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CURRENT STATE-OF-THE-ART OF TsAGI STUDIES IN THE AREA OF HELICOPTER AERODYNAMICS

BY

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Current State-of-the-Art of TsAGI Studies in the Area of Helicopter Aerodynamics.

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Abstract.

The paper reviews the basic works of TsAGI aimed at providing high-level aerodynamic perfection of helicopters.

Introduction.

Traditionally the activities of TsAGI in the area of helicopters, as it is know, include:

-calculational/theoretical and experimental studies of helicopter aerodynamics;

-calculational/theoretical and experimental studies of helicopter flight dynamics using flight simulators;

-calculational and experimental studies of helicopter strength and structure dynamics;

-studies of markets and prospects of helicopter development.

In the area of helicopter aerodynamics the following basic trends are developing (Fig.1):

-investigation and development of aerodynamic and aeroelastic configurations of main rotor blades;

-investigation and finishing of aerodynamic configurations of helicopter bodies:

-investigation and development of aerodynamic configurations of control devices for helicopter of various configurations;

-examination of problems of helicopter units and elements interference.

Helicopter aerodynamic design system

Evolution and practical use of a helicopter aerodynamic design system as a constituent of a more general system of helicopter development has become one of the major trends of TsAGI's activities.

The aerodynamic design system was first used in the process of development of the heavy transport helicopter Mi-26. The results of the joint venture of TsAGI and the M.L. Mil Design Bureau turned out to be of considerable value. The Mi-26 flight tests have shown that the highest level of lift-to-drag ratio (L/De=4.3) and the highest level of fuel efficiency ($0.75\frac{kg_{fuel}}{T\cdot km}$) were achieved at cruise flight mode. There are still record features for transport helicopters with rear fuselage cargo doors.

The aerodynamic design at TsAGI is presently performed on the basis of an interactive hierarchical system of theoretical and experimental methods of structures, etc., enabling with the use of a structured succession of iterative procedures to find optimized solutions in compliance with the helicopter objective function and the resulting objective functions of its elements (rotor, fuselage, etc.).

The objective function contains criteria of effectiveness and constraints that correspond to the helicopter purpose and conditions of its practical use.

Rotor aerodynamic design system

An important element of the helicopter design system is the rotor aerodynamic design system. This system comprises blocks of programs to compute flows over blade airfoils and rotor aerodynamic, aeroelastisitic and acoustic characteristics (Fig. 2).

The block of the programs to compute the rotor performance uses theories of various level of complexity:

-vortex disk theory with a "rigid" vortex wake using simple analytical algorithms;

-blade theory with a "rigid" vortex wake with non-deformable or elastic blades for any type of fastening the blade to the hub;

-blade theory with a free vortex wake.

In developing the algorithms of computation great attention was focused on the issue of reducing the computer-consumed time. Thus, for example, it became possible to establish a linear relation between circulation along lifting vortex line and elastic deformations in the theory of a rotor with a "rigid" vortex wake on the basis of the analysis of full non-linear equations of blade motion enabling to provide the labour consummation close to the one of calculating the rotor with non-deformable blades.

The rotor computation based on the full non-linear equations of elastic blade motion is used at the stage of developing aeroelastic blade configurations.

In the blade theory of a rotor with a free vortex wake an effective iteration procedure with an original approximation in the form of "rigid" vortex wake is used instead of an ordinary calculation of motion of elements of free vortices in time that enabled to solve this problem using an ordinary PC (Fig. 3 and 4).

One of the objectives of using this theory is investigation of complicated processes of flow around the blade tip part.

Consideration of unsteadiness effects on the aerodynamic loading of blade airfoils is an important and difficult issue of the rotor aerodynamics.

Special experimental equipment has been used for a number of years to investigate

this problem in the wind and water tunnels of TsAGI. This equipment consisted of systems of measuring the distribution of pressure over the blade surface and also forces and moments on narrow blade segments with the use of strain-gauge balances.

Apart from that is a system of exciting the blade oscillations from complex polyharmonic laws by summing any three from the eight harmonics of the oscillations. Visualization of the unsteady flow over an airfoil is made using various techniques, including a high accuracy water tunnel optical method. Investigations of unsteady flow around oscillating airfoils are performed at TsAGI at M<=0.8.

Analysis of the result has revealed that the use of only experimental characteristics of oscillating airfoils at a constant velocity of the undisturbed flow is not sufficient for the complete description of complex processes of a real flow round a blade airfoil under conditions of a dynamic stall.

Therefore TsAGI has concentrated on the study of unsteady feature of airfoils on the basis of measuring the instantaneous pressure on the blade of rotor models in wind tunnels.

The studies have shown that the primary factors defining the change of blade characteristics at a dynamic stall are:

-blade loading Cт/б;

-advance ratio μ;

-rotor effective angle of attack α_s (over the plane of blade tip).

-relative radius of the blade section $\bar{r}$.

Further on, approximate relation between airfoil lift coefficients and its longitudinal moment was built using these parameter (Fig.5-6).

The flight tests at the Flight Research Institute (LII) in regard to measuring the instantaneous pressures on a full-scale rotor blade of a Mi-6 have shown that the above relation is realistic of the dynamic stall processes occurring on the full- scale rotor despite essential differences in the numbers of M and Re and the airfoil geometry (Fig.7-8).

The reason of this phenomenon lies in the fact that the decisive affect on the airfoil at a dynamic stall is produced by a system of vortices formed near the airfoil in the transonic flow, i.e. dynamic component of the fluid motion equations. The role and the Mach number effect is weakened due to a considerable change of the airfoil's liquid contour shape. The approach proposed gave a simple algorithm to estimate the values to be added to the static characteristics CL and Cm in order to approximately account for the dynamic stall effects.

The block of the programs to design the blade airfoils contains:

-a method to calculate an unsteady potential flow round an airfoil under arbitrary laws of variation in time of angle of attack and velocity of the undisturbed flow at small number of M;

-a method to calculate a transonic flow about an airfoil with a simultaneous calculation of elastic deformations of the airfoil's tail part;

-a method to optimize the airfoil geometry in accordance with its objective function.

Consideration of elastic deformations appeared to be of importance for in a transonic flow small elastic deformations are capable to strongly affect the airfoil performance.

An element of the procedure of optimizing the airfoil's contour in accordance with its objective function is shown in. It is seen that an airfoil with a wave shock is transformed into a shockless low drag airfoil.

The rotor aerodynamic design system contains procedures of optimizing the blade aeroelastic configuration taking into account the fuselage inductive effect on the flow over the blade. This account leads to some correction of the geometric parameters of the blade stem part.

The rotor aerodynamic design system also includes:

1)test of airfoils in the T-106 wind tunnel;

2)test of oscillating airfoils in the SVS-2 wind tunnel at Mach number up to 0.8;

3)test of rotor models (with rotor diameters up to 2.5m) of one-rotor and any two-rotor helicopters as well as any type of steering systems;

4)tests of large-scale 4-5m diameter rotor modes at full-scale Mach numbers in the T-104 wind tunnel (Fig.9);

5)tests of full-scale rotors with diameters up to 17m in the T-101 wind tunnel (Fig.10).

The experimental facilities is equipped with up-to-date equipment, measuring and computation systems allowing for an automated definition of aerodynamic, aeroelastic and acoustic characteristics of rotors. The full-scale rotors of Ka-50 and Ka-62 helicopters have gone through complete set of such tests.

The current state-of-art of works to develop aerodynamic airfoils is presented in Fig.11. Correctness of comparison of various airfoils if due to the standard methodology of tests in the T-106 wind tunnel of TsAGI. A peculiar feature of TsAGI's airfoils is a smaller value of the longitudinal moment in the transonic flow zone what is extremely important to minimize the variable part of the hinge moment (Fig.12).

The progress in rotor aerodynamics is demonstrated in Fig.13-14 showing test results of large-scale rotor models.

The latest Russian helicopters Ka-50, Mi-28, Ka-62, Mi-38 and others have improved aerodynamic rotor configurations.

Fuselage aerodynamics.

The fuselage aerodynamic design if based on calculating the potential unseparated flow and separated flow with present streamlines of separation.

