HELICOPTER FLIGHT IN ICING CONDITIONS - OPERATIONAL ASPECTS

By
Captain K. Lande
Helikopter Service AS
Norway

Abstract

Helicopter fligt in icing conditions has developed as a necessary requirement for all weather Instrument Flight Rules (IFR) helicopter operations. The progress has been slow and the manufacturers and authorities have been lagging in developing and certificating rotor de-ice systems. This has forced operators to develop their own operational procedures and has made them capable of dealing with the icing problem.

In Europe the offshore helicopter flying have led to development and certification of helicopters for flight in icing conditions, both with cold blades and with heated blades.

After nearly 30 years of offshore helicopter flying in day and night all weather operations in a hostile area, stretching from the North Sea over the Norwegian and Barent Sea and up to the Arctic area of Spitsbergen of 80° North, the helicopter flight in icing conditions has reached a mature state.

There is a lot of helicopter icing experience among the European offshore helicopter operators which the authorities and manufacturers should draw on in future certification projects.

Introduction

Helicopter operations are still lagging fixed wing operations in some areas; like IFR all weather operations.

Helicopter civil IFR operations on a regular basis were developed during the 70-ties and then primarily in offshore operations over the North Sea. This was caused by necessity in order to support the drilling and oil production in this hostile environment.

It didn't take long to operate over the North Sea until some pilots found themselves in icing conditions, and as had happened many times before in aviation, the day was saved by pilot judgement and good airmanship. The Flight Manual clearly states that flight in icing conditions is prohibited, but the FM does not elaborate on how to operate under IFR conditions without occasionally entering icing conditions unintentionally.

Today in the North Sea we have the world's most IFR experienced helicopter pilots with many of them between 5.000 and 15.000 hours of flying experience. After nearly 30 years of flying over the North Sea, IFR, day and night, many pilots have accumulated a lot of icing experience, both intentionally and unintentionally.

Hence, over the years helicopter icing is not regarded as a problem among North Sea pilots. This does not mean that icing is not taken seriously. It just means that North Sea pilots have learned to cope with icing (Ref 1).

This experience buildup is a long term process.

Helicopter icing over land is a different matter so all helicopter pilots are normally trained to stay out of icing conditions. That was possible in closly controlled military operations where they rarely flew real IFR flying, or canceled flying in bad weather.

When starting flying in the North Sea the nature of flying changed completely, with standard instrument departures, company developed offshore NDB/radar approaches, cruising altitudes of 1000 - 7000 ft, and ILS approaches on a regular basis, with all flights on an IFR flight plan. All this have led to the development of helicopter IFR, all weather operations to a standard very close to fixed wing operations, and day-to-day state-of-the-art helicopter IFR operations are now leading the manufacturers and authorities in experience. Hence, we in European Helicopter Association welcome the dialogue we have today between EHA and Joint Aviation Authorities. Further, we are hoping that the manufacturers and authorities will recognize the vast operational experience EHA's members have accumulated experience operating IFR helicopters in icing conditions, both without (Ref 2) and with (Ref 3) rotor de-ice systems, and take advantage of this during the legislation process.

This experience supplements the work performed by authorities, manufacturers and research organisations (Ref 4).

There are three main reasons for seeking formal icing clearances:

Safety

Flying in the European offshore environment leads to unavoidable penetration of icing conditions. Also the pilots prefer to fly at higher altitudes that allow them more time during any serious emergency, as opposed to creep under the icing zone at 200-500 feet often in tailwind conditions, which is very unfavourable if one has to make a quick emergency landing on the sea.

Comfort

An icing clearance will allow our pilots to penetrate forecasted known icing conditions and allow flight "on top". This will reduce the necessity for flight in turbulence, reduce the time in icing/near icing conditions.

Economy

We will be able to cruise "on top" and hence make use of favourable winds aloft and better fuel economy. Helicopter Operators in Norway have been operating the Eurocopter AS 332L with full rotor de-ice/anti-ice systems since 1988. The system became DGAC and FAA certificated in 1984. After some initial reliability problems the system has now reached a mature state and has proved to be flight essential operating helicopters over the Barent Sea and Spitsbergen.

The Environment

The Norwegian offshore area of operations stretch from the southern North Sea, through the Norwegian Sea and up to the Barent Sea and Spitsbergen. Figure 1.
Most of the accumulated experience is gained in the North Sea up to about 62°N (up to 1980).
From 1980 Helikopter Service has operated from Tromsø (1980-82), Andenes (1983-85) and Hammerfest (1986 -94).
Up to 1988 all the flying over the Barent Sea was without rotor de-ice systems (unheated blades).
From 1988 Helikopter Service has operated three AS 332L with rotor de-ice systems (electrically heated rotor blades).
South of 67°N it rarely happens that freezing level is lower than 1000 feet above sea level. If it is, it is clear sky and no moisture in the air and hence no icing conditions.
Ref 1 shows some meteorological data from the North-East Atlantic. Figure 2.
It shows that the freezing level rarely is less than 1800 feet (950 mb) in this area. Over the North Sea this is closer to 1000 feet.
For the North Sea operators icing has not been a serious problem. However, mixed conditions with heavy snow showers or snow fall mixed with supercooled water has resulted in some incidents with engine flameouts. Occasionally during the winter months, there are some delays due to heavy snow fall which closes the airfields.
Figure 3 shows the frequency of surface OAT < 3°C in precipitation in our area of operations.
It can be seen that in the winter surface OAT is 3°C or less, 15% of the time in the south, to 30% in the north. That may give some indication of the helicopter flight conditions out from Hammerfest in North-Norway.
As Figure 3 shows, even in the summer time you may have som days (2%) with mixed conditions and 0°C OAT at 1500 feet, when departing on an offshore flight from Hammerfest.

Icing forecast will only affect the regularity statistics. During 30 years of offshore flying, Helikopter Service has lost only a few flying days due to icing. There have been a few departures delayed due to SIGMETS concerning icing, but those would not cover an extensive period. The weather has normally improved to allow dispatch within the same day.

In the winter of 1985/86 the AS 332L with unheated rotor blades was operated out of Andenes, North-Norway. It may be surprising to hear that not one day was lost due to icing. That does not mean that de-ice equipment is not needed on aircraft operating off North-Norway. The problem here is that it is dark most of the time and you may enter icing conditions in clouds that do not show up on radar. With freezing level at sea level or below, one does not get rid of the ice. The lessons learned by the pilots were that operating in icing conditions without an escape route was unsafe.

The Helicopter and Icing

The helicopter flight envelope

Most rotorcraft operate at cruise altitudes between 1000 and 7000 feet. In Europe this puts one in the middel of most weather, including icing conditions.
Figure 2 shows the percentage of subzero clouds in the North-East Atlantic, with stratiform clouds, cumuliform clouds and total cloud coverage.
It is clearly indicated that one always will find a height band below the clouds for escape route over the sea in positive temperatures.

North Sea cloud conditions

The typical clouds over the North Sea are of cumuli or stratiform. The water content of these clouds are normally highest in the cumuli clouds. These are normally seen on weather radar and are avoided.
However, it is normally the higher stratiform clouds (stratocumulus or altostratus) between 3000 and 7000 feet that give the problems.
Quite often the water content is not high enough to give a radar indication but it is more than enough to give icing. This may happen during night flying when one does not see the cloud formations visually and they do not show up on the radar. This may be a typical setup for an unintentional penetration into icing conditions. Figure 4. However, the experienced North Sea pilot will not panic, but calmly descend out of the icing zone.
Figure 5 show the water content of North Sea clouds. Typically the cloud tops of stratiform clouds in the North-Sea are around 4000-6000 feet.
The cumuliform clouds typically tops out above 6000 feet and normally it is possible to circumnavigate cumulitops. That is done regardless of indication on the radar just to avoid unnecessary turbulence.

North Sea icing

The icing encountered in the North Sea generally falls within the "academic terms":

- Clear ice: OAT 0° to -5°C.
  . Cumuliform clouds, large droplets.
  . Icing on windshield/airframe/ engine intakes/rotor.

- Rime ice: OAT -5°C and below.
  . Stratiform clouds, small droplets.
  . Icing on windshield/ airframe/engine intakes/ rotor.

- Mixed ice: OAT 0° to -10°C.
  . Icing on rotor below -5°C.

