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Electrical Arc Identified as Likely Source Of In-flight Fire Aboard Swissair MD-11

Inadequate material-flammability-certification standards and the absence of training and procedures for in-flight fire fighting were among the factors cited in the propagation of a fire that became uncontrollable and caused a loss of control of the airplane off the coast of Nova Scotia, Canada.

—

FSF Editorial Staff

About 2131 local time Sept. 2, 1998, a McDonnell Douglas MD-11, registered as HB-IWF and being operated as Swissair Flight 111 (SR 111), struck the Atlantic Ocean about five nautical miles (nine kilometers) southwest of Peggy's Cove, Nova Scotia, Canada. The airplane was destroyed, and the 229 occupants were killed.

The final report on the accident, issued in 2003 by the Transportation Safety Board of Canada (TSB), said that the causes and contributing factors were the following:

- "Aircraft certification standards for material flammability were inadequate in that they allowed the use of materials that could be ignited and sustain or propagate fire. Consequently, flammable material propagated a fire that started above the ceiling on the right side of the cockpit near the cockpit rear wall. The fire spread and intensified rapidly to the extent that it degraded aircraft systems and the cockpit environment, and ultimately led to the loss of control of the aircraft;

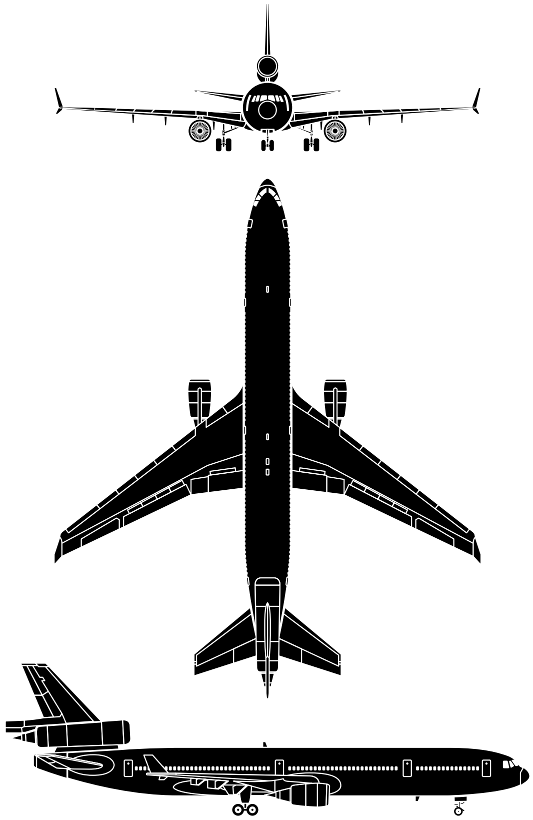
- "Metallized polyethylene terephthalate (MPET)-type cover material on the thermal/acoustic insulation blankets used in the aircraft [to help maintain comfortable temperatures and to reduce noise in the cabin and cockpit] was flammable. The cover material was most likely the first material to ignite and constituted the largest portion of the combustible materials that contributed to the propagation and intensity of the fire;

  - "Once ignited, other types of thermal/acoustic insulation cover materials exhibit flame-propagation characteristics similar to MPET-covered insulation blankets and do not meet the proposed revised flammability test criteria. Metallized polyvinyl fluoride [MPVF]-type cover material was installed in HB-IWF and was involved in the in-flight fire;

- "Silicone elastomeric end caps, hook-and-loop fasteners, foams, adhesives and thermal/acoustic insulation splicing tapes contributed to the propagation and intensity of the fire;

- "The types of circuit breakers (CB) used in the aircraft were similar to those in general aircraft use and were not capable of protecting against all types of wire-arcing events. The fire most likely started from a wire-arcing event;

- "A segment of in-flight entertainment network (IFEN) power supply unit cable … exhibited a region of resolidified copper on one wire that was caused by an



McDonnell Douglas MD-11

The McDonnell Douglas MD-11, a medium/long-range passenger/freight transport airplane, entered service in 1990. A derivative of the Douglas DC-10, the MD-11 has a two-pilot, all-digital flight deck; winglets above and below each wing tip; and a redesigned tail incorporating a 2,000-gallon (7,570-liter) fuel-trim tank. McDonnell Douglas in 1997 merged with The Boeing Co., which terminated MD-11 production in 2001.

