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Chemical Oxygen Generator Activates in Cargo Compartment of DC-9, Causes Intense Fire and Results in Collision with Terrain

The cockpit crew had no means to extinquish or supress the fire because the cargo compartment was not equipped (nor was it required to be equipped) with a fire extinquisher, the official report said.

FSF Editorial Staff

The ValuJet Airlines McDonnell Douglas DC-9-32 had just departed from the Miami (Florida, U.S.) International Airport (MIA), when an intense fire erupted in the forward cargo compartment. As soon as the crew detected the fire, they immediately turned back toward MIA, but the fire burned through the aircraft's control cables and the crew was not able to maintain aircraft control. The aircraft collided with terrain about 27.4 kilometers (17 miles) northwest of MIA.

The two pilots, three flight attendants and all 105 passengers were killed in the May 11, 1996, accident, which occurred during daylight in visual meteorological conditions (VMC). The aircraft, valued at US$4 million, was destroyed.

The final accident investigation report of the U.S. National Transportation Safety Board (NTSB) said, "The probable causes of the accident, which resulted from a fire in the airplane's class-D cargo compartment that was initiated by the actuation of one or more oxygen generators being improperly carried as cargo, were (1) the failure of SabreTech [ValuJet's maintenance contractor] to properly prepare, package and identify unexpended chemical oxygen generators before presenting them to ValuJet for carriage; (2) the failure of ValuJet to properly oversee its contract maintenance program to ensure compliance with maintenance, maintenance-training and hazardous-materials requirements and practices; and (3) the failure of the [U.S.] Federal Aviation Administration (FAA) to require smoke-detection and fire-suppression systems in class-D cargo compartments.

"Contributing to this accident was the failure of the FAA to adequately monitor ValuJet's heavy-maintenance programs and responsibilities including ValuJet's oversight of its contractors and SabreTech's repair-station certificate; the failure of the FAA to adequately respond to prior chemical oxygen generator fires with programs to address the potential hazards; and ValuJet's failure to ensure that both ValuJet and contract maintenance-facility employees were aware of the carrier's 'no-carry' hazardous-materials policy and had received appropriate hazardous-materials training."

On the day of the accident, the accident flight crew flew the aircraft from Atlanta, Georgia, U.S. (ATL) to MIA. The flight arrived at 1310 hours local time, which was 35 minutes late. The flight had been delayed in ATL because of a problem with the right auxiliary hydraulic-pump circuit breaker. The same flight crew and aircraft had been scheduled to depart MIA at 1300 for a return to ATL.

While on the ground at MIA, the flight crew completed the weight-and-balance and performance form for the flight to ATL. The form indicated that the cargo on board included company-owned material (COMAT). The report said, "According to the shipping ticket for the COMAT, the COMAT consisted of two main tires and wheels, a nose tire and wheel, and five boxes that were described as 'Oxy Cannisters — Empty.'

First Officer Discussed Loading Cargo with the Ramp Agent

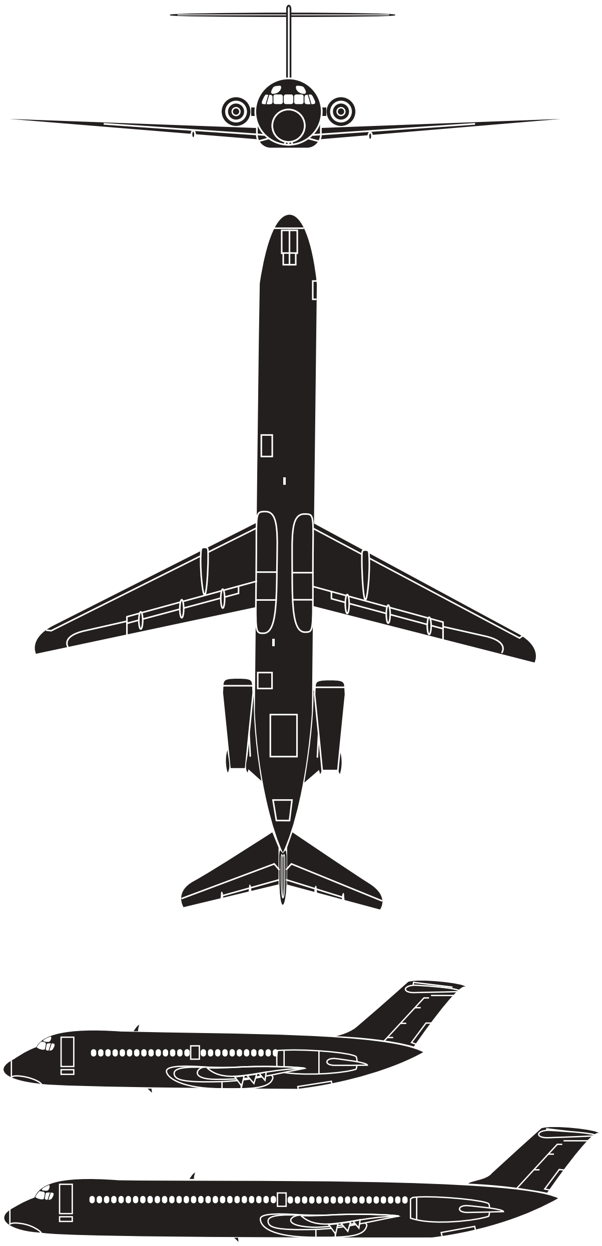
"According to the ValuJet lead ramp agent on duty at the time, he asked the first officer of Flight 592 [the accident flight] for approval to load the COMAT in the forward cargo compartment, and he showed the first officer the shipping ticket. According to the lead ramp agent, he and the first officer did not discuss the notation 'Oxy Cannisters—Empty' on the shipping ticket. According to the lead ramp agent, the estimated total weight of the tires and the boxes was [340 kilograms (750 pounds)], and the weight was adjusted to [680 kilograms (1,500 pounds)] for the weight-and-balance form to account for any late-arriving luggage.

"The ramp agent who loaded the COMAT into the cargo compartment stated that within five minutes of loading the COMAT, the forward cargo door was closed. He could not remember how much time elapsed between his closing the cargo compartment door and the airplane being pushed back from the gate."

The flight pushed back from the gate about 1340 and was cleared for takeoff at 1403:24. Radio communications with Flight 592 during its initial climb were routine. At 1407:22, the flight was instructed by air traffic control (ATC) to turn left to a heading of 300 degrees and to climb and maintain 4,880 meters (16,000 feet), which the first officer acknowledged.

"At 1410:03, an unidentified sound was recorded on the cockpit voice recorder (CVR), after which the captain remarked, 'What was that?'" said the report. "According to the flight data recorder (FDR), just before the sound, the airplane was at [3,243 meters] 10,634 feet mean sea level (MSL), [483 kilometers per hour (kph)] 260 knots indicated airspeed (KIAS), and both engine pressure ratios (EPRs) were 1.84."

The report said, "At 1410:15, the captain stated, 'We got some electrical problem,' followed five seconds later with, 'We're losing everything.'" ATC then instructed the flight to change frequencies. "At 1410:22, the captain stated, 'We need, we need to go back to Miami,' [which was] followed three seconds later by [female] shouts in the background of 'fire, fire, fire, fire.' At 1410:27, the CVR recorded a male voice saying, 'We're on fire, we're on fire.'"



McDonnell Douglas DC-9

The twin-turbofan short/medium range McDonnell Douglas DC-9 was first flown in 1965 and has been stretched to increase passenger seating in several subsequent versions. It has a maximum takeoff weight of 44,450 kilograms (98,000 pounds) and a maximum cruising speed at 7,620 meters (25,000 feet) of 909 kilometers per hour (491 knots). The Series 30 has a range of 2,388 kilometers (1,288 nautical miles) at an altitude of 9,150 meters (30,000 feet) with reserves for a 370-kilometer (200-nautical mile) flight to an alternate and a 60-minute hold at 3,050 meters (10,000 feet).

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

ATC again told the flight to change frequencies and the first officer responded that they needed an immediate return to Miami. The controller instructed the flight to turn left to a heading of 270 degrees and to descend to 2,135 meters (7,000 feet), which the first officer acknowledged. The report said, "The peak altitude value of [3,318 meters] 10,879 feet MSL was recorded on the FDR at 1410:31, and about 10 seconds later, values consistent with the start of a wings-level descent were recorded."

The sounds of shouting on the CVR subsided at 1410:36. The controller then asked the flight about the nature of the problem. "The CVR recorded the captain stating 'fire' and the first officer replying, 'Uh smoke in the cockp … smoke in the cabin,'" said the report. The controller instructed the flight to turn left to 250 degrees and to descend to 1,525 meters (5,000 feet). "At 1411:12, the CVR recorded a flight attendant shouting, 'Completely on fire.'"

Crew Requested Nearest Airport

Eight seconds later, the flight changed heading to a southerly direction. "At 1411:37, the first officer transmitted that they needed the closest available airport," said the report. The controller told the flight to plan on Runway 12 at MIA and to proceed direct to the Dolphin very-high-frequency omnidirectional radio range (VOR) located 5.8 kilometers (3.2 nautical miles) west of MIA.

"At 1411:46, the first officer responded that the flight needed radar vectors," said the report. The controller instructed the flight to turn left to 140 degrees, which the first officer acknowledged.

At 1412:45, the controller instructed the flight to continue turning to 120 degrees, but there was no response from the flight crew. "The last recorded FDR data showed the airplane at [2,196 meters (7,200 feet) MSL], at a speed of [483 kph] 260 knots, and on a heading of 218 degrees," said the report. "The airplane's radar transponder continued to function; thus, airplane position and altitude data were recorded by ATC after the FDR stopped" (Figure 1, page 4).

At 1413:42, the aircraft contacted the ground in the Florida Everglades, about 27.3 kilometers (17 miles) northwest of MIA. "Two witnesses fishing from a boat in the Everglades when Flight 592 crashed stated that they saw a low-flying airplane in a steep right bank," said the report. "According to these witnesses, as the right-bank angle increased, the nose of the airplane dropped and continued downward. The airplane struck the ground in a nearly vertical attitude. The witnesses described a great explosion, vibration and a huge cloud of water and smoke. One of them observed, 'The landing gear was up, all the airplane's parts appeared to be intact, and that aside from the engine smoke, no signs of fire were visible.'

"Two other witnesses who were sightseeing in a private airplane in the area at the time of the accident provided similar accounts of the accident. These two witnesses and the witnesses in the boat, who approached the accident site, described seeing only part of an engine, paper and other debris scattered around the impact area. One of the witnesses remarked that the airplane seemed to have disappeared upon crashing into the Everglades."

Primary Impact Created Crater in Mud and Sawgrass

The report said, "The primary impact area was identified by a crater in the mud and sawgrass. The centerline of the crater was oriented along a north/south axis (10 degrees/190 degrees magnetic) with the narrow end of the crater located to the north. The crater was about [39.6 meters] 130 feet long and [12.2 meters] 40 feet wide. Most of the wreckage debris was located south of the crater in a fan-shaped pattern, with some pieces of wreckage found more than [229 meters] 750 feet south of the crater."

The wreckage was in 2.1 meters (seven feet) of water, with a layer of limestone rock underneath. The report said, "Divers assisting the investigation described a depression in the limestone rock at the impact crater, generally filled with broken rocks; surrounding areas were smoother and more intact … subsurface growth and decaying material prevented viewing beyond several inches below the surface of the water, and when the water was stirred up by the walking searches and the airboats, there was no visibility. The majority of the wreckage was recovered by hand and placed on airboats that transported the pieces to a nearby levee for decontamination. The pieces were then transported by enclosed truck to a hangar for examination.

"The airplane structure was severely fragmented. In general, fewer pieces of right-side forward fuselage skins were identified, and pieces from the right side were generally more fragmented. The majority of the identified pieces were from the wing and fuselage aft of the wing box. Examination of the engines revealed no signs of in-flight or preimpact failure."

