AVIATION INVESTIGATION REPORT
A00Q0141

SMOKE IN CABIN FROM OVERHEATED FAN

TRANSPORT CANADA

CESSNA 550 C-FJCZ

ROUYN-NORANDA, QUEBEC

06 OCTOBER 2000

Aviation Investigation Report

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Summary

A Cessna 550, registration C-FJCZ, serial number 550-0700, took off at 1745 eastern standard time for an instrument flight rules (IFR) flight from Rouyn-Noranda Airport, Quebec to Montréal/Dorval International Airport, with two pilots and one passenger on board. The aircraft was cleared to climb to an altitude of 5000 feet above sea level (asl). When the aircraft levelled off at 5000 feet asl, the captain noticed smoke entering the cabin. The crew advised air traffic control, declared an emergency, and requested clearance to return to Rouyn-Noranda. The crew landed without further incident on Runway 08 at Rouyn-Noranda Airport and taxied to the terminal, where the two pilots and passenger evacuated the aircraft. There were no injuries.

Ce rapport est également disponible en français.

Other Factual Information

History of the Flight

On the afternoon of 06 October 2000, a Cessna Citation II, registration C-FJCZ (flight Transport 858), received clearance for an instrument flight rules (IFR)[1] flight from Rouyn-Noranda Airport, Quebec to Montréal/Dorval International Airport. The clearance indicated that the aircraft must take off on Runway 08 and turn right en route with a clearance limit of 5000 feet above sea level (asl). The aircraft took off at 1745 eastern standard time (EST)[2]. The take-off and initial climb were normal until the aircraft levelled off at 5000 feet asl. At that time, the captain realized there was smoke behind the first officer's seat.

The crew donned their oxygen masks and advised the air traffic controller that there was smoke in the cockpit. The crew declared an emergency and requested to return immediately to Rouyn-Noranda Airport under visual flight rules (VFR). The captain had trouble donning his oxygen mask with his headset on. The first officer also had difficulty with his oxygen mask and with communications with the air traffic control centre.

The captain recognized the terrain and headed for Rouyn-Noranda Airport. The captain tried, without success, to provide oxygen to the passenger. After a brief discussion with the passenger, he concluded that the passenger did not need to don his oxygen mask. Meanwhile, the first officer was still having trouble with his oxygen mask and was silently going through the checklist because there was no verbal communication between the two crew members; they communicated by hand signals. Item 2 of the checklist under *Environmental Smoke and Odour* specifies to select the *OXY MIC* switch to *MASK* to communicate. This item on the checklist was not completed by the crew.

The captain had trouble seeing outside; his vision through the mask window was unclear. To be able to judge the height of the aircraft on the downwind leg, he decided to raise his oxygen mask; he raised it at least twice before the landing. Meanwhile, the first officer decided to remove his oxygen mask completely until the end of the flight to correct the communication problem. The checklist in the *Environmental Smoke and Odour* section was completed, and the *OVHD FAN* switch (item 5) and the *DEFOG FAN* switch (item 6) were selected *OFF*; the first officer does not recall whether or not he selected the *FLOOD COOLING FAN* switch (item 7) *OFF* because it is usually in the *OFF* position on take-off. After these switches were selected *OFF*, the smoke decreased considerably in the cabin.

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[1] See Appendix A - Glossary at for all abbreviations and acronyms.

[2] All times are EST (Coordinated Universal Time [UTC] minus five hours) unless otherwise stated.

The landing was normal, and the aircraft taxied to the terminal, where the occupants evacuated the aircraft. The captain and firefighters proceeded to the aft baggage compartment to locate the source of the smoke. When the compartment door was opened, the smoke was so thick they could not see anything. They tried, without success, to locate the source of the smoke via the aft compartment from inside the aircraft.

Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	-	-	-	-
Serious	-	-	-	-
Minor/None	2	1	-	-
Total	2	1	-	-

Other Damage

Preliminary examination revealed that smoke came from a fan located under the floor in the aft section of the cabin and forward of the pressure bulkhead. It was found that one of the fan housing attachment screws had failed, moved aft, and came into contact with the fan armature, causing the fan to overheat and produce smoke. The 20-amp circuit breaker did not trip to protect the circuit and fan. The cabin fan was damaged as a result of the failure of the housing attachment screw. Burn marks were found on the protective sleeve covering the bundle of electrical wires next to the fan. No damage was observed on the cabin fan motor wiring.

