NINTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No.10

AERODYNAMIC DESIGN ISSUES OF THE ANGLO-ITALIAN EH101 HELICOPTER

F.T. Wilson
Westland Helicopters Ltd

and

G. Pagnano
Costruzioni Aeronautiche Giovanni Agusta SpA

September 13 - 15, 1983

STRESA, ITALY

Associazione Industrie Aerospaziali

Associazione Italiana di Aeronautica ed Astronautica

AERODYNAMIC DESIGN ISSUES OF THE ANGLO-ITALIAN EH101 HELICOPTER

F.T. Wilson
Westland Helicopters Ltd.

and

G. Pagnano
Costruzioni Aeronautiche Giovanni Agusta SpA

ABSTRACT

The Aerodynamic issues affecting the airframe design process are enunciated and discussed.

The philosophy on intake design required consideration of the engine manufacturers' distortion criteria and of the setting of a target for maximum possible total head recovery in hover and forward flight. Also a policy on FOD and icing protection was required and consideration had to be given to the minimisation of re-ingestion. To these ends a programme of wind tunnel testing and icing tests was devised; these are discussed in detail.

The airframe has received particular attention in the rear fuselage and cowling area, a considerable amount of testing on rear fuselage shapes and cowling development having been done.

The philosophy on empennage size and geometry is outlined. Particularly, as regards horizontal tail sizing, the opposing interests of high speed stability and low speed handling are discussed. Also the problem of determining the optimum fin size to minimise tail rotor blockage but to retain sufficient inherent directional stability is highlighted.

The perennial aerodynamicists' problem of drag minimisation is a considerable challenge on the helicopter and the EH101 is no exception. Such aspects of this subject as the optimisation of cowling design to minimise rotor head interference effects, the effects of a rotating head in model testing, the importance of aerodynamics in blade root design and other relevant areas are discussed.

1. INTRODUCTION

The aerodynamic design of rotorcraft has evolved in the last few decades from an almost total concentration on rotors to a greater interest in fuselages, due, mainly to an increase in aircraft speed and to different design objectives of the helicopter (Ref.1 & 2). This effort has concerned not only the parasite drag of the configuration but also the flight characteristics of the aircraft; being dealt with both analytically and experimentally (wind tunnel and flight testing) (Ref.3 & 4).

The use of models in the wind tunnel still remains the most common method of optimising aircraft designs reproducing the very complex aerodynamic interaction problems encountered with rotorcraft (Ref.5). Computing techniques are, however, evolving into useful tools for the analysis of airframe aerodynamic characteristics (Ref.5).

The EH101 helicopter has received special attention to its aerodynamic characteristics which have been optimised through continuous refinement and participation in the design process by aerodynamicists.

This paper outlines the aerodynamic design philosophies and objectives of the EH101 airframe, describes the models and testing used in the aircraft aerodynamic development and discusses the difficulties of reconciling mechanical and structural requirements with aerodynamic considerations. The programme has been conducted jointly by WHL and Agusta as stated in the EH101 technical agreement (Ref.6).

2. AIRCRAFT DESCRIPTION

2.1. General

The EH101 is designed to replace the Royal Navy Sea Kings and the Italian Navy's SH3Ds in the ASW role but will be significantly larger, faster and capable of greater endurance than the Sea King. It will also operate from small ships in all weather conditions including icing.

The civil version will have the ability to transport thirty passengers over 500nm range to civil certification requirements, to support offshore oil rig operations at up to 300nm radius of action, to carry 5500Kg over minimum range and have a high cruising speed.

2.2. Aircraft Description

The aircraft is of conventional single 5-blade main rotor, single 4-blade tail rotor configuration, powered by three General Electric engines.

Leading particulars include :-

Length, rotors turning	22.9 m
Length, folded	15.85m
Main rotor diameter	18.59m
Tail rotor diameter	4.00m
Cabin length	6.50m
Cabin width (at floor level)	2.39m
Cabin height (on centre line)	1.82m
Weight (maximum)	14200kg

See fig.1 for 3 view layout of the aircraft.

3. AERODYNAMIC DESIGN PHILOSOPHY

The role of the aerodynamicist in helicopter airframe design is a difficult one to play with mechanical and structural design considerations invariably taking precedence over aerodynamics. Weight minimisation is also an important factor often opposing aerodynamic interests. However there are several design areas where the aerodynamicist can exercise considerable influence and, even working within difficult constraints, produce an acceptable aerodynamic design.

The side intake is perhaps the best example of this and for the EH101 the design of this item has been significantly influenced by aerodynamics requirements. It was necessary to meet the engine manufacturer's distortion criteria over a range of aircraft operating conditions, to maximise total head recovery in forward flight but at the same time to provide FOD and icing protection.

Rear fuselage aerodynamics has been investigated experimentally by Seddon (Ref.7) where the existence of two possible flow regimes was identified.

For the EH101 some flexibility was possible on the choice of rear fuselage geometry so the effect of various changes was measured in wind tunnel experiments to optimise the rear fuselage design for minimum drag and download.

The initial philosophy on cowl design was to obtain the optimum overall shape enclosing the gearbox and three engines. After wind tunnel testing a good shape was obtained giving low head/cowling interference and low basic cowl drag. However later developments involving such difficulties as flight control linkage design, blade folding clearance and engine maintenance considerations have presented a considerable aerodynamic challenge to contain basic cowl drag and head/cowl interference drag within prescribed target levels required to meet aircraft performance objectives.

The rotor head is possibly the most difficult problem for the helicopter aerodynamicist since this item produces the largest drag increment for a single component and yet is not conducive to aerodynamic fairing because of mechanical difficulties. However some effort can be made to produce local cross sectional shapes consistent with structural integrity but having significantly lower drag coefficient values affecting both translational and rotational power consumption.

Another area where the airframe aerodynamicist has significant influence is the empennage. The problems here are to reconcile the opposing interests of high speed stability and low speed handling and to decide on a suitable fin size to give inherent directional stability without unacceptable tail rotor blockage in hover and quartering flights.

4. MODELS AND WIND TUNNEL TESTING

The tunnels available to WHL and Agusta are the 10' x 8' elliptic tunnel at Yeovil and the 2m open jet tunnel at Milan.

Use has also been made of the 5'6" x 8' approx tunnel at Cowes, the 8' x 6' tunnel at Cranfield and the 2m open jet tunnel of Aermacchi.

The following models have so far been designed, constructed and tested during the aerodynamic development programme.

a. 1/7th Scale Model
- gearbox/engine cowl development
- rotor head testing
- stability
- radome, sponsons development
- drag reduction work (Fig.2)

b. 2/9th Scale Model
- intake testing (Fig.3)

c. 1/12.5 Scale Model with 4 Blade Rotor
- ingestion tests/rotor interaction
- drag breakdown tests
- surface pressure testing
- directional/longitudinal stability

(Fig.4a & b)

d. 1/3.2 Scale Rotor Head
- detailed drag reduction work
- cowl pressures (Fig.5)

5. INTAKES/INGESTION/ICING

5.1. Original Objectives

At all speeds, mass flows and aircraft incidences within the aircraft operating envelope :-

a) to meet intake distortion criteria specified by the engine manufacturer,

b) to minimise pressure loss to 0.5% total head in hover plus the maximum possible recovery of dynamic head in forward flight,

c) to have line-of-sight (FOD) protection on all intakes,

d) to minimise re-ingestion in all flight regimes particularly in hover in and out of ground effect and low speed flight,

e) to assess the ice protection potential of the intakes.

5.2. Model Design and Test Programme

To meet objectives a), b) and c) a 2/9th scale part model has been designed and constructed. Only one side intake plus the centre intake was required. Model design manufacture and testing has been carried out by WHL at Yeovil.

The intake shape (typical horizontal cross section shown in Fig.6), was developed to give good hover performance whilst also providing a good airflow quality throughout the speed and incidence range and maintaining good line-of-sight protection from ice and FOD. This task was made more difficult with the presence of the drive shaft in the intake but experience gained on Lynx proved useful in this problem.

5.3. Results

Typical results from the 2/9th scale model on the side intake are well within GE prescribed limits for circumferential and radial distortion limits for no performance loss. (See Figs. 7 & 8). Tests are still awaited on the effects of changing incidence and yaw but previous experience indicates that the effect will not be large. Pressure loss in hover is only 0.12% of total head and at forward speeds at normal cruise incidences a useful recovery of free stream dynamic head has been achieved (Fig.9).

The re-ingestion problem is associated more with exhaust geometry than with the intake and this is more fully discussed in Section 11.