Neither engine's fire suppression system had been discharged. Investigators attempted to identify continuity of the flight-control cables but were unable to establish continuity for all cables because of the severity of the damage.

Investigators recovered the majority of both wings. "Actuators for the landing gear, slats and flaps were found in their retracted positions," said the report. "Three of the wing spoilers were found in the retracted positions, and one was found at 40 degrees deflection, with impact damage to the forward end of the actuator attachment. …

"Several pieces of the rudder were recovered. The largest piece measured [145 centimeters by 109 centimeters] 57 inches by 43 inches."

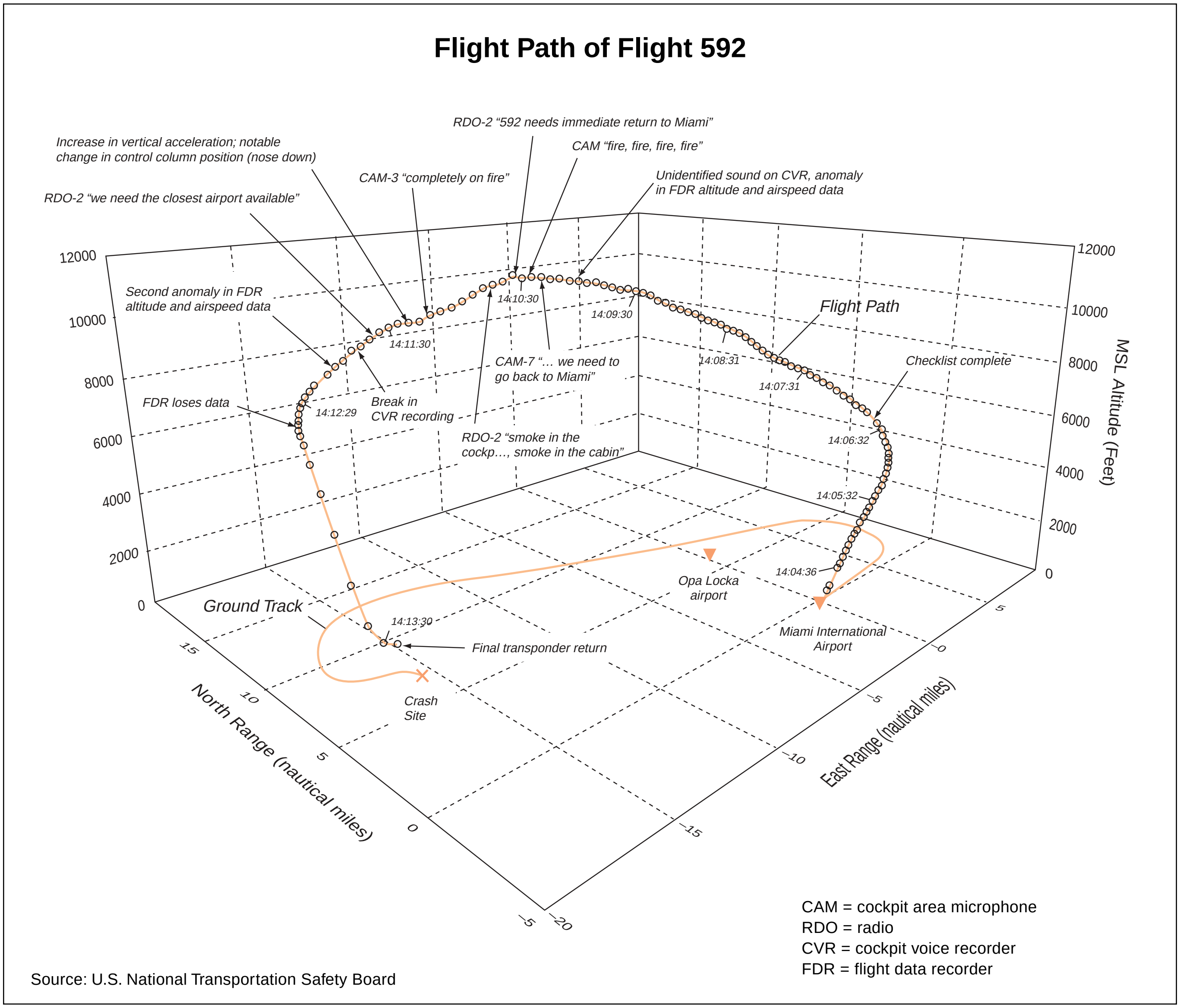


Figure 1

"Passenger-service units from the cabin were found with the oxygen masks in the stowed positions," said the report. "The mask from the cockpit walk-around oxygen bottle was found with the adjustment straps at their loosest positions. Three hand-operated fire extinguishers were found, all with severe impact damage. Because of the impact damage, laboratory analysis could not positively determine if the extinguishers had been used."

Investigators recovered 28 pieces of the chemical oxygen generators that were in the forward cargo compartment. "Nine generators had indentations in their percussion caps consistent with indentations caused by the actuation mechanism," said the report.

One of the aircraft tires that was carried in the forward cargo hold was also recovered and found to have fire damage. The report said, "An unburned piece of lower fuselage longeron (about [30.5 centimeters] one foot long) was found embedded in the tire.

"Debris found inside the tire included a heat-damaged stainless steel oxygen generator end cap with striker bracket attached, an ignitor guide, a metal part similar to an oxygen generator end cap or a heat shield normally located under the end cap, a small piece of resolidified molten metal (not aluminum), an unburned piece of longeron, a small spring, two rivet heads, an aircraft bolt and several more unidentified pieces of metal."

The other aircraft tire that was carried in the forward cargo compartment was located and found to have extensive burn damage. "Nine of the original 12 sidewall plies exhibited fire damage from the outside of the tire inward along the edge of the tear in the sidewall," said the report. "The edges of the tire along this tear were deflected outward, consistent with the tire having ruptured along this tear in the sidewall."

Recovered Wreckage Reassembled

The recovered wreckage from the forward cargo compartment was assembled in a three-dimensional mock-up. The report said, "A [48.3-centimeter by 99-centimeter] 19-inch by 39-inch piece of cargo compartment liner, the exact position of which could not be determined, was found with molten plastic adhered to its interior surface in several locations," said the report. "In some places, the melted plastic was burned and its original color could not be discerned.

"However, in other places, the melted plastic was blue or purple in color, consistent with the color of the plastic wheel covers used for the main and nose-gear tires being carried in the forward cargo compartment. Additional pieces of purple and blue plastic were found sooted and partially burned or melted."

A 43.2-centimeter (17-inch) section of the left side floor beam was recovered and found to have heavy soot and extensive broomstrawing on the inboard fracture surfaces. (Broomstrawing describes how metal appears when it has partially melted, then been subjected to shock loading and fracture.) Evidence of broomstrawing was found on another floor beam piece and on a section of seat track that was attached to it.

No survivors were found in the wreckage. "Human remains were recovered from the accident site over approximately seven weeks," said the report. "Although the remains that were recovered were fragmented and had been exposed to extreme environmental conditions, the Dade County Medical Examiner, with the assistance of the [U.S.] Federal Bureau of Investigation, was able to identify 68 of the 110 persons aboard Flight 592.

"A small amount of human tissue was identified as that of the first officer. However, because of the insufficient amount and the condition of the tissue, toxicology testing was not possible. None of the remains recovered were identified as those of the captain.

"The [NTSB] requested toxicology sampling of the passenger remains in an effort to determine the carbon dioxide and hydrogen cyanide levels that might have been present in the airplane. According to the Dade County Medical Examiner, all of the human tissue and bodily fluids recovered were unsuitable for testing."

The captain, 35, held an airline transport pilot (ATP) certificate with an airplane multi-engine land rating and type ratings in the DC-9, Boeing-737, Fairchild SA-227 and the Beech-1900. She also held flight instructor, ground instructor and ATC tower operator certificates. The captain held a valid FAA first-class medical certificate with no limitations. She had 8,928 hours of flight time, with 2,116 hours in the DC-9 and 1,784 hours as pilot-in-command (PIC).

In October 1993, "ValuJet made a conditional offer of employment to the captain, stating that the captain would be hired by ValuJet upon the successful completion, at her expense, of the ValuJet initial pilot training program conducted by FlightSafety International (FSI)," said the report.

Captain Received Hazardous Materials Training

During her training at FSI, "[The captain] attended sessions on hand-held fire extinguishers, portable breathing equipment (PBE) and portable oxygen systems, in which students were given hands-on experience discharging each type of fire extinguisher installed on the DC-9," said the report. "Records indicated that she received two hours of training in ValuJet's hazardous materials policies, including the recognition and handling of dangerous articles … ."

The captain became a ValuJet employee in November 1993. She was assigned as a DC-9 first officer in December 1993 and was assigned as a captain in May 1994. The captain's training records indicated no unsatisfactory results on any of her PIC proficiency checks.

On the day of the accident, the captain reported for duty at Dallas/Fort Worth (Texas, U.S.) International Airport (DFW) at 0704. "At the time of the accident, she had accumulated about 7.2 hours of duty time and 3.7 hours of flight time (including the accident flight)," said the report.

The first officer, 52, held an ATP certificate and ratings for airplane single-engine and multi-engine land, and a type rating in the DC-9. He also held flight engineer and airframe/powerplant mechanic certificates. The first officer had 6,448 hours of flight time, with 2,148 hours of DC-9 experience. He had 400 hours as a McDonnell Douglas MD-80 international relief captain for another air carrier.

The first officer held a restricted/special issuance first-class medical certificate. "FAA records indicated that the FAA Aeromedical Certification Division was monitoring the first officer for a self-reported history of diabetes (a disqualifying condition for an unrestricted medical certificate)," said the report. The first officer was taking medication to lower his blood sugar levels and, to monitor his medical condition, he was required to undergo a complete medical re-evaluation of his condition every six months.

In October 1995, the first officer received a conditional offer of employment from ValuJet and began training at FSI. The first officer received the same training as the captain in the recognition and handling of hazardous materials, hand-held fire extinguishers and portable oxygen systems. In November 1995, the first officer became an employee of ValuJet and was assigned as a first officer in December 1995.

Cockpit Voice Recorder Transcript, ValuJet Airlines Flight 592, May 11, 1996

Time	Source	Content
1410:03	**CAM**:	[sound of chirp heard on cockpit area microphone channel with simultaneous beep on public address/ interphone channel]
1410:07	**CAM-1**:	what was that?
1410:08	**CAM-2**	I don’t know.
1410:12	**CAM-1**:	** (‘bout to lose a bus?)
1410:15	**CAM-1**:	we got some electrical problem.
1410:17	**CAM-2**:	yeah.
1410:18	**CAM-2**:	that battery charger’s kickin’ in. ooh, we gotta.
1410:20	**CAM-1**:	we’re losing everything.
1410:21	**DEP**:	Critter five nine two, contact Miami center on one thirty two forty five, so long.
1410:22	**CAM-1**:	we need, we need to go back to Miami.
1410:23	**CAM**:	[sounds of shouting from passenger cabin]
1410:25	**CAM-?**:	fire, fire, fire, fire [from female voices in cabin]
1410:27	**CAM-?**:	we’re on fire, we’re on fire.
1410:28	**CAM**:	[sound of tone similar to landing gear warning horn for three seconds]
1410:29	**DEP**:	Critter five ninety two contact Miami center, one thirty two forty five.
1410:30	**CAM-1**:	** to Miami.
1410:32	**RDO-2**:	uh, five ninety two needs immediate return to Miami.
1410:35	**DEP**:	Critter five ninety two uh, roger, turn left heading two seven zero. descend and maintain seven thousand.
1410:36	**CAM**:	[sounds of shouting from passenger cabin subsides]
1410:39	**RDO-2**:	two seven zero, seven thousand, five ninety two.
1410:41	**DEP**:	what kind of problem are you havin’.
1410:42	**CAM**:	[sound of horn]
1410:44	**CAM-1**:	fire.

