Final Report

A330-300, REGISTRATION 9V-SSF

DUAL ENGINE SURGE

23 MAY 2015

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Transport Safety Investigation Bureau
Ministry of Transport
Singapore

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The Transport Safety Investigation Bureau of Singapore

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GLOSSARY OF ABBREVIATIONS

AMM	:	Aircraft Maintenance Manual
ATC	:	Air traffic control
CSN	:	Cycles since new
CVR	:	Cockpit voice recorder
ECAM	:	Electronic Centralised Aircraft Monitoring
EEC	:	Electronic engine controller
EPR	:	Engine pressure ratio
EPRA	:	Actual EPR
EPRC	:	Commanded EPR
FADEC	:	Full Authority Digital Engine Control
FDR	:	Flight data recorder
HSN	:	Hours since new
HPC	:	High Pressure Compressor
HPT	:	High Pressure Turbine
IPC	:	Intermediate Pressure Compressor
MCT	:	Maximum continuous thrust
QAR	:	Quick access recorder
VSV	:	Variable stator vane

SYNOPSIS

On 23 May 2015 an Airbus A330 was flying from Singapore to Shanghai, China. When the aircraft was about 130 NM to the south-east of Hong Kong, it encountered an area of adverse weather.

The flight crew received a message on the aircraft's Electronic Centralised Aircraft Monitoring (ECAM) display indicating that the aircraft's right engine had surged. Before the flight crew took action, the right engine had self-recovered from the surge, but the ECAM message was replaced by another ECAM message indicating that the left engine had surged. In response, the flight crew went through the Engine Stall checklist and determined that the left engine needed to be shut down. The flight crew then carried out a controlled descent to 26,000 feet. Subsequently, the left engine was restarted. The flight then continued, with both engines running normally, to Shanghai without further incident.

The Transport Safety Investigation Bureau classified this occurrence as an incident.

AIRCRAFT DETAILS

Aircraft type	:	Airbus A330-300
Operator	:	Singapore Airlines
Aircraft registration	:	9V-SSF
Numbers and type of engines	:	2 X Rolls-Royce Trent 772B-60
Engine hours/cycles since new	:	In international waters about 130 NM southeast of Hong Kong
Date and time of incident	:	23 May 2015
Location of occurrence	:	12:56
Type of flight	:	Schedules passenger flight
Persons on board	:	192

1 FACTUAL INFORMATION

All times used in this report are Coordinated Universal Time (UTC). Singapore time is eight hours ahead of UTC.

1.1 History of the flight

1.1.1 An Airbus A330-300 aircraft was flying from Singapore to Shanghai. The aircraft was cruising at 39,000 feet in international waters about 130 NM southeast of Hong Kong[1], with a heading of 028 degrees. The flight crew observed weather cells along their flight route. They planned to deviate to the right to avoid the weather cells. They requested Air Traffic Control (ATC) for clearance to turn right to a heading of about 080 degrees. ATC granted the request.

1.1.2 Sometime after the aircraft had turned to 080 degrees, the flight crew, taking into consideration the weather radar information, decided on a route that would bring the aircraft through the weather but that would avoid areas of higher weather cell intensity. They requested ATC for clearance to turn left to a heading of 020 degrees. ATC granted the request. The flight crew turned to 020 degrees at 12:56:34 hours. They prepared the aircraft for possible turbulence by turning on the seat belt sign in the cabin and making an announcement through the public address (PA) system. They also set a target aircraft speed of 0.78 Mach, which was the turbulence penetration speed[2] recommended by the aircraft manufacturer. As a further precautionary measure, they turned on the wing anti-ice and selected continuous ignition for both engines[3].

1.1.3 Subsequently the aircraft entered a weather cell. The aircraft engines experienced surges[4] while in the weather cell. The flight crew first became aware of a surge when they saw the aircraft's Electronic Centralised Aircraft Monitoring (ECAM) displaying a message indicating that Engine No. 2 (the right engine) had surged and the message was accompanied by a list of response actions to be executed by the flight crew. The first response action was to reduce the Thrust Lever from Climb Thrust detent to Idle detent to reduce engine thrust. However, before the flight crew could complete the

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[1] The location was within the Hong Kong Flight Information Region, which was controlled by Hong Kong's air traffic control authority.

[2] Turbulence penetration speed is the speed recommended by the aircraft manufacturer to be adopted by a flight crew when they intend to fly their aircraft through an area of turbulence.

