INCIDENT

Aircraft Type and Registration:	Cessna 550 Citation 11, G-VUEA
No & Type of Engines:	2 Pratt & Whitney JT15D-4 turbofan engines
Year of Manufacture:	1991
Date & Time (UTC):	21 April 2003 at 2025 hrs
Location:	On approach to Runway 24 Right at Manchester Airport, Manchester
Type of Flight:	Positioning
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Cockpit defog fan overheated and failed. Considerable smoke in cabin
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	46 years
Commander's Flying Experience:	2,750 hours (of which 250 were on type) Last 90 days - 70 hours Last 28 days - 30 hours
Information Source:	Aircraft Accident Report Form submitted by the commander and follow-up activity by the AAIB.

History of the flight

The aircraft was engaged on a positioning flight between Edinburgh and Manchester, with only the two flight deck crew on board. Whilst being vectored by ATC for an approach to Runway 24 Right at Manchester, and as the aircraft was descending through about FL80, the crew became aware of a strong smell of burning electrical insulation. The passenger cabin was seen to be completely filled by smoke which obscured its rearmost part. There was no smoke in the cockpit at this stage, despite there being only an open curtain separating the two areas.

The commander instructed the co-pilot, who was handling the aircraft through the autopilot system, to don his oxygen mask. As the co-pilot was so doing, the commander made a MAYDAY call to ATC though this was hindered by thick smoke which by this time was entering the cockpit area and causing the commander breathing difficulties. Immediately after the MAYDAY transmission, the commander donned his oxygen mask; as he did so, the smoke was beginning to obscure the instrument panel and forward vision from the cockpit.

With no malfunctions apparent in the cockpit, the commander initiated the SMOKE REMOVAL emergency drill from memory. His action was to open the dump valve to depressurise the aircraft, which caused a partial clearance of the smoke. The commander made the decision not to carry out any further emergency drills as the crew were becoming engaged in preparation for the approach and landing, which he considered to be his priority. Manchester ATC provided the crew with an expeditious routing towards the localiser for Runway 24 Right, though communications with ATC were difficult due to a high noise level in the cockpit, which was attributed mainly to noise from the oxygen masks. The weather at Manchester Airport was reported as CAVOK with light surface winds.

Whilst on a visual final approach, the smoke concentration began to increase again, which the commander thought may have been due to reduced airflow into the cabin from the throttled back engines. However, the smoke concentration was not sufficient to restrict forward vision. The aircraft landed normally and the crew bought it to a stop on the runway before shutting down both engines and removing all electrical power. The pilots evacuated the aircraft without difficulty through the main door and as they did so the Airport Fire Service arrived at the aircraft. Inspection by the fire crew revealed no signs of fire, though smoke continued to emerge from the open door for a further 20 minutes.

The only injuries sustained were a sore throat and chest which the commander experienced as a result of inhaling smoke whilst making the initial distress call.

Aircraft examination

It was established by the operator that the circuit-breaker protecting the motor of the cabin defog fan blower had tripped, apparently as a result of a fault within the motor. The motor was found to be defective and was passed to the AAIB for further examination.

Component examination

Examination of the cabin defog fan revealed no evident damage to the fan unit but considerable resistance to rotation of the shaft. Contamination of the gauze type filters on the external vent holes of the motor with a black sticky residue was evident. Strip examination confirmed that the interior of the motor had grossly overheated, melting and degrading much of the insulation therein. There was, however, no evidence of any point of concentration of burning or local overheat. The commutator was severely worn but the brushes remained in good condition. Black staining and a deposit of sticky residue were present in two of the airflow paths from the motor into the fan case. One motor bearing was confirmed to be very stiff in operation, indicating that seizure had occurred at some stage.

The cabin defog fan had a life of 3,500 airframe hours between overhaul or replacement with a service exchange unit and the failed unit had been installed for 2,090 airframe hours since new. The part number of this component has been superseded and the type is no longer supplied as a replacement item. There is no indication, however, that the unit type which failed on this occasion was not permitted to operate up to its quoted overhaul life. A continuing component reliability analysis programme carried out by the aircraft manufacturer does not produce conclusive statistical evidence of the reliability of the failed unit type.

