NINTH EUROPEAN ROTORCRAFT FORUM

Paper No. 99

DEVELOPMENT AND TESTING OF THE A129 AIR INTAKE

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September 13 - 15, 1983
STRESA, ITALY

Associazione Industrie Aerospaziali

Associazione Italiana di Aeronautica e Astronautica

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ABSTRACT

The design and development of the air intake system of the A129 antitank helicopter is presented with a discussion on the results of the testing conducted.

With a main objective of a good intake/engine compatibility but also looking for the best aircraft/intake integration by means of a careful aerodynamic design, an experimental program has been conducted both on the intake alone (full scale component testing) and on models of the complete aircraft.

Testing during the development and the qualification phases is described with regard to test conditions and results.

The A129 intake, a dynamic one featuring an inertial separator system, has been shown to have excellent aerodynamic characteristics (pressure loss and pressure distortion) allowing good engine performance. In order to obtain the longest engine life special attention was paid to the internal design which resulted in good protection from erosion across a wide range of sand environments. A FOD efficiency of almost 100% has been achieved.

The intake does not need any heating for flight in trace icing condition, but an antiicing system based on bleed hot air provided complete protection in icing conditions conforming to AVP 970.

Scaled wind tunnel testing analized the effect of the intake/cowling design on the aircraft stability and drag characteristics.

Further wind tunnel tests are planned to assess the intake/airframe integration, together with the flight testing.

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1.0 INTRODUCTION

The design of intakes for helicopters is a special subject where a number of interdisciplinery problems are met; the integration with the airframe is affected to a great extent from the interaction between rotor and inlet and from the fuselage shape.

The aerodynamic design of the engine installation and especially of the intake must depend upon the size, type and mission of the helicopter as shown in ref. 1.

During the engine installation it is usual for the engine manufacturer to assist the airframe designer in choosing the best solution to fit the requirements.

With the aim of a good engine-airframe integration special care has to be devoted to the intake design in order to optimize the aerodynamic and environmental characteristics. Due to the current limitations of theoretical methods for these analyses, testing on models in facilities is necessary to develope the inlet and achieve the required performance. A fully 3D aerodynamic and trajectory prediction method must be developed and verified before model tests can be significantly reduced. Some work along these lines is in progress (see ref. 2).

This paper presents a summary of the experimental activity conducted on the A129 air intake during a 3-year joint programme between AGUSTA and ROLLS-ROYCE that followed an entensive 5-year programme by ROLLS-ROYCE on a number of separator concepts.

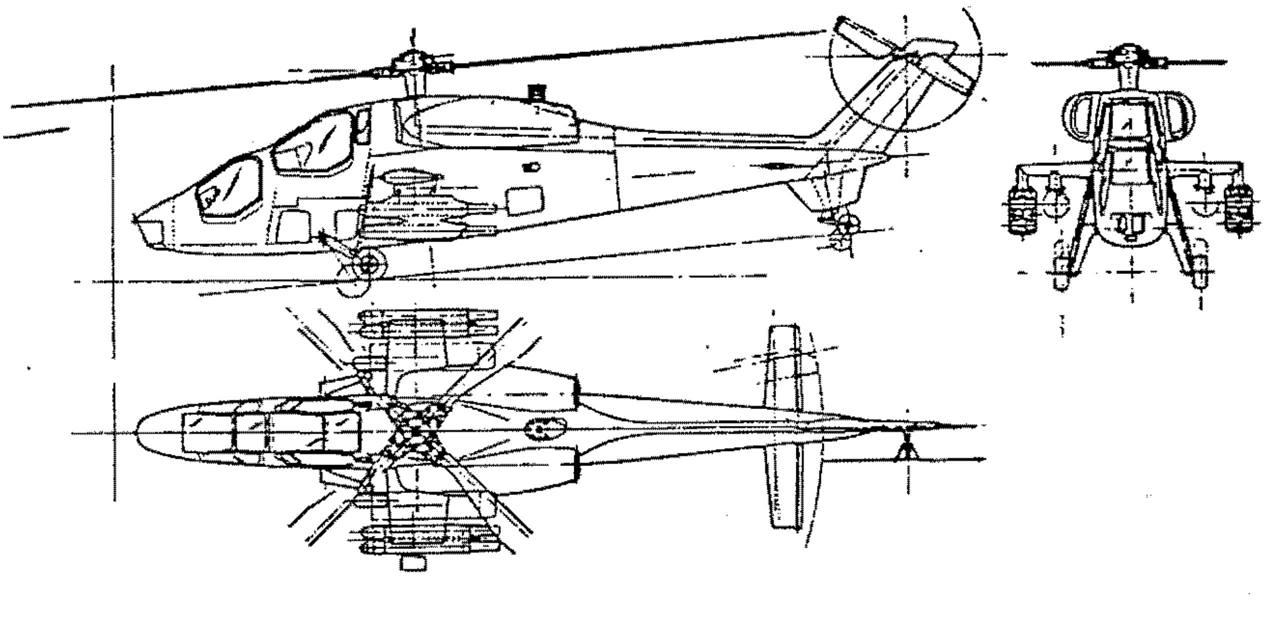
After a short description of the A129 helicopter and of its intake requirements, the development phase consisting of aerodynamic, sand filtration and icing tests on a full scale model will be discussed. Some results from wind tunnel are also shown and the planned flight testing is mentioned.

2.0 A129 DESCRIPTION

The AGUSTA A129 is a light, twin turboshaft powered, combat helicopter under development for the Italian Army use, primarly in the anti-tank role. It has a single, four-blade, articulated main rotor and a two-blade, semirigid, tail rotor. The crew of two is seated in tandem with the aircraft commander/pilot seated aft and above the copilot/gunner. Armament is carried on four pylons mounted on stub wings. The primary armament is the HUGHES Aircraft Company TOW missiles system. Rockets, machine guns pods, and external fuel tanks can also be carried on the armament pylons.

Propulsion is provided by two ROLLS-ROYCE GEM-2 MK.1004D engines capable of developing up to 918 SHP each.

The take-off gross weight in the Italian Army primary mission configuration is 8080 lbs (3665 Kg).



AGUSTA A129

3.0 INTAKE DESIGN

The A129 intake design is based on the inertial separator scheme; the scavenge by-pass flow is designed to give high separation efficiency and is entrained by an exhaust ejector thus ensuring a high reliability and low cost design.

The intake was initially designed to follow as closely as possible to the optimum geometry evolved from earlier ROLLS-ROYCE research tests. Subsequently the engines moved outboard for consideration of engine vulnerability and the intake design changed slightly to the current configuration, chosen for the prototype aircraft.

Configuration changes were applied during the development phase on the basis of the test results. This evolution concerned mainly the internal design in order to improve the performance in terms of pressure loss and distortion or F.O.D; visualization with wool tufts showed a region of flow separation at the bend and suggested the fairing of the gimbal shroud and an entry lip change. This action resulted in a lower ΔP at about the same distortion level. These modifications naturally had an effect on the dust filtration characteristics and on the response in icing environment.

The A129 air intake can accomodate a vortex pack to enhance its dust filtration efficiency, as is required for desert operation. This activity is in progress and results (both from ground and flight testing) will be presented in a future paper.