[3] Wing anti-ice and engine continuous ignition will be turned on automatically if icing is detected.

[4] A gas turbine engine surge (sometimes referred to as an engine stall) happens when the airflow through the engine is disrupted and this may result in momentary loss of power whereas a stall can mean a surge but can also mean that the engine has stopped producing thrust. The ECAM actions by the flight crew are the same for both a surge and a stall and the aircraft manufacturer has retained its naming convention of calling the checklist "Eng Stall".

first response action, the ECAM message was displaced by a second ECAM message indicating that Engine No. 1 (the left engine) had surged, together with a list of response actions by the flight crew

1.1.4 The ECAM message pertaining to Engine No. 1's surge was displayed above that pertaining to Engine No. 2's surge[5]. As such, the flight crew carried out the list of response actions pertaining to Engine No. 1's surge. This led to a point where the flight crew had to decide whether to shut down Engine No. 1. As the ECAM message pertaining to Engine No. 1's surge was still displayed, the flight crew believed that Engine No. 1 was still in a surge condition and therefore decided that they would need to shut down the engine. FDR data showed that Engine No. 1 had actually self-recovered in the meantime but this was not known to the flight crew.

1.1.5 The flight crew declared Mayday to ATC and then shut down Engine No. 1[6]. With only one engine functioning normally, it would not be possible to maintain a cruise at 39,000 feet. So the flight crew, with ATC's clearance, descended the aircraft to a cruise level of 26,000 feet.

1.1.6 The flight crew considered the options of diverting to Hong Kong or Guangzhou and continuing to proceed towards Shanghai. They noted that diverting to Hong Kong or Guangzhou would involve flying through weather cells again. They also noted that proceeding to Shanghai would pass by Xiamen and Hangzhou, which could be used as a diversion airport if needed, and that the route toward the northeast appeared clear of weather. Thus, the flight crew decided to continue to proceed to Shanghai.

1.1.7 While cruising at 26,000 feet on their way towards Shanghai, the flight crew managed to restart Engine No. 1. Engine parameters appeared normal and the flight crew cancelled the Mayday.

1.1.8 When the aircraft was approaching Xiamen airport to the northeast, an assessment on the status of the aircraft was carried out and the flight crew consulted with the operators' control centre via satellite communications. The flight crew noted that the engine parameters all appeared normal, and maintained their decision to fly to Shanghai. The aircraft landed in Shanghai without further incident.

1.1.9 Data from the aircraft's Flight Data Recorder (FDR) showed that both engines surged and recovered in quick succession. All in all within a span

[5] The ECAM system display logic was that items of higher priority would be display above items of lower priority. The aircraft manufacturer's ECAM display methodology was such that Engine No. 1 would be accorded a higher priority over Engine No. 2 when both engines experienced a similar issue.

[6] The flight crew had noted that the ECAM message pertaining to Engine No. 2's surge had cleared. Thus they believed that Engine No. 2 had returned to normal, since there was no more response action displayed in respect of Engine No. 2 and since the relevant engine parameters appeared normal.

of 12 seconds, Engine No. 2 surged three times and Engine No. 1 two times, and Engines No.1 and No. 2's first surges occurred at about the same time at 12:56:56 hours, which was about 22 seconds after the aircraft's left turn to a heading of 020 degrees.

1.2 Post-occurrence activities

1.2.1 The following ground inspections and tests were carried out on the two engines in Shanghai:

Type of inspection	Results
Borescope inspection	No damage found at the front and rear of the engines
Variable Stator Vane (VSV) and Full Authority Digital Engine Control (FADEC) tests	No faults found
Inspection of magnetic chip detectors (MCDs)	The MCDs were clean, suggesting that there were no metal particles from engine damage observed.
Engine ground runs, including High Pressure Compressor (HPC) surge margin acceptance test	No abnormality found

1.2.2 Subsequently the aircraft flew back to Singapore without any incident.

1.2.3 After returning to Singapore, the High Pressure Compressor surge margin acceptance test was repeated on both engines and no abnormality was found.

1.2.4 The aircraft could have been released for service with the two engines. However, the operator decided on a new policy of not pairing new engines on new twin-engined aircraft. New aircraft that were delivered with new engines would have one of the engines replaced by a relatively older engine.

1.2.5 Thus, Engine No. 1 was chosen to be removed from the aircraft. The operator and the engine manufacturer then decided to also have the engine disassembled in an engine overhaul facility in Singapore for an examination.

