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**REDUCTION OF HELICOPTER VULNERABILITY  
WHAT ARE THE LIMITS ?**

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### INTRODUCTION

A reduction in the vulnerability of helicopters has become a necessity. It is essential if they are to retain the role which they play at the present time in modern armed forces.

This reduction in vulnerability must remain compatible with the cost and performance constraints imposed by the various military programs. These constraints can generally be expressed as a maximum weight constraint for the project.

The optimum reduction in vulnerability of a military helicopter is therefore a matter of finding a compromise. It is difficult to base this compromise on an objective analysis since there is no precise definition of vulnerability. It is

based more on a subjective analysis relying on experience gained by both operators and manufacturers in this respect.

Faced with this problem, Aerospatiale Helicopter Division has had to develop its knowledge and ability in the field of vulnerability reduction over the past few years. This paper gives an overview of the results obtained.

The paper is presented as follows :

- Main threats to a helicopter operating over land
- An attempt to define the notion of vulnerability
- Vulnerability analysis model
- Solutions adopted for reducing vulnerability
- Conclusions.

## 1- THREATS TO A MILITARY HELICOPTER OPERATING OVER LAND

The threats to which military helicopters operating over land are likely to be exposed are many and varied, ranging from projectiles fired from a personal weapon to ground-to-air or air-to-air missiles. They depend to a large extent on the possible theater of operation of the helicopter.

Leaving aside nuclear, biological and chemical threats which do not fall within the scope of this paper, we have retained the following in the vulnerability reduction studies as being the main threats :

### - Small caliber projectiles

- 7.62 mm (cal 30) armor piercing projectile fired from 100 m.
- 12.7 mm (cal 50) armor piercing incendiary projectile fired from 800 m.

### - Medium caliber projectiles

- 23 mm high explosive incendiary (HEI) shell.
- Burst fragmentation from missiles exploding in the proximity of the helicopter.

This list of threats gives rise to two comments :

- The 23 mm HEI shell is the maximum caliber of projectile against which protection of the helicopter may be envisaged.
- Protection against fragmentation charges of missiles can be obtained by strengthening the helicopter or by reducing its detectability and making use of counter-measures. These last two possibilities are complementary.

## 2- NOTION OF VULNERABILITY - AN ATTEMPT AT A DEFINITION

The notion of vulnerability is hazy. There are no units for measuring vulnerability. Furthermore, it is a relative notion which is essentially statistical and which is dependent on the context in which the helicopter is situated.

Since clear definitions are needed as a basis from which to work on an industrial level, it has been necessary to render the notion of vulnerability more precise.

The **physical** vulnerability of a helicopter is defined as the mean probability of stopping the flight (or mission) by a **single** hit from a given threat at any point on the aircraft. The helicopter is assumed to be in level flight at very low altitude. Each point of the helicopter has an identical probability of being hit. All directions of attack are equiprobable.

Having established this definition, it becomes possible to quantitatively assess the vulnerability of a helicopter. It should, however, be noted that this definition is not particularly applicable with respect to vulnerability to fragmentation charges detonated by proximity fuses.

## 3- VULNERABILITY MODELS

Various vulnerability models have been developed.

The main ones are :

- Project model
- Development model

These first two models are used to analyse vulnerability to small and medium caliber projectiles.

Others models :

- Fragmentation charge model
- Model predicting behavior after damage.

### 3.1 - Project model

After identifying the sensitive or vulnerable elements, they are represented by rectangle parallelipeds characterized by their surface area presented in the two main directions,  $Ox$  and  $Oy$ .

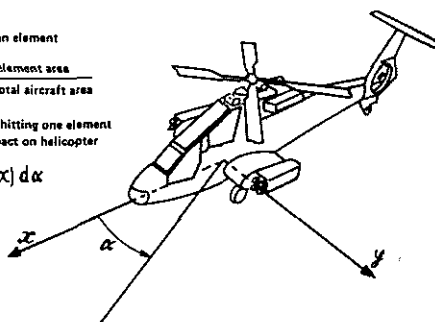
The sectors representing the angles at which an element may be hit are also determined : sectors where the element is not masked by another element or by armor plating.

