NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

November 20, 2008

Powerplant Group Chairman's Factual Report – Addendum 1
Engine Starting System

NTSB ID No.: DCA-07-MA-310

A. ACCIDENT

Location:	Lambert Field – St. Louis International Airport, St. Louis, Missouri
Date:	September 28, 2007
Time:	1:16 PM Central Daylight Time
Aircraft:	American Airlines McDonnell Douglas DC-9-82 (MD-82), N454AA, Flight 1400

B. POWERPLANTS GROUP

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C. SUMMARY

On September 28, 2007, at 1:16 PM central daylight time, an American Airlines (AA) McDonnell Douglas DC-9-82 (MD-82), N454AA, flight 1400, executed an emergency landing at Lambert-St Louis International Airport (STL), St. Louis, Missouri, after the flight crew noticed a warning light indicating that the left-hand start valve was open and subsequently received a left-engine fire warning during departure climb from the airport. Upon receiving the left-engine fire warning, the flight crew performed an in-flight shutdown of the left-hand engine and discharged both aircraft engine fire bottles into the left engine. During the single engine return approach to the airport, the nose landing gear did not extend and the landing attempt was rejected. During the go-around, the flight crew was able to extend the nose landing gear using the emergency landing gear extension procedure and a successful single-engine landing was made on runway 30L where STL Airport Rescue and Fire Fighting Vehicles met the aircraft. After landing the 2 pilots, 3 flight attendants, and 138 passengers deplaned via the airstairs and no occupant injuries or fatalities were reported. The airplane was operating on an instrument flight rules flight plan under the provisions 14 Code of Federal Regulations, Part 121 from St. Louis International Airport (STL) to Chicago O'Hare International Airport (ORD), Chicago, Illinois.

The airplane sustained substantial damage. The left-hand engine nacelle cowling was destroyed due to fire. The pylon skin and engine mounts were heat affected, as was an area of fuselage skin around the pylon intersection. For details of the engine condition please refer to the DCA07MA310 Powerplant Group Chairman's Engine Factual Report.

The air turbine starter valve air filter (ATSV-AF) media was deteriorated leaving the internal cap free within the housing. About 30% of the filter media remained but was separated from it's fitting and found pressed against the inner wall of the housing. The air filter cap was found covering the air outlet within the ATSV-AF housing.

The air turbine starter valve (ATSV) manual override pin was found buckled within the melted debris of the ATSV housing. The manual override button sleeve in the ball valve housing exhibited score marks consistent with contact against the manual override pin.

A review of AA documentation for manual override engine start procedures found that the only authorized written procedure was in the AA Maintenance Procedures Manual (MPM) 80-2. This procedure was similar to the procedure found in Boeing Dispatch Deviation Guide (DDG) 80-2. Both procedures direct opening of the ATSV by using the "manual hex head feature". The AA MPM 80-2 procedure specifies use of a special wrenching tool to accomplish the task. Discussions with AA ground personnel found that utilization of the "manual hex head feature" to open the ATSV was considered to be very time-consuming due to the requirements of firstly locating the wrenching tool and secondly opening and closing the lower cowl in order to use the wrench. Therefore AA ground personnel reportedly utilized the quicker manual override push button procedure to accomplish manual engine starts. The Boeing maintenance manual directs activation of the manual override push button after ATSV replacement. The purpose of this procedure is to test the manual override function after ATSV installation. This maintenance manual procedure only applied during ATSV replacements and would not typically be accessed and read by ground personnel prior to accomplishing manual engine starts during line operations. During line operations, the MPM is the applicable manual that contains the procedure to accomplish manual engine starts. The maintenance manual procedure for testing of the manual override function allows only the use of finger pressure to depress the manual override push button on the ATSV. During accomplishments of manual engine starts during line operations, AA ground personnel reportedly found the use of finger pressure to activate the ATSV to be impractical and difficult to accomplish. Therefore a levering device instead of finger pressure was reportedly used to depress the manual override push button.

Based on the experience of an operator who encountered an inadvertent ATSV OPEN condition and air turbine starter (ATS) deployment during climb-out in December 1996, Boeing issued an All Operator Letter (AOL) in December 1997 informing operators that using a screwdriver or similar levering tool to depress the manual override button on the ATSV could deform the manual push button pin internally. Furthermore, Boeing revised the maintenance manual ATSV install / test procedure to include a caution note to only use finger pressure and not screwdrivers or similar leverage tools in order to avoid possible damage to the air turbine starter (ATS).

