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ROTOR HEAD/PYLON PARASITE DRAG REDUCTION

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1. INTRODUCTION

A power analysis, for a helicopter in forward flight, shows the power absorbed by the main rotor (Ref. 1-6).

This part of the power is distributed equally among the blade drag power and the fuselage parasite drag power.

The breaking-down of parasite drags reveals the high value of the drag generated by the rotor head assembly (Ref. 2).

Part of this drag varies with the aircraft size. On a light helicopter, such as the SA 341 "GAZELLE", this drag amounts to 40 % of the total parasite drag, but on the SA 330 "PUMA", which is a medium size aircraft, it falls to 30 %.

The present fuselageshaving already an excellent finesse, the rotor head/pylon assembly is the sole part of the helicopter where an attempt for improvement may be fruitful, if the rotor itself is excepted.

The improvements which may be achieved on these assemblies, from the drag aspect, are very spectacular.

This has been revealed during the wind tunnel study made on the SA 341 "GAZELLE" by AEROSPATIALE, Marignane.

It has shown the interest of total fairings on the rotor head.

The results of this study have been materialized by the manufacture of the fairing used for the world speed record broken in 1970 by GAZELLE (Ref. 3).

Therefore, it is no longer necessary to demonstrate the efficiency of these fairings, at least as regard drag reduction. Their main inconvenient remains their overall dimensions and weight, thus we have been led to look for more compact solutions, even partial, and in particular to reduce or cancel the rotor head wake effect causing flow deflections and interactions on the fin-stabilizer-tail rotor assembly and on the main rotor itself.

2. DRAG GAINS DUE TO TOTAL FAIRINGS

2.1. "Record" type fairing

Since the total fairings proved to be very efficient on the "SA 341" helicopter as they reduced the rotor head drag by 47 %, we have adopted the same system on the SA 360 "DAUPHIN".

As far as this aircraft is concerned, the rotor head drag is 47 % of the aircraft total drag.

The research work made on a small scale (1/7.7) model has allowed the development of very interesting total fairings ("record" fairing) since they reduce the parasite drag of the helicopter by 1.15 sq. metre to 0.82 sq.metre, that is a 29 % gain on the total drag or 61 % of the rotor head drag.

The final shapes are shown on figure 1 ; the gain difference with respect to the SA 341 "GAZELLE" results from an optimization of the main rotor shaft fairing lips. During these tests, it was noted that the rotor head fairing, on its own, could reduce only a small part of the rotor head drag. Should the sole rotor head be shrouded, the most important drag reduction would be obtained by reducing the rotor head diameter, but then, there are technological problems the solution of which is not always compatible with aerodynamic imperatives.

Considering the important gains obtained thanks to these total fairings, the analysis was made more deeply by subjecting these same fairings, but at full scale, to wind tunnel tests. As they have not yet been experimented in flight, we cannot make a flight test - wind tunnel correlation as for the 341 GAZELLE.

As the full scale model was particularly large, only a partial model could be subjected to the wind tunnel tests.

The upper part of the aircraft including the rotor head and the engine cowlings, rests upon a flat plate. The interest of these large scale tests is to know accurately the drag of the rotor head components with a realistic Reynolds number and to check that the solutions found on a small scale are still available on the aircraft.

When defining the rotor head drag, we have shown up the importance of the overspeeds due to the fuselage. The influence of the mini-body shape upon the drag values (figure 2) has been figured out by comparing the drags of the small scale partial models. The gains due to the total fairing are 33 % for the partial model fitted on the plate instead of 61 % for a complete model. The minimum difference in gain between the full and 1/7.7 scales can be attributed, for a same installation, to Reynold numbers with different surface conditions (roughness etc...).

The results are summed up in the following table.

Configuration	Scale	Gain
Complete model	1/7.7	61 %
Partial model on mini-body	1/7.7	58 %
Partial model on plate	1/7.7	33 %
Partial model on plate	1	28 %

Drag gains at various scales (rotor head non rotating).

So, the drag gains due to rotor head fairings on aircraft are estimated at 60 %.

Figure 3 gives the drag of the rotor shaft and head components in percentage of the assembly total drag. The important drag of the rotor head upper section, especially the sleeves, can be seen on this figure. This means that it is necessary to shroud the blade sleeve and cuffs to obtain a substantial reduction of the drag. This problem has been solved by placing the upper section in a revolving cover.

Below this cover, the pylon has a streamlined shape and its lips are intended to create (outside the cover) an underspeed area.

We have already appreciated the efficiency of these total fairings, but they complicate the maintenance of the aircraft and increase its weight. Modifications made for simplification and lightening can be detrimental to the initial gains and must be checked by additional tests.

This led us to contemplate other solutions.

2.2. Compact solutions

From a given fuselage, we improved the finesse in order to develop compact solutions. The process followed is shown on figure 4.

As the rotor head is compacted by 30 %, the best position of a rotor head with respect to the fuselage, with the rotor head shrouded or not (diagrams 1 and 2) has been defined for various versions. When the rotor shaft drag is not concerned, an optimum height can be seen on diagram 3. The drag increase beyond $h/R = 0.35$ is due to the drag of the rotor head support rod.

An intermediate fairing enclosing the engines and the transmission assemblies blend a curved section, aft of the rotor head, and a streamlined section forward. The drag of this assembly is reduced further by this fairing.

The gain is 40 % on the total drag, with respect to the basic version and comes down to 35 % when the rotor head is shrouded but not compacted.

This shape corresponds to light aircraft having engines located outside the fuselage.

