FINAL REPORT

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In accordance with the provisions of SI 205 of 1997, the Chief Inspector of Air Accidents, on 29/03/2008, appointed Mr. Paddy Judge as the Investigator-in-Charge to carry out a Field Investigation into this Serious Incident and prepare a Synoptic Report.

Aircraft Type and Registration:	DC-8-63F, N865F
No. and Type of Engines:	4 Pratt and Whitney JT3D-7
Aircraft Serial Number:	46088
Year of Manufacture:	1969
Date and Time (UTC):	28 March 2008 @ 22.40 hrs
Location:	Shannon Airport (EINN), Ireland
Type of Flight:	Commercial Air Transport Non-scheduled - International Cargo
Persons on Board:	Crew - 4 Passengers - 0
Injuries:	Crew - Nil Passengers - Nil
Commander's Flying Experience:	9,581 hours, of which 2,834 were on type
Notification Source:	Station Manager, Shannon ATC
Information Source:	Pilot Report Form submitted by Pilot, AAIU Investigation

SYNOPSIS

Shortly after take-off from Runway (RWY) 24 at EINN, while still in the initial climb phase, the cargo aircraft suffered a series of compressor stalls to the No. 1 engine. This engine was shut down and shortly afterwards a compressor stall occurred on a second engine. The aircraft declared an emergency, descended to increase speed and turned back towards EINN. After engine anti-ice was activated the engines stabilised and later the No. 1 engine was successfully restarted. The aircraft subsequently landed safely on RWY 24 at EINN with all four engines operating normally having been airborne for 14 minutes. There was no damage.

FINAL REPORT

1. FACTUAL INFORMATION

1.1 History of the Flight

The aircraft took-off from EINN with Qatar (OTBD) as its planned destination. Its cargo was 34,911 lbs of personnel baggage (clothing and personal belongings). The aircraft climbed through a thin cloud layer extending from 900 ft to 1,200 ft. The aircraft was clear of cloud when the occurrence began with a series of compressor stalls[1] on No. 1 engine. The Flight Crew successfully shut the engine down. However, shortly after the engine was shut down a compressor stall occurred on No. 2 engine.

The aircraft then declared an emergency and was vectored by ATC directly towards EINN airport. A "Four Engine Flame Out" checklist was completed by the Flight Crew, which required all fuel booster pumps, crossfeeds and engine anti-ice to be selected on. Following this the engines immediately stabilised. Engine No.1 was then relit and normal operation was recovered.

The flight subsequently returned to EINN with all four engines operating where it made an overweight landing on RWY 24.

At the time of the occurrence the aircraft was passing over the village of Askeaton in Co. Limerick. Residents in the locality reported loud bangs and seeing flames coming from the aircraft and informed Gardaí of an aircraft in trouble.

1.2 Pilot Flying (PF)

The Pilot-in-Command was the handling pilot or Pilot Flying (PF). The PF had a United States issued FAA Airline Transport Pilot licence. He was currently rated on type and had a valid DC8 Type Rating issued on 11 May 2007. His FAA Medical Certificate Class 1, was issued on 18 March 2008. He had 2,834 hours flying on type and 9,581 hours total.

The PF stated that the ATIS[2] at 21.30 hrs reported that the air temperature was 6° C and that the runway surface was dry. The aircraft was at a heavy weight for take-off. On passing 1,000 ft the PF called for flaps up and climb power. Just after moving the flap lever handle the No. 1 engine suffered compressor stalls. They discontinued the climb check and proceeded to shut down the engine using standard procedures. Just as they completed the in-flight shutdown of the engine and called for an emergency return to EINN, the No 2 engine compressor stalled. They then commenced a four engine failure checklist "*due to the disimproving situation*". This entailed opening the fuel crossfeed valves, switching on all fuel booster pumps and engine anti-ice. The engines stabilised almost immediately. The PF stated that they were at an altitude of approximately 1,600 ft, when the problem with the second engine began, and started a descent to maintain airspeed. When the second engine stabilised they completed a restart checklist on the No. 1 engine which started and ran normally. They then returned for an uneventful ILS approach and landing at EINN.

The PF subsequently stated that he believed that they had picked up ice on the engine inlet probes and that the use of engine anti-ice caused a return to normal engine operation and performance.

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[1] See **Section 1.7** for further information.
[2] ATIS: Automatic Terminal Information Service (transmits a current weather report for an airport).

