ENGINE AIR PARTICLE SEPARATOR PANELS FOR HELICOPTER ENGINE PROTECTION

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Abstract

The paper defines the principles of operation, design, installation and performance of engine air particle separator (EAPS) marketed by the Pall Group of Companies under the registered trade mark "Centrisep". A comparison of EAPS and engine mounted particle separators is made.

The major environmental problems of helicopter operation and their effect on engines and air inlet systems are defined. Operational limitations, cost of ownership and failure modes data are presented. A summary of the approach taken by airframe and engine manufacturers to the problems is included.

EAPS design requirements are defined and details of the development of the product and photographs of a number of helicopter installations presented. The performance details include flow/pressure loss characteristics, engine inlet flow distortion, dust and foreign object separation efficiency, salt spray removal, water removal and icing performance data. Data on engine life improvement factors versus dust separation efficiency and test dust particle size distribution graphs are included.

Development potential for the EAPS and methods for enhancing engine protection, improving helicopter installed performance and reducing flight restrictions are described.

A comparison between EAPS and engine mounted particle separators is presented with both installation design constraints and performance data considered. Design requirements for the two systems and the levels of environmental protection offered are highlighted.

Introduction

The paper is based on personal experience gained over 20 years direct involvement at Rolls Royce Small Engine Division and Aircraft Porous Media Europe Ltd (APME), and presents information on Engine Air Particle Separators (EAPS) based on the Centrisep inertial separator tube herein after referred to as the vortex tube.

The advent of the gas turbine engine and the subsequent rapid development of helicopters in the military and commercial fields highlighted a number of significant operational problems, with dust erosion being one of the major causes of premature engine removal. Pall Corporation recognised the need for equipment to reduce the erosion problem and developed a miniature axial flow separator tube specifically for aerospace applications.

Research effort continues to enhance the individual tube performance and engineering development is aimed at optimising designs to suit specific helicopter requirements and to reduce installed power loss.

Principles of EAPS and Tube Operation

The operating principle of the vortex tube is shown in Figure 1. The tube comprises two components, namely the vortex tube and the outlet tube. For EAPS units the vortex tubes are fitted into an inlet tube plate and the outlet tube fitted into an outlet tube plate. The overall depth of the resulting panel being approximately 60mm..

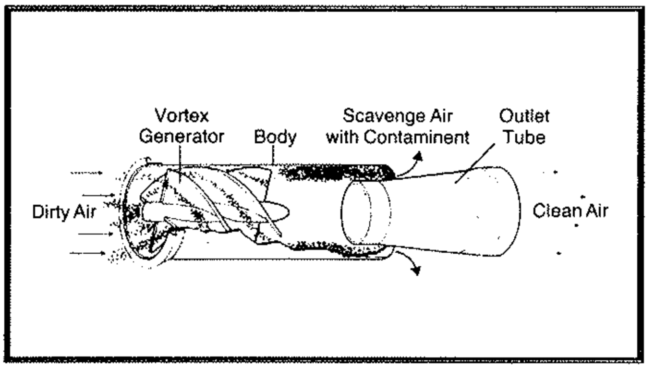


Figure 1
Operating Principle of Axial Flow Vortex Tube

Air is drawn through the vortex tube by the engine suction and is caused to swirl by a fixed vortex generator. The swirling flow imparts a centrifugal force on the dust particles which causes them to migrate towards the outer wall of the vortex tube. An annular gap is formed between the vortex and outlet tube through which the dust laden air is extracted by means of a separate scavenge system (See figure 2). Development of the tube has enabled separation efficiencies of 93 to 98.5% with AC Coarse test dust to be achieved by a single stage panel with scavenge flows of between 7.5 and 15% of the engine flow.

The EAPS tube lay-out is designed to take into account the engine air inlet duct profile and helicopter fuselage configuration. The vortex tube lay-out is defined after the panel air mass flow distribution has been calculated to ensure that the specification pressure drop is met and that the scavenge system efficiency and hence panel dust

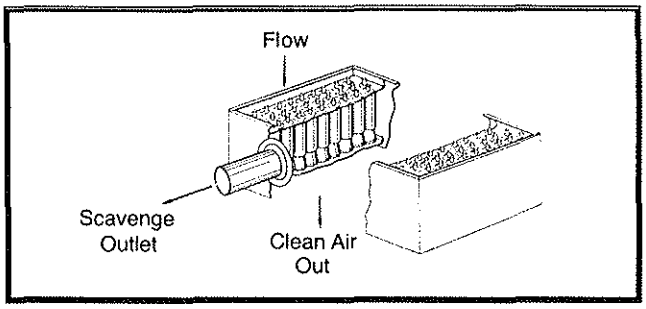


Figure 2
EAPS Panel Scavenge System

separation efficiency are achieved. A typical side entry panel tube and scavenge lay-out is shown in Figure 3. Each design is specifically matched to the helicopter installation and flight envelope requirements. EAPS can be produced as flat, curved or combinations of flat and curved panels to reduce installed drag and increase the aesthetic quality of the installation. The EAPS scavenge systems are chosen to suit the helicopter application and the scavenge flow induced by one of the following methods:

(a) Scavenge fans (electrically, hydraulically or mechanically driven

(b) Engine bleed air ejectors

(c) Engine exhaust ejectors

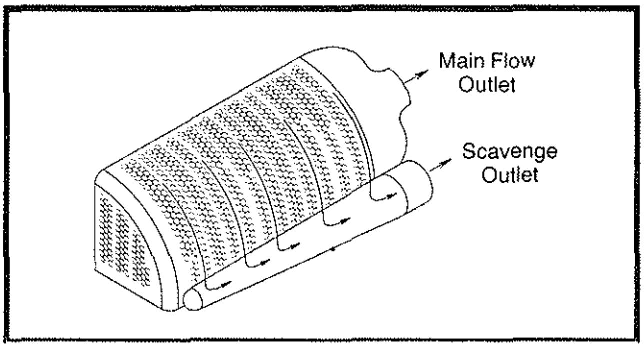


Figure 3
Tube and Scavenge Passage Layout for Side Entry Panels

Helicopter Engine Protection Requirements

The five main environmental and operational problems for helicopter engines are:-
1) Foreign object damage (F.O.D.)
2) Airborne dust;
3) Ice ingestion and Icing
4) Salt spray
5) Snow.

Bird ingestion is not generally considered to be a serious operational problem but due account of the requirement is taken by helicopter and engine manufacturers.

Foreign object, ice,water and snow ingestion can cause the immediate shut down of an engine due to damage and excessive vibration or flame-out.

Dust erosion and salt spray fouling cause a gradual reduction in engine power and surge margin which can cause flame-out problems or force the pilot to land or terminate his mission. Dust ingestion has been quoted to have caused engine rejection after as little as 13 desert landing and many cases have been reported where engine life has been only 45 hours. Under severe weather conditions and operating rescue missions over the sea, salt spray fouling has reduced engine power to below the safe minimum level in a matter of 3 to 5 hours.

Cost of Ownership

EAPS units can significantly reduce operating costs particularly under severe dust conditions. The immediate

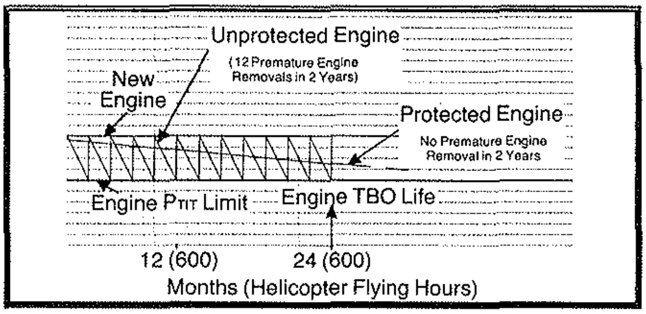


Figure 4
The Effect of Good Dust Protection on Engine Life

value can be seen when operators achieve only 50 to 100 hours engine flying life before an overhaul is required. When operating without EAPS overhauls often cause logistic problems and the loss of the engine for several weeks or months while they are returned to the engine manufacturer or overhaul base.