An important tool of developing improved fuselage configuration at TsAGI is experiment, that is usually realized with design bureau. These experiments are carried out both on isolated fuselage models and on models with operating rotors.

Fig. 15 shows progress in the fuselage drag of heavy transport helicopters with a rear cargo door. The fuselage drag of the Mi-38 is twice lower than that of the Mi-8, its prototype.

To achieve this an extensive program of experimental studies has been fulfilled investigating a number of alternative of solutions.

Considerable progress in the direction has been obtained for the Ka-62 helicopter (Fig.16). Comparison test of fuselage models of the helicopter and the Sikorsky S-76 (as prototype) have shown that the fuselage drag of the Ka-62 may be 25% less than of the S-76. This result was obtained also on the basis of a great number of tests of various alternative variants of the fuselage aerodynamic configurations.

Of special attention at TsAGI is the problem of local aerodynamics of fuselages. As an example of this activity may serve investigations on drag reduction of fuselages of the Mi-8, Mi-38 helicopters by aerodynamic improvements of the body near the exhaust manifolds (Fig.17).

A noticeable effect is achieved by a method of suppressing the diffuser-induced separations by air bleeding from the engine cooling system into the separation area (Fig.18). The fuselage drag in this case is reduced considerably (Fig.19).

Of great use for the investigations on fuselage aerodynamic improvements are full-scale tests of fuselages in the T-101 wind tunnel of TsAGI.

Great attention was paid to the issue of studying the TsAGI's most recent jet system with an adjustable thrust vector of the tail nozzle and a slotted system of super circulation where efficient progress had also been made in the area of drag reduction (Fig.20).

Conclusions.

TsAGI possesses a multi-year experience of studies in the field of aerodynamics and dynamics of helicopters that had found its implementation in national helicopters and in some joint design with foreign countries.

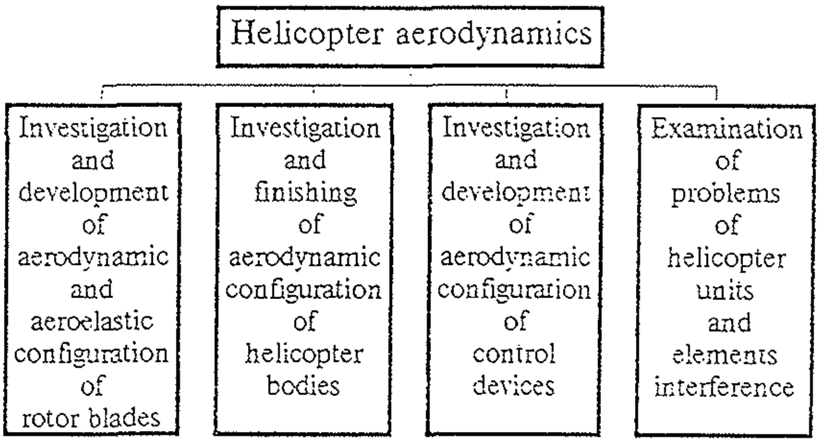

Helicopter aerodynamics
Investigation and development of aerodynamic and aeroelastic configuration of rotor blades
Investigation and finishing of aerodynamic configuration of helicopter bodies
Investigation and development of aerodynamic configuration of control devices
Examination of problems of helicopter units and elements interference

Fig. 1

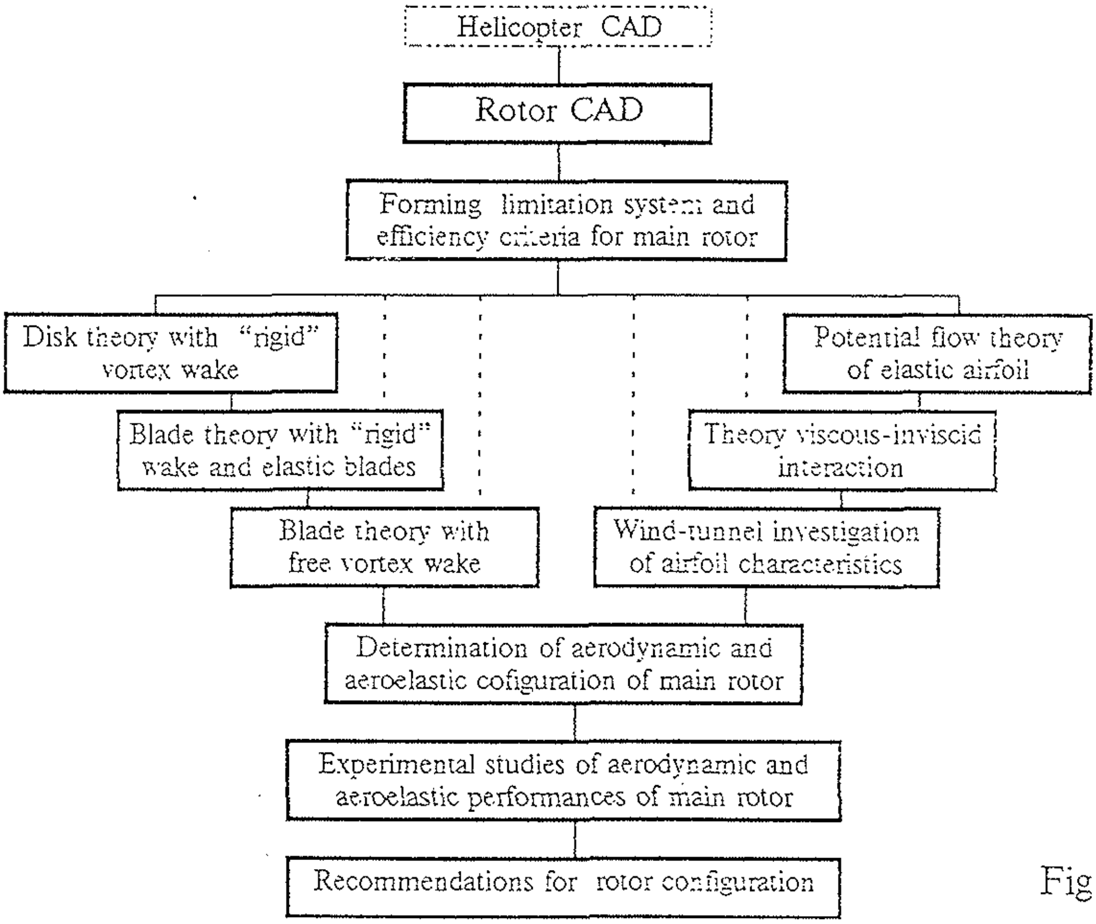

Helicopter CAD
Rotor CAD
Forming limitation system and efficiency criteria for main rotor
Disk theory with "rigid" vortex wake
Blade theory with "rigid" wake and elastic blades
Blade theory with free vortex wake
Potential flow theory of elastic airfoil
Theory viscous-inviscid interaction
Wind-tunnel investigation of airfoil characteristics
Determination of aerodynamic and aeroelastic cofiguration of main rotor
Experimental studies of aerodynamic and aeroelastic performances of main rotor
Recommendations for rotor configuration

Fig. 2

Tip vortexes of rotor blades.

