Start-Up Problems

An in-flight engine fire followed maintenance technicians' use of an inappropriate procedure to manually start a balky engine on an MD-82.

BY LINDA WERFELMAN

An inappropriate manual engine-start procedure used by American Airlines maintenance personnel on a McDonnell Douglas MD-82 led to the uncommanded opening of an air turbine starter valve (ATSV) and a subsequent engine fire during climb-out, the U.S. National Transportation Safety Board (NTSB) said in its final report on the Sept. 28, 2007, accident at Lambert-St. Louis International Airport.

As the crew returned to the departure runway for an emergency landing, the nose landing gear failed to extend. They conducted a go-around, used emergency procedures to extend the landing gear and then carried out the emergency landing. None of the 143 people in the airplane was injured, but the fire caused substantial damage to the airplane.

The NTSB cited the inappropriate engine-start procedure as the probable cause of the accident and said that the fire was prolonged by the flight crew's "interruption of an emergency checklist to perform nonessential tasks." The NTSB cited as a contributing factor "deficiencies in American Airlines' continuing analysis and surveillance system (CASS) program."

The day of the accident, as the crew prepared for their flight, they were unable to start the left engine. Similar engine-start problems had been reported repeatedly in the days preceding the accident. On this occasion, maintenance personnel manually opened the ATSV while the captain held the engine-start switch in the "START" position; on the second attempt, the engine started.

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Airport vehicles surround an MD-82 after an emergency landing in St. Louis in 2007. Below, an airport worker examines soot near the left engine.

The flight crew told accident investigators that the first indication of a problem came at about 1313 local time, when the first officer told air traffic control that the left engine "ATSV OPEN" light had illuminated. The cockpit voice recorder recorded "a sound similar to the engine fire warning bell" at 1313:55, followed by the first officer's statement that the "LEFT ENGINE FIRE" warning light had illuminated and the crew's declaration of an emergency.

The first officer discharged two fire-extinguishing bottles and then lowered the landing gear handle. A controller in the airport's air traffic control tower said that the nose landing gear had not extended, and as the crew began a go-around, the controller added that he saw "quite a bit of black … soot … on that engine."

About the same time, the airplane lost both electrical power, including the auxiliary power that should have kept the airplane systems operating, and hydraulic power for the right side. The crew — with assistance from an off-duty captain who had flown the accident airplane on the previous flight — performed the "Emergency Gear Extension" checklist and heard the nose gear being extended, although landing gear indication lights did not illuminate.

The airplane landed at 1332, and the crew stopped it on the runway to allow aircraft rescue and fire fighting personnel to apply fire-extinguishing material to the left engine before passengers were deplaned.

U.S. National Transportation Safety Board

Manufactured in 1988

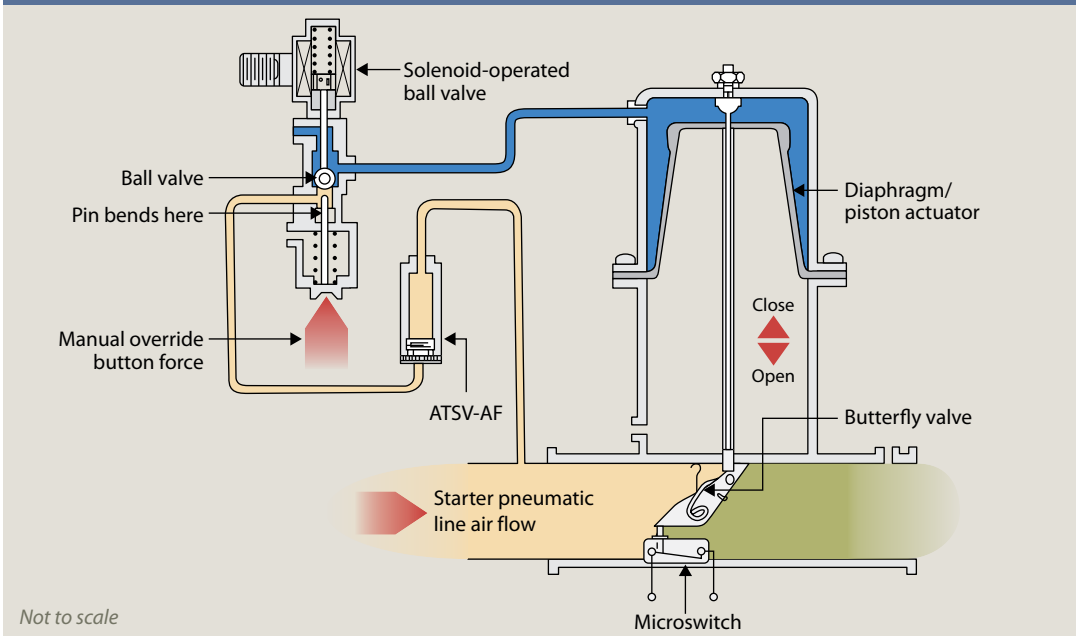
The accident airplane was manufactured in 1988 and purchased the same year by American Airlines; at the time of the accident, it had 57,744 flight hours and 30,254 cycles. Its two engines were Pratt & Whitney model JT8D-219 dual-rotor turbofans. The left engine had 43,784 total flight hours, with the last major maintenance and inspection performed 5,339 hours before the accident; the right engine had 59,507 flight hours, with the last major maintenance and inspection 76 hours before the accident.

