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# Ice accretion in aircraft engines

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**Abstract*: Aircraft icing is a serious issue for the aviation industry as it has caused many accidents. It should be studied and reduced to assure safety to the mankind. This paper focuses on the factors which cause ice accretion inside the aircraft engine and the methods implemented to prevent the ice formation or to get rid of the ice already accreted.***

**Key words:** icing, propeller, super-cooled, turbo-fan

## 1. INTRODUCTION

Aircrafts often fly at high altitudes and at this height the ice crystals in the convective weather is identified as the cause of ice accretion in the engine which further causes effects such as power loss, engine surge, stall, flameout and rollback. It also causes blade damage in some cases- tip curls and separations. There have been many power loss events, which took place since the early 1980s, of aircrafts flying at higher altitudes where super-cooled liquid droplets exist. These droplets may form by condensation or rapid cooling of water in the clouds. However, these droplets may collide and combine with ice crystals to form more substantial and spherical particles like hail. The super-cooled liquid droplets impel the leading edge of an aerofoil and freezes on impact. It was considered that the ice formation does not take place inside the engine as the temperature is high there. But after investigating the engine failure events it was found that the ice crystals can occur deep inside the engine where surfaces are warmer than that of freezing. Above the higher altitude (8000ft) icing does not take place as the water droplets are already frozen. The rate of ice accretion is greater when the water content in the cloud is more. When the temperature of the air is more, it requires more amount of water at saturation than cool air and it implies that a warm cloud base contains more water. Thus, in summer season ice accretion due to water content is more as clouds are warmer and at winter the ice accretion rate is lower.

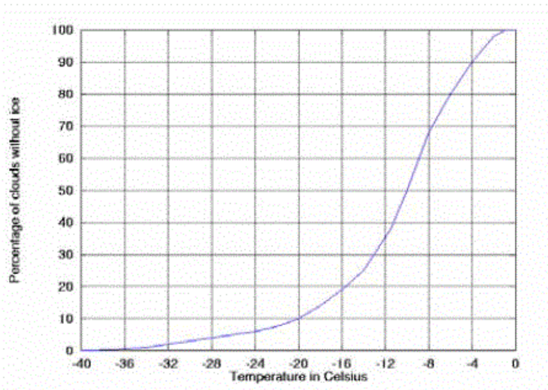


**Fig. 1: Frequency of ice crystals in clouds**

*How is ice formed in the engine?*

The actual phenomenon of the accretion of ice crystals inside the engine is not discovered completely. But the investigations and research shows an overall mechanism of the ice crystal accretion. When the ice particles enter the engine, they undergo an increase in temperature which is above freezing and hence the ice will melt. These particles when they strike the engine surface, they create a liquid film which will then capture the incoming ice particles. Due to the difference in the temperature, heat transfer will take place between the liquid and the ice which further melts the captured ice. The thickness of this liquid film increases as more and more ice particles enter the engine. Now this liquid film cools the surface of the engine until the freezing point is reached. As soon as the temperature is below the freezing point, the liquid film starts freezing to form ice. This phenomenon is known as ice crystal icing. The ice can continue to form until the supply of liquid stops. According to this mechanism, the formation of ice can take place behind the fan or the compressor well inside the engine core.

Consider the trajectory of single droplet approaching a body and its equation is obtained by using Newton's second Law, $\bar{F}=m\bar{a}$, to the droplet. The equation is expressed as,

$$\frac{d^2\bar{x}}{dt^2} = \bar{P} + \bar{M} + m\bar{g} + \bar{B} + \bar{D}$$

Where x is the position vector of the droplet, t is time, P is the pressure gradient term, M is the apparent mass term, mg is the gravity force, B is the Bassett (unsteady) history force, and D is the drag force.

Fig. 2 shows a typical turbofan engine and potential ice accretion sites.