- probability of hitting an element

$$f(\alpha) = \frac{s_x \cos \alpha - s_y \sin \alpha}{s_x \cos \alpha + s_y \sin \alpha} = \frac{\text{element area}}{\text{total aircraft area}}$$

- average probability of hitting one element whatever type of impact on helicopter

$$\sum_{\text{on all elements}} \frac{1}{\pi} \int_0^{\pi} f(\alpha) d\alpha$$



This gives :

Hit probability on an element in direction  $\alpha$

$$f(\alpha) = \frac{\text{Element surface area}}{\text{Aircraft surface area}} = \frac{s_x \cos\alpha + s_y \sin\alpha}{S_x \cos\alpha + S_y \sin\alpha}$$

Hit probability on one of the vulnerable elements, for all directions :

$$\sum_{\text{elements}} \frac{1}{\pi} \int_0^{\pi} f(\alpha) d\alpha$$

Mean VULNERABILITY of the helicopter irrespective of location and direction of hit : hit probability on one of the elements X, probability of destruction of this element.

i.e. 
$$\sum_{\text{elements}} \frac{1}{\pi} \int_0^{\pi} f(\alpha) d\alpha \times p$$

Where p = probability of destruction of each element when hit.

This model was originally intended for assessing small caliber armor piercing projectiles but is also used for medium caliber (23 mm) HEI shells. In this latter case the helicopter is broken down into zones comprising one or more components ; the effect of a hit in a zone is derived from experience.

Another specific feature of this method is that it can analyse sector vulnerability if specific sectors of attack are to be examined.

### 3.2 - Development model

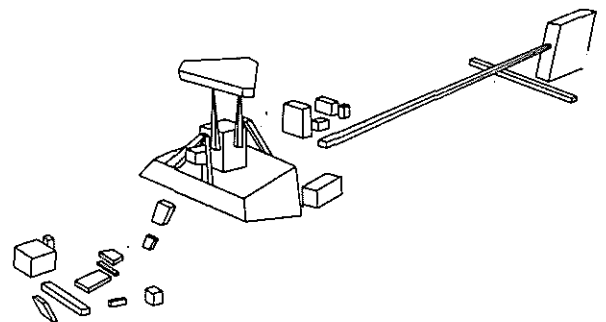
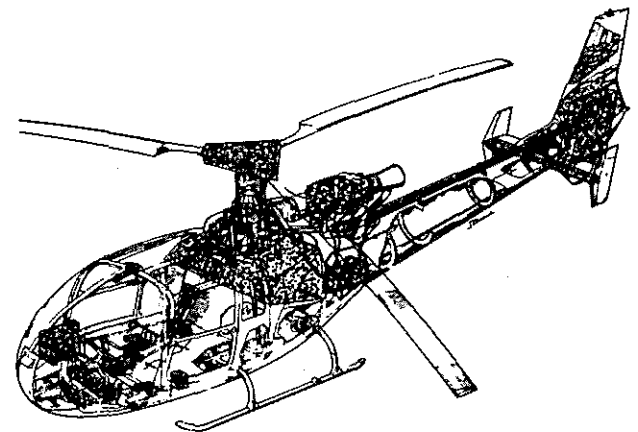
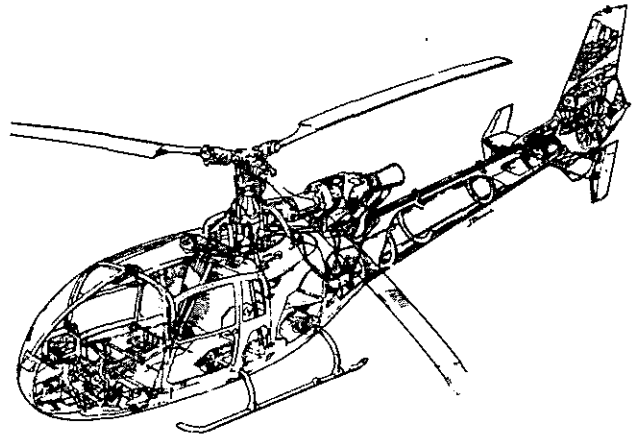
This is much more complicated than the previous model since it provides a much more detailed representation of the helicopter. It has been developed in collaboration with CELAR (Centre Electronique de l'Armement, France).

Representation of the helicopter also implies a breakdown into polyhedrons as shown below.