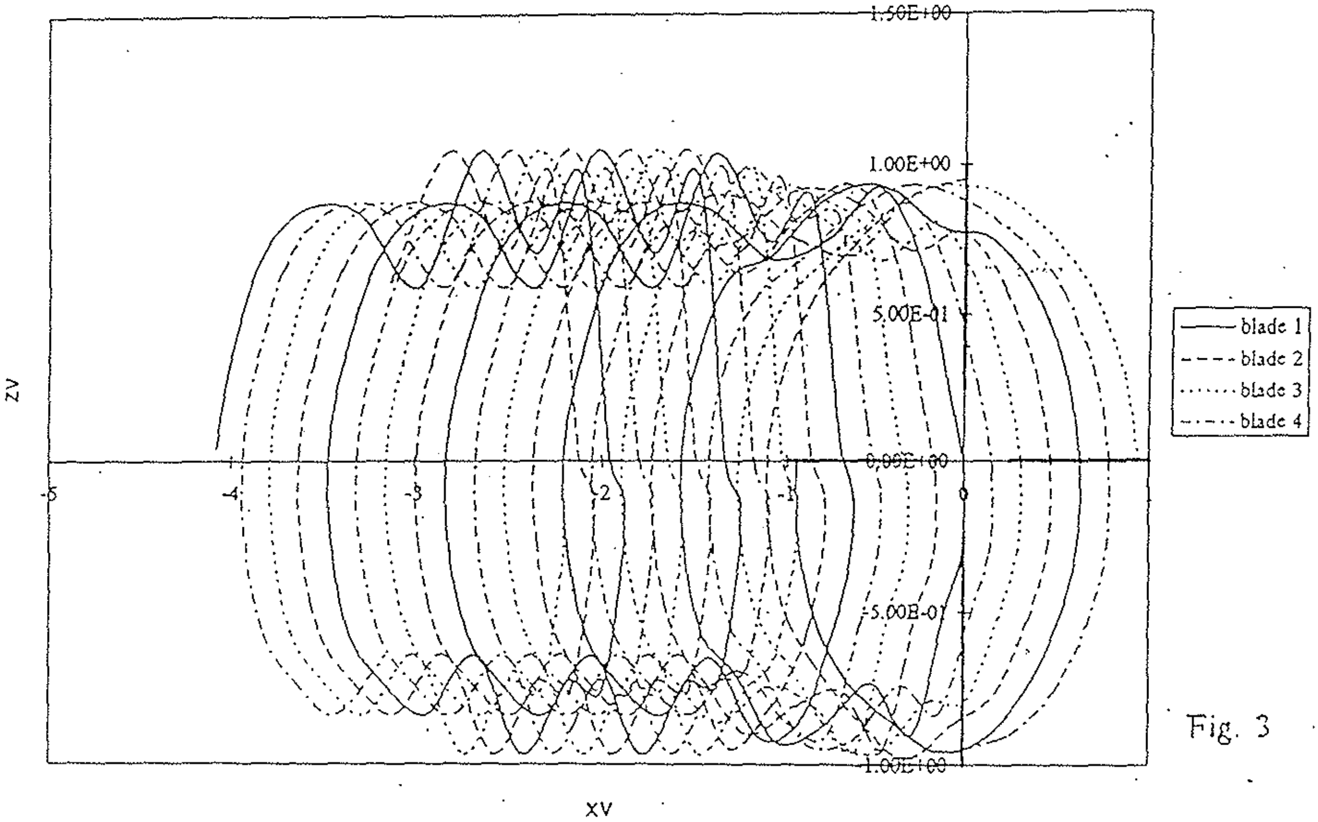


Fig. 3

Distribution of induced velocity along rotor blade.