- Mixed conditions: OAT +0° to -2°C.
  . Icing on windshield and in engine intakes.

There are no statistical evidens regarding the frequency of different icing types but pilots have observed a lot of mixed ice of the "horn" type. Figure 6. (Ref. 4, Figure 3). This is easily observed on door handles, OAT probes and other protruding items on the rotorcraft.

Icing criteria

Engine intakes of all IFR helicopters should be cleared for icing conditions even if the helicopter does not have an icing clearance. This requirement is based on many years experience.
Ref. FAA AC 20-73 para 13. Figure 7.
Here FAA recognizes the need for engine anti-ice, but the text in AC 20-73 paras 13 and 34 is somewhat misleading.
Experience has shown numerous times that the engine intake must be protected against ice conditions for continuous operation even if the rotorcraft does not have a formal icing clearance.
The present regulations, as indicated above, contain some dangerous pitfalls since it has been proved that it is possible to have engine intake icing in the temperature band between -2°C and +2°C . An illustration of this is S-61N which have had several cases of ice ingestion in mixed conditions.
The AS 332L double engine flame-outs further underline this point. In this case it was later proven during testing that the icing conditions encountered exceeded the certification requirements. This is a clear indication that the engine intake protection requirement should be separated from the rotor and airframe ice protection.

The AS 332L which encountered double engine flame out was flying in mixed conditions which is quite typical of the North Sea environment, with + OAT close to 0°C which does not result in any rotor icing. Even FAA accepts that rotor icing will not occur above 25°F (-4°C). Ref. AC 20-73, para 34. Further to illustrate this point reference is made to some helicopter accidents in the UK believed to have been caused by engine ice ingestion. All these engine related incidents/accidents could have been avoided if the engine intakes had been thorougly tested against intake icing conditions. This underline the requirement to define helicopter icing in three separate areas:

- Engine intake icing
- Airframe icing
- Rotor icing

Further, the incidents clearly indicate the need for ice protection in engine intakes of all IFR certified rotorcraft for continous operation in icing/mixed conditions down to -5°C.
Turbine engines have proved to withstand up to 125-130 grams of ice/water ingestion before flaming out.
Hence, it is vital to protect the engines against ice shedding, either from the intake itself or from other parts on the helicopter.

Helicopter engine intake icing

Looking at past experience reference is made to existing intake designs:

S-61N is generally acceptable but there have been some incidents of ice ingestion from shedding ice from airframe structure forward and to the side of the ice shield.

B-212 has very good engine protection since ice ingested is bypassing the engine. Figure 8.

AS 332 intake protection is not ideal. Ice is proved to be accumulating in the forward part of the intake at OAT + - 0°C.
This was the case of the beforementioned double engine flame out and has necessitated intake heating.
If the intake screen had allowed air to enter behind the screen the engine would have access to alternate air even if the intake was iced up. Figure 9.

BV234LR has a very good intake protection.
Even if the screen is iced up completely, the engine is guaranteed continuous operation.
The BV234LR was initially equipped with engine anti-ice. This feature was later, as a result of the Boeing/RAF icing trials, proved to be unnecessary and removed.

Airframe icing

Airframe icing may result in three problem areas:

- Increased weight.
- Increased drag.
- Danger of ice shedding and damage to rotor blades.

Experience has shown that ice shedding is not a problem. Weight and drag as a result of ice accumulation has no significant impact on rotorcraft operations.

Rotors and flight controls icing is the real problem with rotorcraft icing. However, it is generally accepted that rotor icing is not a problem above -5°C. Hence, practically all helicopter rotors are capable of sustaining icing conditions down to this OAT. This indicates that it should not be very difficult to certify all IFR helicopters down to -2°C in icing conditions. This can be performed in natural icing conditions over the sea with positive OAT escape area. This also confirms the European operators view that all existing offshore helicopter types should be cleared for a limited icing clearance down to -5°C.
Of the existing limited icing clearances in effect today (UK), we can see that a remarkable low OAT is achievable on some aircraft without de-iced rotorblades.

Stress buildup in rotating parts and in the flight controls is one possible critical area of helicopter icing. However, the experience with the existing types in North Sea operations has shown that stress is not a limiting factor.

Main Rotor Blades can sustain -5°C in icing conditons. Hence, there is no different life limit on rotor blades whether the aircraft is certificated in icing or not. The stress levels in the rotor blades in icing conditions within the UK clearance does not exceed the normal limits. Experience also shows that if icing occurs the action taken by the pilot (if any) should be to lower collective.

Tail Rotor Blades can sustain temperatures down to -10°C due to the higher RPM which prevents ice buildup.The stress levels in TRB are within the certified limits and the life limit is not changed as a result of a limited icing clearance.

Rotor Head icing is usually not causing any problems. However, icing testing on the CH-47C Chinook and AS 332L has indicated the need for droop stop protective covers in heavy icing. This is to prevent malfunction during shut down as a result of icing up. This is probably not required for limited clearances as the aircraft will fly in positive OAT before shut down.

Rotor Control stresses may be a limiting factor for limited icing clearances in addition to torque buildup and rotor vibrations. This is a factor the crew normally are not aware of and must be cleared by the manufacturer.
The past experience with existing types indicates that this is not a serious problem.
Again, there is no different life limit on parts for icing certificated aircraft compared to standard aircraft (S-61N, AS 332L, B-214ST).
The most critical parts in this relation is probably the tail rotor pitch links.
This has shown up during icing trials but has not been a problem in service.
However, tail rotor pitch links are some of the weaker parts on a helicopter and it would be assuring if these could be designed with more redundancy.

Cruise Guide Indicator used on the BV234LR during the icing trials of this rotorcraft was proven to be of great importance. It was verified that if the CGI was kept within the green band the stress levels in rotor controls were within the endurance limits. Practical experience has confirmed this.

Worst conditions in relation to limited icing clearances with unheated blades are reached when the icing zone on the MRB has reached 50-75% of the blade radius. This will impare the autorotation RPM and further icing will severely limit the lifting capability of the blade.
However, increased torque and rotor vibrations will, long before this occurs, have given the crew indications causing them to leave the icing zone.

Rotor vibrations are normally the limiting factor for continued flight in icing conditions. The rotor vibrations are normally accompanied by increased torque values. When this occurs there is no longer any advantage of being in the icing zone and the crew will start a descent at this point. This is a very important aspect of flying in icing conditions.
There is no longer any benefit if the required torque and the vibrations have increased. Continued flight in these conditions will result in reduced comfort and higher fuel consumption, reduced airspeed and may result in loss of range to a dangerous level.
A rule of thumb indicates that the numerical drop in IAS will match the numerical increase in torque, i.e. 10% increase in torque will be accompanied by a 10 kts reduction in IAS.

Performance loss of rotorcraft in icing is a result of increased drag and reduced lift on the MRB. The increase of aircraft weight is normally negligable and well inside the normal weight envelope.
The AS 332L without rotor de-ice system has a limitation of 12% torque increase due to icing, limited by 81% total torque, which is equivalent to maximum continuous power twin engine.
Likewise the Flight Manual Supplement indicates a possible drop in autorotational RPM of 15 RPM (6%) within the certified limited icing envelope.

The Requirements

So far the requirements for certification of rotorcraft in icing conditions are based on the US FAR 29/JAR 29,

Appendix C, or the equivalent UK BCAR G 610. The FAR 29 icing criteria covers only full icing clearances. Figure 10-11.

The alternatives are:

- No icing clearance
- Full icing clearance
- Engine icing clearance

The engine icing clearance however, depends largely on the type of total icing clearance. It has been proved several times that the engine icing protection of a non-icing certificated rotorcraft is of very limited value.
Ref. AS 332L double engine flame outs. The engine intakes were certificated to FAR 29, Appendix C requirements. Figure 12.
These requirements are clearly not sufficient for North Sea conditions.
Subsequent tests indicated that actual North Sea conditions could cause intake ice build up in the order of 200 grams ice compared to the engine flame out limit of 130 grams. Figure 13.
Comparing the actual conditions with the FAR 29 requirements (Figures 14-15) it is easily seen that the test requirements are not sufficient for clearing the engine intakes, while they may well cover the rotors and airframe. Figure 16 shows the factory issued Service Bulletin ordering installation of electrical heating mats in the air intake of the AS332L.