4.0 MODEL DETAILS

To assess the performance of the A129 air intake a full scale glass fiber model was manufactured to measure the aerodynamic, dust filtration and icing characteristics.

The model, which is shown in fig. 1 , was manufactured in two halves plus a removable drive shaft fairing. A removable panel in the outboard wall allowed access to the engine duct and splitter for observation and alterations.

In the aerodynamic tests the complete model including a GEM inlet casing was fitted with compressor entry plane total, static and yawmeter instruments. These were removed when F.O.D. separation tests were being conducted.

The same model was also used in the dust cell for the filtration efficiency tests and for the icing tests when fitted with hot air anti-icing system.

5.0 TEST PROGRAMME

Previous research test results on similar intakes has shown that this type of intake is rather insensitive to the effects of forward speed, especially in the presence of the fuselage boundary layer diverter.

Static tests were therefore considered to be sufficient to ensure the intake conformed with the engine requirements; nevertheless, the aerodynamic interaction of the fuselage upstream of the intake (window corners) in special flight attitudes was analysed via small scale wind tunnel tests and can be the objective of further analysis.

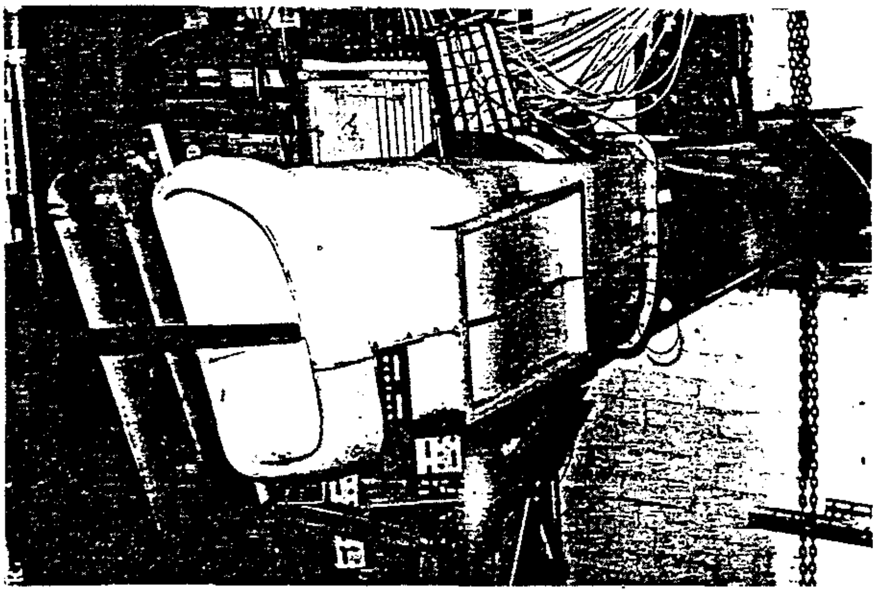


Fig. 1 - INTAKE MODEL

The experimental activities conducted were:

- Static Aerodynamic Tests
  - Pressure loss
  - Pressure distortion
  - Foreign object ingestion (F.O.D.)
- Dust Separation Tests
  - Separation efficiency (BS1701-MIL.SPEC)
- Icing Performance
  - AVP 970 - MIL SPEC
- Small Scale Wind Tunnel Tests

This programme of tests was conducted jointly by AGUSTA and R.R. in accordance with technical support agreement.

The facilities chosen to run these activities were:

- ROLLS-ROYCE Halford Lab.-Hatfield	ENGLAND
- M.V.E.E. Dust Test Fac. - Christchurch	ENGLAND
- LUCAS Altitute TestFac. - Burnley	ENGLAND
- AGUSTA Wind Tunnel - Bresso (Milan)	ITALY

The flight testing is scheduled to start in Sept. '83 at Cascina Costa (ITALY).

6.0 AERODYNAMIC TESTS

6.1 Test arrangement

Tests were conducted on a suction rig, which is shown in fig. 2. It comprised the A129 intake model coupled to a GEM inlet casing with main (engine) and scavenge ducts leading via orifice meters to a single constant speed fan fitted with an inlet throttle valve.

Instrumentation comprised the GEM compressor entry traversing rakes plus flow wall statics in the intake scavenge duct.

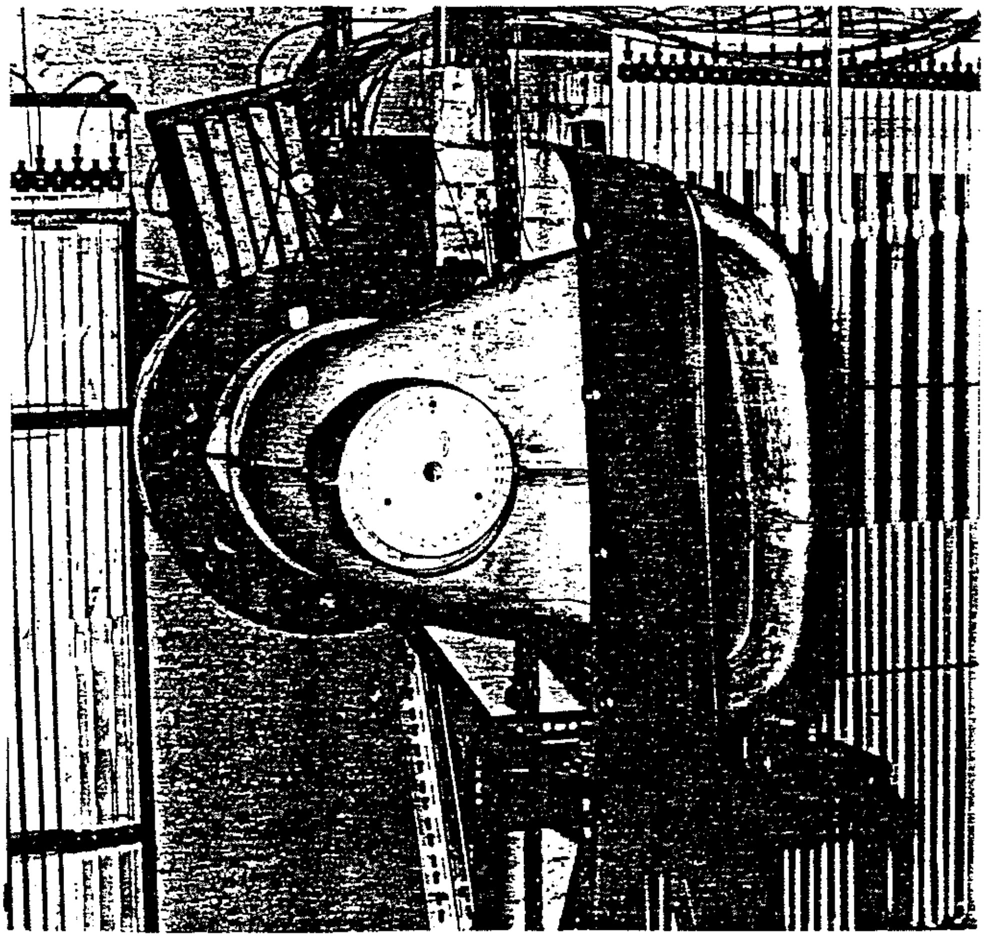


Fig. 2 - AERODYNAMIC TEST RIG.