Icing tests on a similar intake at full scale in the Pyestock Cell 3 West facility have indicated that satisfactory anti-icing performance can be achieved within allowable electrical power requirements and tests on the definitive airframe/intake shape are planned.

6. ROTOR HEAD

The EH101 main rotor head system is of an articulated type, 5 bladed with folding capability. The fail safe design features the use of composite and elastomeric materials giving a saving in weight and complexity and increased safety.

The rotor head is the largest drag producing component and has received special aerodynamic attention throughout the development programme. The aim has been to minimise frontal area and to provide cross sectional shapes consistent with minimum drag wherever possible.

6.1. Models and Tests

Some current techniques on rotor head model testing have been described by Roesch and Dequin (Ref.8). Similar and other independently developed methods have been employed on the EH101 programme.

Three separate test programmes have been followed on rotor head viz :-

a) 1/7th scale testing with rotating head and separate drag and torque balance (WHL),

b) 1/12.5 scale tests with static head (Agusta),

c) 1/3.2 scale tests at Cranfield (WHL and Agusta).

1/7th scale testing provides total rotor head drag and torque data and allows calculation of head/fuselage interference.

To date three rotor head designs have been assessed by this method viz :-

(i) semi-rigid design with 10.5% hinge offset

(ii) articulated design with 5% hinge offset

(iii) revised articulated design with 5% hinge offset.

6.2. Rotor Head Drag and Torque

Design (i) had the lowest frontal area and hence drag and the design change to the 'articulated' concept (ii) resulted in a significant increase in rotor head frontal area and drag. To contain aircraft drag within previously targetted levels therefore, it was decided to initiate a rotor head drag reduction programme. A revised design (iii) was produced with significantly lower basic and interference drag. Also cowling development designed to reduce head/cowl interference was undertaken with some success. (Section 7).

In addition, detailed drag reduction work has been done at Cranfield on the 1/3.2 scale model mainly on the use of a 'beanie' fairing mounted above the rotor head. This fairing has the advantage of fairing blade de-icing switch gear whilst simultaneously reducing rotor head drag.

6.3. Rotational Power

Rotor head rotational power is measured on the 1/7th scale model from hover throughout the aircraft speed range. Suitable scaling parameters are used as follows :-

$$\frac{V_M}{\Omega_M R_M} = \frac{V_F}{\Omega_F R_F} \qquad \text{for same advance ratio}$$

and

$$\frac{P_F}{P_M} = \left(\frac{\Omega_F}{\Omega_M}\right)^3 \left(\frac{R_F}{R_M}\right)^5$$

where V = forward speed Ω = head rotational speed R = typical radius
P = power Suffix M = model Suffix F = full scale

Due to the long lead time required to implement changes to the head design an estimating method has been developed enabling rapid assessments to be made of the effect of proposed geometric changes in rotational power and drag. The method is based on a simple sectional integration around the azimuth, and gives excellent data correlated by experimental evidence on a preliminary head design. See Figs.10 to 13 inclusive.

Blade root design is also important in the total power consumption of the rotor head and this problem has been approached by measuring the drag of the blade root in a specialised experiment on a single representative blade arm and using the results obtained in the rotational power theory.

The total power consumption obtained is divided, for convenience into a constant rotatational power in hover and an equivalent drag at a nominal cruise speed. For the rotor head itself, drag is measured on a rotating head and torque is measured at hover and forward speed. The additional rotational power due to forward speed is converted into an equivalent drag and added to the blade root term. Thus we have a total drag term for rotor head and blade roots, an additional equivalent drag due to rotation and a rotational power in hover (see Fig.14).

We believe that this method adequately accounts for all the power requirements of the rotor head out to the working area of the rotor and that by identifying the various components a proper understanding of their contribution has been achieved.

7. COWL DEVELOPMENT

The 1/7th model has been used for basic airframe and cowling development over the last two years. At a very early stage before lines were hardened a model was constructed to give an early indication of aerodynamic characteristics for performance and stability calculations.

After engine positions were decided and the gearbox size and shape fixed, an all enclosing cowl was developed with the following objectives :-

a) minimum basic drag
b) minimum rotor head/cowl interference
c) optimum conditions for efficient intake functioning.

However, the cowl shape developed proved to be impracticable for reasons of blade folding and engine maintenance, and accommodation had to be made for flight controls. To avoid excessive drag penalties due to these concessions to practicabilities an extensive drag minimisation programme was undertaken.

The cowl shape which has evolved is now considered to be close to the optimum within the constraints imposed by design. For example whilst we know that it is possible to reduce drag further by such items as inboard fairings at the rear of the side nacelles, this would produce unacceptable problems with engine accessibility.

Much attention has been paid to the effect of small changes in cowling geometry on drag and all possible beneficial changes discovered in the wind tunnel have been incorporated into the design.

8. FUSELAGE

The nose and centre section geometry have been generally decided by cabin size considerations, forward visibility and structural requirements.

However some aerodynamic influence was possible in the rear fuselage region. Testing at Yeovil and Cowes, on a variety of rear fuselage configurations, has indicated that the EH101 design ramp angle of 17.5° and half closure angle of 10° have produced a fuselage with very nearly the minimum possible drag (fig.15) and with minimum download. The effect of ramp edge radii (both lateral and side edges) was not found to be significant for tapered rear fuselages of low ramp angle, particularly with sponsons fitted.

9. STABILITY CHARACTERISTICS

Tail surface effectiveness has been obtained from wind tunnel data using models with both tail-on and tail-off configurations at different fuselage attitudes. The location and size of the tailplane and fin have been defined to satisfy the trimming requirements, whilst, at the same time, minimising the induced effects in terms of drag and/or weight.

9.1. Longitudinal Stability

The objective was to provide a horizontal stabiliser sufficiently large to give inherent stability and provide a means of trimming for minimum rotor head moment (within folding constraints). In addition, it was necessary to ensure that potential low speed handling problems associated with main rotor wake impingements are minimised. These two requirements tend to oppose each other.

The location of the tailplane is determined not only by the aerodynamic considerations but also by structural and maintainability problems. The low position of the end of the tailboom offers a good compromise between trimming aspects and stress/weight considerations.

A symmetrical tailplane of 4m span and aspect ratio of 3.39 was chosen with an aerofoil section of NACA4415 inverted (to give bias towards an anticipated download). Wind tunnel tests on the 1/7th scale model indicate a modest amount of longitudinal static stability at cruise attitudes which is considered adequate. Provisionally a tailplane angle of zero has been chosen for the Naval and Civil variants but the final setting will be determined by flight testing.

Using a parameter based on tailplane volume, main rotor disc area and main rotor control power a number of helicopters have been assessed some of which have low speed handling problems. The chosen EH101 tailplane has been considered by this method and should be sufficiently small to avoid such difficulties.

Wind tunnel testing showed that simple analysis models of the aerodynamic behaviour of the tail plane correlated well with measured data.

Fig.16 shows the results obtained in terms of tail plane lift coefficient compared with theoretical values. The results show that the fuselage wake does not seem to affect the tail plane (or fin) efficiency, confirming the good aerodynamic design of the fuselage.

9.2. Directional Stability

Fin sizing does not usually include the effect of dynamic pressure loss caused by the fuselage wake impinging on the tail but directional stability can be strongly affected by the airframe, especially by rotorhead, cowling and exhaust design.

Static directional stability was therefore studied using a 'breakdown' method. This involves adding each component to the basic fuselage and measuring the yaw response of the aircraft. Flow visualisation showed how the flow field in the fin region was affected by each component.

Another factor to be considered when deriving fin area is its blocking effect on the tail rotor airflow.

An interesting result is that the sponsons have a stabilising effect on directional stability.

10. ROTOR/AIRFRAME INTERACTION

The test programme also includes the analysis of airframe characteristics in the presence of the rotor wake. A scale model rotor was manufactured by WHL and is now installed in the Agusta wind tunnel (see fig.5).

Force measurements will be taken for various fuselage configurations and flight conditions (both the rotor parameters and the fuselage attitudes) in the rotor flow field. These will allow modifications to be made to the airframe if necessary, which will allow for the effects of rotor wake in the airstream.

It is also expected to be able to run this kind of testing with a fuselage pressure model to achieve comaprisons between pressure distribution and airloads with and without the rotor wake.

A preliminary study of the rotor wake characteristics is planned including flow visualisations and hot wire measurements.

11. INGESTION TESTS

One of the hazards in cowling design and engine installation definition is the re-ingestion of hot gases. This problem was experienced by Turczeniuk and led to detailed investigation in the wind tunnel. (Ref.9). To ensure that such a risk is avoided on EH101, a wind tunnel activity has been planned on a 2/25 scale model which simulates the mass flows into and out of the engines. The model is strut mounted with the airflow of one side engine plus the centre engine represented. Construction is mainly of glass reinforced plastic.