The standard passenger version has accommodations for 323 passengers. The mixed passenger/cargo (combi) version has accommodations for 214 passengers.

The MD-11 is powered either by three Pratt & Whitney PW4460 turbofan engines, each rated at 60,000 pounds static thrust (267 kilonewtons), or by three General Electric CF6-80C2D1F turbofan engines, each rated at 61,500 pounds static thrust (274 kilonewtons).

Standard fuel capacities are 40,183 gallons (152,092 liters) for the passenger version and 38,650 gallons (146,290 liters) for the combi version and the freighter version.

Maximum takeoff weight is 625,500 pounds (283,727 kilograms) for all versions. Maximum landing weights are 430,000 pounds (195,048 kilograms) for the passenger version, 458,000 pounds (207,749 kilograms) for the combi and 471,500 pounds (213,872 kilograms) for the freighter.

Maximum operating Mach number is 0.945. Maximum level speed at 31,000 feet is Mach 0.87 (511 knots). Maximum design ranges with fuel reserves are 6,791 nautical miles (12,577 kilometers) for the passenger version, 6,273 nautical miles (11,618 kilometers) for the combi and 3,626 nautical miles (6,715 kilometers) for the freighter.♦

Source: *Jane's All the World's Aircraft*

arcing event. [An IFEN provides on-demand audio/video entertainment/information through interactive displays installed at passenger seats.] This resolidified copper was determined to be located … in the area where the fire most likely originated. This arc was likely associated with the fire-initiation event; however, it could not be determined whether this arced wire was the lead event;

- "There were no built-in smoke-and-fire detection-and-suppression devices in the area where the fire started and propagated, nor were they required by regulation. The lack of such devices delayed the identification of the existence of the fire and allowed the fire to propagate unchecked until it became uncontrollable;

- "There was a reliance on sight and smell to detect and differentiate between odor or smoke from different potential sources. This reliance resulted in the misidentification of the initial odor and smoke as originating from an air-conditioning source;

- "There was no integrated in-flight fire fighting plan in place for the accident aircraft, nor was such a plan required by regulation. Therefore, the aircraft crew did not have procedures or training directing them to aggressively attempt to locate and eliminate the source of the smoke, and to expedite their preparations for a possible emergency landing. In the absence of such a fire fighting plan, they concentrated on preparing the aircraft for the diversion and landing;

- "There is no requirement that a fire-induced failure be considered when completing the system safety analysis required for certification. The fire-related failure of silicone elastomeric end caps installed on air-conditioning ducts resulted in the addition of a continuous supply of conditioned air that contributed to the propagation and intensity of the fire; [and,]

- "The loss of primary flight displays and lack of outside visual references forced the pilots to be reliant on the standby instruments for at least some portion of the last minutes of the flight. In the deteriorating cockpit environment, the positioning and small size of these instruments would have made it difficult for the pilots to transition to their use and to continue to maintain the proper spatial orientation of the aircraft."

The airplane had departed at 2018 from John F. Kennedy International Airport in Jamaica, New York, U.S., for a scheduled flight to Geneva, Switzerland, with two pilots, 12 flight attendants and 215 passengers aboard.

The captain, 49, had 10,800 flight hours, including 900 flight hours in type. He was a Swiss air force fighter pilot before being employed by Swissair in 1971 as a DC-9 first officer. He began flying as a captain in 1983 and completed MD-11 transition training in 1997. At the time of the accident, he was an MD-11 line pilot and instructor pilot.

"He was described as someone who created a friendly and professional atmosphere in the cockpit and was known to work with exactness and precision," the report said. "To increase his aircraft knowledge, the captain would question technical specialists in the maintenance department about the aircraft and its systems."

The first officer, 36, had 4,800 flight hours, including 230 flight hours in type. He was a Swiss air force fighter pilot before being employed by Swissair in 1991 as an MD-80 first officer. He completed MD-11 transition training in May 1998. At the time of the accident, he was an MD-11 simulator instructor and transition instructor.

"He was considered to be experienced, well qualified, focused and open-minded in performing the duties of a first officer," the report said. "His cockpit discipline was described as ideal. He was described as a partner in the cockpit, with a quiet and calm demeanor; he was assertive when appropriate."

The airplane was manufactured in 1991 and had accumulated 36,041 airframe hours, all with Swissair.

The first officer was flying the airplane on autopilot at Flight Level (FL) 330 (approximately 33,000 feet) at 2110, when the captain and he detected an unusual odor and observed a small amount of smoke entering the cockpit from behind and above them.