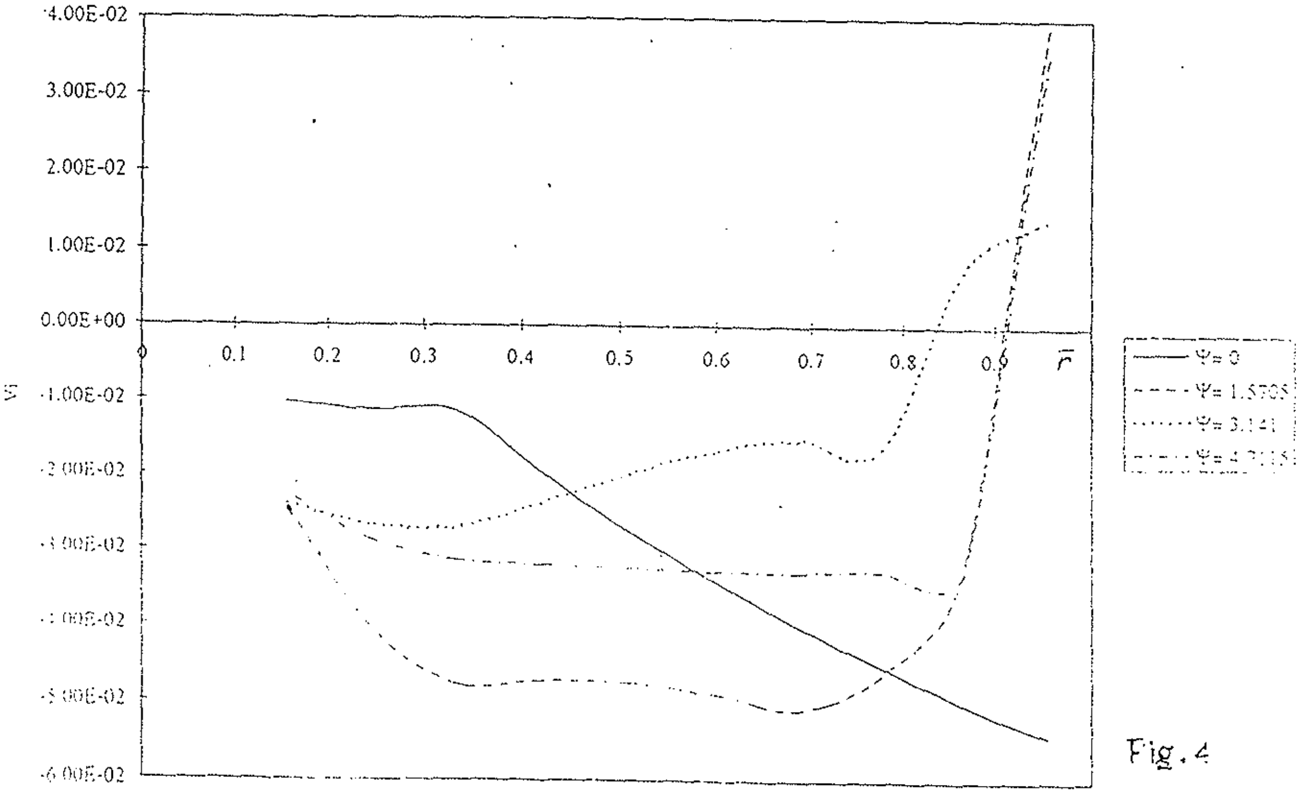


Fig. 4

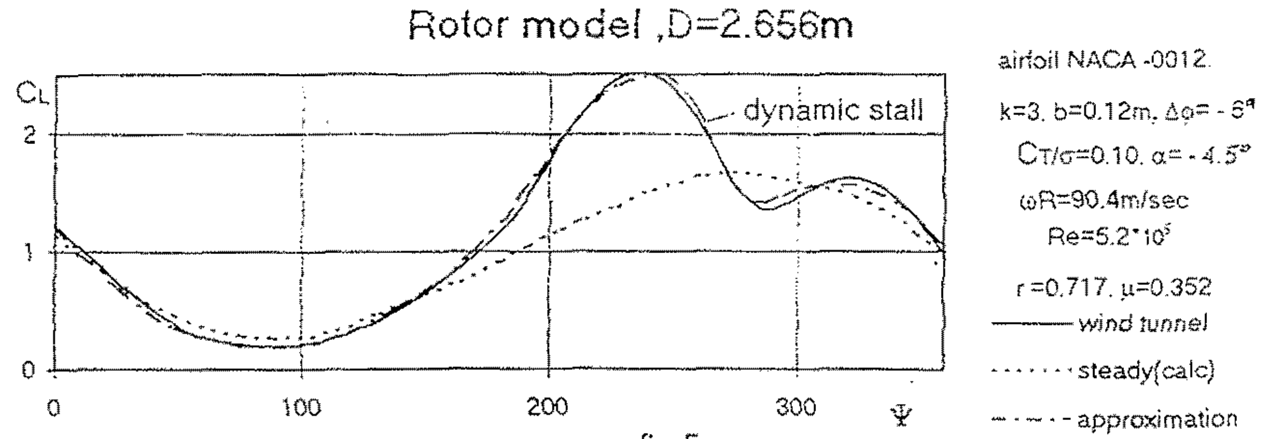


fig.5

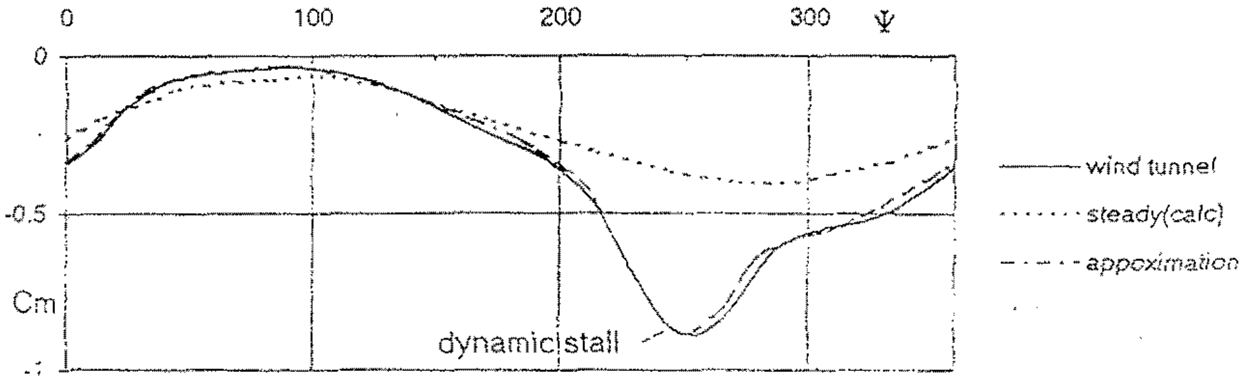


fig.6

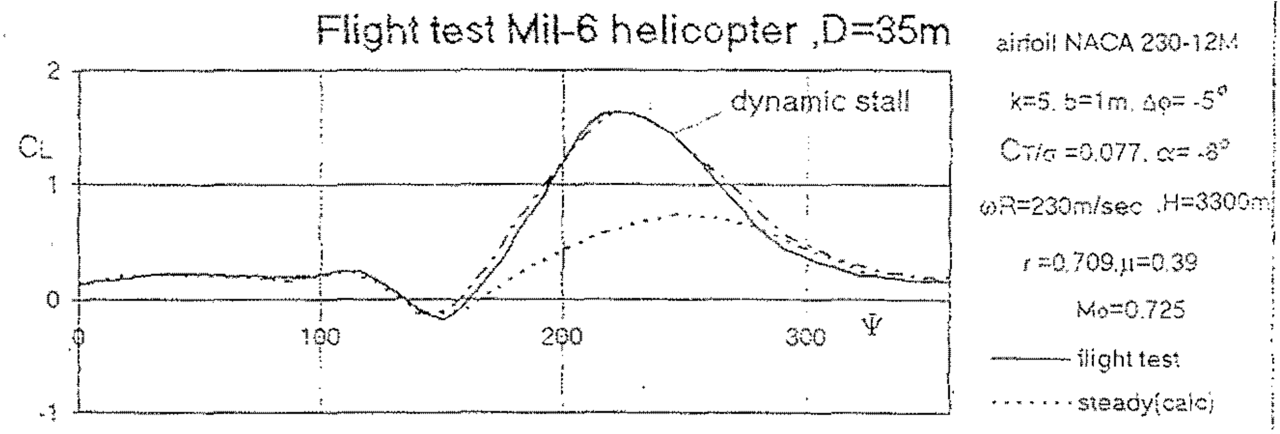


fig.7

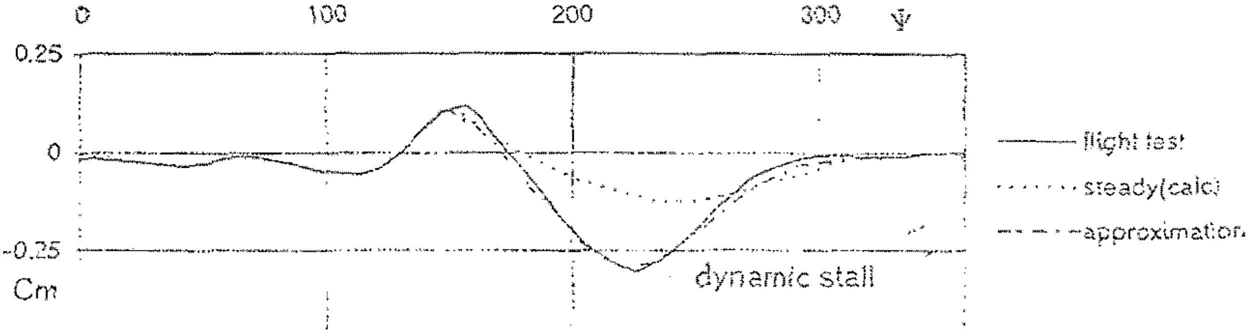


fig.8

