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SPECIAL DOUBLE ISSUE

After Smoke Detected in Cargo Compartment Crew Lands DC-10, Then Fire Destroys Aircraft

Although there were only minor injuries in the evacuation, the evacuation was delayed by the flight crew's failure to depressurize the aircraft. Investigators were unable to determine the fire's ignition source but found evidence of undeclared hazardous cargo.

FSF Editorial Staff

In the early-morning darkness of Sept. 5, 1996, the crew of a McDonnell Douglas DC-10-10CF cargo aircraft operated by Federal Express Corp. (FedEx) landed their aircraft at Stewart International Airport, Newburgh, New York, U.S., after the flight crew was alerted during cruise flight by the smoke-detector system that there was smoke in the cabin cargo compartment. The captain and flight engineer were slightly injured while evacuating the aircraft, and the first officer and two nonrevenue passengers — the aircraft's only other occupants — evacuated without injury. The aircraft was destroyed by fire.

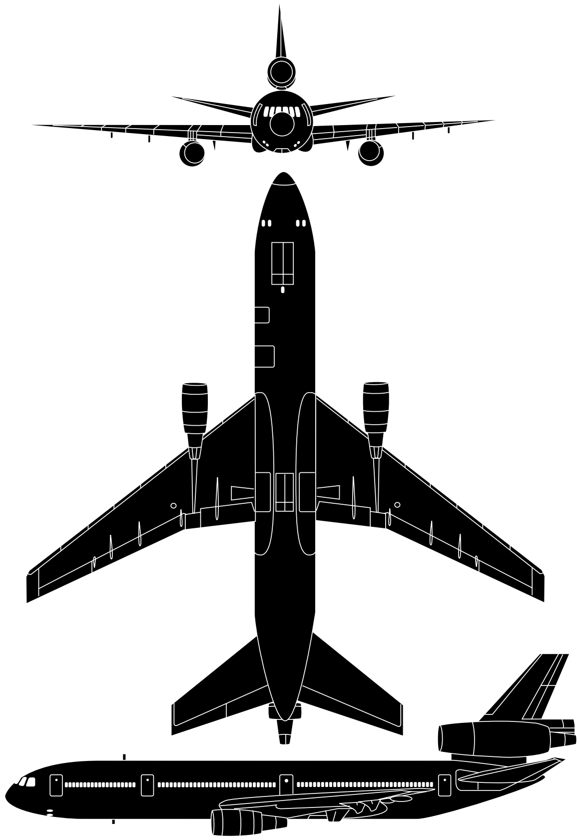
The U.S. National Transportation Safety Board (NTSB), in its final accident report, determined that the probable cause of the accident was "an in-flight cargo fire of undetermined origin."

FedEx Flight 1406 was en route from Memphis, Tennessee, U.S., to Boston, Massachusetts, U.S., with a scheduled return flight to Memphis. The flight engineer said that prior to the flight he was briefed by a FedEx dangerous-goods specialist about hazardous materials in cargo containers in cargo positions 1L/1C and 3R (Figure 1, page 3) and about the Halon-hose connections to the container in cargo position 1L/1C, which was designed to hold flammable goods.

"The dangerous-goods specialist then gave the captain the Notification of Dangerous Goods Loading Form (Part A) containing required [by the U.S. Department of Transportation (DOT)] hazardous-materials information, which the captain signed," said the report. "According to the FedEx flight operations manual, 'Appropriate parts (A; B and/or BR; C and/or CR) of the Notification of Dangerous Goods Loading Form … are required for each departure.'

"The Part A forms list the class of hazardous materials and where they are on the airplane, and [serve] as the required written notification to the pilot-in-command. The Part B forms are the individual shipping documents for each shipment of hazardous materials, other than radioactive materials. The Part BR forms are for shipments of radioactive materials. The Part C and CR forms are comparable to the Part B and BR forms, respectively, but are used for domestic shipments only."

Flight 1406, operating under U.S. Federal Aviation Regulations (FARs) Part 121, took off from Memphis at 0242 local time, with the first officer as the pilot flying (PF) and



McDonnell Douglas DC-10-10CF

The McDonnell Douglas DC-10-10 was the first model in the DC-10 series, and first flew in August 1970. The aircraft, powered by General Electric CF6-6D or CF6-6D1 turbofan engines, was produced in an initial version with a maximum takeoff weight of 410,000 pounds (185,970 kilograms) and a range of 3,600 miles (5,795 kilometers). A later version with added center-wing fuel capacity has a maximum takeoff weight of 455,000 pounds (206,385 kilograms) and a range of 4,205 miles (6,768 kilometers).

Normal cruising speed is Mach 0.82, with a service ceiling of 34,800 feet (10,605 meters) with the CF6-6D engine or 35,200 feet (10,730 meters) with the CF6-6D1 engine. The DC-10-10CF was designed as a passenger version of the DC-10-10 that could be easily and quickly converted to cargo use.

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

the captain as the pilot not flying. The two nonrevenue passengers were seated in a foyer area directly behind the cockpit (Figure 2, page 4). The flight crew said that the engine start, taxi, takeoff and climb were normal.

"The airplane's upper cargo deck was loaded with 23 cargo containers and one cargo pallet," said the report. "The lower forward cargo compartment contained six cargo containers, and the lower aft cargo compartment contained seven containers."

At 0536:23 the aircraft was at flight level (FL) 330. The cockpit voice recorder (CVR) recorded the captain asking, "What the hell's that?"

Both the first officer and the flight engineer said, "Cabin cargo smoke."

The captain said, "You see that … we got cabin cargo smoke … cabin cargo smoke."

The flight engineer said, "Cabin cargo smoke, oxygen masks on."

The report said, "The CVR indicates that the crew then donned oxygen masks and established crew communications, as is required by the first two steps on the Fire & Smoke Checklist … .

"During postaccident interviews and in his deposition, the captain stated that he initially donned his smoke goggles, but had to remove his eyeglasses to do so. During the landing phase of the flight, he removed his goggles so he could replace his glasses. The captain also said that the goggles were dirty and scratched. The first officer stated that he elected not to wear his smoke goggles because he felt that they would unduly restrict his peripheral vision. The flight engineer initially donned his smoke goggles, but then removed them after noting that no smoke was entering the cockpit."

At 0536:40, the flight engineer said, "Okay, it's no. 9 smoke detector." The first officer suggested that the passengers enter the cockpit. They did so and then donned oxygen masks.

At 0537:56, the captain said, "Okay, it's moving forward whatever it is … it's up to [smoke detector no.] 7." The captain asked the flight engineer to test the smoke-warning system, and during the test several lights were flashing rather than steady.

The report said, "The FedEx DC-10 flight manual states, 'If a flashing [cargo fire/smoke-detector] indicator light is observed during the normal test procedure of the cargo fire/smoke-detector units, the crewmember is alerted that the detector unit connected to the flashing light is beginning to deteriorate. *A flashing indicator light does not signify an inoperative fire/smoke detector.* … A totally inoperative fire/smoke-detector unit will not illuminate during the normal test procedure. (Emphasis in original.)"

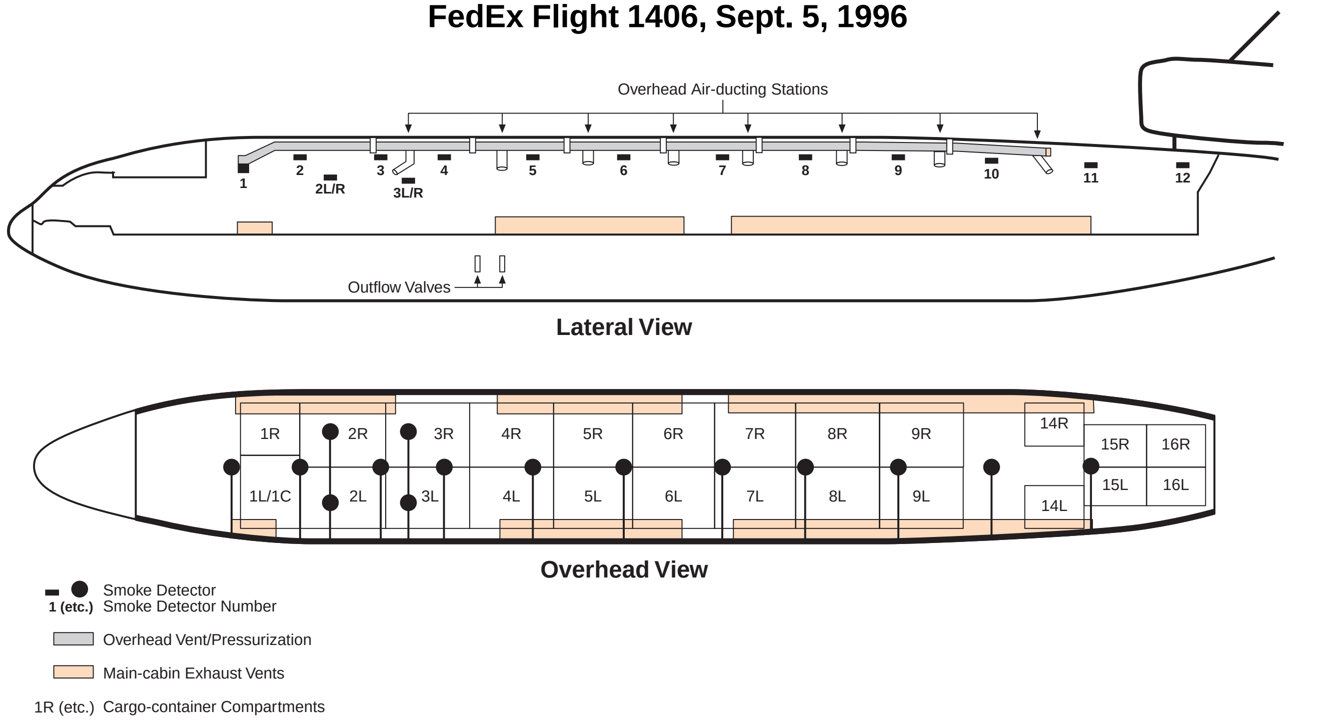
At 0539:28, the captain said, "That's seven and eight."

At 0539:31, the flight engineer said, "Those others may be failing in the blinking mode."

The captain said, "I got 10 now," and then, "We've definitely got smoke, guys … we need to get down right now, let's go."

The captain chose to have the first officer continue as PF while the captain communicated with air traffic control and worked with the flight engineer on performing the checklists.

