TWELFTH EUROPEAN ROTORCRAFT FORUM

Paper No. 78

WIND TUNNEL TESTING AT AGUSTA

G.Pagnano

Costruz.Aeron.G.AGUSTA

Cascina Costa (VA) - Italy

September 22 - 25, 1986

Garmisch-Partenkirchen
Federal Republic of Germany

Deutsche Gesellschaft für Luft- und Raumfahrt e. V. (DGLR)
Godesgerger Allee 70, D-5300 Bonn 2, F.R.G.

12th European Rotorcraft Forum
Paper no. 78

W I N D   T U N N E L   T E S T I N G   A T   A G U S T A

G.PAGNANO - Costr.Aer.G.AGUSTA, Italy

ABSTRACT

The most recent experimental activities conducted at AGUSTA, in the company-owned facility, are described.

After presentation of the wind tunnel characteristics, including a short history of the plant, the typical applications conducted are presented, starting with Airframe Aerodynamics; i.e. testing on fuselage and components, using force, pressure measurements and flow visualizations, all conducted with the objective of optimizing drag and stability characteristics, of assessing interference problems and determining airloads, to support the aerodynamic design and analysis.

Emphasis is given to the modular design of the models and details are provided of the test techniques in use, as well as several results and correlations.

The Propulsion System is then considered, with description of testing of a quarter scale Intake model, also compared with flight tests.

The investigation of exhaust ingestion performed on a scaled model with rotor wake simulation was the subject of a dedicated activity, whose technique and experience are reviewed. The paper also touches the problems of using Rotor models, applying wake survey methods and analyzing rotor/ fuselage interference.

After description of the Store Separation Studies performed on Froude-scaled models and presentation of some of the results, the Conclusions list the current plans for the development and research of tunnel techniques, in the field of experimental aerodynamics applied in an industrial environment.

1. - INTRODUCTION

The increased attention to aerodynamic aspects of rotorcraft, due to the requirements for higher performance and also to the need for a preliminary validation of both conventional and new concepts, has brought to a greater request for tools to be used in aerodynamic design and analysis (ref.1).

Apart the constant improvements in analytical methods, paced by the growth in computing power, the role of experimental aerodynamics has also changed, and today wind tunnel testing plays an increasingly important part both for airframe development and for rotor aerodynamics.

Large facilities exist nowadays where rotor testing on sophisticated models can be performed.

However the basic development work is still conducted in small facilities, usually owned by the helicopter manufacturer, in order to provide inside capability; this is the case in the AGUSTA company.

In this tunnel, a pioneering role in the helicopter field was played in the late 60's by the work of P.BELLAVITA on the A109 development (see fig.1), consisting of application of a simplified rotor to induce downwash on a small scale fuselage model, this providing a new approach to fuselage design.

Since then, the improvement of test techniques and instrumentation in this facility (now owned by AGUSTA), have increased the exploitation of this small scale tunnel, which is now optimized and well suited for performing useful testing in support of aerodynamic design and analysis.

An introductory chapter summarizes the history of the facility and presents its major features.

The most significant activities conducted during past years are then reviewed, divided according to the application: starting with Airframe Aerodynamics, the force, pressure, visualization tests are described, followed by Propulsion System testing.

Following this, a discussion of Rotor Testing is included and a chapter dedicated to Store Separation Test concludes the presentation.

In all cases, the test techniques and the results obtained are discussed, including the problems associated with quality of results and their validation, obtained with analytical methods, tunnel comparison, flight data correlation.

The beneficial effects of the collaborative programs during these years are acknowledged, as a means of exchange of information and opportunities of comparison, allowing a general improvement of confidence; examples of these activities have been already presented (refs.2 and 3).

The current status of collaborative programs is discussed in the Conclusions, which also includes considerations of development and research plans.

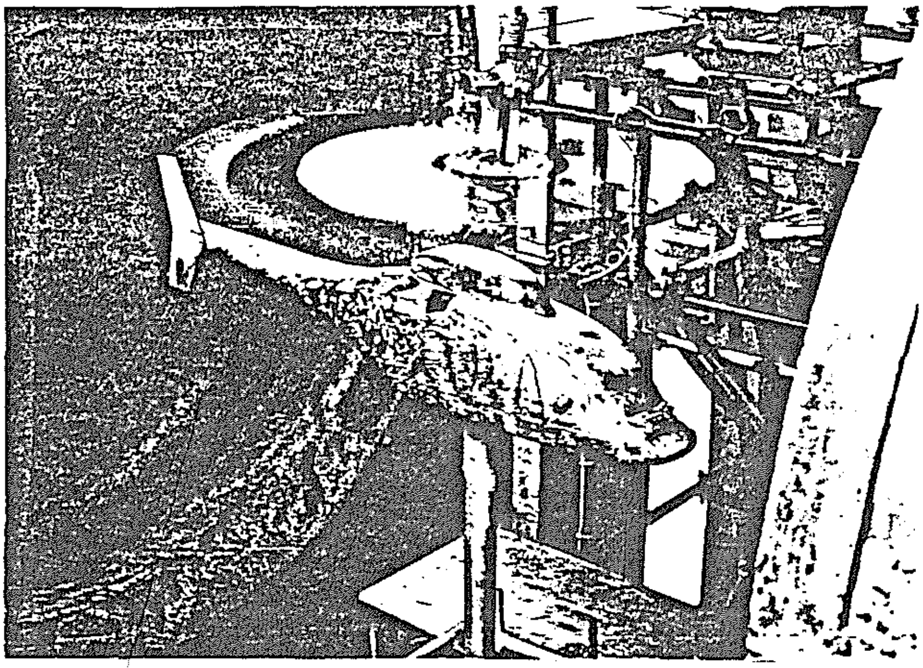


Fig. 1 - LAMPBLACK VISUALIZATIONS ON AN A109-G MODEL (YEAR 1969)

2. - DESCRIPTION OF THE FACILITY

2.1 HISTORY

The AGUSTA wind tunnel is located at Bresso, just north of Milan, in an industrial area near the local airfield.

The plant was built in 1935 by BREDA, as described in ref.4 , to be applied in the design of large fixed-wing aircraft of the prewar period.

After Second World War, the problems in the Italian aeronautical field determined a period of closure of the facility, until during the 60ties Politecnico of Milan reopened it for student utilization.

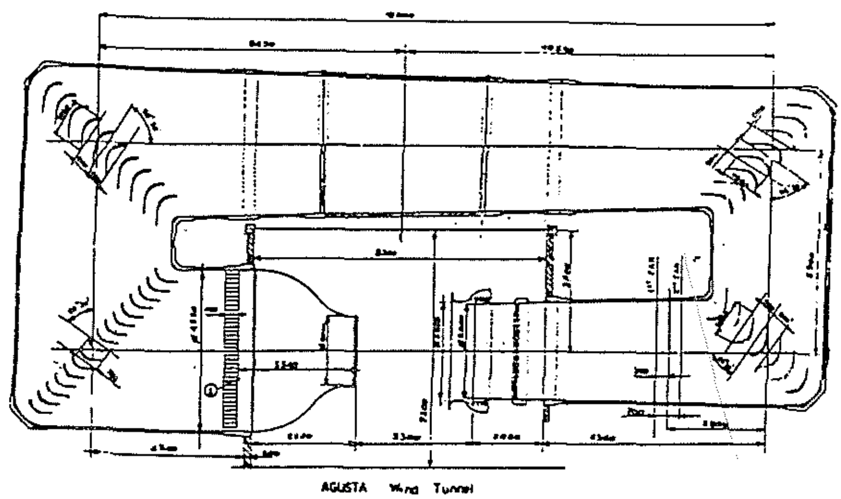
Then Aermacchi continued to run the facility, deciding after some time to build a similar one closer to the plants in Varese; see ref.5 for comparison of the application of this kind of tunnel in a fixed-wing oriented company.

AGUSTA, whose first utilization of the tunnel was in the late 60ties, decided to enter the tunnel and use it, first on a rental basis with Politecnico, then by purchasing the plant at the beginning of 1981.

Now the tunnel belongs to AGUSTA S.p.A., but it is run by the personnel of the Aerodynamics Dept. of Costr. Aer. G.AGUSTA, leader company of the AGUSTA Helicopter Division.

2.2 TUNNEL CHARACTERISTICS

The tunnel is a closed-return, single circuit, open jet test section type, as shown in fig.2 , where also the other important features are given.