Each engine had an engine-start system consisting of a pneumatic air turbine starter (ATS), an ATSV — which the report described as an "electrically controlled and pneumatically operated butterfly-type valve" that controls airflow into the ATS, an ATSV air-filter assembly, an engine-start switch, an "ATSV-OPEN" light, an engine-start system wiring harness and a pneumatic line that carries air from the pneumatic power source to the ATSV inlet (Figure 1, p. 36).

The ATS on the accident airplane was overhauled and installed in 2006 and had accumulated 3,234 operating hours since overhaul. The ATSV was overhauled on Aug. 29, 2007, and was installed in the accident airplane on Sept. 27, 2007, one day before the accident.

Under normal conditions, the ATS operates "when the electric start switch is held in the 'ON' position and supplies 28 volts of electric power to the ATSV solenoid," the report said. "When the solenoid retracts, it allows the ball valve to unseat and air to flow into the piston/diaphragm housing, causing the piston to move and the butterfly valve to open. When the ATSV butterfly valve is opened, airflow at a pressure of about 30 [psi] is directed into the ATS inlet, causing the ATS turbine to rotate at a high speed and provide rotational power to the engine core. The opening of the butterfly valve closes the ATSV microswitch, completing the indicating light circuit and causing the 'ATSV-OPEN' light to illuminate. Once the engine has

Major ATSV Components



AF = air filter; ATSV = air turbine starter valve

Source: U.S. National Transportation Safety Board

Figure 1

reached self-sustaining speed and the pilot shuts off the engine-start switch, the ATSV solenoid is de-energized, causing the ATSV to close and terminate the start cycle. The 'ATSV-OPEN' light goes off and stays off as long as the ATSV remains in the closed position."

With typical pressure during a normal start of 30 to 40 psi, the accompanying temperature is 300 to 400 degrees F (149 to 204 degrees C). If an ATSV is open during takeoff or some other time when the engines are operating at a high-power setting, the pressure can increase to 80 to 90 psi, with a temperature of 560 to 600 degrees F (293 to 316 degrees C). If an ATSV is open while an engine is operating at a high power setting, however, the ATS would not be connected to the engine; instead, it would be "freewheeling" — or spinning freely at maximum speed.

Manual Engine Starts

The airline's MD-80 *Maintenance Procedures Manual* described one approved procedure for manually starting an engine. Instructions called for maintenance personnel to "open the ATSV using an approved, specialized wrench to turn the wrenching flats on the upper end of the butterfly valve shaft and request that the flight crew activate the engine-start switch," the report said. "The procedure further instructs maintenance personnel to close the ATSV using the wrenching flats and verify that the ATSV is closed."