The obvious effect of good dust protection can be seen from figure 4. In this case we assume that the engine life due to erosion is 100 hours, the annual flying hours 600 and an engine TBO life of 1200 hours. By fitting EAPS having a dust separation efficiency of 95%, the engine life improvement factor would be approximately 20:1. The engine should therefore achieve its TBO life without removal for erosion damage. During a two year period a helicopter flying with no EAPS would require 12 engine overhauls to repair erosion damage compared with one for the helicopter fitted with EAPS. The EAPS protected engine would probably be repaired during the normal life overhaul period despite the fact that the turbo machinery components have a further 800 hour potential life remaining. Overhaul at the TBO life period would avoid an unscheduled engine removal after a further 1 year and 4 months of operation.The decision to change turbo machinery parts at the TBO life is made by individual operators based on repair logistics and the overall cost of engine overhaul and turbo machinery spare parts.

In many military applications FOD (foreign object damage) accounts for a significant number of premature engine rejections which increase operational costs. The fitting of EAPS will eliminate or significantly reduce premature engine rejections caused by FOD and hence provide further cost savings. Figure 5 presents a scenario where the engine erosion life data used for figure 4 are combined with one annual unscheduled engine removal for FOD. An attempt has been made to present the data as a percentage of the engine new build price. The graph shows the order of cost savings which can be made by the introduction of EAPS. Maintenance costs for the EAPS

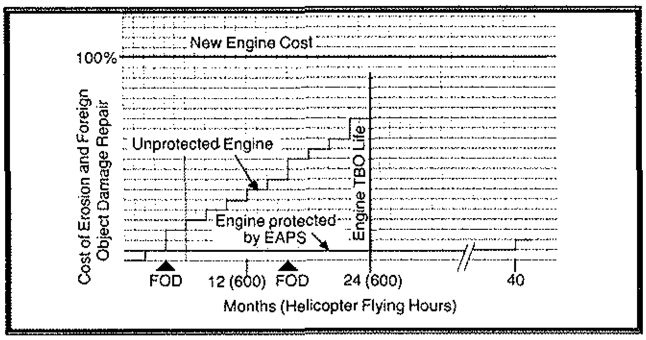


Figure 5
Cost of Dust Erosion and Foreign Object Damage

are insignificant because the cost of scavenge fan spares, spare seals etc. are a very small percentage of the price of an engine (less than 0.05%). No account is made of the cost of shipping or the loss of revenue due to the helicopter being unavailable whilst the engine is removed and replaced.
The operational benefits associated with providing a clean air supply to helicopter engines will lead to enhanced engine reliability by reducing or eliminating secondary failure modes and servicing requirements.

Potential secondary failure modes arising from unfiltered air entering the engine are:

1. Components in engine bleed air fed systems become fouled by dust and oil mist.

2. Oil systems become contaminated by dust calling for more frequent oil and filter changes and increased component wear rates.

3. Dust contaminants restrict cooling holes in turbine blades and cause failure through overheating.

4. Glazed dust deposits on turbine blades caused by melting fine silica dust particles in the combustion chamber.

5. Dust deposits in turbomachinery blade roots causing very high vibration levels.

6. Seal erosion.

7. Accelerated bearing wear.

8. Reduced combustion chamber life due to erosion damage.

9. Compressor fouling.

10. Overheating due to blockage of heat exchangers

Approach to Engine Protection Problems

Initial progress in the development of protection systems for gas turbine engines was slow because the responsibility for providing adequate air inlet systems was not clearly defined as an airframe or engine manufacturers task.
Local solutions were developed in an ad-hoc manner until the mid sixties when engine manufacturers were initiating research into engine mounted particle separators with the main objective of reducing foreign object damage. The development and testing indicated that gravimetric dust separation efficiencies of 80 to 85% could be achieved with AC coarse and BS1701 coarse test dusts. The pressure on engine manufacturers was further increased by military users, who raised more demanding specification requirements for foreign object and dust ingestion tolerance. The introduction of axi-symmetric (see figure 6) engine integral particle separators (EIPS) causes serious debates amongst engine design teams

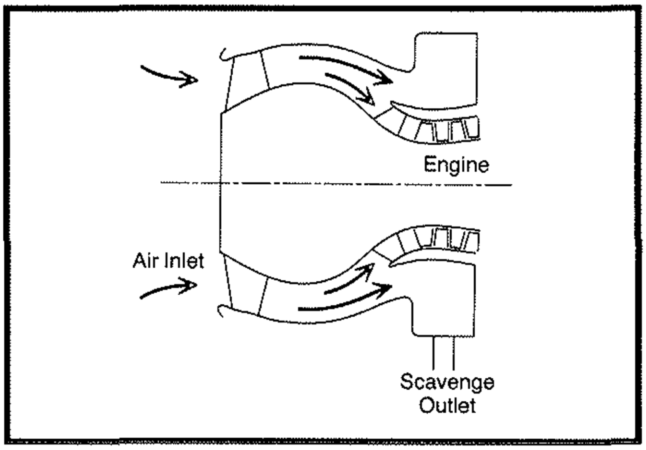


Figure 6
Axi-Symmetric Particle Separator for Engine Mounting

because the engine becomes less attractive due to its increased installation volume and weight and because the separator performance can be significantly influenced by the upstream inlet duct configuration. The increased engine length also has a significant effect on the c of g position of the engine relative to the rotor hub axis and hence calls for balancing weights forward of the rotor hub axis for front drive engine configurations.

Some engine manufacturers have provided integral separators for many years and Pratt and Whitney introduced an inertial separator concept for the PT6 engine which formed an integral part of the Airframe installation.

Airframe manufacturers originally approached the subject of engine protection from dust ingestion by the introduction of felt and oiled screens which imposed serious operational restrictions.
Debris screens are now widely used to provide FOD protection only. Much work has been done but screens which are fine enough to adequately protect the engine from FOD are prone to ice very rapidly and hence lead to engine flame-out. The use of debris screens is usually

restricted to operation above +5°C ambient air temperature unless extensive testing is carried out to certify its use below +5°C, or if the engine has a good capability to ingest ice without damage or flame-out. By-pass facilities are provided with most FOD screen installations.

Some airframe manufacturers have designed their engine inlet installations to incorporate EAPS as standard or optional equipment and have obtained icing and snow clearances for the helicopter. This solution provides a very high level of engine protection and design flexibility.

Pall Corporation have been working closely with airframe manufacturers to provide airframe mounted EAPS and directly with some operators to design, build, fit and certify EAPS for their helicopters since the 1960's.

EAPS

A large number of EAPS produced by our company have been successfully operating and protecting engines for over 20 years. Figures 7 to 12 inclusive show examples and the variety of design configurations. Some of the EAPS units designed in conjunction with helicopter manufacturers are listed as thus:

Aerospatiale:	SA315-SA316B; SA330-AS332; SA341; SA350; SA355; SA365;
Agusta:	A109, A109K; A129.
Bell :	206.
Boeing Helicopter Company:	CH47
MBB	BO105; BO105LS;
MBB/KAWASAKI	BK117.
Westland:	Lynx; W30; Commando.

Helicopters for which EAPS have been developed for specific operators are:

Bell:	205, 209(Cobra)
Sikorksky	CH53.

Pressure Drop

Hover Conditions. The pressure loss of the EAPS is dependant upon the vortex tube flow rate and downstream engine inlet duct configuration.

The normal design objective is for a maximum pressure drop of 10 mbar at the 100% NG mass flow rate and standard ISA sea level conditions. The pressure drop can be reduced to 6 mbar without a significant loss of dust separation efficiency by reducing the design point tube flow rate (increasing the number of tubes).

An additional pressure drop is created by the engine and air inlet ducts and these are generally of the order of 3 to 5 mbar but if incorrectly matched to the EAPS can cause an interactive loss of some 5 to 10 mbar depending upon the configuration.