Systems and Cargo-container Compartments of DC-10-10CF, FedEx Flight 1406, Sept. 5, 1996



Source: U.S. National Transportation Safety Board

Figure 1

After the captain informed the U.S. Federal Aviation Administration (FAA) Boston Air Route Traffic Control Center (ARTCC) of the emergency at 0540:43, Flight 1406 was cleared for immediate descent to 11,000 feet. The captain later said that although he did not call for the Emergency Descent Checklist, he believed that he had completed all the checklist items from memory.

The ARTCC controller told the pilots that the Albany (New York, U.S.) County Airport was about 50 miles (80 kilometers) ahead of the aircraft and Stewart was 25 miles (40 kilometers) behind.

But at 0542:36 the ARTCC controller said, “I’ve got Albany in your 11 o’clock and about 45 miles [72 kilometers] or Stewart in your southwesterly position and, ah, 40 miles [64 kilometers] … your choice.”

The captain chose to divert to Stewart and was given vectors to the airport.

At 0541:41, the flight engineer began the Cabin Cargo Smoke Light Illuminated Checklist. At 0543:02, he said, “I’m manually raising the cabin altitude … there is smoke in the, ah, cabin area.” The CVR recorded the flight engineer asking five times, between 0543:22 and 0549:09, what the three-letter identifier for Stewart was. The identifier (SWF) was, nevertheless, supplied by ARTCC twice, at 0543:47 and 0546:26.

The report said, “During postaccident interviews, the flight engineer told [NTSB] investigators that he was confused by some items on the Cabin Cargo Smoke Light Illuminated Checklist and acknowledged that he did not accomplish step no. 6, Cabin Air Shutoff T-Handle (when the T-handle is pulled, airflow is maintained to the cockpit area, but all airflow is shut off to the main-deck cargo area).

“Regarding step no. 7, Maintain 0.5 [Differential] Pressure Below FL 270, or 25,000 [Feet] Cabin Altitude Above FL 270, [the flight engineer] acknowledged that he did not attempt to maintain 0.5 pounds per square inch (psi) differential pressure, but said that he had selected ‘manual’ on the outflow valve control and ‘cranked it open a couple of times.’”

The flight was handed off from ARTCC to New York terminal radar approach control (TRACON). In response to a question from TRACON, the captain indicated that there were hazardous materials on board. The captain said in talking to investigators that as the aircraft approached Stewart, visibility in the cockpit was good, but he could smell smoke through his oxygen mask.

Flight 1406 was cleared for landing on Runway 27, and the aircraft was landed at 0554:28. The captain took over the controls from the first officer during the rollout and stopped

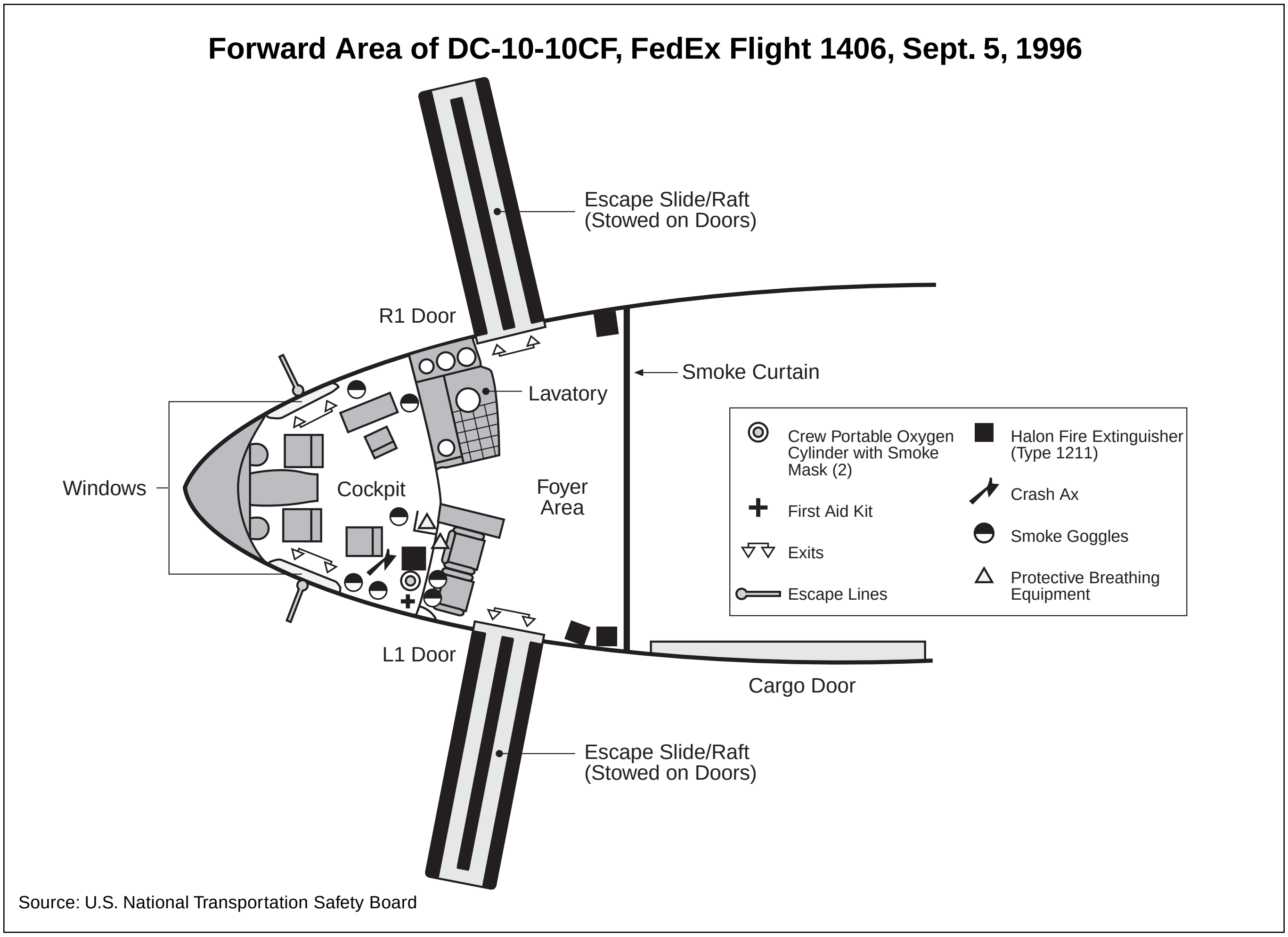


Figure 2

the aircraft on a taxiway, where aircraft rescue and firefighting (ARFF) trucks were positioned.

Weather at the time of the landing was recorded by the Stewart tower as: wind from 280 degrees at four knots; surface visibility two miles (3.2 kilometers) with mist; broken clouds at 3,000 feet above ground level and an overcast layer of clouds at 7,000 feet above ground level; temperature 64 degrees Fahrenheit (F; 18 degrees Celsius [C]); dew point 63 degrees F (17 degrees C); and altimeter setting 30.18 inches of mercury (1022 hectopascals).

"The flight engineer said that when he opened the cockpit door after landing, he saw that the foyer area was full of smoke, and he could not see the smoke barrier [a curtain] at the aft end of the foyer," said the report. "The captain later told investigators that both he and the flight engineer called for an emergency evacuation. The CVR indicates that at 0555:07, the captain stated, 'We need to get the [hell] out of here," and that 12 seconds later the flight engineer said, 'Emergency ground egress.'"

Both the captain and the flight engineer later said that the Emergency Evacuation Checklist had not been performed, although the flight engineer said that he had turned off the battery switch.

The flight engineer attempted to open the L1 (forward left) and R1 (forward right) doors, but was initially unsuccessful; at the same time, the captain attempted to open the cockpit window and felt resistance, then a hissing sound when air escaped. The captain shouted that the aircraft was still pressurized.

The flight engineer then depressurized the aircraft by rotating the outflow valve control, and again attempted to open the L1 and R1 doors. Both evacuation slides deployed (although the L1 door opened only partially) and the captain and the first officer were able to open their cockpit windows.

The report said, "The L1 and R1 cabin doors are plug-type doors that are normally powered up and down by an electric motor through a gearbox, cable drums, sprockets and torque tube, and one-eighth inch [0.3-centimeter] nylon-coated drive cables that are attached to the door. During emergency operation, an air motor drives the door open [using air supplied from a] bottle charged with nitrogen to 1,500 psi.

"The door is designed to open when activated when the cabin pressure differs by less than approximately 0.5 psi from the external pressure. If an attempt to open the door is made with the pressure differential greater than 0.5 psi, the bottle pressure will bleed off and the door will not open. A ratchet-type lock prevents the door from closing all the way if it is only partially opened."

The captain and first officer remained in the cockpit, their upper bodies outside the windows, until the flight engineer and the passengers had evacuated the aircraft by the R1 evacuation slide. The captain and first officer then used the cockpit windows' escape ropes to evacuate, during which the captain suffered rope burns on his hands and the flight engineer's forehead was slightly cut.

"The flight engineer said that while he was in the airplane, the smoke was 'oily and sooty' and acrid smelling, and that it made breathing unpleasant and difficult," said the report. "He said that before he left the cockpit, he used his oxygen mask to fill his lungs with oxygen and then entered the foyer area. He stated during his deposition that he did not consider using the PBE [protective-breathing equipment] that was available in the cockpit because he was anxious to open the exit doors, and he thought [that] this could be accomplished relatively quickly. He also indicated that he forgot that the PBE was available in the cockpit."

Initially, firefighters entered the foyer area, from which they attempted to extinguish the fire using hand-held hoses, but their access to the cargo compartment was blocked by the cargo net and the forward cargo containers. After some difficulty, they opened the fuselage cargo door about 0650 and again attempted to extinguish the fire by aiming hand-held hoses into the cabin. About 0655, one hour after the aircraft landed and about one hour and 19 minutes after the illuminated smoke-detector lights were seen, fire burned through the top of the fuselage.

"Some of the witnesses … and video footage taken by firefighters of the right side of the airplane indicate that early visible flames came through the top of the fuselage at a point approximately even with the trailing edge of the wings (in an area roughly corresponding to the junction of cargo container rows 8 and 9)," said the report. "However, a FedEx mechanic who had assisted firefighters in opening the cargo door said that just before observing the fire erupting through the top of the fuselage he saw paint bubbling, aluminum melting and 'fingers' of fire coming from the left side of the fuselage five [feet] to eight feet [1.5 meters to 2.4 meters] back from the left wing (which roughly corresponds to the forward portion of cargo container position 6L)."

The incident commander reconsidered the firefighting strategy after the fire penetrated the fuselage.

"Firefighters began using truck-mounted turrets aimed at the breached areas of the fuselage," said the report. "These firefighting efforts continued until approximately 0925, when the fire was extinguished and cleanup operations began.