6.2. Test Procedure

The intake was tested statically over a range of scavenge flow, with measurements of mass flows and recording of the instrument spool reading at 15° circumferential intervals. These data were then processed and the results given in graphical form when necessary.

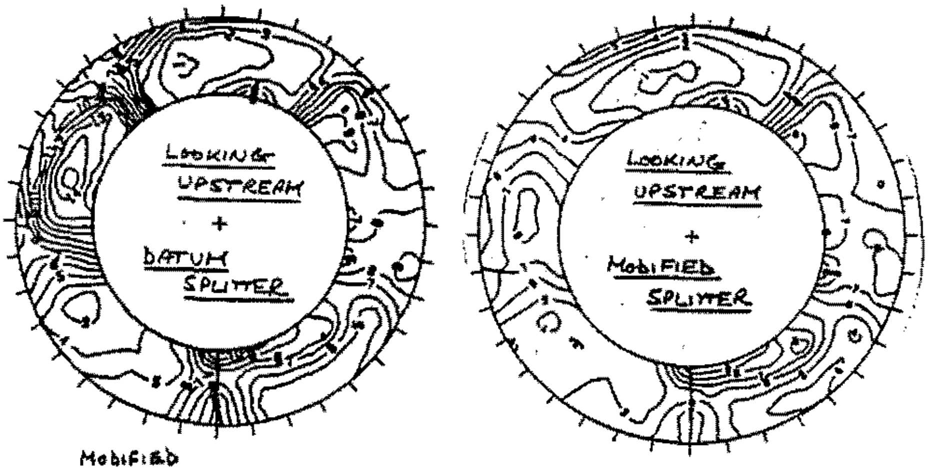
The pressure distortion parameter D.C.60 is defined as the difference between the lowest total pressure meaned over any 60° sector and the averaged total pressure over the whole compressor face divided by the mean dynamic head.

6.3. Test Results

The pressure loss distribution at the compressor entry plane is shown in fig. 3;the profile of the splitter lip was modified in order to improve the flow quality.

The pressure loss characteristics of this geometry at the design engine and scavenge flows was less than predicted; the pressure distortion and swirl angle were well below the limits stated in the engine manual. Also the circumferential variation in total pressure and flow angle did not exceed the values representing dangerous mechanical excitation for the compressor blades.

It is planned to have comparison and correlation between these static data and the tunnel and flight testing results.



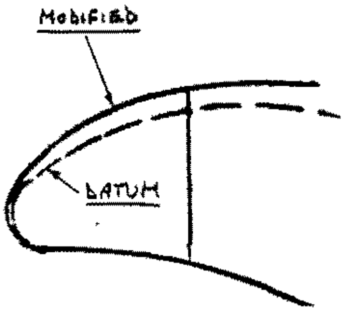


Fig. 3 - SPLITTER MODIFICATION EFFECT ON PRESSURE LOSS DISTRIBUTION.

7.0. FOREIGN OBJECT SEPARATION TESTS

7.1. Test Rig and Method

The same test rig was used for the separation tests. Debris was introduced into the inlet by three methods namely:

a) Using a chute.

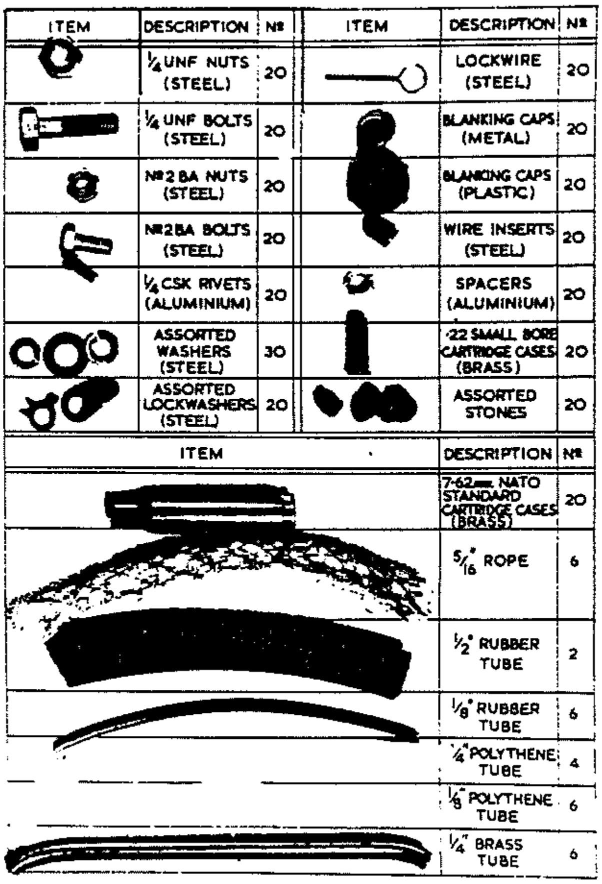
b) By leaving debris lying in the inlet before start up.

c) By throwing items by hand.

Tests were conducted at a scavenge ratio of 50% and at an engine flow equivalent to a power of 680 SHP.

A total 21 different object were used as shown in figure 4.

FIG. 4 FOREIGN OBJECT DETAILS



ITEM	DESCRIPTION	Nº	ITEM	DESCRIPTION	Nº
	¼ UNF NUTS (STEEL)	20		LOCKWIRE (STEEL)	20
	¼ UNF BOLTS (STEEL)	20		BLANKING CAPS (METAL)	20
	Nº 2 BA NUTS (STEEL)	20		BLANKING CAPS (PLASTIC)	20
	Nº 2 BA BOLTS (STEEL)	20		WIRE INSERTS (STEEL)	20
	¼ CSK RIVETS (ALUMINIUM)	20		SPACERS (ALUMINIUM)	20
	ASSORTED WASHERS (STEEL)	30		·22 SMALL BORE CARTRIDGE CASES (BRASS)	20
	ASSORTED LOCKWASHERS (STEEL)	20		ASSORTED STONES	20

ITEM	DESCRIPTION	Nº
	7·62mm NATO STANDARD CARTRIDGE CASES (BRASS)	20
	5/16" ROPE	6
	½" RUBBER TUBE	2
	⅛" RUBBER TUBE	6
	¼" POLYTHENE TUBE	4
	⅛" POLYTHENE TUBE	6
	¼" BRASS TUBE	6

All the items shown were used for each test. Items such as tubing and rope were tossed into the inlet by hand; the rest were fed in down the chute.

Following each test the debris traps were opened and a record was made of the number and types of object collected from the scavenge and engine traps.

7.2. Test Results

The intake was found to be virtually 100% efficient at separating foreign objects. Out of a total of more than 1300 items fed into the inlet not one item was found in the engine trap.

During the tests the debris chute position was moved from the centre to the fuselage wall and down to the bottom of the inlet. Complete separation of all debris was achieved for all positions.

7.3. Simulated Engine Start

These tests were conducted by leaving a representative of each debris type on the bottom surface of the intake about 6 inches from the entry plane.