A preliminary test of this nature was conducted at Agusta on a 1/14th scale model; no provision was made for rotor wake simulation and the results are produced as pictures of smoke visualisation of the exhaust gas trajectories in different flight regimes.

The re-ingestion study to be conducted on the EH101 configuration will still make use of flow visualisations but in the presence of a rotor wake and in or out of ground effect.

On the basis of the results from the preliminary tests, the programme includes flight conditions more likely to give re-ingestion problems. The use of TV recording will allow the analysis of transient conditions as well as of level flight regimes to be done. It is hoped eventually to measure aircraft intake air temperature to allow correlations with the qualitative results obtained from the model.

12. MISCELLANEOUS

12.1. Cooling

There will be a serious attempt on EH101 to minimise the drag due to cooling. The intention is to provide faired inlet scoops or flush intakes in high pressure areas and to eject the air in suitable locations at or near free-stream speed wherever possible.

12.2. Weapons

To ensure maximum performance of the naval version it is necessary to contain the weapons drag to the minimum possible. It has been found that the carrier is by far the largest contribution to drag and therefore the carrier frontal area will be kept to an absolute minimum consistent with structural integrity. Also, carrier fairings, which have been found beneficial, will be employed where practicable.

12.3. Antennae

Chin mounted radome drag has been minimised by paying special attention to the lower edge radius which must be as high as possible (fig.17) and to the lower surface shape which should be slightly domed for preference. General aerial drag will be minimised by careful attention to positioning and shape.

12.4. Engine Installation Loss

Jet exhaust angle to aircraft centre line will be kept to a minimum (consistent with the best solution for re-ingestion avoidance) to minimise engine airflow momentum loss.

12.5. Sponsons

Drag and download of sponsons can be significant and care has been taken to reduce both these effects by judicious fairing design. Light stores will be carried behind the undercarriage and the drag effect of these items has been kept to a minimum by incorporating them into the basic sponson design.

13. CONCLUDING REMARKS

As part of the overall design collaboration on the EH101 helicopter the airframe aerodynamic design has been jointly approached by the aerodynamic departments of the two companies. Suitable scale models have been manufactured and tested in the wind tunnels at Milan and Yeovil to assess and optimise the aerodynamic efficiency of the helicotper.

Inspite of the opposing interests of structure and mechanical requirements, there has been considerable progress so far in the achievement of aerodynamic objectives.

Further experimental work is planned, particularly for the rotor head, rotor/fuselage interaction, intake/cowling tests and exhaust re-ingestion avoidance.

14. REFERENCES

1. Venegoni, Magni and Baldassarrini — An Industrial Rationale for the Aerodynamic Design of the Fuselage for a High Performance Light Helicopter. Presented at the 3rd European Rotorcraft Forum - Aix en Provence, France 1977, Paper 44.

2. B. Franderburgh — Aerodynamic Design of the Sikorsky S76 Helicopter Presented at the 39th AHS Forum, 1978, Paper 06.

3. G. Wright, M. Lappos — Sikorsky S76 Helicopter, Handling Qualities, Design and Development, AHS Journal, Jan. 1981

4. H. Huber, T. Masue — Flight Characteristics Design and Development of MBB/KHI BK 117 Helicopter - Presented at the 7th European Rotorcraft Forum - Garmisch September 1981, Paper 35.

5. D. Clark, F.T. Wilson — A Study of the Effect of Aft Fuselage Shape on Helicopter Drag - Presented at the Sixth European Rotorcraft Forum 1980, Paper 50.

6. B.J. Main, P. Alli — EH101 Design, A Collaborative Programme - 8th European Rotorcraft Forum, Aix en Provence, 1982 Paper 1.3.

7. J. Seddon — Aerodynamics of the Helicopter Rear Fuselage Upsweep, 8th European Rotorcraft Forum, Aix en Provence, 1982, Paper 2.12.

8. P. Roesch, A.H. Dequin — Experimental Research on Helicopter Fuselage and Rotor Hub Wake Turbulence, 39th AHS Forum, St. Louis, May 1983, 74-1

9. B. Turczeniuk — Exhaust Gas Re-ingestion Measurements, AHS Journal, July 1982.

ACKNOWLEDGEMENTS

The authors wish to thank the staff of the Bresso and Yeovil wind tunnels for their invaluable contributions to the testing activities.

Unpublished material on tailplane handling problems was made avialable to the authors by Mr. J. Perry, Chief Aerodynamicist of Westland Helicopters Ltd.