After the accident, airline maintenance personnel told investigators that the approved procedure was "very time-consuming and could take about 20 to 40 minutes to perform because the required specialized wrench was not part of the standard tool kit and so had to be found; then, the cowl latches and lower door had to be opened, the engine-start sequence performed and the lower door closed."

The maintenance personnel said that, "instead of using the approved procedure, they usually chose to use a prying device to reach, depress and hold down the ATSV's manual override button, which is accessed through a small panel located on the forward lower cowl door."

After a 1996 incident … Boeing … cautioned maintenance personnel not to use any tool to depress the manual override button.

Boeing Procedures

The Boeing MD-80 *Aircraft Maintenance Manual (AMM)* describes two approved procedures for manually starting engines, one of which resembles the approved procedure used by American Airlines and calls for a special wrench to be used to turn the wrenching flats on the butterfly valve shaft. The second method calls for maintenance personnel to

depress the manual override button, which activates the ATSV.

After a 1996 incident involving an uncommanded ATSV-open event during climbout, Boeing issued All Operators Letter 9-2549, which cautioned maintenance personnel not to use any tool to depress the manual override button. The investigation of that incident determined that the manual override button had stuck in the override position because its internal pin had been bent.

Boeing added the following to the *AMM*:

> *Use only hand pressure to depress override button. Use of screwdriver or other type of prying device to depress override button can deform slender pin mechanism inside valve. A deformed override button pin can hold solenoid switcher ball off its seat, which allows valve to open uncommanded when air pressure is available to engine start valve.*

After the accident, in April 2008, Honeywell approved an American Airlines plan to redesign the internal override pin to ensure that a prying tool could not be used to push it. The airline began modifying MD-80 ATSVs in February 2009 to incorporate that change; the alterations are expected to be completed by August 2010.

Maintenance Programs

At the time of the accident, the American Airlines maintenance program for its MD-80s included a fixed interval inspection program, which called for a maintenance C check and inspection every 5,000 flight hours. Maintenance records showed that all required checks had been performed, including cleaning of the ATSV air filter on March 16, 2006. Required C check procedures did not include a detailed visual inspection of the filter element — a provision that was added after the accident.

"A review of American Airlines' ATSV-related maintenance troubleshooting procedures found no specific written guidance relating to a failed ATSV or ATSV air filter," the report said. "A review of the accident airplane's maintenance logbooks dated from Sept. 1 to Sept. 27, 2007, indicated that the ATSV air filter had been removed and replaced on the airplane on Sept. 17; the engine start switch had been changed on Sept. 19; and the ATSV had been replaced six times from Sept. 16 to Sept. 27, 2007 (the same period that the reported engine-start problems occurred.) …

"The logbook review also revealed that the ATSV [maintenance] was deferred and put on the MEL [minimum equipment list] four times. The deferred status was canceled three times after maintenance was performed (ATSV changed), an operational check was made, and the automatic start sequence was deemed satisfactory. After the accident, American Airlines revised its engine

McDonnell Douglas MD-82

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The MD-82 is one of a series of jet transports that are derivatives of the Douglas DC-9, which first flew in 1965. The MD-80 has longer wings, a longer fuselage and more fuel capacity than the DC-9 and an integrated digital flight control system.

The prototype MD-80 flew in 1979, and the airplane entered production the following year as the MD-81. Production of the MD-82 began in 1981. The airplane, designed for operation at high-density-altitude airports, has Pratt & Whitney JT8D engines.

Production of a second version of the MD-82 began in 1982. The second version of the MD-82 has a greater maximum takeoff weight — 149,500 lb (67,813 kg), compared with the first version's 147,000 lb (66,679 kg). Both versions have a maximum landing weight of 130,000 lb (58,968 kg).

The MD-82 has a two-pilot flight deck and can accommodate 172 passengers. Maximum cruise speed is 0.8 Mach. Normal cruise speed is 0.76 Mach. Maximum range with 155 passengers is 2,049 nm (3,795 km).

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

ATSV MEL procedures to require that the air supply line from the ATSV be disconnected and that any of the disconnected lines be capped, which renders the ATSV actuating part inoperable and prevents inadvertent activation on takeoff."