The first results determined some modification to t eometry; in fact the entry lip was reshaped in order to p eparation which created a vortex entraining the objects an their ingestion in the engine duct during start up. The inl profile was also modified to ensure that heavy objects rol scavenge duct.

A totally satisfactory behaviour (100% separation) both up and running conditions was then reached.

8.0. DUST AND SAND SEPARATION TESTS

8.1. Test Arrangement and Instrumentation

The test arrangement is presented in figs. 5 and 6, where th intake full scale model is shown in the test cell of the environmen dust testing facility at M.V.E.E. - Christchurch.

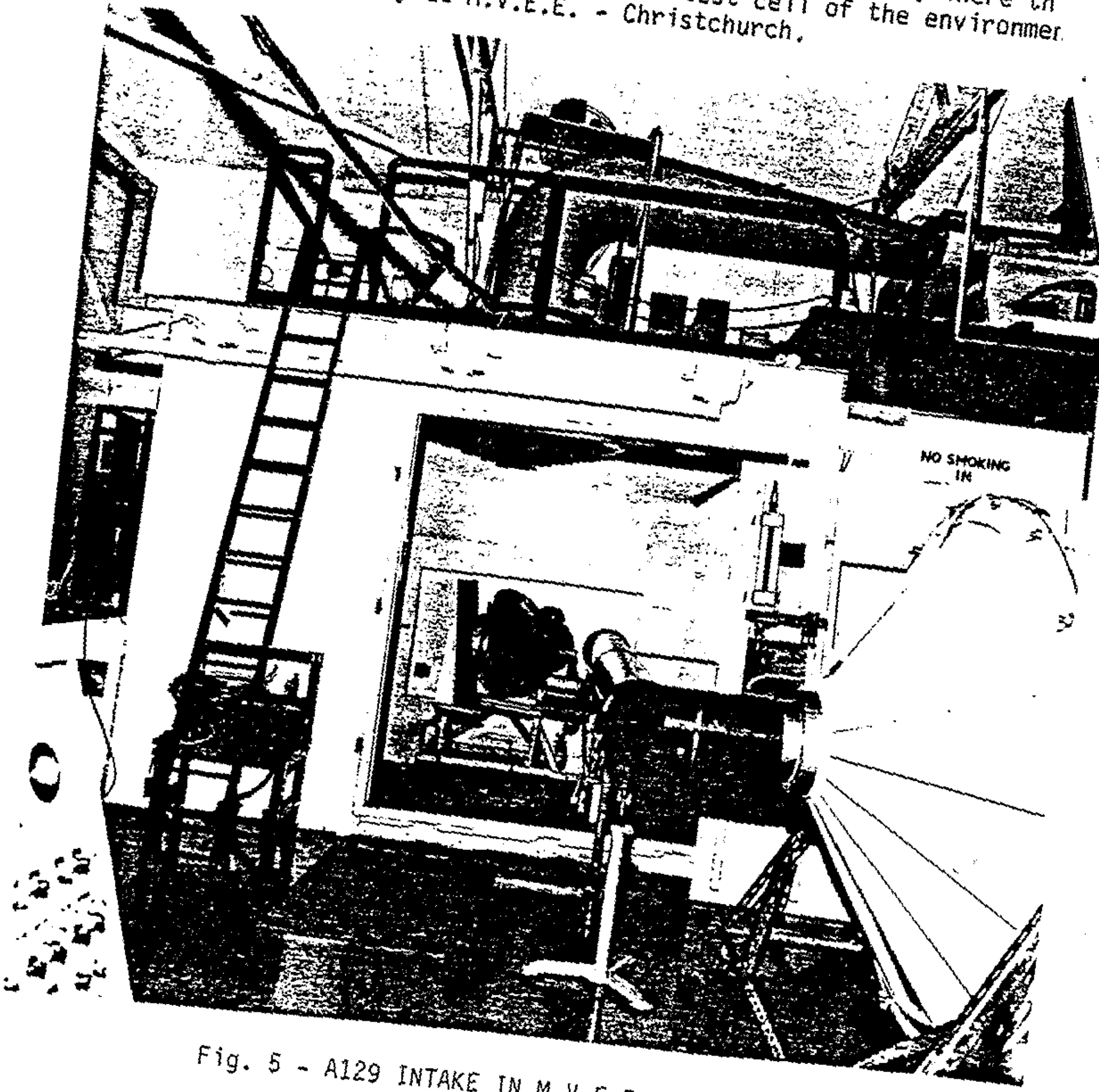


Fig. 5 - A129 INTAKE IN M.V.E.E. TEST CHAMBER

Master filters composed of FM004 spun glass fibre enabled weights of dust passing into the engine and scavenge line respectively to be measured after each test.

Dust particle size was measured at the separator inlet and engine plane respectively. Two methods were used :

a) Iso-kinetic sampling with cyclone separator and Coulter Counter Analysis, and

b) Knollenburg 230X occulted laser sampler analysis.

The iso-kinetic system removes a particle from the airstream for subsequent analysis by Coulter Counter. The Knollenburg occulted laser on-line sampler counts particles in the undisturbed airstream.

Airflow rates in the engine and scavenge ducts were measured by turbine flowmeters.

