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AEROSPATIALE'S EXPERIENCE ON HELICOPTER FLIGHT IN ICING CONDITIONS

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1– INTRODUCTION

Helicopter operation in icing conditions is becoming more frequent with the possibility of IFR flight for civil applications, and particularly due to the pressure of military operators wishing to improve availability of their aircraft.

Without rotor icing protection, the flight limits are soon reached in icing conditions. Ice buildup demands extra power and generates unacceptable vibration levels and even loss of control due to blade stall caused by a change in the airfoil shape ; the limits established subsequent to various flight tests made flying in icing conditions possible without rotor protection systems but operational restrictions on the helicopter envelope are still present.

With a view to overcoming these restrictions, it has been necessary to protect the rotors against ice accretion. From 1964, preliminary tests on the Alouette III and Super Frelon were conducted and led to the electric main rotor deicing and electric tail rotor anti-icing systems which have been chosen for the SA 330 Puma.

This protection system was developed initially in simulated icing at the Ottawa's NRC (National Research Council) hover spray rig (Figures 1, 2 and 3) and then in the course of several test campaigns in natural icing. Each difficulty encountered led to an improvement in the system. This development work culminated on 25 April 1978 in the «all-weather flight» certification of the Puma after 71 flying hours in icing conditions. The French Army Air Corps (ALAT) and the Flight Test Center (C.E.V.) performed an additional 65 hours (including 10 hours for a humanitarian mission in Iceland) in actual icing with three aircraft to check and confirm the operational capability of the Puma.

Advantage was taken of this experience to define an improved deicing system for the AS 332 Super Puma.

A certain number of flights without rotor or horizontal stabilizer protection, to check behavior of the Super Puma in the event of total failure of the deicing system with a view to certification of this system, led to a practical flight envelope being defined for flight without protection.

This paper is intended to give a brief overview of the progress of work made by Aerospatiale on deicing and anti-icing systems for aircraft in the Puma family.

2– ICING ENVELOPE AND ASSOCIATED CONDITIONS

The maximum icing conditions likely to be encountered in flight are given in FAR, Part 25, Appendix C «Airworthiness Standard for Transport Category Airplanes». The regulations which have been retained for certification of the SA 330 and AS 332 are as per FAR, Part 29.

They define the maximum liquid water content (LWC) with respect to ambient air temperature and droplet diameter for continuous icing conditions (stratiform clouds) and intermittent icing conditions (cumuliform clouds) for a given cloud horizontal extent (17.4 NM for continuous and 2.6 NM for intermittent icing) ; for clouds of different lengths, a correction factor related to the length is applied to the basic LWC.

Figures 4 and 5 present the Appendix C to FAR Part 25, «Liquid Water Content as a function of temperature and drop size». For illustration, the four degrees of icing severity defined by Lockeed, California, for the U.S. Army and the three degrees of icing severity defined by BCAR are provided on these figures.

The altitude and temperature envelope is also defined for the two types of icing (Figure 6). It can be seen that it extends considerably beyond the flight envelope of present day helicopters.

The FAR regulations do not set the additional meteorological conditions associated with icing (Figure 7) in which helicopter operation must still, however, be substantiated, in particular : lightning, snow, hail, freezing rain, ice cristals, mixed conditions, gusts, etc ...

The protection systems fitted to the SA 330 Puma and AS 332 Super Puma have been designed so that these aircraft can encounter all atmospheric conditions in complete safety.

3– FLIGHTS IN ICING CONDITIONS WITHOUT PROTECTION : SA 330 AND AS 332 AIRCRAFT

The experience gained in icing conditions without protection on both the Puma aircraft No. 4 in 1979 (over 9 hours in actual icing up to 9000 ft, – 9° C) and Super Puma No. 2005 (14 hours 15 mn up to 8000 ft, – 13° C) gives rise to the following comments :

- Although flight without protection is not recommended, it is possible to fly in icing conditions with certain reservations, the first being to be able to leave the icing conditions at any time if one of the flight limitations is reached. This requires knowledge of the cloud conditions along the entire track or, more simply, a minimum altitude band at positive temperature. Deterioration of performance, flying qualities and vibration level, and sometimes damage to the main rotor blades (through ice shedding) occur and, although not immediately jeopardizing flight safety, may lead to the need for repairs.

  From this experience and the conclusions drawn, it seems possible to operate the AS 332 Super Puma without full icing protection in the following flight conditions.