The first officer had been on duty for three days before the accident. His flight and duty times on the day of the accident were approximately the same as those of the captain.

Aircraft Maintenance History Reviewed

Investigators reviewed the maintenance history on the accident aircraft. “On the day of the accident, the airplane was delayed in departing the gate at Atlanta … because the right auxiliary hydraulic-pump circuit breaker popped,” said the report. “After examining the pump, cleaning the cannon plug pins and reconnecting the cannon plug, a mechanic was able to reset the circuit breaker without any further difficulty.

“During the flight from Atlanta to Miami, the public address (PA) system stopped functioning. According to passengers on that flight, the flight attendants used a megaphone to communicate with the passengers while the airplane remained airborne but discovered during the taxi to the gate that the PA system was once again operable.”

When the aircraft arrived at the gate, “a SabreTech mechanic ... entered the electrical equipment bay just aft of the nose-wheel well and checked the PA amplifier to see if it was hot,” said the report. “[The mechanic] reported that it was not hot, and that it was loose in its mount. He therefore secured the amplifier, and the PA system was once again operable. He said that he did not notice any unusual smells, noises or vibrations while working in the equipment bay and that the captain had said that no circuit breakers had popped en route to Miami. ...

“At the time of the accident, there were three open MEL [minimum equipment list] items and one open configurations deviations list (CDL) [changes to aircraft configuration that may be deferred] item being carried for [the accident aircraft]. Those items were as follows:

- “Left fuel-flow gauge inoperative;
- “Cockpit interphone inoperative;
- “Autopilot porpoising;
- “Flap-hinge fairing removed.”

Investigators reviewed ValuJet’s maintenance program. “At the time of the accident, [ValuJet] had contracts with 21 FAA-certificated maintenance facilities and repair stations to service its airplanes when the airplanes were away from ValuJet’s maintenance facilities or to perform C-check or greater heavy maintenance,” said the report. SabreTech was one of three contractors that were authorized to perform all of the required inspections on ValuJet’s aircraft including heavy maintenance.

During January 1996 and February 1996, ValuJet purchased two MD-82s and one MD-83. The three aircraft were ferried to Miami for SabreTech to perform modifications and maintenance. "One of the maintenance tasks requested by ValuJet was the inspection of the oxygen generators on all three airplanes to determine if they had exceeded the allowable service life of 12 years from the date of manufacture," said the report. It was determined that the majority of the oxygen generators on two of these aircraft were past the expiration date. ValuJet directed SabreTech to replace all oxygen generators on these two aircraft (Figure 2, page 8).

The MD-80 maintenance manual directs maintenance personnel to follow work card 0069, which outlines a seven-step process for the removal of an oxygen generator. The report said, "Step 2 states, 'If generator has not been expended, install shipping cap on firing pin.'" (The term safety cap is used in the MD-80 maintenance manual and in the NTSB report, rather than the term shipping cap, which is used on the work card.) The report said that the MD-80 manual also warns that an oxygen-generator canister is not to be disposed of until the generator is initiated and its chemical core is fully expended.

Handling for Unexpended Generators Not Specified on Work Card

The report said, "Although work card 0069 warned about the high temperatures produced by an activated generator, it did not mention that unexpended generators required special handling for storage or disposal, that out-of-date generators should be expended and then disposed of or that the generators contained hazardous substances/waste even after being expended; further, the work card was not required to contain such information." The report said that because this information was not contained on work card 0069 and because the card provided no reference to the appropriate section of the MD-80 maintenance manual, the mechanics responsible for removing the oxygen generators from the MD-80s were not able to determine the hazardous nature of the generators by reading only the information provided on the work card.

"According to the SabreTech mechanics, almost all of the expired or near-expired oxygen generators removed from the two airplanes were placed in cardboard boxes, which were then placed on a rack in the hangar near the airplane," said the report. "However, some of these generators (approximately a dozen) were not put in boxes, but rather were left lying loose on the rack."

The mechanic who signed the work card for one of the aircraft stated that "he was aware of the need for safety caps [on the oxygen generators] and had overheard another mechanic who was working with him on the same task talking to a supervisor about the need for caps," said the report. "This other mechanic

1410:46	**RDO-2**:	uh, smoke in the cockp … smoke in the cabin.
1410:47	**DEP**:	roger.
1410:49	**CAM-1**:	what altitude?
1410:49	**CAM-2**:	seven thousand.
1410:52	**CAM**:	[sound similar to cockpit door moving]
1410:57	**CAM**:	[sound of six chimes similar to cabin service interphone]
1410:58	**CAM-3**:	OK, we need oxygen, we can't get oxygen back there.
1411:00	**INT**:	[sound similar to microphone being keyed only on interphone channel]
1411:02	**CAM-3**:	*ba*, is there a* way we could test them? [sound of clearing her voice]
1411:07	**DEP**:	Critter five ninety two uh, when able to turn left heading two five zero. descend and maintain five thousand.
1411:08	**CAM**:	[sound of chimes similar to cabin service interphone]
1411:10	**CAM**:	[sounds of shouting from passenger cabin]
1411:11	**RDO-2**:	two five zero seven thousand.
1411:12	**CAM-3**:	completely on fire.
1411:14	**CAM**:	[sounds of shouting from passenger cabin subsides]
1411:19	**CAM-2**:	outta nine.
1411:19	**CAM**:	[sound of intermittent horn]
1411:21	**CAM**:	[sound similar to loud rushing air]
1411:38	**RDO-2**:	Critter five ninety two we need the uh, closest airport available.
1411:42	**DEP**:	Critter five ninety two, they're gonna be standing standing by for you. you can plan … .
1411:45	**CAM**:	[one minute and twelve second interruption in CVR recording]
1412:57	**CAM**:	[sound of tone similar to power interruption to CVR]
1412:57	**CAM**:	[sound similar to loud rushing air]
1412:57	**ALL**:	[sound of repeating tones similar to CVR self test signal start and continue]
1412:58	**DEP**:	… contact Miami approach on, correction you, you, keep on my frequency.

1413:05	**DEP**:	American nine sixty turn left heading two seven zero, join the WINCO transition.
1413:09	**AA960**:	heading two seven zero to join the WINCO transition, Amer …
1413:11	**CAM**:	[interruption of unknown duration in CVR recording]
14??:??	**UNK**:	***. [radio transmission from unknown source]
14??:??	**ALL**:	[sound of repeating tones similar to CVR self test signal, starts and continues]
14??:??	**CAM**:	[sound similar to louder rushing air]
14??:??		End of recording

RDO	=	Radio transmission from accident aircraft
CAM	=	Cockpit area microphone voice or sound source
ALL	=	Sound source heard on all channels
INT	=	Transmissions over aircraft interphone system
DEP	=	Radio transmission from Miami departure control
AA960	=	Radio transmission from American Flight 960
UNK	=	Radio transmission received from unidentified source
-1	=	Voice identified as pilot-in-command (PIC)
-2	=	Voice identified as co-pilot
-3	=	Voice identified as female flight attendant
-?	=	Voice unidentified
*	=	Unintelligible word
( )	=	Questionable insertion
[ ]	=	Editorial insertion
…	=	Pause

Source: U.S. National Transportation Safety Board

stated in a postaccident interview that the supervisor told him that the company did not have any safety caps available.

"The supervisor stated in a postaccident interview that his primary responsibility had been issuing and tracking the jobs on [the aircraft from which the oxygen generators had been removed] and that he did not work directly with the generators. He stated that no one, including the mechanics who had worked on the airplanes, had ever mentioned to him the need for safety caps."

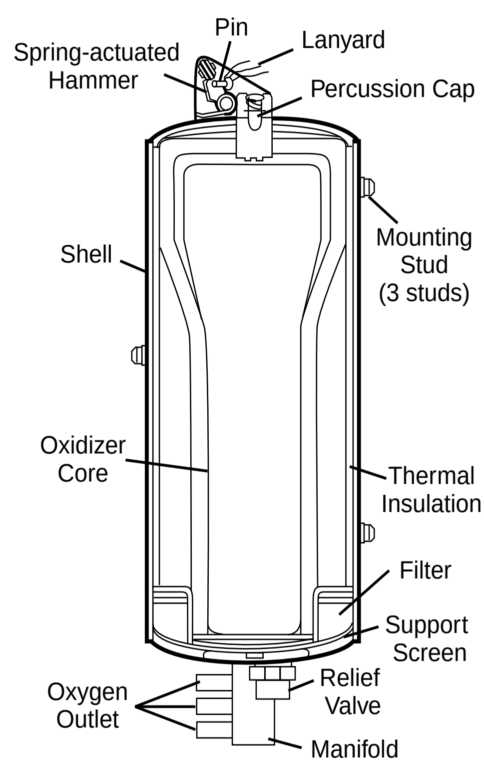
The report said that it was clearly specified on work card 0069 that installation of safety caps on any oxygen generator was required if the generator had not been expended after it was removed from an airplane. Although the signatures of mechanics and supervisory personnel on work cards are intended to verify that all steps on the work cards have been completed, SabreTech personnel signed off work card 0069, but safety caps were never installed on the oxygen generators.

The report said, "The mechanic who signed work card 0069 for [one of the aircraft] said that some mechanics had discussed using the caps that came with the new generators, but the idea was rejected because those caps had to stay on the new generators until the final mask drop check was completed at the end of the process … . When asked if he had followed up to see if safety caps had been put on the generators before the time he signed off the card, he said he had not.

"According to this mechanic, there was a great deal of pressure to complete the work on the airplanes on time and the mechanics had been working 12-hour shifts seven days per week." The mechanic said that one of the SabreTech supervisors assigned him the task of signing off the work card.

The mechanic said that "they did not discuss or focus on the safety caps at the time of this request or the signoff," said the report.

Chemical Oxygen Generator, Cut-away View



Source: U.S. National Transportation Safety Board

Figure 2

Chemical Oxygen Generators Carried Aboard ValuJet Flight 592

The chemical oxygen generators carried as cargo aboard ValuJet Flight 592 had been removed from a McDonnell Douglas MD-80 passenger emergency oxygen system. Upon activation, "[The generators] provide emergency oxygen to the occupants of the passenger cabin if cabin pressure is lost," the report said. "The oxygen generators, together with the oxygen masks, are mounted behind panels above or adjacent to passengers. If a decompression occurs, the panels are opened either by an automatic pressure switch or by a manual switch, and the mask assemblies are released.

"Each mask is connected to its generator in two places. A plastic tube through which the oxygen will flow is connected from the mask-assembly reservoir bag to an outlet fitting on one end of the oxygen generator. Additionally, a lanyard, or slim white cord, connects each mask to a pin that restrains the spring-loaded initiation mechanism (retaining pin). The lanyard and retaining pin are designed such that a [0.45-kilogram to 0.9-kilogram] one-pound to two-pound pull on the lanyard will remove the pin, which is held in place by a spring-loaded initiation mechanism.

"When the retaining pin is removed, the spring-loaded initiation mechanism strikes a percussion cap containing a small explosive charge mounted in the end of the oxygen generator. The percussion cap, when struck, provides the energy necessary to start a chemical reaction in the generator oxidizer core, which liberates oxygen gas. A protective shipping cap that prevents mechanical activation of the percussion cap is installed on new generators. The shipping cap is removed when the oxygen generator has been installed in the airplane and the final mask drop check has been completed.

"The oxidizer core is sodium chlorate ($NaClO_3$), which is mixed with less than 5 percent barium peroxide (BaO_2) and less than 1 percent potassium perchlorate ($KClO_4$). The explosives in the percussion cap are a lead-styphnate-and-tetracene mixture.