Figure 13 shows a typical front drive engine EAPS lay-out with side entry vortex tubes.

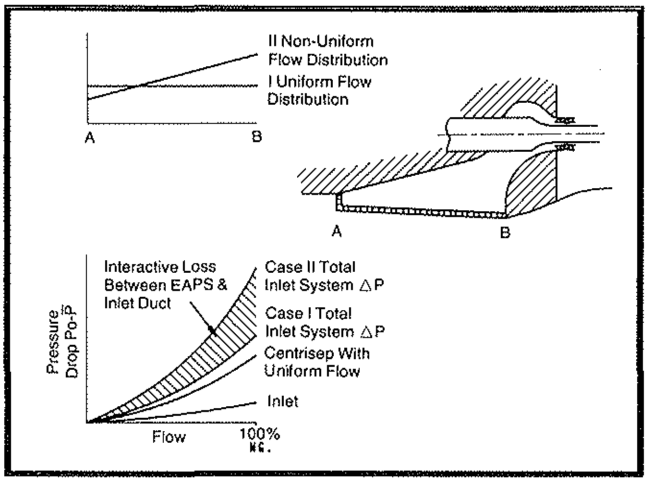


Figure 13
Side Entry EAPS for Front Drive Engine Installation

The aim of the airframe and EAPS designers is to provide compatible air inlet duct and EAPS configurations which achieve a uniform tube flow across the EAPS and hence create the lowest installation pressure drop. Failure to observe and address this requirement can lead to vortex tube flow variations of as much as five to one within the EAPS panels. Flow gradients increase the EAPS pressure drop and this is referred to as an interactive loss and is shown on Figure 13.

Forward flight conditions. EAPS pressure losses under forward flight conditions can be designed to suit each helicopter and the EAPS is configured to suit the helicopter type, role, overall environmental protection and performance requirements.

Side entry EAPS are extremely good in icing conditions and enable the helicopter drag to be minimised. Pressure recovery can be increased by angling the rear of the EAPS panels outwards but this eventually reduces icing performance and increases the helicopter drag. Additional gains over the side entry panel ram pressure recovery can be achieved by installing turning ramps or vanes facing upstream of the EAPS panels.

A by-pass door can also be incorporated to obtain the maximum ram pressure recovery and or cater for the unlikely case of the EAPS becoming partially blocked by paper, plastic or grass, etc.

Examples of EAPS installations incorporating by-pass doors for ram recovery are shown in Figures 7 & 11.

Figures 7, 8, 9 and 10 show examples of side entry tube panels and figure 12 shows an example of EAPS with both forward facing and side entry tube panels.

Inlet Flow Distortion

Engine manufacturers flow distortion specification requirements are noted and observed during the EAPS design and development phases. Tests are carried out with the air inlet duct and engine entry duct to measure both the total installation pressure drop and the engine