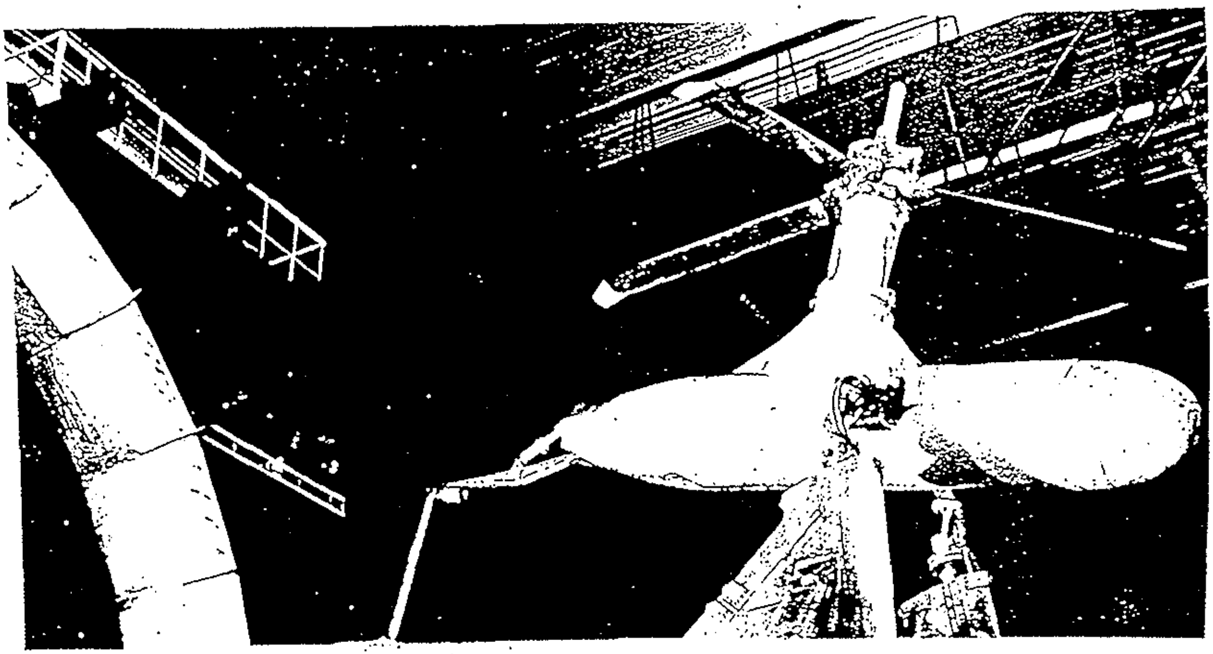


Fig. 9

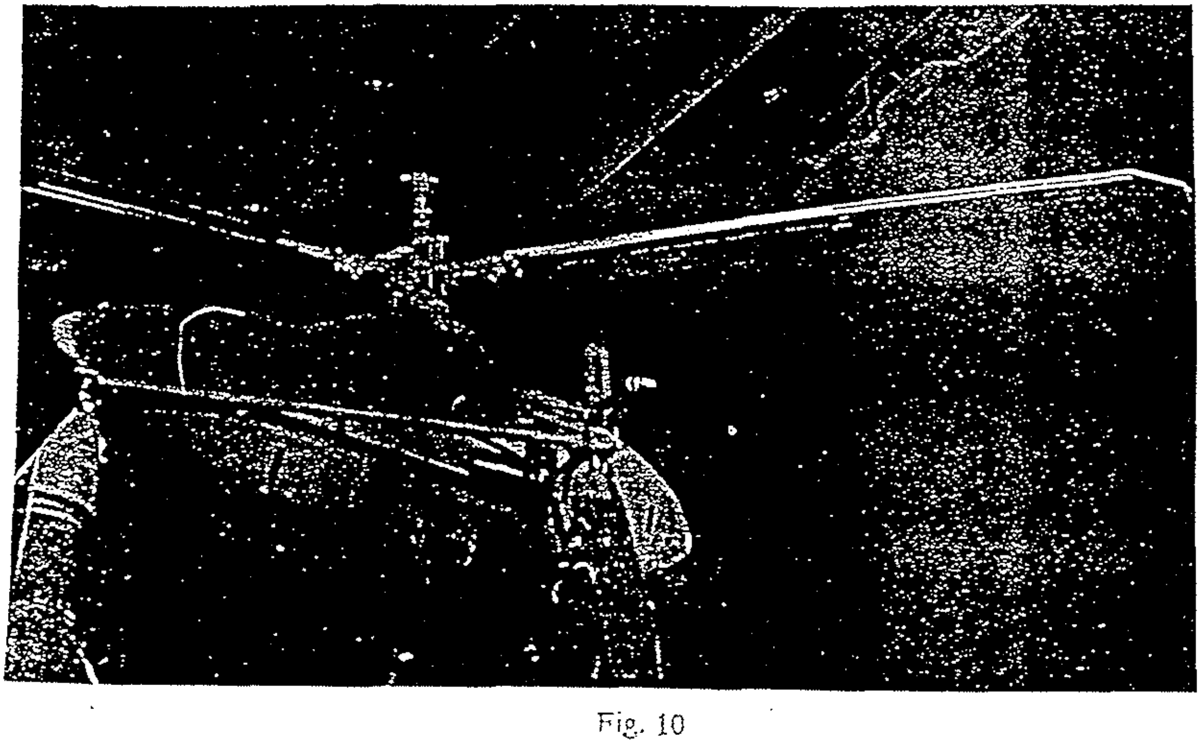


Fig. 10

HELICOPTER AIRFOIL EFFICIENCY

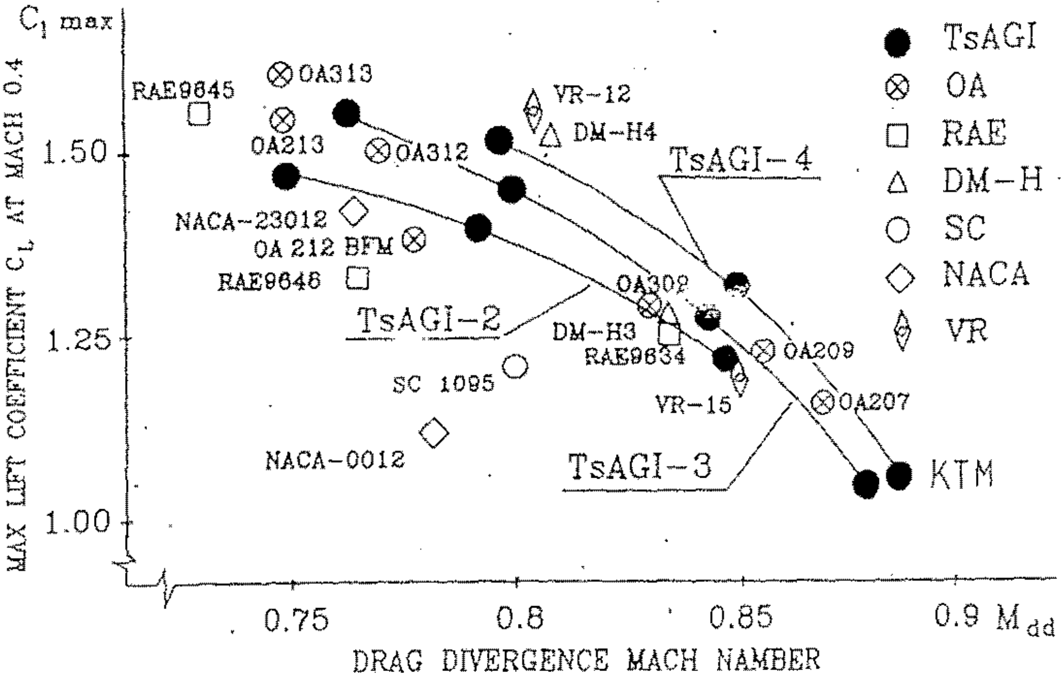


Fig.11

AIRFOILS FOR BLADE TIP

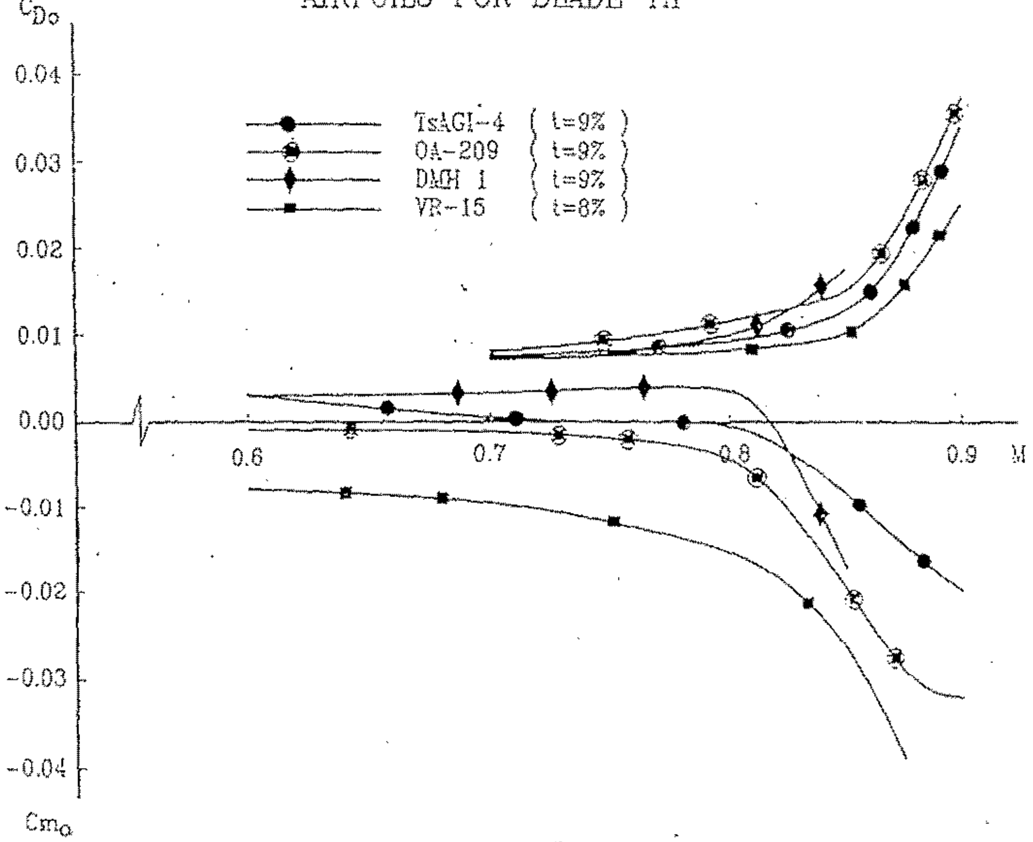
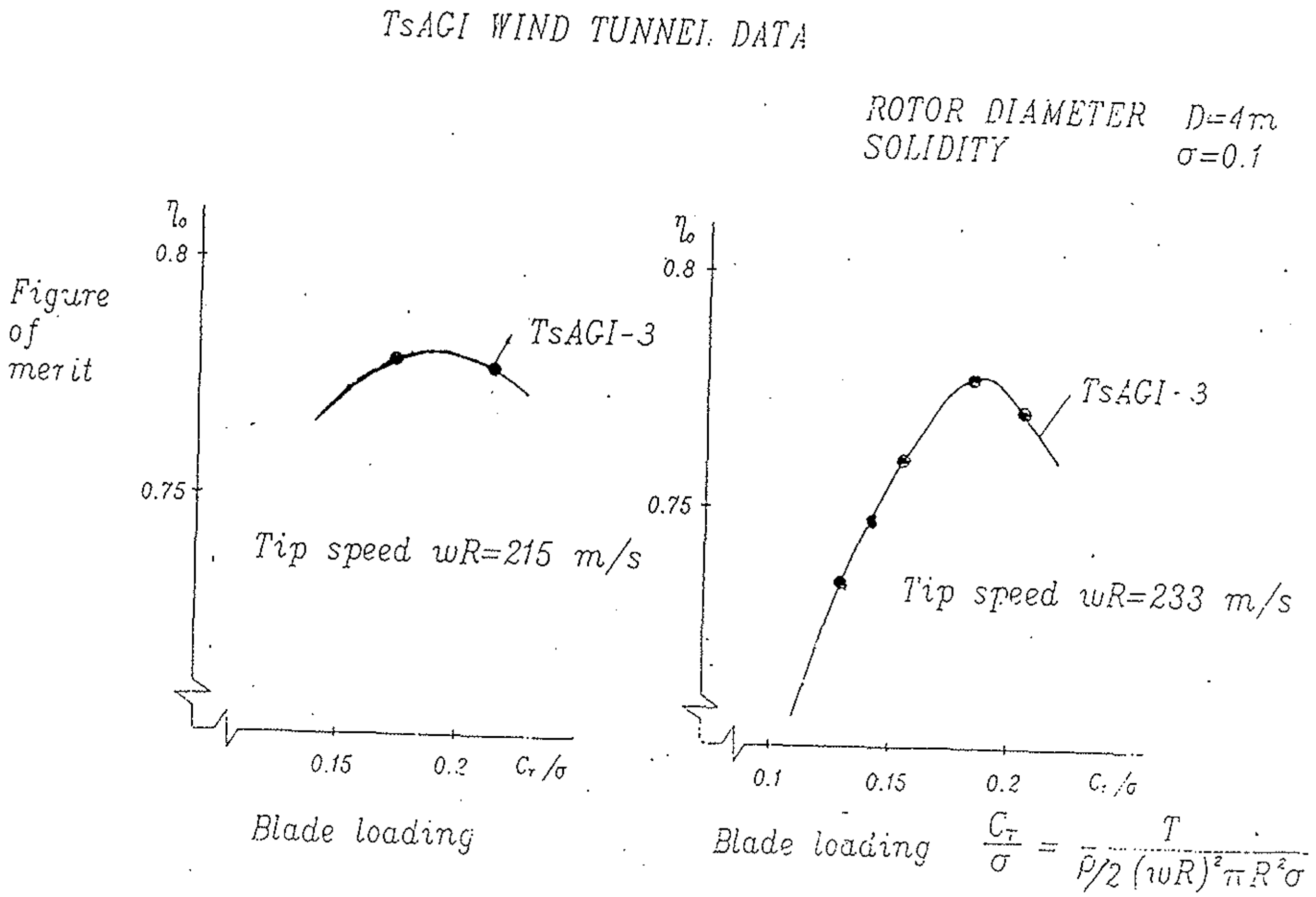


