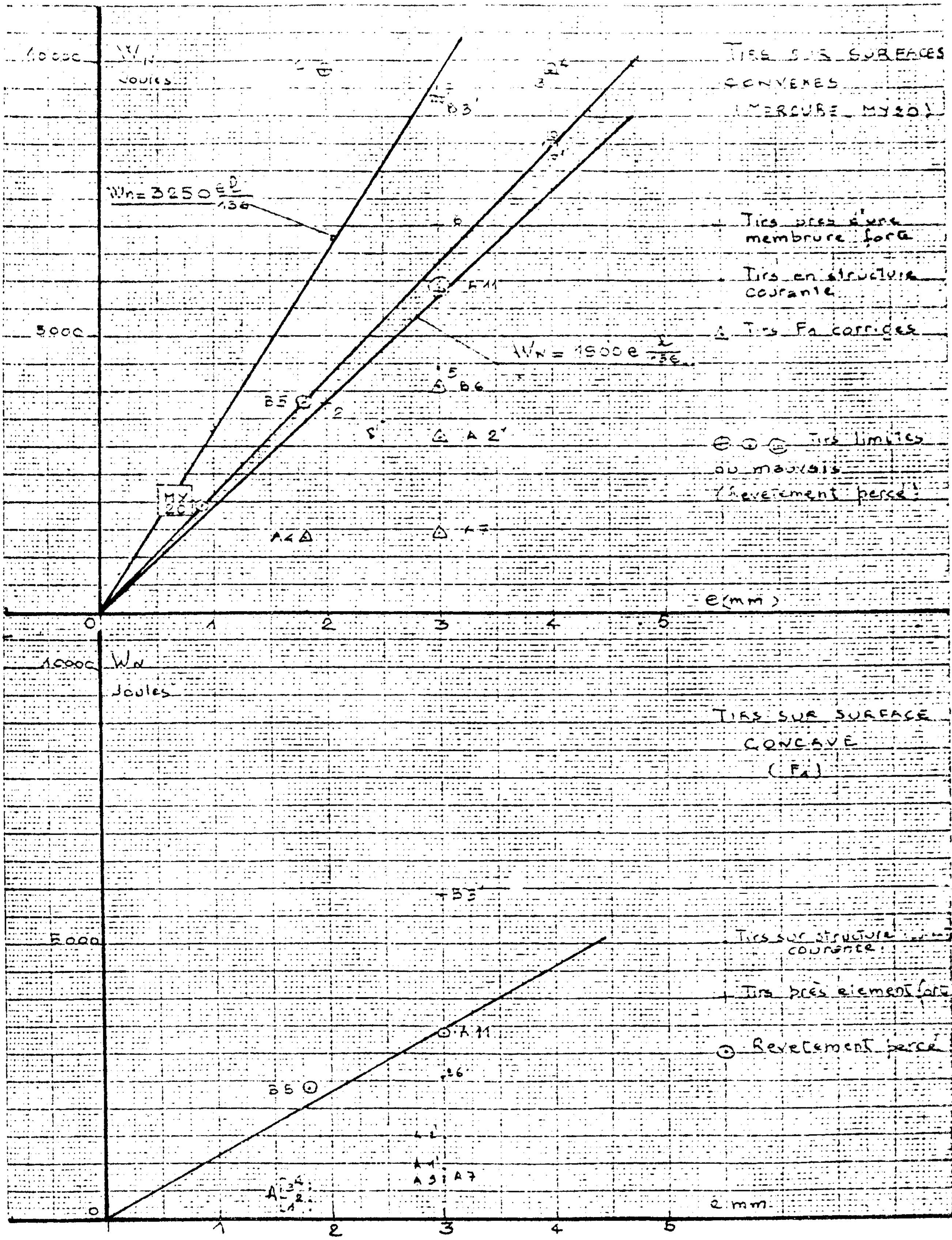


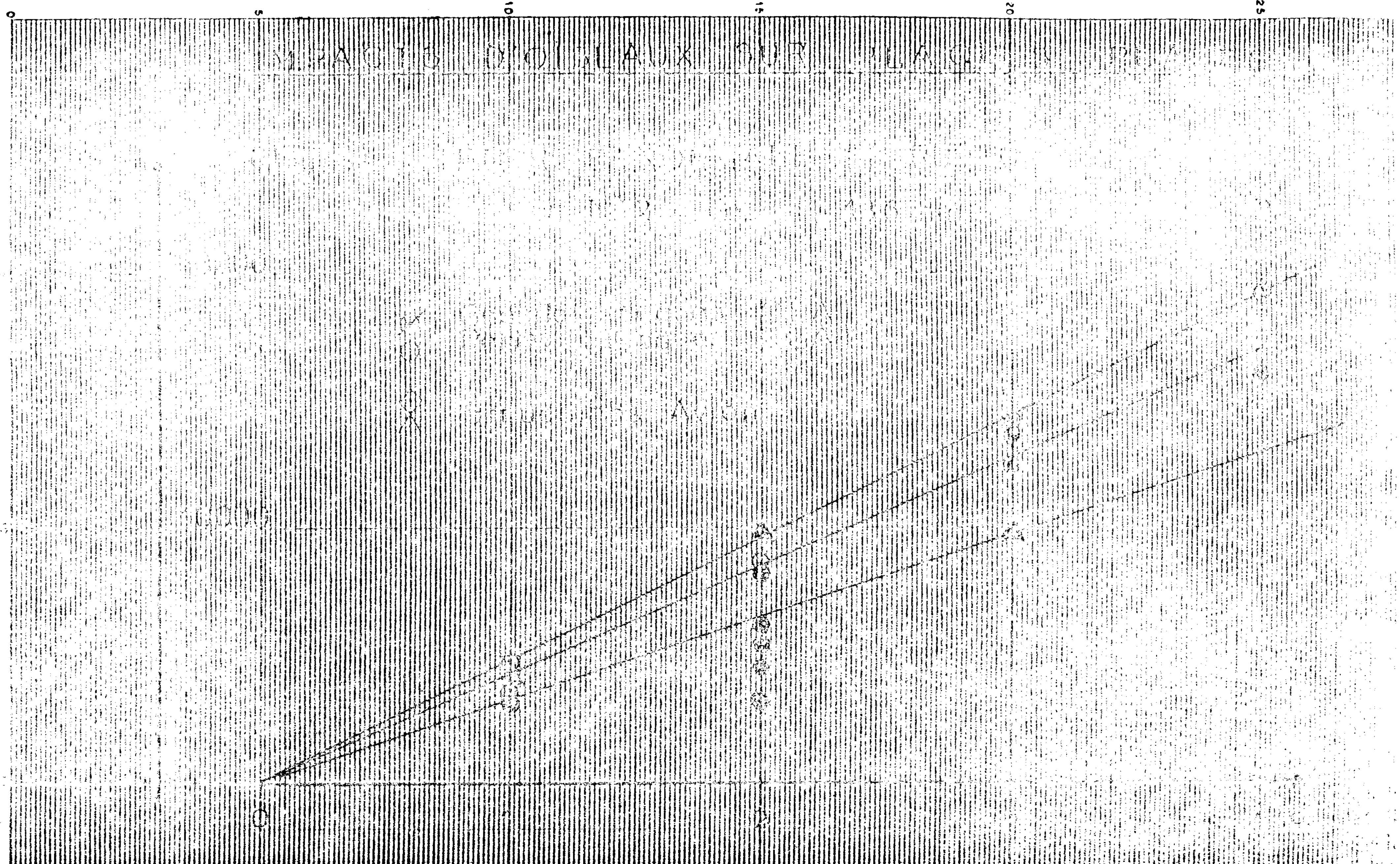
Figure 3

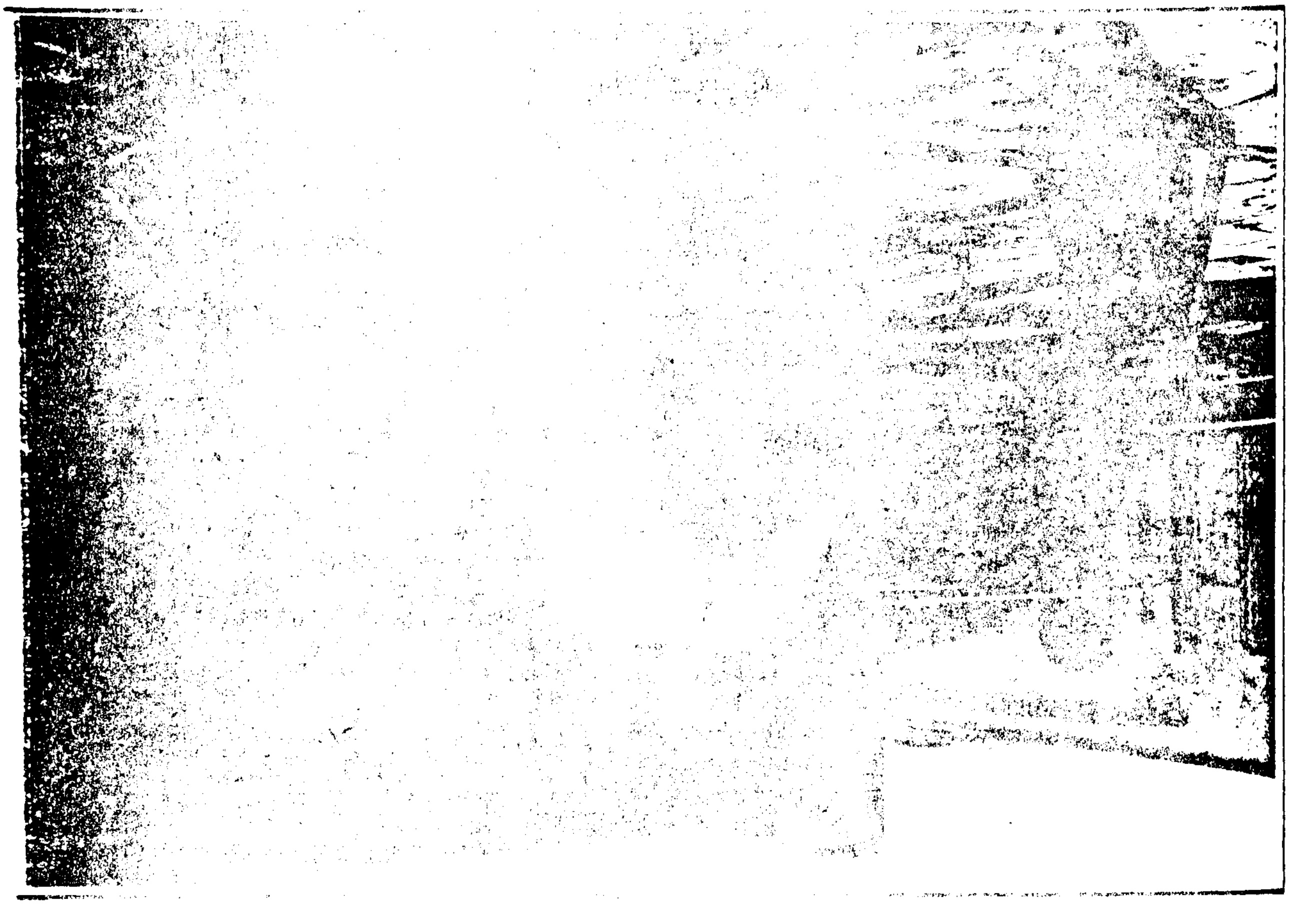
Figure 4