1.3 ATC Approach Controller

On climbout the Tower Controller called the Approach Controller to release the aircraft to the Shannon Area Control radio frequency, in accordance with normal procedures. The aircraft was released but shortly afterwards it called the Tower Controller requesting an immediate vector back to EINN, but did not give a reason. The aircraft was transferred to the Approach Controller's frequency, who took control of the traffic. At the time the aircraft was approximately 4 nm south of the airport. The Approach Controller initially gave the aircraft a heading towards a left downwind leg for RWY 24 and instructed it to climb to 3,000 ft. Although there is higher ground on a left hand downwind the Approach Controller was not then aware that the aircraft had a problem climbing.

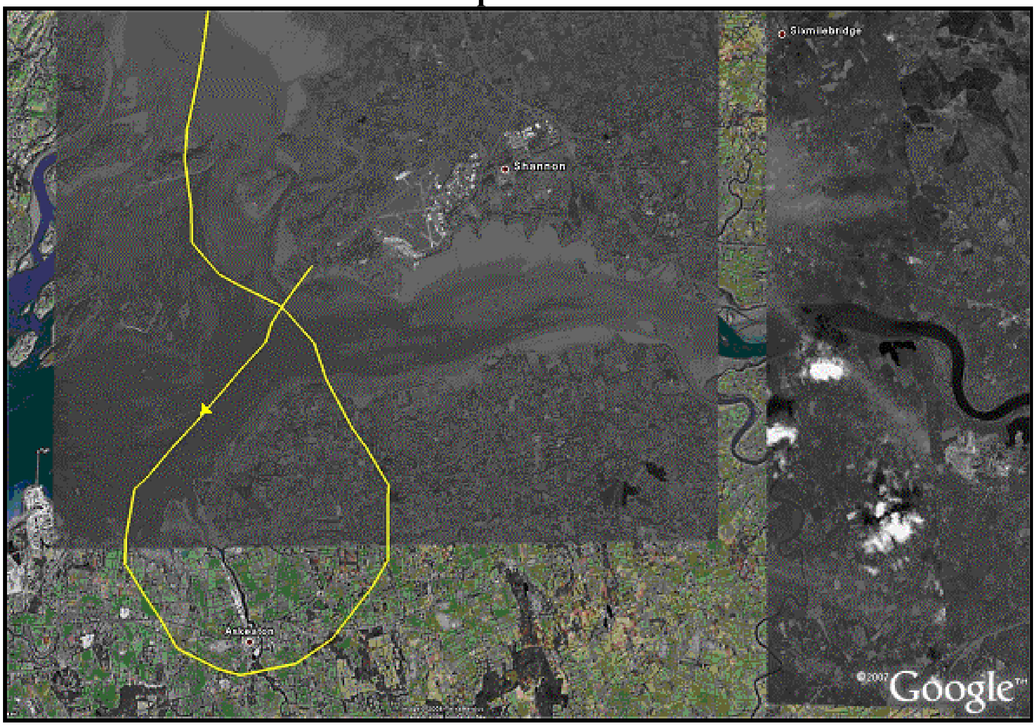
The Approach Controller became very concerned when, in a series of radar sweeps, he saw the altitude of the aircraft descending rapidly and he thought the aircraft may have called a Mayday, but was not sure. He was concerned that the aircraft might not make it to the airport and gave it a heading directly towards RWY 06 at the airport, which would place it in an obstacle free area over the river Shannon estuary.

When the Flight Crew had stabilised the situation he asked them if they wanted to continue for a landing on RWY 06, as there was a substantial tailwind on that runway. They replied that they did not, so he gave the aircraft a new heading for a right hand downwind for RWY 24 and vectored the aircraft for a landing on that runway.

1.4 ATC Records

Shannon ATC provided ATC recordings, which included a copy of radar data, to the Investigation. **Graphic No. 1** shows the track of the aircraft during the occurrence, as derived from the radar track. The radar position, speed and altitude of the aircraft is recorded every 5 seconds.