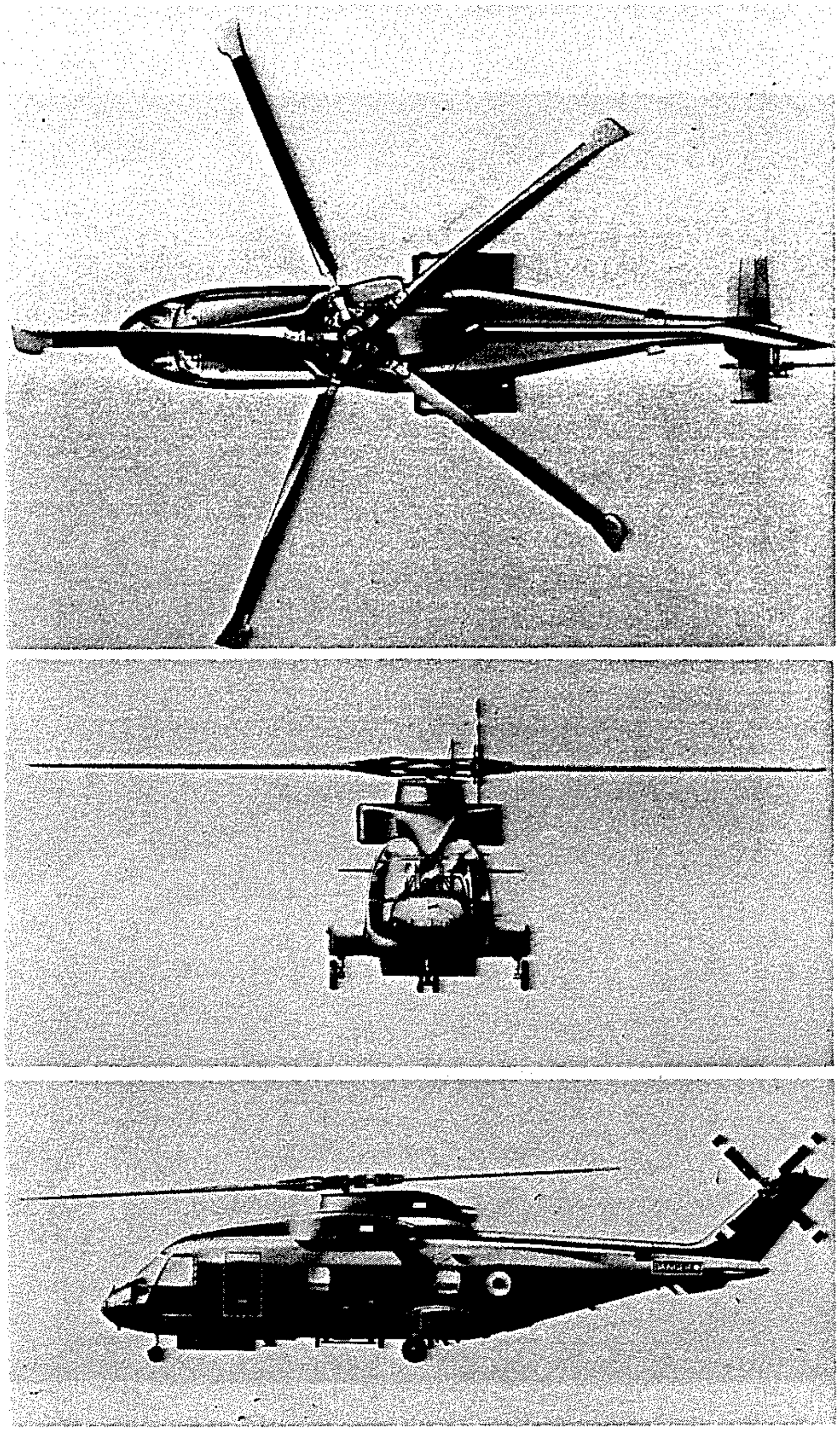


FIGURE 1

3 VIEW LAYOUT OF EH101

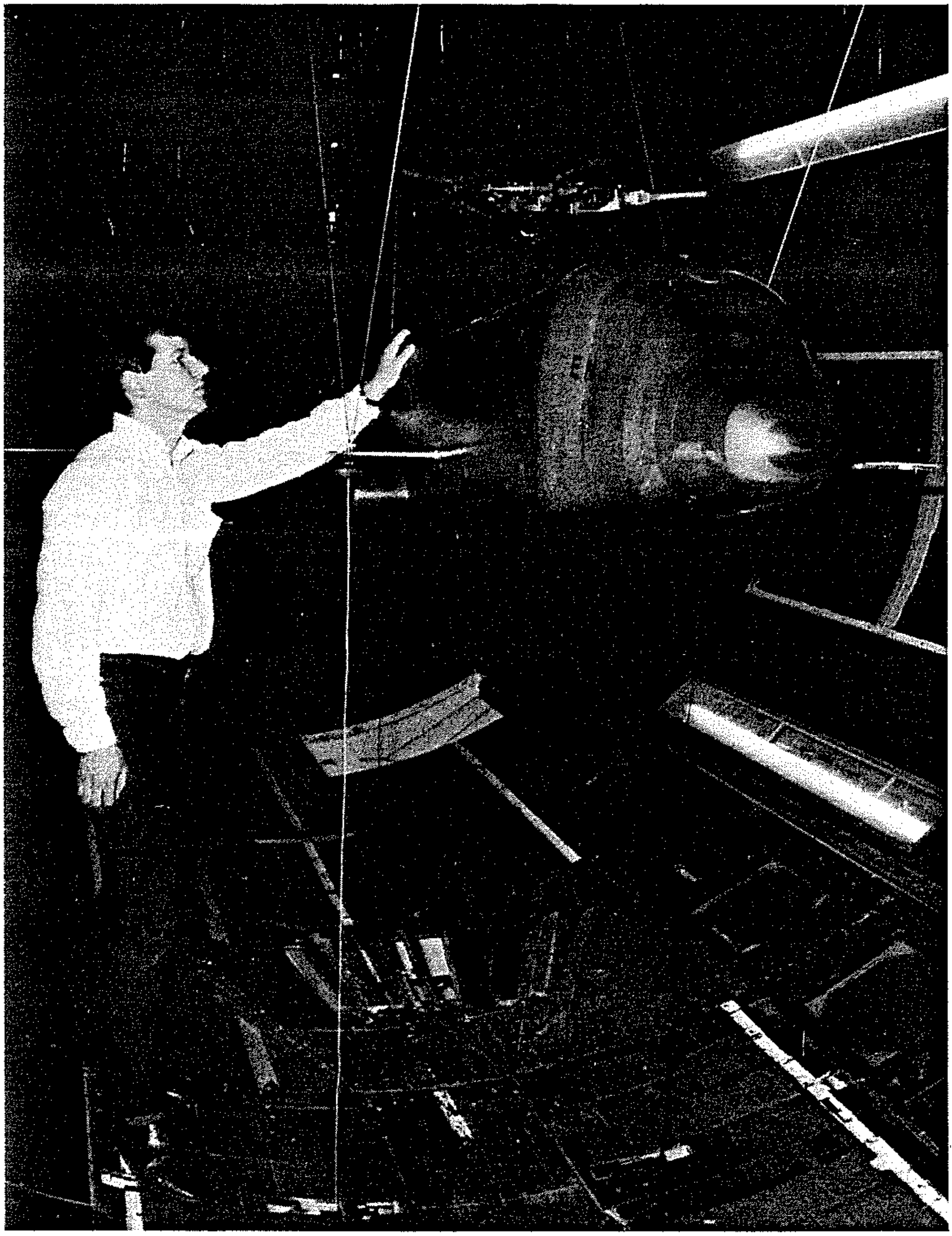


FIGURE 2