OBLIQUE SHOOTINGS ON SURFACES

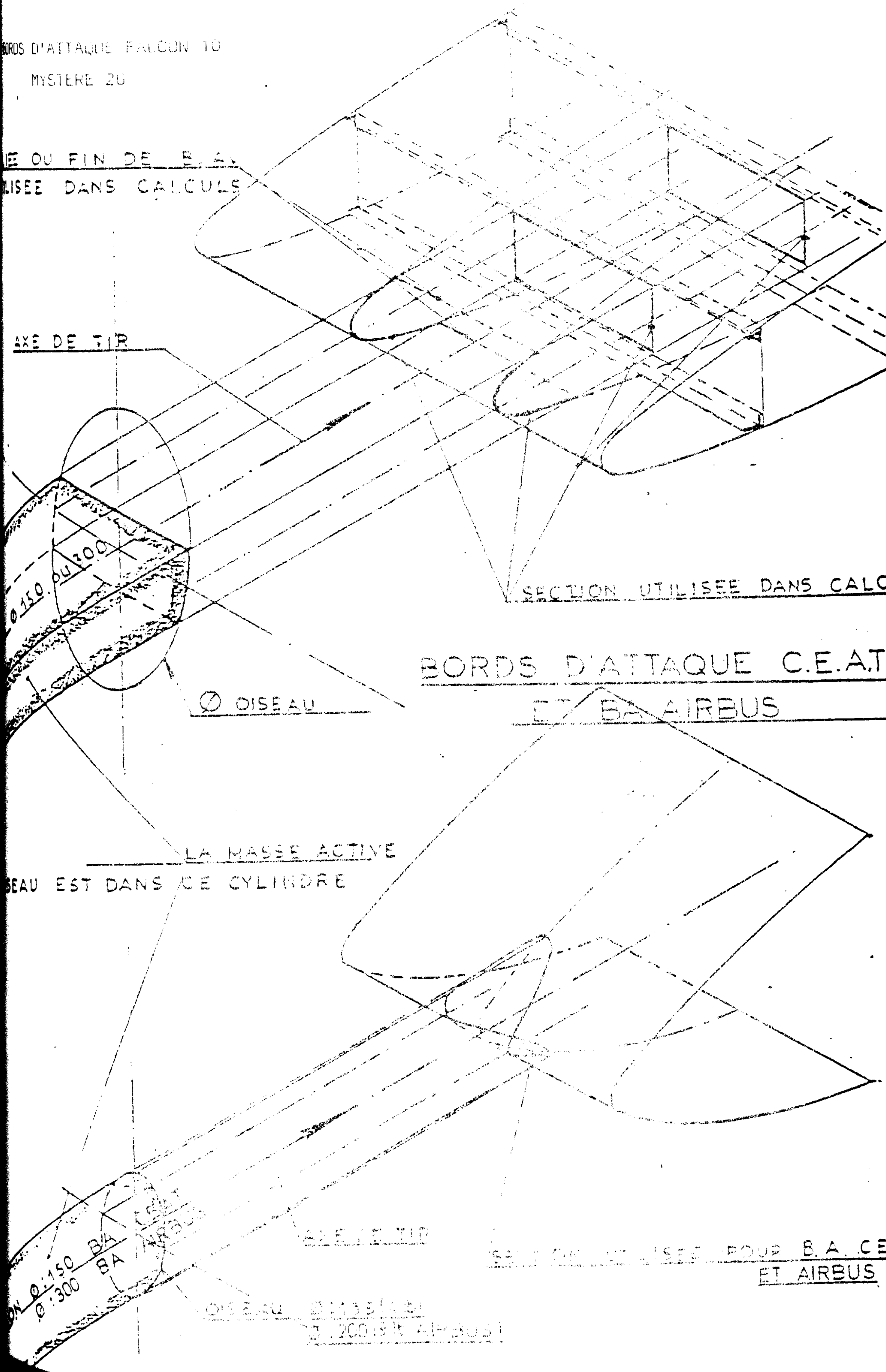
Normal kinetic energy function of the skin thickness




0
5
10
15
20
25



BORDS D'
MY
PLIEE O
UTILISEE
AXE
ON Φ 150
OISEAU
ANON Φ


BORDS D'ATTAQUE FALCON 10
MYSTERE 20
OU FIN DE B.A.
DANS CALCULS
AXE DE TIR
Ø 150 OU 300
SECTION UTILISEE DANS CALC
Ø OISEAU
BORDS D'ATTAQUE C.E.A.T
ET BA AIRBUS
LA MASSE ACTIVE
EAU EST DANS CE CYLINDRE
Ø:150 BA C.E.A.T
Ø:300 BA AIRBUS
POUR B.A. CE
ET AIRBUS