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MATHEMATICAL MODEL FOR  
VULNERABILITY  
QUANTIFICATION

DIVISION INTO POLYHEDRONS



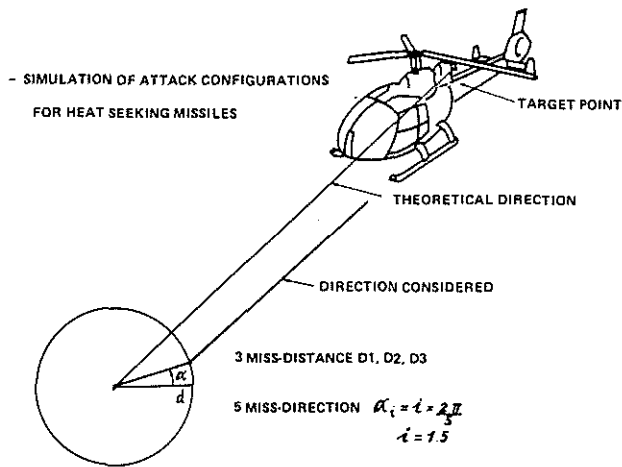
The «probability of destroying an element if hit» data are entered into the model face per face. The possibility of a projectile destroying two elements by passing through each in turn is considered with calculation of the residual speed of the projectile after the first obstacle.

Analysis of the effect of a hit with respect to continuation of the flight or mission is obtained from a functional analysis and the interdependency of vulnerable elements.

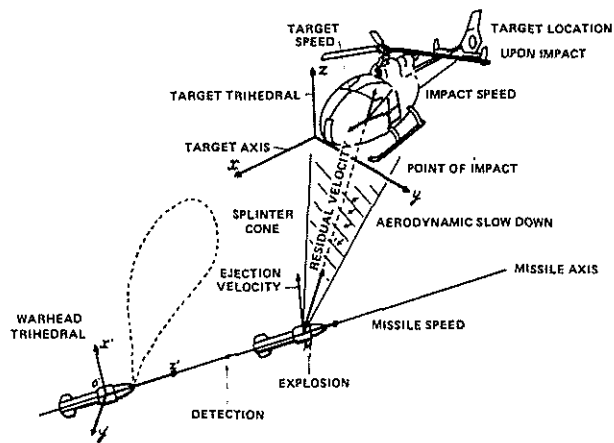
### 3.3 – Vulnerability model for fragmentation charges

In this case, our definition of physical vulnerability is invalidated since the missile is fitted with a proximity fuse.

Together with CELAR, we have had to develop a specific model extrapolated from the first. 210 attack configurations are considered which are broken down into 14 attack directions with 3 MISS DISTANCES and 5 MISS DIRECTIONS for each direction.



The final attack characteristics are taken into consideration allowing for the parameters of charge detonation and the fragmentation distribution by weight and speed.

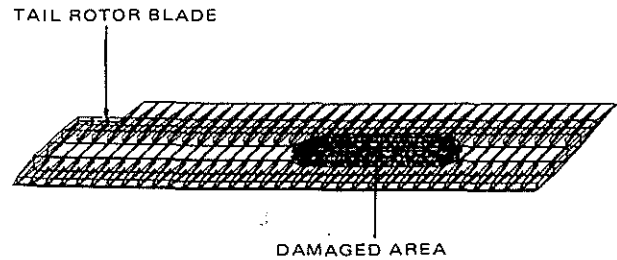


The model then determines the elements hit or damaged by one or more fragments. Combination of individual damage gives the global result of the effect of the threat to the helicopter.

### 3.4 – Damage prediction model

Apart from the models for quantifying the physical vulnerability, we are developing models for predicting the residual strength after a hit in order to try and reduce the number of destructive tests which must be carried out to define a means of protection.

We have, for example, used a finite elements calculation program to determine the residual strength of a blade simulating damage by a projectile. A static tests / calculation comparison showed correlation to be very good.



## 4 – POSSIBLE SOLUTIONS FOR REDUCING VULNERABILITY

Numerous firing tests have been carried out : over 1000 small caliber armor piercing projectiles fired, over 200 23 mm HEI shells fired. They have enabled us to identify the weak points of the helicopter and define methods of protection.