"There were melted and partially consumed aluminum fuselage skin, longerons and frames throughout the interior fuselage. … The fuselage crown was consumed by the fire … from approximately the middle of container row 4 to the middle of container row 5. The frame flanges on either side of this consumed area of the fuselage crown were burned and melted. The left side of the fuselage crown was also consumed by fire [in] an area corresponding to approximately the middle of cargo container 6L [that is, the container in cargo position 6L] to the middle of cargo container 9L."

Areas in the lower cargo compartment were scorched, but none of the cargo containers in the lower forward and lower center cargo compartments were damaged, and the lower aft cargo compartment was empty.

The fuselage separated at fuselage station (FS) 1531 and FS 1986 (between cargo container rows 8 and 9 and between cargo container rows 15 and 16). The interior skin of the separated section was sooted at the crown.

"Soot deposits on the left side of the cabin interior just forward of FS 1531 (which was at the front of cargo container row 9) were in a 'V' pattern with the lowest point of the 'V' being on the floor level at the fuselage-separation point," said the report. [According to standard fire-investigation principles, the narrow point of a conical "V" pattern indicates the fire's origin.]

The airplane, whose replacement cost was estimated at US$95 million, was destroyed by the fire. Most of the cargo was destroyed by fire, smoke and the firefighting agent applied during ARFF operations. The destroyed cargo was valued at an estimated $300 million.

The captain, 47, had been flying for FedEx since 1979. He held an airline transport pilot (ATP) certificate and, at the time of the accident, he had 12,344 hours of flight time, with 883 hours in type as first officer and 1,621 hours as captain.

The captain had a first-class medical certificate with the restriction, "must wear corrective lenses."

The first officer, 41, was hired by FedEx in 1989. He had an ATP certificate and a type rating in the McDonnell Douglas DC-9. His first-class medical certificate carried the restriction, "must wear corrective lenses," and the first officer indicated that he had worn his eyeglasses at all times during the accident flight.

At the time of the accident, the first officer had 6,535 hours of flight time, with 1,101 hours in the DC-10 as a flight engineer and 237 hours as a first officer.

The flight engineer, 45, had been flying for FedEx since March 1996. He had an ATP certificate and was type-rated in the

Boeing 737. His first-class medical certificate included the restriction, "must wear corrective lenses," and he told investigators that his eyeglasses were needed only for distant vision and that he removed them periodically. He said that he was not wearing his eyeglasses during the emergency portion of the accident flight.

At the time of the accident, the flight engineer had 3,704 hours of flight time, with 188 hours in the DC-10 as flight engineer.

After leaving the aircraft, the flight engineer provided firefighters with the top sheet of Part A of the "Notification of Dangerous Goods Loading."

The report said, "A 'Dangerous Goods Separation Pouch' for each cargo container that transports a declared hazardous-materials package is inserted into the Part A envelope. … The Part A and the separation pouch do not indicate the specific hazardous materials and the quantities on board the airplane.

"Specific information about the hazardous materials in a given package, such as the proper shipping name, United Nations identification number, and hazard class, quantity and 24-hour emergency telephone number, is found on the 'Notification of Loading of Dangerous Goods (Parts B or C)' … ."

ARFF at Stewart was provided by the New York Air National Guard (ANG), assisted by municipal fire departments. The Stewart FedEx station manager arrived at the ramp facility about 0603, and personnel were in communication by telephone with the FedEx Global Operations Command Center (GOCC) in Memphis. State and local emergency, police, environmental-protection and health agencies also responded to the accident.

The report said, "Both the initial incident commander and the ANG fire chief (who took over at 0700 as incident commander) indicated that they were concerned about the safety of the firefighters and the possible exposure of personnel at the scene to the hazardous materials or their combustion by-products. Consequently, both requested (but did not receive) copies of what they referred to as 'manifests' from the flight crew and other FedEx representatives so they could identify the specific hazardous materials on board and their quantities and locations on the airplane.

"The ANG fire department log had entries at 0730, 0815 and 1125 logging ANG personnel's efforts to have FedEx fax copies of the 'manifest' to airport operations or to the FedEx ramp facility at Stewart. The fire chief also stated that he gave a local FedEx employee two fax numbers at the ANG command center, and he assigned two ANG personnel to stand by those machines. However, no faxes from FedEx were received at those machines."

FedEx told NTSB investigators that the FedEx dangerous-goods hub in Memphis and the GOCC faxed several copies of Part A, Parts B, BR or CR, the Dangerous Goods Separation Pouches and the weight-and-load plans at various times during the morning to the emergency-operations center at Stewart.

"The airport operations log contained entries at 0635 that the FedEx 'manifest' had arrived by fax, and, at 0656, that additional hazardous-materials 'manifest' information had been received," said the report. "Airport officials who received those faxes indicated that [the faxed documents] were of poor quality and therefore did not provide them with the needed information."

After delivering the Part A form to firefighters, the flight engineer told firefighters that the Part B forms and other documentation were on the back of the cockpit door.

"However, [the Part B forms and other documentation] were not retrieved until the day after the accident when the burned and water-soaked remains of the shipping documents were recovered," said the report. "During the deposition proceeding, the ANG fire chief stated that about one hour and 15 minutes after the firefighting operation began, FedEx employees advised that the Part Bs were on the aircraft. The fire chief indicated that no attempt was made to retrieve the Part Bs at that time because of the severity of the fire."

The ANG base commander attempted to learn, from FedEx's vice president for security, details of the hazardous materials aboard the aircraft.

"According to the ANG command post chief, the vice president advised the command post chief that he could not provide the information because the [NTSB] had taken over the investigation," said the report. "In a Jan. 27, 1997, letter of explanation to the [NTSB], FedEx stated that the vice president's actions were consistent with company policy, which dictates that once the [NTSB] has taken control of an aircraft-accident investigation, all information pertaining to that investigation is to be forwarded to the [NTSB]. The FedEx letter also stated that at the time of the ANG request, the senior [New York Department of Environmental Conservation] law-enforcement officer, the [New York State Police] and other appropriate state officials already had copies of documents listing the hazardous materials on board."

Investigators assessed the damage to cargo containers and their contents.

"The cargo containers that had been in the main cabin were removed from the airplane and arranged in the same order in which they had been in the airplane," said the report. "A conical 'V' burn pattern was observed from right to left and from forward to rear with the lowest (deepest-burned) area centered over container 6R. It was observed that the cargo in containers surrounding 6R (position 6L, 7R and 5R) was burned to a greater depth along the sides next to container 6R than in the other areas of those containers."

The containers in positions 1L/1C and 3R held declared hazardous materials.

The container in cargo position 1L/1C had soot on the upper outside but no soot inside.

"The contents of container 1L/1C were secured by netting, and the packaging was tight and in place," said the report. "No discrepancies were noted during the postaccident examination regarding the separation, segregation and orientation of the packages in the container." Only one package within the container showed signs of damage, caused by leakage from a cooler pack.

The container in cargo position 3R was severely burned on the sides, although not on the bottom.

"The cargo container was emptied and its radioactive contents inventoried," said the report. "All of the inner containers for the radioactive materials were found intact. Ten separate shipments of radioactive materials were found in the container. All other recognizable shipments declared as hazardous materials were also unloaded from 3R and inventoried. Some contents were consumed by fire; others had sustained some level of water [damage] and/or fire damage."

The container in cargo position 6R was the only one to exhibit fire damage in every level of its contents, as well as its bottom.

"Container 6R's aluminum roof, three Lexan® walls and nylon roll-up curtain (the fourth wall) were completely consumed by fire, except for a small portion at the bottom center of the aft Lexan wall," said the report.

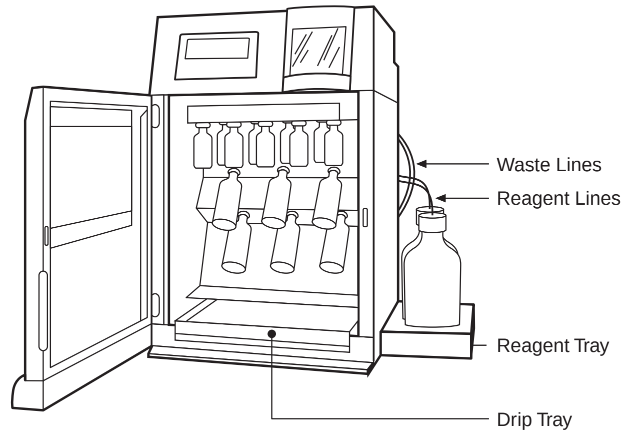
Four shipments were included in the container in cargo position 6R: one of industrial metal valves, one of an Expedite Model 8909 DNA [deoxyribonucleic acid, the cell-nucleus component that transmits hereditary characteristics] synthesizer (Figure 3) and two separate computer shipments.

The report said, "The [DNA synthesizer] unit contained several bottles with labels that included flammability symbols, and some of the bottles contained liquid. One large bottle in the aft row had a very strong odor when it was removed from the unit. Because this unit was found at the lowest point of the 'V' burn pattern, the [NTSB] investigation evaluated and analyzed the liquids contained in this unit.

"According to PerSeptive [Biosystems Inc., the manufacturer], when the synthesizer is set up for normal operation, the reagent bottles contain a variety of liquid reagents, several of which are regulated as hazardous materials, including acetonitrile and tetrahydrofuran (THF), both of which are classified as flammable liquids under the DOT hazardous-materials regulations."

The glass bottles inside the DNA synthesizer and portions of the tubes affixed to the bottles were removed and labeled.

Expedite Model 8909 DNA Synthesizer



Source: U.S. National Transportation Safety Board

Figure 3

The report said, "On Dec. 16 and 17, 1996, at the NASA [U.S. National Aeronautics and Space Administration] Kennedy Space Center [near Cape Canaveral, Florida, U.S.], investigators documented and analyzed the fluids and debris recovered from the DNA synthesizer; fluid removed from the industrial valves; green, red and cream-colored material found on the inboard side of the [6R] container floor; and burned debris that had been removed from cargo container 6R.

"Gas chromatography/mass spectrometry was used to analyze the residues left in the bottles of the accident synthesizer. Specifically, investigators looked for the presence of the 15 chemicals used in the DNA synthesizer and for the presence of aqueous film-forming foam, a fire-fighting agent that was sprayed on the accident airplane."

Investigators attended demonstrations of the process that had been used to purge and dry the bottles in the DNA synthesizer when the synthesizer had been prepared for shipping by its owner, Chiron Corp. The residues left in the bottles from the second of the two demonstrations, which took place at the U.S. Armed Forces Institute of Pathology (AFIP) [Washington, D.C., U.S.], were analyzed for comparison with the residues found in the DNA synthesizer aboard the accident aircraft.