- Open Jet Test Section (2 m dia, 2.5 m length)
- Simple return Circuit; Contraction Ratio 5.18
- D.C. Driving Motor, 200-600 kW (800 RPM typ.)
- Two 8-bladed Corotating Fans, Variable Pitch
- Test Speed from 0 to 70 m/s (Typical Speed 50)
- Turbulence Factor 1.2; Duct Loss Factor k_0=0.26

Fig. 2 - TUNNEL LAYOUT AND CHARACTERISTICS

The investments on the facility have concerned both the building, restored to a functional level, and especially the rigs and the instrumentation.

In the following chapters, under each heading concerning a typical application, details will be provided of the test rig configurations used, followed by description of the dedicated instrumentation and data acquisition techniques.

It is to note that the Bresso facility has local Model Shop capacity, used for adjusting and minor modifications, whereas the basic model manufacturing is performed at Gallarate in the Lofting and Model Shop.

The design and development of the models are care of the personnel of Aerodynamics Dept., with continuous link and support of the Preliminary Design Dept.

The computer system, based on an HP1000-F, is operated by tunnel personnel, running FORTRAN programs for control, acquisition and processing purposes, which are developed with support of SANDRA (Data Acquisition Group of the Flight Testing Dept., at Cascina Costa).

The tunnel data are made available to the other groups at C.Costa by transfer on mag. tapes; it is under study to link the tunnel H.P. computer to the AGUSTA Mainframes, to allow faster access to test results.

A group of aerodynamicists is located at Bresso, who act as Project Engineers for all testing phases, from definition to reporting; they also take care of the development and qualification of the test techniques, with joint effort of the operative personnel.

The Experimental Aerodynamics Group at Bresso has then capability to deal with requirements from both internal and external customers, operating as a service.

3. - TESTING

In the following, the typical testing activities conducted at the tunnel are described, with several details of the applications and of test results.

The different tests are separated according to their objectives, as Airframe Aerodynamics, Propulsion System, Rotor Aerodynamics and Store Separation.

3.1 - AIRFRAME AERODYNAMICS

The most used application of a small subsonic tunnel concerns the Configuration Development and Drag and Stability Verification of *fuselages* and *fuselage components*; the aerodynamic characteristics to be obtained range from global forces to pressure distribution, and require different approaches with regards to test technique to be applied.

3.1.1 - Fuselage Force Testing

With the objective to obtain an optimum aerodynamic design or to provide the global aerodynamic characteristics of a configuration, the technique being used most frequently is the force testing on modular models.

Limiting ourselves to the isolated fuselage tests (rotor wake effect will be dealt with in par 3.3), the current practice at AGUSTA is based on a single strut-supported test set-up (see fig.3), allowing movements in the ranges $-30° \leq \alpha \leq 30°$ and $-180° \leq \alpha \leq 180°$, with force measurements taken by internal six-component balances.

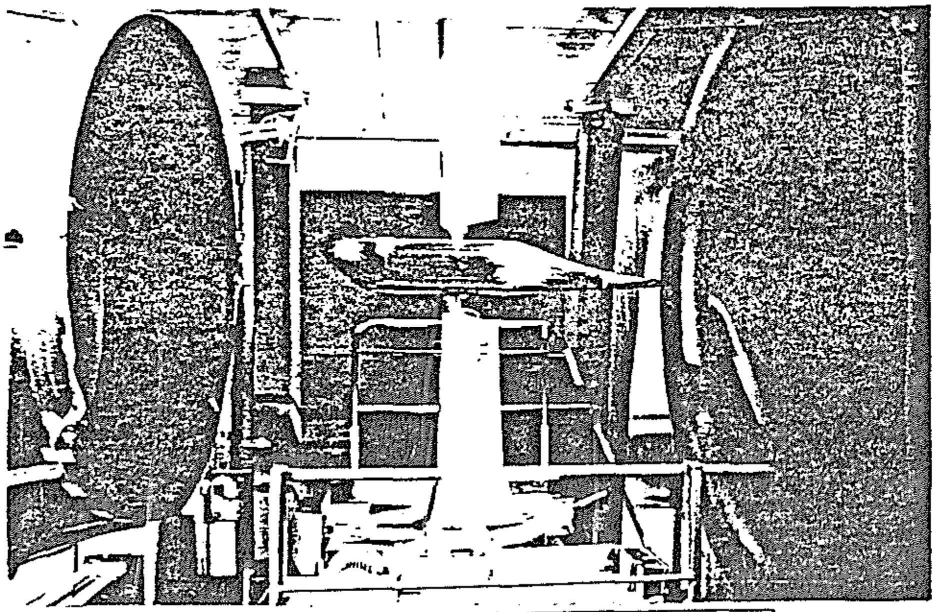


Fig. 3 - TEST STAND FOR FORCE TESTING

The models are manufactured in wood and fiberglass, with machined metal parts for the modules and the support system attachments (see fig.4).

The test conditions, specified in a test program, depend on the objectives, e.g. whether drag studies, or stability analyses, or high angles conditions are required; these define the range of variables (sweeps in α or β, angle increments, tunnel speeds, model configuration, etc.).

The test procedure of model buildup, as for drag breakdown, need to be specified: current practice at AGUSTA is to add to the basic fuselage the components up to complete configuration (cowling; M.R.Head; sponsons; appendages; tail surfaces; followed by the only provisional parts): this sequence is also useful for analysis of the contributions of each component to other characteristics, say to directional stability.

The approach followed is clearly identified in the final report of the aerodynamic characterization.

After the initial zero readings, the measurements are taken during run at each data point: the signals from the balance are amplified and processed either by a scanner system or by an A/D converter. The data are then stored in the computer memory for subsequent processing.

The test corrections applied concern, as usually, the support interference effects (obtained by tests in the direct / inverted model modes), plus tunnel corrections (as buoyancy effects, flow characteristics). The scale effects are dealt with by application of transition devices on both fuselage and tail surfaces (this solution is preferred to applying no tripping devices), and by suitable extrapolation to full-scale values. An example of use of surface oil patterns to define application of tripping devices is dealt with in par. 3.1.3.

These corrections are subject to continuous refinements, based on analyses and testing of dedicated models, flow surveys, etc., and are rechecked at each new application.

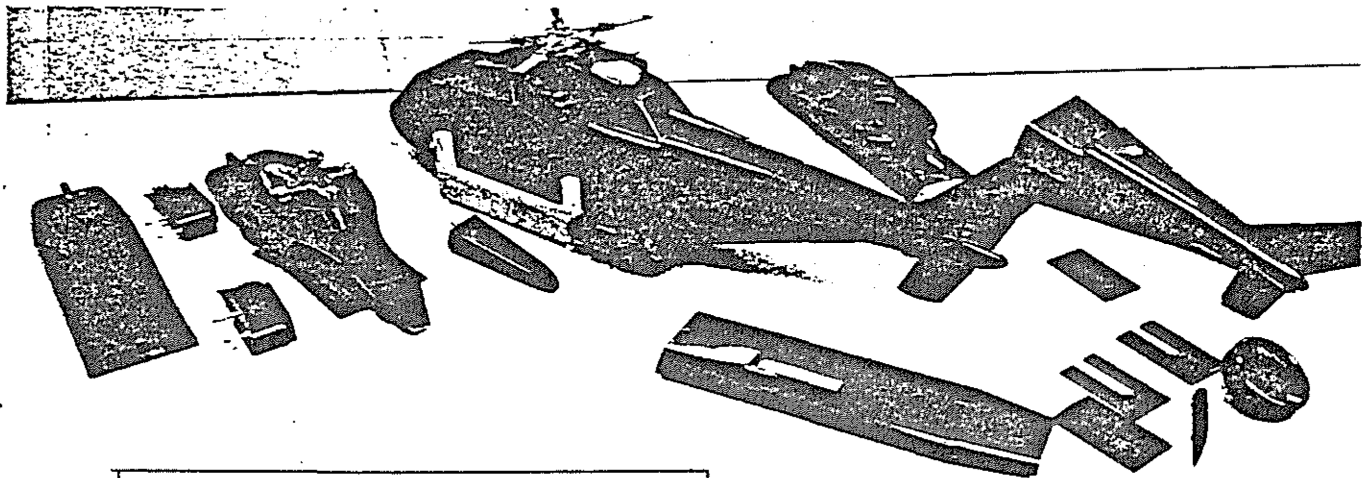


Fig. 4 - FUSELAGE MODULAR MODEL

The results are then presented both in tabular form and as plots for their use in aerodynamic analysis, performance estimates, handling qualities and flight simulator programs; if required further processing can be done (as calculation of slopes and curvatures of forces vs angles, or extrapolation to high angles).