"When heated to its decomposition temperature by the action of the percussion cap, a chemical reaction begins in the core whereby the $NaClO_3$ is reduced to sodium chloride (NaCl) and the oxygen is liberated as a gas. The oxygen flows through the granular insulation between the chemical core and the outlet shell of the generator toward the outlet end of the generator. At the outlet end, the oxygen flows through a series of filters, through the outlet manifold, and into the plastic tubes connected to the reservoir bags on the mask assembly.

"The chemical reaction is exothermic, which means that it liberates heat as a by-product of the reaction. This causes the exterior surface of the oxygen generator to become very hot; the maximum temperature of the exterior surface of the oxygen generator during operation is limited by McDonnell Douglas specification to [286 degrees C] 547 degrees F when the generator is operated at an ambient temperature of [21 degrees C to 26 degrees C] 70 degrees F to 80 degrees F. Manufacturing test data indicate that when operated during tests, maximum shell temperatures typically reach [232 degrees C to 260 degrees C] 450 degrees F to 500 degrees F.

"The amount of oxygen required to be produced by a generator as a function of time is not constant; it is specified by the aircraft manufacturer in accordance with the emergency descent profile the aircraft is expected to follow after a loss of cabin pressure to reach an altitude where supplemental oxygen is no longer required. The amount of oxygen required at higher altitudes is greater than the amount needed at lower altitudes. Therefore, the chemical core has a larger diameter at the initiation end than at the outlet end to provide more oxygen at the beginning of the reaction. ...

"The outlet end of the [generator] also contains two self-closing pressure relief valves. These valves are designed to open if the pressure in the generator exceeds [20.4 kilograms per square centimeter] 45 pounds per square inch gauge (psig)]."♦

The report said that one of the SabreTech inspectors who signed the final inspection block on the nonroutine work card for one of the airplanes knew that the generators needed safety caps, but signed the card anyway. This inspector relied on the word of supervisory personnel that safety caps would be installed by the shipping and stores department without ever verifying that this step had been done.

Two of the three technical representatives responsible for overseeing SabreTech's work for ValuJet and one ValuJet quality assurance inspector said that they were unaware of the safety-cap issue. "However, one of the technical representatives said that on or about April 10 he was watching the SabreTech mechanics remove several oxygen generators and later noticed generators sitting on a parts rack near one of the ValuJet airplanes," said the report. Although the technical representative noticed that the generators lacked safety caps, he did not discuss this with the mechanics. The technical representative said that he made requests to both a SabreTech supervisor and the SabreTech project manager for the boxes to be moved away from the aircraft. The technical representative said that the box was moved approximately three weeks after his initial request but that he did not know what became of the box or the oxygen generators.

"The SabreTech inspector, supervisor and project manager all denied during interviews ... being approached by the technical representative or knowing anything about an issue having to do with a need for safety caps on the oxygen generators," said the report.

Three boxes of the expired or near-expired oxygen canisters "were taken to the ValuJet section of SabreTech's shipping and receiving hold area by the mechanic who said that he had discussed the issue of the lack of safety caps with his supervisor," said the report. "According to the mechanic, he took the boxes to the hold area at the request of either his lead mechanic or supervisor. He said that he placed the boxes on the floor, near one or two other boxes, in front of shelves that held other parts from ValuJet airplanes. He stated that he did not inform anyone in the hold area about the contents of the boxes."

Two other boxes of the oxygen canisters were placed in the same area, but it could not be determined who placed them there. "According to the director of logistics at SabreTech, at the time the five boxes were placed in the hold area for ValuJet property, no formal written procedure required an individual who took items to the shipping and receiving hold area to inform someone in that area what the items were or if the items were hazardous," said the report.

The aircraft-maintenance service agreement between ValuJet and SabreTech called for SabreTech to retain any items that were removed and were not reinstalled on the aircraft until disposal was authorized in writing by ValuJet. Nevertheless, the report said, "According to a SabreTech stock clerk, on May 8 he asked the director of logistics, 'How about if I close up these boxes and prepare them for shipment to Atlanta.' He [the stock clerk] stated that the director responded, 'Okay, that sounds good to me.'" Believing he had the director's concurrence, the stock clerk reorganized the five boxes, placed bubble wrap in the top of each box, closed the boxes and applied a blank SabreTech address label and a ValuJet COMAT label with the notation 'aircraft parts' to each box. The report said, "The director of logistics indicated he did not give permission to ship the boxes and that nobody had asked him what to do with the boxes. ...

"According to the stock clerk, on the morning of May 9, he [the stock clerk] asked a SabreTech receiving clerk to prepare a shipping ticket for the five boxes of oxygen generators and three DC-9 tires (a nose-gear tire and two main-gear tires)," said the report. " ... According to the receiving clerk, the stock clerk gave him a piece of paper indicating that he should write, 'Oxygen Canisters — Empty,' on the shipping ticket."

"The stock clerk said he identified the generators as 'empty canisters' because none of the mechanics had talked to him about what they were or what state they were in."

The stock clerk said "he identified the generators as 'empty canisters' because none of the mechanics had talked to him about what they were or what state they were in, and that he had just found the boxes sitting on the floor of the hold area one morning," said the report. "He said he did not know what the items were, and when he saw that they had green tags on them he assumed that meant they were empty."

Red "condemned parts" tags should have been used for the generators rather than the green "repairable parts" tags that were used, according to SabreTech's FAA-approved inspection-procedures manual. Although the wrong parts tag was used, "... it probably did not contribute to the mishandling of the generators that ultimately led to the generators being loaded into the forward cargo compartment on Flight 592," said the report.

The report said, "Many of the shortcomings discussed ... (including the SabreTech mechanics' failure to install safety caps, their improper maintenance entries, their use of improper tags and the inadequate communications between the maintenance shop floor and stores department) result from human failures that might have been avoided if more attention were given to human factors issues in the maintenance environment."

According to Part 121 of the U.S. Federal Aviation Regulations (FARs) that establishes limitations on duty time for individuals performing maintenance on Part 121 airplanes, including those who work at a Part 145 repair station, individuals must be off duty for 24 consecutive hours every seven consecutive days. However, the option exists to give the equivalent number of off-duty hours within the span of a calendar month. This regulation allows for mechanics to work as many as 26 consecutive days, taking all of their off-duty time at the end of the month.

The report said, "The [NTSB] concludes that the current duty time limitations ... may not be consistent with the current state of scientific knowledge about factors contributing to fatigue among personnel working in safety-sensitive transportation jobs. Accordingly, the [NTSB] believes that the FAA should review the issue of personnel fatigue in aviation maintenance; then establish duty time limitations consistent with the current state of scientific knowledge for personnel who perform maintenance on air carrier aircraft."

The report said that neither SabreTech nor ValuJet provided an employee-training course on hazardous-materials recognition or on shipping of hazardous materials. "[SabreTech] personnel relied on prior experience to recognize hazardous materials," said the report. "The director [of logistics] indicated that SabreTech had no prior experience handling oxygen generators."

On the day of the accident, the stock clerk told a SabreTech driver to take the three tires and five boxes to the ValuJet ramp area. Upon arrival at the ValuJet ramp, the driver was directed by a ValuJet ramp agent to unload the material onto a baggage cart.

Ramp Agent Stated Cargo Not Secured

The ValuJet ramp agent who loaded the boxes and tires into the accident aircraft told investigators that "he remembered hearing a 'clink' sound when he loaded one of the boxes and that he could feel objects moving inside the box," said the report. "He [the ramp agent] told [NTSB] investigators that when the loading was completed, one of the large tires was lying flat on the compartment floor, with a small tire [lying] on its side, centered on top of a large tire. He further indicated that the COMAT boxes were also loaded atop the large tire, positioned around the small tire, and that the boxes were not wedged tightly. ... The ramp agent said that the cargo was not secured, and that the cargo compartment had no means for securing the cargo" (Figure 3).

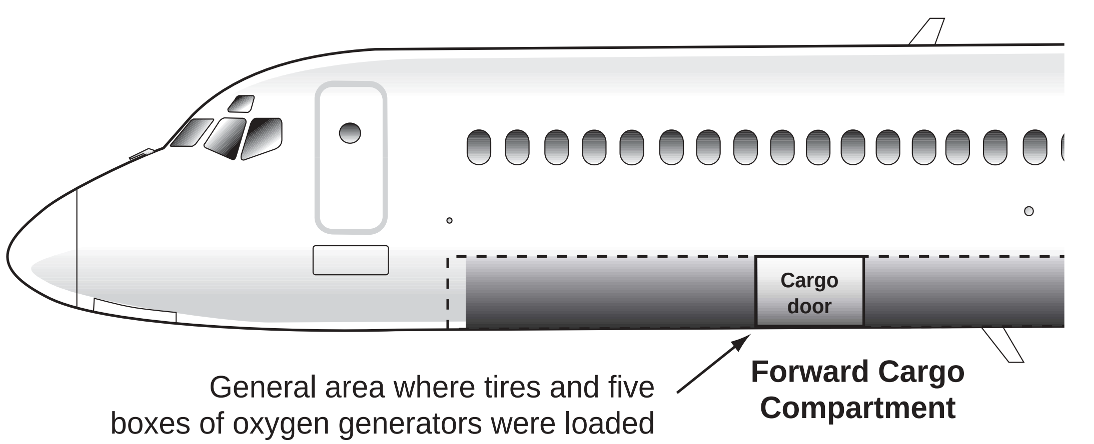
Investigators examined the wreckage to determine the source of the fire that crippled the accident flight. "The wreckage that was recovered provided evidence of fire damage throughout the majority of the forward cargo compartment and areas of the airplane above it, with the most severe fire damage found in the ceiling area of the forward part of this compartment," said the report. "Other areas of the airplane did not show significant fire damage, including the cockpit and the electronics compartment of the airplane located beneath the cockpit.

"The airplane's electrical system was examined for indications as to what caused the electrical problems initially noted by the flight crew. However, because so much of the wiring ran adjacent to the cargo compartment and because so many of those wires were severely damaged, the source of those electrical anomalies could not be isolated.

"Examination of the heat-damaged wire bundles and cables revealed no physical evidence of short circuits or of burning that could have initiated the fire. Further, the heat and fire damage to the interior of the cargo compartment was more severe than the damage to the exterior, consistent with the fire having been initiated inside the cargo compartment. (The cargo-compartment liner, which was designed to keep a fire contained within the cargo compartment, would also have functioned to keep an externally initiated fire out of the compartment.) Finally, the heat-damaged wire bundles were not routed near the breached area of the cargo compartment, whereas the boxes containing the oxygen generators were loaded into the area directly beneath the breached area of the cargo compartment. Thus the electrical system was not a source of ignition of the fire."

Investigators examined the chemical oxygen generators that were carried aboard the accident flight and recovered from the accident site. When examining the units, they discovered that: "Safety caps were not installed over the percussion caps that start a chemical reaction in the oxygen generators; lanyards for the retaining pins for the percussion caps' spring-loaded actuation mechanism were not secured on several generators;

DC-9-32 Forward Cargo Compartment



Source: U.S. National Transportation Safety Board

Figure 3

and the generators were not packaged adequately to prevent generators from striking the actuation mechanism or dislodging retaining pins on adjacent generators," said the report.

Cargo-compartment Conditions Simulated at Fire-test Facility

"A series of five tests involving oxygen generators was conducted at the FAA's fire-test facility near Atlantic City, New Jersey, [U.S.] …," said the report. The tests used an instrumented McDonnell Douglas DC-10 cargo-compartment test chamber which is larger than, but similar to, the cargo compartment of the DC-9. The report said, "All tests were initiated by pulling the retaining pin on one of the generators located at the top of a box. … In the final test, two boxes of oxygen generators were placed on top of a main-gear tire pressurized to [22.7 kilograms per square centimeter] 50 pounds per square inch – psi. [Three other] boxes of generators were placed around the tire. Luggage was stacked around the tire and boxes of oxygen generators. … About 10 minutes after ignition, the ceiling in the DC-9 type cargo compartment reached about [1,093 degrees C] 2,000 degrees F; after 11 minutes, the temperature was about [1,538 degrees C] 2,800 degrees F. About 11.5 minutes after ignition, the temperature at this location exceeded the temperature measurement capabilities of the system greater than [1,760 degrees C] 3,200 degrees F. Sixteen minutes after the ignition generator was activated, the tire ruptured. …

"Based on the results of the [NTSB's] fire tests … the physical evidence of fire damage in the forward cargo compartment of the accident airplane, and the lack of other cargo capable of initiating a fire in the forward cargo hold, the [NTSB] concludes that the activation of one or more chemical oxygen generators in the forward cargo compartment of the airplane initiated the fire on ValuJet Flight 592.