The powerplant group convened on three occasions: The first, on September 29 to October 1, 2007 in the American Airlines hangar in Lambert Field in St. Louis, Missouri to review the damaged powerplant in-situ. The second, on November 7 & 8, 2007 at the Honeywell facilities in Tempe, Arizona where the ATS and the ATSV were disassembled and examined. The third on February 19-20, 2008 at the PTI facilities in Oxnard, California where the ATSV air filter was torn down and examined. This report combines the factual information gathered from these meetings.

D. <u>DETAILS OF INVESTIGATION</u>

D.1 Overview

This report contains the factual data of the engine starter system, which includes the air turbine starter (ATS), air turbine start valve (ATSV) and the air turbine start valve air filter assembly (ATSV-AF) investigation. The powerplant factual report is a separate document.

D.2 Powerplant Starting System Description

D.2.1 <u>Pratt & Whitney JT8D Engine Starting System Description</u>

The start system for the Pratt & Whitney JT8D engine consists of the following components (Photo 1):

- A pneumatic pressure source
- Engine start switch (ESS) and ATSV ‘OPEN’ warning light
- Engine start system wiring harness
- Air turbine start valve (ATSV)
- Air turbine starter (ATS)
- ATSV air filter assembly (ATS-AF)
- Starter pneumatic line

D.2.2 Pneumatic Pressure Source

Pneumatic pressure for engine starting can be obtained from any of the following sources (Photo 2):

1) The onboard auxiliary power unit (APU).
2) Cross-bleeding compressor bleed air from the opposite engine operating near idle power.
3) An external pneumatic supply, such as a ground power cart, connected to the fuselage ground pneumatic connector.

According to Boeing, the typical qualities of the air supplied to the ATS during a normal start are approximately 30-40 pounds per square inch (psi) at 300-400 degrees Fahrenheit (F). The pressure and temperature of the air will be reduced during the conversion to rotational torque within the ATS resulting in an exhaust temperature out of the ATS of approximately 200 degrees F.

If the ATSV is inadvertently commanded open while the engines are at a high power setting, then the qualities of the air supplied to the ATS will be approximately 80-90 psi at 560-600 degrees F. Because the engine is running, the ATS will be in a freewheeling state and no energy will be converted to rotation within the ATS and the exhaust temperature will be approximately the same as the inlet temperature of 560-600 degrees F.

D.2.3 Engine Start Switch (ESS) Description

The ESS is located on the forward overhead panel in the flight deck. The ESS controls the electrical operation of the ATSV solenoid. The switch is a toggle type switch and when placed and held in the ON position, sends a 28V signal to the ATSV solenoid. The switch also activates the engine ignition system.

The overhead annunciator panel contains a warning light that alerts the pilot of an open ATSV condition (Photo 3). The butterfly position micro-switch within the ATSV triggers this light.

D.2.4 Engine Start System Wiring Harness Description

The engine start system wiring harness is a small sub-component of the main airframe wiring harness. Four wires run from the ATSV to the flight deck. Two are used to activate the solenoid of the ATSV via the ESS and the other two are used by the butterfly position micro-switch on the ATSV to indicate an ATSV OPEN condition on the annunciator panel in the flight deck.

The (ATSV) 'start valve open' indicator light circuit supplies a constant 28-volt supply to the ASTV butterfly position micro-switch and requires a connection to ground via the butterfly position micro-switch actuation to illuminate the annunciator panel warning light.

D.2.5 Air Turbine Start Valve (ATSV) Description

The ATSV (Photo 4 & Photo 5) is a diaphragm/piston actuated, butterfly-type pneumatic valve and is electrically controlled and pneumatically operated. The ATSV functions to control the flow of bleed air to the ATS.