  - Maximum altitude about 8000 ft
  - Minimum temperature from -6^{o} to -10^{o} depending on icing severity
  - Icing severity : light to moderate
  - To these limitations should be added a maximum torque increase limit in level flight
  - If one of the above limitations is reached, or if abnormal flying qualities or major changes in the vibration level occur, it is necessary to fly off the icing environment
  - The main rotor blades and other exposed vital parts must be inspected for signs of impact after flight in icing conditions with actual ice buildup.

  Nevertheless, the additional minimum equipment required on the basic aircraft for flight within this limited icing envelope should comprise :

  - Restrainer fairings
  - Ice detector (providing icing severity)
  - Weather radar

- The basic aircraft is normally fitted with protection against unexpected icing and environmental conditions as follows : (Figure 8)

  Engine air intake screens

  Electrically anti-iced pitot heads

  Electrically anti-iced cockpit windshields

  Lightning protection for rotors, fuel tanks and fuel tank vents.

4– ICING PROTECTION SYSTEM ON THE AS 332

This section covers the icing protection system description, the instrumentation used during system substantiation, the flight tests conducted in icing conditions and the system substantiation.

4.1 – Description of Super Puma Icing Protection Package

As compared to the basic aircraft, the «icing» category Super Puma is fitted with the following protection :

- Electrically deiced composite main rotor blades (Figure 9)
- Electrically anti-iced composite tail rotor blades (Figure 10)
- Control, monitoring and distribution electronics for main and tail rotor blades
- Slip rings for electric power distribution on main and tail rotors (Figures 11 and 12)
- Lightning protection for complete deicing system
- Pneumatic deicing of horizontal stabilizer
- Weather radar
- Ice detector
- Various fairings.

The protection system for the Super Puma has been derived from that on the Puma with the following improvements :

- Simultaneous deicing of the 4 main rotor blades made possible by an increase in electrical power generation, retaining the cycling sequence used on the Puma (Figure 13). This improvement has led to a reduction in the vibration level in icing conditions.
- Adaptation of the heating power to the composite tail rotor blades to maintain the same surface temperatures as on the metal blades of the Puma.
- Pneumatic deicing of the horizontal stabilizer made necessary by its different shape and increased aerodynamic effectiveness, to improve the flying qualities at high speed (Figure 14).
- Use of the basic AS 332 air intake screens in icing, substantiated in an icing wind tunnel and then in flight.

4.2 – Super Puma Instrumentation

The icing tests call for special instrumentation in addition to the conventional performance and flying quality measurements :

The following icing parameters have been measured :

a) Water content

- by commercially available ice detectors (Figure 15)
  - Leigh
  - Rosemount
- by a more sophisticated Johnson-Williams hot wire detector (Figure 16)
- by a fixed probe fitted with a graduated plate (Figure 17).

Droplet diameter

- laser measurement of water droplet diameter using Knollenberg FSSP (Figure 18).

c) **Static temperature**

- precise measurement using a reverse flow probe.

The deicing parameters were measured at various stages of development and certification work : rotor deicing and anti-icing currents, blade temperatures, stresses and vibrations at various points on the helicopter.

The engine air intakes were monitored simply by using rear view mirrors in the cockpit. A camera was fitted during initial development work on the Puma (Figure 19).

In fact, one of the difficulties with instrumentation for the icing tests is that there are two contradictory requirements :

a) **The need** to measure the aircraft characteristics and to see the ice buildup.

b) **The need** to preserve the external configuration of the helicopter in order not to change the ice buildup and the helicopter's behavior.

The compromise between both these requirements led to the following measurements on the Super Puma :

24 basic parameters

4 icing parameters

12 deicing parameters

23 stresses and vibrations.

All these parameters are recorded on magnetic tape and partly displayed at the flight engineer's station for the purpose of conducting the tests (Figure 20).

4.3 — Flight Tests

The major part of the tests was devoted to finding the most varied natural icing conditions. When these conditions were encountered, correct operation of the various icing protection systems was checked, mainly in cruising flight but also in all other configurations (climb, descent ; approach and go-around, engine failure simulation, etc ..). The aircraft behavior was also assessed in the event of partial or total failure of the protective systems. These tests were carried out up to the maximum aircraft weight.

Main rotor deicing proves effective for all the icing conditions encountered. After the flights, when the ground temperature was negative, the extent of the various buildups (Figures 21 and 22) was measured and checks were made particularly to ensure that there were no traces of refreezing on the main rotor blades. Apart from the cyclic torque variations associated with the deicing cycle, no significant change in the mean torque value was observed in flight during the longest periods in icing conditions (1 hr 50 mn).

The deiced Super Puma, under development since 1981, has now accumulated 55 flying hours in actual icing conditions in France, Scotland and in the extreme north of Norway, encountering icing conditions down to -20° C. It has successfully performed all the certification tests, particularly the demonstrations of partial or total failure of the protective systems, with a view to DGAC and FAA certifications.