Personnel Information

General

	Captain	First Officer
Age	45	54
Pilot Licence	Airline Transport Aeroplane	Airline Transport Aeroplane
Medical Expiry Date	01 March 2001	01 December 2000
Total Flying Hours	16 120	9585
Hours on Type	90	500
Hours Last 90 Days	24	9
Hours on Type Last 90 Days	24	9
Hours On Duty Prior to Occurrence	11	11
Hours Off Duty Prior to Work Period	15	15

Crew

The captain and the first officer were certified and qualified for the flight in accordance with existing regulations. The captain was promoted to captain on the Cessna Citation on 10 August 2000. At the time of the occurrence, both crew members held an airline transport licence.

Crew Training on Use of Oxygen Mask

The oxygen mask windows were covered with a plastic protective film that could be removed by pulling a tab. The film provides added protection against scratches and can be removed quickly in the event of icing due to depressurization. Transport Canada (TC) produced a video to show pilots how to use their oxygen mask. The video shows that the oxygen mask window is covered with a transparent protective film and shows how to remove it when donning the mask.

The crew members were not familiar with the oxygen masks and did not know how to use them properly; the masks caused problems for them with regard to communications and visibility.

Aircraft Information

Manufacturer	Cessna Aircraft Corporation
Type and Model	550
Year of Manufacture	1992
Serial Number	550-0700
Certificate of Airworthiness	11 May 1992
Total Airframe Time	3622
Engine Type (number of)	Two Pratt & Whitney JT15D-4
Maximum Allowable Take-off Weight	14 100 lb
Recommended Fuel Types	Jet A, A-1, A-2, Jet B and JP-4
Fuel Type Used	Jet B

The aircraft take-off weight was 12 248 pounds; the maximum allowable take-off weight is 14 100 pounds. The centre of gravity was within prescribed limits.

Meteorological Information

Weather conditions at 2200 UTC was as follows: winds from 050 degrees at six knots, visibility 10 statute miles, light rain showers, a layer of broken clouds at 1700 feet, a layer of broken clouds at 4000 feet; temperature four degrees Celsius; dew point three degrees Celsius; altimeter setting 30.00 inches of mercury.

Cabin Fan and Defog Fan

Description

The cabin fan motor, part number 12323-2, serial number 1990, manufactured by Advance Industry, is fitted with a 20-amp circuit breaker marked *CABIN FAN*. The cabin and defog fans are both powered from the No. 1 DC bus bar and protected by a single 20-amp circuit breaker, part number S2899L20.0, marked *CABIN FAN*. The cabin fan motor has a data plate that shows information on capacity corresponding to 9 amps at a continuous 28 volts direct current (DC).

The overhead ventilation outlets for the cabin fan are located along the cabin and cockpit ceiling. Air is forced through these outlets by the cabin fan, which conditions and recirculates fresh air. A system of ducts carries air to the outlets located along the upper cabin panel and to two outlets in the cockpit.

The cabin fan is located under the floor in the ventilation system at station 345. The fan has two speeds and is controlled by a switch, marked *OVHD,* that has three positions (*LOW, OFF, HIGH*). In addition, the *OVHD* fan switch, when selected to HI, also controls two divider fans. These fans provide supplemental cockpit ventilation. Operation of the *OVHD* switch is as follows: when the cabin fan is on HI, the divider fans are on, and when the cabin fan is on LOW, the divider fans are off.

According to the training manual used by TC Aircraft Services Directorate (TC ASD) and the manufacturer's maintenance manual, a smoke detector is installed in the duct system. Since the smoke detector duct is connected to the fan intake, smoke in the aft section is detected immediately via the fresh air duct in the cockpit. A small orifice distributes air continuously and alerts the pilots when there is smoke in the system. C-FJCZ was not equipped with this installation. It was later found that this feature was not installed on aircraft having a serial number greater than 0696.

The defog fan is used to increase airflow via the foot outlet, windshield outlets and side window outlets in the cockpit. The defog fan switch is marked *DEFOG* and has three positions (*LOW, OFF, HIGH*); it is located on the right side of the instrument panel near the cabin fan switch.