The ATSV consists of several components:

- A butterfly plate and flow body with appropriate in-line end flanges for direct mounting to the ATS and the starter pneumatic line.
- A diaphragm/piston type pneumatic actuator mechanically coupled through a lever arm to the butterfly shaft.
- A ball valve operated via a solenoid.
- A solenoid manual override button for control of the ball valve position in the event of an inoperative solenoid.
- A butterfly position micro-switch on the end of the butterfly shaft that energizes the ‘start valve open’ warning light on the annunciator panel in the flight deck when the butterfly valve is at a 3º open angle or greater.
- A mechanical pointer for visual indication of valve position.
- An external pressure relief valve.

Normal operation (Photo 6) begins when the ESS is held in the ON position, thus supplying 28 volts is to the ATSV solenoid. When the solenoid retracts, it allows a small ball valve to unseat and move to the opposite seat subsequently allowing air to flow into the piston/diaphragm housing causing the piston to move, and via a crank, turn the butterfly valve open. A small ¼-inch air line draws air from the starter pneumatic line and provides pneumatic pressure to activate the ATSV control system and butterfly valve. The ATSV-AF assembly is located in this ¼-inch air line. The butterfly valve, when open, allows the air pressure from the main ATS pneumatic supply to flow into the inlet of the ATS. The butterfly valve operation also closes the butterfly position micro-switch, completing the circuit and illuminates the ‘start valve open’ light in the flight deck.

In the event of loss of air pressure, loss of electrical power from the ESS, or if the solenoid is non-functional, a wrench can be used on the ATSV wrenching flats to directly open the butterfly valve via the butterfly shaft. This method requires the unlatching and opening of the lower cowl door. Alternatively, the solenoid manual override button method can be used to start the engine. The solenoid manual override button can be accessed through a small panel located on the forward lower cowl door (Photo 7 & Photo 8).

D.2.6 Air Turbine Starter Valve-Air Filter Assembly (ATSV-AF) Description

The ATSV-AF assembly (Photo 9) is a stainless steel wire mesh filter contained within a stainless steel housing. The filter element consists of two layers of stainless steel mesh, a fine outer layer and a courser inner layer. The mesh layers are pleated, welded into a circular shape and then brazed onto a cap and the lower fitting. This filter prevents particles that are in the main pneumatic supply line from entering the ATSV ball valve and solenoid. The filter is a 75-micron indicating that it is intended to filter out all particles larger than 0.00295-inches. The filter is mounted in a vertical position with the fitting end facing downward via a bracket on the engine H-flange external to the engine fan duct near the 9 o'clock position[1] (Photo 10).

D.2.7 Air Turbine Starter (ATS) Description

The ATS consists of the following major components:

- A housing and scroll.
- A single-stage turbine wheel.
- A reduction gear train.
- An overrunning clutch and splined output shaft.

The starter gears and bearings are lubricated by a self-contained oil system. A quantity of 375 milliliters of oil is contained in the ATS gearbox cavity. The housing also incorporates a mounting flange to match the pad on the engine accessory gearbox.

When the ATSV butterfly valve is activated, air-flow and pressure is directed into the ATS nozzle, causing the ATS turbine to spin at a high speed. This rotation is transmitted through the ATS reduction gearbox and clutch and then to the engine accessory gearbox providing rotational power to the engine core through a towershaft and high-pressure compressor (HPC) front hub mounted bull gear. Once the engine has reached light-off speed and is self-sustaining, the pilot then shuts off the ESS causing the ATSV butterfly valve to close and the ATS to stop. The engine start cycle takes approximately 30 – 40 seconds to accomplish. The ATS clutch automatically dis-engages once the engine has reached self-sustaining speed, which is approximately 35-40% revolutions per minute (RPM). The ATS can easily withstand a normal cycle time of 30 to 40 seconds with these parameters. The Honeywell ATS design specification allows a 5-minute start followed by a 2-minute cool-down cycle under the above air qualities.

According to the American Airlines AMM 71-00-00-5, the starter duty cycle limits are:

1) Three successive 30 seconds start attempts i.e.; 90 seconds ON-5 minutes OFF

[1] All orientation and directional references such as top and bottom, front and rear, right and left, and clockwise and counter clockwise are made aft looking forward unless noted otherwise. ALF indicates 'aft looking forward'. FLA indicates 'forward looking aft'.