In the case of heavy aircraft, there is no intermediate fairing separating the rotor head from the fuselage. The rotor head drag can be reduced still more by modifying slightly the shapes of the fuselage but the gains are not so important as those obtained with compact fairings (Ref. 4).

As a general rule, we do not pretend to cancel the drag of the rotor head assembly ; however this drag is always accompanied with a strong wake. The study of drag can be complete only when we know the path followed by the wake and its effect on the rear sections of the helicopter.

3. ANALYSIS OF WAKES

The rotor head wake presence is revealed by changes in the aircraft flying qualities, action on stabilizer or fin and vibrations felt in the cabin.

The first aspect is shown on figure 5, where are given longitudinal stability curves for a helicopter with and without rotor head and also with total fairings. At high negative incidence angles, the wake causes an interaction on the stabilizer and reduces its efficiency. This very conventional aspect is mentioned for reference only and will not be developed.

The vibrations felt have a different origin. They may be divided into two categories :

- Vibrations in $b\Omega$

A wake generated by the forward parts of the aircraft may interfere with the blades and the resulting loads are transmitted to the structure through the rotor shaft and the main gear box mount.

- Low frequency vibrations

Part of the structure vibrates at its natural frequency : it is a vibration directly felt and its origin may be detected rather easily.

In some cases, the impression felt in the cabin is a "seeving" effect, that is a lateral acceleration which may be associated to random loads on the fin. Often, this "seeving" effect is felt more strongly at high speed.

The rotor head wake effects vary from one aircraft to another and on a same helicopter depend on the flying attitude.

The first studies on wake have been made by visualization, mainly by wool tufts, but they did not allow its accurate location nor, its quantification.

3.1. Determination of the average velocities in the wake

To know the effect of various fairings on the wakes, a curve of the velocities, aft of a rotor head, has been plotted. These tests have been conducted on the mock-up shown in figure 2.

Velocities were determined from the indications given by a pitot head located behind the mock-up.

The curves, shown in figure 6, give the velocity levels in a plane perpendicular to the aircraft centre line for various versions of fairings.

It can be seen that the spinner (spherical cover fitted on the hub) changes the wake distribution. It reduces the under-speed condition in the aircraft centre plane, but, in the average, the rotor head "image" is not changed, as the spinner does not modify the rotor head drag. The spinner accelerates the flow, the result being that part of the wake receives new energy while the wake is deflected downwards.

The interest of installing a spinner has been confirmed in flight. On the SA 360 "DAUPHIN", the stabilizer vibrations have been eliminated by the wake deflection.

In the case of total fairings, the under-speed condition is reduced appreciably and the wake tends to rise.

The determination of velocities in the wake shows the flow trend. Thus, the location of particularly perturbed areas are known but there is no information on the dynamic phenomena occurring on the fin-stabilizer assembly. The velocity determination is a time-consuming process as a large number of test points are required to plot the velocity chart.

3.2. Analysis of wakes by pressure determination

Instead of following the wake in space from the rotor head, it is possible to place a total pressure sensor on the aircraft section under study and by analyzing the signal generated by the sensor, determine the wake impact.

On figure 7, the total pressure change versus time is shown. Three conditions may be distinguished :

- outside the wake, the signal is stable
- at the boundary, sudden random pressure variations, separated by periods of stability
- in the wake, strongly perturbed signal the spectral analysis of which does not reveal any predominant frequency. Further, the signal amplitude shows the wake turbulent condition in the flow direction and, therefore, may be used to quantify it.

The experimentation has been conducted on a small scale mock-up (fig. 8), equipped with a motor to drive the rotor head. Four pitot heads are installed on the rear sections.

Through the signal amplitude variation versus the aircraft incidence angle, it is possible to locate, at each pitot head position, the wake of the various components.

On the basic aircraft (without fairing), the rotor shaft and head wakes can be seen, there are the peaks appearing on the curves. By comparing the pitot head angular positions and the aircraft incidence angles, it is possible to determined the wake location.

For example, at $\alpha s = 0°$, the rotor head wake is concentrated at the sensor n° 3 and the pylon wake is located at the tail boom/fin junction.

It is difficult to be more accurate in the interpretation of the results, at least for the angular locations, due to the interactions between the aircraft shape and the wake. The fuselage creates flow deflections depending on its attitude.

This experimentation, which was conducted with the rotor head at rest, has shown that it was possible to determine the wake of the various rotor head components. To be closer to the reality, the rotor head has been set in rotation (fig. 9).

The various wakes are still visible but at different positions and levels.

The effect of partial or total fairings at a given location on the aircraft can be seen. On the figure, it is the sensor located at mid-fin.

Figure 9a shows that a total fairing, such as defined in paragraph 2.1, moves the peaks towards the negative incidence angles and attenuates them. It is mainly the rotor pylon wake which is affected, at least at this level. As high speed flights are made at low negative incidence angles (0 to -5°, depending on the location of the aircraft centre of gravity), it may be seen that the wake amplitude, according to the criteria selected, is practically divided in two at the fin centre section.

For partial fairings, the conclusions (fig. 9b) are different. So for a fairing made of flattened cylindrical cuffs and a spinner the rotor head and pylon wakes are coïnciding and raised towards the fin tip.

Thus, it is possible to locate and quantify a wake through a simple process.

At its boundary, it has been noted that the dynamic pressure shows sudden variations. This strenghten the assumption that there is a relation of cause to effect between the fin penetration into the wake boundary and the "seeving" motion felt in the cabin.

4. CONCLUSIONS

Wind tunnel tests are a convenient "tool" for analysing the helicopter drag, particularly that of the rotor head/pylon assembly and studying fairings for the latter.