4.4 — Substantiation of Icing Protection Systems

The engine fitted with its air intake was tested in an icing wind tunnel under FAR 25 conditions, and then in flight. Figure 23 shows that the buildup occurring in flight on the side wall of the air intake screens remains porous and cannot cause complete blockage of the air intake.

The deicing and anti-icing systems on the SA 330 and AS 332 aircraft have been designed to ensure protection throughout the FAR 25 icing envelope in continuous or intermittent icing conditions. Substantiation of system effectiveness is based on in-flight measurements and observations in simulated or natural icing conditions in an extended envelope (Figure 24), and also on a theoretical analysis which itself has been substantiated by comparison with measurements taken in flight and in an icing wind tunnel. A mathematical model validated down to the temperatures explored was used to ascertain that the system remains effective at -30° C, and that the cycle change (operating time shifted from 10 sec. to 16 sec.) is definitely needed at -10° C.

The pneumatic deicer on the horizontal stabilizer was developed and substantiated in an icing wind tunnel and then in flight.

The deicing system lightning protection and structural strength of the rotor blades were tested by lightning simulation. An actual lightning strike - which impinged on three out of four blades of the AS 332 - occurred during the flight tests, with no damage to the icing system, which emphasized the effectiveness of the lightning protection.

The ability to withstand hailstones was checked and found correct for components which could give rise to a dangerous situation if damaged (main and tail rotor blades, engine air intakes, front cockpit windshields).

5– CONCLUSIONS

A new dimension has been reached in helicopter IFR flight as a result of the various campaigns for development and certification of the deicing and anti-icing protection systems on the Puma and Super Puma in natural icing conditions. With the protection systems fitted, it is now possible to fly without icing limitations. This has recently been proved, during ferry flights to Norway and Scotland where these helicopters were flown like fixed-wing aircraft to an IFR flight plan, irrespective of the conditions encountered.

The tests carried out without icing protection have led to :

- A better definition of the procedures to be followed in the event of failure of one of the protective systems during flight in icing conditions, and an indication of the technical tolerances when completing a mission with certain system failures.
- The definition of a practical flight envelope (altitude, temperature, icing severity) and the aircraft limitations to be respected, with a view to improving the availability of Puma and Super Puma helicopters.

In the light of these results and additional substantiations, the French Aviation Authorities granted a Type Certificate for flight in forecast icing conditions without restrictions for the Puma on 25 April 1978, and for the Super Puma on 29 June 1983.

REFERENCEES :

Ref 1; Protection systems againts icing on the PUMA . JC LECOUTRE 1978 .

Ref 2: AGARD Advisary report 166. Rotorcraft status and prospects 1981.