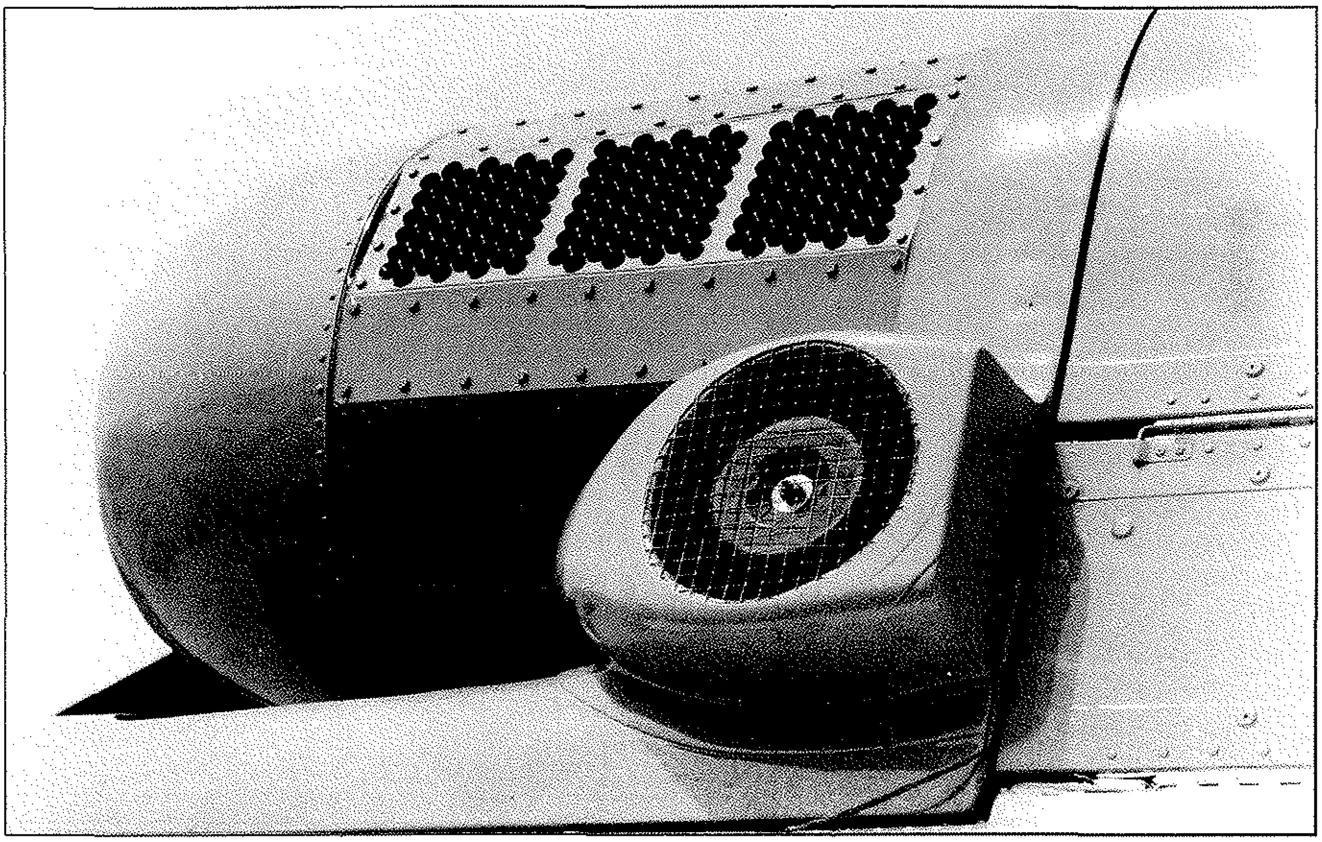


Figure 7
Photograph of Super Puma Centrisep

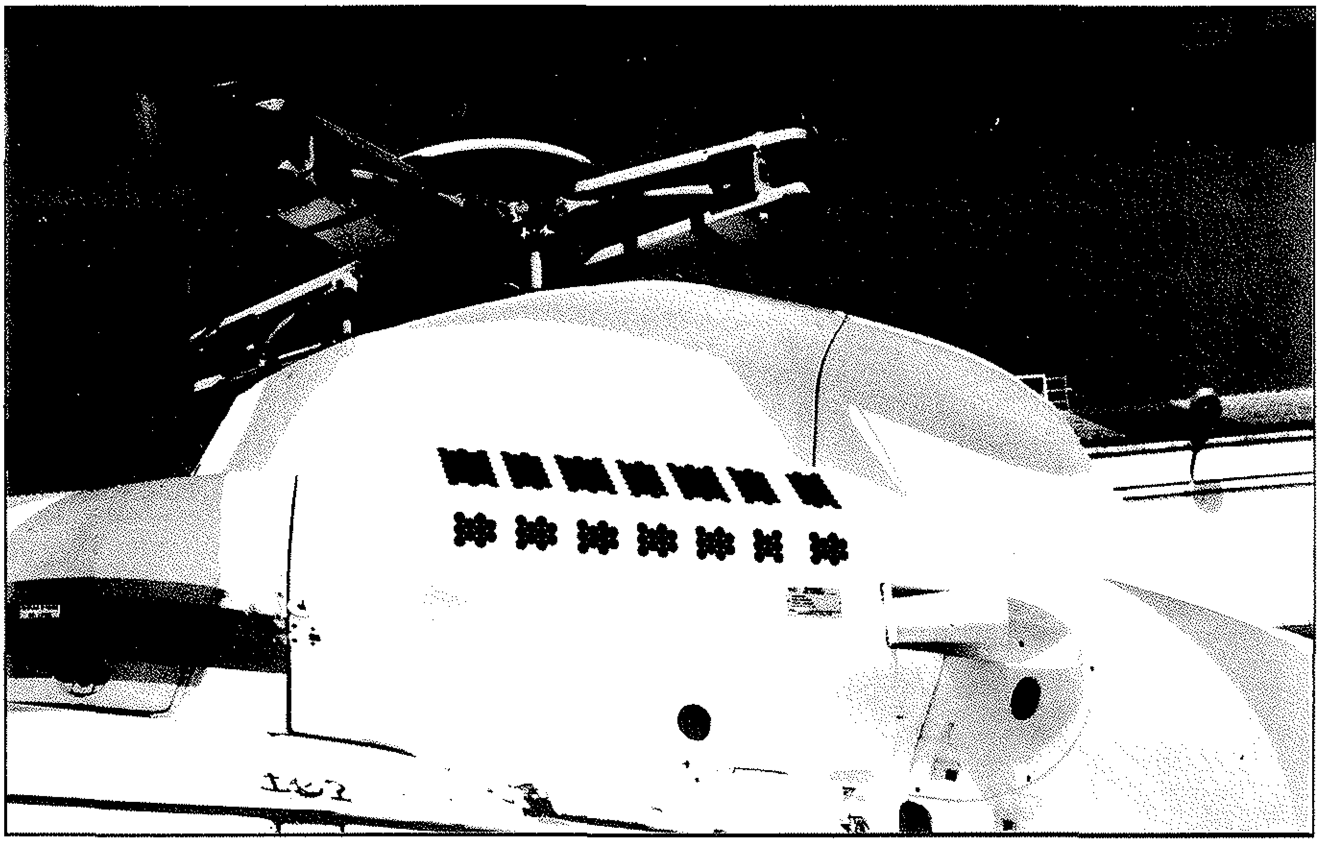


Figure 8
Photograph of Dauphin Centrisep

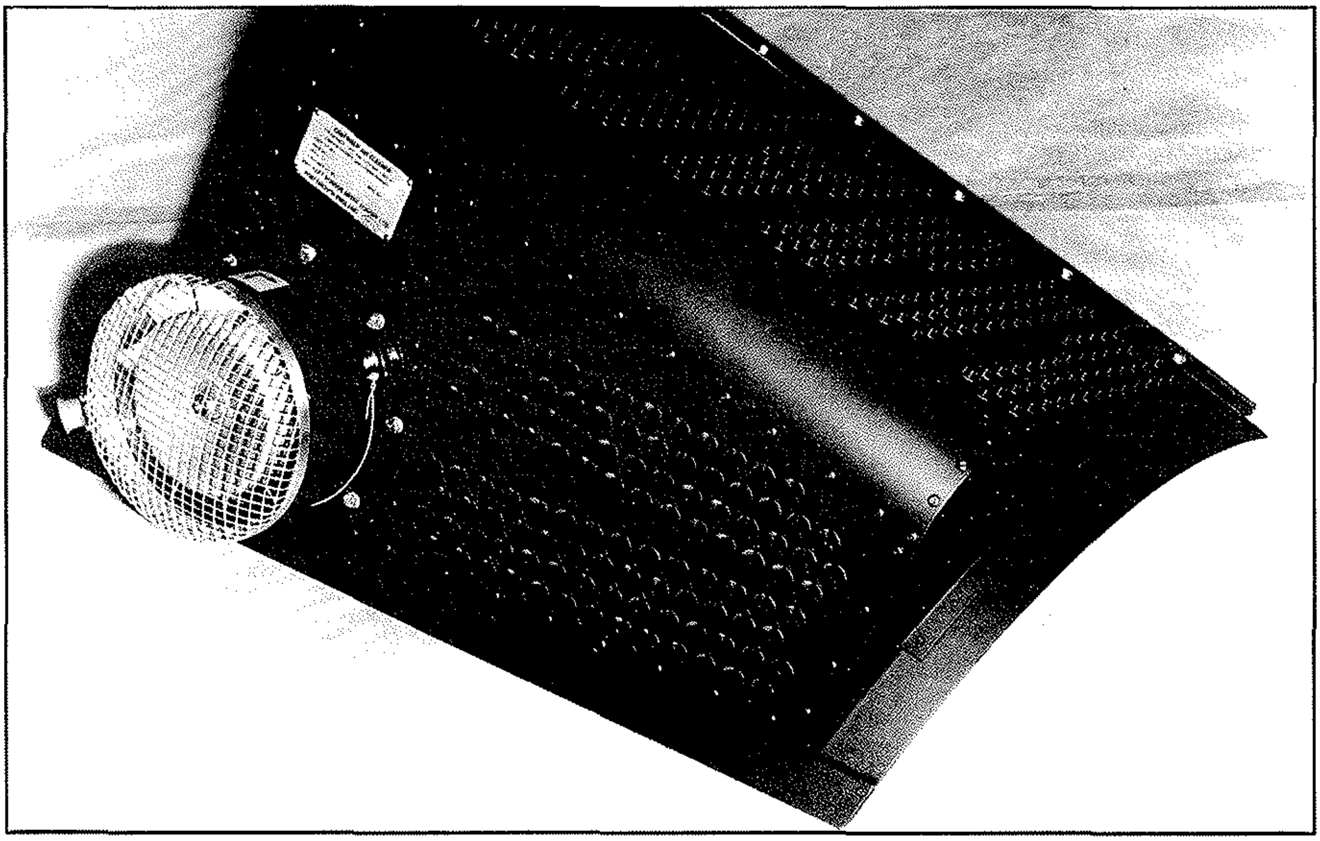


Figure 9
Photograph of Agusta 109K

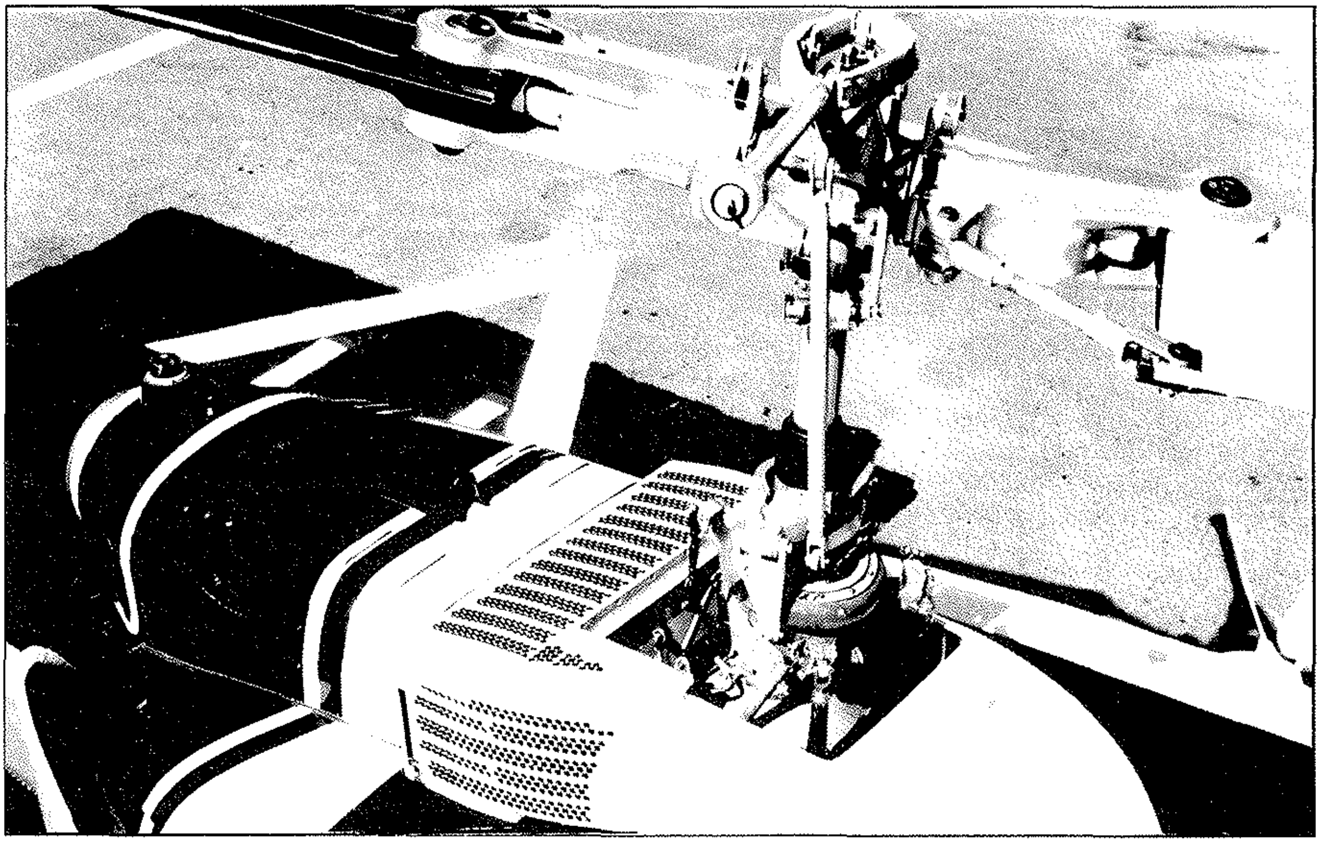


Figure 10
Photograph of Bell 205 Centrisep

Figure 11
Photograph of Centrisep installed on MBB BO-105

Figure 12
Photograph of Westland Commando Centrisep

entry plane flow distortion using a minimum of 72 area weighted total pressure probes.

The fitment of EAPS often improve engine entry plane flow distortion levels on helicopter installations incorporating plenum chambers due to the turbulent mixing created by the vortex scrubbing downstream of the vortex tube panel. Flow distortion levels are reduced as a result of the mixing of helicopter fuselage boundary layer entering the engine. The turbulence created by the vortex scrubbing also eliminates the formation of wall vortices which would otherwise lead to high levels of flow distortion at the engine entry plane. The vortex scrubbing action fully mixes the incoming airflow and hence reduces the level of temperature distortion and the risk of engine power loss or surge under hovering conditions caused by the re-ingestion of hot exhaust gases.

Dust Separation Efficiency

Before presenting dust separation efficiency data it is perhaps important to understand the particle size distributions of the more internationally known test dusts. The main test dusts are AC coarse, AC fine, BS1701 coarse and MIL-E-5007C. The first three can be considered to be dust but MIL-E-5007C contains dust and sand particles. The dust particle size distribution is shown on Figure 14. The MIL-E-5007C test dust has

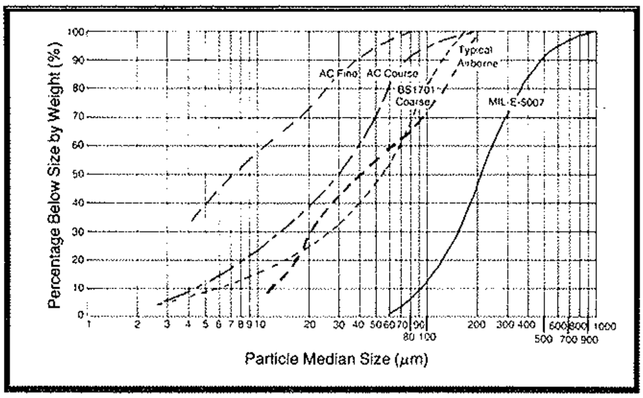


Figure 14
Graph showing Test Dust Particle Size Distribution and Typical Airborne Dust Sampling Analysis

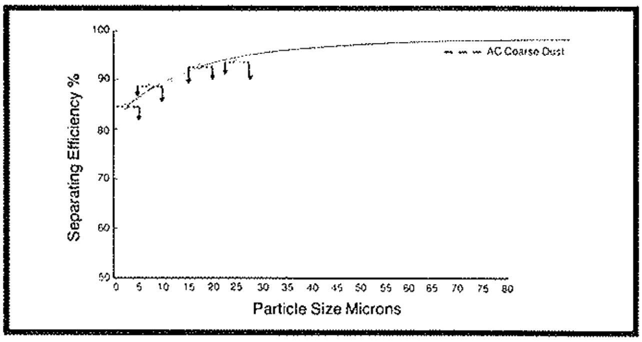


Figure 15
Graph showing Separation Efficiency versus Dust Particle Size