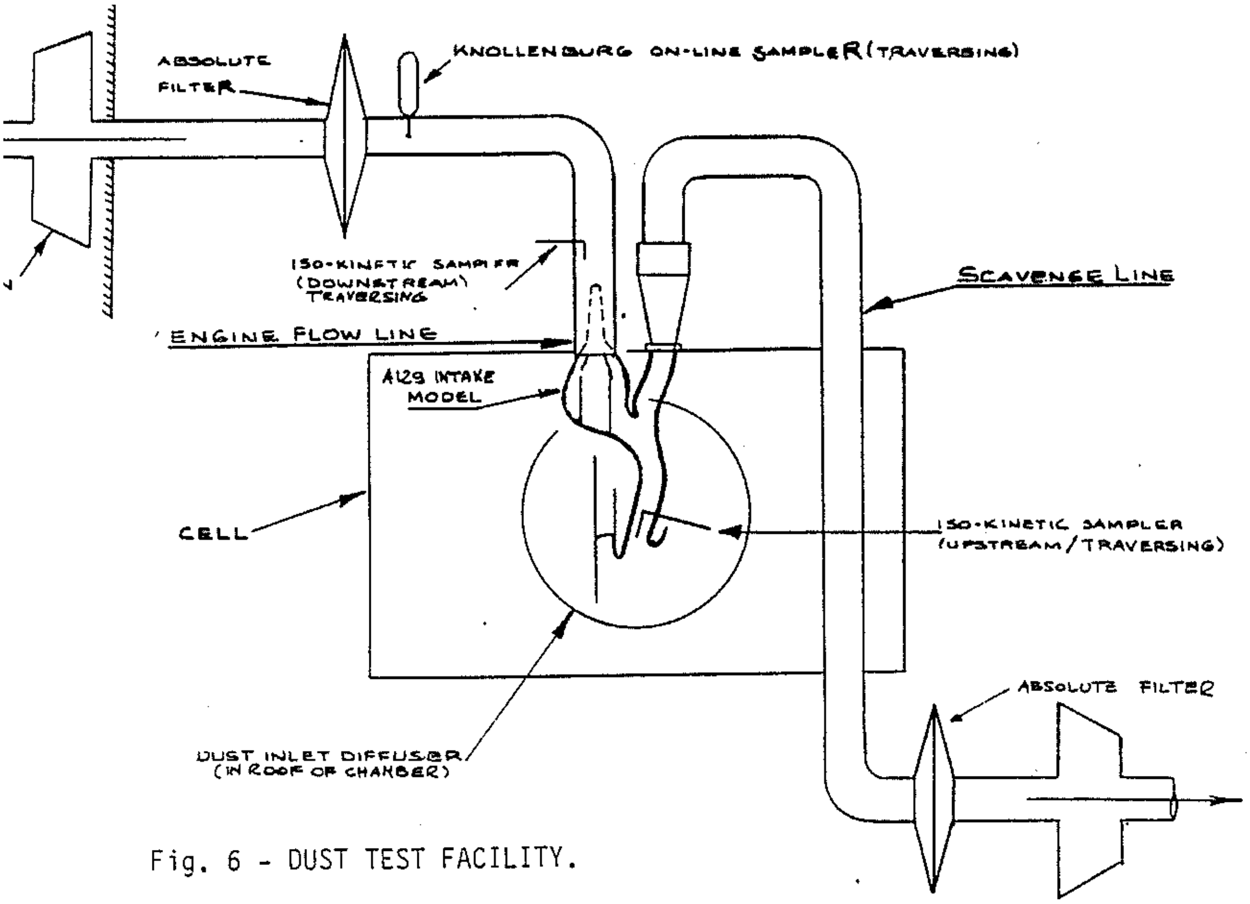


Fig. 6 - DUST TEST FACILITY.

8.2. Test Procedure

Prior to test commencement, pitot static traverses were carried out in the planes selected for iso-kinetic sampling. This data was used for setting the probe air flow rate to achieve iso-kinetic conditions.

At this point the test procedure was the same for each test and was as follows:

i) Record dry weights of all filters and BCURA sample collection chambers.

ii) Start pumps and set airflows.

iii) Record:

  a) Ambient Humidity
  b) Cell temperature
  c) Airflows

iv) At five minute intervals move engine line isokinetic sampling probe to new radial position and reset sample airflow rate.

v) At ten minute intervals move engine duct Knollenberg laser to new radial position.

vi) After 30 minutes turn off dust feeder and shut down all pumps. Record laser output.

vii) Remove filters from main and scavenge ducts, dry to constant weight.

viii) Remove BCURA sampling chambers, dry to constant weight and store for subsequent analysis.

8.3. Analysis and Interpretation of Results

8.3.1. Definition of Efficiency

Filtration efficiency is here defined in terms of the reduction in dust concentration at engine entry.

i.e. $\eta_c = 1 - C_e/C_1$ C_e = dust concentration presented to engine

C_1 = dust concentration at separator entry

Concentration is difficult to measure directly and η_c must therefore be expressed in terms of dust weights on engine and scavenge line master filters respectively, and scavenge fraction (known from mass flow measurements):

$\eta_c = 1 - C_e/C_1 = 1 - (1 + S)\cdot W_e/(W_e + W_s)$

assuming dust lodging in separator is small.

8.3.2. Estimation of separator performance on standard dust types

Although dust manufactured to a standard specification may be fed into the dust cell, the size distribution at engine entry will differ from this due to increasing proportions of larger particles falling out of the dust cloud onto the floor (fig. 7.1). The efficiency measured from weights on the master filters will therefore be inappropriate to the fed dust and the true efficiency must be calculated. This can be done either from a knowledge of the efficiency/size characteristic or by detailed traversing.

An efficiency size characteristic can be derived from sampling-upstream and downstream of the filter or be performing narrow band or discrete size tests over the range for which the efficiency is required.

Sampling is prone to inaccuracies arising from inlet biasing and non isokinetic conditions (fig. 7.2. shows the possible result if the engine duct sampler flow is set too high). Testing at discrete sizes overcomes these problems but introduces the question of the importance of dust interaction. This effect is considered small at low dust concentrations.

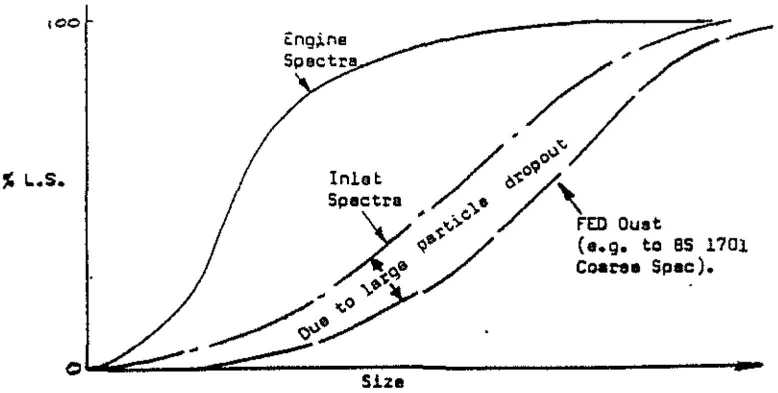


Fig. 7.1

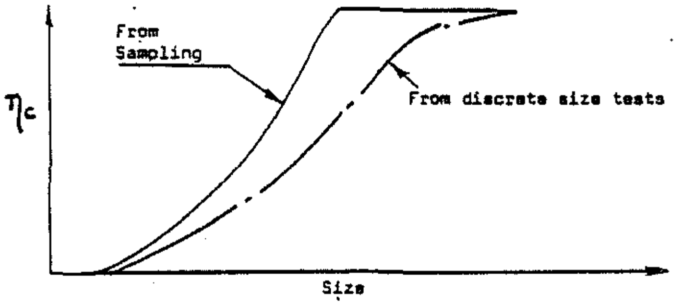


Fig. 7.2

Further, inaccuracies can be introduced by only sampling at a single point, or even at a single plane. Life improvements based on these results would therefore be erroneous.

Narrow band tests give a more realistic efficiency characteristic and these have therefore been used to estimate separator dust performance.

8.3.3. Life Improvement Factor

Life Improvement Factor is the reduction in total erosivity for a particular inlet dust type and is defined as follows:

$$\text{L.I.F.} = \frac{\text{Integrated inlet erosivity}}{\text{Integrated engine entry erosivity}} =$$

$$= \frac{\int_0^{max} \varepsilon \cdot W_1 \cdot ds}{\int_0^{max} \varepsilon \cdot (1-\eta_c) \cdot W_1 \cdot ds}$$

ε = erosivity

W = dust weight at a size s in cloud

L.I.F. therefore represents the increase in erosion life that is afforded to an engine by fitting the separator.

8.4. Objectives and Test Programme

The test programme was designed to enable the following intake characteristics to be determined:

a) The concentration efficiency (η_c) on BS 1701 coarse test dust.

b) The variation in η_c with particle size using narrow size band test dusts and by dust sampling.

c) The variation in η_c with engine flow on BS 1701 coarse test dust.