Limited Icing Clearances

Limited icing clearances have been in use since 1972 (S-61N).
In addition there are now 30 years of helicopter flight experience in the North Sea. This has inevitably resulted in a lot of inadvertant penetration into icing conditions. This has learned the North Sea pilot to respect - but also to live with the icing conditions.

After 30 years of operations in the North Sea winter environment one can take a look at the experience with the most common types:

S-61N was given a UK limited icing clearance in 1972. In Norway the S-61N was introduced in 1966. Already in the first winter of operation there was an incident of engine flame out due to ice ingestion.

This was before the ice shields were installed. After that time there has been three incidents with engine flame out due to ice ingestion.
One occured when doing hover training during fog conditions with OAT near 0°C without engine intake anti-ice system on. This caused accumulation of ice in the intake duct which finally was ingested by the engine.
The two other cases were caused by slush/ice accumulations during parking in heavy snow/sleet.
The ice accumulated on the aircraft was not removed before take-off and some ice was ingested into an engine.
Ironically the S-61N aircraft is the most proven civil helicopter in limited icing conditions but the least documented.
The sister ship Westland Sea King, has a military clearance for operating in limited icing in OAT down to -10°C with metal blades. The metal blades on the Sea King is comparable to the metal blades on the S-61N.
A survey among pilots indicates that there is no problem of entering icing conditions down to -5°C, as long as you have a possibility to escape by descending to positive OAT, minimum 500 feet above sea level. The icing is observed on the windshield wipers and sponsons. At the lower end of the temperature band between 0° and -5°C a slight increase in vibration is noticed.

Bell 212 was the second offshore helicopter type, introduced in Norway in 1973 (except for some limited use of a Bell 206 for shuttle).
Since these aircraft were primarily used for shuttle flying in the Ekofisk, Frigg and Statfjord areas, the experience of entering icing conditions is limited.
However, there have been a few cases where pilots have reported flight in limited icing conditions without problems.
Possible ice formed on the intake will when falling off, bypass the engine intake and exit with the exhaust. In addition the engines themselves are protected by intake screens.
The rotor system is basically the same as on other Bell helicopters which has proved to be quite resistant against icing.

Bell 214ST has a UK limited icing clearance down to -10°C up to 10.000 feet. This is a very impressive icing envelope without heated blades.
The CAA approved icing kit includes Engine Inlet Screens in addition to the standard Engine and Engine Inlet Anti-ice system. These systems should be on when OAT is 4°C or below, and visible moisture is present.

BV 234LR was introduced in UK in 1981 and in Norway in 1983.
The aircraft came with standard heated windshield, engine inlet screens and engine anti-ice.
It was interesting to note that the engine anti-ice needed only to be used at OAT of -10°C and below.
The CH-47/BV 234 aircraft has been put through a lot of icing tests. As a result CAA was about to grant a limited icing clearance down to -7°C, before the aircraft was removed from UK register in 1987.
Later testing of the Chinook includes fully de-iced rotor blades. An interesting result of these tests is the deletion of the engine anti-icing system. The tests also proved that the engines got sufficient air through the alternate path behind the screens when these were blocked.

This emphesise the point that engine intakes should have

engine anti-ice system unless extensive testing proves that they are not needed.
It is interesting to note that the BV 234LR and AS 332L have operated in the same icing conditions and AS 332L had to leave the zone due to rotor icing while the BV 234 did not have rotor icing.

AS 332L has had a UK limited icing clearance since 1983.
This rotorcraft has the most accumulated data from flying in icing conditions in civil operations.
When comparing the AS 332L to BV234LR, B214ST and S-61N there seem to show up two interesting points:

- The larger the blade section (BV 234/ B214ST) the better is the icing resistance.
- Metal blades seem to shed ice easier than composite blades (S-61N versus AS 332L).

These are pilot's subjective observations only and formal flight testing may prove different.

In Norway AS 332L with de-iced blades are operated north of 67°N and with non de-iced blades south of this area.

Performance - Generally there is a decrease in airspeed accompanied by a numerically similar increase in total torque. The Flight Manual Supplemet indicates a loss of up to 6 % autorotational RPM within the Flight Manual Supplement limitations.

Vibrations - The increased rotor vibrations is normally the deciding factor for leaving the icing zone.

Handling - No handling problems were evident within the FMS limitations.

Stress - The icing trials performed by Aerospatiale proved that within the limitations of the FMS the stress levels are within the endurance limits.
Hence the component life limits are the same for UK aircraft with a limited icing clearance as the standard AS 332L without such a clearance.

Rotor De-ice Systems

Evaluation programme

So far the AS 332L is the only Western built civil helicopter flying with full rotor de-ice system. Figure 17. The system was certificated by DGAC and FAA in 1984. Helikopter Service and Luftransport ordered a total of 8 aircraft with complete de-ice systems. These were the first civil helicopters equiped with rotor de-ice systems certificated for public transport operations and both the operators and NCAA were very cautious in exploring these systems.
Hence the operators and NCAA agreed on an evaluation programme to be completed before the formal Norwegian certification was granted. This cautious approach proved to be of great significance.
As it turned out both Helikopter Service and Luftransport experienced some "narrow escapes" due to failure of de-ice system's rotating parts. (Ref 6). Generally the incidents were caused by failing parts on the tail rotor anti-ice system, causing damage to tail rotor and main rotor blades with some dramatic results.
Hence, the NCAA ordered the evaluation programme to be terminated and the parts to be removed.
The system had to be redesigned and recertificated by the manufacturer and DGAC before the operators could continue the evaluation process.
This illustrates the danger of introducing new or modified helicopter systems into operation without the necessary mature state. Unfortunately there have been several cases where helicopters or systems have been put into passenger transport service with the formal certifications, but without the necessary maturity.

In 1987 the new modified and recertificated de-ice systems were reinstalled and an agreement with NCAA regarding the evaluation programme was reached. The programme was divided into three separate phases:

Phase 1 was an initial operational and technical evaluation of the suitability of the systems. A part of this evaluation was also to evaluate the aircraft in limited icing conditions without use of de-ice system but having the system as a back-up. (Ref 6). During this phase positive escape routes over the sea were required.
The operational results were very good but the technical standard was not acceptable.

Phase 2 started in 1988 with the evaluation of the modified systems.
The limitations agreed on with NCAA were for phase 2: "Operations in known icing conditions shall be limited to flights over open water and instrument approaches to airports located within safe escape route criteria".
Safe escape route is defined as the maximum distance and enroute altitude to open water where a safe descent to lower altitude out of icing conditions can be performed:

- Distance 30 NM
- Altitude 6.000 feet PA

The results from Phase 2 evaluation were acceptable and in 1989 the Phase 3 (final phase) evaluation started.

Phase 3 evaluation continued with escape restrictions, but increased values:

- Distance (60 NM) equivalent to 30 minutes flying time.
- Altitude 10.000 feet PA.

Evaluation results

The results from Phase 2 and 3 evaluations of the redesigned systems were very good.

- Reliability has showed marked improvment over the Phase 1 results. There were some system failures necessitating the crew to change system in use. In general the system failures are short circuits or faulty logic.

Operational aspects

The de-ice system functions as expected. The operational advantages have been confirmed. With the system it is possible to penetrate areas with forecasted icing conditions, and be able to cruise on top of cloud covers for better comfort and economy. However, this capability cost the payload of two passengers.

Reliability

There were system failures but no severe malfunction of the redesigned system was experienced. However, the system required increased maintenance. For instance some rotating parts are life limited to 400 hrs.

Impact on punctuality/regularity

Flying in North-Norway, over the Barent Sea and Spitsbergen, without a rotor de-ice system is considered unsafe and the system is considered flight essential.

Impact on transport economy

- 2 passengers less in payload.
- Little impact on range.
- 3-4 kts reduction in speed is compensated for by better cruise performance at altitude.
- There is an increased maintenance burden to keep the system operational.

General operational characteristics

The evaluation has shown that the system can cope with the Norwegian offshore winter environment. The accumulated operating time with four aircraft with the systems - ON is approximately 700 hrs, of which approximately 300 hrs. are in actual icing conditions. The lowest temperature we have recorded so far is - 23°C at 8.000 feet PA. Figure 18. The highest altitude we have recorded using the system is 9.000 feet PA. Standard procedure is to operate the system in normal mode where the heating mats are cycled on and off in a certain order.