Testing of Cabin Fan Motor

The cabin fan motor was retrieved, together with the housing attachment screw that had moved outward. The attachment screw was removed; it showed wear marks caused by rubbing against the motor armature. The motor could turn freely with no signs of rubbing or bearing damage. The motor exterior showed heat damage around the rubber wire grommet. Other rub marks were observed on the end of the motor and were consistent with the material of the protective sleeve around the main wire bundle, specification number 6508011.

During tests at the TSB Engineering Branch Laboratory, the motor was connected to a 28 volt DC source protected by a 20-amp circuit breaker. An ammeter was used to measure the motor load at all times. Electric current was applied to the motor, and the current demand was about 40 amps for a period of 12 seconds, at which time the breaker tripped. This test was repeated, with the same result. On the third test, a thermocouple was attached to the motor to measure the temperature on the motor body. On this test, current demand was 26 amps for a period of 3 minutes and 50 seconds. The motor gave off a large quantity of smoke and reached a

temperature in excess of 320 degrees Fahrenheit (°F), when the test was purposely stopped. The breaker did not trip. When the load was removed, the temperature continued to rise to 340°F. No forced air was applied to the motor during these tests.

The Cessna Citation was approved in accordance with part 25 of the *Federal Aviation Regulations.* FAR 25.1357 specifies that protective and control devices in the generating system must "be designed to de-energize and disconnect faulty power sources and power transmission equipment from their associated busses with sufficient rapidity to provide protection from hazardous over-voltage and other malfunctioning." In addition, "each circuit for essential loads must have individual circuit protection."

Another analysis focussed on the failed attachment screw. Analysis revealed that the crack had propagated progressively and continuously. This mode of propagation is consistent with low cycle fatigue. It was determined that the screw weakened and eventually failed in service under normal load when the fatigue crack reached a critical size. There was no indication that the crack was present when the screw was installed during overhaul.

Minimum Equipment List and Certification

A master minimum equipment list (MMEL) is an approved document specifically prepared to prescribe how a given type of aircraft can be used with unserviceable equipment. The MMEL lists, for a given aircraft type, the equipment that may be unserviceable under certain conditions, and it serves as the basis for the minimum equipment list (MEL).

According to the MEL for the Cessna Citation (Part 21, Item 17), the aircraft may be flown without restriction even if the cabin fan is unserviceable. However, as the defog fan is not covered by the MEL; it becomes essential for take-off.

The Cessna Citation was built in the United States to US certification requirements, pursuant to Federal Aviation Regulations 25 (FAR 25), effective 01 February 1965. The aircraft was imported into Canada in 1992 and was issued a Canadian certificate of airworthiness. Canadian type certificate A-130, under *Equivalent Safety Items, (6)*, states that the aircraft must meet certification standard FAR 25.773(b)(2) with regard to crew visibility. Visibility must be maintained at all times, especially in rain and/or icing conditions. This standard states that the pilot-in-command must have a secondary means of maintaining good visibility in the conditions specified in FAR 25.1353(a). The latter standard states that electrical equipment, controls and wiring must be installed so that operation of any one unit or system of units will not adversely affect the simultaneous operation of any other electrical unit or system essential to safe operation.

The certification standard for this aircraft requires that a defog fan be installed and, consequently, that electrical power be supplied to it. Based on this standard, the power supply to the defog fan is automatically an essential load. FAR 25.1357(e) requires that each circuit for essential loads have individual circuit protection.

The Cessna Citation was also approved in accordance with FAR 25.1309, which requires that equipment, systems, and installations whose function is required must be designed to ensure that they perform their intended functions under any foreseeable operating condition. The aircraft systems and associated components, considered separately and in relation to other systems, must be designed so that the occurrence of any failure condition which would prevent the continued safe flight and landing of the aircraft is extremely improbable. The occurrence of any other failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions must be improbable. Each installation whose function is required and which requires a power supply is an essential load on that power supply.

Electrical System

Load Analysis

Under the Canadian standard set out in Part V, section 551.200(2)(I) of the *Airworthiness Manual*, electrical load analysis is "a requirement for the initial certification of the aircraft type". The electrical load used is that indicated in the Cessna maintenance manual. In this load analysis, the defog fan was powered from the left main bus bar via circuit breaker 23 marked *CABIN FAN*. The cabin fan was categorized as 4 amps, but the fan installed was rated at 9 amps; it was powered via the same breaker as the defog fan.