For an existing helicopter, the SA 360 "DAUPHIN", we have designed rotor head fairings capable of reducing its drag by nearly 60 % (that is 29 % of the aircraft CxS) ; these gains being confirmed by comparison tests at various scales.

By combining, at the beginning of the design stage, the technological and aerodynamic requirements, it is possible to reduce still further the aircraft drag (gain of 40 % on the total drag).

The detailled analysis of wakes has shown the interest of partial fairings, the effect of which is to relocate the wakes and reduce their impact on the aircraft rear section.

We have developed a mean to study the rotor head wake (variation of total pressure VS. time) which seems promising as the results of these tests are correlated with the pilots' feelings in flight.

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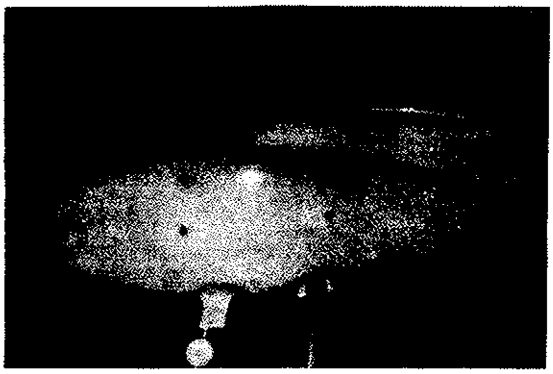
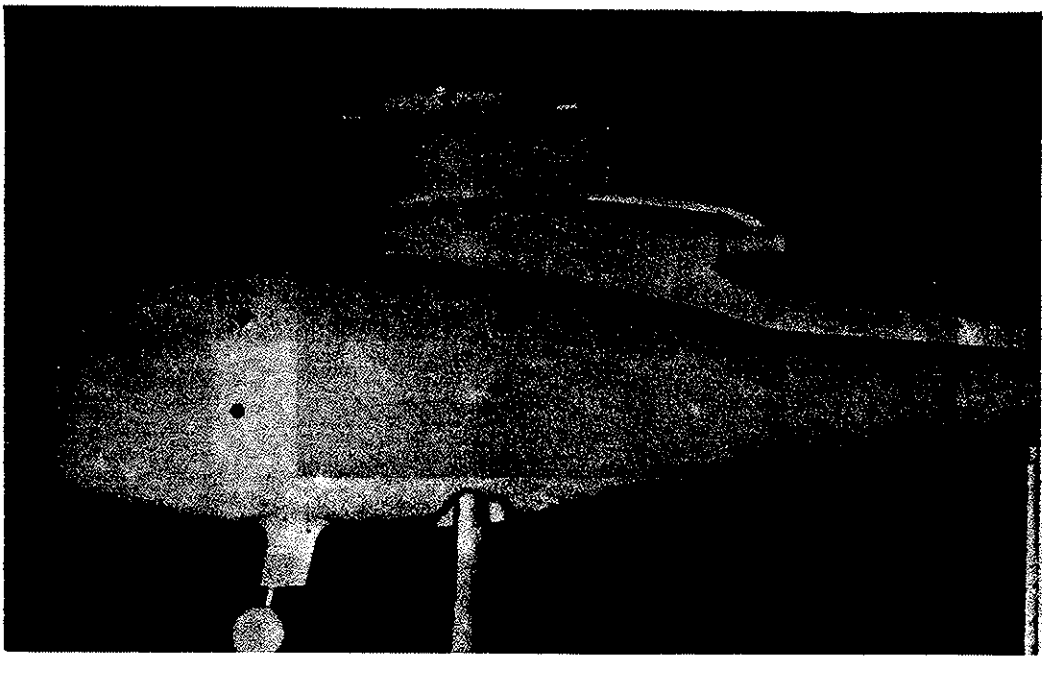
NOTATIONS

Vo	Forward speed (m/sec.)
V	Local speed (m/sec.)
b	Number of blades
Ω	Rotational speed (rd/sec.)
CxS	Parasite drag (m2)
Cm	Pitching moment coefficient = $\dfrac{M}{\frac{1}{2}\rho S V^2}$
α_S	Aircraft incidence angle