"The [NTSB's] analysis, therefore, first examines the accident sequence including the initiation and propagation of the onboard fire and the adequacy of air carrier and FAA efforts to minimize the hazards posed by fires in cargo compartments of commercial airplanes." The NTSB's analysis also explored "the pilots' performance and actions when they became aware of the fire shortly after takeoff from Miami and the adequacy of smoke protection equipment and smoke evacuation procedures aboard air carrier aircraft."

Investigators attempted to determine when the accident flight crew first became aware of the fire and how quickly the fire spread. The report said, "The first indication of a problem during the accident flight occurred at 1410:03, approximately six minutes after Flight 592 took off from Miami, when the CVR recorded an unidentified sound, which prompted the captain to ask, 'What was that?'" Simultaneously with the unidentified noise recorded on the CVR at 14:10:03, the FDR recorded an indicated airspeed decrease of 61 kph (33 knots) and a pressure altitude drop of 249 meters (817 feet). "The FDR airspeed and altitude returned to normal within four seconds …," said the report. "Within 12 seconds, the captain reported an electrical problem, and at 1410:25, there were voices shouting 'fire, fire, fire,' in the passenger cabin."

The tires being transported as cargo were loaded in the accident-aircraft cargo compartment just forward of the cargo door. As a result, the tires were located just above the aircraft's left static ports. The report said, "An increase of [337 kilograms per square meter] 69 pounds per square foot in the static pressure sensed by a static-pressure sensor on the airplane would result in an [249-meter] 817-foot decrease in altitude (as recorded by the FDR)." It was also determined that a static-pressure increase of this particular magnitude would result in an airspeed reduction of about 74 kph (40 knots). "The FDR altitude and speed data are based on readings from the left alternate static port, which is located on the left side of the fuselage … indicating that the unidentified sound on the CVR and the FDR anomaly at 1410:03 were most likely caused by the rupture of an inflated tire in the forward cargo compartment after the tire was partially burned through by fire," said the report.

Investigators analyzed when the fire aboard the accident flight might have been initiated. "Activation of a generator would have been most likely to occur during an event that could cause movement or jostling of the contents of the boxes," said the report. "Accordingly, the [NTSB] considered whether the fire might have been started as a result of one or more generators being activated during the loading process, which likely ended before 1340:29 when the passenger safety briefing was recorded on the CVR. The tire ruptured more than 30 minutes later. The [NTSB] also considered whether the fire could have resulted from an oxygen generator being activated during the takeoff roll, which began about 1403:34. However, this was only six [minutes] to seven minutes before the tire ruptured."

Based on the fire tests conducted during the investigation, the NTSB concluded that "one or more of the oxygen generators likely were actuated at some point after the loading process began, but possibly as late as during the airplane's takeoff roll," said the report.

"The investigation examined why there was not an earlier indication of smoke and/or fire in the cabin than the first audible report at 1410:25," said the report. "Several factors might account for the lack of warning from smoke earlier in the fire sequence. First, the cargo-compartment liner is designed to limit the amount of ventilation to and from the cargo compartment; consequently, so long as the liner is intact, the smoke will not readily escape into the passenger compartment.

"Second, any smoke that did escape would not have readily entered the air flow in the passenger cabin, which comes from overhead and down into the area between the airplane outer skin and the cargo liner, then moves aft and exits through the outflow valve.

"Third, the oxygen generators would have initially fed the fire with an abundance of oxygen, tending to minimize the amount of smoke and resulting in a very rapidly developing fire. All of these factors in combination most likely prevented any noticeable migration of smoke from the forward cargo compartment into the passenger cabin or cockpit until relatively late in the development of the fire. Although black soot deposits on some of the overhead luggage compartments indicate that black smoke ultimately reached the passenger cabin, this smoke probably did not reach the passenger cabin until after the fire had breached the cargo compartment ceiling.

"Because the cargo compartment where the fire occurred was a class-D cargo compartment and was not equipped (nor was it required to be equipped) with a smoke-detection system, the cockpit crew of ValuJet Flight 592 had no way of detecting the threat to the safety of the airplane from the in-flight fire until the smoke and fumes reached the passenger cabin. Further, because the cargo compartment was not equipped (nor was it required to be equipped) with a fire-suppression system, the cockpit crew had no means available to extinguish or even suppress the fire in the cargo compartment.

"If the fire started before takeoff and a smoke/fire-detection warning device had activated, the flight crew most likely would not have taken off. However, the [NTSB] concludes that even if the fire did not start until the airplane took off, a smoke/fire warning device would have more quickly alerted the pilots to the fire and would have allowed them more time to land the airplane.

"Further … if the airplane had been equipped with a fire-suppression system, it might have suppressed the spread of the fire (although the intensity of the fire might have been so great that a suppression system might not have been sufficient to fully extinguish the fire) and it would have delayed the spread of the fire, and in conjunction with the early warning it would likely have provided time to land the airplane safely.

"Although class-D cargo compartments are designed to suppress fire through oxygen starvation, this accident and events before this accident illustrate that some cargo, specifically oxidizers, can generate sufficient oxygen to support combustion in the reduced ventilation environment of a class-D cargo compartment."

On Feb. 3, 1988, American Airlines Flight 132, a McDonnell Douglas DC-9-83, experienced an in-flight fire while en route to Nashville (Tennessee, U.S.) International Airport from DFW. During final approach, a flight attendant and a nonflying first officer notified the cockpit crew of smoke in the passenger cabin. The fire, which was not extinguished during flight, eventually breached the cargo compartment, causing the cabin floor over the midcargo compartment to become hot and soft. After landing, the 120 passengers and six crew members safely evacuated the airplane. A postaccident investigation revealed that hydrogen peroxide solution (an oxidizer) and a sodium orthosilicate–based mixture had been shipped and loaded into the class-D midcargo compartment. The chemicals had been improperly packaged and had not been identified as hazardous materials. After hydrogen peroxide had leaked from its container, the fire had started in the cargo compartment. Following this incident, said the report, "the [NTSB] recommended that the FAA require fire/smoke-detection and fire-extinguishment systems for all class-D cargo compartments … .

"As recently as August 1993, although the FAA had investigated several incidents of fire that were initiated as a result of oxidizers in the cargo compartments of airplanes, the FAA responded to [the NTSB's recommendations] stating that fire/smoke-detection and fire-extinguishment systems were not cost-beneficial, that it did not believe that these systems would provide a significant degree of protection to occupants of airplanes, and that it had terminated its rulemaking action to require such systems.

"The [NTSB] concludes that had the FAA required fire/smoke-detection and fire-extinguishment systems in class-D cargo compartments, as the [NTSB] recommended in 1988, ValuJet Flight 592 would likely not have crashed. Therefore, the failure of the FAA to require such systems was causal to this accident.

"The crash of ValuJet Flight 592 prompted the FAA to state in November 1996 that it would issue an NPRM [notice of proposed rulemaking] by the end of the summer of 1997 to require, on about 2,800 older aircraft, the modification of all class-D cargo compartments to class-C cargo compartments, which are required to have both smoke-detection and fire-extinguishment systems. The accident also prompted the [Air Transport Association of America] to announce in December 1996 that its members would voluntarily retrofit existing class-D cargo compartments with smoke detectors. [As this issue goes to press,] the [NTSB] is unaware that any airplanes have been modified and are in service. [See "Cargo Compartment Classification Requirements," page 14.]

"On June 13, 1997, the FAA issued an NPRM that would require the installation of smoke-detection and fire-suppression systems in class-D cargo compartments. According to the NPRM, the airline industry would have three years from the time the rule became final to meet the new standards. The FAA

"Some cargo, specifically oxidizers, can generate sufficient oxygen to support combustion in the reduced ventilation environment of a class-D cargo compartment."

Cargo-compartment Classification Requirements

In 1946, three classes of cargo- or baggage- compartments were defined and requirements for fire-detection and -suppression systems were established under regulations governing commercial air transport operations in the United States.

A class-A compartment is typically a small compartment used for crew luggage and is located near the cockpit. Because a fire in this compartment could be readily detected and extinguished by a crew member, there is no requirement for a special liner to prevent a fire from spreading.

Class-B compartments are remote from the flight deck, but still have sufficient access to allow a crew member to extinguish an in-flight fire in any part of the compartment with a hand-held fire extinguisher. A liner to retard flame penetration must be provided to prevent a fire from spreading outside of the cargo compartment. Class-B compartments can range in size from small baggage compartments inside the pressurized areas of executive jets to the large cargo portions of cabins of aircraft designed to transport both passengers and cargo.

Class-C compartments are those that do not fit into the Class-A or class-B categories. Rather than a requirement for in-flight accessibility, class-C compartments are required to have built-in fire-suppression systems to control fires.

In 1952, class-D and class-E compartments were defined.

Class D compartments are remote from the flight deck and are not accessible to crew members in flight. No smoke- or fire-detection or fire-suppression system is required; nevertheless, class-D compartments are designed with ventilation systems that severely restrict the availability of oxygen. Liners resistant to flame penetration are required.

Allowed only on aircraft used solely for cargo transportation, class-E compartments are equipped with smoke- and fire-detection equipment as well as a means of shutting off the flow of ventilating air to or within the compartment. Class-E compartments are often the entire cabin of an all-cargo aircraft.

To increase protection from in-flight fires, on Feb. 10, 1998, the U.S. Federal Aviation Administration (FAA) issued a final rule, Revised Standards for Cargo or Baggage Compartments in Transport-Category Airplanes, that requires cargo- or baggage-compartment fire-safety standards to be upgraded by eliminating class-D compartments as an option for future type certification. Additionally, the final rule requires that existing class-D compartments in transport-category airplanes certified prior to Jan. 1, 1958 that are used for air-carrier or commercial operations under U.S. Federal Aviation Regulations Part 121 be modified, as applicable, to meet class-C or class-E standards. The final rule said, "The FAA has elected to delay rulemaking pertaining to Part 135 operators for further study."

The final rule said, "When first defined, class-D compartments were envisioned to be small compartments ... and were to suppress a fire by severely restricting the amount of available oxygen. Later, however, larger class-D compartments were installed in transport category airplanes, increasing both the amount of potentially combustible material and the available oxygen. Although there is little or no flow of air into a class-D compartment at the time a fire occurs, there is oxygen available from the air already contained in the compartment. In some instances, particularly when the compartment is larger or only partially filled, the oxygen already present in the compartment may be sufficient to support an intense fire long enough for it to penetrate the liner. Once the integrity of the liner is compromised, there is an unlimited flow of air into the compartment, resulting in an uncontrollable fire that can quickly spread throughout the rest of the airplane."

The final rule requires compliance within three years of its March 19, 1998, effective date. Air carriers may begin retrofitting their aircraft immediately, and will be required to make quarterly progress reports to the FAA.♦

indicated that it anticipated issuing a final rule by the end of 1997. The [NTSB] is disappointed that more than one year after the ValuJet crash and nine years after the [1988 DC-9 accident], the class-D cargo compartments of most passenger airplanes still do not have fire/smoke-detection or -suppression equipment and there is no requirement for such equipment."