These methods of protection can be divided into 4 categories :

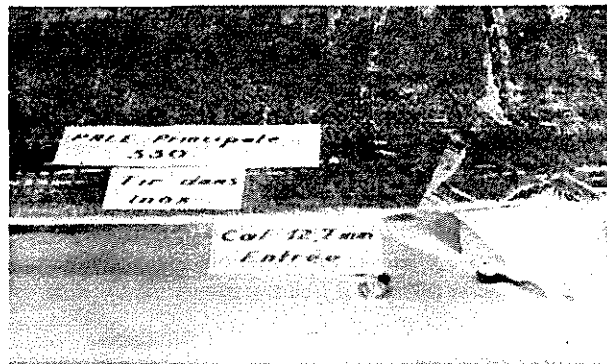
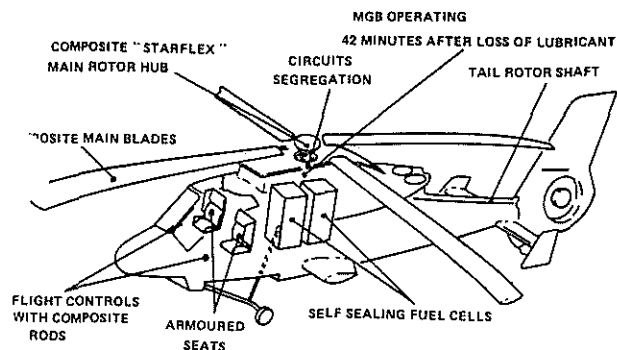
- Simple protection with no increase in weight
- Protection resulting from technological developments
- Protection resulting from specific developments
- Protection by armor plating.

### 4.1 – Simple protection with no increase in weight

This is the result of specifications concerning vulnerability being taken into consideration at the project stage.

Entering such specifications in the selection has an effect on :

- Aircraft architecture
- Dimensioning of specific sub-assemblies.



The following may be given as an example :

- Architecture giving distinct separation of redundant systems : hydraulic systems, electrical circuits.
- Masking of vulnerable elements by solid invulnerable assemblies.
- Locating of vital components vulnerable to 23 mm HEI shells away from cowlings and fairings to prevent highly destructive direct hits.
- Adoption of large diameters, with respect to the caliber of the projectile against which protection is sought, for transmission components such as flying control rods and tail rotor drive shafts.

#### 4.2 - Protection resulting from technological developments

The greatest technological development concerning helicopters is the extensive use of composite materials in the manufacture of assemblies such as rotor blades, rotor hubs, etc ...

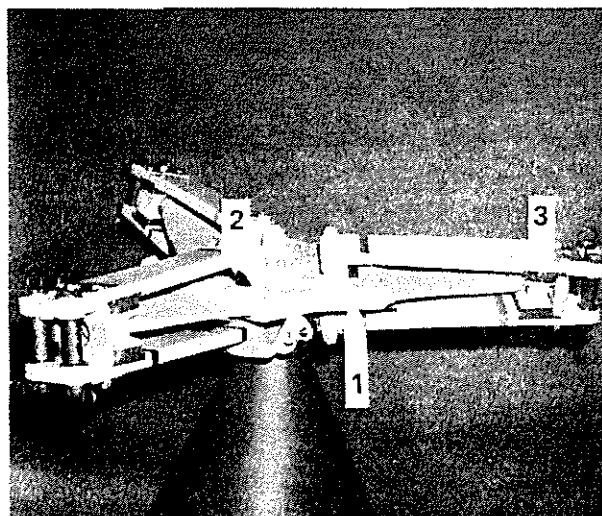
- Protection resulting from the use of composite materials : Three examples may be given

##### (1) Main rotor blades

The main rotor blades are the first mechanical components to have benefitted from composite materials. There are many advantages : insensitivity to corrosion, unlimited service life, optimization of aerodynamic profile, and in particular, insensitivity to the notch and shape effects. Composite materials therefore render the blades totally insensitive to piercing by small projectiles, as we have been able to demonstrate in tests (in fatigue tests at maximum flight loads, survival is considerably greater than mission duration and no spreading of the damage was observed).

##### (2) Starflex type composite main rotor hub

As opposed to a conventional metal hub using bearings for flapping and incidence hinges, which make it highly vulnerable to a hit, the Starflex main rotor hub made entirely of composite materials utilizes the flexibility of these materials and elastomeric bearings for flapping and drag hinges.