The pilots believed the odor and the smoke had emanated from the air-conditioning system.

Conversation recorded by the cockpit voice recorder (CVR) indicated that the smoke cleared after about 30 seconds and that the pilots believed the odor and the smoke had emanated from the air-conditioning system. The report said that there was no indication on the CVR recording or in data recorded by the flight data recorder (FDR) that the crew conducted the "Air Conditioning Smoke" checklist at the time.

"Most aircraft crews are likely unaware that under certain conditions, a fire could ignite significant flammable materials in hidden areas of the aircraft and spread rapidly," the report said. "Had the pilots been aware that flammable materials were present in the attic space [the area above the cockpit/cabin ceiling] of the MD-11, this knowledge might have affected their evaluation of the source of the odor and smoke."

A flight attendant who had been summoned to the cockpit told the captain that she smelled an odor in the cockpit but had not smelled the odor in the cabin.

At 2113, the pilots again observed smoke. The captain said, in Swiss-German, "That's not doing well at all up there." The pilots then discussed alternate airports and weather conditions at the airports.

At 2114, the captain declared pan-pan, an urgent condition, and told a Moncton [New Brunswick, Canada] Area Control Center (ACC) controller that there was smoke in the cockpit and that they wanted to divert the flight to Boston, Massachusetts, U.S., which was about 300 nautical miles (556 kilometers) southwest.

The controller told the crew to turn right toward Boston and to descend to FL 310. The controller then asked the crew if they preferred to fly the airplane to Halifax, Nova Scotia, which was about 56 nautical miles (104 kilometers) northeast. The crew said yes (Halifax International Airport was a Swissair-designated alternate airport for MD-11 flights), and the controller told them to fly directly to Halifax.

The pilots donned oxygen masks. They were given weather information for Halifax by the crew of another airplane.

Weather conditions in Nova Scotia were affected by a weak ridge of high pressure and by a hurricane centered about 300 nautical miles (556 kilometers) southeast of Halifax. Halifax International Airport had surface winds from 100 degrees at 10 knots, 15 statute miles (24 kilometers) visibility, a broken ceiling at 13,000 feet above ground level (AGL) and an overcast at 25,000 feet AGL. Surface temperature was 17 degrees Celsius (C; 63 degrees Fahrenheit [F]).

At 2116, the controller told the crew to descend to 10,000 feet and asked for the number of passengers and the amount of fuel aboard the airplane. The captain told the controller to stand by for the information.

The captain had summoned the lead flight attendant to the cockpit. He told him that there was smoke in the cockpit and that the cabin crew was to prepare for a landing in Halifax in 20 minutes to 30 minutes.

"The tone of the captain's voice did not indicate that the situation was sufficiently critical to warrant an emergency," the report said. "However, he indicated that the passengers were to be briefed that the flight was landing immediately."

At 2118, the controller gave the crew a different radio frequency to use for communication with Moncton ACC. The captain was conducting a checklist and had transferred radio-communication duties to the first officer, who continued to fly the airplane on autopilot. When the first officer established communication with Moncton ACC on the assigned radio frequency, he said that the airplane was descending through 25,400 feet on a heading of 050 degrees, on course to Halifax.

"The controller cleared SR 111 to 3,000 feet," the report said. "The pilots requested an intermediate altitude of 8,000 feet until the cabin was ready for landing."

At 2119, the controller told the crew to fly a heading of 030 degrees and to expect clearance to land on Runway 06 at Halifax

International Airport. The runway was 8,800 feet (2,684 meters) long and had a back-course instrument landing system (ILS) approach procedure.

The controller said that the airplane was 30 nautical miles (56 kilometers) from the runway threshold. At the time, the airplane was descending at 3,300 feet per minute through 21,000 feet; indicated airspeed was 320 knots. The first officer told the controller that they "needed more than 30 nautical miles" to conduct the descent. The controller told the crew to fly a heading of 360 degrees.

"At [2121], the controller made a second request for the number of persons and amount of fuel on board," the report said. "SR 111 did not relay the number of persons on board, but indicated that the aircraft had 230 tonnes [506,000 pounds/230,000 kilograms] of fuel on board (this was actually the current weight of the aircraft, not the amount of fuel) and specified the need to dump some fuel prior to landing. [Maximum landing weight was 430,000 pounds (195,048 kilograms); maximum overweight landing weight was 481,485 pounds (218,402 kilograms).] The controller asked the pilots whether they would be able to turn to the south to dump fuel or whether they wished to stay closer to the airport."