"The largest liquid sample in the accident synthesizer (approximately five milliliters in the AUX 3 reagent bottle) had a concentration of 4.3 percent of acetonitrile and 0.01 percent of THF," said the report. "This is equivalent to about 200 microliters of acetonitrile and 0.5 microliters of THF. In comparison, the AUX 3 bottle from the synthesizer that was purged at AFIP, according to the procedures in PerSeptive's manual, contained only 66 microliters of acetonitrile and 0.2 microliters of THF. Thus, after the accident, the AUX 3 bottle

Cockpit Voice Recorder Transcript
FedEx Flight 1406, Sept. 5, 1996

Time	Source	Content
0536:00	CAM	[start of transcript]
0536:00	CAM-1	oh you were back there when we discussed all this, I forgot.
0536:04	CAM-1	this thing's on a … this thing is on a check status.
0536:07	CAM-2	is it?
0536:07	CAM-1	it's just the fact that they got the paperwork all screwed up.
0536:10	CAM-2	we'll couple it up?
0536:12	CAM-1	you just want to go ahead and couple it yourself and just go ahead and make the landing?
0536:15	CAM-2	yeah, do they want an autoland though?
0536:17	CAM-1	yeah.
0536:18	CAM-2	they do want an autoland?
0536:18	CAM-1	yeah.
0536:19	CAM-2	***.
0536:20	CAM-1	just follow through on it? … it's visual, I don't give a #.
0536:23	CAM-1	what the hell's that?
0536:25	CAM-2,3	cabin cargo smoke.
0536:27	CAM-1	you see that … we got cabin cargo smoke … cabin cargo smoke.
0536:31	CAM-3	cabin cargo smoke, oxygen masks on.
0536:36	CAM-3	slash courier communication established.
0536:38	CAM-1	alright we got it.
0536:40	CAM-3	okay it's number nine smoke detector.
0536:40	BCNTR	fedex fourteen zero six turn twenty degrees left vectors behind company for boston.
0536:44	CAM-3	let the courier know.
0536:46	RDO-1	understand twenty left for fourteen zero six?
0536:49	BCNTR	that's correct … I have company traffic about twenty-five north of ya at thirty-three also going into boston … he's an airbus.
0536:56	RDO-1	roger.
0536:59	BCNTR	I didn't figure I'd have to vector this early in the morning.
0537:03	CAM-2	why don't you have those guys come up here.
0537:08	INT-1	there you go … everybody checked in.
0537:09	INT-2	okay why don't you have those —
0537:11	INT-3	okay second officer up.
0537:18	INT-2	why don't you have those guys come up here.

from the accident synthesizer contained about two and a half times the amount of acetonitrile and THF as did the AUX 3 bottle from the synthesizer purged at AFIP using the prescribed PerSeptive procedures."

To learn why the hazardous chemicals were found in greater quantities in the DNA synthesizer from the accident aircraft than in a DNA synthesizer correctly purged in a demonstration, investigators studied the procedures that had been used to prepare the synthesizer for shipment, which had been performed by a PerSeptive field engineer at the Chiron laboratory on Aug. 28, 1996.

The report said, "In a Sept. 16, 1996, interview 11 days after the accident, the field engineer described the next steps he took to prepare the machine for shipment as follows. He ran the 'prime all' function three times on each column position, and then emptied all of the bottles by turning them upside down until they stopped dripping. [In a footnote, the report said, "The 'prime all' cycle function draws some liquid from every reagent bottle so that every flow path in the machine is flushed."]

"He then ran the 'prime all' function again three times on each column position to dry the instrument. (When the 'prime all' function runs without liquid in the bottles, a dry, inert gas is pumped through the flow paths and bottles.) He said that he did not remove the internal reagent bottles after these drying cycles, but that he visually inspected them and they appeared dry. He said that he then depressurized the synthesizer by disconnecting the inert gas supply and loosening each internal reagent bottle to relieve the internal pressure."

On April 4, 1997, Chiron sent the NTSB a computer diskette on which was a data file named "history.log," containing records of the manual inputs that the field engineer had performed when he prepared the synthesizer for shipment. Among the data on the diskette were 57 entries signifying "manual function invoked."

In a follow-up interview on Aug. 28, 1997, the field engineer said that the first seven and the last six of the "manual function invoked" entries were for the "prime all" functions that he performed to flush and dry the synthesizer.

The report said, "The field engineer explained that the remaining 44 'manual function invoked' entries in the 'history.log' file … were the result of his having invoked the 'prime individual' function [for a particular bottle position] a number of times for each reagent position on each of the two columns.

"He acknowledged that these additional functions were not prescribed by PerSeptive as part of the normal purging procedure, but indicated that he took these additional steps to ensure that fluid from each reagent position was being properly delivered. (He stated that he did not have written guidance with him when he purged the accident synthesizer, but that he based the purging on Service Note 89-006, 'Preparing an Expedite System for Storage or Transport.')"

At the end of the August 1997 interview, the field engineer said that he was "100 percent certain" that no fluids were visible in the synthesizer after the purging was completed.

"The field engineer stated that he saw no leakage, malfunction or operational problems and that he did not observe anything unusual about the instrument during the purging and drying process," said the report.

On Aug. 30, 1996, a Chiron research scientist completed and signed a Chiron "Outgoing Procedure Checklist."

"The form provides information to Chiron's shipping department about the contents of the package and other shipping information, such as the recipient's address and telephone number," said the report. "The entry to indicate if the package contained hazardous materials was marked 'N' (for 'No') and had a handwritten entry reading, 'Instrument was thoroughly decontaminated of all chemicals.' The research scientist acknowledged that he did not verbally confirm with the PerSeptive field engineer that the synthesizer had been decontaminated."

Investigators searched for other cargo that might have ignited the fire.

The report said, "The salvaged cargo (from containers other than 6R and the hazardous-materials containers), which had been packed and stored in approximately 122 large cardboard boxes, was searched for aerosol cans and other items that might have constituted undeclared shipments of hazardous materials. Seven aerosol cans and various other items were retrieved. Because all the aerosol cans were breached, it was determined that their testing would not be of value because it would not reveal their original contents.

"Testing of other items revealed that the liquids in four plastic bottles and several milliliter … vials had a hydrogen-ion concentration (pH) of 1.0; the liquid in another plastic bottle had a pH of 1.8; the liquid in a plastic cylinder had a pH of nearly 9.0. There were also two containers of liquid with flash points of 60 degrees C (140 degrees F) and 65 degrees C (149 degrees F), respectively."

Four separate packages, damaged by fire and water, found among the cargo debris contained a total of 91.6 pounds (41.5 kilograms) of marijuana.

The NTSB considered the actions of the flight crew in the emergency descent and landing.

"Although the airplane was landed successfully, several required items were not accomplished during the descent and

0537:22	**INT-1**	okay we're getting two of them now.
0537:26	**INT-1**	let's get on it … on the red tabs there and ah —
0537:29	**INT-2**	why don't you have those guys come up here?
0537:31	**INT-1**	let's open the door and see what it looks like.
0537:42	**CAM-3**	why don't you guys come up.
0537:48	**INT-1**	let's find out what we've got going here.
0537:56	**INT-1**	okay it's moving forward whatever it is … it's up to seven.
0538:06	**INT-3**	okay fire and smoke … oxygen mask and smoke goggles as required on one hundred percent … crew and courier communication established … that completes the phase ones.
0538:14	**INT-1**	roger.
0538:17	**INT-3**	cockpit door and smoke screen closed.
0538:27	**INT-3**	it's closed … if descent is required proceed to step six … if descent not required proceed to step fourteen.
0538:38	**INT-1**	have you run a a —
0538:40	**INT-3**	pull cabin air.
0538:42	**INT-3**	type of smoke or fire on step fourteen … descent not required.
0538:48	**INT-3**	cabin cargo smoke.
0538:55	**INT-3**	can best be recognized by checking smoke detectors second officer's panel by observing smoke or fire in the main deck cargo area … that completes ah fire and smoke going to cabin cargo smoke.
0539:07	**INT-1**	what we've got is cabin cargo, right?
0539:11	**INT-3**	that's affirmative.
0539:13	**INT-1**	alright … have you run the test on it yet?
0539:18	**INT-3**	doing that now.
0539:28	**INT-1**	that's seven and eight.
0539:31	**INT-3**	those others may be failing in the blinking mode.
0539:37	**INT-1**	the blinking mode is a normal test is it not?
0539:41	**INT-3**	pardon me?
0539:43	**INT-1**	they should come on blinking on the test, isn't that correct?
0539:45	**INT-3**	no they should come on steady on the test.
0539:47	**INT-1**	okay.
0539:47	**INT-3**	everything should come on steady.
0539:49	**INT-1**	okay.
0539:50	**INT-3**	okay ready to run the cabin cargo smoke light —

0539:52	**INT-1**	I got ten now.
0539:55	**INT-3**	ready to run the cabin cargo smoke light illuminated.
0539:57	**INT-1**	go ahead.
0540:01	**INT-3**	okay it says pack function selectors two off … two are off.
0540:07	**INT-1**	we've definitely got smoke guys … we need to get down right now let's go.
0540:18	**RDO-1**	okay what's the closest field I wonder … here let me talk to them here.
0540:22	**RDO-1**	center fedex fourteen zero six.
0540:24	**BCNTR**	— saying something about the closest field I'll get back to that in a second but one hundred heading seven thousand expect straight in runway six.
0540:30	**RDO-1**	let's run it, let's get this thing depressurized … let's get it down.
0540:34	**RDO-1**	center fedex fourteen zero six.
0540:38	**RDO-1**	center fedex fourteen zero six.
0540:40	**BCNTR**	fedex fourteen zero six go ahead … you have a problem?
0540:43	**RDO-1**	yes sir we do … we have smoke in the cabin at this time … we're at three three zero … we'd like to proceed direct and we need to descend at this time.
0540:53	**BCNTR**	fedex fourteen zero six roger descend and maintain one one thousand … stewart altimeter three zero one five and if you want to go to albany it's in your eleven o'clock and about fifty miles … stewart is probably the closest airport it'll be at ah hundred and eighty degree turn and about twenty-five miles.
0541:11	**RDO-1**	okay stewart field ah and a right turn to ah a hundred and eighty degrees now?
0541:17	**BCNTR**	you'd make a left hand turn to a heading of two four zero and it is uhm let's see now twenty-five miles … left turn heading two four zero.
0541:27	**RDO-1**	left turn two four zero … say the weather at stewart.
0541:32	**CAM-1**	(go ahead turn).
0541:35	**INT-3**	okay ready to run when you are.
0541:38	**INT-1**	okay run the checklist.
0541:41	**INT-3**	okay courier mask and goggles verify on one hundred percent … cockpit air outlets open … they are open … it says ah land as soon as possible … and we are descending now … if unable to extinguish fire and smoke manually raise cabin altitude to twenty-five thousand … while you're in a descent to eleven?
0542:03	**INT-1**	roger, go ahead and start raising it.

landing," said the report. "The flight engineer failed to perform step no. 6 of the Cabin Cargo Smoke Light Illuminated Checklist (pulling the cabin-air shutoff T-handle). If he had done so, airflow would have been shut off to the main cargo-deck area while being maintained to the cockpit. The [NTSB] concludes that the flight engineer's failure to pull the cabin-air shutoff T-handle … allowed the normal circulation of air to continue to enter the main cargo area, thereby providing the fire with a continuing source of oxygen and contributing to its rapid growth."