The NTSB examined the circumstances that led to the shipment of the oxygen generators as well as the procedures used for shipping company material and hazardous materials. "The analysis also evaluates concerns raised regarding the adequacy of the FAA's hazardous-materials program; ValuJet's outsourcing of maintenance and training activity; the company's oversight of its contract maintenance facilities; and the FAA's oversight of ValuJet and ValuJet's contract maintenance facilities," said the report.

At the time of the accident ValuJet had a "will-not-carry" hazardous-materials program that required that all materials identified as hazardous be refused for shipment. Investigators reviewed the process by which the oxygen generators were loaded onto the accident aircraft. The report said, "… Because the five boxes of chemical oxygen generators that were delivered to the ValuJet ramp had no hazardous-material markings or labels, and because the shipping ticket that the SabreTech employee provided to the ValuJet lead ramp agent indicated that the boxes contained empty oxygen canisters, neither the ValuJet lead ramp agent nor the ramp agent who loaded the boxes were provided with information to indicate the hazardous nature of the COMAT shipment. Based on the description of the COMAT on the shipping ticket, they might have assumed that the boxes contained empty (nonhazardous) oxygen cylinders. Therefore, the lead ramp agent likely was not prompted to discuss the contents of the COMAT shipment with the SabreTech employee or the flight crew.

"The shipment also included three aircraft tires, the carriage of which was not prohibited by the hazardous-materials regulations so long as the tires were not over-inflated. Although the lead ramp agent testified that he had shown the shipping ticket to the first officer, it is unlikely that the first officer would have considered empty oxygen canisters or aircraft tires as potentially hazardous. Based on the available information, the flight crew would have had no reason to know or suspect that hazardous materials were being proffered for carriage aboard the airplane. …

"The COMAT was not secured inside the cargo compartment by netting, straps or any other means of preventing movement of the items. Although it is possible that the generator(s) that initiated the fire actuated as a result of being struck by unsecured cargo … it cannot be conclusively determined whether unsecured cargo played a role in actuating the generators."

Investigators reviewed the decisions and actions of the flight crew during the emergency. Twenty seconds after the flight crew discussed the electrical problems, the first officer requested clearance from ATC to return to Miami. The airplane then leveled off and began to descend before receiving clearance from ATC. "Although the captain decided immediately to return to Miami and initiated a descent, for the next 80 seconds the airplane continued on a northwesterly heading (away from the Miami airport) while the flight crew accepted ATC vectors for a wide circle to the left and a gradual descent toward Miami," said the report.

Investigators evaluated the malfunctions that occurred during the 80-second period in which the aircraft continued on a northwest heading, away from Miami. The report said, "The flight crew's comments about the electrical problems indicate that the fire had probably already escaped the cargo compartment by 1410:12. (However, it probably had not yet burned through the cabin floorboards.) The flight-crew comments recorded by the CVR from 1410:12 through 1410:22 reflect the pilots' concerns about and attention to these electrical problems. It is possible that these concerns continued to occupy some of the pilots' attention during the initial period of their attempt to return to the ground."

> ***"The development of malfunctions from the electrical system to engine-thrust controls and flight controls indicates a progressive degradation in the airplane's structural integrity and flight controls."***

FDR data indicated that at about 1410:26 the right-engine EPR decreased to flight idle and the left-engine EPR remained at its previous setting. The reduction in thrust was most likely intended to reduce power for the descent. "The activation of the landing gear warning horn at 1410:28 suggests the flight crew had reduced power to idle …," said the report. "Because the flight crew would not have intentionally reduced thrust on one engine only, they must have been unable to reduce the thrust on the left engine because of fire damage to the engine-control cable located above the compartment. The inability to reduce left-engine thrust could have distracted the flight crew.

"Further, the thrust asymmetry continued throughout the period and in a sideslip and lateral accelerations that were not corrected with rudder application," said the report. "Therefore, left wing–down (LWD) aileron deflections would have been necessary to keep the airplane from rolling to the right. Because there were no right-roll indications in the FDR heading data, the flight crew must have been applying the LWD control inputs."

At 1410:20, the FDR recorded an increase in vertical acceleration to about 1.4 G without any control-column input. The report said, "Subsequently, the control-column position was moved forward about five degrees to reduce vertical acceleration back to 1.0 G. At this time the airplane leveled temporarily at about [2,897 meters] 9,500 feet.

"These events indicate that the flight crew was confronted with a disruption in pitch control (in the elevator or trim systems) and was active in maintaining at least partial control of the airplane," said the report. "The pilots could have found the disruption in control to be distracting, and the level-off is consistent with their attempts to handle the pitch controls carefully. The development of malfunctions from the electrical system to engine-thrust controls and flight controls indicates that the flight experienced a progressive degradation in the airplane's structural integrity and flight controls.

"At 1412:00, FDR-recorded altitude suddenly decreased and no longer agreed with the altitudes recorded from radar transponder returns (these altitudes are derived from different static sources). The disagreement between altitude values indicates that the fire damage continued to increase.

"Radar data show that at 1412:58, when the airplane was at [2,257 meters] 7,400 feet, it began a steep left turn toward Miami and a rapid descent. For the next 32 seconds, the descent rate averaged about [3,660 meters] 12,000 feet per minute, and the airplane turned from a southwesterly heading toward the east. If asymmetric thrust were providing right-yaw/rolling moments during this turn, the flight crew would have had to counter this tendency with continuing left-roll control inputs throughout the turn. The radar data indicated the left turn, then stopped on a heading of about 110 degrees at 1413:25, which was toward MIA. Further, the rapid descent rate was being reduced, with the last transponder-reported altitude at [274 meters] 900 feet. The control inputs required to balance asymmetric thrust during the steep left turn, followed by the level-off, indicates that the flight crew initiated a turn and descent and that the captain and/or the first officer were conscious and applying control inputs to stop the steep left turn and descent (until near 1413:34). Thus, the airplane remained under at least partial control by the flight crew for about three minutes and nine seconds after 1410:25.

"Ground scars show that the airplane was in a large right-roll angle and steep nose-down attitude at impact. To achieve that attitude and fly through the position indicated by the primary radar return recorded at 1413:39, the airplane would have had to start rolling to the right at 1413:34, at least eight seconds before the crash."

Investigators were unable to determine conclusively the reason for the loss of control. "However, examination of the wreckage showed that before the impact the left-side floor beams melted and collapsed, which would likely have affected the control cables on the captain's side," said the report. "It is possible that the first officer might have taken over flying from the captain, but the remaining control cables also were possibly affected by distorting floor beams.

"The loss of control was most likely the result of flight-control failure from the extreme heat and structural collapse; however, it is possible that the flight crew was incapacitated."

"Based on the continuing degradation of flight controls and the damage to cabin floorboards in the area of the flight controls, the [NTSB] concludes that the loss of control was most likely the result of flight-control failure from the extreme heat and structural collapse; however, the [NTSB] cannot rule out the possibility that the flight crew was incapacitated by smoke or heat in the cockpit during the last seven seconds of the flight."

Investigators reviewed ValuJet's guidance and training in fire and smoke emergencies that were provided to the accident flight crew. "ValuJet had established four emergency procedures for handling fire and smoke from electrical-system and air conditioning (pressurization)–system malfunctions, removing smoke from a pressurized airplane and removing cockpit smoke from an unpressurized airplane," said the report.

The pilots were clearly aware of smoke and fire aboard the airplane. Therefore, "the [NTSB] evaluated the effect of the flight attendants' actions on the flight crew, the flight crew's use of the ValuJet smoke evacuation procedures and emergency equipment, and the adequacy of that equipment," said the report.

"When the flight attendant first opened the cockpit door at 1410:52, some smoke from the cabin area was likely introduced into the cockpit environment. However, during the one minute and 42 seconds in which the CVR operated continuously after the emergency began (including the times that the cockpit door was open), the flight crew made no comments about breathing or vision difficulties, nor were there any sounds of coughs from the crew members during this period."

There were no comments or sounds indicating flight crew physical impairment on the CVR. As a result, the [NTSB] concluded that very little smoke entered the cockpit prior to the last recorded crew comment on the CVR at 1411:38. The report said, "However, the [NTSB] is concerned that if the smoke concentrations on the cabin side of the door had been severe when the flight attendant opened the door, her actions could have resulted in the introduction of incapacitating smoke into the cockpit."

The investigation revealed that the interphone system between the cockpit and the cabin was inoperative during the accident flight. With the interphone system inoperative, the crew was required to use an alternate procedure so that the flight attendants could have signaled the flight crew in order to gain access to the cockpit. A prearranged code for knocking on the cockpit door would have been sufficient as an alternate procedure.

"The [NTSB] concludes that the current MEL requirements for the development of an 'alternate procedure' for an inoperative service interphone are inadequate for a cabin-fire situation," said the report. "Therefore, the [NTSB] believes that the FAA should specify, in air carrier operations master MELs, that the cockpit-cabin portion of service interphone system is required to be operating before an airplane can be dispatched.

"Evidence recovered at the accident site indicates that the pilots were active in attempting to remove smoke from the cabin and cockpit before impact, and in doing so they had executed portions of the ValuJet emergency procedures for handling smoke . …

"The four ValuJet emergency procedures for handling smoke and fire uniformly instructed the pilots to don their oxygen masks and smoke goggles as the first item to be performed on the emergency checklist," said the report. An analysis of the flight crew's cockpit conversation indicated that "… neither the captain nor the first officer donned their oxygen masks during the period of the emergency in which the CVR was operative and the pilots were speaking. …

"Because smoke goggles of the type provided to the flight crew must be donned subsequent to the oxygen mask to have any effect, the pilots probably did not don their smoke goggles from the onset of the emergency. …

"Although ... the donning of oxygen masks and smoke goggles would not have assisted the crew in the initial stages of the emergency (because of the absence of heavy smoke in the cockpit), early donning of the smoke-protection equipment might have helped later in the descent if heavy smoke had entered the cockpit."

The NTSB attempted to determine why the accident flight crew did not don their smoke-protection equipment early in the emergency. The flight crew's training records indicated that both pilots had used the smoke-protection equipment during simulator training.

ValuJet records indicated that in September 1995, the captain of ValuJet Flight 592, while flying as PIC of a ValuJet flight that departed DFW, "experienced an emergency that was later determined to have involved an overheated air-conditioning pack," said the report. Shortly after taking off from DFW, the flight crew was notified by the flight attendants that there was smoke in the cabin. The flight crew made an immediate return to DFW because the threat of a fire existed. The first officer who was on that flight stated that he and the captain "discussed whether to don their oxygen masks and smoke goggles as they maneuvered to descend and return to the airport," said the report. "They decided that the situation did not warrant donning the masks or goggles. According to the first officer, no visible smoke was in the cockpit, although they could smell smoke. The airplane returned safely to DFW. …

"In the captain's previous incident involving smoke in the cabin from an overheated air-conditioning pack, she had obtained a successful outcome without donning the mask and goggles. This might have predisposed her to decide not to don an oxygen mask and smoke goggles when the emergency began on the accident flight."

Survey Reveals Most Pilots Unlikely to Don Smoke Goggles and Masks

During the investigation, the NTSB conducted an informal survey of pilots from several air carriers. Most pilots said that for situations such as reports of galley fire, smoke in the cabin or a slight smell of smoke in the cockpit, they would not don masks and smoke goggles. The report said, "Based on the circumstances of this accident and the results of its survey, the [NTSB] concludes that there is inadequate guidance for air carrier pilots about the need to don oxygen masks and smoke goggles immediately in the event of a smoke emergency. …

"Based on the [NTSB]'s simulator evaluation of the equipment furnished to the flight crew of ValuJet Flight 592 and its informal survey of air carrier pilots, the [NTSB] concludes that the smoke-goggle equipment currently provided on most air carrier transport aircraft requires excessive time, effort, attention and coordination by the flight crew to don. Consequently, the [NTSB] believes that the FAA should establish a performance standard for the rapid donning of smoke goggles, then ensure that all air carriers meet this standard through improved smoke-goggle equipment, improved flight crew training or both."