Graphic No. 1

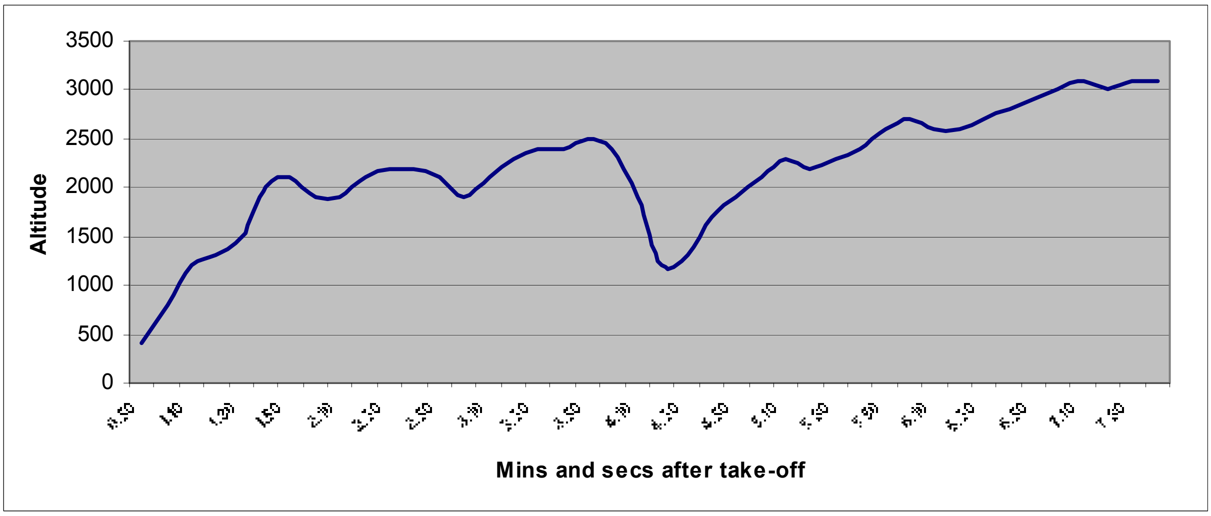


Track of N865F over ground

The aircraft took off from RWY 24 at 22.18 hrs. At 22.21 hrs, three minutes later, it declared an emergency and requested to return to the airport. It was then changed to the radio frequency of the Radar Approach Controller who vectored the aircraft left onto a northeasterly heading and instructed it to maintain 3,000 ft.

The aircraft then passed by the village of Askeaton (located inside the lowest point of the track in **Graphic No. 2**) at 2,400 ft in a descending left turn. At 4 minutes and 15 seconds after take-off the recording shows that the radar Minimum Safe Altitude Warning (MSAW) system activated to warn the Controller of an unsafe condition. The MSAW activated as the aircraft descended through 1,700 ft to a minimum altitude of 1,100 ft during the occurrence. The MSAW then stayed active for 20 seconds until the aircraft climbed back through 1,500 ft, at which point it was established on a northeasterly heading. The following graph shows the height of the aircraft during the occurrence, as recorded by ATC radar.

Graphic No. 2



Radar Recording

The aircraft descended from 2,400 ft to 1,100 ft in 30 seconds, or a descent rate of 2,600 ft/min. ATC voice recordings show that the ATC controllers were monitoring the aircraft and were extremely concerned about the unusual descent, its rate and the developing situation, as evidenced by the internal communications between the Approach Controller and the Tower Controller on their mutual telephone line.

1.5 Performance

The flight plan called for 150,000 lbs (68,039 kgs) of fuel with a scheduled flight time of 6 hours 56 minutes (150,350 lbs of fuel was on board at take-off). Although the aircraft was heavy it was not at maximum take-off weight and consequently, as per normal operational procedures, a reduced take-off thrust setting of 44°C was used to minimise wear on the engines. **Table 1** summarises the key aircraft performance criteria relevant to this occurrence.

Table 1

Basic Weight of Aircraft (lbs)	152,127
Cargo	34,911
Zero Fuel Weight	187,238
Actual Fuel Load	150,350
Take Off Weight	337,588
Maximum Runway Weight	351,800
VMCA[3] one engine inoperative	118 kts
VMCA two engines inoperative on one side	208 kts

Note: All weights are in lbs.