The most important point is to validate the results obtained from the tunnel; one procedure followed at AGUSTA consists of comparison of flight test data with results from trimming analyses (or flight simulator) using tunnel test results as input for aerodynamic characteristics.

As an example, fig.5 shows how well C-81 results, using fuselage data from force tests on a 15% scale model correlates with actual flight data for a tailplane-off configuration of the A129 helicopter, in terms of attitude and controls.

Here, as in most cases, the tunnel data for drag are corrected to include the terms based on assumption or estimates (excrescences, engine loss, etc.); as far as drag is concerned, care should also be taken in using the power measurements from flight tests to obtain drag.

Another way of validation consists in the comparison of tunnel results from different facilities on the same configuration, with care of the differences in support system, flow conditions, model scales, corrections, etc.

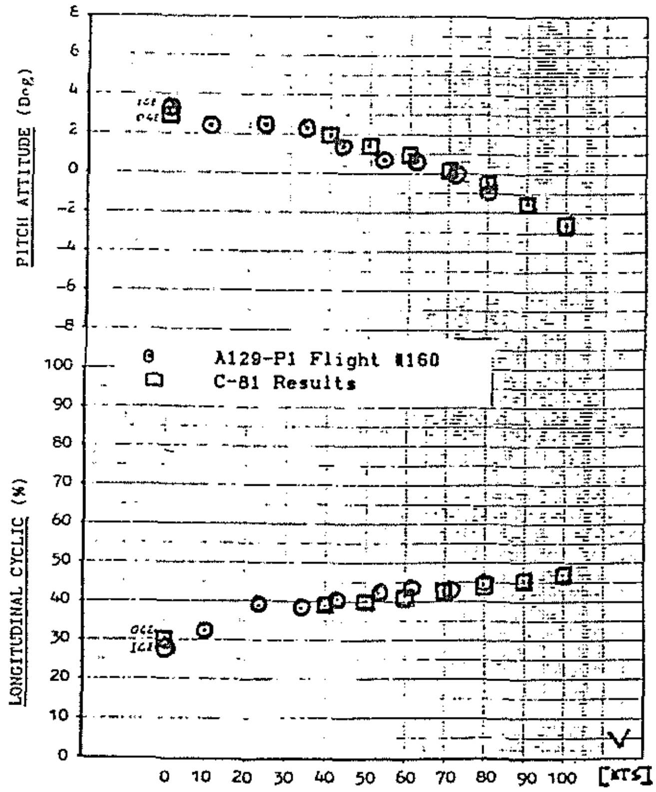


Fig. 5 - COMPARISON OF FLIGHT RESULTS AND TRIMMING DATA USING TUNNEL CURVES

This is the case of the EH-101 and of the collaborative program with W.H.L., some example of which were described in ref.3; current activities for the NH 90 FPDS also allow comparison of this kind, having as a term of reference the LST-NOP.

It can be stated that Agusta experience in application of tunnel results in support to flight testing in terms of evaluation of expected effects of configuration changes, is positive; in any case, continuous development is required to improve the confidence in using tunnel data to predict full-scale performance.

Another point which is to be stressed concerns the model manufacturing: the time needed to realize a model must be as short as possible, to prevent unuseful testing on out-of-date configurations. The use of CAD-CAM procedures can possibly be a solution to this problem.

Special care is dedicated to tail surfaces finishing and setting procedure; development for installing small balances for measurements of local loads is in course.

Refinement of simulation of propulsion system is also a subject for further studies, in order to obtain a more precise drag evaluation of engine installation.

3.1.2 Pressure Measurements

In the aim of providing data for airloads and help interpreting force test results, surface pressure measurements are made on special models, whose only difference from force models consists in instrumentation, being scale, modular solution and attachment system the same.

The walls of the model are thicker (usually 5 to 8 mm when in fiberglass) to allow insertion of metal tubes to realize pressure tappings; positioning and drilling of the holes is made on C.N. machines.

The internal design provides accommodation for the Scanivalves and the plastic tubing (see fig.6).

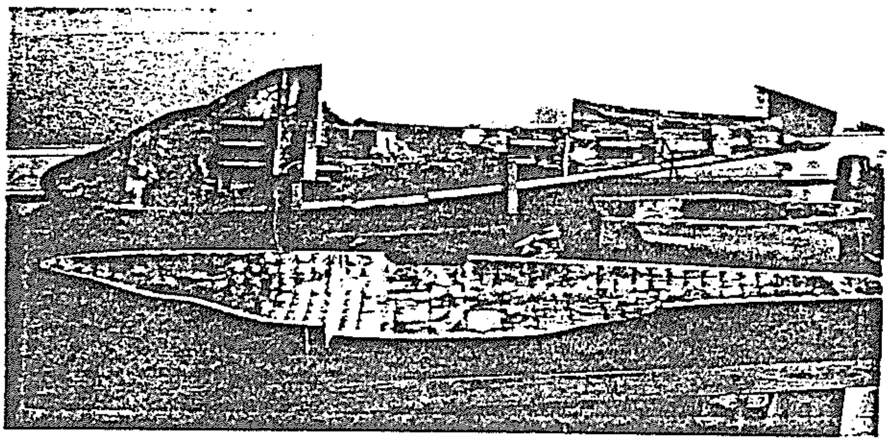


Fig. 6 - FUSELAGE PRESSURE MODEL

All the system is remotely controlled by computer, the acquisition being performed by A/D Converter technique, whose application allows a drastic reduction in testing time compared with the Scanner solution. The current time for each run on a given test condition on a 400-probed model is less than 1 minute.

Data analysis requires the storage of both probe coordinates and pressure results, plus a dedicated processing for local analysis on regions or components.

The available programs provide both a 'box' method for surface analysis with contour output (see fig.7) or a cross section representation with either normal or polar vectors.

The pressure measurements are a good experimental data base for panel method validation: in the attached flow case, where a potential solution is valid, the results correlate well, as in the case of the EH 101 nose, compared in fig.7.

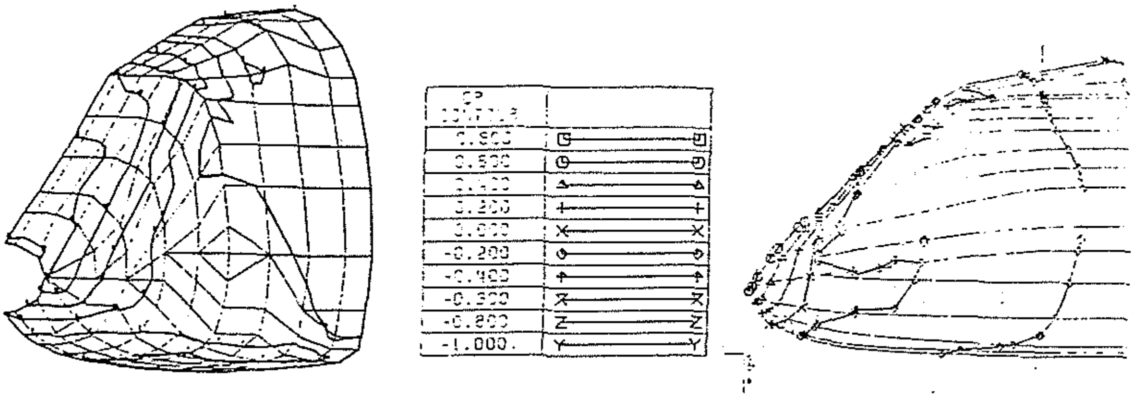


Fig. 7 - COMPARISON OF PRESSURE MODEL MEASUREMENTS AND PANEL METHOD RESULTS

A comparison has also been conducted between flight tests and tunnel measurements, in the case of the A109 Emergency Version, whose doors where instrumented and tested on the basic model; fig.8 shows the pressure distributions obtained in the two tests.

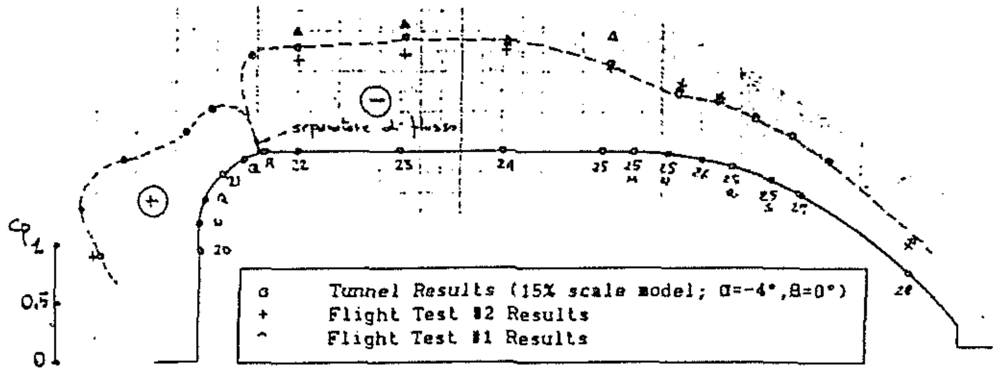


Fig. 8 - COMPARISON OF PRESSURE MODEL MEASUREMENTS AND FLIGHT TEST RESULTS

The same criteria (Scanivalve system, automatic control and acquisition, graphical output), is used for wake surveys using rakes with pneumatic probes; some details of the traversing system are given in par. 3.3.