During certain temperature and LWC combinations experience has shown some heavy icing where the normal mode is not capable of de-icing the blades. This has generally occured with temperatures between -8°C and -16°C at altitudes between 5.000 feet and 9.000 feet PA during level cruise or cruise climbs to get on top of cloud covers or buildups.
Observed icing during these cases has reached up to 70 mm ice. Figure 19. During these icing conditions the normal mode was not able to de-ice the blades and the aircraft behaved the same way as with unheated blades, i.e. the torque started to increase with an accompanied numerical equal drop in IAS, and increased vibrations. Under these circumstances the crew selected severe mode where increased heating of a reduced number of heating mats were able to de-ice blades and restore the situation.

This is a stress relieving situation for the crew. It took some trips before the crew got confident in the system and initially some pilots were descending out of the icing zone before they really could evaluate the full capability of the de-ice system. This reaction was quite natural and acceptable and is illustrative for the general problem of helicopter pilots versus rotor icing. Before one has tried it, it is a scary business. When one has experienced rotor icing several times and learned to cope, it is not so scary anymore.
However, there is one icing situation where even the full de-ice system falls short - freezing rain. That is also the only limitation for the full de-ice system of the AS 332L, and that is quite remarkable considering the definition of severe icing: "The rate of accumulation is such that de-icing/anti-icing equipment fails to reduce or control the hazard. Immdediate diversion is necessary". Figure 20.
Further, it is confirmed that airframe icing causing added weight and drag on the helicopter fuselage is negligable and can be disregarded. It is the rotor icing which is causing performance reduction.

In Norway AS 332L is operated with de-iced blades north of 67°N and with non de-iced blades south of this area.

Future Icing Clearances

Basic IFR

As indicated previously there are ample experience data gained from helicopter icing to claim that the definitions of helicopter icing needs to be separated from equivalent fixed wing definition. The most severe icing experiences have been related to engine icing and not to rotor icing, which previously was the most feard icing among helicopter pilots.
Hence, European Operators have discussed the need for a revised definition of helicopter icing where the engine is separated from rotor and airframe.

The proposed definition is:

- Engine icing.
- Rotor/flight control icing.
- Airframe icing.

Engine icing

As indicated previously serious engine icing may occure around + - 0°C. Therefore all IFR certificated helicopter intake/engine installations should be cleared down to -5°C even if flight in icing conditions is not approved. The present certification standard needs to be changed to separate the engine from the rotor testing.

Rotor/flight control icing

Helicopters with unheated blades should be certificated down to -5°C and up to 5.000 feet PA as a basis. Lower temperatures and higher altitudes could be applied for depending on the type of rotor system.

Airframe icing

Airframe icing is generally not a problem for helicopters. However, the need for horizontal stabilizer de-ice system should be considered and may be the limiting factor with unheated blades.

Cold blades

- Helicopters with unheated blades should be able to satisfy requirements for flying in limited icing conditions over open water with positive OAT escape routes.

Heated blades

Helicopter icing certification with heated rotor blades may continue according to present certification requirements. However, as shown previously there is still a need for separating the engine case from the rotor case. The AS 332L system has reached a mature state, but future designs need improvements in cost effectiveness.

Conclusions

From an operator's view the following conclusions regarding certification of helicopters for flight in icing conditions can be drawn:

1. Helicopter flight in icing conditions has developed to a safe and practical stage, both with restricted unheated blades and unrestricted heated blades.

2. Helicopter icing definition should reflect the different requirements for protection of:

   - Engines
   - Rotor/flight controls
   - Airframe/stabilizers

3. Icing clerances for helicopters should be developed further, and should include:

   - Basic IFR
   - Unheated blades with escape route
   - Heated blades without restrictions

4. Engine intake anti-ice is required for continuous operation in near icing conditions for all IFR aircraft.

5. There is a lot of helicopter icing experience from 30 years of European offshore operations, which the authorities and manufacturers should draw on in future certification projects.

References

1. Symposium Paper - Dr. Forrester, D.A. "Where and when helicopter icing occurs." Helicopter Rotor Icing Symposium. The Royal Aeronautical Society, 1986.

2. Flight Manual AS 332L Special Supplement No. 10.54. "Flight in Icing Conditions without Icing Protection." Aerospatiale. CAA approved, 08.11.83.

3. Flight Manual AS 332L Supplement no. 10.13. "Protective Equipment for Flight in Icing Conditions for Aircraft Equipped with Grid Type Air Intakes." Aerospatiale. DGAC approved, 07.01.87.

4. Symposium Paper - Gent, R.W. "Rotor Icing Research at RAE Farnborough." Helicopter Rotor Icing Symposium.

5. Symposium Paper - Capt. Lande, K. The Royal Aeronautical Society, 1986. "Limited Icing Clearances - An Operators view ." The 8th European Helicopter Association Symposium, 1990.

6. Symposium Paper - Capt. Lande, K. "Helicopter Flight in Icing Conditions - An operators view." The 4th European Helicopter Association Symposium, 1986.

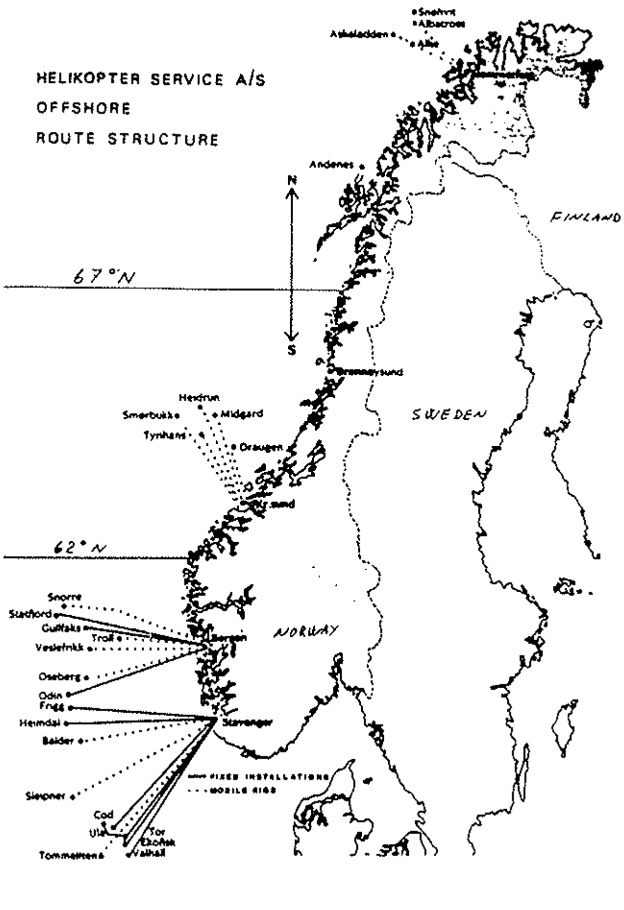

FIGURE 1. OFFSHORE ROUTE STRUCTURE.