1.6 Weather

A meteorological aftercast was requested from Met Eireann for the time of the event. The aftercast stated that the weather situation at the time was as follows:

General Situation:	A complex low pressure system off the north and northwest coast of Ireland maintained a strong unstable west to southwest airflow over the area
Wind:	Surface wind: 240º/17 kts 2000ft: 260º/40 – 45 kts
Weather:	Isolated showers, some heavy and of hail
Visibility:	10 km +
Cloud:	FEW020 SCT042 BKN080
Temperature/Dew-Point:	06º/03º C
MSL Pressure[4]:	1001 hPa

The aftercast stated that ambient freezing level was between 2,000 and 2,500 ft, which suggested that there would not have been ambient icing below 2,000 ft. However, it stated that there was certainly convection in the area at the time and radar images suggested some moderate to heavy showers at, or nearby, the site of the incident.

In strong convection, there could have been airframe icing below 2,000 ft. Standard airframe icing would require the existence of super-cooled water droplets and so such icing would only occur in cloud. The aftercast also noted that engine icing does not require the pre-existence of super-cooled water droplets.

[3] VMCA: Minimum control airspeed in flight
[4] MSL pressure: Mean Sea Level pressure or QNH.

1.7 Powerplant Information

The aircraft was equipped with four Pratt & Whitney JT3D type engines, which have a relatively low bypass ratio[5]. This engine type has two independent axial compressors, a low pressure and a high pressure compressor, each driven by its own turbine.

A turbojet engine is dependent on a smooth controlled airflow through the engine with a gradual build up of pressure prior to combustion. Pressure is built by rows of rotating vanes alternating with rows of stator vanes that correct the airflow. Excess pressure at any stage or starving the air intake supply causes a distortion in the pressure gradient. This distortion or excess air pressure can build until it is momentarily relieved by air flowing forward and out through the engine inlet (in the wrong direction though the low pressure compressor) resulting in a compressor stall or a "backfire" or bang.

The high pressure compressor and the subsequent combustion stages are then unexpectedly starved of air causing a very rich fuel/air mixture which does not fully combust and the over-rich mixture frequently ignites in the tail pipe as it is ejected overboard. The resulting flame can usually be seen at night burning downstream of the engine. Older technology low bypass ratio turbojet engines, such as the JT3D as fitted in this aircraft, are much more liable to and tolerant of compressor stalls than modern high bypass turbojet engines. The JT3D is quite robust in this area, as it was originally designed for military applications and capable of being fitted with an afterburner.

The internal air pressure between the axial compressors (the inter-stage pressure) is regulated by a Surge Bleed Valve (SBV) that is scheduled to open when excessive air pressure at low power settings builds up between the compressors. Consequently the SBV is scheduled to open at low power settings. The pressure sensors for operating the SBV are PT2 (a probe mounted in the engine inlet) and the interstage pressure itself. Engine inlet icing on the JT3D engine can cause blocking of the PT2 probe thus distorting the command signal to the SBV.

The power generated by the JT3D engine is indicated by Engine Pressure Ratio (EPR) guages that sense the difference in air pressure between the air entering and leaving the engine. In an icing situation EPR readings can become erroneous and erratic as the inlet pressure sensor, mounted at the engine inlet, ices over.

1.8 Engine Anti-ice System

Engine icing can affect the engine power output where ice on the vanes disturbs and/or reduces the smooth airflow through the engine core. To avoid this problem an engine anti-ice system is fitted that functions by diverting hot air from the engine compressor around the engine nacelle inlet and through the inlet stator vanes, thus melting any ice that might form there. Use of engine anti-ice results in significant power loss from this engine and has an adverse affect on the maximum weight at which the aircraft can take-off due to a reduction in climb thrust. Consequently, engine anti-ice is only used operationally when needed. This lower bypass ratio engine tends to be more susceptible to engine icing than more modern high bypass ratio types. This is due to the design of the engine nacelle and inlet whereby the first stage of the compressor is a fixed vane, or stator blade, rather than the large rotating blades of the modern high bypass turbojet engines that tend to shed ice as they turn at high speed.

[5] Bypass Ratio: The ratio of air that flows through the bypass fan duct to that which flows through the core of the jet engine

Icing on the stator blades of this engine reduces and distorts the airflow through the engine. Large accumulation of ice can damage the engine when it breaks off and is injested through the core. For this reason the ice protection system fitted to this engine is operated as an anti-icing rather than a de-icing system (where ice is allowed to accumulate prior to activation of the engine anti-icing system). Therefore the engine anti-ice system should be activated whenever icing conditions are anticipated.