3.1.3 Flow Visualizations

In order to interpret force and pressure results and as a means for analyzing aerodynamic interaction between components, several techniques can be employed which provide flow field pictures.

As a preliminary study, the wool tufts technique is a simple method to obtain useful information; at Agusta, the application of Nylon Tufts in a UV-light environment has been developed, with very interesting results also on fixed wing application, or tail surfaces (fig.9).

An example of comparison of tunnel flow visualizations and flight surveys using wool tufts can be found in ref.6.

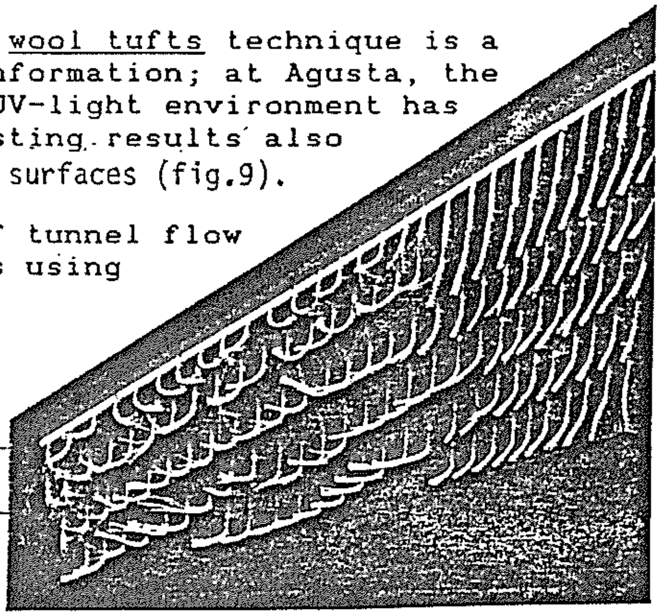


Fig. 9 - UV-LIGHT TUFT VISUALIZATION

For surface flow analysis, the oil smears technique is applied where details are needed of the behavior of the 3-D boundary layer, as in the case of identifying regions of separation and transition (fig.10): a typical use concerns the application of tripping devices (type and position) on tail surfaces, by comparison of surface flow characteristics with and without tripping, at various tunnel speeds and model attitudes.

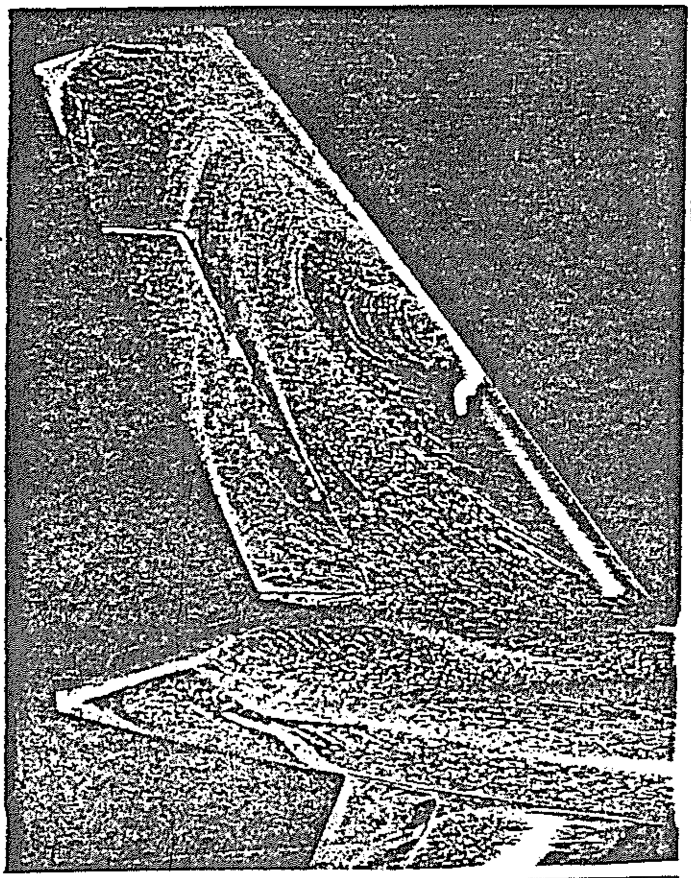


Fig.10 - SURFACE OIL VISUALIZATIONS

Other cases where this technique is useful are cowlings and rear fuselage regions, to observe the changes in flow conditions (transition or separation) as affected by interaction of other components or by test conditions.
Being the models painted in dull black, the powder used is typically china clay or titanium dioxide.

For flow field analyses, more sophisticated techniques are in use, including the so-called Light Cuts (or Light Planes) obtained by a Laser-generated light source, which can be disposed and moved as required in the tunnel working section. This application is very useful in wake surveys, from rotor wake analysis to all cases where a spatial definition of the phenomenon is required.

As tracing means both smoke (fig.11) and Helium Bubbles (fig.12) are used, being this latter method also liable to quantitative applications; in the same way the laser beam is prone to an use in advanced measuring systems, like L.D.A..

The pictures show the fuselage wake structure at the tailplane, obtained with smoke generation and a long time exposure with light cut at the station; and the pattern of streamlines at the mean chord of the tailplane.
Both tests were conducted on a 1/10th scale model.

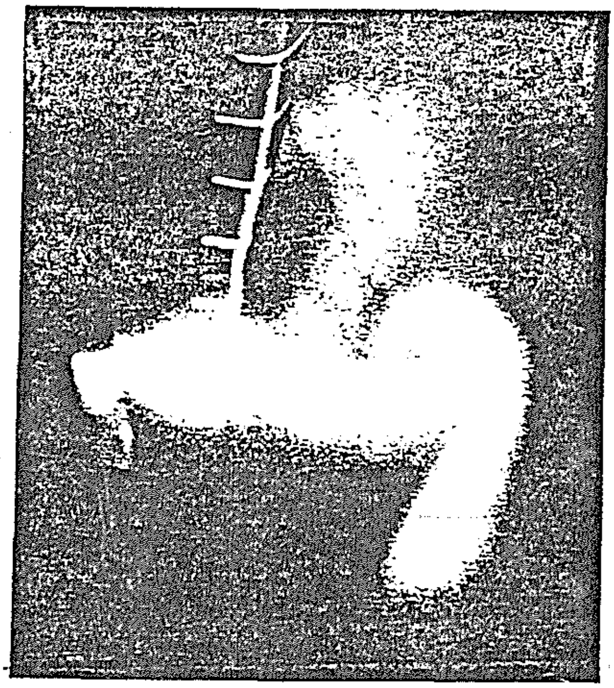


Fig.11 - LIGHT CUTS WITH SMOKE

All these visualizations are recorded on photographs or on video tapes; this latter technique allows analysis of unsteady or time-dependent phenomena, in a simpler way compared with static pictures (see also par.3.4).

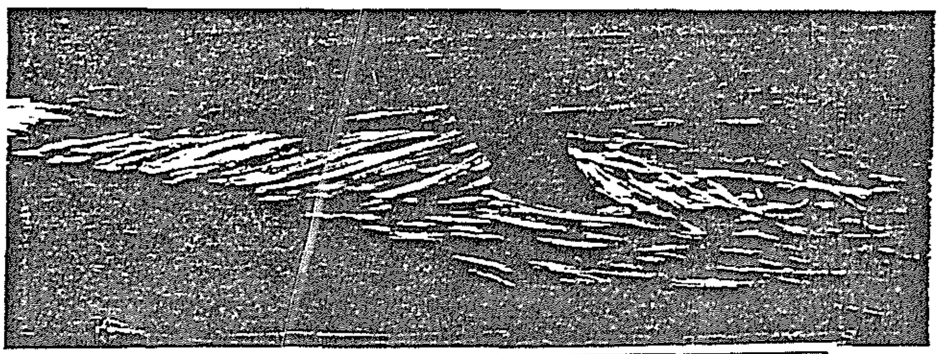


Fig.12 - LIGHT CUTS WITH He BUBBLES

This subject is considered as a most important tool in wind tunnel testing, so continuous research effort is dedicated to it.