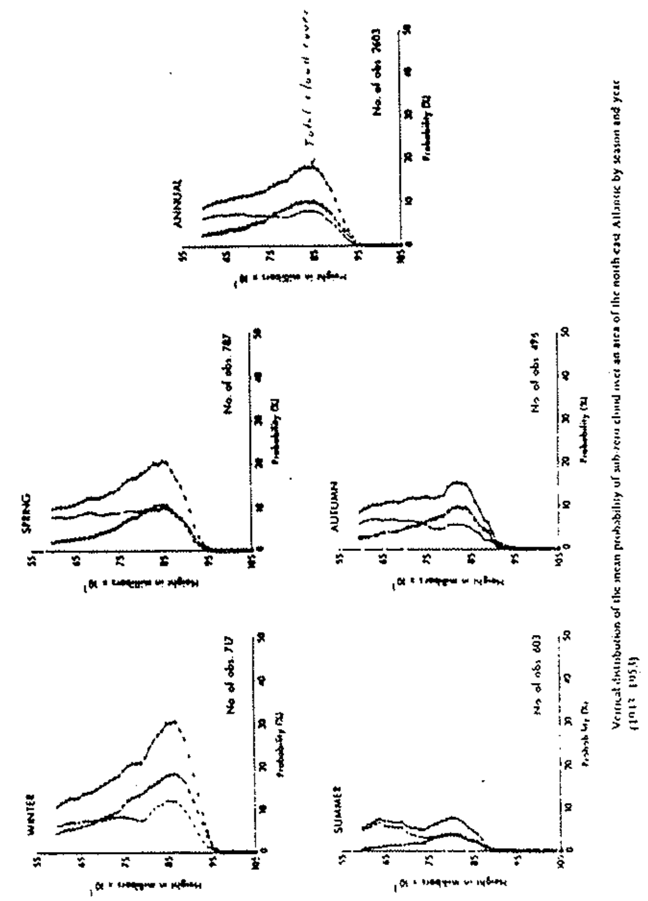

FIGURE 2. SUB-ZERO CLOUD COVER OVER NORTH-EAST ATLANTIC

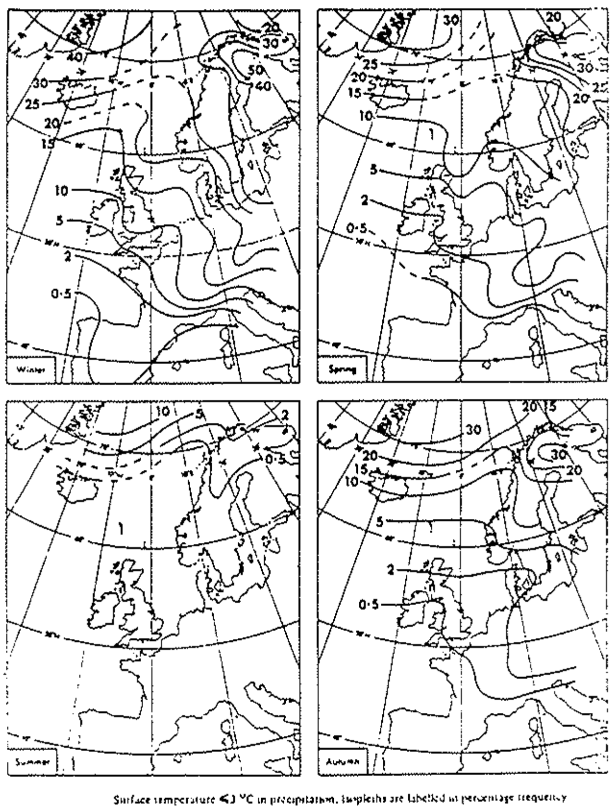

FIGURE 3. SURFACE TEMP < 3°C

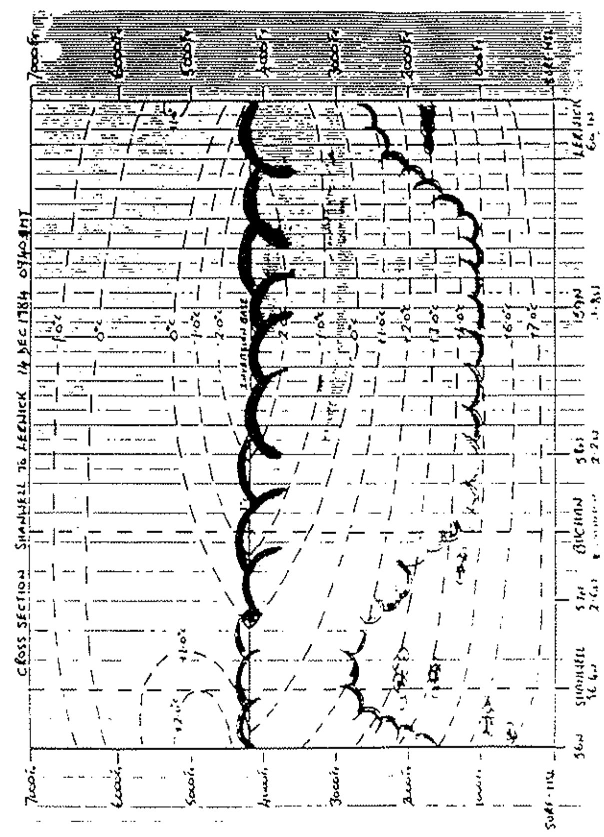

FIGURE 4. TYPICAL TEMPERATURE DISTRIBUTION

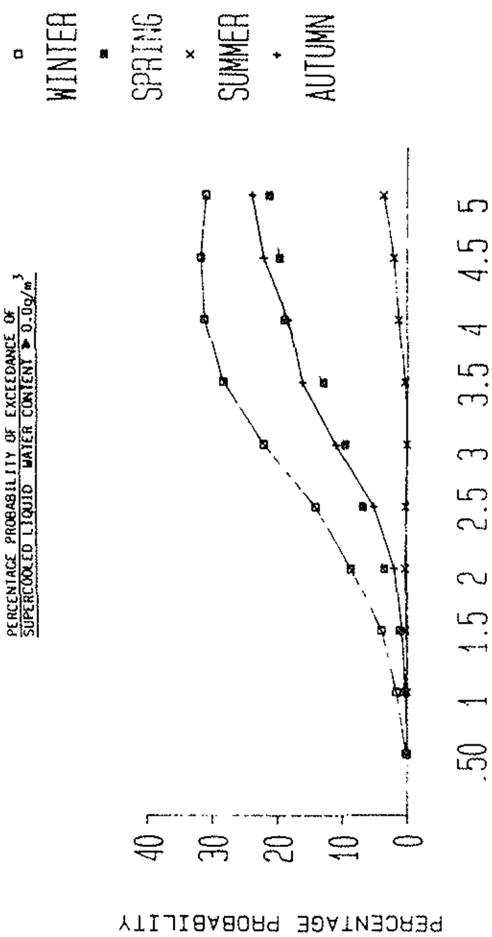

FIGURE 5. TYPICAL CLOUD DISTRIBUTION.

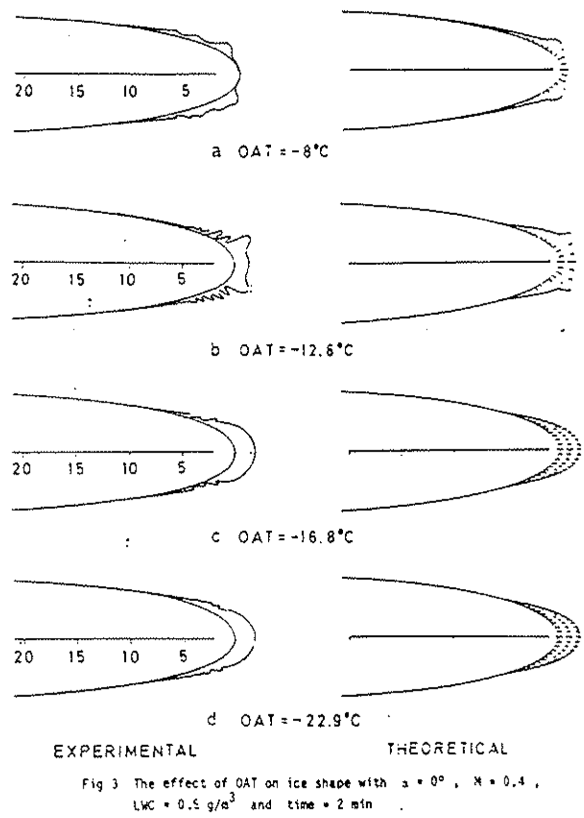

FIGURE 6. TYPICAL ICE SHAPES.

AC 20-73

PARA. 13. HELICOPTER OPERATIONAL FACTORS

CURRENT DEVELOPMENT OF HELICOPTER ROTOR SYSTEM DE-ICING OR ANTI-ICING MEANS HAS NOT PROVIDED SYSTEMS OR HARDWARE DEEMED ACCEPTABLE BY HELICOPTER MANUFACTURERS. THEREFORE, ALL HELICOPTERS TO DATE HAVE BEEN RESTRICTED AGAINST OPERATING IN ICING CONDITIONS. THIS RESTRICTION DOES NOT INSURE THAT ICING CONDITIONS WILL NOT BE ENCOUNTERED INADVERTENTLY. THEREFORE, IT IS NECESSARY THAT THE POWERPLANT BE PROTECTED AGAINST THE EFFECTS OF ICE ACCUMULATION AS SPECIFIED IN THE REGULATIONS; HOWEVER, CONTINUING EXPOSURE TO ICING CONDITIONS MAY CAUSE THE HELICOPTER TO BECOME INCAPABLE OF SUSTAINING FLIGHT. IN VIEW OF THIS, THERE APPEARS TO BE LITTLE CONSTRUCTIVE PURPOSE IN REQUIRING AN INDEFINITE PROTECTION OF THE HELICOPTER POWERPLANT INSTALLATION AGAINST ICE CONDITIONS AS LONG AS THE PROTECTION THAT IS PROVIDED ASSURES A LEVEL OF SAFETY EQUIVALENT TO THAT REQUIRED BY THE REGULATIONS THROUGHOUT CONDITIONS AND DURATION OF EXPOSURE UNDER WHICH FLIGHT CAN BE MAINTAINED.