Part of O^{per} I^{nstr} 190 (Operations Instruction) published by the engine manufacturer in August 1972 was concerned with engine icing in "*axial compressor, non-afterburning turbojet and turbofan engines*" and is reproduced in **Appendix A**. Of particular relevance to this occurrence are the following extracts:

AIR INLET ANTI-ICING

The engine air inlet cowl lips, the inlet duct, the inlet duct struts, and the compressor inlet guide vanes of axial compressor turbojet and turbofan engines are susceptible to icing under the same general conditions that cause wing and wind- shield ice to form. In fact, air inlet icing may occur even at temperatures well above freezing, when there is no evidence of other icing on the aircraft. Once inlet ice commences to form, an appreciable accumulation can build up with startling rapidity.

Ice at the engine air inlet results in a loss of thrust that may be noted by a drop in engine pressure ratio if the condition is sufficiently severe. One of the first indications of ice may very likely be a compressor stall which could be slight, "snorting," or very pronounced.

When visible moisture is present in the outside air, engine inlet icing can occur at temperatures quite a number of degrees above freezing, particularly under static conditions. The increase in air velocity as air enters the aircraft inlet duct, the engine compressor inlet, and the compressor inlet guide vanes causes a drop in the temperature of the entering air. Thus, moisture in the outside air becomes supercooled as it passes through the engine inlet. This can result in engine inlet icing, even though external ice is not seen forming elsewhere on the aircraft.

1.9 Further Technical Examination

A heavy weight landing check was later conducted which did not reveal any defects. A technical examination by the Operator's maintenance personnel revealed no damage to the engines and no fuel contamination. A later engine ground run, at power settings up to take-off power, confirmed that the engines were operating normally.

1.10 Operator

1.10.1 Operator's Operations Manual

The Operator's DC 8 Aircraft Operations Manual, Limitations, Page 2-13-1, issued 01-01-03, states, inter alia:

Anti-Icing

Engine Anti-ice shall be on when:

A. Outside air temperature is 6ºC (42ºF) or below and visible moisture is present. Fog shall be considered visible moisture when it limits visibility to one mile or less.

B. *Outside air temperature is 6ºC (42ºF) or below and dew point is within 3ºC (5ºF) of outside air temperature.*

C. Icing conditions are suspected.

Maximum RAT[6] For Engine Anti-Ice: +10°C (50°F)

However, the same engine is also fitted to the Boeing 707 aircraft where its Operations Manual, in Taxi-out Procedure, states that *"icing conditions exist when the OAT on the ground and for take off is 10ºC or below, and visible moisture in any form is present (such as clouds, fog with visibility of one mile or less, rain, sleet and ice crystals).*

According to Boeing Long Beach engineering, differences in criteria for icing conditions (OAT 6ºC or below versus OAT 10ºC or below) are based on certification criteria differences between heritage Boeing and heritage Douglas aircraft, certification testing, service experience, etc. All Douglas heritage models use the same certification criteria. Both heritage Boeing and heritage Douglas criteria are accepted by the FAA.

1.10.2 Operator's Subsequent Change of Procedure

After the incident, the Operator's Director of Operations wrote to all flight crew informing them of this occurrence and that, "*rapid icing of the engine inlets was the most likely cause*". He also implemented a Flight Operations policy "*to strongly encourage the use of engine anti-ice for departures when icing conditions are in any way suspect and the temperature is below 10ºC"*. If performance limited then the new procedure *"strongly encourages the use of the engine anti-ice after completion of the second segment climb at 400 ft."*

2 ANALYSIS

2.1 General

When compressor stalls occurred on No. 1 engine the PF decided to shut down the engine as a precautionary measure. Then a compressor stall occurred on No. 2 engine. At that point the crew commenced an emergency four engine failure checklist due to the deteriorating situation. This checklist included activating the engine anti-ice system after which the engines stabilised. After the flight a technical examination of the engines was conducted. This found no abnormality or malfunction with any of the engines. Further engine ground runs confirmed that there was no mechanical or technical malfunction and that the engines were undamaged.

2.2 Engine Icing

The lack of any engine abnormality together with the climatic conditions reported at the time indicates that the probable cause of the engine problems was engine icing. This is reinforced by the fact that when the Flight Crew selected the engine anti-icing systems on the engines stabilised and normal operation was recovered. In cases of severe engine icing the inlet cowl and the inlet guide vanes become covered in thick ice and the subsequent shedding of the ice can cause significant internal engine damage.

[6] Ram Air Temperature: The temperature of the air being encountered by the aircraft.