$CxS = 1.15\ m^2$



$CxS = 0.61\ m^2$

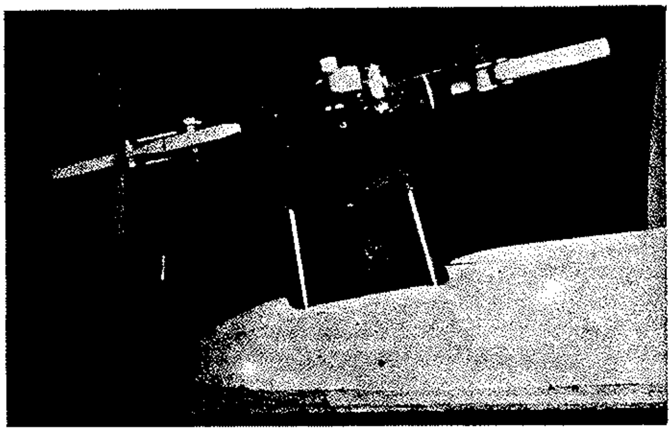


$CxS = 0.82\ m^2$

Fig 1 Drag reduction produced by total fairings

1/7.7 scale
with flat plate

1/7.7 scale
with mini body



1/1 scale
without fairing
with flat plate

1/1 scale
with fairings
with flat plate

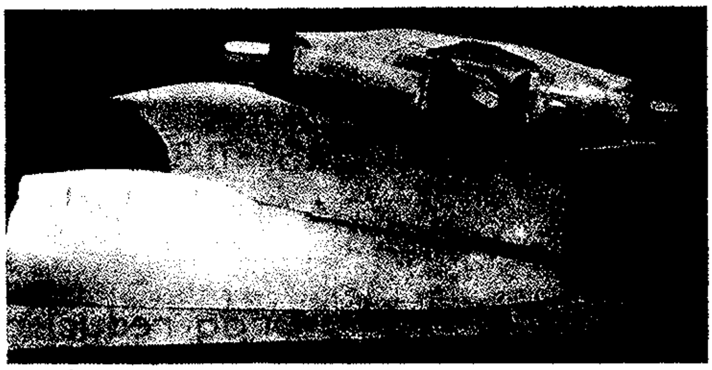
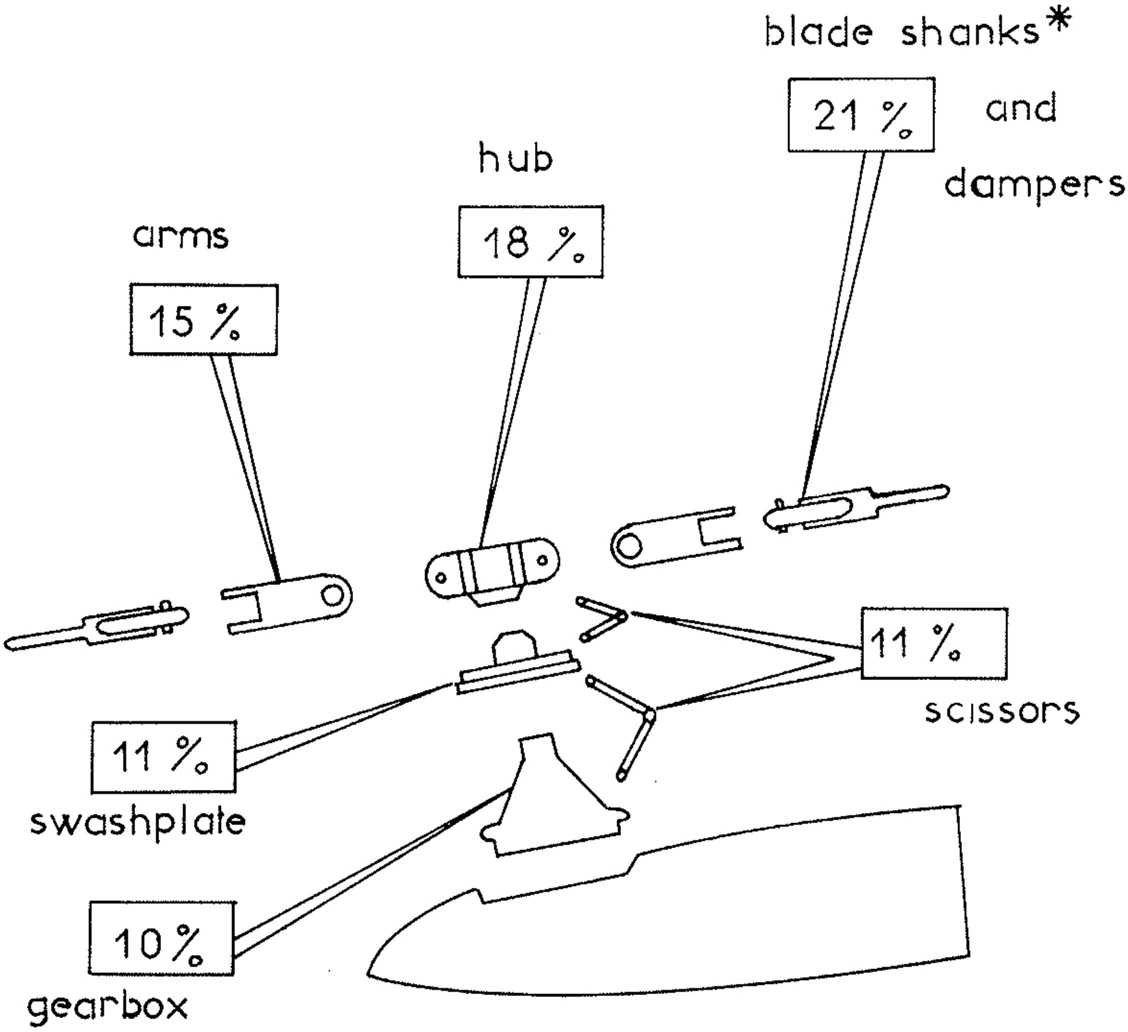