The tests were conducted using three basic categories of dust/ sand as follows: (Fig. 8)

i) BS 1701 Coarse test dust (mass flow, scavenge and geometry effect).

ii) Narrow band dusts synthesised from BS 1701 Coarse (dust size effects).

iii) Def. Stan. 7-55 Sand. This was used to assess the separator performance in large size sand similar to the U.S. MIL 5007C spec. Analyses of all these are given on Fig. 8.

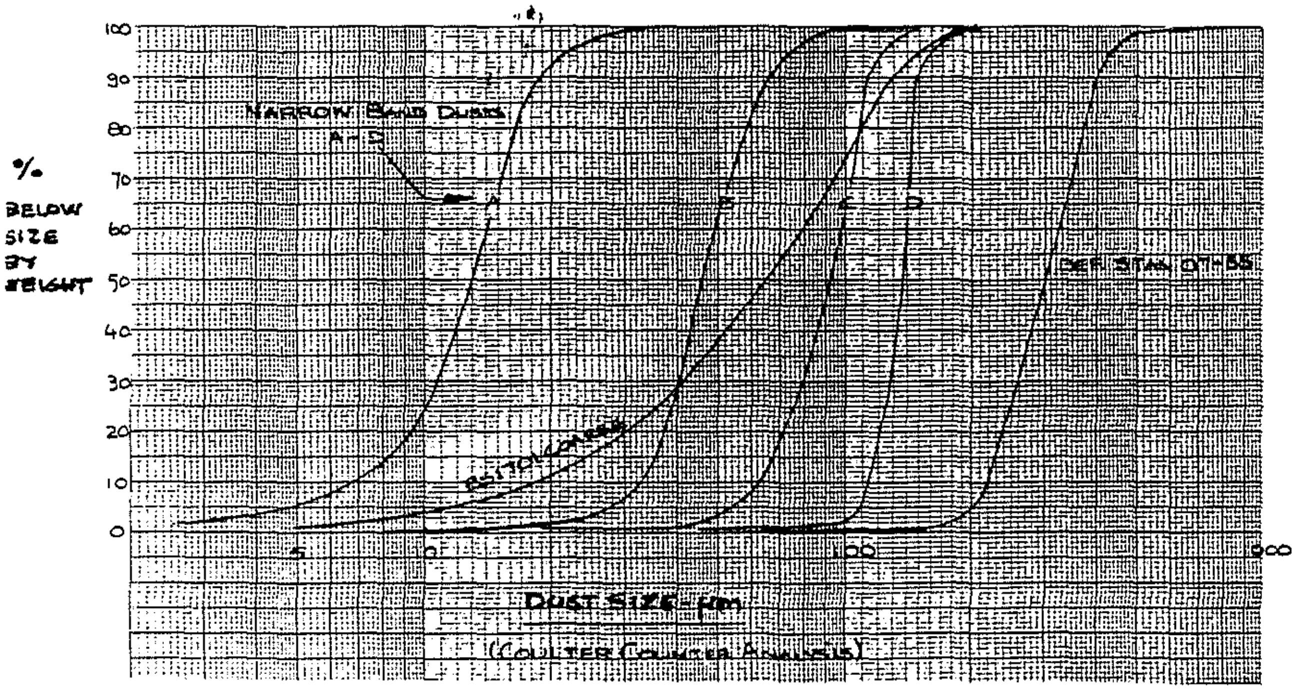


Fig. 8 - STOCK DUST SIZES

8.5. Results

Several configurations were tested, including changes in the intake entry geometry and modifications to the duct shape in order to increase flow curvature without unacceptable increases in pressure loss or distortion.

Besides geometry effects, other parameters were varied to analyse the corresponding variation in filtration efficiency.

Scavenge effect showed that both η_c and L.I.F. increase progressively with scavenge over the range tested.

Variations in engine mass flow (+/-10%) at constant scavenge demonstrate insignificant changes in separator performance.

As expected, performance is a strong function of dust particle size; this analysis was based on the median particle size at separator inlet (analysed from iso-kinetic sampling). Four of the narrow band sizes were synthsized from B.S. 1701 coarse, another for Def. Stan. 7-55 dust, which is slightly coarser than MIL 5007 C. Spec.

The progressive increase in η_c with particle size is followed by a reduction probably due to large particles impacting the outer wall and being deflected into the engine duct (bounce). The dust efficiency vs size characteristic has been used to calculate life improvement factors.

The configuration giving the best compromize between filtration efficiency and pressure loss resulted in η_c of about 96% and an L.I.F. of almost 30 in MIL. Spec. coarse dust.

9.0. TESTS IN ICING CONDITIONS

9.1. Introduction

Previous tests on an earlier standard of intake had indicated the approximate anti-icing requirements and in conjunction with aerodynamic, dust and foreign object ingestion tests the modified standard of intake for prototype phase was developed.

A number of antiicing systems were considered including:

1) Hot air
2) Electrical heating
3) Electrical pulse
4) Pneumatic (Inflation Boot)

Hot air was selected on the basis of simplicity, and reliability. The system comprises a P3 driven ejector entraining ambient air which ensures that the composite intake cannot overheat if the system is selected at high ambient temperature. The engine intake is also hot air de-iced but uses undiluted P3 air.

The test programme was composed of an initial exercise to develop the antiicing system to a satisfactory level of performance, followed by investigation of the behaviour of the intake and antiicing system over a wide range of icing conditions.

The tests were carried out in two phases at the LUCAS Altitude Test Facility, Burnley, Lancashire.

9.2. Model Details

Four windows were provided in the model to allow television viewing of ice accretion during tests. These windows are provided with means for supplying hot air to the surface of the glass to reduce ice formation.

9.3. Anti-icing System Details

The anti-icing system was designed using the results of earlier tests and can be broadly divided into two components.

i) The aircraft system using diluted P3 air and ducted to the intake flow splitter lip and outer wall regions, and

ii) The engine system, which will bleed small quantities of undiluted air from the aircraft system prior to the ejector. A restrictor plate is positioned in this line in order to preserve engine casing material integrity in the event of the system being inadvertently switched "ON" during non-icing conditions.

9.4. Test Arrangement

The test arrangement is shown in fig. 9.

Supercooled water droplets are created by the spraymast and are then carried in the airflow within the approach duct to the model intake. The approach duct changes in cross-sectioned shape from circular at the spraymast to a shape that matches the model intake at the discharge plane. During tests at reduced engine mass flow, the excess flow spills from the gap between the approach duct and the model intake.

The discharge from the GEM inlet casing is ducted to a collection chamber which retains shed ice fragments for examination. The model scavenge flow is ducted directly into cell exhaust via a measuring section and valve.

Hot air is supplied to the model heated lip and to the GEM inlet casing from a facility supply via a flow measuring section and valve.