The investigation revealed that many of the smoke goggles used by U.S. air carriers are kept in sealed plastic wrapping. The plastic wrapping is thick enough so that pilots have to use either both hands or their teeth to open the bag.

The report said, "The [NTSB] is concerned that flight crews attempting to don these smoke goggles in an emergency might be unable to open the wrapping material quickly because the configuration of the equipment requires that the oxygen mask be secured over the pilot's face before attempting to don the smoke goggles. The [NTSB] concludes that the sealed, plastic wrapping used to store smoke goggles … poses a potential hazard to flight safety."

"The smoke-goggle equipment currently provided on most air carrier transport aircraft requires excessive time, effort, attention and coordination by the flight crew to don."

In reviewing ValuJet's emergency procedures, investigators found that ValuJet had not adopted a procedure for passenger-cabin smoke evacuation developed by Douglas Aircraft Corp. "This procedure calls for partially opening the right forward service door at the front of the cabin, then opening the passenger aft (tailcone) entrance door," said the report. "According to Douglas, if these doors are opened, the 'airflow will sweep smoke forward [to the open service door]' and the procedure is effective in clearing smoke from both the cabin and cockpit area. This procedure has been adopted by some operators of the DC-9, and similar procedures have been adopted by some operators of Boeing 747 airplanes, but the procedure has not been adopted by most U.S. air carriers. …

"In this accident, the [NTSB] concludes that because of the rapid propagation of the oxygen-fed fire and the resulting damage to the airplane's control cables and structure, the use of the Douglas smoke evacuation procedures would likely not have affected the outcome. The [NTSB] also recognizes that airlines that have not adopted these procedures might have what they believe to be legitimate safety reasons for that decision.

"Nevertheless, the [NTSB] also concludes that the Douglas DC-9 procedures involving partial opening of cabin doors for in-flight evacuation of smoke or fumes from the passenger cabin and similar procedures adopted by some operators of other transport-category airplanes might clear smoke sufficiently in the cabin (and prevent entry into the cockpit) to prolong the occupants' survival time during some fire and smoke emergencies. …

"The [NTSB's] investigation … examined the handling of the chemical oxygen generators … and considered whether actions could have been taken or procedures could have been implemented to prevent the unauthorized placement of these generators on Flight 592. …

"The [NTSB] determines that the failure of both ValuJet and SabreTech to ensure that safety caps were available and installed on the chemical oxygen generators in accordance with prescribed maintenance procedures contributed to the cause of this accident.

"The [NTSB] is alarmed at the apparent willingness of mechanics and inspectors at the SabreTech facility to sign off on work cards indicating that the maintenance task had been completed, knowing that the required safety caps had not been installed, and the willingness of those individuals and other maintenance personnel (including supervisors) to ignore the fact that the required safety caps had not been installed. …

"The [NTSB] concludes that improper maintenance activities and false entries pose a serious threat to aviation safety and must be curtailed. Thus, the [NTSB] believes that the FAA should evaluate and enhance its oversight techniques to more effectively identify and address improper maintenance activities, especially false entries."

"The [NTSB] concludes that improper maintenance activities and false entries pose a serious threat to aviation safety and must be curtailed."

Air Carrier's Oversight of Repair Station Found Inadequate

Investigators reviewed ValuJet's oversight of SabreTech. "As an air carrier choosing to subcontract its heavy-maintenance functions to SabreTech (among other contractors), ValuJet should have overseen and ensured that it understood the activities of SabreTech to the same extent that it would oversee its in-house maintenance functions and employees," said the report. "Although ValuJet conducted an initial inspection and a subsequent audit of SabreTech, and assigned three technical representatives to the facility, there was limited ongoing oversight of the actual work SabreTech was performing for ValuJet.

"ValuJet failed to provide significant on-site quality assurance at SabreTech's Miami facility. As a result, ValuJet failed to recognize the need for and coordinate the acquisition of oxygen generator safety caps and failed to discover the improper maintenance sign-offs indicating that safety caps had been installed. ValuJet also did not recognize and correct SabreTech's use of the wrong parts tags on the expired oxygen generators or ensure that SabreTech's employees were trained on ValuJet's hazardous-materials practices and policies.

"Further, ValuJet failed to recognize and possibly accepted SabreTech's lack of procedures for communicating the hazardous nature of aircraft items left in the shipping and stores area and failed to identify these inadequacies in SabreTech's procedures during its audits and oversight of SabreTech. The FAA's postaccident surveillance findings of inadequate manuals, training and procedures in the maintenance work being performed for ValuJet by other subcontractors is also suggestive that ValuJet provided inadequate oversight of its maintenance subcontracting before the accident. Accordingly, the [NTSB] concludes that ValuJet failed to adequately oversee SabreTech and that this failure was a cause of this accident."

The investigation reviewed the FAA's oversight of ValuJet Airlines. The Atlanta FAA Flight Standards District Office (FSDO) was responsible for overseeing ValuJet's operations. "The surveillance conducted by the Atlanta FSDO … identified many specific problem areas within ValuJet's flight operations and in-house maintenance functions," said the report. "The Atlanta FSDO reacted properly in targeting ValuJet for more intensive surveillance based on its surveillance findings and the air carrier's accident/incident record through the beginning of 1996. …

"This additional surveillance of ValuJet resulted in conclusions by the FAA at the local FSDO level that certain system functions of ValuJet (such as the maintenance reliability program) were performing inadequately. Finally, in February 1996, the FSDO attempted to correct the deficiencies it had identified at ValuJet with a systemic remediation — it halted the growth of the air carrier. …

"By the time ValuJet's growth was halted, it had already outgrown its capability to adequately coordinate and oversee its maintenance functions. This should have been apparent to the FAA earlier, especially given the exceptional pace at which ValuJet was adding airplanes and routes, and its continued outsourcing of its heavy-maintenance functions. …

"After the accident, FAA surveillance during the special-emphasis inspection program identified several deficiencies in ValuJet's auditing and oversight of maintenance subcontracting; that these deficiencies were identified by the FAA only after the accident indicates the inadequacy of the FAA's preaccident surveillance of ValuJet's maintenance subcontracting activities."

In June 1996, ValuJet ceased all revenue operations after executing a consent order with the FAA. The order stated that ValuJet had "conducted airworthiness and aircraft maintenance related activities, and flight operations, contrary to and in violation of the FARs," said the report. "In the order, ValuJet agreed to pay the FAA US$2 million as a remedial (not punitive) payment … ."

The FAA returned ValuJet Airlines' air carrier operating certificate in August 1996. The report said, "The FAA press release of that date stated the following:

- "This action will permit ValuJet to resume operations at a future date if the airline is found to be managerially and financially fit by the [U.S.] Transportation Department, which today issued a tentative finding of ValuJet's economic fitness;
- "The approval follows ValuJet's compliance with a June [1996] … consent order and is the result of an intensive FAA review of ValuJet's revised maintenance and operations programs as well as the airline's management capacity and organizational structure;
- "In accordance with the consent order, and as a result of the FAA evaluation, ValuJet will fly as a smaller airline upon returning to service, starting with up to nine aircraft and adding up to six more over the next few days when it's back in service;
- "ValuJet had 51 aircraft in operation when it ceased operations [in June 1996]. The airline has also sharply reduced the number of outside contractors it will use, and will initially fly one configuration of the DC-9 instead of 11 configurations previously in service;
- "When it returns to service, ValuJet will receive certificate management oversight from the FAA to focus on key areas which have been amended as a result of changes to its policies and procedures;
- "As part of its rigorous evaluation, the FAA required ValuJet to revise its maintenance program and procedures, and retain maintenance personnel in those procedures;
- "The FAA required ValuJet to revise its organizational structure and add additional maintenance and management personnel to increase oversight and strengthen control over its maintenance program; [and;]
- "The FAA conducted complete records-review and conformity checks on each ValuJet aircraft before it was returned to service; required ValuJet to retrain and recheck all ValuJet pilots, instructors, and check airmen; reviewed all ValuJet maintenance and training contracts; required the airline to include contractors performing substantial maintenance and training to be listed on its operations specifications; and inspected ValuJet line facilities maintenance bases, maintenance controls and dispatch operations."

In September 1996 ValuJet resumed operations.

Investigators reviewed ValuJet's procedures for boarding and accounting for lap children. The report said, "… One passenger aboard the accident flight, an unticketed passenger who was boarded by ValuJet as an under-two-year-old lap child (but who was actually four years old), was not immediately accounted for postaccident by ValuJet. The child was not listed on the passenger manifest for the accident flight or on any other record maintained by ValuJet. …

"Based on the failure of the ValuJet passenger manifest and other postdeparture records to account for the lap child on the accident flight, the [NTSB] concludes that ValuJet did not follow its internal procedures for boarding and accounting for lap children. Further, the [NTSB] notes that although [FARs Part 121] requires airlines to maintain a list of the names of all passengers aboard its flights, the procedures established by ValuJet did not call for recording the names of lap children aboard its flights."

"Had the FAA required fire/smoke-detection and fire-extinguishment systems in class-D cargo compartments, ValuJet 592 would likely not have crashed."

Based on its investigation, the NTSB developed a number of findings, the most significant of which were the following:

- "The activation of one or more chemical oxygen generators in the forward cargo compartment of the airplane initiated the fire on ValuJet Flight 592. One or more of the oxygen generators likely were actuated at some point after the loading process began, but possibly as late as during the airplane's takeoff roll;
- "Even if the fire did not start until the airplane took off, a smoke/fire warning device would have more quickly alerted the pilots to the fire and would have allowed them more time to land the airplane;
- "If the plane had been equipped with a fire-suppression system, it might have suppressed the spread of the fire (although the intensity of the fire might have been so great that a suppression system might not have been sufficient to fully extinguish the fire) and it would have delayed the spread of the fire, and in conjunction with an early warning it would likely have provided time to land the airplane safely;

- “Had the [FAA] required fire/smoke-detection and fire-extinguishment systems in class-D cargo compartments as the [NTSB] recommended in 1988, ValuJet 592 would likely have not crashed;

- “Given the information available, the ramp agents’ and flight crew’s acceptance of the company materials shipment was not unreasonable;

- “ValuJet’s failure to secure the cargo was not unreasonable;

- “The loss of control was most likely the result of flight-control failure from the extreme heat and structural collapse; however, the [NTSB] cannot rule out the possibility that the flight crew was incapacitated by smoke or heat in the cockpit during the last seven seconds of the flight;

- “Only a small amount of smoke entered the cockpit before the last recorded flight crew verbalization at 1411:38, including the period when the cockpit door was open;

- “The current minimum equipment list requirements for the development of an ‘alternate procedure’ for an inoperative service interphone are inadequate for a cabin-fire situation;

- “There is inadequate guidance for air carrier pilots about the need to don oxygen masks and smoke goggles immediately in the event of a smoke emergency;

“Improper handling of oxygen generators could be reduced by affixing an effective warning label.”