2) Subsequent start attempts 30 seconds ON, 5 minutes OFF or 60 seconds ON, 10 minutes OFF.
3) Dry motoring 90 seconds ON, 15 minutes OFF

D.2.8 Starter Pneumatic Line Description

The starter pneumatic line, part number (P/N) 5938254-1 (Photo 11 & Photo 2), collects airflow that is available from the auxiliary power unit (APU) pneumatic supply, the pneumatic ground cart, or the opposite powerplant and directs it via a 3-inch diameter stainless steel pipe to the inlet of the ATSV.

D.3 Component In-situ Examination

D.3.1 Engine Start Switch (ESS)

The ESS P/N 2TL11-82, vendor code 91929, was removed from the overhead panel and tested for continuity and 'short' errors. No fault was found.

D.3.2 Engine Start System Wiring Harness

D.3.2.1 Engine Start Wiring Harness - Fuselage Segment

The segment of the ATSV wiring harness from the flight deck overhead panel to the inboard left hand engine pylon firewall connector was tested for continuity and 'short' errors. No fault was found.

D.3.2.2 ATSV Wiring Harness - Nacelle Segment

The left-hand nacelle segment ATSV wiring harness, P/N 5938354-509, from the outboard of the left hand engine pylon firewall connector to the ATSV, was not intact. The pylon Canon plug was present, in its correct secured location, and all the pins within the plug were present but damaged due to heat (Photo 12).

The entire nacelle wire harness was damaged due to heat to various extents. Some lengths were only charred while others had the insulation melted, exposing the bare wire. The ATSV wiring harness near the ATSV had separated (Photo 13). The two ATSV connector plugs, which connect to the solenoid and the micro-switch, were not in their correct location, were separated from the wiring harness and found loose within the debris in the lower cowl door still connected to the melted portion of the ATSV control housing. There were four 1-foot long bare wires still connected to them, two to each Canon plug. There was electrical continuity between the four pylon connector pins and these bare wires near the ATSV but because the insulation material from many of the wires in the bundle was missing, the possibility exists that the continuity was due to other wire paths in the bundle. The ATSV wiring harness nacelle segment could not accurately be tested.

D.3.3 Air Turbine Starter Valve (ATSV)

The ATSV, P/N 979410, serial number (S/N) 5606C, was overhauled by American Airlines on August 29, 2007. It was installed after overhaul, on the accident aircraft on September 27, 2007 at the American Airlines maintenance facilities in Dallas/Fort Worth, Texas.

Only the ATSV flow body and butterfly plate were in place between the ATS and the starter pneumatic line (Photo 14 & Photo 15). The piston/diaphragm and its housing were melted and separated from the housing. The actuator housing over the torsional return spring of the butterfly valve was melted allowing the spring to rotate freely. The solenoid and ball valve assembly housing was melted and the solenoid and ball valve assembly as well as the ATSV manual start push button were found at the bottom of the lower cowling door within a melted metallic puddle (Photo 16). When the ATSV was removed, the butterfly valve was observed seized in the CLOSED position.

The ATSV was removed in St. Louis, Missouri and sent to Tempe, Arizona for further examination on November 7 & 8, 2007.

D.3.4 Air Turbine Starter Valve - Air Filter Assembly (ATSV-AF)

The ATSV-AF assembly, P/N 11-10579, S/N 6628 was externally intact and removed from the engine and sent to the manufacturer, PTI Technologies in Oxnard, California for a detailed teardown.

D.3.5 Air Turbine Starter (ATS)

The ATS, model number ATS100-239, series number 4, P/N 383342-1-1 and S/N 21095 was overhauled by American Airlines on June 1, 2006. It was installed after overhaul on the accident aircraft on July 21, 2006. It had accumulated 3,234 hours since installation.

The air turbine starter was in-place between the engine gearbox and the ATSV (Photo 17). The aluminum gearbox housing on the front side, forward of the scroll housing, was melted through 360^o of its circumference and separated from the scroll housing. The planetary gears of the gearbox were exposed. The turbine rotor, with intact spline shaft, was found lying in the exhaust bell (Photo 18). The blade tips were worn down by approximately ¼ inch and rolled over with material deformation in the direction opposite of rotation. The turbine bearing could be rotated with mild hand effort, and was very rough. The input spline bearing could be easily rotated by hand effort but the shaft rotation did not cause the planetary gears to rotate along with it.