1/7TH SCALE MODEL IN WHL WIND TUNNEL

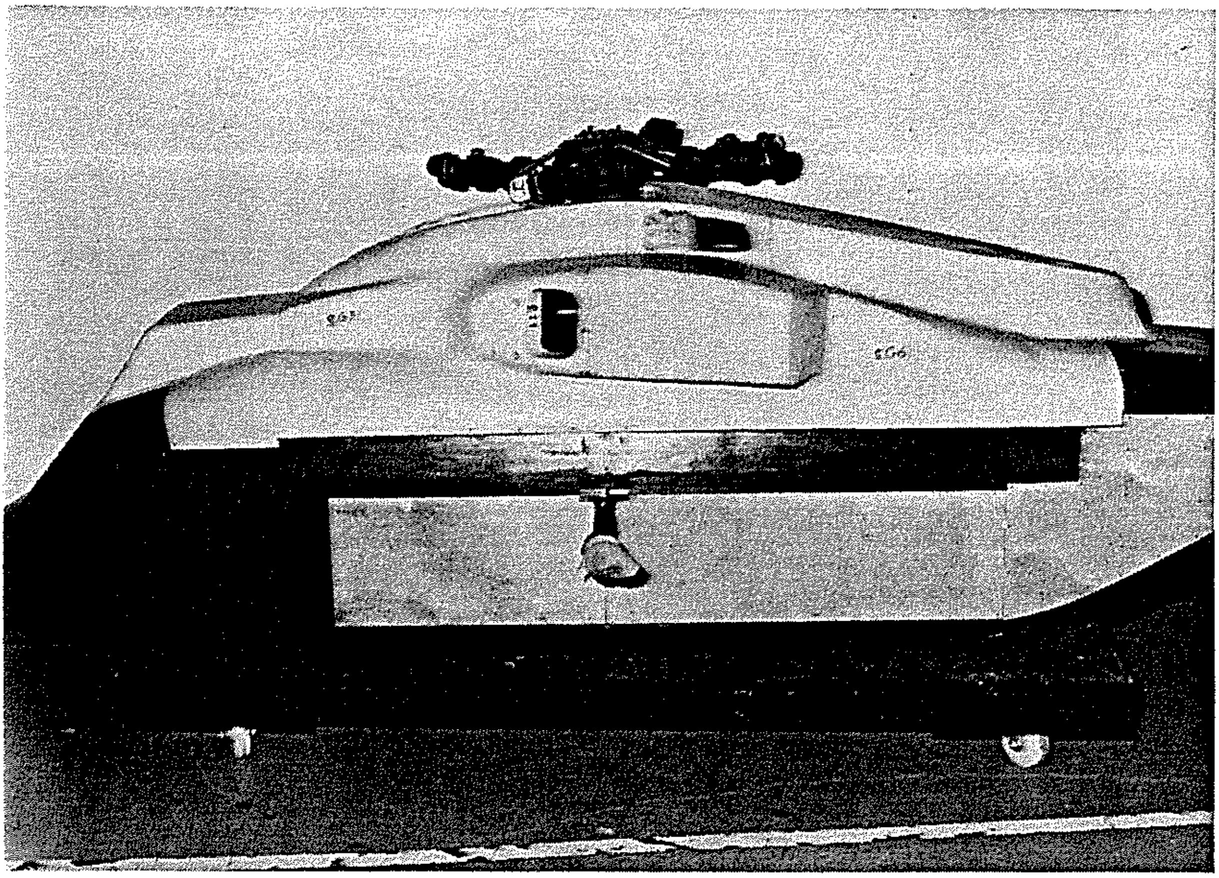
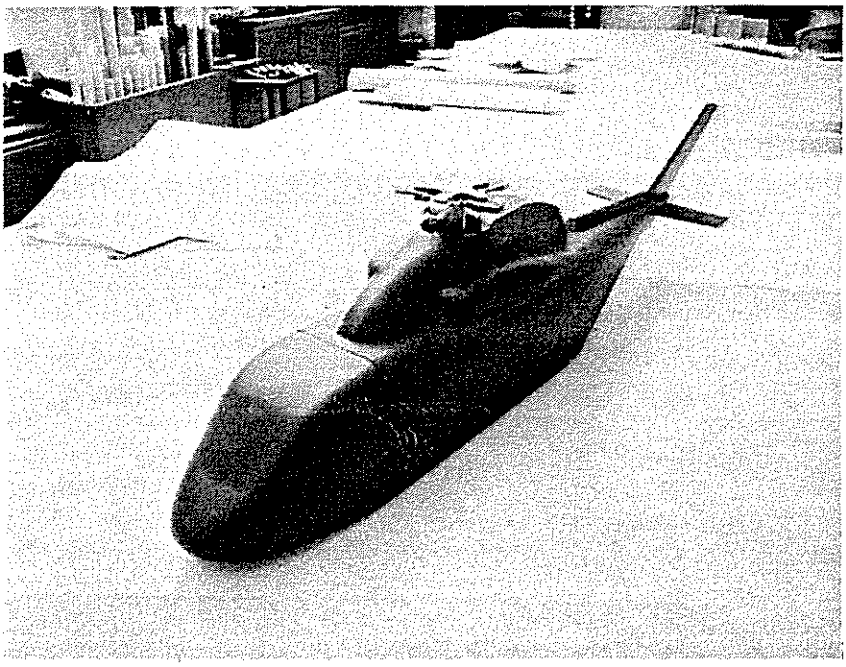
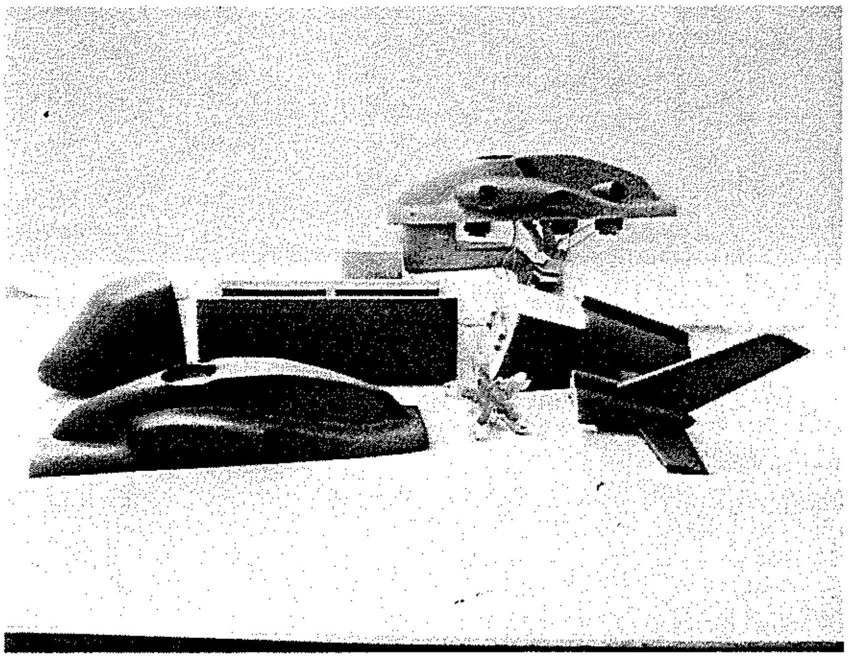