been introduced within the last 15 years or so as a challenge to EIPS. The EAPS deals extremely effectively with AC coarse and BS1701 coarse dusts and achieves gravimetric dust separation efficiencies of up to 98%. The gravimetric efficiency for MIL-E-5007C dust is better than 99%. The coarse particles of the MIL-E-5007C will not usually be ingested by the EAPS tubes because the inlet air drag force on the particles are less than the gravitational force and hence a considerable amount of external separation of large particles occurs. Figure 15 shows a graph of typical separation efficiency versus dust particle size. Independent rig tests carried out on an EAPS panel showed that the dust particle sizes on the downstream side of a panel ranged from 0 to 7µm with a median size of 2.5µm.

Two stage EAPS panels have demonstrated dust separation efficiencies of better than 90% with AC fine dust and a downstream particle size range from 0 to 5µm and a median size of 1.2µm. Two stage panels would not normally be used for airborne applications due to the additional weight and power loss penalties.

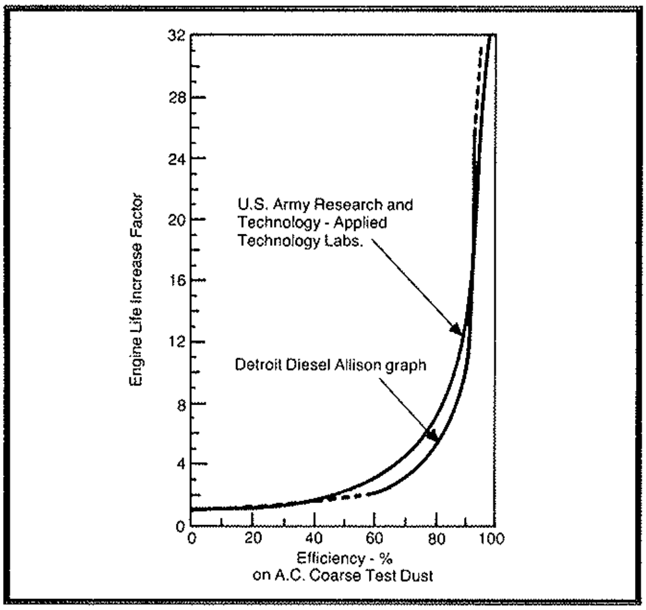


Figure 16
Effect of Air Cleaner Efficiency on Gas Turbine Engine Life

Figure 16 presents a graph of dust separation efficiency versus engine erosion life improvement factor showing the importance of achieving better than 90% efficiency with AC coarse test dust. The EAPS virtually eliminates the dust particles above 5 µm and hence reduces the engine erosion damage to the minimum. Rig tests on a small gas turbine engine demonstrated that the EAPS produced an engine life improvement factor of 18:1 based on erosion damage. Dust separation efficiency can be further enhanced to 99.5% by the addition of a cleanable Mist Eliminator panel downstream of the EAPS Panel.

Foreign Object Separation

EAPS provide a good level of protection against Engine

FOD due the nature of the design and size of tube. The maximum sized spherical object which can pass through the tube is 6 mm diameter. The likelihood of the ingestion of such a large object is very small and would only occur if the EAPS panel faces upwards. Particles greater than 500μm would not normally be ingested by side facing panels. Removable fine debris screens can be fitted on the upstream side of the tube panels to enhance FOD protection for specific operational conditions.