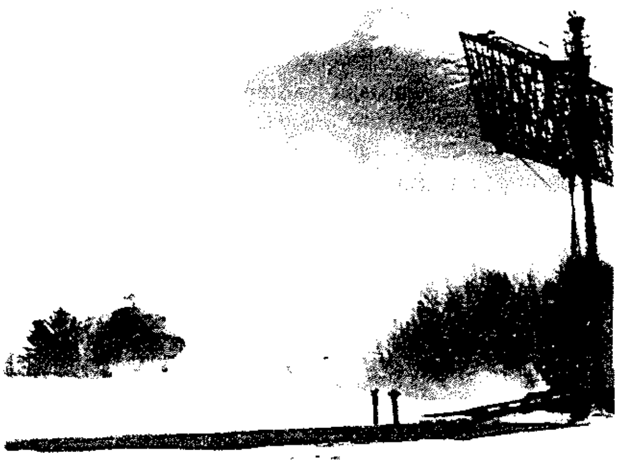


Fig. 1 : ARTIFICIAL ICING TEST IN CANADA SA 330

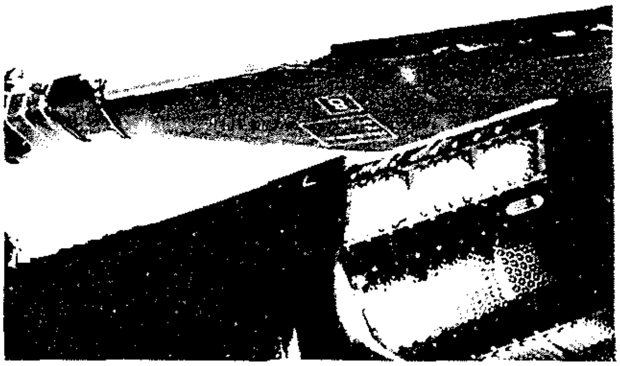


Fig. 2 : ICE BUILDUP DURING DEVELOPMENT OF THE SA 330 IN NATURAL ICING ENVIRONMENT

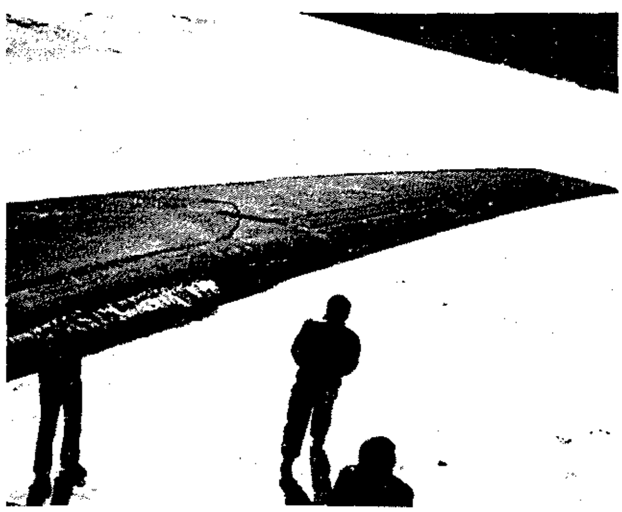


Fig. 3 : ICE BUILDUP DURING DEVELOPMENT OF THE SA 330 IN NATURAL ICING ENVIRONMENT

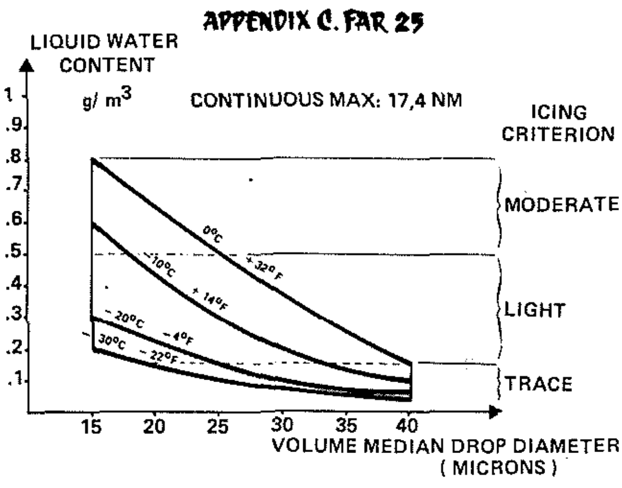


Fig. 4 : F.A.R. 25 - CONTINUOUS MAX. CONDITIONS

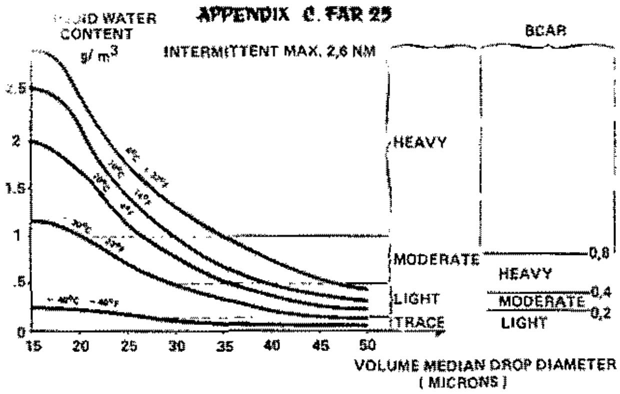


Fig. 5 : F.A.R. 25- INTERMITTENT MAX.CONDITIONS

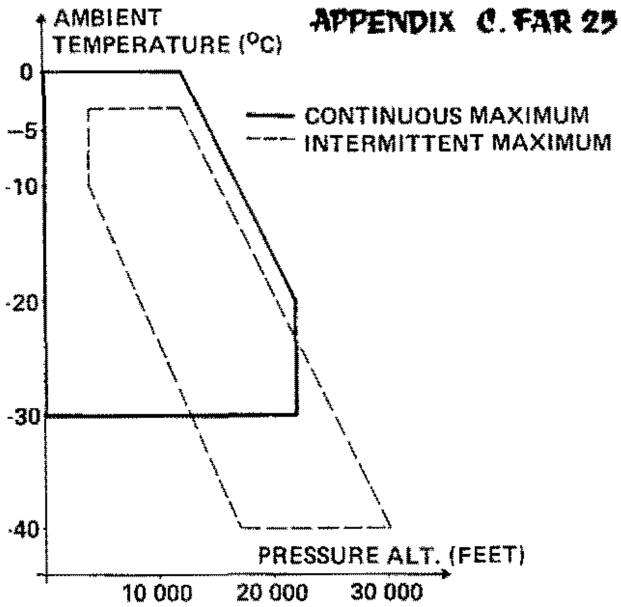


Fig. 6 : F.A.R. 25 - APPENDIX «C»