Circuit Breakers and Wiring

Circuit breakers are designed to cut off the electric current under specific overload conditions. They must be matched to the performance of the electrical wiring when exposed to overload and must open the circuit before heat damages the wiring harness, including the connectors. Breakers are not designed to protect electrical equipment in the circuit which, in some cases, has its own built-in protective device or mitigation system. A circuit breaker must trip (open the circuit) before any component in the circuit overheats and generates smoke or fire. Furthermore, information provided by Cessna indicated that vendor specifications for the thermal type S2899L20.0 circuit breaker at minimum limit ultimate trip is 110% (22 amps) for one hour at 25°C and the maximum limit of ultimate trip is 150% (30 amps) for one hour at 25°C.

The electrical system in the *CABIN FAN* circuit breaker protects two circuits: the defogging system circuit and the cabin fan circuit. According to the certification standard, the defog fan circuit is essential for flight but the cabin fan circuit is not essential. In the electrical installation observed on C-FJCZ, the cabin fan circuit operates on a regular basis while the defog circuit is used at specific times during the flight and/or when weather conditions require an additional air supply.

The electrical wiring used in both electrical systems is 16 American Wire Gauge (AWG). According to aviation industry standards, this wiring must be protected at all times by a circuit breaker rated at a maximum of 15 amps. As shown in the laboratory tests, if a fault occurs in one of the two circuits when only one circuit is in use, the 20-amp breaker will not trip to protect the circuits. Also, there was a discrepancy in the wire gauge used in this installation. The cabin fan is supplied via a 12-inch length of 18 AWG MILW16878 type E. Again according to aviation industry standards, 18 AWG wire must be protected by a breaker with a rating not exceeding 10 amps. With 18 AWG wire supplying the cabin fan connected to the aircraft's 16 AWG circuit, the most vulnerable part of the system was the cabin fan wiring, not the breaker.

Deficiencies

In the parts department, two fans were found that showed excessive wear at the point where the wire bundle was close to the fan. This condition was caused by wires rubbing on the fan housing. TC conducted an inspection campaign on these aircraft, and on 5 of the 9 aircraft inspected, inadequate spacing was observed between the cabin fan and the protective sleeve on the right main harness.

Various reports have been prepared by the US Federal Aviation Administration (FAA) and the National Transportation Safety Board concerning problems related to incorrect assembly of electrical wiring and wiring harness spacing in reference to AC 43-13-1A and AC 65-15 documentation. FAA inspections revealed several deficiencies on various aircraft built by Boeing, Cessna and Beechcraft. Since 1986, there have been 18 occurrences in Canada and the United States involving the Cessna Citation that were directly related to smoke in the cabin caused by fans. At least three of these occurrences were directly linked to smoke caused by a cabin fan whose circuit breaker failed to trip.

Analysis

The crew was qualified for the flight. However, they were not familiar with the oxygen masks, which caused visibility and communication problems. Moreover, the crew was not familiar with the oxygen system for passengers.

One of two screws used to attach the cabin fan armature had a crack. The screw eventually failed in service under normal load when the fatigue crack reached a critical size. There was no indication that the crack was present at the time of the overhaul. The torque applied by the aircraft maintenance engineers is the torque indicated in AC 43-13-1A (general procedure manual). It could not be determined whether or not excessive torque was applied during the overhaul, which would have weakened the screw. These safety devices would not have prevented the screw failure.

The two fresh air outlets in the cockpit do not have a small orifice that would allow the crew to promptly detect smoke in the ducts. This description of the installation and orifice are taken from a training manual used by TC ASD and the manufacturer's maintenance manual. None of the individuals interviewed were aware of this installation. According to Cessna Corporation, the holes in the fresh air outlets in the cockpit were absent on aircraft with serial number 0696 and on. This change was primarily driven by customer dissatisfaction. A letter of agreement between the FAA and Cessna indicated that the aft cabin/laboratory be declared a storage area instead of a baggage area. As such, a smoke/fire monitoring system was no longer a requirement.

Airworthiness standards must be met when an aircraft is certified. Also mandatory is compliance with FAR 25.1309, which requires that the occurrence of any other failure conditions which would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions must be improbable. In the event that the cabin fan (MEL) fails and the circuit breaker trips, the defog fan (not covered by the MEL) would become unserviceable. If the defog fan (which is essential for flight) is unserviceable, the aircraft safety would be compromised in certain critical phases of the flight such as the descent, approach and landing.