There was no evidence of this having happened in the occurrence as post flight maintenance ground inspection found no abnormality in any of the engines and further ground running of the engines confirmed that all engines were operating normally.

Although it is likely that icing of the PT2 probe affected the SBV operation, it is unlikely that this had any significant bearing on the event, as the SBV is scheduled to open at low power settings and the engines were operating at a high power setting at the time. Had an SBV incorrectly opened then the power from the engine would have reduced resulting in a lower EPR indication and, with an interstage pressure lower than normal compressor stalls were consequently unlikely.

2.3 Meteorology

The outside air temperature at EINN was +6ºC but there was no evidence of visible moisture and the runway was reported dry. According to procedures in the aircraft Operations Manual there was no requirement to use engine anti-ice for take-off. As the aircraft was heavy the decision of the PF not to use engine anti-ice for take-off was reasonable, as this loss of power would have significantly reduced the climb performance capabilities of the aircraft.

After take-off the PF reported that the aircraft climbed through a thin, 300 ft thick, cloud layer beginning at 900 ft. According to the meteorological analysis, this height was well below the ambient freezing level of 2,000 to 2,500 ft. Although airframe icing would not have been expected below 2,000 ft the meteorological reports states that there was convection in the area at the time and that radar images suggest some moderate to heavy showers at, or nearby, the site of the occurrence. Such climatic conditions can unexpectedly generate significant engine intake icing in this type of turbojet engines, particularly when the aircraft crosses the saturation boundary from cloud into clear air and where air temperature suddenly drops.

2.4 Aircraft Control Issues

As the aircraft climbed through 1,000 ft the flaps were retracted and the airspeed increased. The increasing speed increased ram air pressure which, in turn, increased engine compressor pressures, thus magnifying any disturbance of the airflow through the engine. The occurrence manifested itself with a series of compressor stalls on No. 1 engine. The Flight Crew successfully shut that engine down, unaware that icing was the cause. At that point the VMCA was 118 kts, a speed the aircraft was well in excess of. However, while the engine was shut down a compressor stall then occurred on No. 2 engine. At that point it was critically important to retain control of the aircraft, as with a failure of two engines on one side of the aircraft (Nos. 1 and 2), the VMCA or the minimum airspeed required to directionally control the aircraft in the yaw axis rose significantly to 208 kts, an increase of 90 kts. Therefore the PF needed to immediately increase his speed to above 208 kts. As a result the PF descended, a fact that caused significant and justifiable concern to the ATC controllers, who were not informed of the reason for the sudden descent because the efforts of the Flight Crew were directed towards retaining control of their aircraft. Although local residents may also have been concerned due to the loud bangs and flames seen coming from the aircraft nevertheless the minimum altitude recorded during the occurrence was 1,100 ft.

2.5 ATC

ATC initially vectored the aircraft for a routine return to RWY 24 and climb to 3,000 ft. The subsequent decision by the Approach Controller, when he realised the developing serious situation, to vector the aircraft directly towards RWY 06, an area clear of obstacles, was clear thinking and correct.

If the situation had deteriorated further this decision offered the best possibility of an optimum outcome. The Investigation therefore commends the Approach Controller on his quick thinking and the clarity of his instruction during this emergency situation.

2.6 Flight Operations in Engine Icing Conditions

It is not easy to recognise engine icing, particularly where no airframe icing exists. Occasionally, a fluctuating or changing EPR reading may warn the pilot. Compressor stall may very likely be the only evidence that inlet ice has formed, as EGT and Fuel Flow change may be too slight to be noticed or come too late to enable the pilot to take timely corrective action. The rise in EGT, often associated with inlet icing, frequently results from already formed ice passing through the engine core, and not from ice build-up at the inlet.

The Flight Crew of the aircraft were not familiar with Irish climatic conditions or how quickly it can generate engine icing. It is also probable that there was no airframe icing or any evidence of engine icing existed until abnormal operation of the engines manifested itself through compressor stalls. These compressor stalls were the result of engine inlet icing and disturbance of the inlet airflow and not due to icing of the sensors. As there was no evidence of airframe icing the crew were slow in recognising the cause of the engine abnormality. When a similar malfunction manifested itself on a second engine the Flight Crew properly declared an emergency and commenced a checklist that successfully resolved the situation. The de-icing system cleared the engine intakes and sensors so the engines and their indications immediately stabilised. Engine No.1 was then restarted and normal operation was restored. However, better anticipation of the climatic conditions by the Flight Crew would have resulted in engine ignition and anti-ice being sequentially selected on each engine, prior to or immediately on entering the cloud bank. The Investigation notes that the Operator has issued a new Instruction to pilots, which strongly encourages the use of engine anti-ice for departures when icing conditions are in any way suspect if air temperature is below 10ºC. This increases the guidance temperature at which engine ice might occur by +4°C. In view of this Instruction no Safety Recommendation is considered necessary.