3.1.4 Airframe Components

It is often necessary to concentrate on a single component either for more detailed analysis or for reducing the scale effects associated with complete models.

In these cases, large scale partial models are used, allowing a better definition of the geometry, although with lack of a complete interaction simulation.

Leaving the engine installation components to the next chapter, we will concentrate on the most peculiar component of the helicopter, the Rotorhead.

A. ROTORHEAD TESTING

In order to support the aerodynamic design of this component, with development of feasible fearings (stubs, shanks, beanies) to reduce drag and power, a large scale model was used in a series of static tests during early stages of the EH 101 program (see ref.3).

There the model configuration consisted of a 1/3.2 scale head, with allowed rotation about the shaft axis, plus a cowling model to reproduce the supervelocity effects; no spinning was possible and only static measurements of internal drag (basic drag and interference) were available.

These data were compared with results from a complete model, at 1/7th scale, tested at W.H.L. tunnel.

The rotorhead model, designed and manufactured at Agusta (see fig.13), reproduced both foldable and unfoldable geometries of the blade stubs, with different limits in the applicable fairings; it was interfaced with a rotating system, developed at W.H.L., to rotate the head allowing a cyclic pitch movement to be induced to the arms, by a cam mechanism.

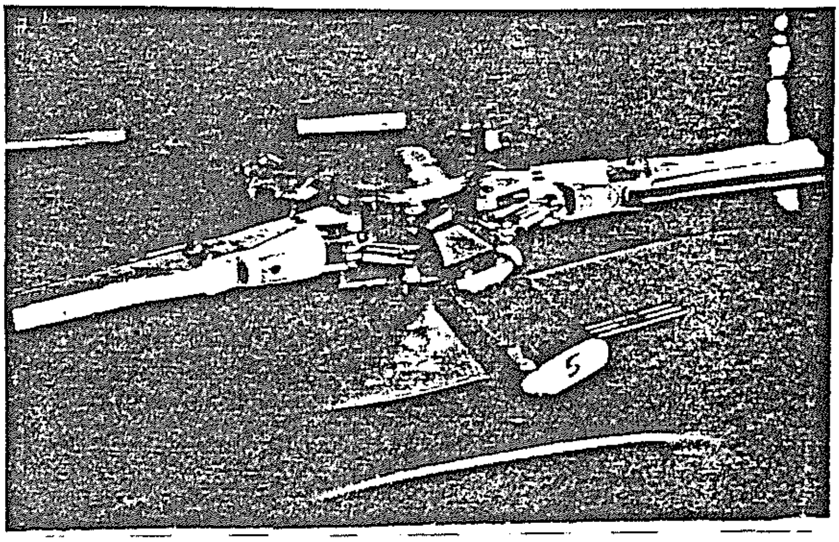


Fig.13 - 1/7th SCALE ROTORHEAD MODEL

This set-up has been tested at Agusta, as shown in fig.14, on a partial model, where no global forces can be measured.

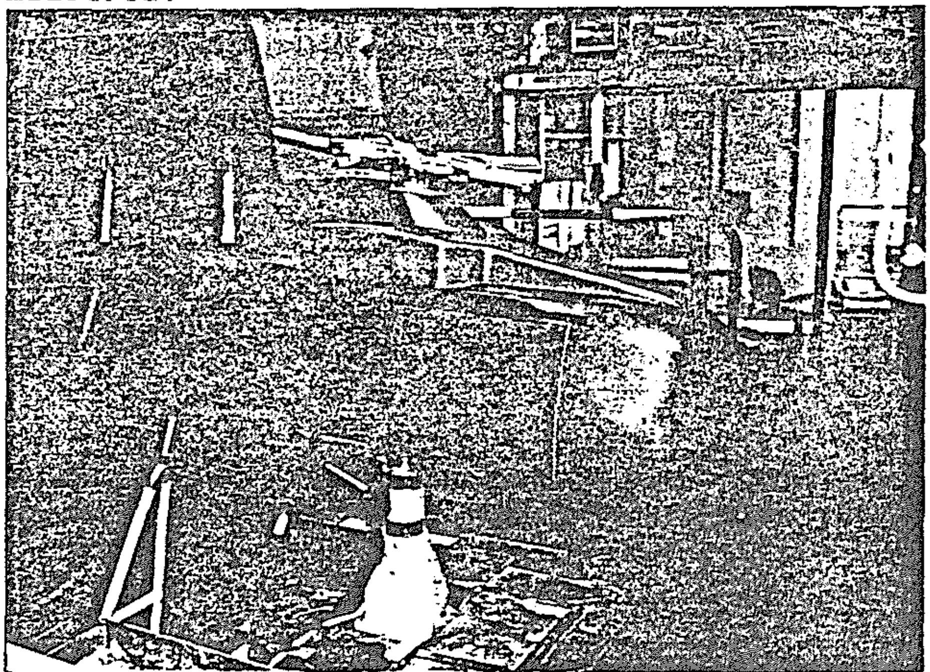


Fig.14 - FUSELAGE PARTIAL MODEL

As a means of comparison, statics on the cowlings were used, providing correlation for the supervelocity flowfield at the rotorhead to be similar in both the 1/3.2 and 1/7 scale cases, this latter also in two different facilities, i.e. Yeovil (W.H.L.) and Bresso (Agusta).

The instrumentation is limited to two load cells, one reading the axial force component on the head, the other providing the torque value, by a special support of a d.c. motor driving the head and whose control allow r.p.m. variation.

The data acquisition procedure required a careful preliminary calibration of the system, and definition of the good range of operation based on the dynamics of the system; this was found at 750 r.p.m., and the signal from the load cell was filtered at 10 Hz to give a reliable average value.

Aside from force and torque measurements, flow visualizations using a strobo-light technique was usefully applied for local analysis.

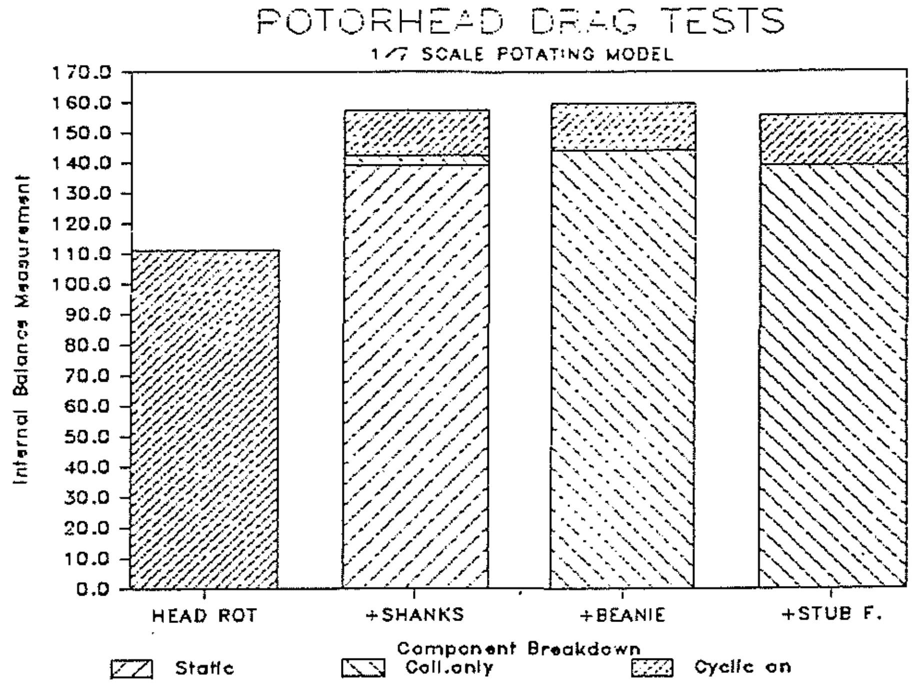
The results provide an assessment of the drag level of the different configurations, obtained by applying several added parts; also the effects of cyclic pitch presence on drag and torque was evaluated.

Test conditions, in terms of attitude and control settings, were provided by trimming analysis for the complete helicopter.

As an example, fig.15 shows the effect of application of different stub fairings, taking the basic configuration as reference.

The effect of cyclic pitch is also given in the same figure: based on these results, it is confirmed that no assumption can be made about the importance of rotation on drag, both on head alone and with blade shanks (see ref.1).