The airline's maintenance program also included CASS, which is designed according to federal regulations as a risk management system that provides "a continuous cycle of surveillance, investigations, analysis and corrective action" aimed at maintaining consistently airworthy aircraft and ensuring that all maintenance action is performed in accordance with company manuals.

About four months after the accident, on Jan. 23, 2008, a similar ATSV incident occurred when another American Airlines aircraft was on climb-out from Salt Lake City. The crew returned to the departure airport, and an inspection revealed that there had been no fire but that the ATS was damaged and the filter element had separated from its base.

After that incident, the ATSV air filter assembly from the airplane's left engine was sent to the manufacturer, PTI Technologies, and then to the NTSB Materials Laboratory for examinations, which found that part of the filter mesh was embedded in the internal threads and that some areas showed "severe rubbing damage." NTSB examination of seven ATSV air filter assemblies from other American Airlines airplanes found that several were damaged. An examination of 15 assemblies by PTI found that most had minor "dents and dings"; in three, the filter mesh was torn; one filter had dents "consistent with impact damage"; and another had a damaged mesh pack side seal, the NTSB said.

Filter Had Disintegrated

The accident investigation found that the mesh in the accident ATSV air filter "had disintegrated and that about 70 percent of the material was missing," the report said.

The investigation also found that American Airlines maintenance personnel did not comply with the company's procedures for cleaning ATSV air filters during maintenance checks.

"Maintenance records indicated that [the] filter-cleaning procedure had been accomplished on the accident airplane's left engine ATSV air filter during the last C check," the report said. "However, the fatigue and fretting damage observed on the accident ATSV air filter element, which had developed over a long period of time, was so extensive that it would have been clearly visible to the naked eye when the filter element was removed from its housing to perform the cleaning procedure, if the cleaning procedure had actually been performed during the previous C check. In fact, given the degree of fatigue and fretting damage, it is unlikely that it was checked in accordance with American Airlines' procedures during the airplane's last few C checks, despite what the maintenance records showed."

Because of the inadequate cleaning, the damaged air filter was not detected, the report said.

The post-accident examination of the ATSV air filter also revealed that the deterioration of the filter mesh had allowed the end cap to separate and to move into a position where it "could block the airflow from the ATSV air filter to the ATSV … and prevent airflow to the ATS, causing an intermittent engine no-start condition," the report said.

The report added, "Because no failure of an ATSV air filter had ever been recorded, the condition was not recognized and therefore not properly addressed by maintenance personnel, which allowed an engine no-start to recur the morning of the accident."

At that point, maintenance personnel used the prying device to push the ATSV manual override button. This procedure bent the manual override button's internal pin, which allowed the ATSV to open during flight, causing the ATS to freewheel.

The uncommanded ATSV opening, combined with the freewheeling ATS, would have directed a stream of air at a temperature of 600 degrees F (316 degrees C) — and perhaps momentarily as high as 2,000 degrees F (1,093 degrees C) — into the engine nacelle; this could have been an ignition source, the report said. Fire damage precluded a determination of what type of combustible material was involved, although the report noted that it might have been oil, hydraulic fluid or fuel.

The report also criticized the CASS program for its failure to detect "maintenance procedures that were not in accordance with written manuals and guidelines."

In addition, the report said that Boeing and PTI inspection criteria for the ATSV air filter are "inadequate to detect early-stage fatigue fractures in the outer mesh of the filter element" and that filter design precludes inspection of the inner mesh.

The report included eight safety recommendations to the U.S. Federal Aviation Administration, including one calling for a review of all uncommanded ATSV-open events in MD-80s and another to require Boeing to "establish an appropriate replacement interval for [ATSV] air filters installed on all MD-80 series aircraft" (*ASW*, 6/09, p. 8).

This article is based on NTSB accident report NTSB/AAR-09/03, In-Flight Left Engine Fire, American Airlines Flight 1400, Mc-Donnell Douglas DC-9-82, N454AA, St. Louis, Missouri, September 28, 2007. *Adopted April 7, 2009.*