CONDITIONS :	possible action on :
LIGHTNING	- heating strips
	- electric components
SNOW	- air intakes
HAIL	- rotor blades
	- windshields
	- airframe
FREEZING RAIN	- hub
	- rotors
	- airframe
RAIN	- rotor blade leading edge
	- slip ring
	- air intakes
VIBRATIONS	- heating strips
	- slip ring
GUSTS	

Fig. 7 : ASSOCIATED CONDITIONS

Fig. 8 : GENERAL VIEW OF SUPER PUMA No. 2005 USED FOR THE ICING TESTS

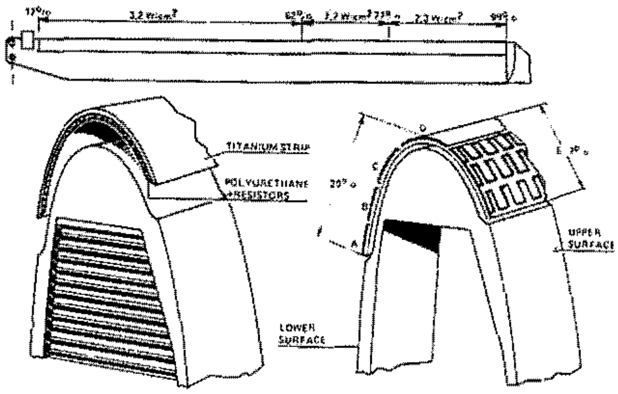


Fig. 9 : SA 330 AND AS 332 DEICED MAIN ROTOR BLADE

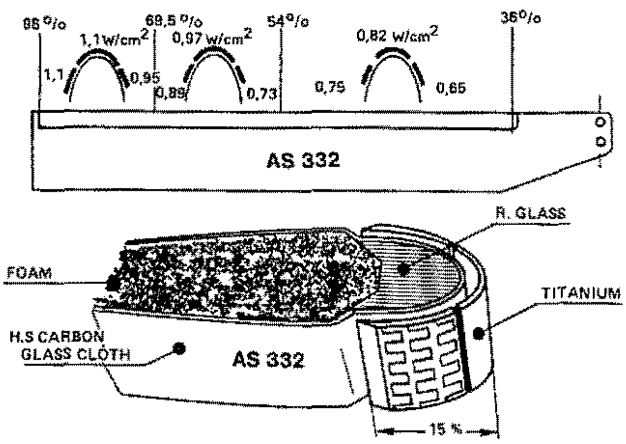


Fig. 10 : AS 332 ANTI-ICED TAIL ROTOR BLADE

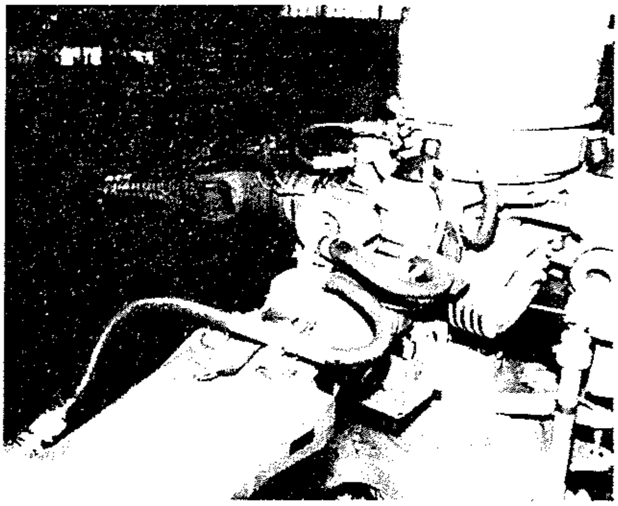


Fig. 11 : DEICED AS 332 MAIN ROTOR HUB

	TEMPERATURE > − 10° C	TEMPERATURE < − 10° C
	d-e-c-b-a	d-e-c-b-d
WORKING TIME	10 SEC	16 SEC
REST TIME	43	67
TOTAL	93	147
	d-e-c	d-e-c
WORKING TIME	10	16
REST TIME	23	35
TOTAL	53	83