At the time, the airplane was over land. The first officer and the captain discussed whether they should fly south and dump fuel over the ocean, or fly to the airport and land. The first officer told the controller that they would accept a turn to the south.

(Based on airplane-performance calculations and analysis of the propagation of the fire, the report said, "From any point along the Swissair Flight 111 flight path after the initial odor [was detected] in the cockpit, the time required to complete an approach and landing to the Halifax International Airport would have exceeded the time available before the fire-related conditions in the aircraft cockpit would have precluded a safe landing.")

The controller told the crew to turn left to a heading of 200 degrees and to advise when they were ready to dump fuel. The controller also said that the airplane was 10 nautical miles (19 kilometers) from the coast and about 25 nautical miles (46 kilometers) from the airport. The first officer said that they were turning and that they were descending to 10,000 feet to dump fuel.

The first officer asked the captain if he was conducting the "Air Conditioning Smoke" checklist. The captain said that he was conducting the checklist. The checklist called for isolation of each of the three air-conditioning packs to decrease the amount of smoke in the cockpit and for use of the "Smoke/Fumes of Unknown Origin" checklist if the pack-isolation procedure failed to cause the smoke to decrease.

Soon after the systems failures began to occur, the fire likely breached the cockpit-ceiling liner.

At 2123, the captain asked the first officer to confirm selection of the "CABIN BUS" switch to the "OFF" position. (The switch is used for emergency load-shedding, to remove electrical power from cabin-service equipment.)

"Selecting this switch to the 'OFF' position is the first item on the Swissair 'Smoke/Fumes of Unknown Origin' checklist," the report said. "With the switch in the 'OFF' position, the recirculation fans are turned off, and the airflow above the forward ceiling area would have changed from a predominant flow aft, toward the fans, to a predominant airflow forward, toward the cockpit."

About this time, the fire breached a silicone elastomeric end cap on an air-conditioning duct, causing a large volume of conditioned air to enter the attic area and accelerate the propagation of the fire.

The report said that the airplane's groundspeed was almost seven nautical miles (13 kilometers) per minute and that the airplane had traveled farther north during the turn than the controller expected. The controller told the crew to turn left to a heading of 180 degrees and said that the airplane was 15 nautical miles (28 kilometers) from the coast. The crew acknowledged and said that the airplane was in level flight at 10,000 feet.

"The controller notified SR 111 that the aircraft would be remaining within about 35 to 40 nautical miles [65 to 74 kilometers] of the airport in case they needed to get to the airport in a hurry," the report said. "The pilots indicated that this was fine and asked to be notified when they could start dumping fuel."

At 2124, the FDR began to record several aircraft-system failures, including loss of data to some of the pilots' electronic displays, and disconnection of the autopilot. The first officer told the controller that they had to hand-fly the airplane and asked for clearance to fly the airplane between 11,000 feet and 9,000 feet. The controller told the crew that they could fly the airplane any altitude between 5,000 feet and 12,000 feet.

The report said that the controller assumed that the crew's statement about being required to hand-fly the airplane was an indication that manual control was a Swissair requirement during fuel-dumping operations.

The report said that soon after the systems failures began to occur, the fire likely breached the cockpit-ceiling liner and caused dense smoke to enter the cockpit. Both pilots simultaneously declared mayday, a distress condition. The first officer told the controller that they were beginning to dump fuel and that they had to land immediately. At the time, the controller was communicating via land line with a Halifax flight service specialist.

"The controller indicated that he would get back to them [the crew] in just a couple of miles," the report said. "SR 111 acknowledged this transmission."

At 2125:02, the first officer again declared mayday. The controller acknowledged the transmission and cleared the crew to dump fuel. There was no response from the crew.

At 2125:20, the captain told the first officer that something was burning. The first officer said that his side of the instrument panel was "all dark," indicating that his electronic flight instrument displays had failed.

At 2125:41, the CVR, the FDR and the very-high-frequency (VHF) radios ceased functioning.

"When the pilots did not acknowledge the controller's clearance to commence fuel dumping, and when immediately thereafter the aircraft's Mode C [altitude-reporting] transponder stopped providing data to the ATS [air traffic services] radar, the controller interpreted this cessation of information from SR 111 to be the result of an electrical load-shedding procedure that Swissair used during fuel-dumping operations," the report said. "This interpretation was based on the controller's experience with military aircraft refueling exercises carried out over Nova Scotia."