Military helicopters operating with EAPS as standard equipment have demonstrated a very low level of engine F.O.D. Unconfirmed results of recent Royal Navy operational trial with EAPS fitted to a number of Sea King helicopters have shown a marked reduction in engine F.O.D.

Salt Spray Removal

EAPS units remove between 60% and 90% of rain and salt spray depending upon water droplet size and concentration and whether the EAPS has tube panels facing upwards. Rig tests have shown large scatter on results due to the difficulty of controlling the test air relative humidity and hence the evaporative effects on water droplets.

The salt spray removal efficiency of the EAPS can be significantly enhanced by the addition of a vertically installed Mist Eliminator which raises the overall efficiency to better than 99.6%.

Icing Performance

Extensive rig, flight trials and operational experience has been gained on EAPS units over the past 12 years and the data shows that a good operational icing and snow performance can be achieved. Testing has been carried out and experience gained on helicopters produced by Aerospatiale, Agusta, Bell, MBB/Kawasaki and Westland and tests are planned for new applications. EAPS are cleared for ice and snow flying by MOD (PE) CAA and FAA on a number of helicopter installations.

The subject of icing is too large to adequately cover in this paper and could be considered as a topic for a subsequent paper. This section will be confined to providing basic information on the subject of EAPS icing.

The fact that the EAPS is not heated ensures that under almost all icing conditions the ice accretes on the tubes and supercooled water droplets do not pass through to form ice which could represent a potential engine FOD hazard. This fact has been confirmed on a number of rig tests where fine screens have been placed downstream of the panel to indicate whether supercooled water droplets pass through the panel.

The other important feature of cold running inlet systems is that ice melts from the outside and remains keyed to the cold surface underneath until a large percentage of ice has melted and run off as water which does not damage the engine if ingested. Melt off tests have shown that only small ice particles pass through the tube during melt-

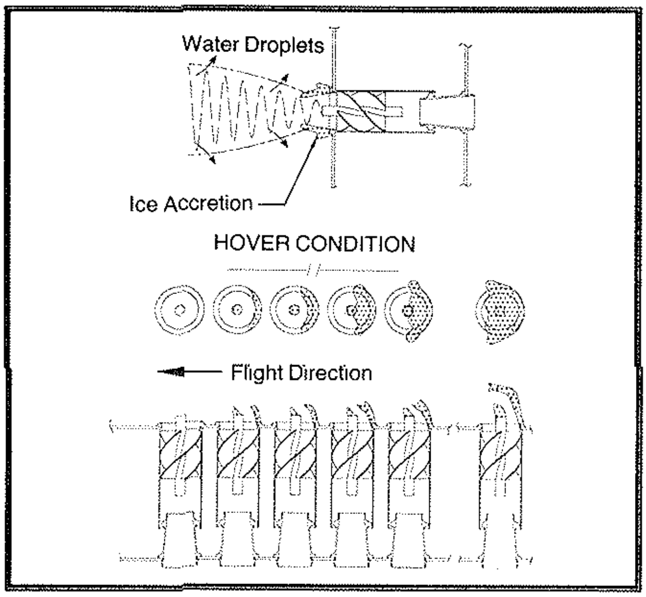


Figure 17
Typical Ice Accetion Patterns for a tube under Hovering and Flight Conditions

off and the size is limited to that which will pass through the curved vortex generators. Typical ice particle sizes found downstream of a horizontally mounted panel (the worst case for ice ingestion) was some 3 mm diameter by 5 mm long. Most gas turbine engines are capable of ingesting ice of such a size without incurring damage. Figure 17 shows the typical ice accretion pattern for a tube under hovering and forward flight conditions. The hovering in icing case is not expected to occur

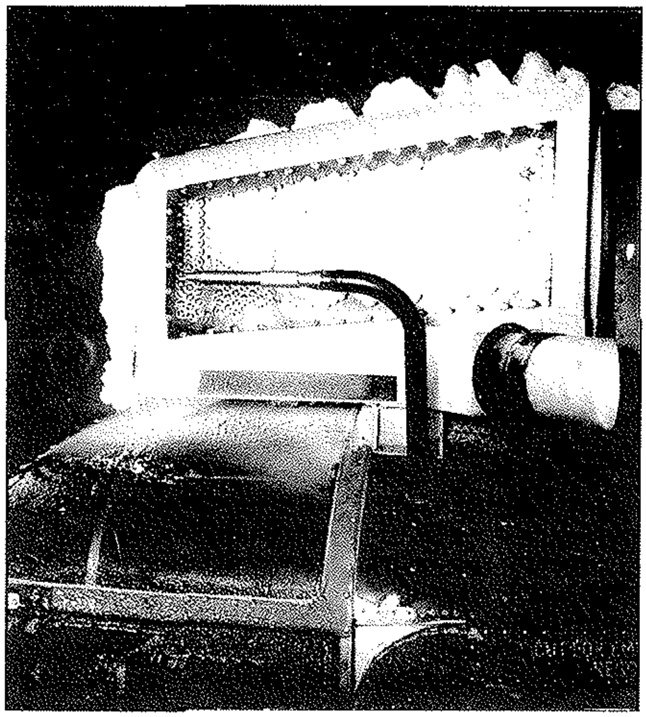


Figure 18
Westland Helicopter Commando Centrisep Icing Trials at NGTE

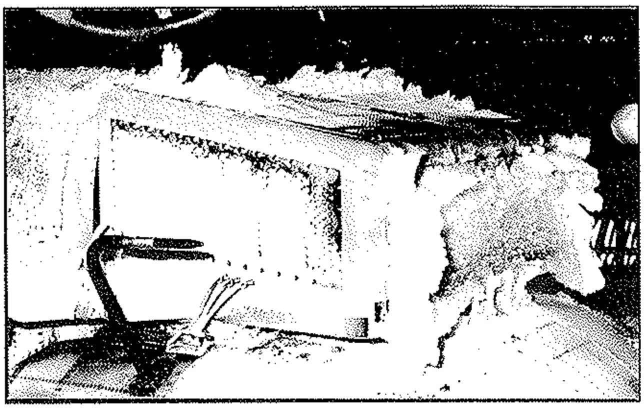


Figure 19
Westland Helicopter Commando Centrisep Icing Trials at NGTE

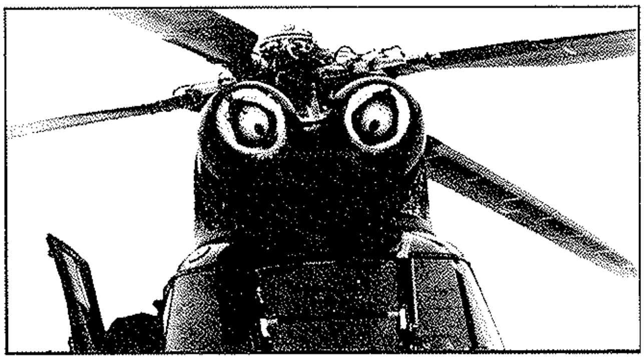


Figure 20
Aerospatiale Super Puma Centrisep Flight Trials in Icing

frequently because of the inherent danger and would normally be considered as a transient condition other than for specialised helicopter roles.The side entry tubes of the EAPS build and shed ice under forward flight conditions and can operate under severe icing conditions without imposing a serious pressure loss problem. The EAPS have been tested under icing conditions which exceed the capability of many helicopter rotor and anti-icing

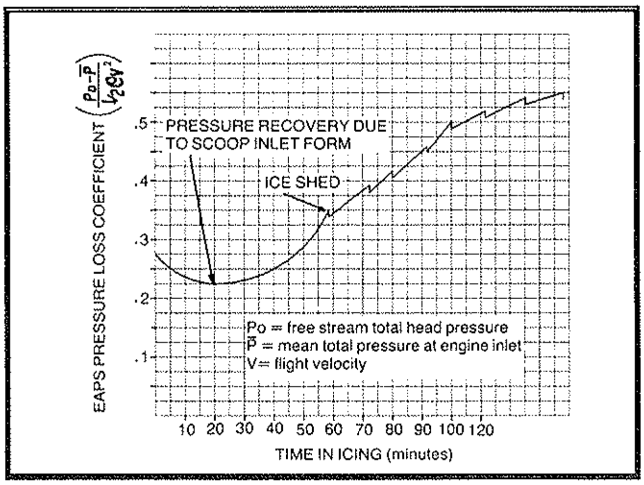


Figure 21
Typical EAPS Pressure Loss Versus Time in Icing Characteristic

systems. Examples of EAPS icing tests can be seen in Figures 18 and 19 which show severe rig icing test results in Cell 3 West at NGTE and natural icing of a SuperPuma helicopter (figure 20).