PARA 34. HELICOPTER ENGINE INLET AND ROTOR

IF COMPARATIVE TESTING OF THE ENGINE INLET AND THE ROTOR SYSTEM IS TO BE USED TO ESTABLISH EQUIVALENT SAFETY, IT SHOULD BE CONDUCTED UNDER CONDITIONS WHICH PROVIDE KNOWN VALUES FOR WATER CONTENT, DROPLET SIZE, AND TEMPERATURE. HOWEVER, CLOUD HORIZONTAL EXTENT NEED NOT BE CONSIDERED IF IT CAN BE POSITIVELY ESTABLISHED THAT ALL ICING CONDITIONS WHICH RESULT IN SIGNIFICANT ICE ACCRETION ON THE ENGINE INLET ALSO RESULT IN INTOLERABLE ICE ACCUMULATIONS ON THE HELICOPTER ROTORS. SUFFICIENT VARIATIONS OF THE ICING PARAMETERS SHOULD BE INVESTIGATED TO ASSURE THAT THE CONDITION FOUND CRITICAL FOR THE ENGINE INLET IS ALSO CRITICAL FOR THE ROTOR SYSTEM. EXPERIENCE HAS SHOWN THAT AT HIGH AMBIENT TEMPERATURES (ABOVE 25° F.), ROTOR ICE SHEDDING OCCURS AT TIME INTERVALS WHICH PREVENT ICE BUILDUPS.

FIGURE 7. AC 20 - 73.

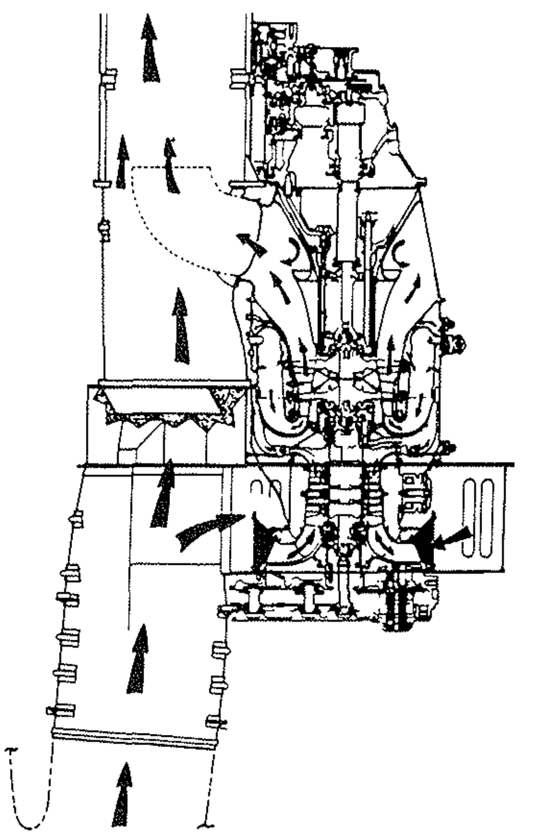

FIGURE 8. BELL 212 ENGINE INLET.

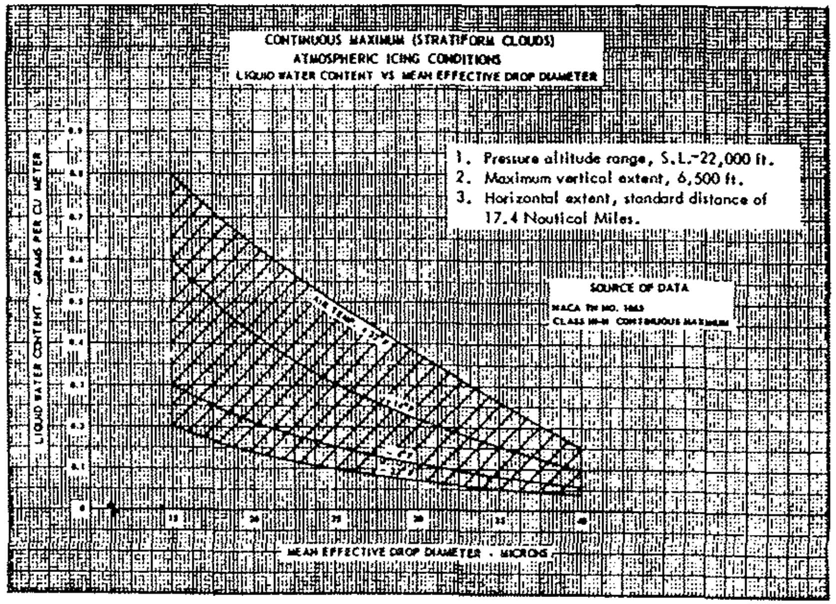

FIGURE 11. FAR 29 CONTINOUS ICING

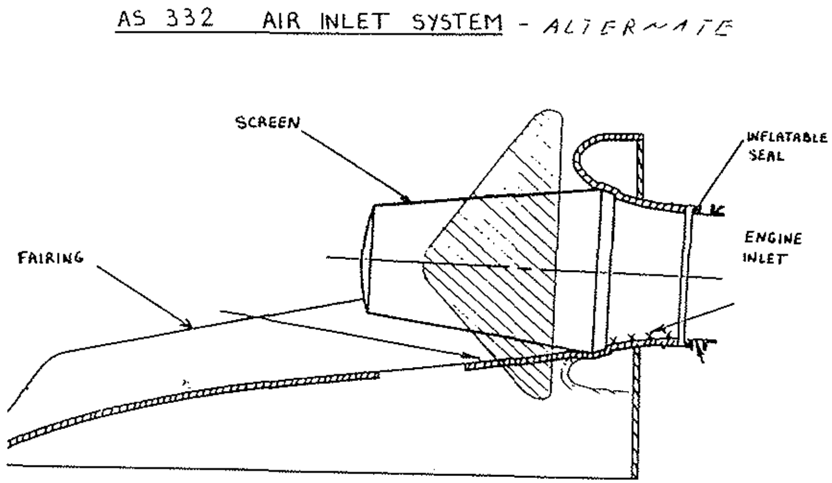

FIGURE 9. AS332 ENGINE INLET.

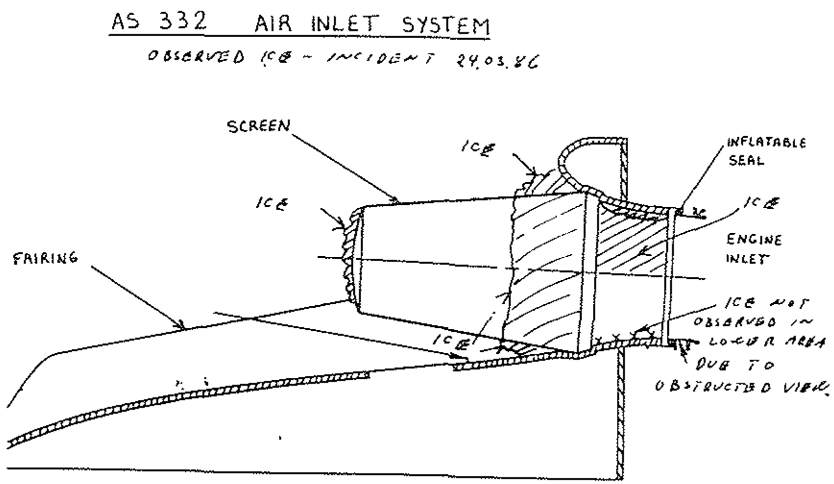

FIGURE 12. AS332 INLET ICING.