Fig. 13 : DEICING SEQUENCE ON AS 332 MAIN ROTOR BLADE

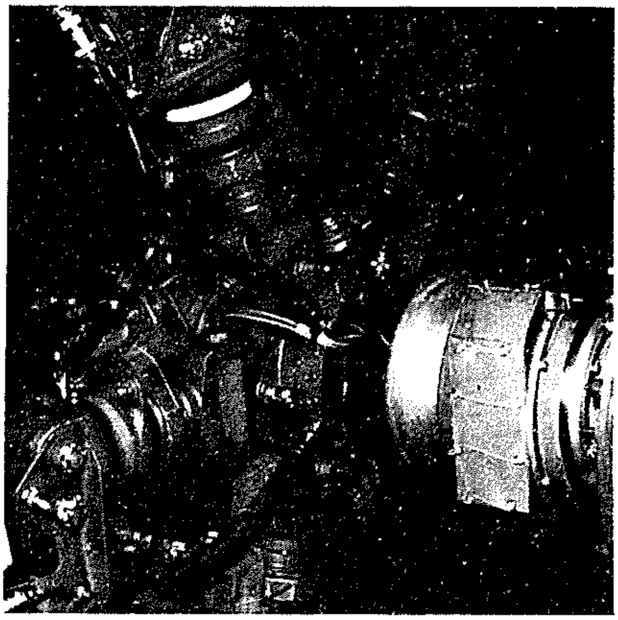


Fig. 12 : ANTI-ICED AS 332 TAIL ROTOR HUB

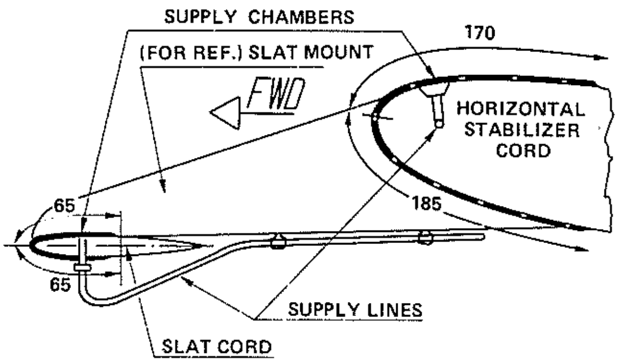


Fig. 14 : AS 332 HORIZONTAL STABILIZER PNEUMATIC DEICING

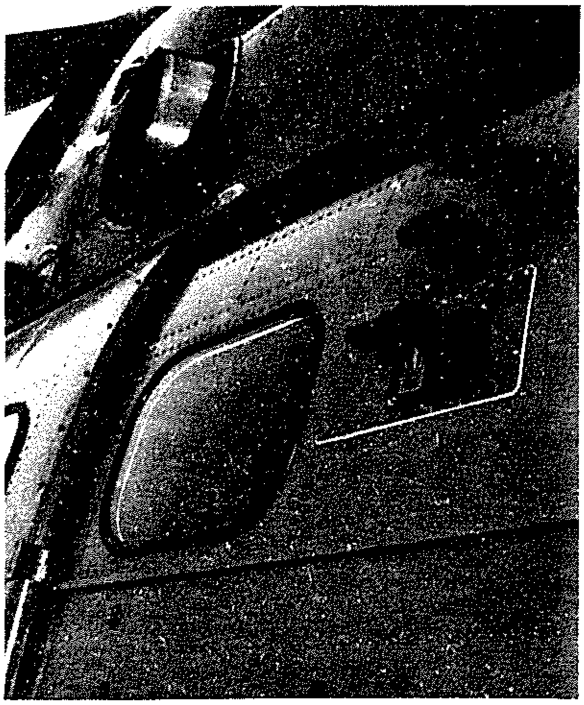
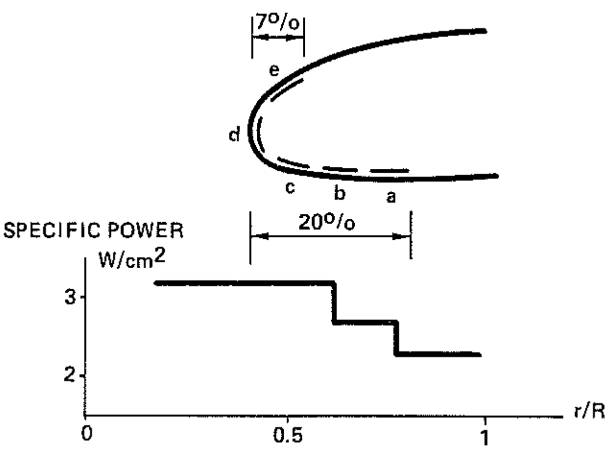
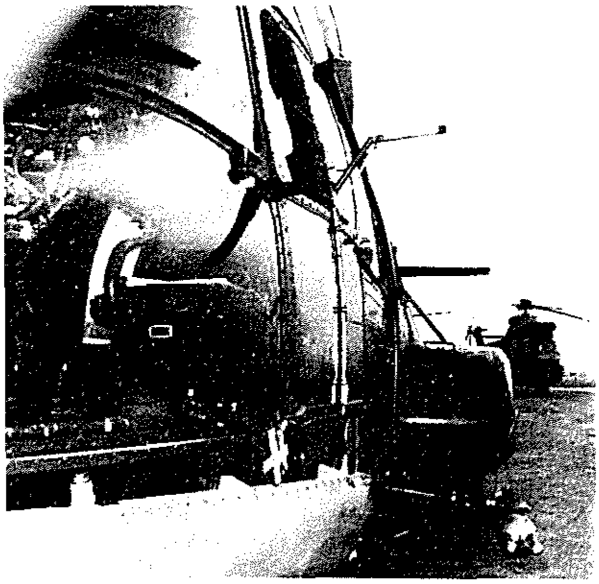
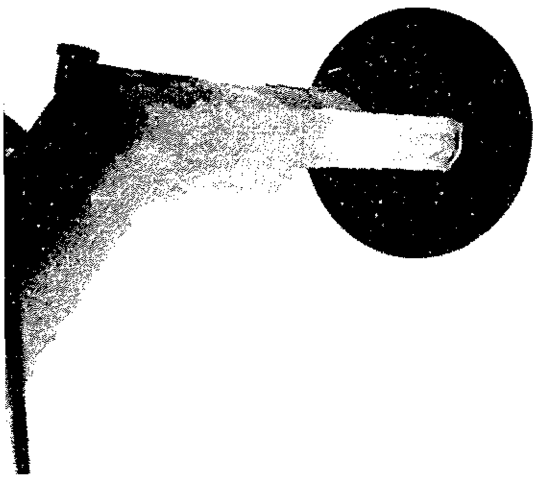