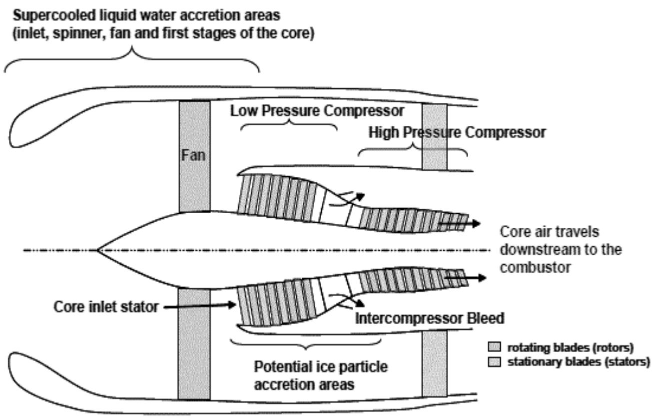


**Fig 2: Potential ice accretion sites in a typical turbofan engine**

## 2. EFFECTS OF ICE CRYSTAL ICING

There are plenty of effects of engine core icing, intake or fan icing. These include:

(a) Damage to the fan blade: It may be caused when the frozen deposits from the intake is not removed before the engine starts. The ice blade tip may also get damaged if extreme amount of ice continues to build up on the fan blades at low thrust settings and a sudden application of high thrust follow.

(b) Engine core damage: If the ice accretes in the intake ring, the ice particles may dissociate and be ingested by the engine which may result into fractional loss of thrust or could even cause flameout and damage the engine.

(c) Compressor stall or surging: Stall or surge occurs when there is a partial or complete disruption of the air flow in the compressor. This disruption of airflow is caused when ice forms on the compressor blades. This may result in momentary power drop or loss of compression and high exhaust gas temperature which further affects the fuel flow to the engine.

## 3. ICE PROTECTION

*Prevention*

When the air temperature is close to or below freezing and moisture in the form of precipitate or condensate is present, it gives rise to threat for ice formation. Also when humid air comes in contact with a cold structure, ice may form. To secure the engine against the damage caused by the ice particle accretion, the following precautions should be taken foregoing take off:

(a) A detailed preflight inspection should be done to check if any existing ice deposits are present. There are two important factors to check for- the atmospheric temperature and the engine temperature. It may happen that due to the heat of the engine the existing ice may have melted and then refrozen at places where the temperature is low, such as bottom of the intake or places which cannot be seen easily. If the intake was not fitted with any cover or a blank when bad weather existed, the intake inspection should be more thorough.

(b) If the aircraft has fan engine, ensure that there is no ice at the bottom of the engine which is preventing the fan from free rotation. Also the back side of the fan and compressor blades should be checked to ensure that there is no ice formed as ice will generally tend to form at the back of the blades due to airflow in a running engine.

(c) If any ice deposits are found to exist at the sites discussed above, they should be immediately removed with the help of a brush or broom. For the ice on the blades of propeller or compressor, suitable methods must be used to remove the ice as those are the most delicate parts. Ice may be removed by a low flow hot air source such as a low capacity heater.

*Anti-icing*

Once the aircraft is ready for the flight and the engines are started, the flight crew should take every possible step to ensure there is no ice formation prior to take off. Hence, the aircraft is provided with an anti-icing system. It is a precautionary measure that protects against ice or snow formation on the aircraft surfaces for limited duration. This is fulfilled by applying anti-icing fluids. Sometimes a liquid film of undiluted fluid is applied to the aircraft surfaces to ensure effective anti-icing. The more continuous and brief is the anti-icing fluid application process the more will be the hold-over time, provided the process is carried out close to the departure time. To ensure uniform coverage by the fluid, it should be checked that the fluid is dripping off the leading edges and tips.

The aircraft surfaces once coated by the anti-icing fluid should not be coated again directly on top of the previous layer. If the precipitation continues, the existing layer of the anti-icing fluid will be diluted and in some duration of time refreezing of may start. Moreover, the double coating would affect the flow-off characteristics of the aircraft while take-off. During the application process of the coating, the engines should not kept running ore kept at idle and the air conditions should be OFF. All preventive measures should be taken to minimize the anti-icing fluid entry to the engines, other inlet/outlet and control surface cavities.

Analysis of weather conditions and engine conditions is required to determine whether an anti-icing system is required or not. Fig. 3 illustrates a schematic of a typical turbofan engine area which is considered for anti-icing.