FIGURE 3

2/9TH SCALE MODEL



4a



4b

FIGURE 4a & 4b

1/12.5 SCALE MODEL FUSELAGE

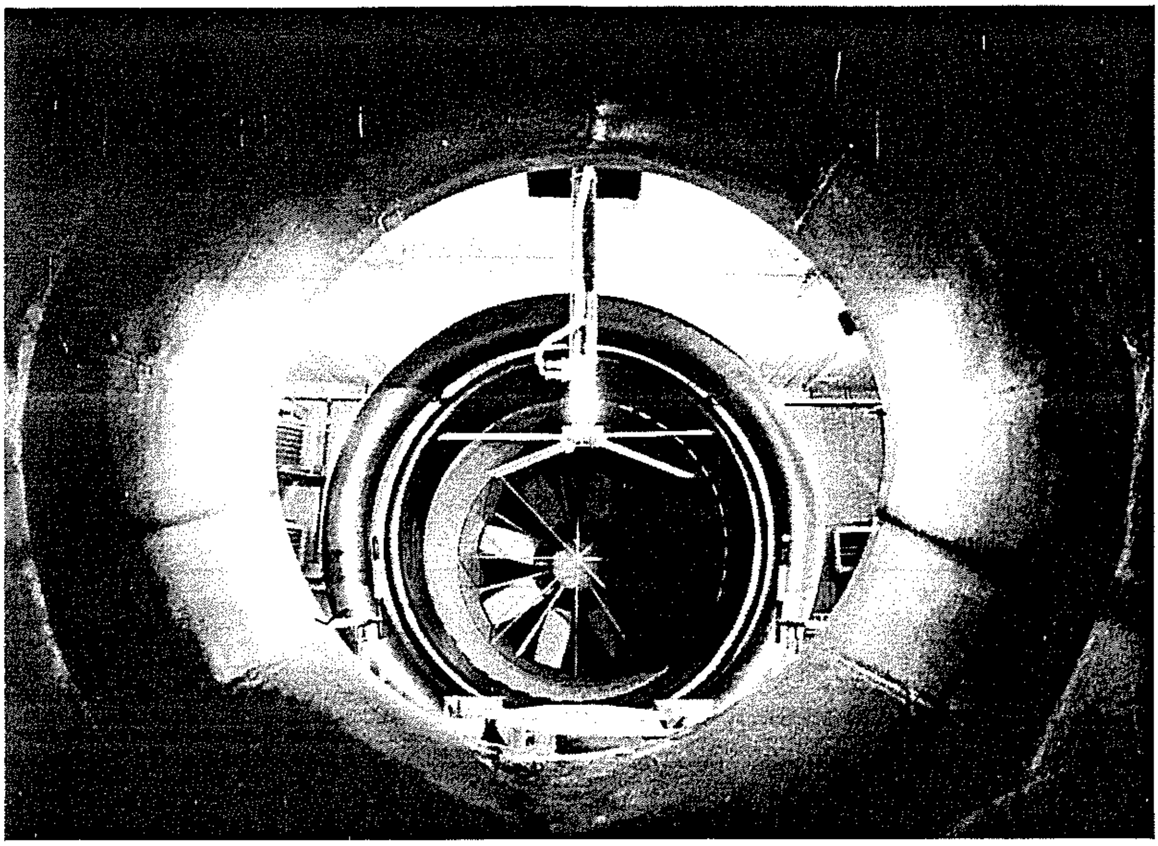


FIGURE 5

1/12.5 SCALE MODEL ROTOR

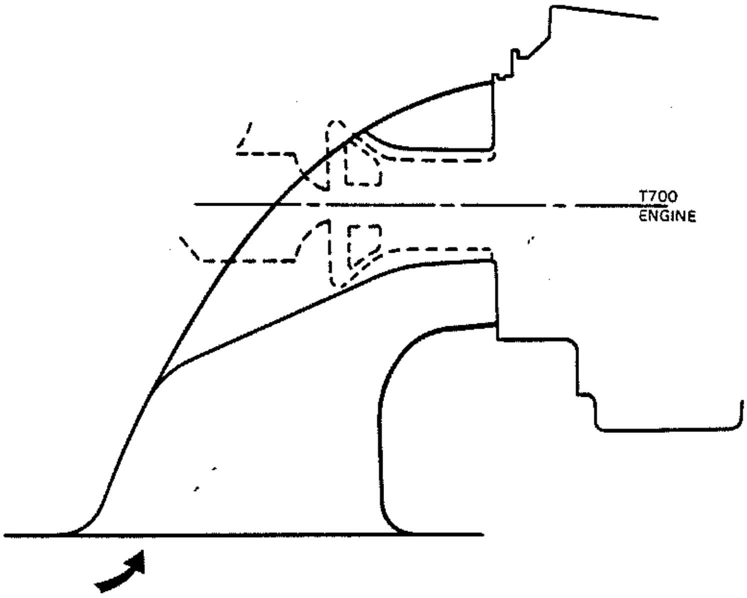


FIGURE 6

CROSS SECTION OF INTAKE

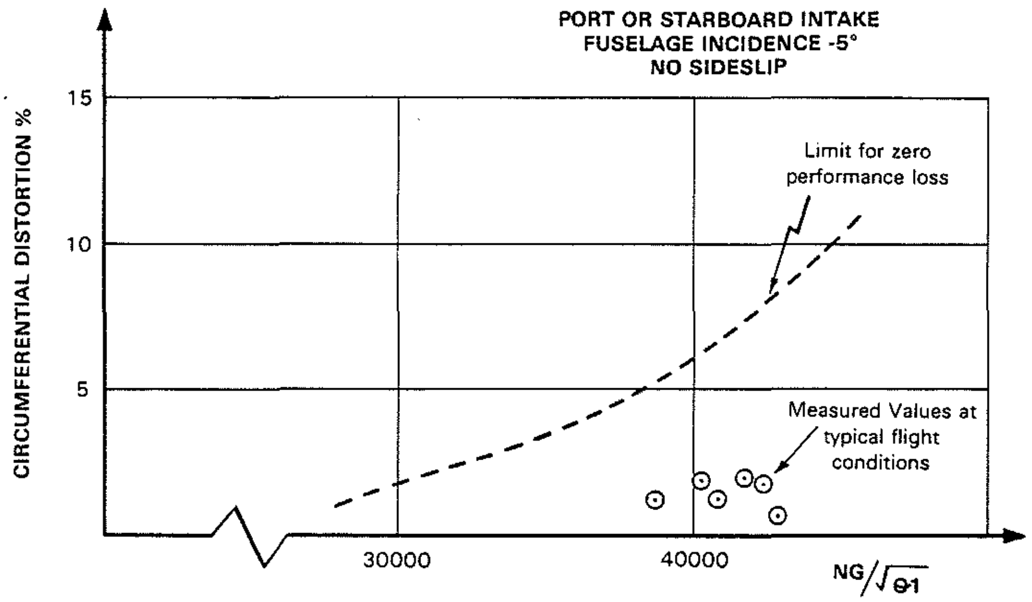


FIG. 7 CIRCUMFERENTIAL DISTORTION INDICES

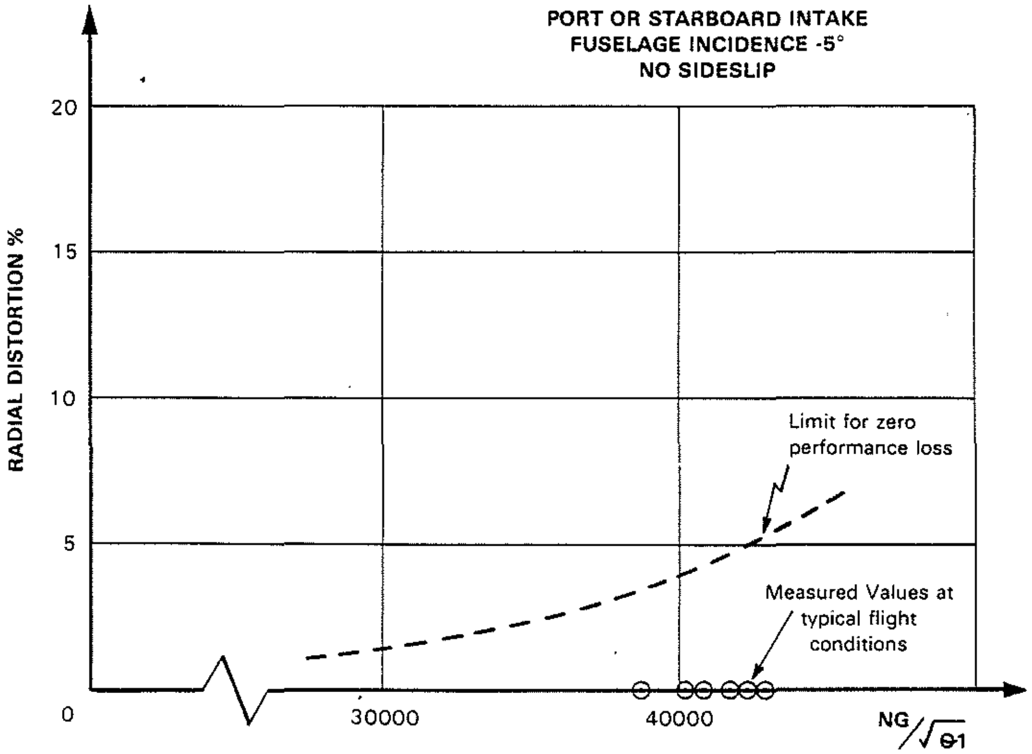


FIG. 8 RADIAL DISTORTION INDICES