- “The pilots did not don (or delayed donning) their oxygen masks and smoke goggles, and in not donning this equipment they were likely influenced by the absence of heavy smoke in the cockpit and the workload involved in donning the type of smoke goggles with which their airplane was equipped;

- “The smoke-goggle equipment currently provided on most air carrier transport aircraft requires excessive time, effort, attention and coordination by the flight crew to don;

- “The sealed plastic wrapping used to store smoke goggles in much of the air carrier industry poses a potential hazard to flight safety;

- “Emergency cockpit vision devices might have potential safety benefits in some circumstances;

- “Emerging technology, including research being conducted by the [U.S.] National Aeronautics and Space Administration [NASA], might result in improvements in the potential to provide passenger respiratory protection from toxic cabin atmospheres that result from in-flight and postcrash fires;

- “Because of the rapid propagation of the oxygen-fed fire and the resulting damage to the airplane’s control cables and structure, the use of the Douglas smoke evacuation procedures would likely not have affected the outcome. The Douglas DC-9 procedures involving partial opening of the cabin doors for in-flight evacuation of smoke or fumes from the passenger cabin and similar procedures adopted by some operators of other transport category airplanes might clear smoke sufficiently in the cabin (and prevent entry into the cockpit) to prolong the occupants’ survival time during some fire and smoke emergencies;

- “Given the potential hazard of transporting oxygen generators and because oxygen generators that have exceeded their service life are not reusable, they should be actuated before they are transported;

- “Because work card 0069 did not require an inspector’s sign-off at the completion of each task, and there was no requirement for it to do so, there might have been no inspection of the maintenance work related to the removal of the chemical oxygen generators. Had work card 0069 required an inspector’s sign-off, one of the inspectors involved with the two airplanes might have noticed that safety caps had not been installed on any of the generators;

- “Had work card 0069 required, and included instructions for, expending and disposing of the generators in accordance with the procedures in the Douglas MD-80 maintenance manual, or referenced the applicable sections of the maintenance manual, it is more likely that the mechanics would have followed at least the instructions for expending the generators;

- “Had a warning label or emblem clearly indicating the significant danger posed been affixed to each generator, personnel handling the generators, including the personnel in shipping and stores who prepared them for shipment to Atlanta, might have been alerted to the need to determine how to safely handle and ship the generators;

- “The existing prohibition against transporting oxygen generators on passenger aircraft has not been completely effective, and improper handling of oxygen generators could be reduced by affixing an effective warning label or emblem on all existing and newly manufactured chemical oxygen generators to clearly identify the dangers and hazards of unexpended generators and the severe consequences that can occur if mishandled;

- "Although the installation of safety caps would not likely have prevented the oxygen generators from being transported aboard Flight 592, it is very likely that had safety caps been installed, the generators would not have activated and the accident would not have occurred;

- "Improper maintenance activities and false entries pose a serious threat to aviation safety and must be curtailed;

- "Although the use of the wrong parts tag was an additional failure of SabreTech to perform maintenance activity in accordance with prescribed maintenance procedures, it probably did not contribute to the mishandling of the generators that ultimately led to the generators being loaded into the forward cargo compartment on Flight 592;

- "The maintenance duty-time limitations of [FARs] Part 121.377 may not be consistent with the current state of scientific knowledge about factors contributing to fatigue among personnel working in safety-sensitive transportation jobs;

- "The lack of a formal system in SabreTech's shipping and receiving department, including procedures for tracking the handling and disposition of hazardous materials, contributed to the improper transportation of the generators aboard Flight 592;

- "The failure of SabreTech to properly prepare, package and identify the unexpended chemical oxygen generators before presenting them to ValuJet for carriage aboard Flight 592 was causal to the accident;

- "Some aspects of air carrier maintenance programs do not adequately reflect the human factors issues involved in the air carrier maintenance environment;

- "Contrary to its authority, ValuJet's practices before the accident might have included the shipment of hazardous aircraft-equipment items aboard company airplanes;

- "The procedures of many air carriers for handling COMAT are not fully consistent with the hazardous-materials regulations and the guidance provided on Dec. 13, 1996, by the Research and Special Programs Administration on the transport of COMAT by air carriers;

- "It is equally important that employees of both air carrier and of the relevant subcontractors be thoroughly versed and trained on the handling of hazardous materials and on the air carrier's authority to transport hazardous materials;

- "Had ValuJet implemented a program to ensure that its subcontractor maintenance-facility employees were trained on the company's lack of authority to transport hazardous materials and had received hazardous-materials recognition training, SabreTech might not have mishandled the packaging and shipment of the chemical oxygen generators that were loaded on Flight 592;

- "ValuJet failed to adequately oversee SabreTech, and this failure was a cause of this accident;

- "Before the accident, the [FAA's] oversight of ValuJet did not include any significant oversight of its heavy-maintenance functions. The FAA's inadequate oversight of ValuJet's maintenance functions, including its failure to address ValuJet's limited oversight capabilities, contributed to this accident;

- "The continuing lack of an explicit requirement for the principal maintenance inspector of a Part 121 operator to regularly inspect or surveil Part 145 repair stations that are performing heavy maintenance for their air carriers is a significant deficiency in the [FAA's] oversight of the operator's total maintenance program;

- "The manner in which the [FAA's] Southern Region applied the results of the [FSDO] staffing-level models was not sufficiently flexible to account for a rapidly growing and complex air carrier and resulted in an inadequate level of inspector resources in the Atlanta FSDO;

- "In part, because he was responsible for so many operators, the principal maintenance inspector assigned to oversee the SabreTech facility in Miami was unable to provide effective oversight of the ValuJet heavy-maintenance operations conducted at that facility;

- "Had the [FAA] responded to prior chemical oxygen-generator fires and allocated sufficient resources and initiated programs to address the potential hazards of these generators, including issuing follow-up warnings and inspecting the shipping departments of aircraft maintenance facilities, the chemical oxygen generators might not have been placed on Flight 592;

- "The limited authority of the U.S. Postal Service [USPS] and the [FAA] to inspect and thus successfully identify undeclared hazardous materials in U.S. mail loaded on airplanes creates a situation in which undeclared

"Maintenance duty-time limitations may not be consistent with scientific knowledge about fatigue."

shipments of hazardous materials can readily find their way aboard passenger airplanes;

- "Because of the lack of information regarding products approved for transportation by the [Department of Transportation's] Bureau of Explosives, Research and Special Programs Administration cannot adequately ensure that these products are being packaged and shipped safely in the transportation environment;

- "ValuJet did not follow its internal procedures for boarding and accounting for lap children; [and,]

- "It is essential that air carriers maintain easily accessible and accurate records of the names of both ticketed and unticketed passengers aboard their flights for retrieval in the event of an accident or emergency."

As a result of its findings, the NTSB made the following recommendations to the FAA:

- "Expedite final rulemaking to require smoke-detection and fire-suppression systems for all class-D cargo compartments;

- "Specify in air carrier operations master minimum equipment lists that the cockpit-cabin portion of the service interphone system is required to be operating before an airplane can be dispatched;

- "Issue guidance to air carrier pilots about the need to don oxygen masks and smoke goggles at their first indication of a possible in-flight smoke or fire emergency;

- "Establish a performance standard for the rapid donning of smoke goggles; then ensure that all air carriers meet this standard through improved smoke-goggle equipment, improved flight crew training, or both;

- "Require that the smoke goggles currently approved for use by the flight crews of transport-category aircraft be packaged in such a way that they can be easily opened by the flight crew;

- "Evaluate the cockpit emergency-vision technology and take action as appropriate;

- "Evaluate and support appropriate research, including the [NASA] research program, to develop technologies and methods for enhancing passenger respiratory protection from toxic atmospheres that result from in-flight and postcrash fires involving transport-category airplanes;

- "Evaluate the usefulness and effectiveness of the Douglas DC-9 procedures involving the partial opening of cabin doors and similar procedures adopted by some operators of other transport-category airplanes for evacuating cabin smoke or fumes, and based on that evaluation, determine whether these or other procedures should be included in all manufacturers' airplane flight manuals and air carrier operating manuals;

- "Require airplane manufacturers to amend company maintenance manuals for airplanes that use chemical oxygen generators to indicate that generators that have exceeded their service life should not be transported unless they have been actuated and their oxidizer core has been depleted;

- "Require that routine work cards used during maintenance of Part 121 aircraft (a) provide, for those work cards that call for the removal of any component containing hazardous materials, instructions for disposal of the hazardous materials or a direct reference to the maintenance-manual provision containing those instructions and (b) include an inspector's signature block on any work card that calls for handling a component containing hazardous materials;

- "Require manufacturers to affix a warning label to chemical oxygen generators to effectively communicate the dangers posed by unexpended generators and to communicate that unexpended generators are hazardous materials; then require that aircraft manufacturers instruct all operators of aircraft using chemical oxygen generators of the need to verify the presence of (or affix) such labels on chemical oxygen generators currently in their possession;

- "Require all air carriers to develop and implement programs to ensure that other aircraft components that are hazardous are properly identified and that effective procedures are established to safely handle those components after they are removed from aircraft;

- "Evaluate and enhance [the FAA's] oversight techniques to more effectively identify and address improper maintenance activities, especially false entries;

- "Review the adequacy of current industry practice and, if warranted, require that Part 121 air carriers and Part 145 repair facilities performing maintenance for air carriers develop and implement a system requiring items delivered to shipping and receiving and stores areas of the facility to be properly identified and classified as hazardous or nonhazardous, and procedures for tracking the handling and disposition of hazardous materials;

- "Include in [the FAA's] development and approval of air carrier maintenance procedures and programs explicit consideration of human factors issues including training, procedures development, redundancy, supervision and the work environment, to improve the performance of personnel and their adherence to procedures;

- "Review the issue of personnel fatigue in aviation maintenance; then establish duty-time limitations consistent with the current state of scientific knowledge for personnel who perform maintenance on air carrier aircraft;
- "Issue guidance to air carriers on procedures for transporting hazardous aircraft components consistent with Research and Special Programs Administration requirements for the transportation of air carrier company materials; then require principal operations inspectors to review and amend, as necessary, air carrier manuals to ensure that air carrier procedures are consistent with this guidance;
- "Require air carriers to ensure that maintenance facility personnel, including mechanics, shipping, receiving and stores personnel at air carrier–operated or subcontractor facilities are provided initial and recurrent training in hazardous-materials recognition and in proper labeling, packaging and shipment procedures with respect to the specific items of hazardous materials that are handled by the air carrier's maintenance functions;
- "Ensure that Part 121 air carriers' maintenance functions receive the same level of [FAA] surveillance, regardless of whether those functions are performed in house or by a contract maintenance facility;
- "Review the volume and nature of the work requirements of principal maintenance inspectors assigned to Part 145 repair stations that perform maintenance for Part 121 air carriers and ensure that these inspectors have adequate time and resources to perform surveillance;
- "Develop, in cooperation with the [USPS] and [ATA], programs to educate passengers, shippers and postal customers about the dangers of transporting undeclared hazardous materials aboard aircraft and about the need to properly identify and package hazardous materials before offering them for air transportation. The programs should focus on passenger baggage, air cargo and mail offered by [USPS] customers; [and,]
- "Instruct principal operations instructors to review their air carriers' procedures for manifesting passengers, including lap children, and ensure that those procedures result in a retrievable record of each passenger's name."

The NTSB made the following recommendation to the Research and Special Programs Administration: "Develop records for all approvals previously issued by the Bureau of Explosives and transferred to the Research and Special Programs Administration and ensure all records, including designs, testing and packaging requirements, are available to inspectors to help them determine that products transported under those approvals can be done safely and in accordance with the requirements of its approval."

The NTSB made the following recommendations to the USPS:

- "Develop, in cooperation with the [FAA] and the [ATA], programs to educate passengers, shippers and postal customers about the dangers of transporting undeclared hazardous materials aboard aircraft and about the need to properly identify and package hazardous materials before offering them for air transportation. These programs should focus on passenger baggage, air cargo and mail offered by [USPS] customers;
- "Develop a program for [USPS] employees to help them identify undeclared hazardous materials being offered for transportation; [and,]
- "Continue to seek civil enforcement authority when undeclared hazardous-materials shipments are identified in transportation."

The NTSB made the following recommendation to the ATA: "Develop, in cooperation with the [USPS] and the [FAA], programs to educate passengers, shippers and postal customers about the dangers of transporting undeclared hazardous materials aboard aircraft and about the need to properly identify and package hazardous materials before offering them for air transportation. The programs should focus on passenger baggage, air cargo and mail offered by [USPS] customers."♦

Editorial note: This article was adapted from *In-flight Fire and Impact with Terrain, ValuJet Airlines Flight 592, DC-9-32, N904VJ, Everglades, near Miami, Florida, May 11, 1996*. Report no. NTSB/AAR-97/06. The 257-page report contains figures and appendixes.

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