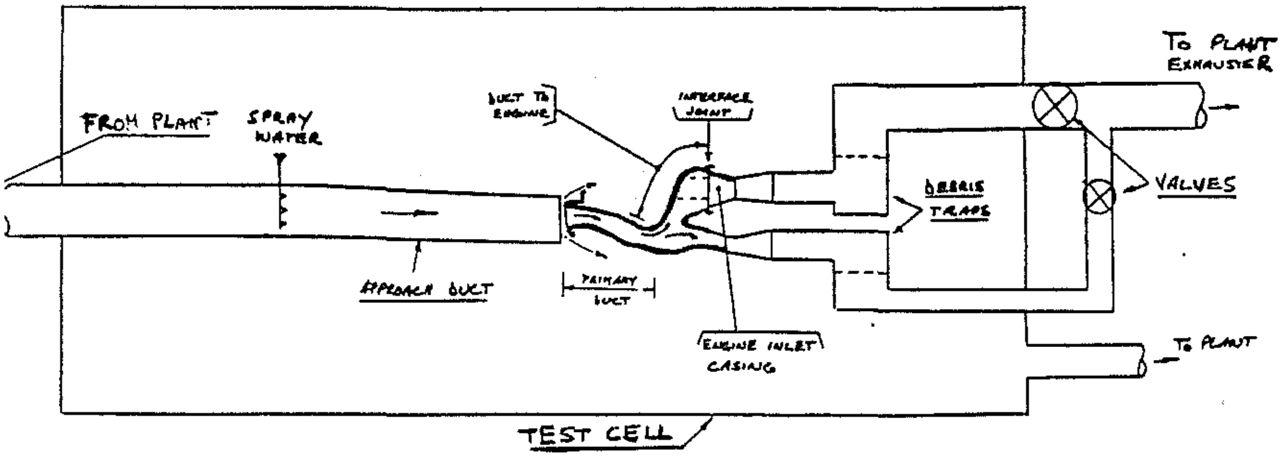


Fig. 9 - ICING TEST FACILITY ARRANGEMENT.

9.4.1. Test Conditions and Preliminary Calibrations

The intake and antiicing system was evaluated at conditions corresponding to Flight Idle and Max. Continuous.

In order to achieve the equivalent corrected flows, the tests were run at 5000 ft. pressure altitude, at the icing condition appropriate to the test.

Preliminary icing calibrations were conducted to qualify the inlet icing distribution (inlet gauze tests) and to demonstrate the specified icing droplet size.

9.5. Test Programme

PART I - System optimisation

The antiicing system was optimised at a single icing condition for Flight Idle/Max. Continuous engine powers.

Each test assessed the effect of ejector nozzle size (aircraft system) and engine antiicing flow restriction size on ice growth.

PART II - Icing Envelope Investigation

The intake (with optimised antiicing system) was subjected to three icing regimes:

i) Tests in Trace Icing conditions to investigate the feasibility of zero antiicing requirement at this conditions.

ii) Tests in moderate (AP 970/FAR PART 25 Continuous Maximum) icing cond's

iii) Tests in moderate (AP 970/FAR PART 25 Periodic Maximum) icing cond's

These test conditions are identified in fig. 10.

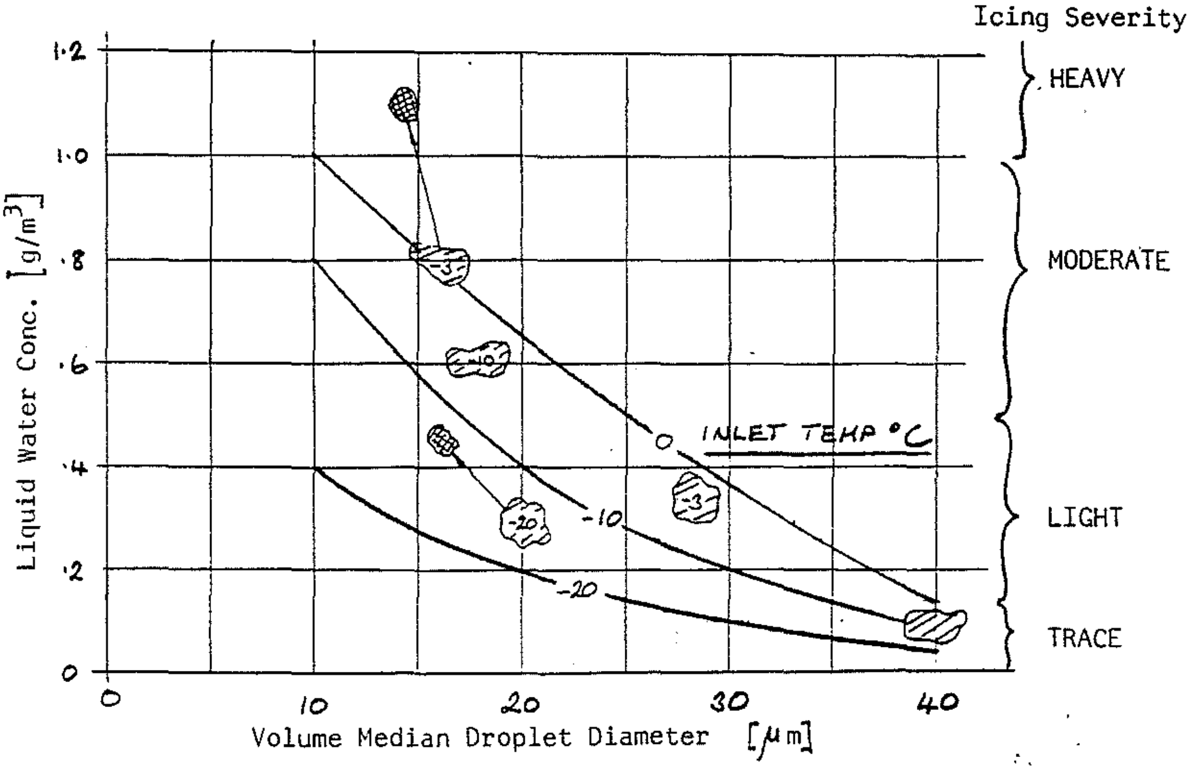


Fig. 10 - TEST POINTS PLOTTED ON FAR PART 25 CONDITIONS.

9.6. Test Procedure

The procedure for all tests was as follows:

1. Set T.V. camera at chosen view point
2. Set plant to schedule conditions including aircraft system, inlet casing system and camera window hot air supplies.
3. Run spraymast water supply to steady state as specified in schedule.
4. Record Icing Conditions Parameters.
5. Switch off water and hot air supplies after 30 mins.
6. Reduce cold air flow to allow access to cell.
7. Remove inlet casing from A129 intake and inspect and photograph interior. Use mirror to inspect leading edge of heated splitter and outer wall areas of aircraft intake. Remove and photograph casing inlet gauze fitted.

A gauze was fitted to the discharge plane of the approach duct and to the inlet plane of the GEM inlet casing during the initial calibration tests. The mesh sizes were as follows:

a) Approach duct : 2 mesh 18 SWG.
GEM Inlet Casing : 4 mesh 18 SWG.

The inlet casing gauze was trapped in the joint between the outer casing lip and the model inlet.

9.7. Results and Discussion

Icing tests in both AVP 970 and MIL Spec. conditions down to -20°C were successful with no ice forming on surfaces where shedding would lead to engine ingestion. Engine bleed air heating was found to be necessary on the splitter, drive shaft cover and at the engine interface as shown in fig. 11.