3. CONCLUSIONS

(a) Findings

1. The aircraft was properly certified by the USA FAA for the purpose of the flight.

2. The Flight Crew was properly licensed with valid medicals by the USA FAA.

3. The Flight Crew was experienced and familiar with the aircraft.

4. Engine anti-ice was not used during initial climb.

5. The aircraft passed through a thin cloud layer at about 900 ft where meteorological conditions were probably conducive to the formation of engine ice.

6. Following compressor stalls on No. 1 engine the engine was shut down.

7. Shortly after that engine was shut down a compressor stall then occurred on No. 2 engine.

8. The Flight Crew declared an emergency to Shannon ATC.

9. The PF correctly descended the aircraft in order to gain speed and maintain control of the aircraft.

10. The minimum altitude reached in this descent was 1,100 ft.

11. ATC properly vectored the aircraft directly towards EINN.

12. Following activation of the engine anti-ice system the engines stabilised, normal operation resumed and an uneventful landing ensued.

13. No damage was found to the engines during the post landing inspection.

(b) Probable Cause

The probable cause was rapid icing of the engine nacelles, resulting in compressor stalls.

(c) Contributory Cause

Delayed recognition of engine icing by the Flight Crew

4. SAFETY RECOMMENDATIONS

This Report does not sustain any Safety Recommendations.

APPENDIX A

Pratt and Whitney Aircraft – PWA Oper Instr 190, dated August 1972, Page 63 to 66

AIR INLET ANTI-ICING

The engine air inlet cowl lips, the inlet duct, the inlet duct struts, and the compressor inlet guide vanes of axial compressor turbojet and turbofan engines are susceptible to icing under the same general conditions that cause wing and wind-shield ice to form. In fact, air inlet icing may occur even at temperatures well above freezing, when there is no evidence of other icing on the aircraft. Once inlet ice commences to form, an appreciable accumulation can build up with startling rapidity.

Ice at the engine air inlet results in a loss of thrust that may be noted by a drop in engine pressure ratio if the condition is sufficiently severe. One of the first indications of ice may very likely be a compressor stall which could be slight, "snorting," or very pronounced. Ice at the inlet reduces airflow and internal pressure. Because fuel flow is controlled by a pressure signal from the engine burner section, fuel flow will be reduced as icing at the inlet causes burner pressure to fall off. The fuel flow reduction, however, may be too slight to be noticed, and therefore is not considered a positive indication that ice has started to accumulate. Nevertheless, the reduced burner pressure and fuel flow will allow a build-up of engine inlet ice without the exhaust gas temperature increasing significantly until the ice becomes quite heavy. Often, ice will commence to break off before a rise in exhaust gas temperature is observed. The rise in exhaust gas temperature, often associated with inlet icing, frequently results from ice passing through the engine, and not, as is commonly supposed, from ice build-up at the inlet. Therefore, exhaust gas temperature is not considered a reliable indication that ice is commencing to form at the air inlet of axial compressor engines. A large build-up of ice on the guide vanes and struts can result in compressor damage or possibly an engine flameout.

Even though one uses anti-ice heat on the ground during suspected icing conditions, experience has proven it a wise procedure to visibly inspect the air inlet and inlet guide vane areas for ice, both before engine starting and after engine shutdown, to ensure the absence of internal ice. Such an inspection will aid in preventing inadvertent ice ingestion upon restarting the engine.