Fig.15 - RESULTS



The development of this technique will include fuselage forces measurements in order to obtain interference effects; due to the importance of rotorhead drag level on helicopter characteristics, this testing represents a very useful tool for aerodynamic design support.

B. OTHER COMPONENTS

It is worth mentioning other applications of this sort that can be conducted, like typical 2-D testing, as the case of tail boom cross section models, using both pressure and force measurements, to verify characteristics for download and sidewind conditions.

Tests on airfoils and on finite wings (tailplanes, tail units), or on appendages are feasible, provided the large scale models interface with existing rigs and balance systems, or just require minor modifications to set-up.

3.2 - ENGINE INSTALLATION

Consideration of the aerodynamics of the propulsion system is made with regards to component integration (intakes, exhausts) with the airframe.

3.2.1. Air Intakes

The measurement of aerodynamic characteristics (pressure loss and distortion, both DC60 and swirl angle) is the objective of dedicated tests, usually conducted on large scale partial models, where simulation of mass flow is required at inlets and outlets of the internal flow system under study.

Typical instrumentation are rotating rakes, with total pressure probes and yawmetres, driven by stepping motors remotely controlled. Mass flow simulation is provided by fans, plus flowmetres along the piping for control purpose.
The calibration of these probes is made in the small Calibration Tunnel in the same facility.

Not yet applied are the measurements of drag of internal flow systems, which are under consideration.
Models allow different conditions to be set, in terms of power level, and simulated flight conditions (attitudes, speed); the results are then processed by suitable computer programs to obtain global data.

As already mentioned in ref.2, the A129 air intake was developed with both static tests on a full-scale mock-up and by dedicated testing in wind tunnel on a quarter scale model (fig.16), whose objective was the assessment of interference effects of fuselage in forward flight on intake characteristics.

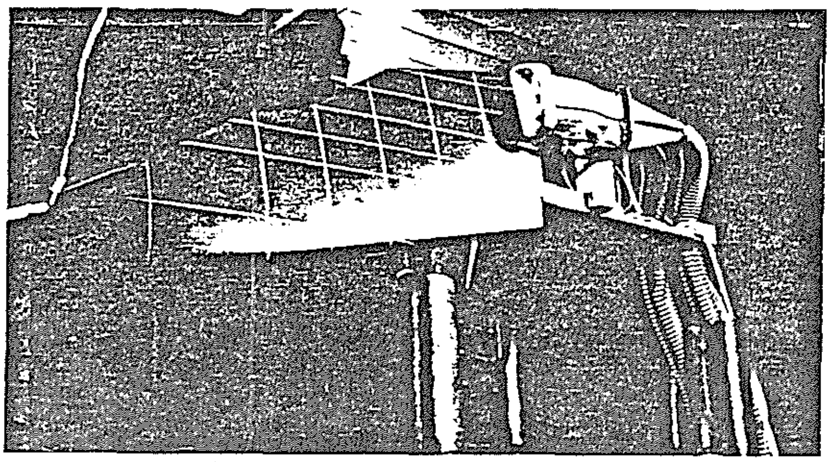


Fig.16 - QUARTER SCALE INTAKE MODEL

Using as a parameter the velocity ratio (σ*V/w) several condition were simulated, including scavenge ratio variations, sideslip angles, descent flight (both attitude and mass flow).

The measurements were taken at two different planes in the engine duct, viz. at the compressor face (where limits are stated for the correct functioning of the engine, in terms of intake parameters), and at a plane where flight instrumentation had to be installed.

The tunnel data then provided a correction factor to be applied to flight measurements, to convert them to engine face.

Fig.17 shows a comparison among the swirl results from different tests, at both planes: compressor face (tunnel and test bed) and the forward plane (tunnel and flight).

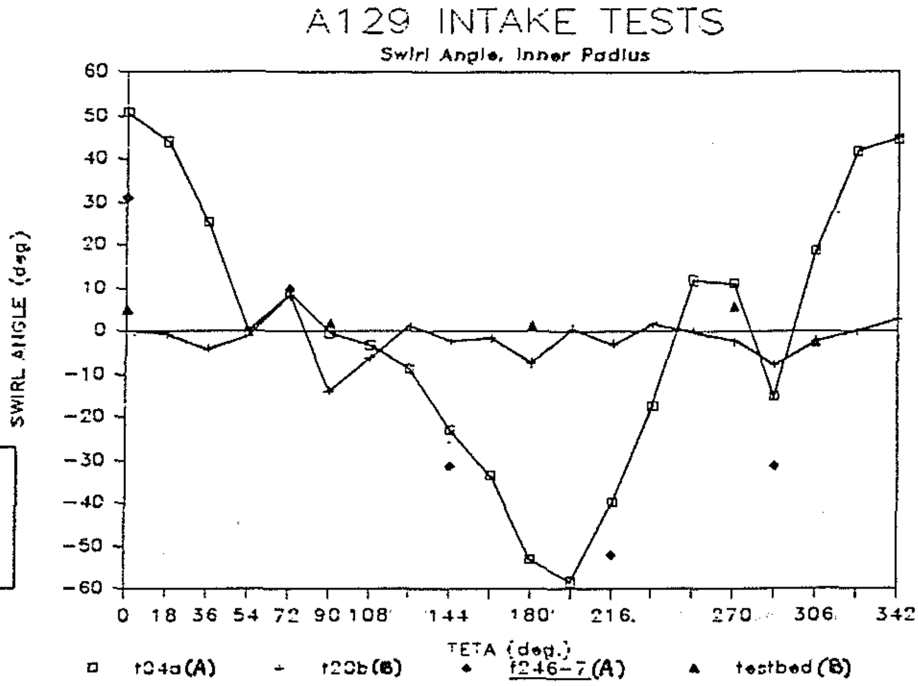


Fig.17 - COMPARISON OF SWIRL ANGLE MEASUREMENTS IN HOVER, FROM TUNNEL, FLIGHT AND TEST BED

3.2.2 Exhausts

Using jet momentum simulation, tests can be conducted on internal flow systems with cold air jets in place of hot gases; this has been applied in test beds for analysis of exhaust ejectors, with use of large fans to induce flows, typical instrumentation for flow measurements and flow visualizations being inserted in the ducts.

This technique is extended to tunnel tests on complete models, aiming at analysis of the external flowfield interference with internal system. This application is dealt with in the following section.

3.2.3. Investigation of Hot Gas Reingestion

During 1984, a dedicated testing was conducted at Agusta in support to the development of the EH-101 helicopter.

Objective of the tests was to analyze the phenomenon of recirculation of exhaust gases on the 3-engined helicopter at different conditions: hovering with wind from different directions, IGE to OGE at various ground distances, including take-off and landing cases.

The test set-up (fig.18) consisted of the fuselage model, 2/25th scale, connected by flexible tubing to centrifugal fans; a movable ground plane was mounted on a support in the test section, allowing variation of relative position between fuselage and ground.

The fuselage model is supported by the usual strut system, remotely controlled for pitch and yaw movements; the rotor model (see detailed description later) was suspended from above, with tilting freedom with respect to the center of rotation of the fuselage.

As mentioned in ref.3, after some preliminary testing on a different model, a special model was designed and manufactured which allow simulation of all 3 engine (both intakes and exhausts).

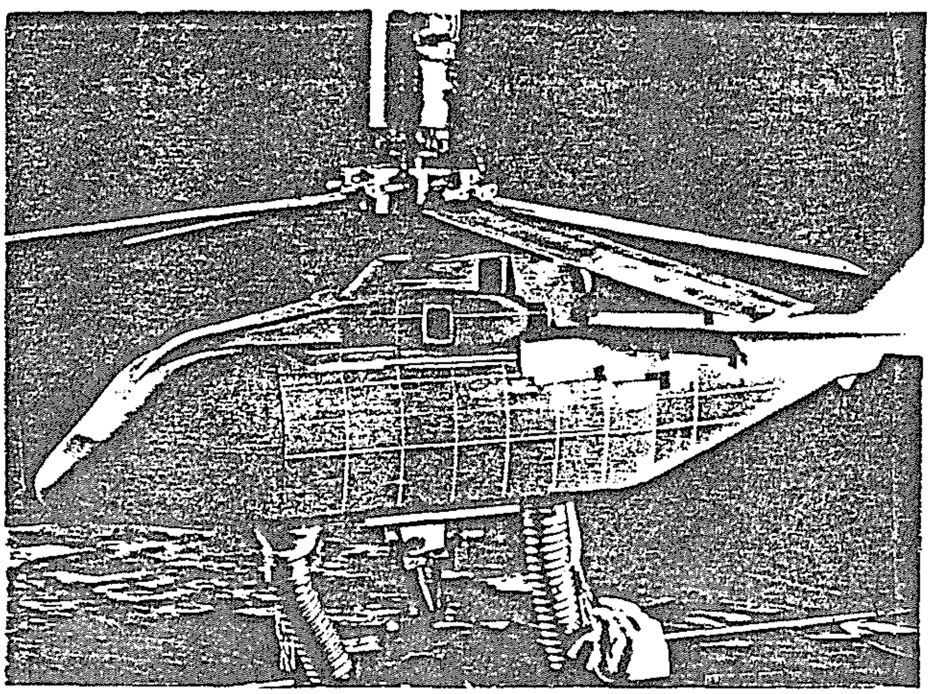


Fig.18 - REINGESTION TEST MODEL

The internal piping system is made in fiberglass and consists of a straightener chamber in the Suction section (intakes) where the 3 ducts join, each having a butterfly valve operated by a d.c. motor plus a measuring section based on total and wall static pressure probes, read by manometre.