1.2.6 There was a significant amount of grey coloured dust deposit found on the aerofoil surfaces of some Intermediate Pressure Compressor (IPC) rotor blades and stator vanes, on the Intermediate Pressure Turbine (IPT) nozzle guide vanes and on the High Pressure Turbine (HPT) stubshaft (see **Figure 1**). The dust was identified to be composed mainly of aluminium and silicon, which were the main constituents of the IPC rotor path abradable material.

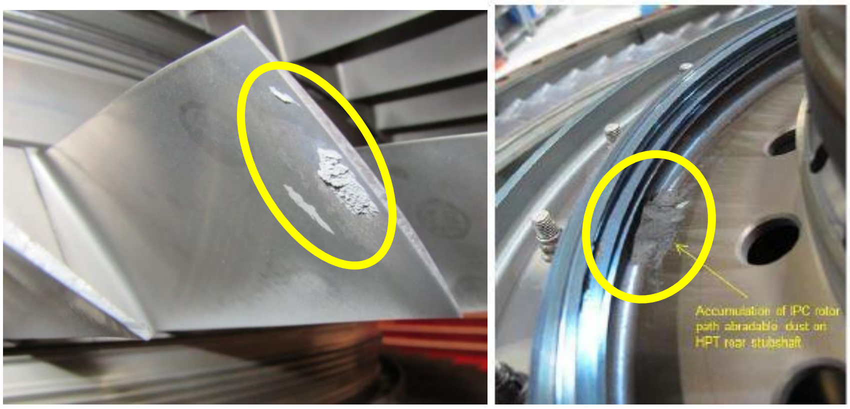

Figure 1. Grey coloured dust deposit found on a Stage 3 IPC rotor blade (left) and the HPT stubshaft (right)

1.2.7 There were signs of heavy rubbing of the rotor path abradable lining at Stages 3 and 6 of IPC. Light rubbing in the rotor paths were seen at Stages 4, 5, 7 and 8, and these rubs were considered typical of operational wear.

1.2.8 There was heavy rubbing at Stages 3, 4, 5, 6 and 7 stator vane shrouds. The rubbing could be attributed to contacts with the air seals of the IPC rotor drum (see Figure 2).

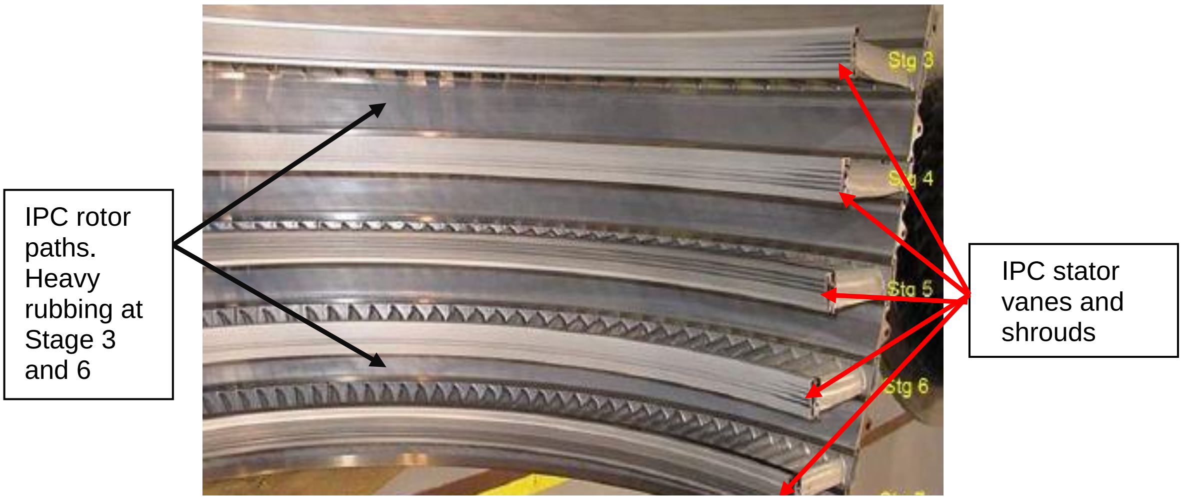

Figure 2. Engine casing showing alternating rotor path channels and stator vanes/shrouds

1.2.9 There were signs of rubbing on the HPC stator vane shrouds. According to the engine manufacturer, the condition of the HPC was typical of normal operational wear.