Arrangement of the air conditioning system

The cabin defog fan is included in the air conditioning system to provide conditioned air to the cockpit foot warmers and windshield and side-window defog outlets. It also influences airflow into the passenger cabin area. A 28V DC electric motor drives a centrifugal fan which receives conditioned air from the engine bleeds via the refrigeration unit and delivers it into the cabin duct system. The unit, which is situated below the floor towards the rear of the cabin, can be selected by the crew and has a high and low speed setting.

A small volume flow rate of air for motor cooling is also drawn into the fan housing from the interior of the motor via four vent holes at the fan end of the motor casing. This cooling air enters the motor casing from the under-floor area, via a further four vent holes with gauze filters. These are positioned in the exposed end cap of the motor. A reduced flow of conditioned bleed air passes from the refrigeration unit into the cabin via the defog fan even when the latter is not operating.

A further fan, the Overhead Blower, supplies conditioned, re-circulated or fresh air to the cabin, depending on temperature conditions. A manual emergency dump valve is provided as part of the pressurisation control system; its purpose is to dump all cabin pressure by commanding both outflow valves to open fully.

Operational procedures

There are three emergency procedures relevant to this incident. These are contained in the Company operations manual which is issued to each pilot and also in an emergency checklist format available in the cockpit. The crew would normally be expected to carry out either the ELECTRICAL FIRE OR SMOKE drill or the ENVIRONMENTAL SMOKE OR ODOUR drill depending on the perceived source of the smoke. Then, if required, the crew would apply the third procedure, SMOKE REMOVAL.

The ENVIRONMENTAL SMOKE OR ODOUR procedure is not intended to be completed from memory. However, it is a relatively straightforward checklist which directs the crew to don oxygen masks and smoke goggles, establish inter-crew communications and then to turn off both the cabin (overhead blower) fan and defog fan. The drill then directs the crew to attempt to isolate the source of contaminated air by selecting either engine bleed air source in turn whilst checking for improvement between selections.

The ELECTRICAL FIRE OR SMOKE procedure is a more complex reference procedure, but does begin with the following memory items:

OXYGEN MASKS	*SELECT 100%, DON*...
MIC SWITCHES	*MIC OXY MASK*
SMOKE GOGGLES	*DON*

If the source of the fire or smoke has been identified, the procedure directs the crew to isolate power from it by pulling the associated circuit breaker (CB). If, as in this case, the source is not identified, the procedure involves removing power to a large part of the electrical system by selecting the battery to an emergency mode, switching off the engine generators and pulling several CBs associated with the DC electrical system. This essentially provides remaining battery power for only those services essential to safe flight. The pilots' instrument displays for G-VUEA were configured with conventional instruments for the co-pilot and EFIS displays for the commander. In the ELECTRICAL FIRE OR SMOKE configuration, the only flight instruments available would be the co-pilot's conventional displays.

The procedure goes on to direct the crew to declare a MAYDAY and to *"LAND AS SOON AS POSSIBLE"*. It then advises the crew to carry out the SMOKE REMOVAL drill if this is warranted. Prior to landing the crew must re-instate the left generator before lowering the landing gear and flaps. Landing distance is increased due to the anti-skid system being inoperative in this configuration.

The SMOKE REMOVAL procedure is also intended to be completed by reference to the checklist. However, some discrepancies were noted between that version in the operations manual and the checklist on the aircraft. Essentially, the drill directs the crew to don oxygen masks and smoke goggles, establish inter-crew communications, deploy the passenger oxygen system and to operate the pressurisation dump valve. The version available on the aircraft did not include a reference to smoke goggles but did include an additional requirement to set a higher cabin altitude on the cabin altitude selector prior to operating the dump valve.

The Company's operations manual, under the heading *"Authority, duties and responsibilities of the commander"* states:

> *'The pilot-in-command shall, in an emergency situation that requires immediate decision and action, take any action he considers necessary under the circumstances. In such cases he may deviate from rules, operational procedures, and methods in the interest of safety.'*

Analysis

It was clear from the internal condition of the defog fan motor and the visible contamination of the passages of the cooling air between the motor and the fan case, that considerable smoke was being drawn from the motor into the cabin air-flow path. The motor appears to have continued to operate at progressively reducing RPM with consequently reduced cooling flow once seizure of the bearing had begun. This appears to have been the cause of the overheating.