- (1) CENTRAL SECTION (STAR)
- (2) LAMINATED THRUST BEARING
- (3) FREQUENCY ADAPTER

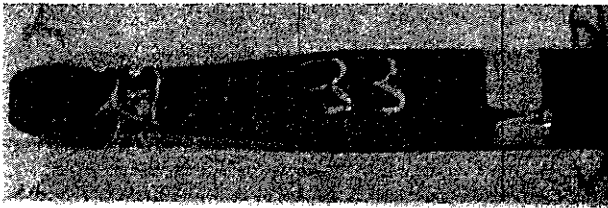
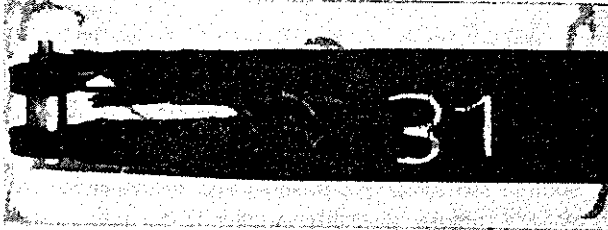
After firing 12.7 mm caliber armor piercing projectiles into all hub components, the fatigue tests demonstrated a survival capability in excess of mission duration.

**(3) Flying controls**

Flying control rods of conventional design are vulnerable to a hit.

The metal body is susceptible to the notch effect after piercing.

We have therefore developed solutions using composite materials for these rods taking full advantage of the winding of fibers to attach the end fittings.



These solutions have proved to be much more resistant to hits than the conventional system.

The three examples which we have quoted serve to illustrate the gain in invulnerability obtained through progress made with respect to materials, with no increase in weight.

**4.3 — Protection resulting from specific developments**

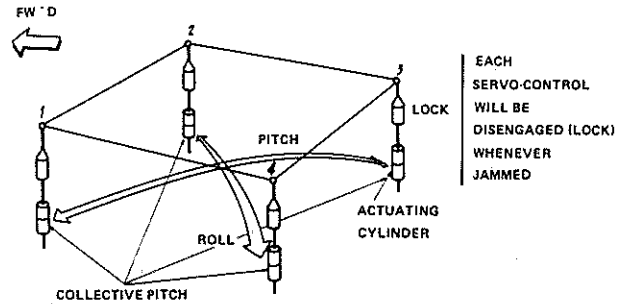
This form of protection nearly always involves an increase in weight.

Two significant examples may be given.

**Flying controls**

Irrespective of the method of transmitting control instructions, the vulnerable point in the system is always the servo controls. There are three possible solutions :

- Armor plating the servo-controls, with a considerable weight penalty.
- Development of specific servo-controls of low vulnerability for military use. These are dual cylinder servos incorporating anti-seizure devices.
- A redundant flying control concept using 4 servos to control the swashplate instead of 3. This concept seems promising and constitutes a weight saving of over 25 % with respect to the other two solutions.



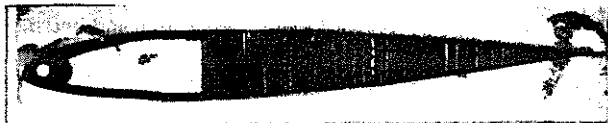
4-servo concept diagram

**Blades with low vulnerability to 23 mm HEI shells**

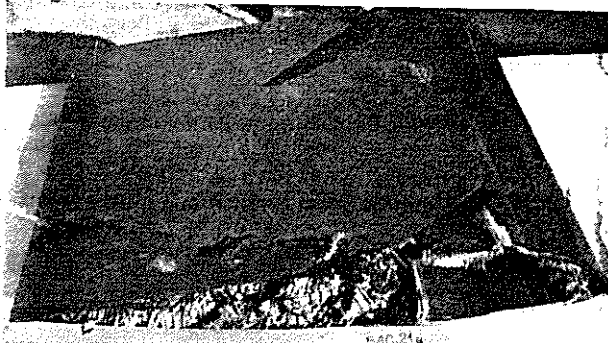
Although composite materials have been shown to make the blades insensitive to the effects of small caliber armor-piercing projectiles without imposing specific design constraints, this is not the case for the 23 mm HEI threat.

Without casting doubt on the use of composite materials, it should be noted that the effects of this threat are very severe. A solution must therefore be found concerning the design concept itself.