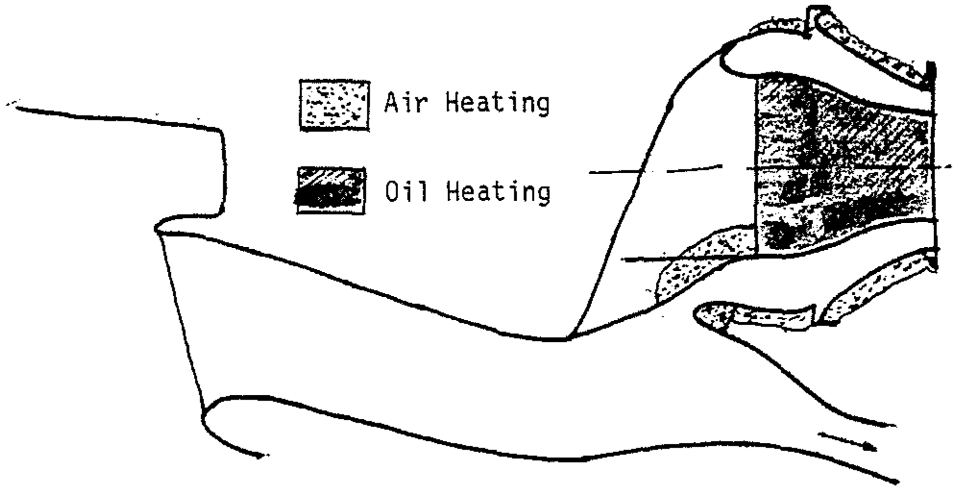


Fig. 11 - HEATED ZONES IN THE A129 INTAKE.

The critical icing conditions were identified as flight idle at -20°C for the heated surfaces and -3°C for other areas where run back ice could cause problems. At no time did ice form on heated surfaces but problems were encountered with run back at the top and bottom termination of the heated splitter. This was overcome by repositioning the hot air discharge slots so that they discharged over the run back areas (fig. 12).

The upstream unheated duct areas of the A129 intake will periodically shed ice but this is not an engine hazard because of the demonstrated 100% efficiency in separating large and small debris (including ice). Shedding tests were performed to reinforce the foreign object test results; no ice was ever found in the trap downstream of the engine intake.

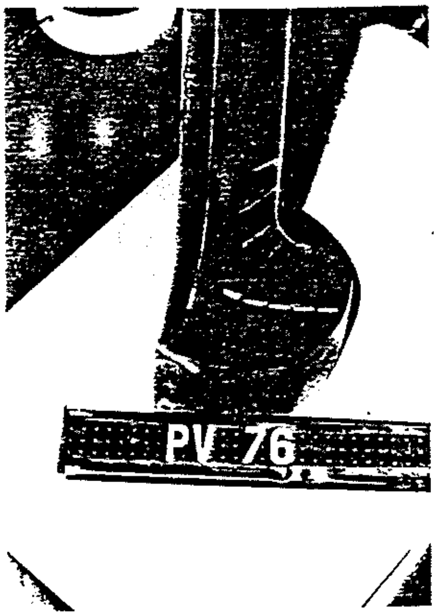


Fig. 12 - SPLITTER DISCHARGE SLOTS

The system will now be verified by flight tests in icing conditions.

10.0 WIND TUNNEL TESTING

Large scale partial models (in this case full-scale) are required to study the internal flow characteristics of an intake. In order to take into account the interference effect due to other components of the aircraft, the scale has to be reduced with the reproduction of a larger portion of the configuration.

Wind tunnel models with the simulation of suction and discharge mass flows of the engine installation allow the study of the interference (and reingestion problems) to be conducted.

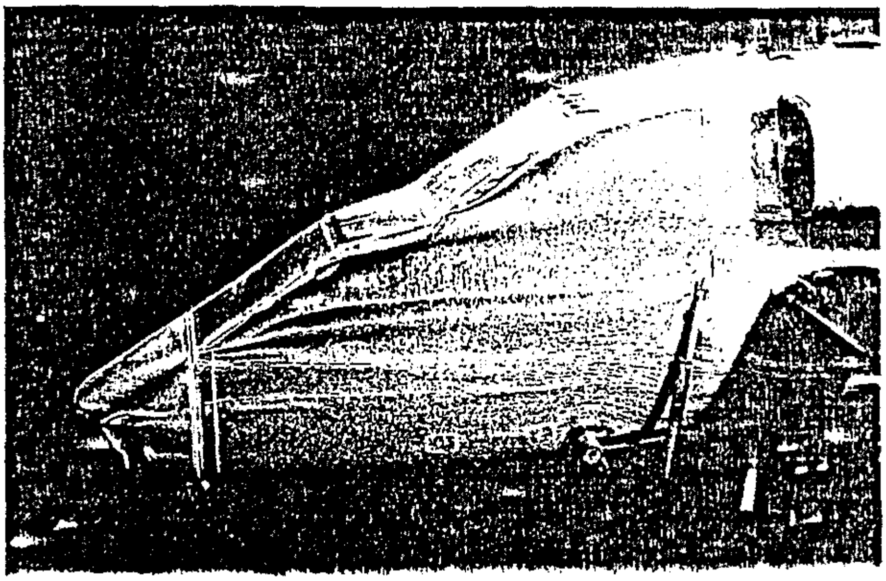
The model for force tests (1/6th scale) was used for a preliminary assessment of the cowling design on the aerodynamic characteristics of the helicopter. At different configurations and attitudes of flight, the flow field past the fuselage was analysed via flow visualization (surface oil, smoke) as shown in fig. 13, with attention to the interaction between nose and intake.

10.1. Engine/Airframe Integration

As mentioned in Ch.5, a dedicated activity on forward flight conditions was thought to be advisable to complete the information from the static tests. A partial model of the forward portion of the fuselage and with the port intake instrumented with pressure rakes, is intended to provide data on the effect of fuselage on pressure loss and distortion of the intake.

The test programme includes different flight conditions with changes in engine rating and flight speed.

Fig. 13 - FLOW VISUALIZATION ON A 1/6th SCALE MODEL.



It is planned to get the pressure measurements in two different planes at the compressor entry; one is the same as for static tests, the other is the plane of measure of flight testing. It is then expected to gain insight in the evolution of flow in the engine entry region and to make useful correlation between the 3 kinds of tests, in terms of pressure distribution and flow angularity.

The flight test results could provide a feed-back on the current intake design, such as to determine further tests to be conducted; in this case a greater use of small scale wind tunnel models is planned.

11.0. CONCLUSIONS

This paper intended to describe the experimental activities conducted in a joint programme by AGUSTA and ROLL-ROYCE in the development of the A129 air intake.

Tests were conducted on a full scale model to measure aerodynamic characteristics and foreign objects separation; environmental testing showed good results both in dust filtration efficiency and in icing conditions.

While further wind tunnel activities are in course or are planned, the chosen intake configuration has been installed on the A129 prototype for flight testing. Further analysis and testing can be required on the basis of flight results or in order to enhance some performance of the intake.

Acknoledgments: Thanks to the testing facilities personnel for their assistance; to John HOBBS of R.R. for his support in preparing this paper.

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