1.2.10 Apart from the heavier than normal abradable lining rubs, the wear and tear of the engine was considered typical of an engine of a similar age.

1.3 Aircraft information

1.3.1 The aircraft was new in service. It was delivered to the operator on 30 March 2015. The engines were delivered with the aircraft. At the time of the occurrence, the aircraft had clocked 386 flight hours and 85 flight cycles and both the engines had clocked 719 hours since new (HSN) and 169 service cycles since new (CSN).

1.3.2 The engine's compressor section was surrounded by the engine casing. The engine casing with the compressor rotor formed alternating sections of stator vanes (stationary parts) and rotor blades (rotating parts). The stator vanes with the rotor blades worked together to compress and channel pressurised air through the engine in multiple stages of compressions. In order to maximise the compression efficiency of the air passing through each stage, the engine manufacturer had incorporated minimal clearances between the rotor blade tips and the rotor path on the engine casing so that air losses by backflow are minimised. This was done by using lining with abradable material in the rotor path which the blade tips cut into. As the engine was running, the blade tips might come into contact with the abradable lining owing to centrifugal forces as the rotor rotates, thus abrading the rotor path lining to create an optimum clearance fit.

1.3.3 For the engines in this occurrence, the abradable lining was made of an aluminium and silicon-based material.

2 ANALYSIS

The investigation looked into the following:

a. Engine surge
b. Release of IPC rotor path abradable lining material
c. Flight crew actions

2.1 Engine surge

2.1.1 The investigation team believed that the engine surge in Engine No. 1 was most likely a result of the release of IPC rotor path abradable lining material. Although Engine No. 2 was not disassembled and examined, the investigation team believed that Engine No. 2, being as new as Engine No. 1, experienced the engine surge for a similar reason.

2.1.2 The following is the likely sequence of events leading to the surge of Engine No. 1:

a. The tips of Stage 3 and 6 IPC blades contacted and rubbed the abradable lining material.
b. The rubbing caused the abradable lining material to be eroded into small particles which were carried downstream in the airflow.
c. These abradable lining material particles entered the combustion section and ignited, causing a temporary disruption of airflow through the engine.

2.1.3 The release of rotor path abradable material has been known to cause engine surges. If the aluminium and silicon-based rotor path abradable lining is rubbed heavily, the eroded small particles are carried downstream into the core airflow. When the abradable material and air mixture exceeds a certain threshold, the mixture can spontaneously ignite downstream in the hotter stages of the HPC or in the combustor, resulting in an engine surge.

2.1.4 The engine surge would result in a reduction in the engine pressure ratio (EPR). The EEC was designed to recover the engine by reinstating the EPR to the commanded EPR. This reinstating of the EPR accelerated the rotors, which caused a further release of abradable lining material particles. This would, in turn, result in ignition of the abradable lining material particles and a further disruption to the airflow through the engine, thus causing multiple surges. In order to arrest this situation, the EPR had to be reduced. Otherwise, the lining material would continue to be abraded until there was no more contact with the rotor blades, and thus no further release of lining material particles into the airflow.

2.2 Release of IPC rotor path abradable lining material

2.2.1 There are various ways in which the rotor blade tips may come into contact with the rotor path abradable lining, including:

- Engine casing contraction

  IPC engine casing contraction could result from cooling of the engine casing when ingested ice crystals and water droplets are centrifuged out onto the casing by the compressor blades during operation in a particularly cold environment. The engine manufacturer's thermal analysis indicated that, with the prevailing meteorological conditions during the incident flight, the aircraft had most probably ingested ice crystals or super-cooled water droplets. In such a scenario, the IPC engine casing would have contracted as a consequence of a reduction of engine casing temperature. The contraction of the engine casing would significantly reduce the clearances between the rotor blades and the rotor path abradable lining, which resulted in heavy rubbing and subsequent release of excessive abradable material.

- Rotor Dilation

  When the engine rotors accelerate, a small amount of elastic (reversible) radial growth occurs as a result of the centrifugal forces on the components. This growth results in a reduction of the clearance between the compressor blade tips and the abradable linings of the rotor paths, with the possibility of some blade tip incursion producing light rubs.

- Axial load reversal

  During normal operation, the axial load on the Intermediate Pressure (IP) system location bearings is directed towards the front of the engine. According to the engine manufacturer, the axial load on the IP system can reverse under certain flight conditions. The IP system bearing have been designed to have a small amount of axial free movement. This free movement can result in blade tip incursion into the rotor path abradable lining, especially if the blade tips are running close to the rotor path abradable lining.