Fig. 15 : LEIGH AND ROSEMOUNT ICE DETECTIONS





ig. 16 : FIXED PROBE,JOHNSON - WILLIAMS AND FSSP KNOLLENBERG



g. 17 : CEV ICE ACCRETION PROBE

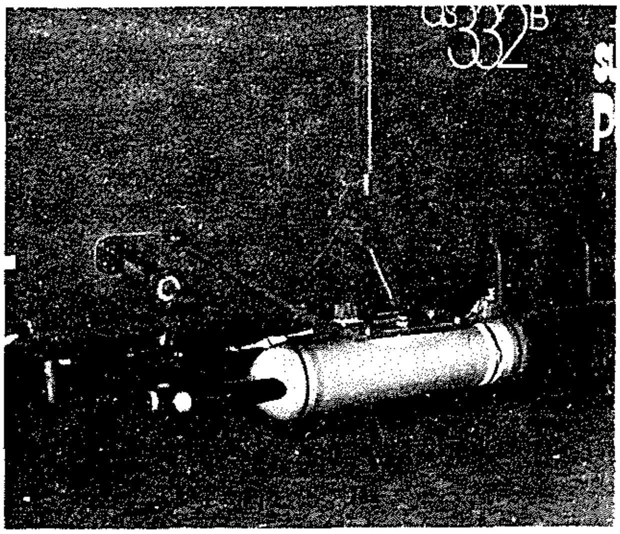


Fig. 18 : FSSP KNOLLENBERG

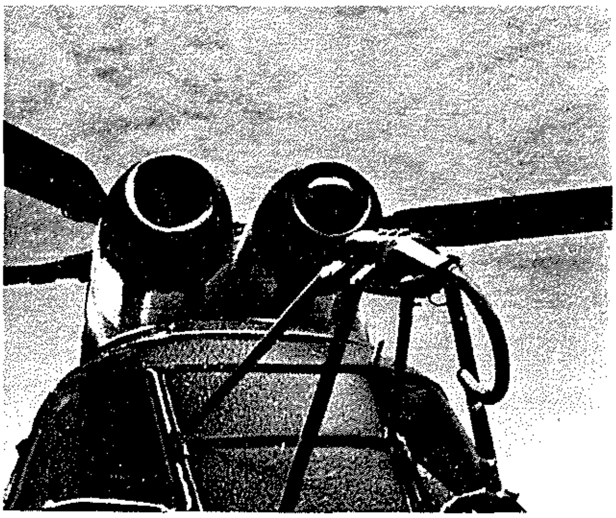


Fig. 19 : SA 330 AIR INTAKES MONITORED BY CAMERA

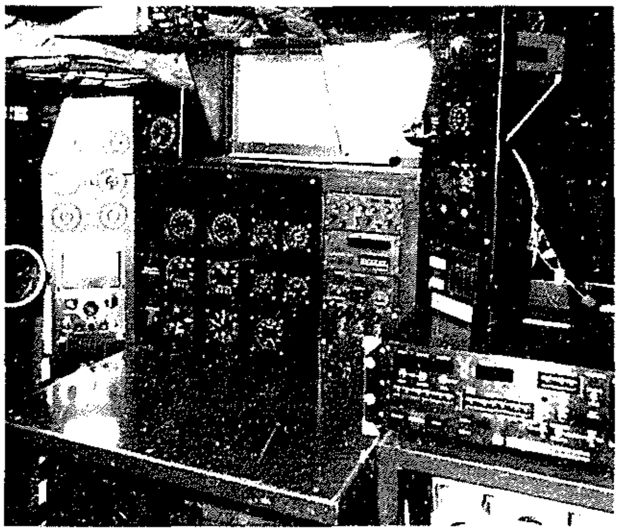