The airplane likely descended through several cloud layers as it was flown toward the ocean. The top of the lowest cloud layer in the area was about 5,000 feet AGL, and the base was about 1,500 feet AGL.

"The fire was encroaching on the pilot-seat positions from the rear of the cockpit."

The report said that the airplane's continued southbound track, away from the airport, "suggests that the condition in the cockpit quickly [had] deteriorated to a point where the pilots were unable to effectively navigate the aircraft."

About 2130, witnesses at St. Margaret's Bay [about 30 nautical miles southwest of the Halifax airport] observed a large aircraft flying low and heard its engines operating. After crossing the shoreline, the airplane began a right turn.

The airplane was descending about 2,000 feet per minute through 1,800 feet when the crew shut down the right engine. The report said that this action might have been in response to a false engine-fire warning and that soon thereafter, the pilots likely were incapacitated or a loss of airplane control occurred.

"There was evidence that melted material had dropped down on the [cockpit] carpet and on the right observer's seat," the report said. "The fire was encroaching on the pilot-seat positions from the rear of the cockpit. … If the pilots were not incapacitated and were still attempting to control the aircraft, [the airplane's attitude on impact] suggests that, in the last minute of the flight, they lost orientation with the horizon."

The airplane struck the water at 2131:18. Structural damage indicated that the airplane was in a 20-degree nose-down pitch attitude and was banked more than 60 degrees right on impact.

"All passengers and crew died instantly from a combination of the deceleration and impact forces when the aircraft struck the water," the report said. "The degree of injury suggests that the longitudinal impact forces were in the order of at least 350 g [i.e., 350 times standard gravitational acceleration]. There were no signs of exposure to heat found on any of the human remains that were recovered."

Most of the wreckage sank in 180 feet (55 meters) of water. About 98 percent of the aircraft, by weight, was recovered.

Damage patterns indicated that the fire was concentrated in the cockpit attic and the forward cabin ceiling (the area primarily above the forward doors, lavatories and galleys), which contained numerous cables and wires.

"The aircraft wiring was severely damaged by the forces of impact," the report said. "Additional mechanical damage could have occurred to some of the wiring during recovery operations. … All of the recovered wires were examined, primarily to identify any with signs of melted copper. As the fire did not reach temperatures high enough to melt copper [i.e., 1,083 degrees C (1,981 degrees F)], any areas of melted copper would indicate that an electrical-arcing event had occurred. … Temperatures at the center of an arc can range up to 5,000 degrees C (9,032 degrees F) or more."

Of the thousands of wire segments examined, 20 wire segments had signs of melted copper. They included four wire segments from the IFEN power-supply-unit (PSU) cables and five segments of the PSU-output-control wire located in the heat-damaged area of the attic.

"The most significant deficiency in the chain of events that resulted in the crash of SR 111 was the presence of flammable materials that allowed the fire to ignite and propagate," the report said. "Testing conducted during the investigation showed that several materials located in the heat-damaged area were flammable, even though they met regulatory standards for flammability. The [MPET] covering material on the thermal/acoustic insulation blankets … was the most significant source of the combustible materials that contributed to the fire."

The report said that when the MD-11 was certificated, the use of insulation blankets covered with MPET (also called metallized Mylar) or MPVF (also called metallized Tedlar) was approved by the U.S. Federal Aviation Administration (FAA). The approval was based on flammability tests required by U.S. Federal Aviation Regulations (FARs) Part 25, the airworthiness standards for transport category airplanes. The tests involved exposing samples of material to the flame from a propane burner for 12 seconds; the regulations required that if the material ignited, the flame had to self-extinguish within 15 seconds and propagate no farther than eight inches (20 centimeters).

During the original flammability tests, the MPET-covered insulation blankets "immediately shriveled up and shrank away from the burner and did not ignite," the report said.

The report said, however, that the flammability tests were not "sufficiently stringent or comprehensive" and did not replicate a full range of potential ignition sources.

"Between November 1993 and March 1999, seven known occurrences took place in which either MPET-[covered] or MPVF-covered insulation blankets had been ignited and propagated flame," the report said. "These occurrences involved one MD-87, one MD-82, two [Boeing] 737-300s in 1994 and 1995, and three MD-11s in 1995. The ignition source for each fire was relatively small, including wire arcing, hot metal shavings and a ruptured light-ballast case."