The ATS was removed and shipped to the Honeywell facilities in Tempe, Arizona for a detailed teardown.

D.4 Detailed Component Teardown Examination

A detailed examination of the ATS and the ATSV was done at the Honeywell facility in Tempe Arizona on November 7 - 8, 2007. A detailed examination of the ATSV-AF assembly was done at the PTI Technologies facility in Oxnard, California on February 19-20, 2008.

D.4.1 Air Turbine Starter Valve (ATSV)

The ATSV assembly was not complete (Photo 19). The butterfly plate and the main flow body were intact. The pneumatic actuator and the servo, which incorporates the ball valve and solenoid valve, were not attached to the main flow housing and were not identified in the materials returned for the examination. The butterfly position micro switch was not present.

The flow body housing of the ATSV was intact. The butterfly plate within the housing was visually examined and it was in the CLOSED position. Additionally, the butterfly valve shaft could not be turned using finger effort. Two ‘drop’ measurements were taken at the extreme positions of the butterfly plate and were 1.543-inches and 1.663-inches respectively. From these measurements, a value of 2.329 degrees butterfly valve angle was calculated, corresponding to a CLOSED valve position. A closed valve position according to Honeywell is a butterfly valve position of less than 3 degrees. Once the melted metallic material was removed from the shaft, the butterfly valve could be rotated using a wrench with light pressure.

No metallic deposit was noted on the upstream or downstream side of the butterfly plate or inner bore of the flow body housing (Photo 20). The actuator side bearings were slightly rust-covered. The water flow pattern on the inner bore and butterfly disk appeared to be consistent with normal operation (Photo 21).

The butterfly valve shaft closing torsion spring was present on the input shaft and appeared to be undamaged (Photo 22). The inner anti-rotation end of the spring was covered with melted soft metallic slag. The aluminum spring carrier was not present; however, the anti-rotation pin was still in its correct location and was retained in this location by melted soft metallic material. When the closing torsion spring hook was rotated to match with the input crank arm crank, the slag was in an orientation that was consistent with the direction of gravity on an installed valve.

The solenoid was found in the debris collected from the bottom of the cowl door (Photo 23). The electrical 'Canon plug' connector was still attached to the solenoid housing. Fractured and exposed electrical harness wires were seen in the 'Canon plug' connector. The solenoid valve assembly was separated from the solenoid housing.

The solenoid housing mounting flange was deformed. The solenoid was disassembled to reveal the armature and the solenoid valve housing (Photo 24). The armature was free to move. There were no witness marks noted on the forward face of the armature. Additionally, there were no axial score marks noted on the plunger rod. The plunger rod face, which is in contact with the ball valve, was slightly worn with a spherical indentation (Photo 25). Based on the measurements of the deformation of the ball valve on the pin surface, the depth of wear was calculated to be 0.002-inches.

The ball and conical seat of the solenoid valve was tested using air pressure. Using a pressure differential of 177 psi, the air leakage rate of a seated ball valve was measured to be approximately .019 lbs/minute. At this leakage rate, a pressure of 0.5 psi would be generated on the opening side of the actuator. According to Honeywell engineering calculations, a pressure of 8 psi is required to open the butterfly valve.

The pressure relief valve was intact however the body was discolored consistent with heat distress. A crack-open test was performed and 10 psi was needed to unseat the valve. The required crack open pressure for this valve is 155 ± 5 psi. The valve was disassembled and all the internal components were present.

A separate container of debris that was collected from the bottom of the cowling door, which was believed to have contained the liberated parts of the ATSV, was also in the shipping container (Photo 19). The aluminum switcher valve housing cap was not present; however, the switcher valve piston and return spring were found separated from its housing and among the debris that was collected from the bottom of the cowl doors. The switcher valve flexible diaphragm was not identified in the materials provided for the examination.

After the Honeywell examination was complete, all the parts were returned to AA facility in Tulsa, Oklahoma where the manual override button was identified (Photo 16). The manual override button was buckled in a S-shape on the slender end of the rod closest to the ball valve (Photo 26). Additionally, the rod end was deformed with a concave spherical indentation giving the sides a buckled 'mushroomed' pattern (Photo 27). This damage was consistent with a compression type overload. The manual override button sleeve in the ball valve housing was scored (Photo 28) from contact against the ridge of the manual override button, consistent with the application of significant force on the manual override button. An exemplar ball valve housing was sectioned and the event manual override button was placed into position showing that contact and binding of the manual override button ridge against the sleeve within the ball valve housing were possible (Photo 29).