Figures 18 and 19 show the inertial effects on the supercooled water droplets and an increase in ice accretion towards the rear of the EAPS. Ice accretions on the Super Puma are very light with much ice formed on the stagnation points on the helicopter airframe and EAPS by-pass door and inlet lip. A close scrutiny of the ice accretions on figure 18 will show similarity to the ice accretion pattern of figure 17.

Figure 21 shows a typical inlet pressure loss versus time in icing graph for an EAPS unit under forward flight conditions. The inlet pressure loss reduces initially as the tube inlet lip accretions form a scoop and hence increase the inlet ram pressure recovery. The ice accretions continue to build and increase the inlet loss due to the restriction in flow area. Tests have shown that ice sheds periodically and the inlet pressure loss versus time in icing graph curve takes the form of a saw tooth. The magnitude of the pressure loss reduction will depend upon the volume of ice shed. Tests have been run for up to $1^1/_2$ hours under maximum continuous and intermittent maximum icing conditions.

Testing

A considerable amount of rig testing is carried out by APME during the design and development phases of EAPS projects. Additional qualification testing is carried out in conjunction with the customer in other appropriate test facilities. Certification is normally covered by the helicopter constructor customer but we are able to carry out flight trials and certification of products developed specifically for an operator.
The EAPS testing covers all environmental conditions including bird and hailstone impact tests.
Compliance with number of environmental specification requirements can be demonstrated by analogy and/or operational experience.

The tests most frequently carried out by the company are:

1. Hover flow/Pressure loss and Inlet flow distortion measurements.
2. Scavenge system calibration.
3. Scavenge fan erosion life.
4. Dust separation efficiency.
5. Functional checks.
6. Vibration.
7. Icing.
8. Pressure differential strength.

Over the past year or so there has been an increase in the number of rig tests carried out on EAPS units to

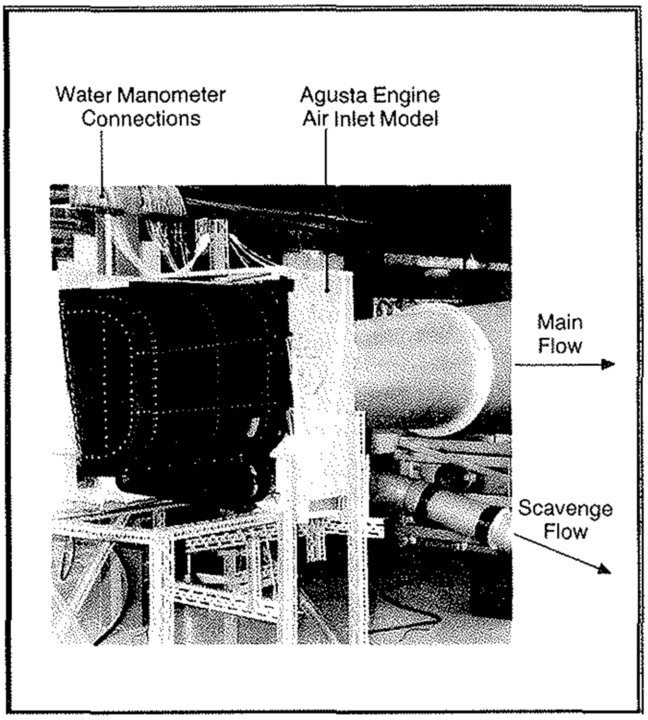


Figure 22
Photograph showing Agusta 129 EAPS Prototype Installed on the Suction Test Rig.

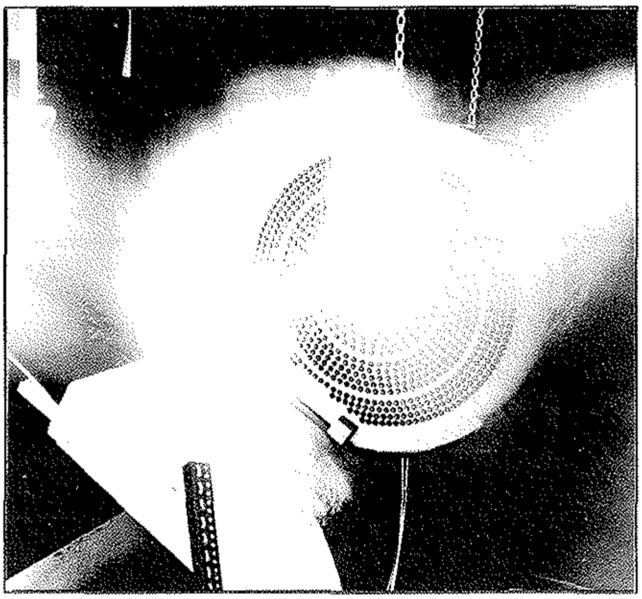


Figure 23
Photograph Showing CH47 EAPS dust separation

investigate the icing performance potential. This activity is expected to continue in the future.

Figure 22 shows an EAPS unit installed on the suction rig instrumented to obtain engine entry plane pressure loss and flow distortion data. The scavenge system is calibrated over the range of engine inlet flows and the effect of the scavenge system on the overall installation pressure loss characteristics quantified.
The CH47 EAPS (Reference 1) is featured in figure 23 during a dust separation efficiency test.

Dust separation efficiency is established by measuring the mass of dust aspirated by the Centrisep and the mass of dust removed via the scavenge system. The mass of dust entering the main engine outlet duct cannot be weighed because the high airflow volume makes it impractical to provide a sufficiently large and efficient dust collection system.

Published results are based on a test repeatability accuracy of 0.5% of the nominal efficiency value.

Scavenge fan erosion testing is carried out with the fan installed as it would be on the helicopter to ensure that the airflow and dust distribution into the fan is representative thus providing accurate data on erosion patterns and rates.

Icing, vibration and other environmental testing is carried out in conjunction with the customers in approved test houses.

Future Development

Future R&D effort will be concentrated mainly upon reducing installed engine power losses and refining design methods which would raise the EAPS dust separation performance to that of a single tube (98.5%). The raising of the EAPS dust separation efficiency from 97% to 98.5% would result in halving the mass of dust entering the engine and hence improve the level of engine protection significantly. For example for each 100 kg of dust entering EAPS having 97% and 98.5% gravimetric dust separation efficiencies, the mass of dust entering the engine would be 3 kg and 1.5 kg respectively. To achieve the same panel performance improvement, the single tube efficiency would have to be increased from say 98.5% to 99.5% and this would almost certainly result in an increase in tube pressure drop. Work will continue on tube development but satisfactory improvements in performance may be difficult to achieve.

Considerable research effort will be applied to investigate fundamental aerodynamic techniques which will enhance the forward flight pressure recovery performance of the EAPS. This work will be aimed specifically at EAPS panel mounted devices which would provide the possibility of a removable "summer" kit.

A review of tube design configurations which would improve forward flight pressure recovery performance will be undertaken.

Engine Mounted Particle Separators.

A number of engine manufacturers have researched axi-symmetric engine inlet particle separators and offer the separators as standard or optional equipment. General Electric, Pratt and Whitney, Rolls Royce and Turbomeca have carried out a considerable amount of work in this field.