When visible moisture is present in the outside air, engine inlet icing can occur at temperatures quite a number of degrees above freezing, particularly under static conditions. The increase in air velocity as air enters the aircraft inlet duct, the engine compressor inlet, and the compressor inlet guide vanes causes a drop in the temperature of the entering air. Thus, moisture in the outside air becomes supercooled as it passes through the engine inlet. This can result in engine inlet icing, even though external ice is not seen forming elsewhere on the aircraft. The greatest temperature drop through the inlet occurs at high rpm during ground operation. The temperature drop becomes less as engine rpm decreases and the airspeed increases after takeoff. Because the temperature drop through the inlet for any given engine installation is partly a function of the configuration of the airframe inlet duct, the aircraft manufacturer must furnish the actual ambient air temperature at which engine inlet anti-icing should be turned on for takeoff when visible moisture is present. This should appear in the aircraft Flight Manual.

The engine anti-icing system, which uses hot compressor bleed air to warm the compressor inlet struts and guide vanes, and usually the engine cowl lips as well, is not a deicing device. To avoid the possibility of ice breaking off and passing through the engine, the anti-icing system should be turned on immediately icing conditions are suspected, in order to preheat the engine air inlet before icing is actually encountered. Anti-icing heat should be used, when needed, for all ground operation, during takeoff and in flight. It is considered very significant that in all instances of inlet ice formation reported on Pratt & Whitney Aircraft engines, *inlet ice has never been known to form if the anti-icing system was turned on in time and a sufficiently high level of thrust was used when icing conditions were severe.*

Like carburettor ice in a reciprocating engine, turbine engine inlet ice often forms when not expected. One bank of clouds may not cause icing, while another, which to all appearances is exactly the same, may induce ice at the inlet. Therefore, it is strongly recommended that the engine anti-icing system be turned on whenever there is the slightest indication or suspicion that inlet icing conditions may exist. The thrust loss will be small when compared with that which might occur once inlet ice commences to form.

At the relatively high thrust settings used during climb or cruise, the anti-icing system will supply excess heat for protection against the accumulation of ice in the inlet section of the engine. To provide a desirable added margin of safety during operation in the lower thrust range of prolonged. periods under severe icing conditions, the engine should occasionally be accelerated to higher thrust settings to provide excess heat for short periods of time. On some engines, an anti-icing regulator is provided to regulate the flow of anti-icing air automatically with changing compressor discharge temperature. The anti-icing regulator reduces the flow of anti-icing air with increasing compressor inlet temperature (Tt2).

CAUTION: Should ice actually commence to form at the air inlet to the engine because the anti-icing system was not turned on soon enough, the throttle setting for the affected engine should be reduced as much as possible as soon as the anti-icing system has been turned on. This will minimize the danger of internal damage to the engine from ingested ice. After the ice has been removed, the engine should be checked at Idle. As soon as engine operation is normal, the throttle may be advanced as required.

Recommendations for the use of the engine inlet anti-icing system are as follows:

1. The engine air inlet anti-icing system should be used during all engine operation, including ground operation and takeoff, whenever icing conditions exist or are anticipated.

2. The thrust loss (EPR decrement) associated with the use of engine and aircraft anti-icing systems must be applied as stipulated in the applicable PWA Specific Operating Instruction.

3. To afford maximum reliability for multi engine aircraft, and when the engine installation in the aircraft permits, Pratt & Whitney Aircraft recommends that whenever engine inlet anti-icing is needed, the engine anti-icing systems be activated on one engine at a time, with sufficient hesitation after activating each engine to ensure that engine operation is normal, until all anti-icing systems are operating. The air inlet anti-icing systems may be activated at any throttle setting.

4. Should inlet icing conditions be encountered prior to activating the anti-icing system, the ignition system should be turned on prior to turning on the anti-icing system to preclude the possibility of an engine flameout due to inlet ice ingestion. Ignition may be turned OFF after a few minutes when the engine has stabilized, unless some other condition requires its continued use. On aircraft equipped with a continuous ignition system, that system may be used in lieu of the standard ignition system for this purpose. Refer to "Use of the Engine Ignition System" in this section.

5. For engines on which provision is made for water injection, and when the engine inlet anti-icing system is activated immediately following a wet takeoff, either the standard or continuous ignition system (depending upon the installation) should be turned on prior to activating the anti-icing system. The ignition should not be turned off until after the engine has stabilized.

6. Should an aircraft be required to hold on the ground in icing conditions for a prolonged period with engines running and anti-icing heat on, the engines should be run up periodically to a thrust level which provides sufficient anti-icing heat to assure that ice is not forming at the front of the engine. When ready to make the takeoff, the engines should again be run up to a high enough thrust level to assure that all are operating normally just prior to beginning the takeoff roll.

- END -