Fig 2 Drag at various scales



* collective pitch at forward speed 12 %

100% = total rotor head

Fig 3 · Relative drag of components

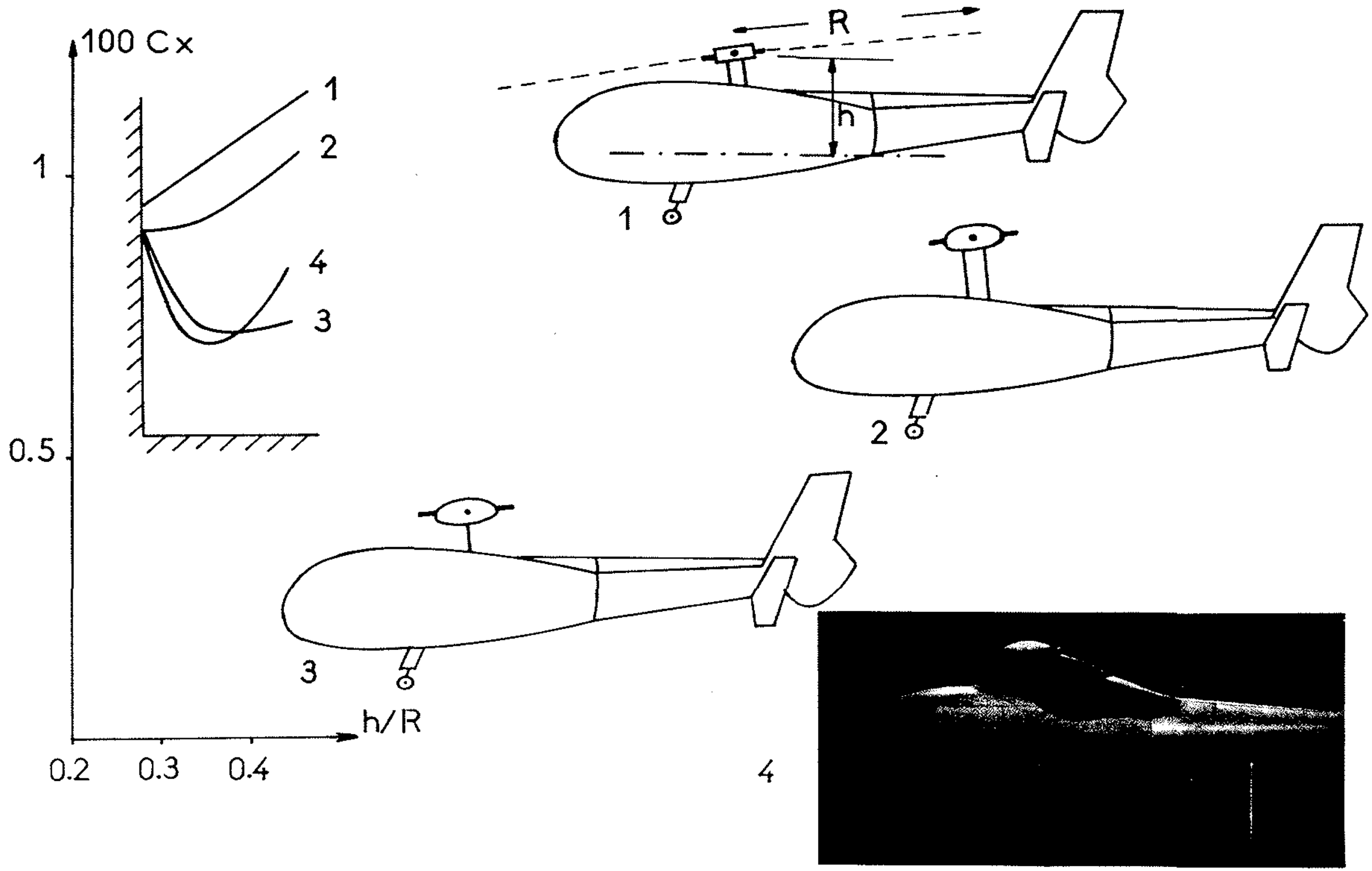


Fig 4 compact shapes

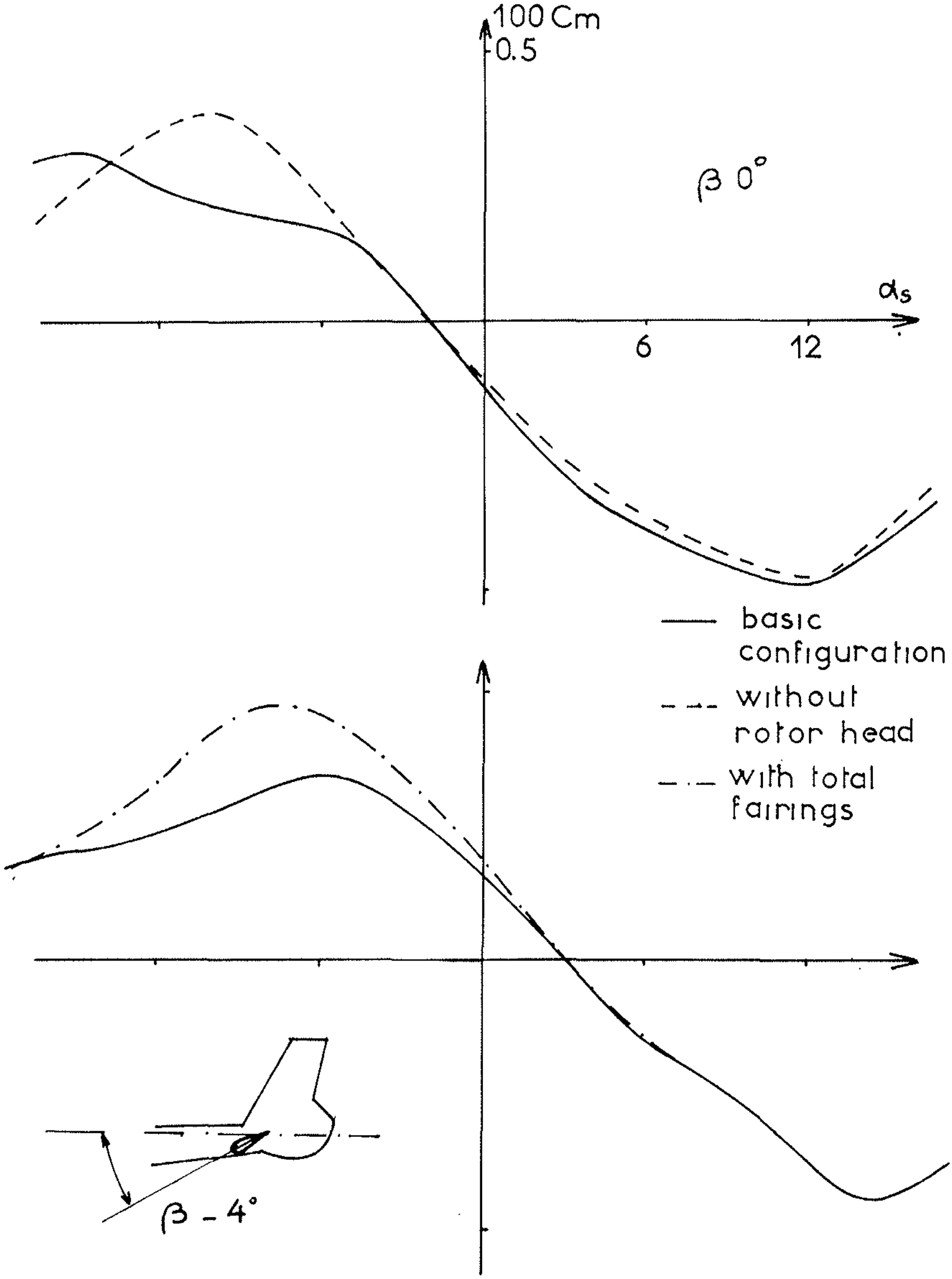


Fig 5 wake effect on pitching moment