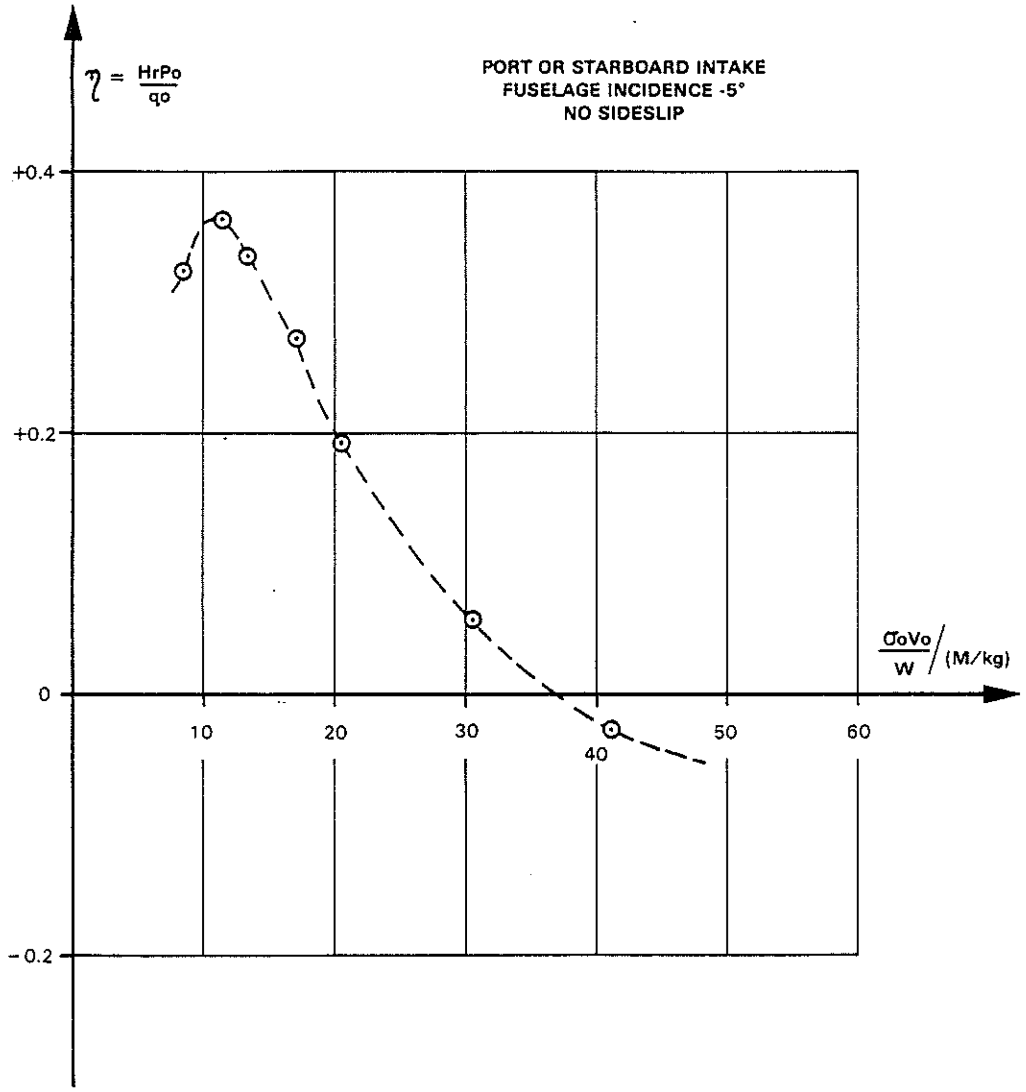


FIGURE 9

INTAKE TOTAL HEAD RECOVERY

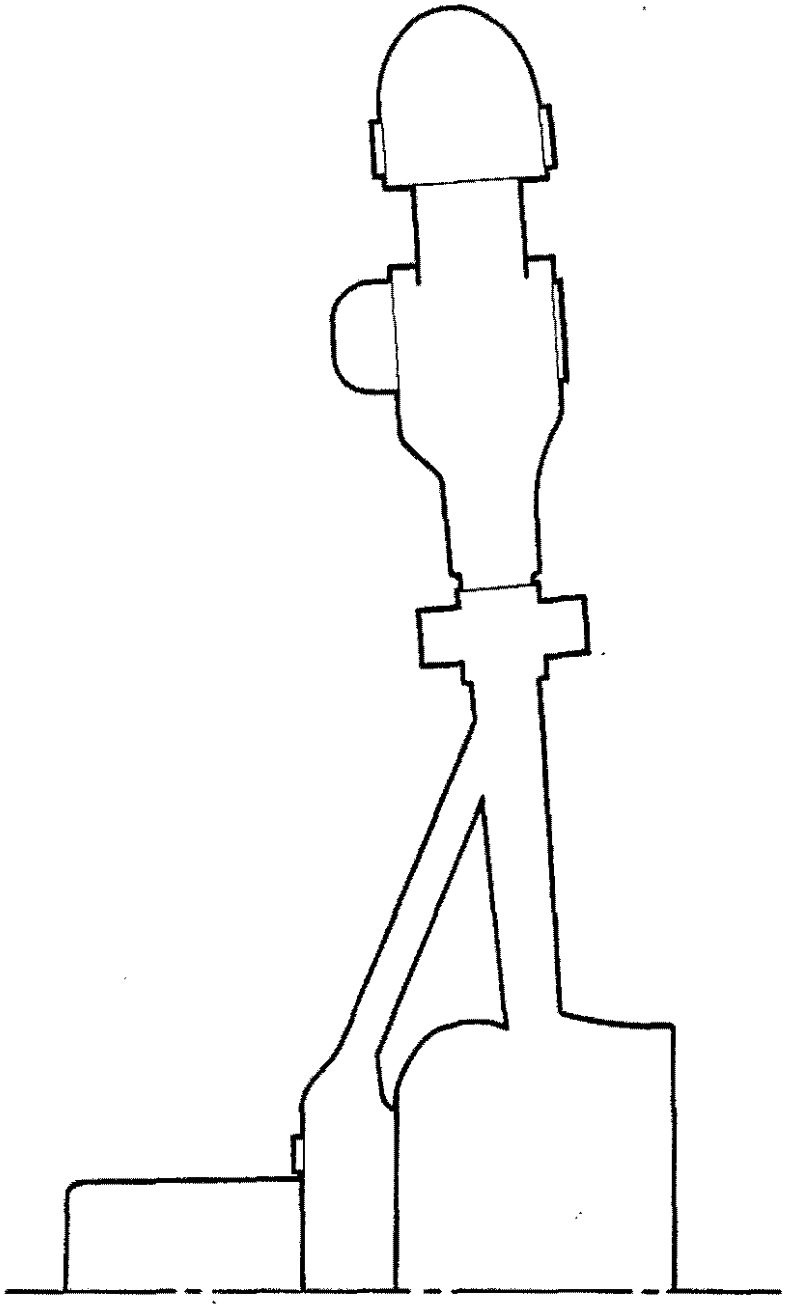


FIGURE 10

EARLY SEMI-RIGID ROTOR HEAD DESIGN

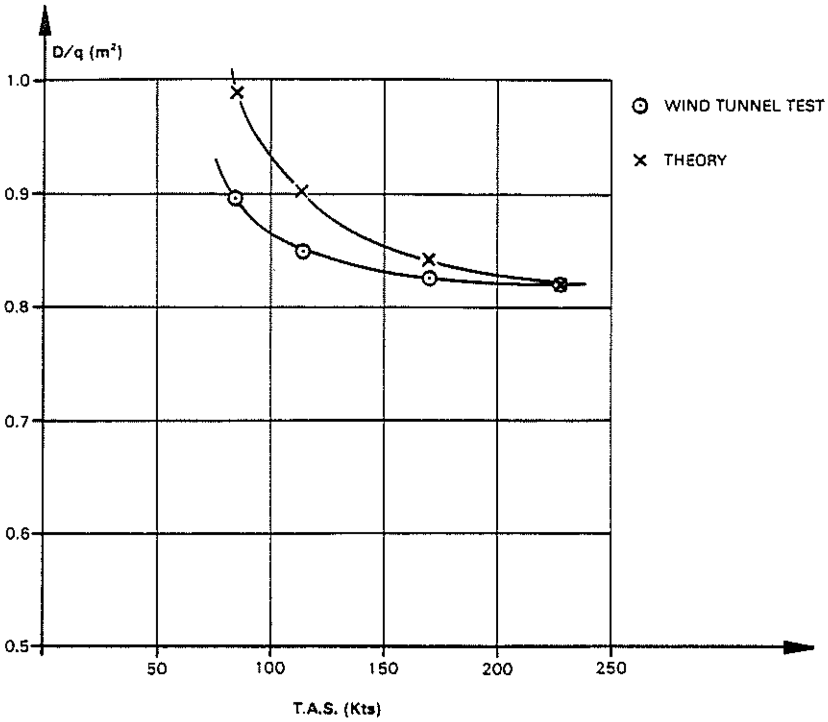


FIGURE 11
COMPLETE HEAD DRAG VARIATION WITH SPEED

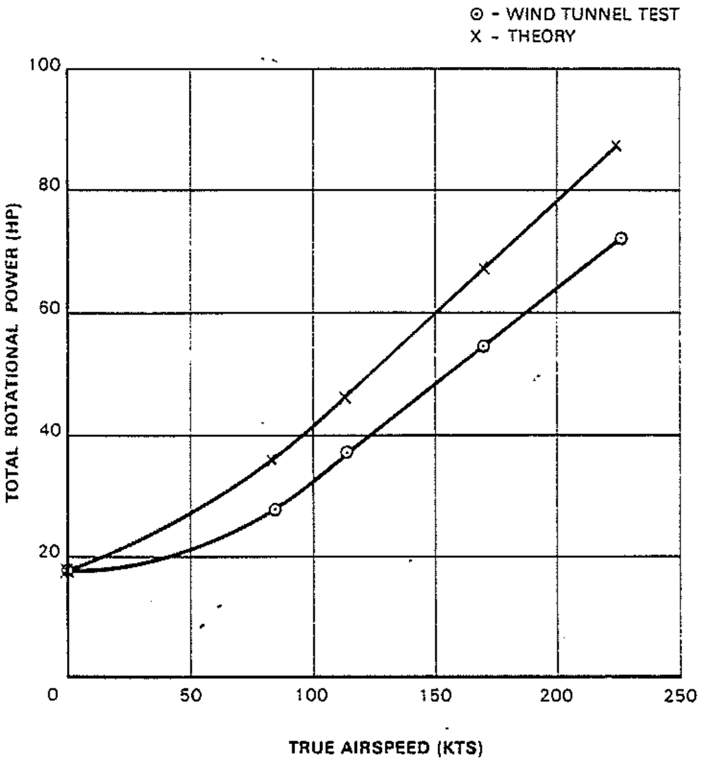


FIGURE 12
TOTAL ROTATIONAL POWER Vs TRUE AIRSPEED

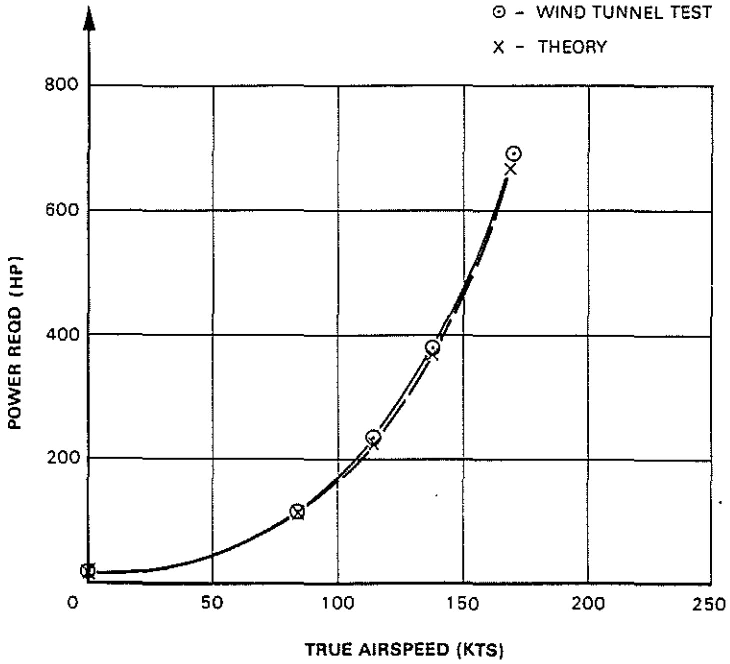


FIGURE 13.