The objective of eventually producing blades with low vulnerability to 23 mm HEI shells has led us to examine design principles different from those which we traditionally employ. We have produced 15 different sections of blade which we subjected to firing tests. These sections were of different design : hollow single-double-or triple-box section spar type of materials used : carbon, glass, kevlar - fiber directions. The weight penalty per unit length, with respect to a conventional blade, adopted for this study was 25 %. Although encouraging for certain blade sections, the results have not yet enabled us to define a solution to the problem. This study is ongoing.



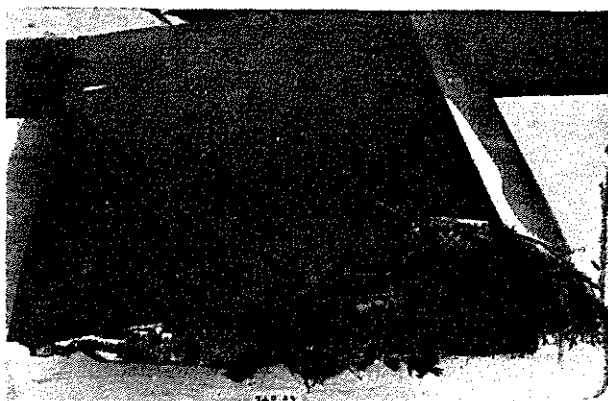
SECTIONAL VIEW BEFORE IMPACT



VIEW OF DAMAGED SECTION AFTER CUTTING



SECTIONAL VIEW BEFORE IMPACT



VIEW OF DAMAGED SECTION AFTER CUTTING



SECTIONAL VIEW BEFORE IMPACT



VIEW OF DAMAGED SECTION AFTER CUTTING

### Fuel tanks

Two problems have to be solved :

- Insuring that the helicopter will have an adequate fuel reserve to continue flight after the tanks have been pierced by a projectile.
- Containing the secondary effects of a high speed projectile hit : hydraulic pressure surge.

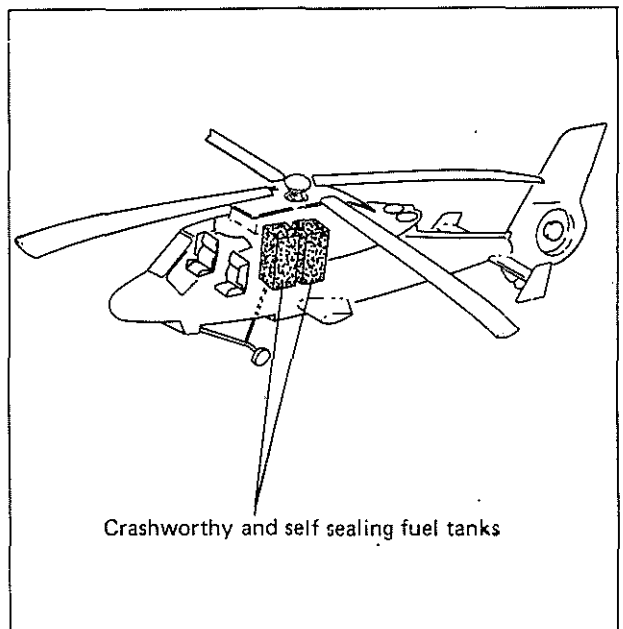
Jointly with two manufacturers, Kleber Colombes and Superflexit, we have developed crashworthy and self-sealing fuel cells withstanding 2 calibers of projectile : 7.62 mm and 12.7 mm. Hydraulic ram effect is contained by the crashworthy properties of the tanks.

For a 4-tons helicopter, the additional weight incurred by installing self-sealing tanks is :

10 kg for the 7.62 mm projectile threat

25 kg for the 12.7 mm projectile threat.

This would insure, at the minimum, 30 minutes flying time after piercing by a projectile.



### 4.4 - Protection by armor plating

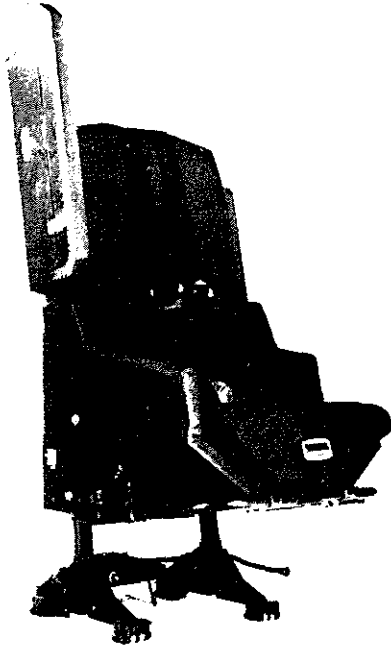
Since protection by means of armor plating gives a high weight penalty, it is used only as a last resort. Studies carried out by Aerospatiale have led to the development of armor plating using composite materials : squares of alumina bonded to a kevlar mat providing a reduction in the weight of the armor plating with respect to steel plating for a given degree of effectiveness. The gains are as follows :