  Stage 3 and 6 IPC stages showed more evidence of rubbing as compared to the other stages. A rearward shift of the IP rotor, would produce a rotor blade to rotor path closure leading to the rubs observed on the axial width of rubs in the IPC shroud abradable lining with the air seals of the IPC drum.

- Rotor blade vibration

  The engine manufacturer indicated that its measurement data showed that IPC blade vibration could result in additional incursion into the rotor path of the abradable lining material. The engine manufacturer had also reviewed the engine certification vibration survey data and found that, within the IP system rotational speed range at the time of the surge event, only Stage 3 IPC could have a mode of vibration that accorded with the measurement data. The close correlation of IP system rotational frequency to blade frequency suggests that blade vibration probably contributed to blade tip contact from Stage 3 IPC with the abradable lining

2.2.2 The operator, following discussion with the engine manufacturer, had decided that its new A330 aircraft that are delivered with new engines will have one of the engines replaced by a relatively older engine. Such a policy seems a prudent one, as the lining material of the older engines, which have been well run-in (i.e. larger clearances with the rotor blades), would be less susceptible to being abraded further and releasing enough small particles to cause disruption to the airflow through the engine.

2.3 Flight crew's actions

2.3.1 As mentioned in paragraph 1.1.4, when responding to the ECAM message pertaining to Engine No. 1's surge, the flight crew had to decide whether to shut down Engine No. 1. As the ECAM message pertaining to Engine No. 1's surge was still displayed, the flight crew believed that Engine No. 1 was still in a surge condition and therefore decided that they would need to shut down the engine.

2.3.2 However, FDR data showed that Engine No. 1 had actually been self-recovering in the meantime but this was not known to the flight crew. The reason the Engine No. 1 surge message was still being displayed is that the Electronic Engine Control (EEC) system was designed to retain the ENG STALL message for 60 seconds[7] even if the engine had been recovering in the meantime.

2.3.3 Had the EEC system updated the engine surge status sooner, the flight crew would have been given a truer picture of the engine's condition, and would most likely not have decided to shut down Engine No. 1.

[7] While the message was displayed via the ECAM system, the message display duration was programmed in the EEC.

3 CONCLUSION

From the information gathered, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

3.1 The two engines encountered engine surges, one after another, while the aircraft was passing through an area of adverse weather.

3.2 The engines, as per design, recognised the engine surges and self-recovered immediately.

3.3 Engine No.1 was disassembled and the examination of the engine suggest that the engine surge in Engine No. 1 was most likely a result of the release of IPC rotor path abradable lining material. Although Engine No. 2 was not disassembled and examined, it is most likely that Engine No. 2, being as new as Engine No. 1, experienced the engine surge for a similar reason.

3.4 The release of the abradable lining material into the combustion section of the engine resulted in a disruption of airflow through the compressor section.

3.5 The "Eng Stall" ECAM message was timed to display for 60 seconds whether or not the engine had self-recovered.

3.6 The pilot while carrying out the ECAM checklist noticed the "Eng Stall" message still displayed and concluded that Engine No. 1 was still in a stalled condition and decided to shut down the engine.

3.7 Engine No. 1 was restarted without issue and the aircraft continued the flight to the planned destination.

4 SAFETY ACTIONS

Arising from discussions with the investigation team, the parties involved have taken the following safety action.

4.1 The aircraft manufacturer has enhanced its Flight Crew Training Manual Section FCTM-AO-70 to provide the following information:

- A brief description of an engine stall
- The possible causes of an engine stall
- The different symptoms of an engine stall
- The procedure associated with an engine stall

4.2 The operator has adopted a policy not to pair new engines on A330 aircraft. New A330 aircraft that are delivered with new engines will have one of the engines replaced by a relatively older one.

4.3 The engine manufacturer has increased the rotor tip clearances, between the engine casing and IPC blades, for Stages 3 and 6 IPC which exhibited evidence of heavy tip rubs.

4.4 In coordination with the aircraft manufacturer, the engine manufacturer will implement a modification, via a service bulletin, to the EEC logic to reduce the display time for the engine surge ECAM checklist to less than 10 seconds. The modification will be applied to all newly manufactures engines and rolled out progressively to all EECs on engines that are currently in service.

5 SAFETY RECOMMENDATION

In view of the safety actions taken by the airline operator, aircraft manufacturer and engine manufacturer, no further safety recommendation is proposed.