Fig.12



$$\frac{C_T}{\sigma} = \frac{T}{\rho/2\,(wR)^2 \pi R^2 \sigma}$$

Fig.13

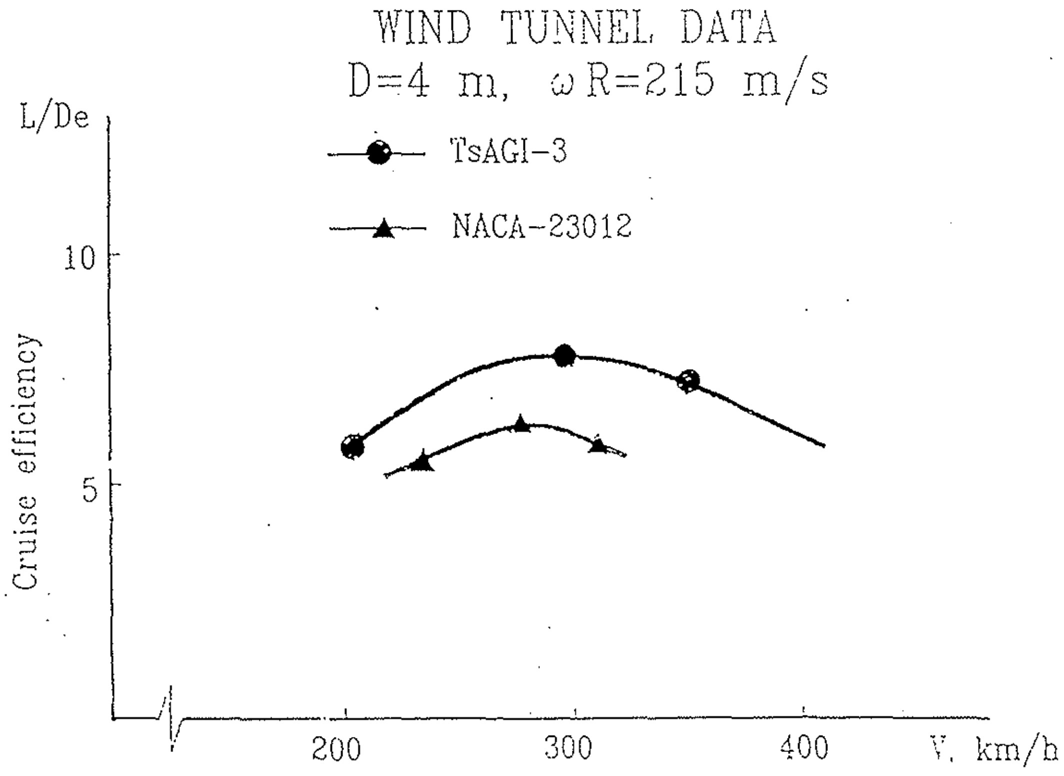
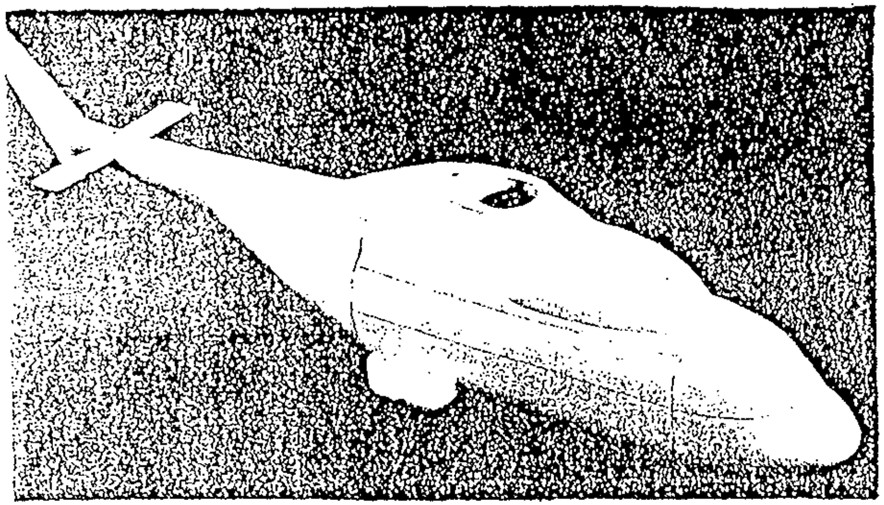