It is presumed that the fan's circuit breaker tripped some time after the motor began to produce smoke, although the precise time in the flight when this occurred is not known. The high temperature already reached by the unit, together with its mass, and the fact that air from the engine bleeds and the refrigeration unit continued to flow through the fan would have resulted in a period between the circuit breaker tripping and the time at which the unit cooled sufficiently to cease supplying smoke to the cabin. The lengthy time during which the hot, non operating motor is capable of generating smoke is confirmed by the period over which smoke issued from the cabin after the aircraft had landed and all systems had been shut down.

Unusually in this case, and because of the role of the defog fan, either the electrical smoke or the environmental smoke procedures would have isolated power to the fan, though the crew had no way of knowing that the fan was the source of the smoke at the time. In this case, the commander identified the smoke as being electrical in origin and although he recognised the serious threat the situation presented, decided that his immediate priority should be to execute an approach and landing as soon as practicable. The commander's decision took into account the limited time available to complete the complex ELECTRICAL FIRE OR SMOKE procedure, and the possible greater hazard of accomplishing an expeditious approach with minimum systems and flight instruments available. The commander did order the donning of oxygen masks as required by the procedure. However, neither crewmember afforded himself the extra protection of smoke goggles, which was one of the memory items, though neither reported any ill-effects or difficulties as a result.

The commander initiated the SMOKE REMOVAL DRILL from memory, operating the manual dump valve to depressurise the cabin. Had he referred to the cockpit checklist, he would have been directed to enter a higher altitude on the pressurisation system's cabin altitude selector. However, this would be a redundant action as the dump valve depressurises the aircraft fully and much quicker than would be achieved by use of the cabin altitude selector. Reference to the cabin altitude selector in the context of this drill was deleted in the company's operations manual. The remaining items on the SMOKE REMOVAL procedure, which mainly concerned the activation of passenger oxygen, were not carried out due to the imminent landing. Operating the dump valve would not have had any effect on the continuing operation of the smoke source but would have reduced the intensity of the smoke in the cockpit. The commander thought that increased smoke concentration when on the approach was due to the engines being throttled back. This was more probably due to a reduced inflow of fresh air via the spring-loaded ram air valve as the aircraft slowed on approach, as the bleed supply from the engines is largely constant at a wide range of power settings.

Aircraft electrical equipment and wiring in general has fuse or circuit breaker protection. These protection items, for a variety of reasons, are generally rated at well above the maximum current normally drawn by the component they protect. There are thus component failure modes in which a unit may continue for a significant period to draw current well in excess of its maximum rated value, yet below the rated value of its protection. Under these circumstances, the failed component rapidly overheats and materials therein begin to degrade and emit smoke. This problem will apply to certain types of failures in a range of electrical components. When they occur in the very small cabin volume of small pressurised business type aircraft, rapid deterioration of cabin visibility and breathable air quality must be expected, particularly if the failure occurs in equipment associated with cabin air distribution. Failures in a component such as a fan motor, representing a large heat sink, can result in a significant quantity of heat becoming present therein. In particular, a fan motor which seizes progressively will draw a high current and generate increasing heat whilst the cooling flow reduces as a result of the drop in fan speed. Even when the power is isolated, after its supply is switched off manually or the circuit breaker trips, such a unit cools only slowly and the resulting flow of smoke can be expected to continue for a lengthy period. It is thus highly desirable to isolate such a failing component at the earliest possible opportunity, ideally before a large temperature rise occurs.

Identifying and isolating the affected equipment, even if successfully carried out, may not always lead to a rapid reduction in the smoke being generated. In this instance, the crew had no way of knowing which component was causing the problem; implementation of either the electrical or environmental emergency procedure, had it been carried out before the CB tripped, may not immediately have affected the amount of smoke entering the cockpit, since engine bleed air continued to flow into the cabin via the fan unit, even when the latter was not operating. However, had the CB not been tripped by this stage, completion of the check list would have removed power from the defective fan at the earliest possible time and ensured that smoke circulation and concentration were minimised.

The commander's decision not to complete the relevant emergency procedures was influenced by the time available and the need to concentrate on the approach and landing. In effect, the commander chose to action what he considered to be the most important part of the procedure, the statement *"Land as soon as possible"*.