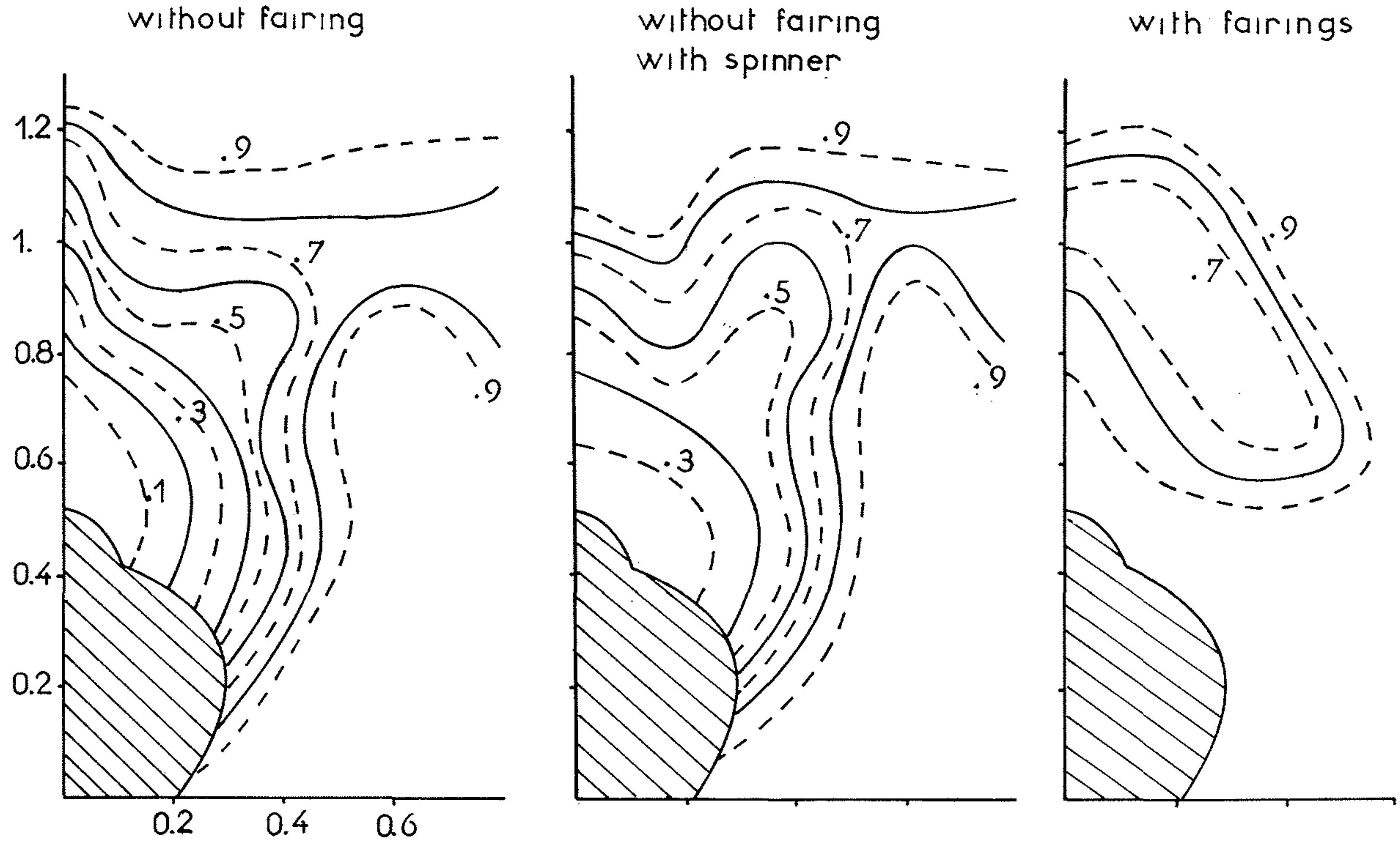


Fig 6 Measure of speed — iso V/Vo

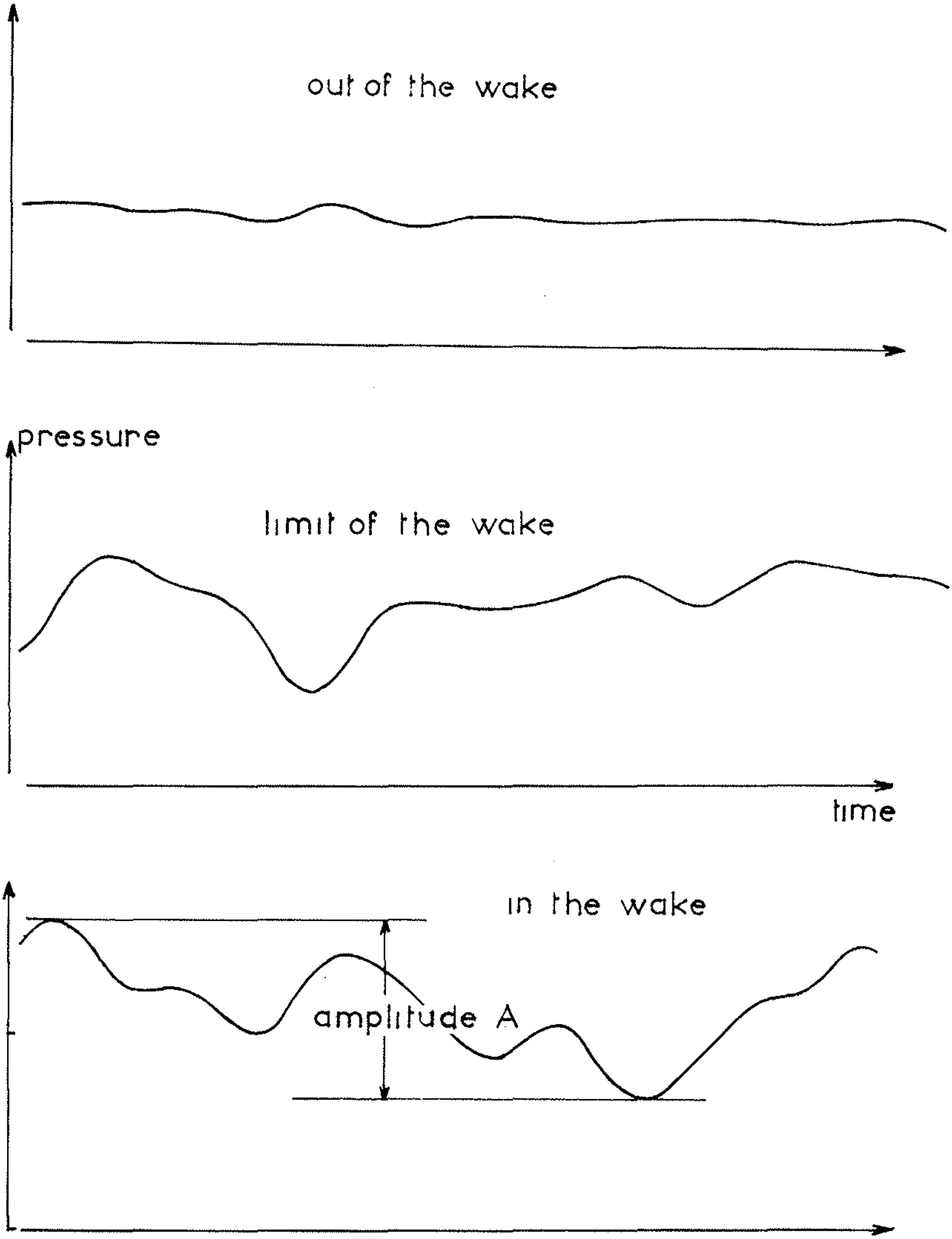


Fig 7 wake analysis by measure of pressure