Fig.14



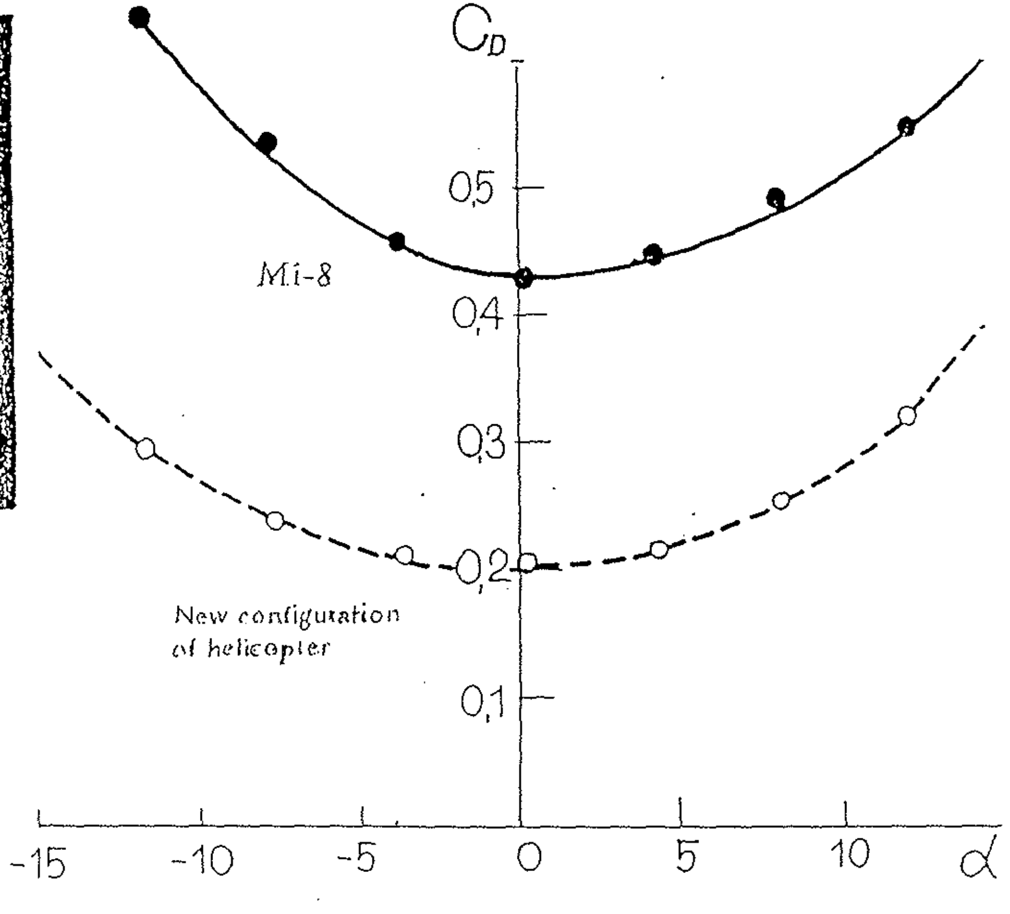

C_D
0,5
0,4
0,3
0,2
0,1
Mi-8
New configuration
of helicopter
-15
-10
-5
0
5
10
α
Angle of attack