The Civil Aviation Administration of China (CAAC), which investigated the occurrences involving one MD-11 and the two B-737s, found that after being ignited, MPET "would be completely consumed by fire," the report said. The CAAC in 1996 told FAA that a "prompt and positive response" was necessary.

"There was no recognized need to train aircraft crews for fire fighting in other than the interior cabin areas."

"FAA stated that they intended to investigate the behavior of insulation-blanket materials under larger-scale conditions," the report said. "The FAA also stated that … the type of CAAC testing conducted (igniting at the sewn edge of the sample material) was not required for certification."

In August 1996, McDonnell Douglas recommended to operators of several of its airplane models that they discontinue use of MPET-covered insulation blankets. In October 1997, the company issued a service bulletin recommending that MD-11 operators replace MPET-covered insulation blankets with MPVF-covered insulation blankets, which were being used in production airplanes.

In 2000, FAA issued airworthiness directives requiring removal of MPET-covered insulation blankets from aircraft and proposed new flammability standards and testing procedures for thermal/acoustic insulation materials.

[FAA on July 31, 2003, adopted new flammability standards and testing procedures for thermal/acoustic insulation materials used in transport category airplanes. The new testing procedures include mounting samples of airplane-fuselage-insulation materials in a radiant panel test (RPT) chamber and exposing the materials to a radiant-heat source and to a propane-burner flame for 15 seconds; the new flammability standards require that if ignition occurs, the flame must not propagate more than two inches (five centimeters) from the burner and must self-extinguish within three seconds. The testing procedures also include exposing samples of materials used in the "lower half" of airplanes with more than 19 passenger seats to a propane-burner flame for four minutes; the flame must not penetrate the blanket, and heat transmitted through the blanket must not exceed specified values. FAA also required that thermal/acoustic insulation materials installed in airplanes manufactured after July 31, 2005, and insulation materials replaced in airplanes after July 31, 2005, must meet the new flame-propagation standards; insulation blankets installed in airplanes manufactured after July 31, 2007, must meet the new flame/heat-penetration standards.][1]

Tests conducted during the accident investigation showed that an electrical arc could ignite MPET-covered insulation blankets.

"It appears that electrical arcs were sufficiently rapid in onset and localized to overcome the propensity of a cover material constructed with thin-film material, such as MPET, to shrink away from the heat source," the report said.

The report said that Part 25 required built-in smoke/fire detection/suppression systems to be installed in specified fire zones, such as engines and auxiliary power units, and in potential fire zones, such as lavatories and cargo compartments, but not in "nonspecified fire zones," such as the cockpit, cabin, cockpit/cabin attics and electrical/electronic equipment compartments.

"Although flammable materials existed in the nonspecified fire zones, the threat of ignition was considered minimal," the report said. "There was no recognized need to train aircraft crews for fire fighting in other than the interior cabin areas, or to design aircraft to allow for quick and easy access to hidden nonspecified fire zones for fire fighting purposes."

In the accident airplane, a 2.5-pound (1.1-kilogram) Halon 1211 fire extinguisher was mounted on the rear wall of the cockpit; the investigation did not determine whether the crew used the fire extinguisher.

Swissair began installing IFENs in its MD-11s in 1996. The installations were performed by contractors in accordance with a supplementary type certificate (STC). The report said that the IFEN in the accident airplane was connected to the electrical system in such a way that it could not be isolated by the flight crew's selection of the "CABIN BUS" switch during emergency load-shedding.

"[The IFEN installation was] approved without confirmation that it was compliant with the aircraft's original type certificate

[and] introduced latent unsafe conditions with the potential to adversely impact the operation of the aircraft during emergency procedures," the report said.

The report said that the resettable thermal CBs typically used in airplanes might not activate (trip) when electrical arcing occurs in the circuits that they protect. If a CB does trip when electrical arcing occurs, resetting the CB might be dangerous.

"There is a widely held view among flight crew and maintenance personnel that one reset of any tripped CB is acceptable," the report said. "Consequently, often the first step in troubleshooting a tripped CB is a reset attempt. There is also a view that the reset of a low-ampere CB is less dangerous than the reset of a higher-ampere CB. However, while the consequences of resetting a low-ampere CB may be less pronounced, under the correct conditions an arcing event involving a low-ampere CB could readily ignite a fire.