ARMOR PIERCING PROJECTILES Caliber	RANGE	ALUMINA/ KEVLAR	STEEL (DOUBLE HARDNESS)
7.62	100 m	40	55
12.7	100 m	74	102
12.7	800 m	55	

Weight  
in kg/m<sup>2</sup>

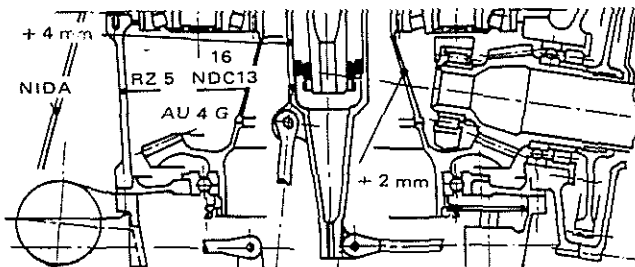
This armor plating is used for crew seats.



#### Semi-armor-plating concept

Protection of vital mechanical components can be looked at from another viewpoint : the semi-armor-plating concept. The aim is to obtain protection by reducing the effectiveness of the projectile to an adequately low level so that it does not damage the component being protected. This is achieved by destabilizing and fragmenting the projectile, and reducing its speed, without attempting to stop it.

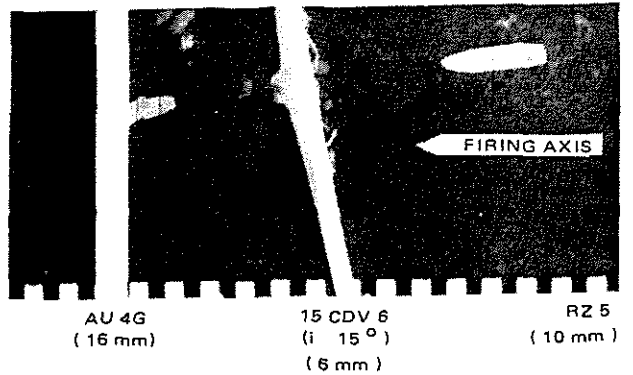
We have taken protection of the central bearing in a main gearbox as an example of the application of this concept.



The central bearing is a vital part. A 12.7 mm armor piercing projectile which passes through the casing and bearing housing retains enough energy to destroy the bearing. It is unrealistic to armor plate the entire gearbox casing.

Tests carried out to determine the energy loss of the projectile after passing through the honeycomb cowling, RZ casing and steel pinion web, have shown that it is possible to protect the bearing by :

- Local additional thickness of 2 mm on the web
- or
- Local additional thickness of 4 mm on the bearing housing.



This protection has been validated by testing as shown in the X-ray successive flashes below.

This protection increases the weight by 1100 grams.

Another example of the application of this concept of semi-armor-plating currently being examined is the bulkhead between the engines on twin-engined helicopters.

## 5- CONCLUSION

This paper has shown that it is possible to significantly reduce vulnerability of military helicopters. Technological developments work to the advantage of reduced vulnerability. Specific technical solutions offer even greater possibilities. The need to take the vulnerability into account from the preliminary project stage must be emphasized, thereby enabling the most suitable architectural solutions to be chosen giving the necessary protection at almost no additional cost.

With a view to establishing the acceptable limits for an anti-tank helicopter in the 4-ton class, we should look at the mean probability of not being able to continue flight after a single hit :

- For a 7.62 mm or 12.7 mm armor piercing projectile, this probability at the present time is 2 % and will be reduced to 1 % in a few years. This takes crew vulnerability into account.
- For a 23 mm HEI shell, it is 20 % and could only be effectively reduced by considerably increasing crew protection, blade strength, and protection of fuel tanks.
- For any greater threat, eg. 30 mm high explosive shells, a reduction in helicopter vulnerability is practically impossible.

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