The report also noted the flight engineer's failure to complete step no. 7 of the Cabin Cargo Smoke Light Illuminated Checklist, which was to maintain a differential cabin pressure of 0.5 psi.

"As a result, the occupants were unable to immediately open and exit from the primary evacuation exits (the L1 and R1 doors) because the airplane was still pressurized," said the report. "The flight engineer acknowledged that instead of manually maintaining the appropriate pressure differential, after he had placed the outflow valve control in the manual position, he only 'cranked it open a couple of times [turns].' Because they were at 33,000 feet and operating on only one pressurization pack, the outflow valve would have been almost completely closed before the flight engineer cranked it. As demonstrated in the [NTSB's] test on a similar DC-10, manually cranking the outflow valve control two times will not perceptibly open the outflow valve from fully closed on a static airplane."

The report said that the flight engineer was "overloaded and distracted" from accomplishing the Fire & Smoke Checklist and the Cabin Cargo Smoke Light Illuminated Checklist, as well as the normal Descent Checklist and Before Landing Checklist, by repeatedly asking for the three-letter identifier for Stewart to obtain runway information for the airport.

Although acknowledging the captain's intention to coordinate the crew's activities during the emergency descent and landing with the first officer as PF, NTSB said that the captain nevertheless did not ensure that all necessary tasks were completed.

"The captain did not call for any checklists to address the smoke emergency, which was contrary to FedEx procedures," said the report. "(The flight engineer initiated the Fire & Smoke and Cabin Cargo Smoke Light Illuminated Checklists.) Nor did he explicitly assign specific duties to each of the crewmembers. The captain also did not recognize the flight engineer's failure to accomplish required checklist items, provide the flight engineer with effective assistance or intervene to adjust or prioritize [the flight engineer's] workload. In fact, the captain repeatedly interrupted the flight engineer during his attempts to complete the Fire & Smoke Checklist, thereby distracting him from his duties." [In a footnote, the report said, "At 0538:38 and 0539:13, the captain interrupted him to ask whether he had run a test on the smoke-detector system, which is not an item listed on the checklist.”]

While preparing for the landing, the captain did not initiate the Emergency Evacuation Checklist, which included an item for depressurizing the aircraft.

“If this checklist had been initiated, it would have provided another opportunity for the crew to accomplish the necessary depressurization that was missed on the Fire & Smoke Checklist,” said the report. “In addition, the captain told investigators that he did not initiate the Emergency Descent Checklist, but said that he thought that he had accomplished the items on that checklist by memory. Although the Emergency Descent Checklist … was probably not applicable to this situation, the captain’s statement is troubling because it suggests a belief that checklist items can be adequately accomplished from memory alone. Finally, the CVR transcript indicates that the captain did not call for an emergency evacuation. (After the captain said, ‘We need to get [the hell] out of here,’ the flight engineer said, ‘Emergency ground egress.’)”

NTSB called for the FAA principal operations inspector for FedEx to review FedEx emergency procedures and training, including crew resource management training, in the light of the accident.

In connection with the captain’s decision and first officer’s decision not to wear their smoke goggles, and the flight engineer’s decision to remove his goggles, the report said, “Evidence in this accident indicates that smoke did not enter the cockpit in significant amounts until after the crew had landed and stopped the airplane,” said the report. “However, the [NTSB] is concerned that under different circumstances, the failure of crewmembers to don smoke goggles or to keep the goggles on during an emergency could adversely affect the outcome.”

NTSB commented on the emergency evacuation.

The report said, “The flight engineer stated that before he entered the foyer area to evacuate via the R1 door, he filled his lungs with oxygen from his oxygen mask. He did not use the PBE, which would have provided him with protection from the smoke while he attempted to open the foyer doors. In postaccident interviews, he stated that he was anxious to open the exit doors quickly, and he forgot that the PBE was available. [NTSB] concludes that crewmembers who do not use [the] PBE during a smoke or fire emergency may place themselves at unnecessary risk in attempting to address or escape from the situation.

“The L1 door was not available as an emergency exit because it only opened partially as a result of the flight engineer’s attempt to open the door while the airplane was still pressurized. … Although the lack of the L1 door as an escape route was not a significant factor in this accident, [NTSB] is

0542:07	**INT-3**	okay continue the descent.
0542:21	**INT-3**	and we now have just detectors eight, nine and ten … we’ve lost detector seven … it’s gone out.
0542:28	**INT-1**	roger.
0542:30	**INT-3**	okay what’s that ah … stand by.
0542:36	**BCNTR**	fedex fourteen zero six I’ve got albany if you want to go up to stewart you can do that … I’ve got albany in your eleven o’clock and about forty-five miles or stewart in your southwesterly position and ah forty miles … your choice.
0542:49	**RDO-1**	okay we need to get it on the ground … we need to get to stewart … give us vectors.
0542:53	**BCNTR**	okay fedex fourteen zero six roger turn left heading two four zero … you can remain in a left hand turn and stewart’s wide open for ya.
0543:00	**RDO-1**	roger.
0543:02	**INT-3**	and I’m manually raising the cabin altitude … there is smoke in the ah cabin area.
0543:03	**CAM**	[sound of overspeed warning alert]
0543:06	**INT-1**	roger.
0543:12	**INT-2**	okay … okay you have an approach plate for us?
0543:25	**CAM-?**	*
0543:22	**INT-3**	what’s the three letter identifier for stewart.
0543:30	**RDO-1**	give me a plate for —
0543:38	**BCNTR**	fedex calling boston say again please.
0543:43	**RDO-1**	center … stewart field … what’s that listed under?
0543:47	**BCNTR**	sierra whiskey foxtrot newburgh new york.
0543:49	**CAM-?**	newburgh new york.
0543:51	**RDO-1**	okay.
0544:04	**BCNTR**	fedex fourteen zero six if you could when you get a chance the uhm fuel on board and souls please.
0544:12	**INT-3**	thirty-three thousand pounds.
0544:14	**RDO-1**	thirty-three thousand pounds … five souls on board.
0544:18	**BCNTR**	could you say that one more time please?
0544:19	**RDO-1**	thirty-three thousand pounds … five souls on board.
0544:19	**CAM**	[sound of overspeed warning alert]
0544:22	**BCNTR**	thirty-three thousand five souls … thank you.
0544:25	**INT-3**	and ah current altimeter.
0544:27	**RDO-1**	current altimeter setting please?

0544:28	**BCNTR**	stewart altimeter three zero one five, sir.
0544:32	**RDO-1**	three zero one five.
0544:34	**INT-3**	three zero one five set in the back.
0544:44	**BCNTR**	fourteen zero six descend and maintain four thousand … you can proceed direct to kingston VOR … that's india golf november … that's for the VOR runway two seven at stewart.
0544:55	**RDO-1**	okay what's that frequency?
0544:57	**BCNTR**	stand by one second … frequency's one one seven point six, sir.
0545:15	**INT-3**	and it looks like we just have smoke detector ten lit now.
0545:19	**RDO-1**	okay, sir, we don't have the VOR approach to two seven on file here on the airplane.
0545:34	**BCNTR**	fedex fourteen zero six roger … would you like a visual to the airport?
0545:36	**RDO-1**	roger, get us down to the airport and we'll take the visual … the only thing we have on board is for the ILS to nine.
0545:44	**BCNTR**	alright ILS to nine is the only thing you can handle okay … it's a two one zero heading now for the airport and it's twenty-eight point two miles from your present position and you can expect a visual.
0545:55	**RDO-1**	roger two one zero.
0545:57	**INT-3**	okay what is the three letter identifier for —
0545:58	**BCNTR**	and fedex fourteen zero six maintain four thousand.
0546:08	**RDO-1**	it's cleared to four thousand now for fedex fourteen zero six?
0546:10	**BCNTR**	fedex fourteen zero six affirmative maintain four thousand.
0546:14	**INT-3**	three letter identifier again for that airport?
0546:19	**RDO-1**	ah stewart?
0546:21	**INT-3**	yeah.
0546:21	**RDO-1**	S-T-W.
0546:26	**BCNTR**	sierra whiskey foxtrot is stewart.
0546:31	**INT-3**	okay we are depressurized.
0546:34	**INT-1**	alright.
0546:41	**RDO-1**	and center, I don't know if I did it before but fourteen zero six is declaring an emergency and we do need equipment standing by.
0546:44	**BCNTR**	fourteen zero six, that's already been taken care of … the equipment will be standing by.
0546:51	**RDO-1**	roger.

concerned that under other circumstances the loss of a passenger-exit door could have serious safety consequences. [NTSB] concludes that crewmembers may not be adequately aware that attempting to open a passenger-exit door when the airplane is still pressurized may result in the door not opening."

Investigators sought to determine where the fire had begun. But the fire lasted for about four hours after smoke was first detected, and conditions changed during that period, which made it difficult to draw conclusions from the remaining evidence.

The report said, "One factor that investigators considered was the 'V' burn pattern that originated at container 6R. It is a basic premise of fire science that such a 'V' pattern often points to the origin of a fire. However, as explained in the National Fire Protection Association's *Guide for Fire and Explosion Investigations*, NFPA 921, 'Each time another fuel package is ignited or the ventilation to the fire changes, the rate of energy production and heat distribution will change. Any burning item can produce a plume and, thus, a "V" pattern. Determining which pattern was produced at the point of origin by the first material ignited becomes more and more difficult as the size and duration of the fire increases.'"

The container in cargo position 6R evidenced the most severe heat and fire damage, and was the only container to show heat damage on its bottom. Nevertheless, NTSB could not confirm that the fire originated in that container.