The Exhaust portion, in a similar arrangement includes a metal pipe section where a smoke probe is fitted, the oil tubing being connected to the control unit.

A cold jet simulation was used for the exhausts, aiming at obtaining the same ratio of momentum for rotor downwash and exhaust jet.

Accordingly, at the engine power condition, the intake flow (defined as intake parameter) was determined.

The test procedure consisted of the preparation of the configuration with zero wind speed, followed by starting of rotor model and fans at the selected condition; at the chosen tunnel speed, after checking the intake and exhaust flows, the smoke was released in each outlet at a time, allowing the path followed by the discharge jet to be visualized. Variations in sideslip angles or in attitudes, requiring control of both fuselage and rotor, were possible during the same run.

Only a qualitative approach was considered in this test series, the results consisting of photographs and video recording of the most interesting cases (as shown in fig. 19). They were taken from different viewpoints, including plan, leeward and windward views; light cuts using also laser-generated planes were applied (see 3.1.3)

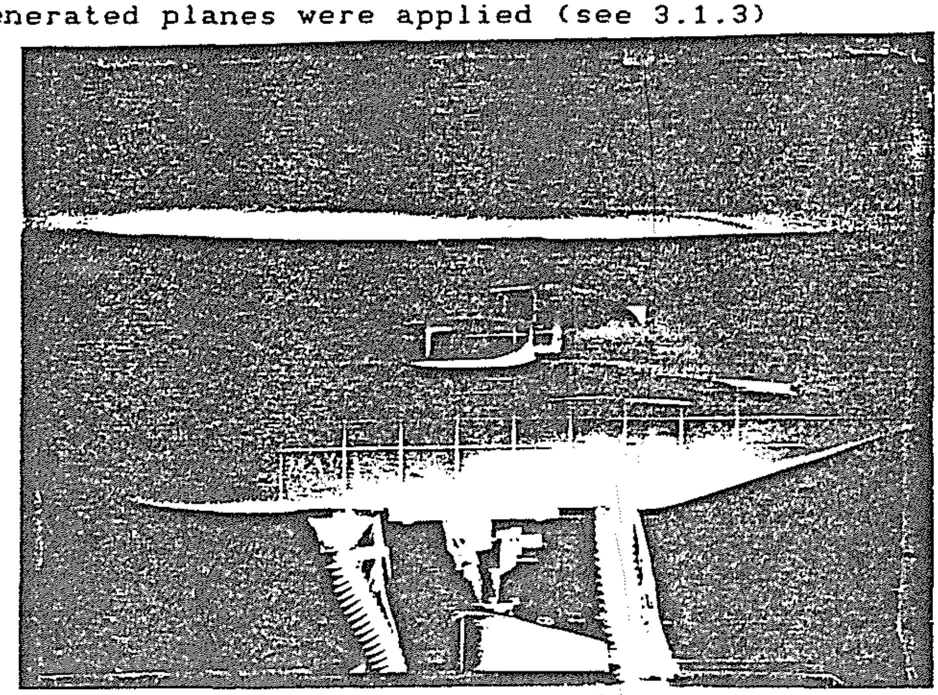


Fig.19 - EXHAUST FLOW VISUALIZATION

A development of this technique consists of a quantitative approach, with use of tracers or hot air in the exhausts together with measurements in the intakes; the simulation of small openings like the cabin conditioning system can also be considered, pending careful evaluation of scale effects.

With such a solution modifications of the exhaust pipes can be applied, evaluating the sensitivity of jet paths to these changes.

The useful information obtained are been applied to development of iron bird configuration; comparison with flight tests is planned, with further tunnel activity if required.

3.3 ROTOR TESTING

The subject of rotor aerodynamics has only recently begun to be approached in wind tunnels, if compared with fuselage aerodynamics.

The use of scaled rotor model in special V/STOL facilities is now widespread, although only a limited number of these tunnels meet the requirements for this testing to be really useful: both isolated rotor testing (for performance and wake analysis) and rotor/fuselage interference studies can be conducted.

In the following we want to discuss the experience at the AGUSTA tunnel in this field, stressing the problems which have to be faced in terms of tunnel requirements, model characteristics and limits of applicability of test results.

3.3.1. Tunnel Requirements

Both the test section (size, type, support system) and flow qualities (turbulence, flow angularity requirements) are very stringent, in order to prevent large corrections to be applied and the occurrence of serious problems due to flow breakdown, recirculation and dynamics of the rotor system.

This means that the decision of using a model rotor in a small tunnel requires a thorough analysis of all these aspects.

The first problem arises for the scale of the model to be suitable for use but compatible with tunnel dimensions and characteristics (useful flow region, support system).

When the test objectives are set (whether performance or stability, i.e. Mach- or Froude-scaling), the expected range of test conditions and resultant loads can be defined, including the support system solution.

Here a major decision is required, either a strut-supported shaft with external drive system or on integrated solution, inside a fuselage model; this latter case can only be practicable for medium to large facilities. The former, requires special attention to pylon- rotor interaction.

The operative limits of the rotor system are then obtained by analysis of rotor/flow interaction, dynamics of the support and load estimates.

3.3.2. Rotor Model

The requirements for controllability of the rotor system are for a reliable and efficient remote control system (collective and cyclic) which allows precise variation of tip-path-plane conditions. This, together with a good balance for global rotor loads, plus control and blade loads measures are the basic requirements.

Further refinements include pressure measurements on the blades, which requires a different approach to data acquisition system (slip ring).

The final scale can affect the geometry similitude of the model, as often is the case for the rotorhead, and this differences have to be investigated with respect to the effects on wake geometry.

The blades need at least to be geometrically similar to the full-scale, but the requirement for a dynamic similarity (i.e. reproduction of first modes) must be met if also blade airloads have to be measured; this of course increases complexity and cost of blades.

3.3.3. Applications

The performable tests fall into two main categories, viz. isolated rotor analysis, both performance and wake survey, and rotor/fuselage interference testing, with possible measurements on both components.

In the case of Wake Surveys, a traversing system is used, to place probes in the flow field near the rotor; a remotely controlled system allows movements of probes and simultaneous data acquisition, either from pneumatic probes or from Hot Wire probes.

A three axis system is available for a complete mapping of the flowfield, plus a rotating head for probe alignment.

It is important to control the positioning of the probes for a reliable measurements, and dispose of a suitable processing of the data for interpretation and analysis.

This is due to the fact that the rotor wake field direction is unknown a priori and a preliminary visualization (with smoke and light cuts) can help identifying location of tip vortex and main direction of local flow.

A suitable calibration of probe support is also required to avoid problems in measurement due to interference.

The acquisition need to be fast enough to store the data from a survey, and successive data processing requires a compact, meaningful graphical presentation.

The knowledge of wake characteristics allows both a comparison with analytical data and the application to rotor/fuselage interference tests.

Force measurements on fuselage with rotor-on and off can be conducted; if the rotor system features a suitable measuring system also fuselage effects on rotor forces and loads can be performed.

The experience with the rotor model shown in fig.18 was limited to wake surveys in hover (IGE and OGE) conditions, followed by force testing on the fuselage model in the presence of a rotor wake; the approach used is based on the preceding considerations.

On the basis of the results of these activities it was decided that the rotor model was suitable for application in the preliminary investigation of hot gas reingestion, with interaction of the rotor wake, as produced by this rotor (see par.3.2.3.), with similarity of the disc loading and averaged downwash.

Current plans for rotor testing at AGUSTA tunnel have been made based on the results of that experience.