COMPLETE HEAD - POWER VARIATION WITH SPEED

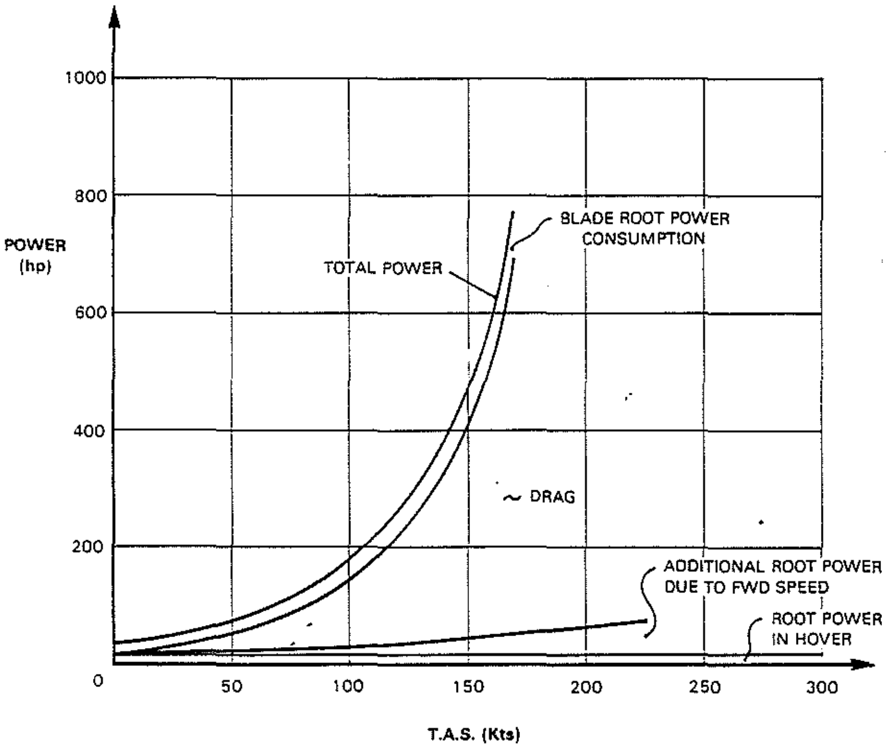
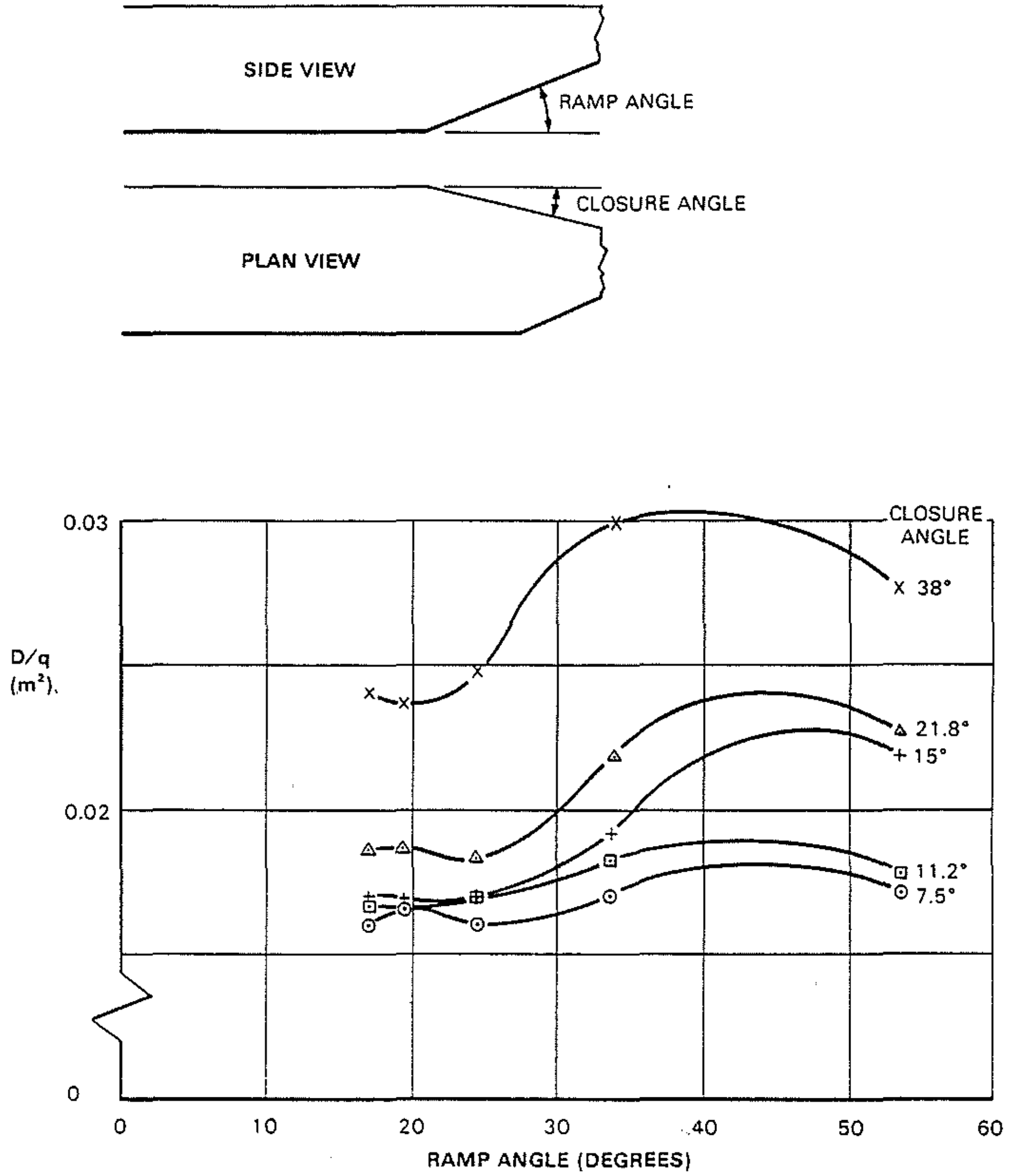


FIGURE 14.

BREAKDOWN OF ROTOR HEAD POWER



FUSELAGE INCIDENCE -3°

FIGURE 15.

D/q Vs RAMP ANGLE

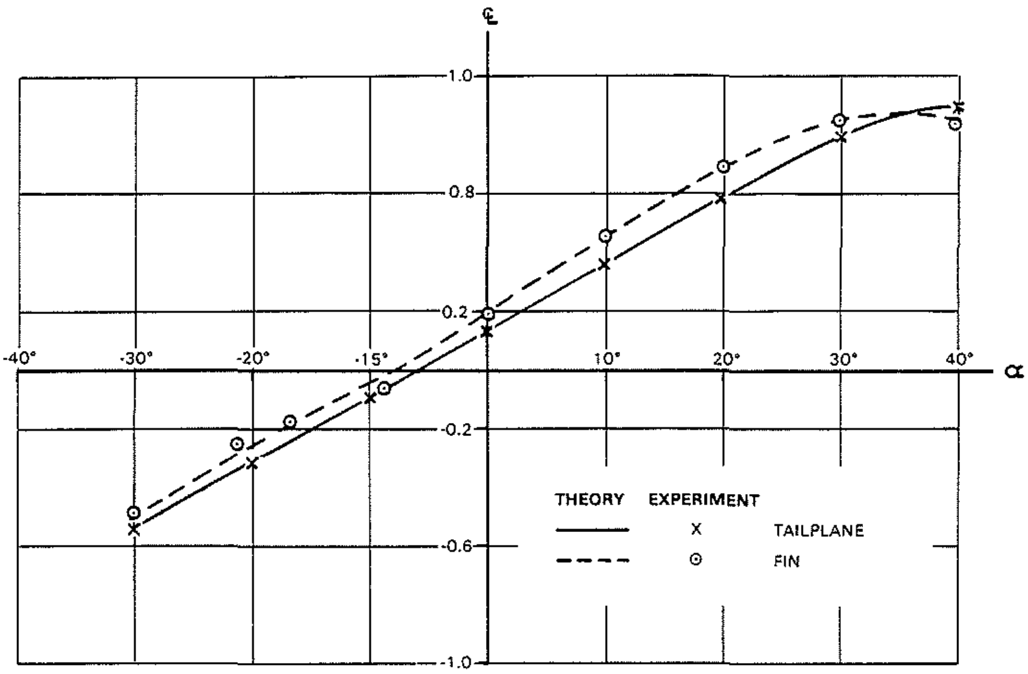


FIGURE 16

C_L Vs FOR EH101 TAILPLANE AND FIN

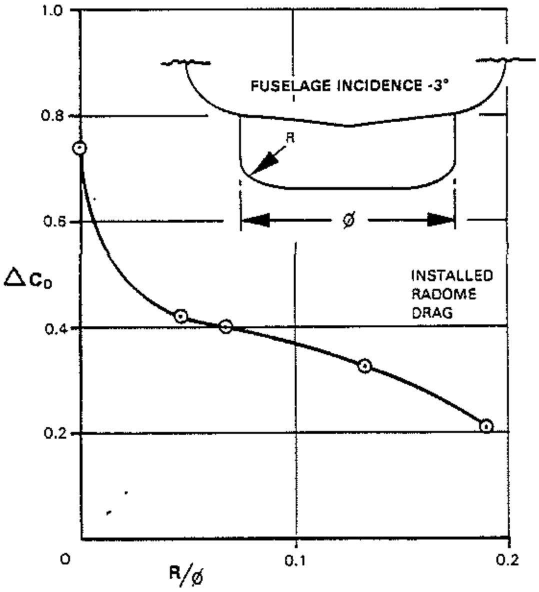


FIGURE 17.

DRAG Vs RADOME RADIUS