Fig. 20 : AS 332 FLIGHT ENGINEER'S STATION

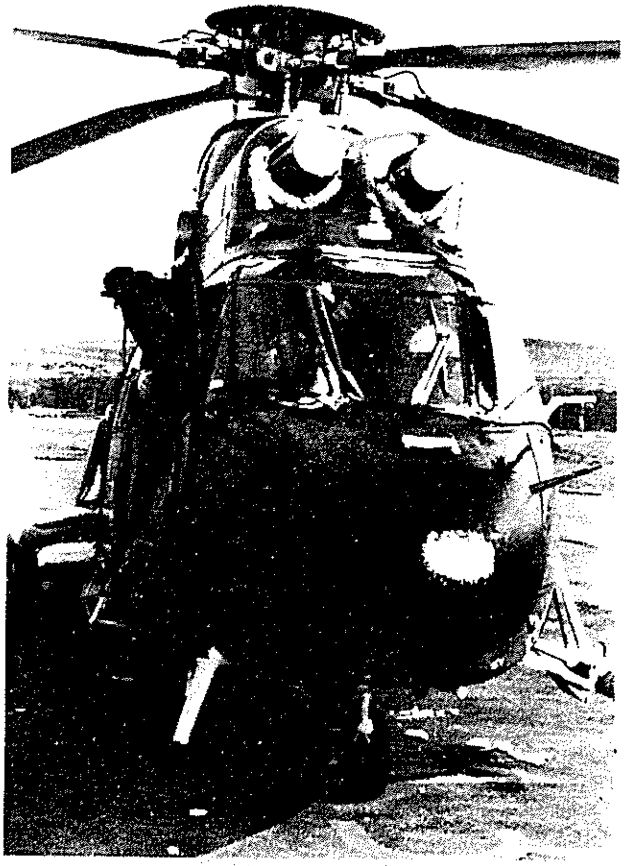


Fig. 21 : ICING AT ABOUT – 12° C ON AS 332

Fig. 22 : ICING BETWEEN – 3° C AND – 6° C ON AS 332

Fig. 23 : ICE BUILDUP ON AS 332 ENGINE AIR INTAKE

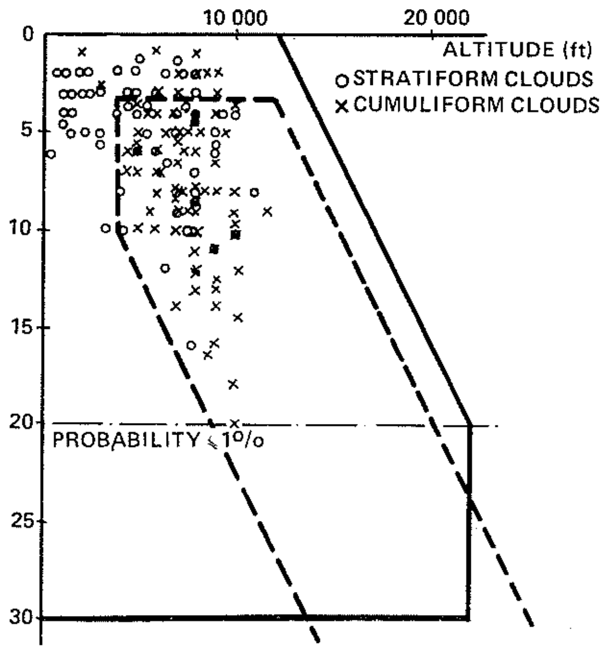


Fig. 24 : ICING CONDITIONS ENCOUNTERED