The report said, "If the fire had not burned so long, the 'V' burn-damage pattern and the extensiveness of the fire damage to 6R would have been stronger evidence of a fire originating inside 6R. Further, the deep burn and severe damage found in container 6R could also be accounted for by the fact that it was relatively empty and therefore largely unprotected by cargo.

"Thus, the Lexan side walls and nylon curtain could have fallen directly onto the floor of 6R and burned there, resulting in the severe damage to the floor of 6R and the exterior surfaces of the synthesizer. When Lexan is heated, it typically burns, melts and puddles, producing heat that would be sufficient to cause the damage to container 6R and its contents. Thus, a fire that originated outside of 6R but eventually spread to that area could have resulted in a similar damage pattern."

NTSB also considered whether the fire might have started aft of container row 6.

"Comments on the CVR suggest that the smoke-detector activation sequence might have begun with detector no. 9 and initially moved forward; this suggests that the fire might have started aft of row 6," said the report. "Further, some of the first flames to have breached the crown were observed approximately above the area occupied by container rows 8 and 9. Although the smoke-detector activation sequence and location of the early breakthrough of flames cannot be considered reliable indicators of a fire's initial location, a possible connection between these factors and the location of the fire's origin could not be discounted."

Containers in rows 8 and 9 and the surrounding areas showed significant burn damage, but the damage appeared to be somewhat less than the damage around the container in location 6R.

The report said, "However, 9L contained a significant quantity of undamaged materials with a low melting point (polyurethane, polystyrene and polyethylene), and the corner posts of that container sustained fire damage only to the forward outboard post. Similarly, containers 9R and 8R contained significant amounts of unburned combustibles (such as paper items) after the fire.

"Thus, in comparing the fire damage in 6R with that in rows 8 and 9, it is possible that the fire in those rows was as significant as that in the area of 6R, but it might have started at or near the top of a container and was unable to progress very far into the volume of cargo loaded into those containers.

"In sum, there was insufficient reliable evidence to reach a conclusion as to where the fire originated."

Unable to determine where the fire originated, investigators sought evidence of an ignition source. Because a chemical smell had been noticed inside the DNA synthesizer, and because other items in the container in location 6R were believed unlikely to have been an ignition source, the synthesizer was given particular scrutiny.

NTSB said that the evidence indicated that the DNA synthesizer had not been completely purged of hazardous chemicals before being placed on the accident aircraft.

The report said, "Although the field engineer [who had prepared the synthesizer for shipment] asserted that there were no problems with the purging of the machine, he also indicated that he performed the additional individual priming functions as an additional measure to ensure that liquid was flowing through the machine. This suggests that he wanted to ensure that liquid was flowing properly. These additional manual priming functions could be consistent with his having made repeated attempts to isolate or correct a perceived problem. Further, the existence of a breach in the system might also explain how chemicals found their way to enclosed areas of the machine that later exhibited severe fire damage.

"Although [NTSB] could not positively determine the specific deficiency in the purging process, the purging and drying procedures performed at PerSeptive's corporate offices and at AFIP demonstrated that when the procedures in Service Note 89-006 were carefully followed, it resulted in the synthesizer bottles containing trace amounts of chemicals less than those

0546:52	**INT-3**	okay, it says fire … check extinguished … the lights are off … it's still smoky out there.
0546:56	**BCNTR**	fourteen zero six fly your present heading … expect a visual approach to the stewart airport from new york approach control … contact new york approach one three two point seven five.
0547:05	**RDO-1**	three two seven five, roger.
0547:08	**INT-3**	caution … no crewmember should leave the cockpit to fight a fire … we're not gonna do that.
0547:14	**RDO-1**	approach, fedex fourteen zero six.
0547:17	**NYAPP**	fedex fourteen zero six new york approach … stewart altimeter is three zero one eight … descend and maintain four thousand … did you figure out what approach you need yet?
0547:24	**RDO-1**	three zero one eight down to four thousand.
0547:27	**RDO-1**	keep the speed up man, don't slow to two fifty … we're in an emergency situation here.
0547:31	**NYAPP**	american fourteen zero six speed's your discretion … speed's not a problem … I just need to know what approach you want?
0547:36	**RDO-1**	roger we do not have a two seven approach plate … all we have is runway nine … if we can get it we'd like to get in there visually if you can line us up.
0547:43	**NYAPP**	roger fourteen zero six … do you want me to run line up for runway niner or runway two seven?
0547:47	**RDO-1**	two seven.
0547:49	**NYAPP**	american fourteen zero six roger … fly heading two one zero … correction fly heading one niner zero.
0547:54	**RDO-1**	one nine zero.
0548:07	**INT-3**	I need the three letter identifier for that airport so I can call it up.
0548:11	**RDO-?**	S-W-F.
0548:13	**NYAPP**	american fourteen zero six be advised stewart weather as of zero nine four five zulu winds are calm … three miles visibility … fog and a broken layer at seven thousand feet … stewart altimeter's three zero one eight.
0548:26	**RDO-1**	three zero one eight, roger.
0548:27	**CAM-2**	slats extend.
0548:29	**INT-3**	okay, land at nearest suitable airport … cabin cargo smoke light illuminated checklist complete.
0548:36	**RDO-1**	okay, they're out, aren't they?

0548:38	**CAM**	[sound of overspeed warning alert]
0548:38	**RDO-1**	get rid of it … but we still need to get this thing on the ground.
0548:41	**CAM-2**	what's the field elevation?
0458:41	**NYAPP**	american fourteen zero six roger … the VOR runway two seven approach course goes off the kingston two four four radial if you want to tune that in.
0548:50	**CAM**	[sound of altitude alert and overspeed warnings]
0548:54	**RDO-1**	roger, two forty-four degree radial.
0548:59	**NYAPP**	american fourteen zero six descend and maintain three thousand.
0549:02	**RDO-1**	three thousand, fourteen zero six.
0549:08	**RDO-1**	boy this sucks doesn't it.
0549:09	**CAM**	[interrupt in CVR audio from tape splice]
0549:09	**INT-3**	is there a three letter identifier —
0549:10	**CAM-2**	is there a VOR or something on the field?
0549:13	**RDO-1**	yeah, two forty-four here … intercept that … that's off the kingston VOR … going into the runway.
0549:17	**NYAPP**	fedex fourteen zero six that's affirmative … on your present … turn ten degrees right to intercept the kingston two four four radial.
0549:23	**RDO-1**	intercept the two four four radial … ten degrees right.
0549:25	**CAM**	[sound of altitude warning]
0549:28	**INT-3**	I can't give you any take-off or landing data.
0549:32	**INT-1**	you can't?
0549:33	**INT-3**	I can't find the airport in my directory.
0549:37	**RDO-1**	just get a weight and use your table tops.
0549:43	**RDO-1**	get rid of the boards.
0549:48	**RDO-1**	three hundred and thirty thousand pounds.
0549:53	**RDO-1**	V ref is one thirty-one for flaps fifty … one thirty-six for thirty-five.
0550:03	**NYAPP**	fedex fourteen zero six turn right heading two two zero to intercept the kingston two four four radial … descend and maintain two thousand five hundred.
0550:11	**RDO-1**	two thousand five hundred and two two zero on the heading.
0550:13	**CAM**	[sound of altitude alert warning]
0550:20	**INT-3**	in range … airspeed bugs.
0550:22	**RDO-1**	okay we're working on it … two seventeen's your top bug.
0550:30	**RDO-1**	one eighty-seven's the next one … one fifty-five … the next one —

found in the accident synthesizer. The most reasonable explanation for the presence of excessive quantities of chemicals in the synthesizer is that one or more of the bottles containing chemical reagents used in the DNA synthesis process (at least one of which contained THF) was not sufficiently emptied before the purging process began."

Investigators acknowledged that the chemical residues in the synthesizer might have been a factor in the fire's ignition, but were unable to say specifically how that event might have occurred.

The report said, "Tests of the liquids from the accident synthesizer showed that flammable chemicals (THF and acetonitrile) were still present in the bottles on the machine after the fire. The quantity of chemicals remaining in the synthesizer's bottles after the fire was insufficient to have caused the external fire damage to the synthesizer and the cargo container. However, it is likely that significant amounts of the chemicals were consumed in the prolonged and intense fire, and thus the synthesizer probably contained much larger quantities of these flammable chemicals before the fire.

"These volatile chemicals — particularly the THF — could ignite a fire. THF, which is highly flammable under any circumstances, can also form unstable peroxides that can explode on contact with certain other materials or autoignite (spontaneously explode) in sufficient concentrations. Although the investigation examined this as a possible ignition scenario, it could not be determined whether the chemicals in the synthesizer played any role in igniting the fire. The investigation could not develop a viable and convincing scenario to explain how the synthesizer could have started a fire."

Other cargo containers and their debris were also examined to seek possible ignition sources, but no sources were identified. Because of deterioration and destruction of some of the cargo, however, NTSB could not rule out the contents of another cargo container as a source of the fire.

NTSB considered the possibility that the marijuana found to have been carried on the accident aircraft might have undergone a reaction, on being exposed to oxygen, that generated heat and combustion.

"The police investigator who documented the marijuana seizures explained that shippers of contraband such as marijuana attempt to reduce the size of the package by 'using a vacuum to vacuum out all the air and get it as compact as possible,'" said the report. "Thus, although the marijuana would have been compressed, there would have been little or no oxygen available to permit or support the biological reaction needed to lead to spontaneous combustion. Further, neither the police investigator nor any of the fire experts or consultants questioned during the course of the [NTSB] investigation were aware of a fire being initiated by spontaneous combustion of a marijuana shipment."

All aircraft systems, including the electrical system, were examined for malfunctions that might have been ignition sources. No malfunctions were found, and NTSB ruled out aircraft systems as an initial cause of the fire.

NTSB expressed concern about the increasing percentage of incidents related to undeclared hazardous materials.

The report said, "The number of hazardous-material releases for aviation, as reported to the DOT Hazardous Materials Information System (HMIS), increased from 163 incidents in 1987 to 1,015 incidents in 1997, an increase of 523 percent. Following changes in the HMIS incident-reporting format in 1990, the number of incidents caused by declared vs. undeclared shipments could also be distinguished. Of the 297 total aviation incidents reported for 1990, 234 incidents (79 percent) were attributed to declared shipments and 63 incidents (21 percent) to undeclared shipments. In comparison, of the 1,015 incidents reported in 1997 (an increase of 242 percent from 1990), 666 incidents (65 percent for 1997) were attributed to declared shipments and 349 incidents (35 percent for 1997) to undeclared shipments.