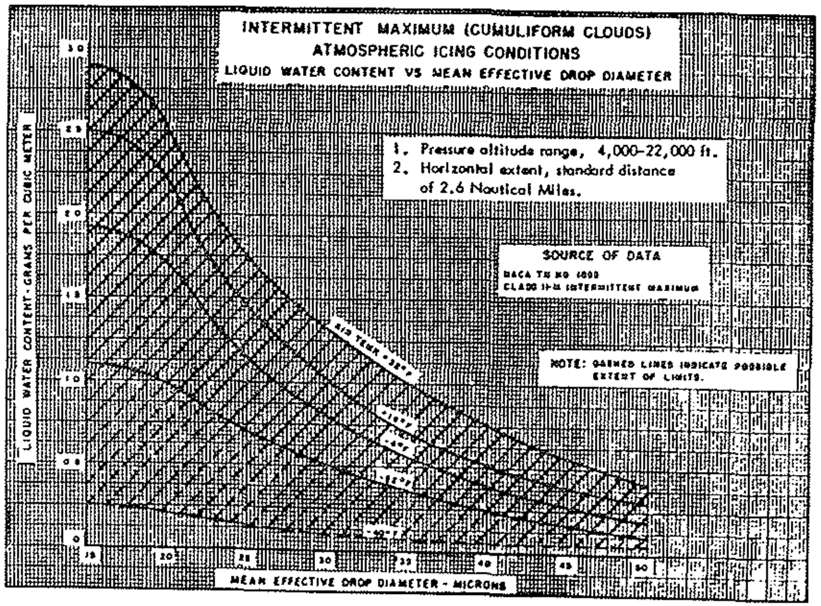

FIGURE 10. FAR 29 INTERMITTENT ICING.

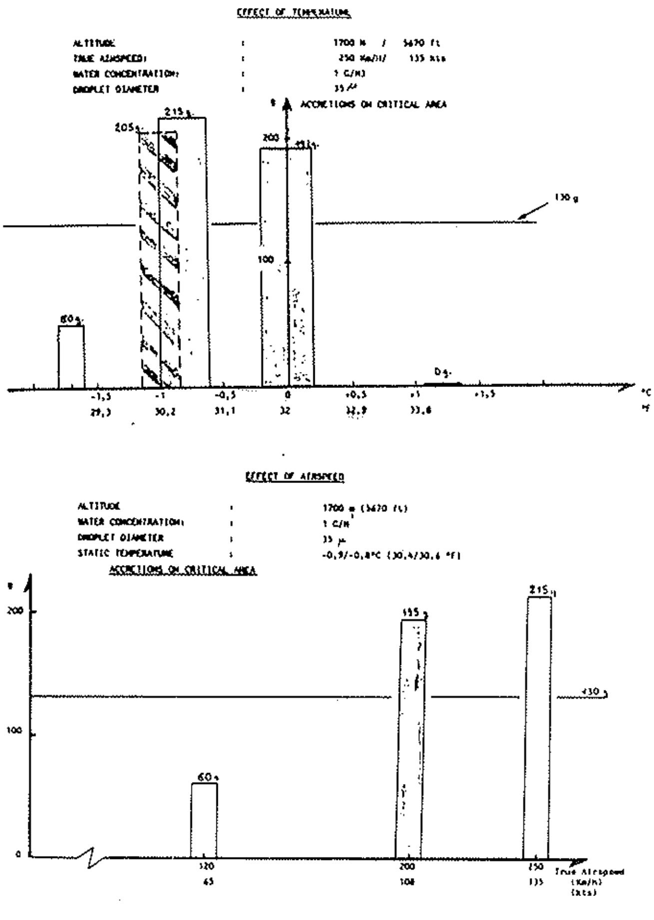

FIGURE 13. AS332 INLET ICE ACCRETION.

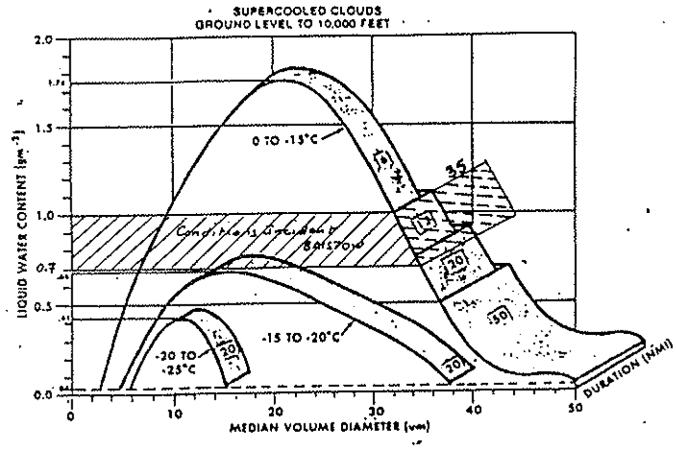

FIGURE 14. ICING INCIDENT.

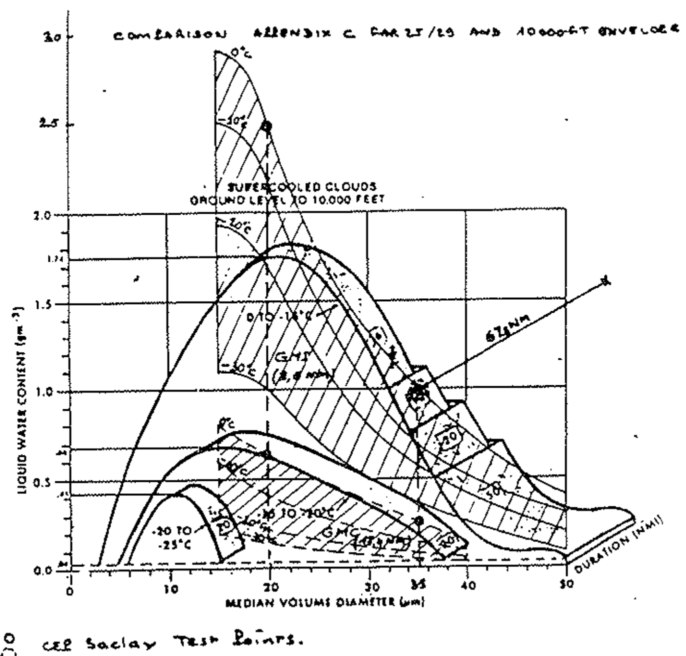

FIGURE 15. ICING COMPARISON

SERVICE BULLETIN

The critical conditions for the air intake were found to be the following :

- Outside air temperature : -1.5°C/+0.5°C
- High cloud liquid water content : 0.7 to 1 g/m³
- Drop diameter : 35μ
- Aircraft speed : 250 km/hr
- Duration : 30 minutes.

In this configuration, a freezing delay phenomenon is responsible for ice forming behind the air intake screen. The risk of engine flameout exists when the weight of the ice deposits ingested by the engine exceeds 130 g (value demonstrated on test bed).

This amount of ice builds up in the critical conditions described above, i.e. liquid water content 0.7 to 1 g/m³, whereas the certification regulation (FAR 25, APPENDIX C) considers a liquid water content of 0.26 g/m³ in the same conditions (drop diameter = 35μ; outside air temperature : 0°C) (Continuous Maximum Icing). The conditions in which ice forms on the front of the air intake screen and which are likely to cause engine flameout, are well beyond the current certification requirements.

NOTE : The current AS 332 air intakes are certified in icing conditions and meet the requirements of FAR 29 - paragraph 1093. Protection is ensured by a front air intake screen (shaped like a truncated cone).

Even though they are well beyond the current certification requirements, these exceptional conditions have been taken into account in order to improve the AS 332 air intake operation in this critical envelope.

The solution adopted to prevent ice building up behind the external screen is one whereby the inside wall of the engine air intake duct (air flow side) is heated by means of electric heating mats (Rated power per engine air intake = 865 W), which are powered by the aircraft three phase AC system.

AMS : 332A07-22-994

1 - Routing of electric harnesses improved by separating air intake 1 and air intake 2 wiring, thus preventing possible interference between the two harnesses.

2 - Protection sheath replaced on the electric harnesses located between the heating mats and connector unit 306H located on the transmission deck (Frame 2480).

3 - Wiring modified and separated inside :
   . control unit 299H
   . relay box 307H.