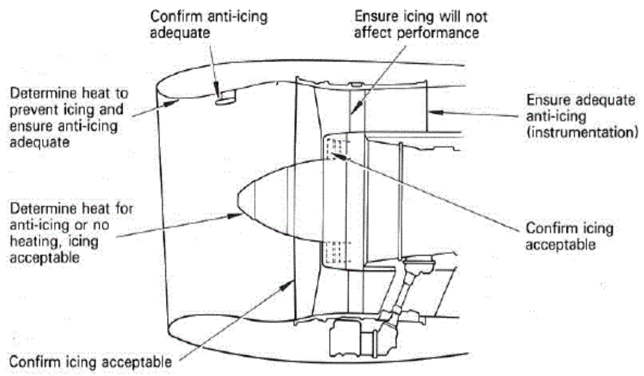


**Fig 3: Areas typically considered for anti icing**

There are mainly two basic systems for ice protection; hot air system is usually used in turbo-jet engines and electrical power in turbo-prop engines. The combination of hot air and electrical power systems can also be used for more effective results. The method used for anti-icing is hot air system as it is used to prevent the formation of ice and the electrical power system is known as de-icing system.

In the hot air system, heat is supplied to the surfaces where the ice accretion is vulnerable. The rotor blades rarely need protection as the ice particles dissociate and disperse with the centrifugal motion. If stators are placed in the first compressor stage, these may require ice protection.

To supply hot air to the parts requiring anti-icing, the heat is taken from high pressure compressor stages and passed through pressure regulating valves. Excess hot air may be allowed to pass through compressor stages again or vented overboard.

*De-icing*

De-icing is the process of removal of accreted ice from the aircraft surfaces. This process is similar to that of anti-icing. Here a de-icing fluid is used to spray on the ice already accumulated. The ice accreted in engines is not removed by spraying fluids as any foreign material should not enter the engine. Therefore, an electrical system is used to get rid of the ice. It is mostly used in the case of turbo-prop engines as it is necessary for the propeller. The air intake cowling, propeller blades and spinner are some surfaces that require electrical heating. It consists of electrical heating pads bonded to the outer surface of the cowlings. The heating pad consists of strip conductors which are sandwiched between the layers of neoprene or glass fiber impregnated with epoxy resin. These pads are coated with polyurethane based paint to protect from rain erosion. When the de-icing system is in process, there are some areas which are continuously heated to prevent the accretion of ice caps forming on the edges and also to limit the size of ice that forms on areas which are heated intermittently.

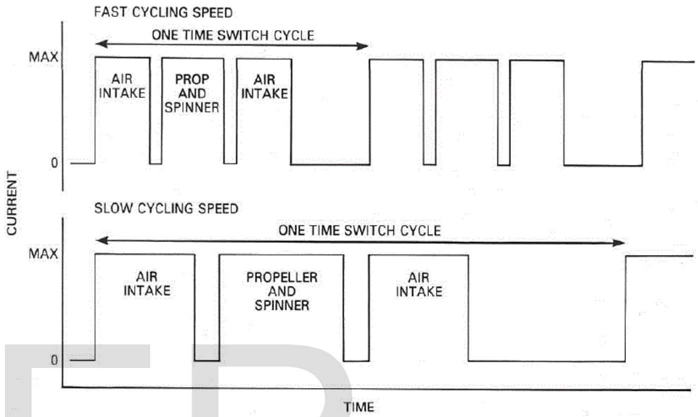


**Fig. 4: Ice protection cyclic sequence**

The generator supplies the electrical power and to limit the size and weight of the generator, cycling of de-icing electrical loads between engine, propeller or airframe takes place. A cyclic sequence chart is shown in Fig. 3. The heating takes place continuously only in some surfaces and thus there is no ice formation. But, for intermittent heating areas, the ice is formed during 'Heat off' period and the adhesion of ice is broken in 'Heat on' period which is then removed by aerodynamic forces.

The cycling time is adjusted such that during the 'Heat off' period the amount of ice that will be formed will be considerable and ensure that it is shed during the 'Heat on' period.

## 4. FUTURE SCOPE

Ice crystals may affect all types of aircrafts and engines. As the technology advances, more and more accidents tend to occur if no precaution is taken for icing problem. The methods of removal or prevention of ice could be improved with further research by introducing more techniques and processes which will be more effective. One such idea is to implement combined anti-icing and de-icing techniques which will double the effect of ice removal process.

Design of different engines is different and hence has different tendencies of ice accretion problem. Improve in technological plan, improved equipments to measure atmosphere, detailed study of physics of ice crystals, accretion and shedding and lastly improvements in testing methods and facilities are some of the criteria which will surely take safety of aircrafts from icing conditions to the next level.

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