"Thus, between 1990 and 1997, the number of hazardous-material releases attributed to declared shipments increased by 185 percent, and the number of hazardous-material releases attributed to undeclared shipments increased by 454 percent. Further, in the two-year period from 1996 through 1997, the number of incidents resulting from undeclared shipments rose 82 percent, from 192 incidents in 1996 to 349 incidents in 1997."

NTSB said that a number of apparently undeclared hazardous materials had been shipped on Flight 1406.

"Because the [DNA] synthesizer was not intended to be shipped with any hazardous materials, it was shipped as general freight and was not packaged or labeled in accordance with DOT requirements and was not accompanied by the required paperwork," said the report. "Because the presence of flammable chemicals in the DNA synthesizer was wholly unintended and unknown to the preparer of the package (PerSeptive) and the shipper (Chiron), it is unlikely that the shipment of those chemicals on board Flight 1406 would have been prevented by better hazardous-materials education or improved screening of packages offered for transportation. However, it does demonstrate the safety threat posed by undeclared and improperly packaged hazardous materials.

"Seven aerosol cans and several plastic bottles containing acidic or alkaline liquids that could be corrosive, and two samples containing potentially flammable or combustible liquids were found in the cargo debris. Although the original contents of the aerosol cans recovered from the accident aircraft could not be determined, aerosol cans, as pressurized containers with compressed gases, are regulated hazardous materials.

0550:41	**NYAPP**	fedex fourteen zero six when you get a second the fire department needs to know if there's any hazardous material on the plane.
0550:48	**INT-1**	(Larry?)
0550:49	**INT-3**	yes.
0550:50	**RDO-1**	yes there is, sir.
0550:53	**INT-1**	okay, it's coming alive.
0550:59	**RDO-1**	go to twenty-five hundred feet.
0551:04	**INT-3**	and I've got additional smoke detectors on now.
0551:06	**NYAPP**	fedex fourteen zero six the lights are all the way up … you can expect to stay on this frequency … you will not have another frequency change … you'll be cleared to land from this ah on this frequency … the airport is at twelve o'clock and ten miles … report in sight.
0551:16	**RDO-1**	fourteen zero six wilco.
0551:21	**RDO-1**	okay, what's your double bug?
0551:23	**NYAPP**	fedex fourteen zero six descend and maintain two thousand three hundred.
0551:26	**RDO-1**	twenty-three hundred, roger.
0551:27	**CAM-2**	flaps fifteen.
0551:28	**RDO-1**	twenty-three hundred.
0551:30	**RDO-1**	what's the double bug in there on the table top … for ah three hundred thirty thousand?
0551:32	**CAM**	[sound of altitude alert warning]
0551:36	**INT-3**	ah three thirty … stand by.
0551:41	**NYAPP**	fedex fourteen zero six … this is not a standard approach … this is an angled approach to the runway.
0551:42	**INT-3**	two fifty-eight is optimum.
0549:32	**RDO-1**	roger.
0551:50	**INT-1**	what'd you get for a double bug?
0551:52	**CAM-2**	hey bruce, I don't have the plate … you're gonna have to talk me in to this.
0551:56	**RDO-1**	I am talkin' you into it … we don't have the plate for this either … we're doing a visual.
0551:59	**INT-3**	okay for thirty-five ah … thirty-five extend that's all I've got.
0552:06	**CAM-2**	flaps twenty-two.
0552:08	**NYAPP**	fedex fourteen zero six descend and maintain two thousand.
0552:10	**RDO-1**	two thousand fedex fourteen zero six.
0552:12	**INT-3**	V ref thirty-five extend is one thirty-six.
0552:13	**CAM**	[sound of altitude warning alert]
0552:15	**NYAPP**	fedex fourteen zero six field is twelve o'clock and seven and a half miles.
0552:17	**RDO-1**	Roger.

0552:21	**INT-3**	one thirty-six for V ref flap … thirty-five extend.
0552:26	**CAM-2**	gear down … before landing checklist.
0552:32	**RDO-1**	I think I'm starting to see the runway out there at twelve o'clock.
0552:38	**RDO-1**	it comes in at an angle.
0552:42	**NYAPP**	fedex fourteen zero six field is now twelve o'clock and five miles … do you need lower?
0552:48	**RDO-1**	yeah affirmative … have they got the lights all the way up … we don't see the runway.
0552:52	**NYAPP**	fedex fourteen zero six that's affirmative … the lights are all the way up.
0552:57	**INT-3**	landing gear?
0552:59	**INT-1**	down and three green.
0553:00	**NYAPP**	fedex fourteen zero six descend and maintain one thousand two hundred.
0553:01	**INT-3**	twelve o'clock.
0553:02	**RDO-1**	that's not it.
0553:06	**INT-3**	thrust computer.
0553:08	**RDO-1**	fourteen zero six … fourteen zero six still doesn't have the field here, sir … we've ah we're visual conditions sir … we do not see the runway.
0553:15	**NYAPP**	fedex fourteen zero six say again.
0553:17	**RDO-1**	yes sir, we do not see the runway ah at stewart … now we have it in sight.
0553:21	**INT-3**	over here at the left.
0553:23	**NYAPP**	fedex fourteen zero six you said you have the field?
0553:26	**RDO-1**	yes sir, I do believe we have the field at this time.
0553:28	**NYAPP**	fedex fourteen zero you're cleared to land runway two seven.
0553:31	**CAM-2**	flaps thirty-five … go right to fifty.
0553:33	**RDO-1**	that's not the right runway I don't think, is it? … yeah it is.
0553:37	**INT-3**	thrust computer.
0553:38	**RDO-1**	okay that's the runway right there.
0553:42	**CAM**	[Ground-proximity warning system (GPWS) one thousand foot call]
0553:42	**INT-3**	thrust computer … antiskid … spoiler.
0553:45	**RDO-1**	test and armed.
0553:49	**RDO-1**	want some flaps fifty.
0553:55	**INT-1**	want the autothrottles?
0554:01	**INT-3**	flaps and slats?
0554:02	**RDO-1**	okay I've got fifty land.
0554:05	**INT-3**	before landing checklist complete.
0554:06	**CAM**	[GPWS five hundred foot call]
0554:08	**CAM**	[two GPWS sink rate warnings]

"The acidic and alkaline liquids in the plastic bottles were also likely subject to the DOT hazardous-materials regulations as corrosive materials. … Consequently, the aerosol cans and the containers of acidic liquid likely constituted undeclared shipments of hazardous materials."

Although marijuana is not classified as a hazardous material by U.S. transportation regulations, and the contraband shipment was ruled out as a factor in the accident, NTSB cited its presence in the accident aircraft as another example of the ease with which undeclared materials can be shipped on commercial flights.

The report said, "[NTSB] is especially concerned that, except in the case of properly packaged and declared shipments of hazardous materials, carriers generally do not inquire about the content of packages being shipped domestically, nor are they required to do so. … Although air carriers and the FAA apparently agree on the seriousness of the problem, consideration is not being given to innovative measures, such as identifying package contents on the airbills or using technologies like x-ray machines to detect undeclared hazardous materials.

"[NTSB] concludes that transportation of undeclared hazardous materials on airplanes remains a significant problem, and more aggressive measures to address it are needed. Thus, [NTSB] believes that, in addition to the efforts already under way by the FAA, the DOT should require, within two years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offered for transportation. The inquiries may include answering individual and specific questions about whether a package contains a substance that might be classified hazardous (e.g., 'Does this package contain a substance that might be corrosive [or flammable, a poison, an oxidizer, etc.]')."

NTSB discussed the importance of ARFF officials being able to obtain timely information about the exact identity and quantity of hazardous materials involved in an aircraft accident or incident. Lacking such information, safety officials cannot be sure what type and level of response are needed to protect lives, property and surrounding communities.

"Neither the assistant fire chief who served as the initial incident commander nor the ANG fire chief received specific information during the firefighting phase of the emergency (before 0925) about the identity of the hazardous materials, their quantities or the number of packages on the airplane," said the report. "By 0700, about one hour after the airplane had landed, the only information about the hazardous materials on board the airplane that had been provided to the initial incident commander came from the Part A form and a handwritten list provided by the FedEx station at the airport.

This information indicated only the hazard classes of the hazardous materials on board the airplane and their location in the airplane by cargo-container position."

FedEx was unable to generate a single data sheet with full details of each shipment of declared hazardous-materials cargo, including the shipping names, identification numbers, hazard classes, quantities, numbers of packages and locations.

The report said, "[FedEx] relied on faxing copies of the individual Part Bs for the approximately 85 hazardous-materials packages on board, which proved to be burdensome, time consuming and, in this case, ineffective. Also, because of the poor quality and legibility of many of the handwritten Part Bs, much of the information was unusable.

"Compared to the other modes of transportation, it is less likely that shipping papers on board an accident aircraft will survive or be accessible because of the greater likelihood of fire and destruction of the airplane. Because of the danger of fire, a flight crew is also less likely to have time to retrieve the shipping papers after a crash. [NTSB] concludes that the DOT hazardous-materials regulations do not adequately address the need for hazardous-materials information on file at a carrier to be quickly retrievable in a format useful to emergency responders."

The report described as "inappropriate" the FedEx vice president's statement to the ANG that copies of the hazardous-materials forms could not be provided to the ANG because NTSB was in control of the investigation.

"Although [NTSB] appreciates FedEx's efforts to recognize [NTSB's] primacy in aircraft-accident investigations, [NTSB] has not promoted, nor does it support, a policy that would interfere with a carrier's ability to assist emergency responders in transportation emergencies, especially when hazardous materials are involved," said the report.

NTSB believed that planning and coordination among the various agencies responding to the accident exhibited deficiencies leading to confusion about the respective responsibilities of the participants.