FIGURE 16. AEROSPATIALE SERVICE BULLETIN.

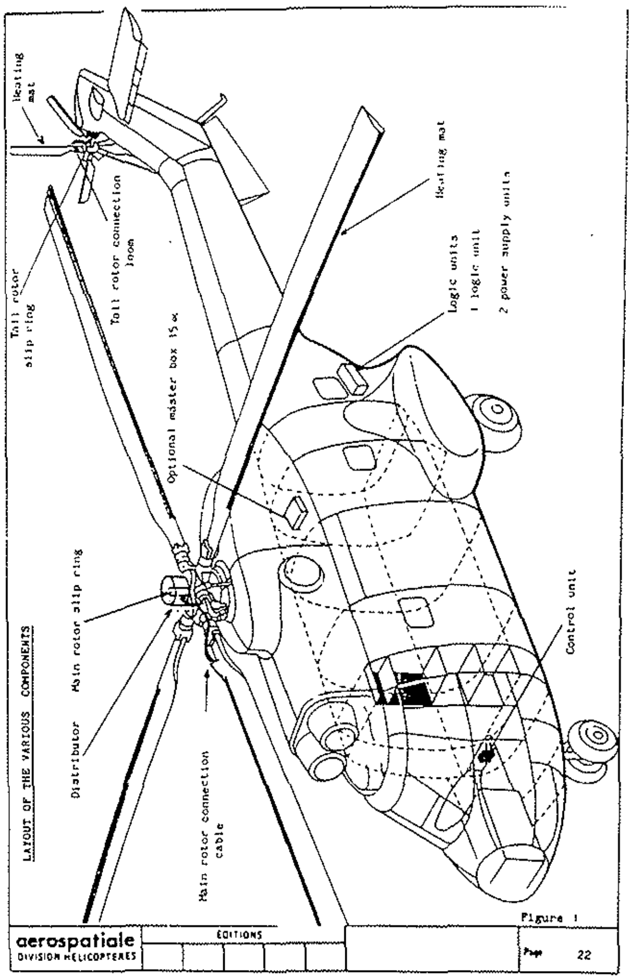

FIGURE 17. AS332L ROTOR DE-ICE SYSTEM.

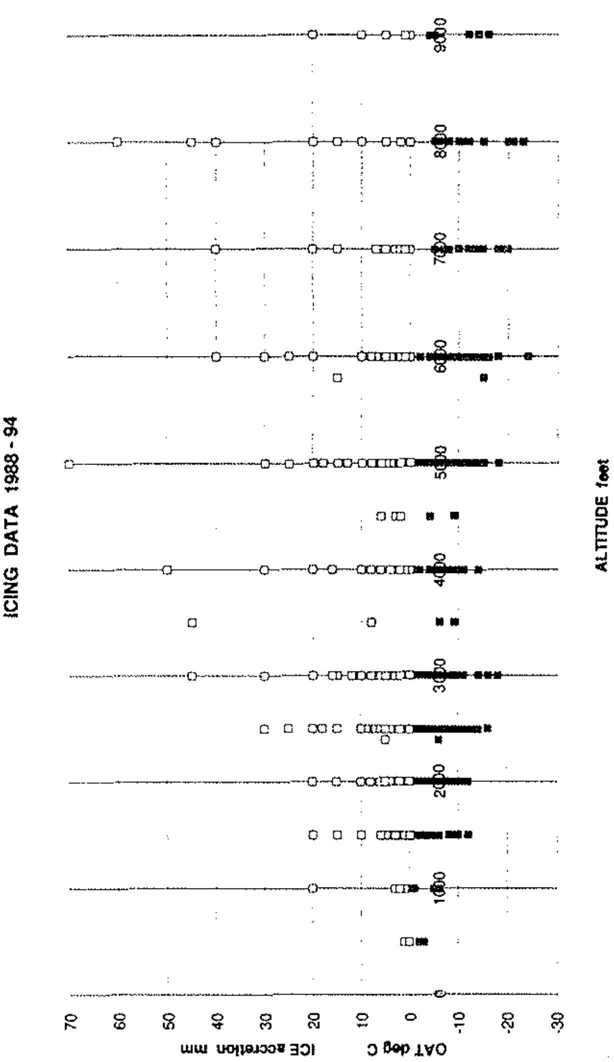

FIGURE 18. HELIKOPTER SERVICE ICING DATA.

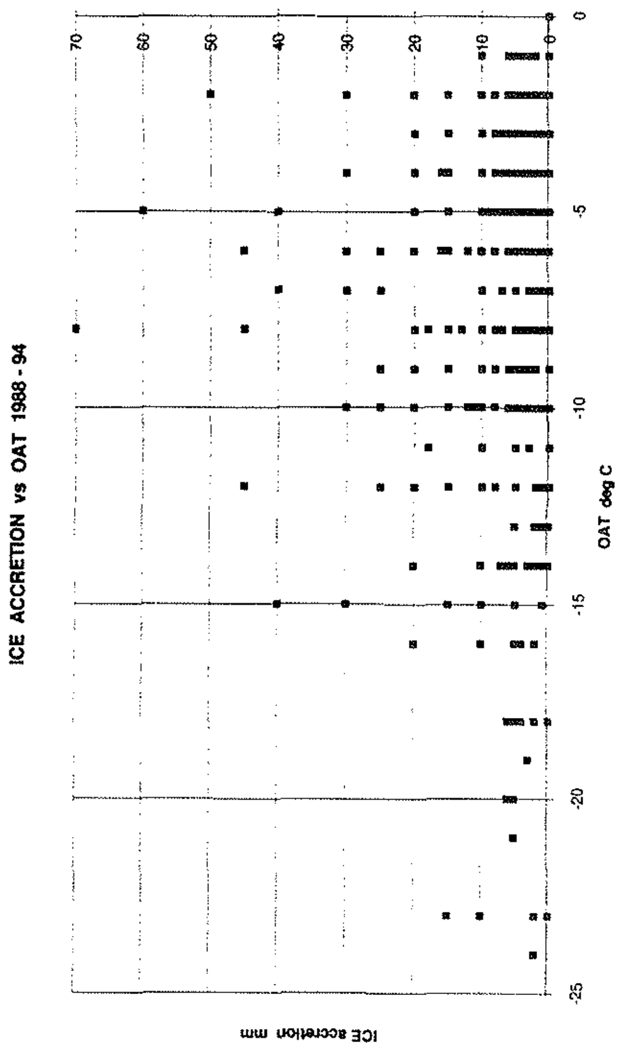

FIGURE 19. HELIKOPTER SERVICE ICE ACCRETION.

ICING DEFINITIONS

THE PRESENT DEFINITIONS OF ICING INTENSITY THAT ARE USED IN THE FORECASTS WERE ESTABLISHED IN 1968 BY THE SUBCOMMITTEE FOR AVIATION METEROLOGICAL SERVICES OF THE FEDERAL COORDINATOR FOR METEOROLOGICAL SERVICES AND SUPPORTING RESEARCH. THEY ARE:

TRACE OF ICING

ICING BECOMES PERCEPTIBLE. THE RATE OF ACCUMULATION IS SLIGHTLY GREATER THAN THE RATE OF SUBLIMATION. IT IS NOT HAZARDOUS EVEN THOUGH DEICING/ANTI-ICING EQUIPMENT IS NOT UTILIZED, UNLESS ENCOUNTERED FOR AN EXTENDED PERIOD OF TIME—OVER ONE HOUR.

LIGHT ICING

THE RATE OF ACCUMULATION MAY CREATE A PROBLEM IF FLIGHT IS PROLONGED IN THIS ENVIRONMENT OVER ONE HOUR. OCCASIONAL USE OF DEICING/ANTI-ICING EQUIPMENT IS USED.

MODERATE ICING

THE RATE OF ACCUMULATION IS SUCH THAT EVEN SHORT ENCOUNTERS BECOME POTENTIALLY HAZARDOUS AND USE OF DEICING/ANTI-ICING EQUIPMENT OR DIVERSION IS NECESSARY.

SEVERE ICING

THE RATE OF ACCUMULATION IS SUCH THAT DEICING/ANTI-ICING EQUIPMENT FAILS TO REDUCE OR CONTROL THE HAZARD. IMMEDIATE DIVERSION IS NECESSARY.

FIGURE 20. ICING DEFINITIONS.