General considerations are that characteristics and applications have to be tailored to the limits of the plant: only general-purpose rotor models are suitable for small scale facilities, where testing can provide assessment of airframe characteristics in a rotor wake presence, and just giving some preliminary information for dedicated tests to be performed on special models in larger facilities.

Another feasible application concerns a fin/rotor set up for fin configuration development and evaluation of blockage effects, whose study is under consideration.

3.4 - STORE SEPARATION ANALYSIS

Although more common in the fixed-wing field, the simulation of store jettison in wind tunnel is becoming now popular in the helicopter world, as a means to perform preliminary analysis of safe release conditions for stores and weapons.

When the rotor wake cannot be simulated, the results are only comparable for high speed conditions, where a direct interaction of store and downwash does not take place.

This testing is still under development and the available results are limited either to fixed-wing cases or to helicopter tests without rotor wake; it is anyway interesting to present the current status of the technique, providing examples of application.

3.4.1. Test Technique

The main objective is to define the critical flight conditions at which the store after separation can follow an unwanted path (too close to fuselage or to its components) or does not meet given requirements (like defined attitudes after a given free flight time).

The test stand for this testing is then modified to allow complete free space under the model, which is suspended from the ceiling by a dedicated support (still allowing α and β movements, the first having a reference point of rotation in the center of tunnel).

The test section includes a net to capture the stores after release; careful placing of the light system is required, as important as the other items in order to obtain a good view of the phenomenon and adequate recording via photographs or video cameras.

The "parent" aircraft model can be the same as for other testing, just including the dedicated instrumentation (like solenoids) for the release control.
The attachment system can also provide the simulation of the discharge load, usually realized by compressed air, if the full-scale system has this feature.

The store models are realized in Froude scaling, for low speed test conditions; it is a matter of experience the decision to utilize reusable models and how precise the dynamic characteristics have to be. This also depends on the application under study.

The basic technique for recording the test is a photographic one, where either the objective is left open during the test, which is conducted at dark with strobo light or, as it is preferred, by having the objective closed by a rotating disk, in a illuminated test stand.

Another promising method uses a video tape recording system, with shutter-type cameras, which provide both the necessary sensitivity to light and the shutter mechanism.

An example of the obtainable results by both techniques is given in fig.20.

The test conditions are set by the flight attitudes and speeds that need to be simulated, where speed scaling is again based on Froude similarity.

For a given case, as soon as the conditions are stabilized, the release takes place with simultaneous control of store release and recording devices operation.

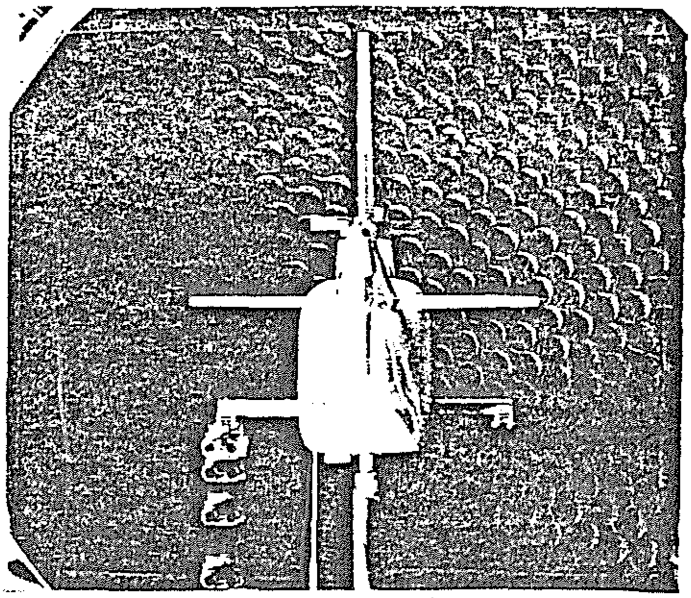


Fig.20 - JETTISON TEST PICTURE

The analysis of results can be performed just after test, if a quick-look camera is used; the use of normal cameras or film requires a long time for developing and printing.

The video technique is immediate, economical and reliable, and also prone to applications for quantitative analysis (by applying digital imaging processing, or by simply hardcopying the obtained pictures on the screen.

With these outputs is also easier to present the results from a series of tests, which can be stored on a video cassette.

A few comments can be made: the first concerns the importance of wake simulation at low speed conditions. Tests are now in preparation whose results will be compared with flight tests; an assessment of the importance of the correct wake simulation should then be possible.

The second regards the application of shutter video cameras, and the implementation of processing techniques to the results; this is the way to be followed at Agusta.

4. - CONCLUDING REMARKS

In the preceding sections details have been provided of the experimental aerodynamic activities conducted in the AGUSTA Wind Tunnel, during the last five years.

The emphasis was on Airframe Aerodynamics, which accounts for the largest occupancy of the facility, both for internal and external customers.

Force testing, pressure measurements, flow visualization techniques on complete fuselage models or on large scale partial models were described, together with comments on current status and further developments.

As examples of other applications, some details of tests dedicated to Engine Installation were given, with emphasis on air intakes and investigation of hot gas reingestion, this latter including aspects related to rotor testing, dealt with in another section.

Store Separation studies concluded the presentation of the typical testing activities.

It was stressed that a small facility has some limitations, which have to be overcome by developing suitable techniques and by improving correlation of test results.

Of course a thorough knowledge of tunnel characteristics is a prerequisite for the evaluation of large investments in the plant (e.g. increased drive system, modifications to tunnel components) and for defining limits of applications and choosing test criteria.

So the continuous learning process of applying test corrections, interpreting results, correlating them to other data, improves the reliability level of the experimental results.

To summarize the issues requiring further refinements:

- Force testing on small scale models:
    - Test corrections (support; scale effects)
    - Models (manufacturing; powerplant simulation)
    - Measurements (e.g. balances for tail surfaces)
    - Techniques (application and interpretation of visualizations)

- Component Testing
    - Qualification of rotorhead/cowls rig testing
    - Qualification of Intake Aerodynamics test

- Rotor Testing
    - Development and Application of a General Purpose Rotor Model for Wake analysis and Fuselage testing, or Fin/Tail Rotor analysis.

- Store Separation Analysis
  - Application of TV Shutter cameras on Helicopter Models, also with rotor wake presence

The related development in instrumentation and data acquisition are included in the objective.

As mentioned, both analytical methods and other experimental results can be used for comparison purpose; the current and future collaborative programs allow direct comparison of tunnel results on reference models, thus supporting the qualification of small scale testing.

Additionally, tunnel test data require intermediate processing for conversion to flight values, or vice-versa.

With a joint effort it is possible to reach a reasonable level of confidence.

It is worth noting how this process of data validation, when performed in an industrial environment, is not only a basic objective from a technical viewpoint, but also is a necessity for confirming the usefulness of the service.

It is thought that the AGUSTA Wind Tunnel has demonstrated its capabilities, with the results from tests conducted in various fields and the experience gained by the personnel.

It is believed that the AGUSTA facility plays an useful and unique role in the Italian aeronautical field, and provides an useful comparison with other similar facilities.

5. - REFERENCES

1) J.J.PHILIPPE-P.ROESCH-A.M.DEQUIN-A.CLER
A survey of recent development in Helicopter Aerodynamics
AGARD-LS-139, "Helicopter Aeromechanics", Roma, 1985.

2) G.PAGNANO-J.R.BALLARD
Development and Testing of the A129 Air Intake
9th Europ.Rotorcraft Forum, Stresa, 1983; paper 99.

3) F.T.WILSON-G.PAGNANO
Aerodynamic Design Issues of the Anglo-Italian EH-101 Helicopter
9th Europ.Rotorcraft Forum, Stresa, 1983; paper 10.

4) M.PITTONI
La galleria del vento dell'Aeronautica Breda
AUTO-MOTO-AVIO, n.5; 1939. Pagg.71-76

5) R.MARAZZI-D.MALARA-M.LUCCHESINI-S.COMORETTO-F.PACORI
Use of a small scale wind tunnel and model shop at Aeronautica Macchi as an industrial tool
AGARD-CP-348, "Wind Tunnels and Testing Techniques", Cesme, Turkey, 1983.

6) M.VENEGONI-E.MAGNI-R.BALDASSARRINI
An industrial rationale for the aerodynamic design of the fuselage for a high performance light helicopter
3rd Europ.Rotorcraft Forum, Aix-en-Provence, 1977; paper 44.

ACKNOWLEDGEMENTS

This paper is dedicated to all those whose effort has permitted to reach the present level in the facility.

Thanks for supporting the preparation of pictures to G.CROSTA and to F.T.WILSON and G.PREATONI for their useful comments.