Installation of the defog fan is a certification requirement for this aircraft and, accordingly, it is an essential load. Under FAR 25.1357(e), each circuit for essential loads must have individual circuit protection.

Identification of the switches and circuit breaker is not consistent. The switches are marked *OVHD FAN* and *DEFOG FAN*, while the breaker is marked *CABIN FAN*.

Electrical load analysis revealed that the cabin fan was categorized as 4 amps, while the fans installed drew 9 amps. The electrical load analysis does not represent the actual load existing in the circuit.

The purpose of a circuit breaker is to open the circuit before the current rating of the wire in the circuit is exceeded. In this occurrence and in the laboratory tests, the current load was exceeded to the point where the fan generated smoke without tripping the circuit breaker. The load capacity of a wire varies according to its gauge. The two fans involved here were installed with 16 AWG and 18 AWG wire. However, the manufacturer elected to protect the system with a 20-amp breaker, resulting in an under-protected system in the event of a failure.

When one of the attachment screws for the cabin fan armature failed, it came into contact with the fan armature, causing sparks, overheating and smoke. The protection circuit should have tripped immediately to prevent further deterioration of the situation, but it was unable to trip because the level of protection provided by the circuit breaker was inadequate. This occurrence is not an isolated case; there have been 18 occurrences in the past involving the same problem, i.e. overheating of the cabin fan causing smoke. In three of the occurrences, the circuit breaker did not trip.

The following laboratory report was completed:

LP 109/00 - *Overhead Cabin Fan Assembly Failure.*

Findings as to Causes and Contributing Factors

1. One attachment screw for the cabin fan armature failed, causing the cabin fan to overheat and generate smoke in the cabin.

2. The 20-amp circuit breaker provided inadequate protection for the cabin fan circuit and defog fan circuit; when the breaker should have protected the electrical circuit, it did not trip.

Findings as to Risk

1. Crew members were not familiar with the oxygen masks, and they experienced visibility and communication problems.

Other Findings

1. According to the training manual used by Transport Canada Aircraft Services Directorate (TC ASD) and the manufacturer's maintenance manual, each of the two air outlets in the cockpit should be equipped with a small orifice to distribute air continuously to alert the crew when there is smoke in the cabin ventilation system. C-FJCZ did not have this installation.

2. When the defog fan (which is essential for flight) is unserviceable, the safety of the aircraft is compromised in certain critical phases of flight.

3. Identification of switches and circuit breaker was inconsistent.

4. Only one circuit breaker was used to protect two electrical circuits with separate functions: the cabin fan (not essential for flight) and the defog fan (essential for flight). According to the certification standard, the defog fan is an essential load and should have individual protection.

5. The cabin fan installed drew 9 amps; this is inconsistent with the manufacturer's electrical load analysis, which specifies 4 amps.

6. The cabin fan was delivered with 18 AWG wiring and was connected to circuits consisting of 16 AWG wire, which made it less resistant to overload than all other components in the circuit.

Safety Action

On 16 October 2000, Transport Canada Aircraft Services Directorate (TC ASD) issued Campaign Notice 851-014 Rev. A for their fleet of Citation C550 aircraft. The purpose of this campaign was to provide an awareness of this occurrence and to provide inspection procedures for TC ASD maintenance personnel. Other actions taken by TC ASD are as follows:

1. Motor mount screws now receive non-destructive testing via magnetic particle inspection during

each overhaul of the subject motor by TC ASD.

2. New oxygen masks have been installed in all Citation C550 aircraft.

3. Modifications relating to the use of oxygen masks during emergency procedures were made to the crew training program.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 05 December 2002.

Appendix A - Glossary

asl	above sea level
AWG	American Wire Gauge
TSB	Transportation Safety Board of Canada
DC	direct current
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
EST	eastern standard time
IFR	instrument flight rules
lb	pounds
MEL	minimum equipment list
MMEL	master minimum equipment list
TC	Transport Canada
TC ASD	Transport Canada Aircraft Services Directorate
UTC	Coordinated Universal Time
VFR	visual flight rules
°F	degrees Fahrenheit