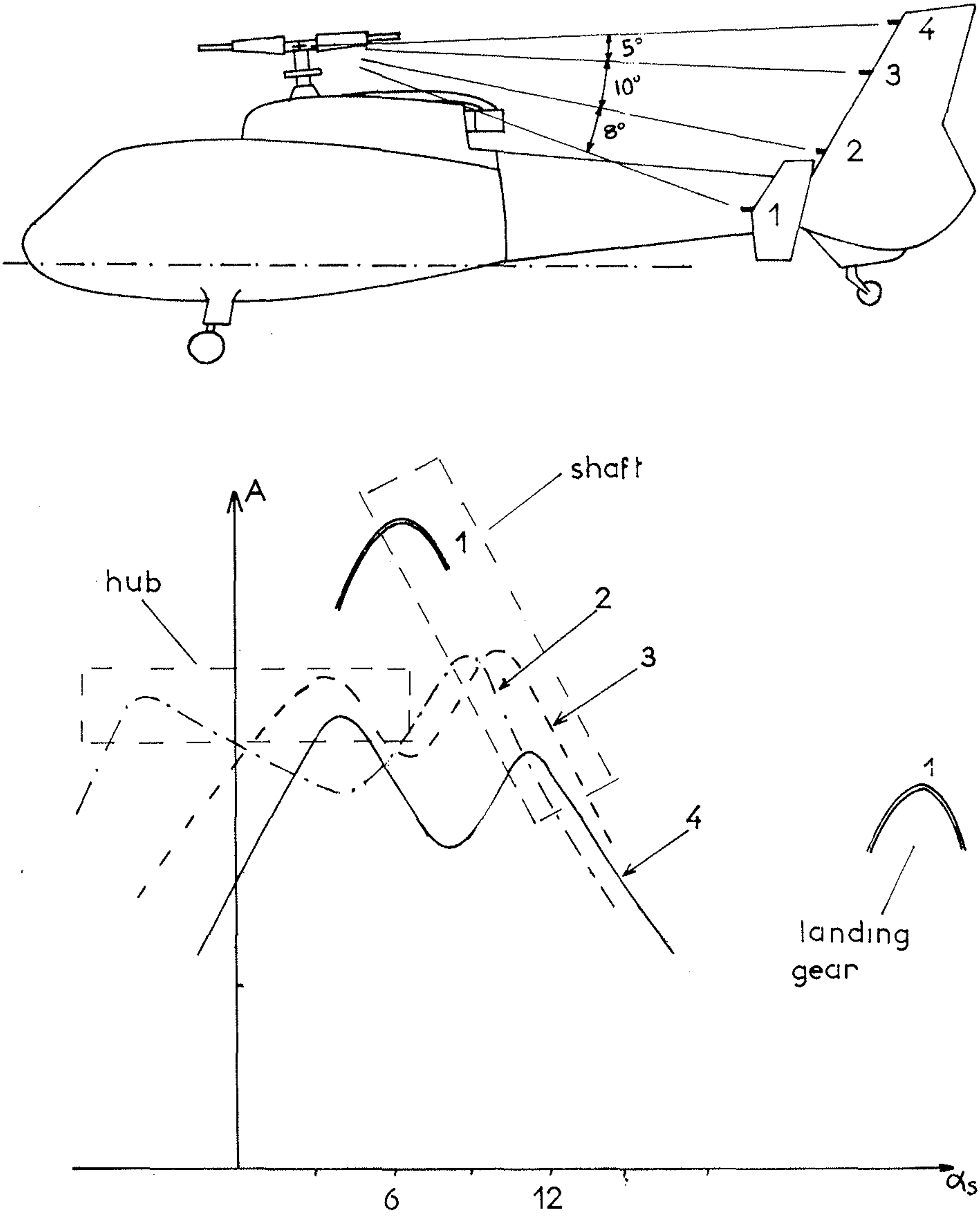


Fig 8 rotor head wake at rest

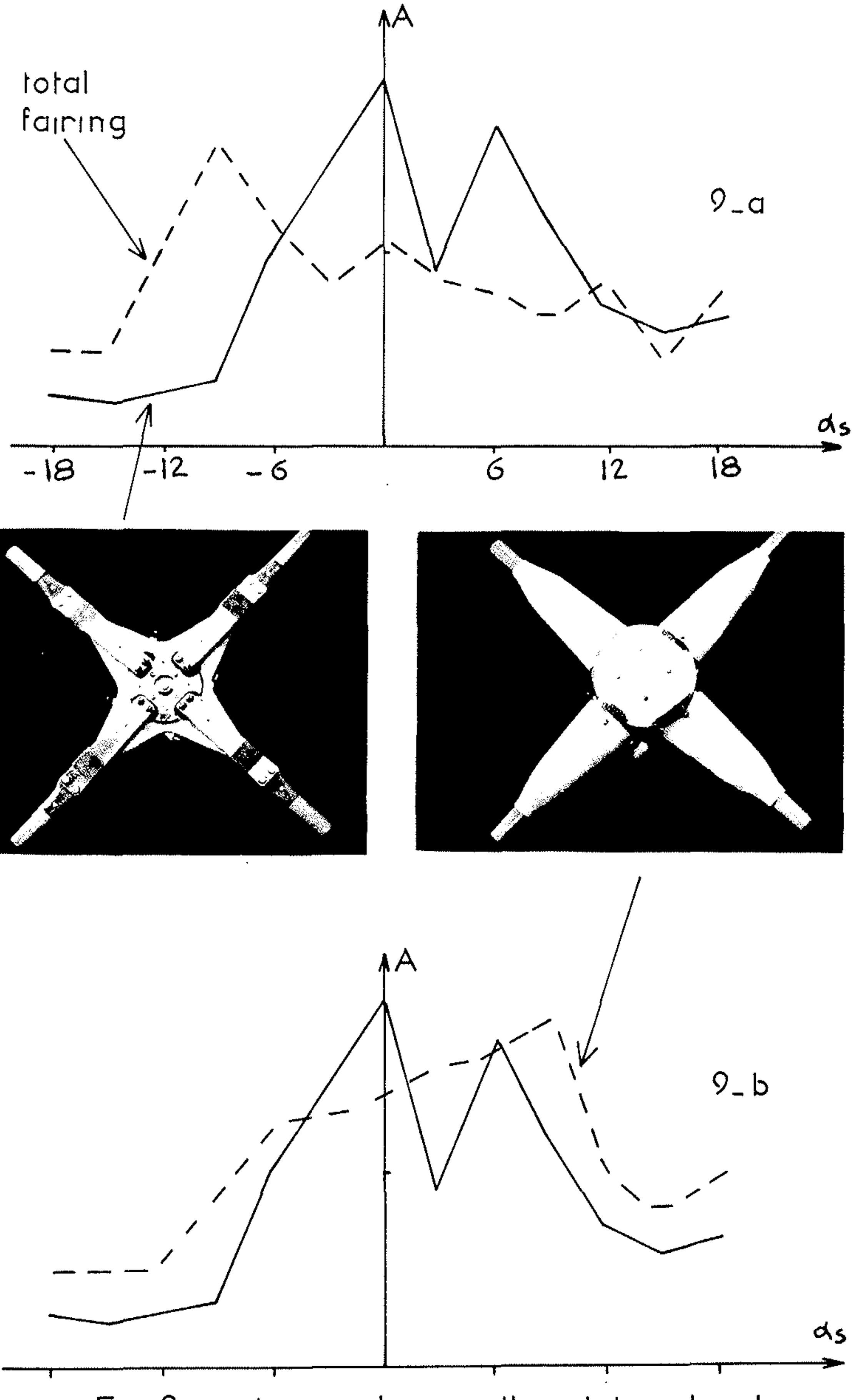


Fig 9 wake analysis with rotating head