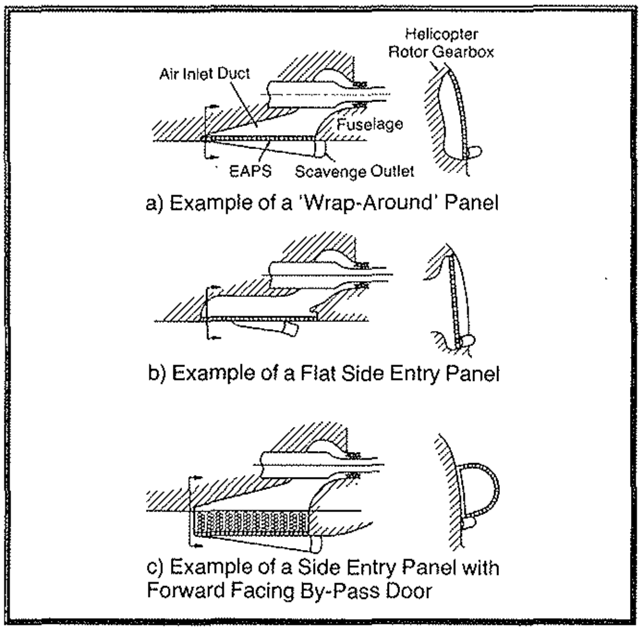
The design considerations and constraints imposed on the engine mounted particle separator are considerable, particularly related to:

1) Anti-icing requirements.
2) Installation volume and length.
3) Weight.
4) Scavenge flow requirements and method of discharge.
5) Matching of residual swirl to compressor characteristics.
6) Sensitivity of particle separator swirl generator vanes to helicopter air inlet swirl/flow distortion.
7) Distribution of unseparated dust entering the engine.
8) Installation flexibility.

Comparison of EAPS and EIPS

Installation Constraints

For front drive engine configuration the installation constraints for EIPS are much greater than for EAPS , particularly if the EIPS is offered as optional equipment. For integral EIPS the engine gearbox can be incorporated in the separator centrebody and thus minimise the overall length of the installation. An optional removable EIPS requires additional length and the separator maximum diameter would probably define the minimum distance between engine centre lines and hence increase the width of cowlings over the engines.The scavenge system has to be either ducted to the engine exhaust pipe or be brought out to the fuselage surface with EIPS whilst the EAPS scavenge exhaust is installed on the fuselage wall.



a) Example of a 'Wrap-Around' Panel

b) Example of a Flat Side Entry Panel

c) Example of a Side Entry Panel with Forward Facing By-Pass Door

Figure 24
Examples of EAPS Configurations for front drive engine

For a twin engined front drive engine installation a minimum of three configurations of EAPS could be provided, namely: a) a wrap around panel; b) a side entry panel; c) a side entry panel with either forward facing panel or by-pass door. The examples are shown in figure 24.

Pressure Drop and flow distortion

The EIPS designer has to keep the overall size of the separator as small as possible and would generally run the air velocities at a higher value than those in the EAPS system. The presence of swirl vanes and straightening vanes in the EIPS would increase the pressure loss. The risk of flow distortion increases if the EIPS does not receive uniform entry flow conditions from the side intake configuration on the helicopter. The EAPS design flexibility enables the designer to produce in conjunction with the helicopter manufacturer systems with total inlet losses of between 7.5 mbar and 15 mbar with very low flow distortion levels. EIPS pressure losses would be expected to be between 12.5 mbar and 17 mbar. The pressure losses quoted above are based on compressor entry plane rather than engine entry plane values to enable a direct comparison to be made.

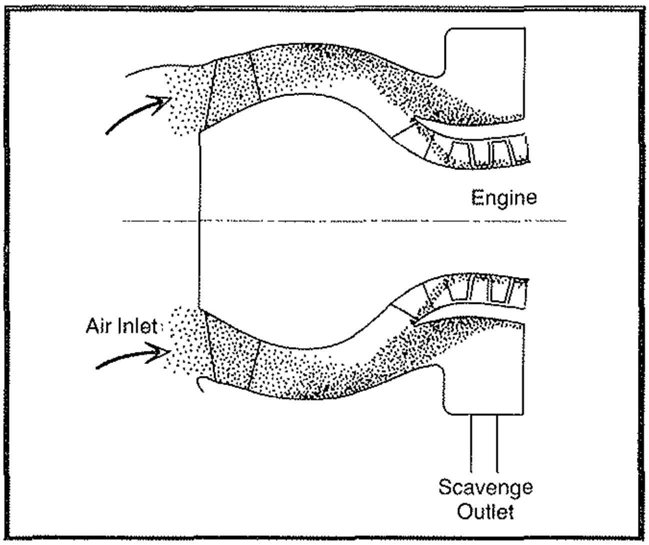


Figure 25
EIPS Dust Particle Trajectory

Dust Separation Efficiency

The dust separation efficiency of the EAPS will be superior to that of EIPS because they are designed specifically to achieve high dust separation efficiency at minimum pressure drop. The EIPS has been developed as a multi-role device which makes it considerably more difficult to achieve good installation, performance and engine protection characteristics.

The nature of the axi-symmetric EIPS design is believed to concentrate dust which has not been separated into a small annular space at the compressor entry plane (See figure 25). The high concentration of dust would cause increased erosion rates on stator vanes of axial compressors and hence reduce the engine erosion life. The high concentration of dust will move from the compressor hub to the blade tip as it passes through the compressor where erosion effects are most critical.
The dust distribution at the compressor entry plane will be governed by the intake configuration between the EAPS and engine. The dust leaving the EAPS would have a near uniform concentration distribution, but some

modification of the dust would occur in the S shaped duct formed on most front drive engine inlet configurations. The inlet geometry to the engine will influence the dust distribution at entry to the compressor.

Based on typical data for EAPS and EIPS if we consider a helicopter which hovers for 20 hours in "zero visibility" conditions (1.4 g/m^3 dust concentration) the engine protected by EAPS would ingest some 140 kg of dust and the engine protected by EIPS would ingest some 740kg/dust. The relative engine life improvements factors would be some 23:1 for the EAPS and 5.5; for the EIPS assuming that the dust enters the engine in a uniformly distributed manner.

Foreign Object Separation

The EAPS would generally be expected to have a better overall performance then the EIPS because the size of particle able to pass through the EAPS tube is very small (6mm diameter maximum). EIPS have demonstrated high foreign object separation efficiencies under rig test conditions but would allow foreign objects of far greater than 6mm diameter to pass through.

Icing Performance

The EAPS has a proven record of icing capability in both rig and natural icing conditions. It would not be necessary to provide inlet or engine anti-icing systems downstream of the EAPS but careful design consideration must be made to eliminate water traps in the downstream engine inlet duct. Any water running through the EAPS panels during melt off or during ground parking must be allowed to drain from the inlet duct to prevent the risk of freezing and subsequent ice ingestion by the engine. Ice ingestion could be a potential engine F.O.D. hazard.

The icing characteristics of EIPS will be dependant upon the upstream inlet configuration and the amount of free water and supercooled water droplets passing through the EIPS. Some anti-icing of the EIPS surface may be necessary to prevent ice accretions and the subsequent risk of engine F.O.D.

Helicopters equipped with EIPS would require some additional form of air intake anti-icing or de-icing equipment to either prevent the formation of ice or shed ice which may be separated by the EIPS. The EIPS weight and power penalties associated with icing requirements would be considerably greater than that of EAPS.

Salt Spray Removal.

EAPS systems with mist eliminator options achieve 99.6% water droplet separation and hence reduce engine fouling and corrosion rates. The EIPS systems water removal will be influenced by the upstream intake profile and water would be expected to run back along the walls of the duct and may or may not be separated by the EIPS. No published data has been seen on EIPS performance against salt spray and mist.

List of References

1. Stallard P. "The Development of an Engine Air Particle Separator System for the CH-47 Helicopter". Aircraft Porous Media Europe Ltd., Portsmouth, England.