Fig.15

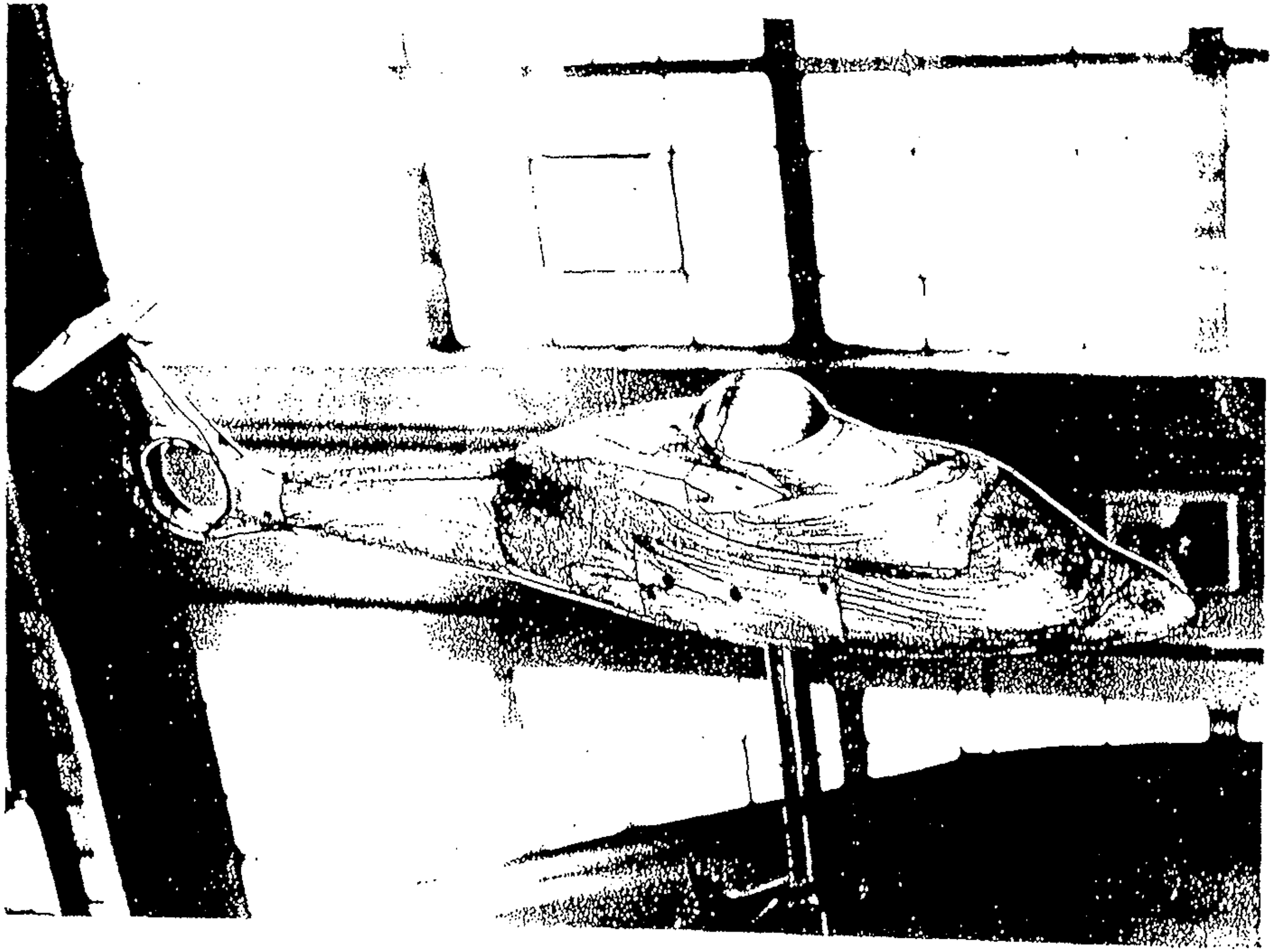


Fig. 16

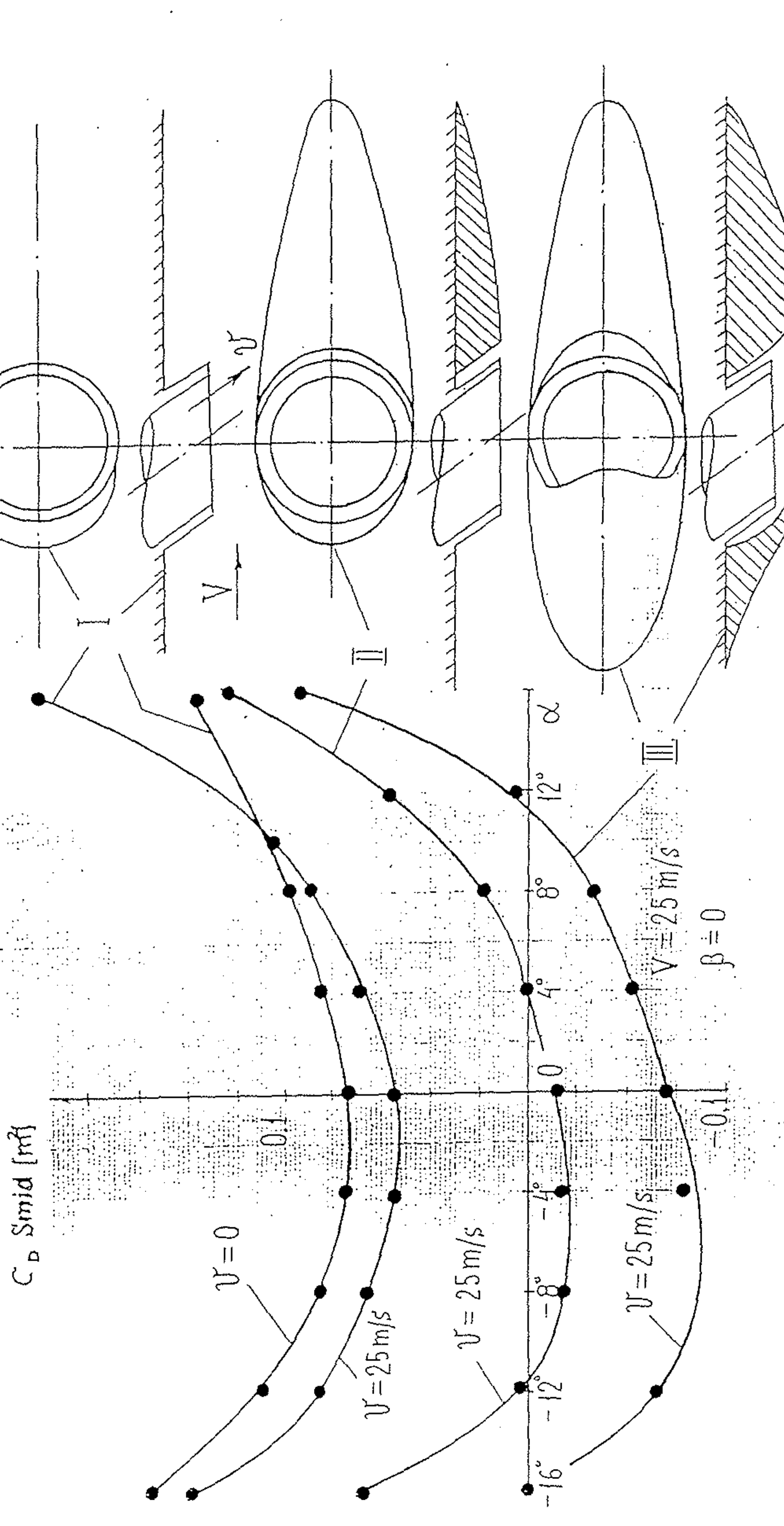

C_D Smid [m²]
0.1
0
-0.1
α
-16°
-12°
-8°
-4°
4°
8°
12°
ϑ = 0
ϑ = 25m/s
ϑ = 25m/s
ϑ = 25m/s
V = 25m/s
β = 0
I
II
III
V
ϑ

Fig. 17

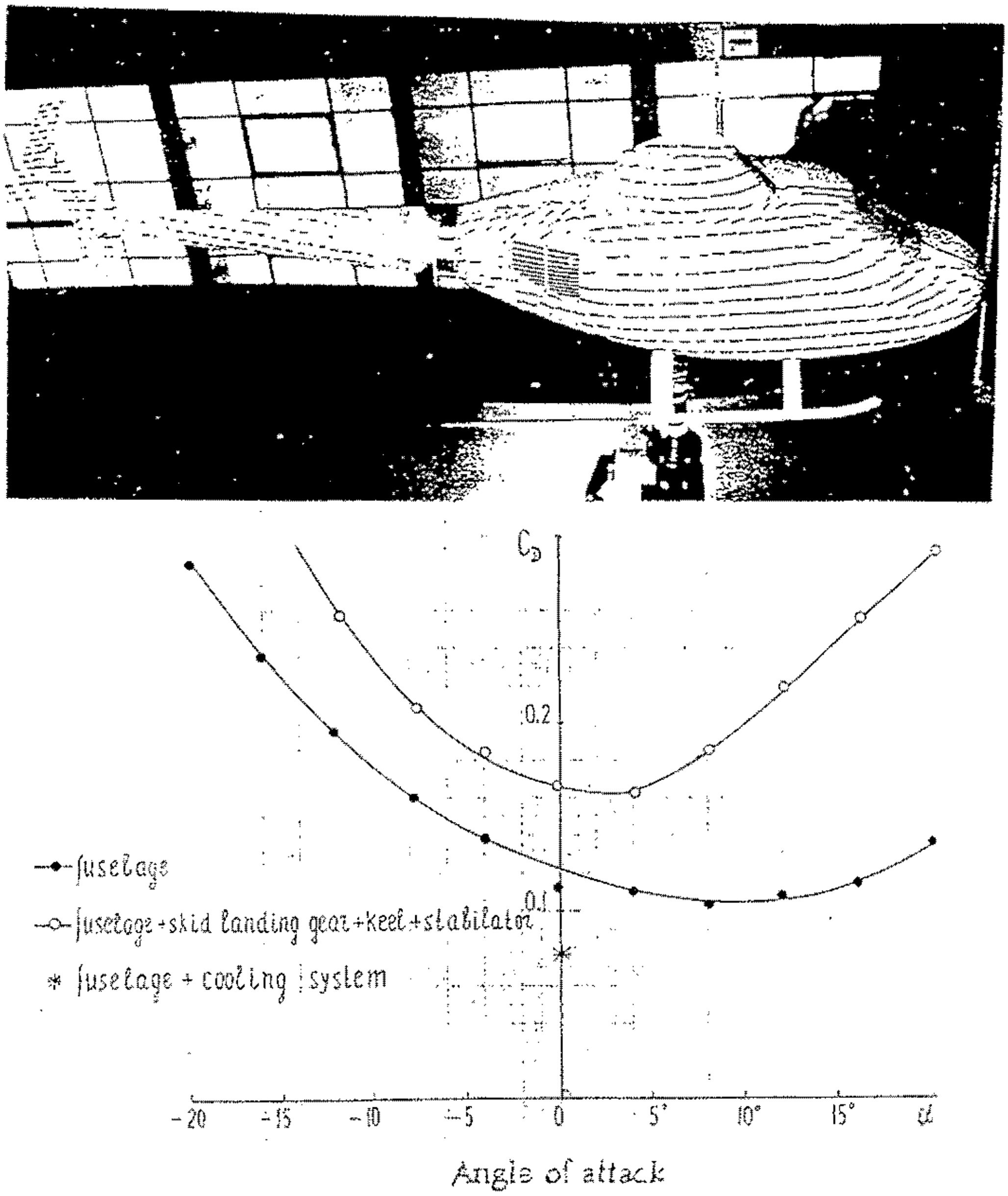


Fig. 18 The model of Mi-34

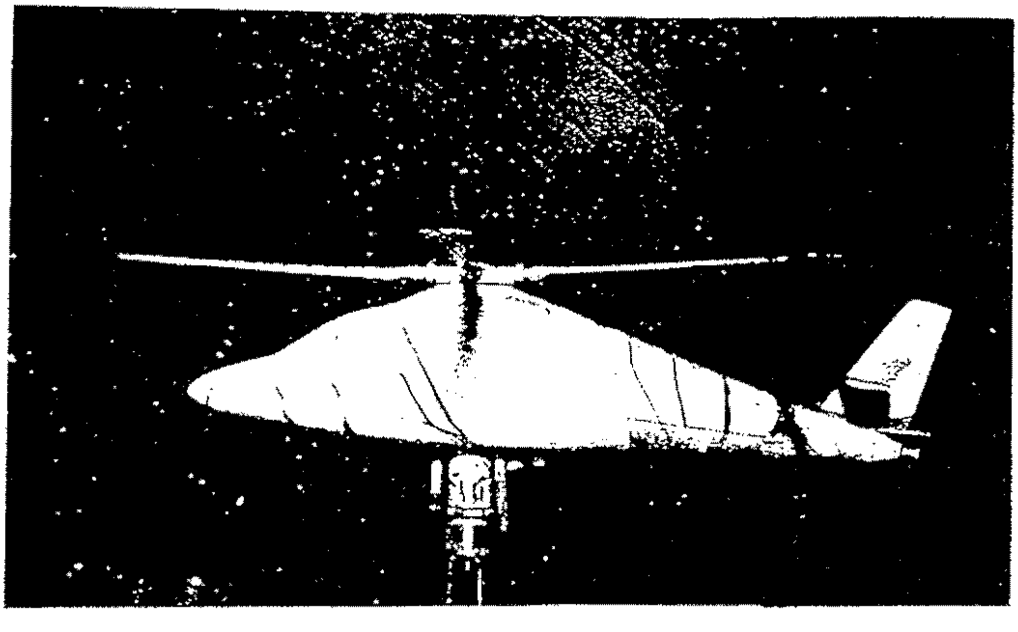


Fig. 19