"Since it is impossible to know whether these conditions exist in any given situation, a tripped CB should not be reset before any associated fault is located and eliminated. … An inappropriate reset can exacerbate the consequences of the initial fault."

The report said that the accident airplane's CVR and FDR provided insufficient information for a full analysis of the factors involved in the accident. The CVR provided a 30-minute recording, which ended when a loss of power from the generator bus occurred.

"A minimum two-hour CVR recording capability would have enabled a quicker and possibly more in-depth assessment of events that occurred earlier in the flight," the report said. "Had the CVR been equipped with an independent power source … the resulting additional recorded information could have facilitated a more thorough understanding of the circumstances faced by the crew in the final minutes prior to the crash."

The report said that when an odor initially was detected in the cockpit, the conversation between the captain and the first officer was recorded by the CVR through the cockpit area microphone. The pilots were not wearing headsets with boom microphones at the time. (Swissair required pilots to use boom microphones when flying below 15,000 feet.) The recorded conversation was difficult to hear and to decipher.

"There was a marked improvement in recording quality after the pilots donned their oxygen masks, which have built-in microphones," the report said.

The accident airplane was equipped with a quick-access recorder (QAR) to support the airline's flight operational quality assurance (FOQA) program. The QAR recorded about 1,500 parameters; the FDR recorded about 250 parameters. Unlike the FDR, however, the QAR was not required by regulations and was not designed to survive an accident. Investigators found 21 pieces of magnetic tape that likely came from the QAR but were unable to extract meaningful information from the tape.

"Such information could have assisted in determining the serviceability of aircraft systems prior to, during and after the initial detection of the unusual smell and subsequent smoke in the cockpit," the report said.

Analysis of recorded cockpit images also might have assisted in the accident investigation, the report said.

"Recently, it has become economically realistic to record cockpit images in a crash-protected memory device," the report said. "Special playback software allows investigators to 'immerse' themselves in the cockpit and virtually view the entire cockpit. Such a capability could have been valuable during the SR 111 investigation."

Nevertheless, the report said that cockpit-image recording likely will not be accepted by the aviation industry unless the recorded images are protected from use in other than safety investigations.

Based on the findings of the accident investigation, TSB made the following recommendations:

- "Regulatory authorities [should] quantify and mitigate the risks associated with in-service thermal/acoustic insulation materials that have failed the radiant panel test;

- "Regulatory authorities [should] develop a test regime that will effectively prevent the certification of any thermal/acoustic insulation materials that, based on realistic ignition scenarios, would sustain or propagate a fire;

- "Regulatory authorities [should] take action to ensure the accurate and consistent interpretation of the regulations governing material flammability requirements for aircraft materials so as to prevent the use of any material with inappropriate flammability characteristics;

- "Regulatory authorities [should] require that every system installed through the STC process undergo a level of quantitative analysis to ensure that it is properly integrated with aircraft type-certified procedures, such as emergency load-shedding;

- "Regulatory authorities [should] establish the requirements and industry standard for circuit breaker resetting;

- "Regulatory authorities, in concert with the aviation industry, [should] take measures to enhance the quality and intelligibility of CVR recordings;

- "Regulatory authorities [should] require, for all aircraft manufactured after 1 January 2007 which require an

FDR, that in addition to the existing minimum mandatory parameter lists for FDRs, all optional flight data collected for non-mandatory programs such as FOQA/FDM [flight-data monitoring], be recorded on the FDR;

- "Regulatory authorities [should] develop harmonized requirements to fit aircraft with image-recording systems that would include imaging within the cockpit; [and,]
- "Regulatory authorities [should] harmonize international rules and processes for the protection of cockpit voice [recordings] and image recordings used for safety investigations."♦

[FSF editorial note: This article, except where specifically noted, is based on Transportation Safety Board of Canada aviation investigation report no. A98H0003, *In-Flight Fire Leading to Collision with Water: Swissair Transport Limited; McDonnell Douglas MD-11, HB-IWF; Peggy's Cove, Nova Scotia, 5 nm SW; 2 September 1998*. The 338-page report contains illustrations and appendixes.]

Note

1. U.S. Federal Aviation Administration (FAA). "Improved Flammability Standards for Thermal/Acoustic Insulation Materials Used in Transport Category Airplanes." Final rule. *Federal Register* Volume 68 (July 31, 2003): 45046.

Further Reading From FSF Publications

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