"More effective preparation for emergencies involving hazardous materials and a system for coordination among the ANG, Stewart International Airport management and all local and state emergency-response agencies are needed," said the report. "[NTSB] is concerned that FAA requirements do not specifically address the need to prepare for hazardous-materials emergencies, and that other airports may be similarly unprepared for hazardous-materials emergencies. … Therefore, [NTSB] believes that the FAA should require all certificated airports to coordinate with appropriate fire departments, and all state and local agencies that might become involved in responding to an aviation accident involving hazardous materials, to develop and

0554:11	**RDO-1**	pull it on up.
0554:16	**RDO-1**	everything's done.
0554:20	**CAM**	[GPWS one hundred foot call]
0554:21	**CAM**	[GPWS sink rate warning]
0554:23	**CAM**	[GPWS fifty, forty, thirty, twenty and ten foot calls]
0554:28	**CAM**	[sound similar to that of touchdown]
0554:29	**CAM**	[sound similar to that of auto-spoiler deployment]
0554:37	**CAM**	[sound similar to that of reverse thrust]
0554:44	**CAM**	[sound similar to that of engine spooling down]
0554:46	**INT-1**	okay, I've got it … nice job.
0554:56	**NYAPP**	fedex fourteen zero six when able you can go over to tower frequency twenty-one eight.
0555:01	**RDO-2**	twenty-one what?
0555:02	**NYAPP**	one two one point eight.
0555:03	**INT-3**	okay on the lights we've got a … (forward fire … I'm deploying aft).
0555:07	**RDO-1**	we need to get the hell out of here.
0555:10	**CAM**	[sound of engine fire warning alarm starts]
0555:12	**INT-3**	agent arm cylinder one switch.
0555:19	**INT-3**	emergency ground egress.
0555:23	**CAM**	[sound of engine fire warning alarm stops]
0555:24	**RDO-1**	blow blow the door.
0555:27	**CAM**	[end of tape]

RDO = Radio transmission from accident aircraft
CAM = Cockpit area microphone sound or source
-1 = Voice identified as captain
-2 = Voice identified as first officer
-3 = Voice identified as second officer (flight engineer)
-? = Voice unidentified
BCNTR = Boston air route traffic control center
INT = Transmissions over aircraft interphone system
-1 = Voice identified as captain
-2 = Voice identified as first officer
-3 = Voice identified as second officer (flight engineer)
NYAPP = New York terminal radar approach control
* = Unintelligible word
# = Expletive deleted
( ) = Questionable text

Note: All times are expressed in eastern daylight saving time. Only radio transmissions involving the accident aircraft were transcribed.

Source: U.S. National Transportation Safety Board implement a hazardous-materials response plan for the airport that specifies the responsibility of each participating local, regional and state agency, and addresses the dissemination of information about the hazardous materials involved."

NTSB reiterated its long-standing concern about the difficulties faced by airport firefighters trying to extinguish aircraft-interior fires. NTSB suggested that fire departments' current technology cannot extinguish an interior fire in time to safeguard occupants and cargo.

The report said, "[NTSB] is aware that the FAA has researched fire-extinguishing systems for airplane interiors, including testing of a water-spray system that would discharge water into a particular area of the airplane when triggered by sensors in that area. Because the system would discharge water only to a focused area of potential fire, it would minimize the total amount of water that would need to be carried on board, thereby reducing the weight penalty of such a system. FAA tests showed that when this system was used to fight a fire, it delayed the onset of flashover [the ignition of unburned gases along the length of the cabin ceiling], reduced cabin-air temperatures, improved visibility and increased potential survival time.

"[NTSB] is concerned about the number of losses that have occurred and concludes that currently, inadequate means exist for extinguishing on-board aircraft fires. Therefore, [NTSB] believes that the FAA should re-examine the feasibility of on-board airplane cabin-interior fire-extinguishing systems for airplanes operating under [FARs] Part 121 and, if found feasible, require the use of such systems.

"[NTSB] realizes that requiring on-board extinguishing systems may not entirely resolve these safety concerns because [the fire-extinguishing systems] may become disabled by crash impacts. Further, [NTSB] realizes that the full implementation of such technology will require a number of years. Therefore, [NTSB] concludes that in addition to the safety benefits provided by on-board extinguishing systems, ARFF capabilities must also be improved so that firefighters are able to extinguish aircraft-interior fires in a more timely and effective manner."

Based on its investigation, NTSB published the following findings:

- "The flight crew was properly certificated and qualified in accordance with the applicable regulations and company requirements. Evidence from crew-duty time, flight time, rest time and off-duty activity patterns did not indicate that behavioral or psychological factors related to fatigue affected the flight crew on the day of the accident;

- "The smoke-detection system installed on the airplane functioned as intended and provided the crewmembers with sufficient advance warning of the in-flight fire to enable them to land the airplane safely;

- "The Boston [ARTCC] and New York [TRACON] controllers responded appropriately once they were aware of the emergency and provided appropriate and needed information to assist the crew in the emergency descent and landing;

- "The airplane was properly certificated, equipped and maintained in accordance with applicable regulations. No evidence of systems, mechanical or structural failures was found;

- "The flight engineer's failure to pull the cabin-air shutoff T-handle, as required by the Cabin Cargo Smoke Light Illuminated Checklist, allowed the normal circulation of air to continue to enter the main cargo area, thereby providing the fire with a continuing source of oxygen and contributing to its rapid growth. However, [NTSB] could not determine the degree to which it might have contributed to the severity of the fire;

- "The evacuation was delayed because the flight crew failed to ensure that the airplane was properly depressurized;

- "The captain did not adequately manage his crew resources when he failed to call for checklists or to monitor and facilitate the accomplishment of required checklist items;

- "Crewmembers who do not use protective-breathing equipment during a smoke or fire emergency may place themselves at unnecessary risk in attempting to address or escape from the situation;

- "Crewmembers may not be adequately aware that attempting to open a passenger exit door when the airplane is still pressurized may result in the door not opening;

- "The DNA synthesizer was not completely purged of volatile chemicals (including acetonitrile and tetrahydrofuran) before it was transported on board Flight 1406;

- "The presence of the aerosol cans, the containers of acidic liquid, as well as several packages of marijuana on board the accident flight illustrate that common carriers can be unaware of the true content of many of the packages they carry;

- "The transportation of undeclared hazardous materials on airplanes remains a significant problem, and more aggressive measures to address it are needed;

- “The [DOT] hazardous-materials regulations do not adequately address the need for hazardous-materials information on file at a carrier to be quickly retrievable in a format useful to emergency responders;

- “FedEx’s policy of providing information only to [NTSB] after [NTSB] initiates an investigation is inconsistent with the need to quickly provide emergency responders with essential information to assess the threat to themselves and the local community;

- “More effective preparation for emergencies involving hazardous materials and a system for coordination among the Air National Guard, Stewart International Airport management, and all local and state emergency-response agencies are needed;

- “Airport emergency plans should specifically address hazardous-materials emergencies;

- “Currently, inadequate means exist for extinguishing on-board aircraft fires; [and,]

- “In addition to the safety benefits provided by on-board extinguishing systems, aircraft rescue and firefighting capabilities must also be improved so that firefighters are able to extinguish aircraft interior fires in a more timely and effective manner.”

NTSB made a number of recommendations to U.S. transportation-safety organizations.

To DOT:

- “Require, within two years, that a person offering any shipment for air transportation provide written responses, on shipping papers, to inquiries about hazardous characteristics of the shipment, and develop other procedures and technologies to improve the detection of undeclared hazardous materials offered for transportation. (A-98-71).”

To FAA:

- “Require the principal operations inspector for [FedEx] to review the crew’s actions on the accident flight and evaluate those actions in the context of FedEx emergency procedures and training (including procedures and training in crew resource management) to determine whether any changes are required in FedEx procedures and training. (A-98-72);

- “Require [FedEx] to modify its evacuation checklist and training to emphasize the availability of protective breathing equipment during evacuations in an environment containing smoke, fire or toxic fumes. (A-98-73);

- “Require all [FARs] Part 121 operators of airplanes that rely on air pressure to open exit doors to make crewmembers aware of the circumstances of this accident and remind them of the need to ensure that the airplane is depressurized before attempting to open the passenger-exit doors in an emergency. (A-98-74);

- “Require, within two years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated, specific information about the identity (including proper shipping name), hazard class, quantity, number of packages and location of all hazardous materials on an airplane in a timely manner to emergency responders. (A-98-75);

- “Require the principal operations inspector for [FedEx] to ensure that all FedEx employees who may communicate with emergency responders about a transportation accident involving hazardous materials understand that they should provide those emergency responders with any available information about hazardous materials that may be involved. (A-98-76);

- “Require all certificated airports to coordinate with appropriate fire departments, and all state and local agencies that might become involved in responding to an aviation accident involving hazardous materials, to develop and implement a hazardous-materials response plan for the airport that specifies the responsibility of each participating local, regional and state agency, and addresses the dissemination of information about the hazardous materials involved. Such plans should take into consideration the types of hazardous-materials incidents that could occur at the airport based on the potential types and sources of hazardous materials passing through the airport. Airports should also be required to coordinate the scheduling of joint exercises to test these hazardous-materials emergency plans.(A-98-77);

- “Re-examine the feasibility of on-board airplane cabin-interior fire-extinguishing systems for airplanes operating under (FARs) Part 121 and, if found feasible, require the use of such systems. (A-98-78); [and,]

- “Review the aircraft-cabin interior fire-fighting policies, tactics and procedures currently in use, and take action to develop and implement improvements in firefighter training and equipment to enable firefighters to extinguish aircraft-interior fires more rapidly. (A-98-79).”

To the FAA Research and Special Programs Administration:

- “Require, within two years, that air carriers transporting hazardous materials have the means, 24 hours per day, to quickly retrieve and provide consolidated specific information about the identity (including proper shipping name), hazard class, quantity, number of packages and location of all hazardous materials on an airplane in a timely manner to emergency responders. (A-98-80)."

NTSB reiterated earlier recommendations to FAA:

- "Issue guidance to air-carrier pilots about the need to don oxygen mask and smoke goggles at the first indication of a possible in-flight smoke or fire emergency. (A-97-58); [and,]

- "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 training or both. (A-97-59)."♦

Editorial note: This article was based on the U.S. National Transportation Safety Board *Aircraft Accident Report: In-flight Fire/Emergency Landing, Federal Express Flight 1406, Douglas DC-10-10, N68055, Newburgh, New York, Sept. 5, 1996.* Report no. NTSB/AAR-98/03, dated July 22, 1998. The 137-page report includes a photograph, figures and appendixes.

Further Reading from FSF Publications

"Chemical Oxygen Generator Activates in Cargo Compartment of DC-9, Causes Intense Fire and Results in Collision with Terrain." *Accident Prevention* Volume 54 (November 1997).

"Hidden, Smoky Fire in MD-87 Aft Cabin Forces Emergency Evacuation After Landing." *Accident Prevention* Volume 53 (December 1996).

Sarkos, C.P. "FAA Proposes New Rules on Cargo Compartment Fire Detection and Suppression." *Cabin Crew Safety* Volume 31 (November–December 1996).

Koenig, R.L. "U.S. Reports Examine New Tools Aimed at Improving Survival Rates in Aircraft Fires." *Cabin Crew Safety* Volume 30 (September–October 1995).

Kapustin, R. "Fire-involved Accidents and Incidents Reviewed." *Flight Safety Digest* Volume 12 (March 1993).

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