According to Honeywell engineering, if the ball valve is unseated by 0.0025-inches, leakage within the ATSV will occur such that the following conditions can exist during airplane operation:

- During engine idle and ground operation of the airplane, the pneumatic supply pressure (from engine 8th stage bleed air supply) to the ATSV would be approximately 20 psi and the air leakage around the unseated ball would not be sufficient to actuate the butterfly diaphragm/piston.
- During takeoff conditions of the airplane, the pneumatic supply pressure to the ATSV would be approximately 95 psi and the air leakage around the unseated ball would be sufficient to actuate the butterfly diaphragm/piston. This can lead to an uncommanded ATSV OPEN event during takeoff and thus an uncommanded ATS start.

It is noted that the ATSV-AF is designed to filter particle sizes of 0.00295-inches and greater and that the ball valve is sensitive to particle sizes of 0.0025-inches.

D.4.2 Air Turbine Starter (ATS)

The ATS was in three pieces in the shipping container (Photo 30). The ATS was separated at the flange between the turbine housing and the planetary gearbox. The turbine wheel assembly was separate.

The rotor assembly is of a two-piece construction consisting of an aft side exducer and an integral turbine wheel/shaft. The rotor assembly exhibited an overall even matte gray-blue deposit. The assembling roll pin of the exducer was in place and intact. The aft face of the exducer hub exhibited rotational score marks. All the blades of the exducer were present. The blades tips exhibited deformation and were rolled in the direction opposite rotation. The leading edge and trailing edges of the blade tips were rounded off producing a 'spoon' shape. The average length of the blades at mid-chord was approximately 1-1/4 inch. The turbine blades were all present. All the tips were 'mushroomed' and exhibited circumferential scoring. The blades were worn down to the same height as the exducer blades on the trailing edge and tapered further inward moving forward along the blade chord (Photo 31).

The aft ball bearing could not be rotated. When attempting to turn the bearing, the inner ring spun on the shaft. The balls were present and evenly spaced but the cage was not present. Only the inner race of the forward bearing (thrust bearing) remained attached to the rotor shaft. The outer race was located in the planetary gearbox bore and the retaining clip was still present. The balls and cage were not present.

The pinion and planetary sun gear were intact but the forward section was deformed and battered in a direction consistent with starter rotation. The aft nut and the anti-rotation pin of the rotor assembly were present.

The inlet/exhaust scroll housing was intact (Photo 32). A small protected area just beneath the inlet flange was sooted from 12 to 3 o'clock. The remaining external surfaces were a gray color. The exhaust basket was intact and still connected to the housing with a v-band clamp. The inlet flange appeared to be undamaged and the v-band clamp was present.

A small segment of the aluminum gearbox housing including 3 fasteners from the 12 to 4 o'clock position was still attached to the connecting flange. The outside of this flange exhibited melted flow condition. The vanes of the scroll were present but were coated with slag and circumferentially scored (Photo 33). The internal surfaces of the airflow path were all coated with a rough metallic deposit. The shroud was rotationally scored. The stop cruciform cage was present and the center puck was rotationally scored on the inside facing surface.

The planetary gearbox housing was separated around 360 degrees. The remaining gearbox housing material aft of the mount flange varied from 1-1/2 to 3-1/2 inches in length. The new material condition of a gearbox is 4-1/4 inches long. The free edges all exhibited melted metal flow condition. One of the oil filler plugs was in place with lockwire present. The second oil filler plug with a lanyard was liberated and located amongst the cowl debris. The threaded features remaining in the housing for the liberated fill plug were present. A portion of the cylindrical housing between the 3 and 4 o'clock position was flared outwards. The inner surface was dry and exhibited a light sooting. The forward as-cast conical surface exhibited a black sooty deposit. The front bearing housing was intact and the bore was coated with a black coke-like deposit.

The planetary carrier assembly was intact and the planetary gears were present but could not be rotated (Photo 34). The assembly exhibited a general black sooty deposit. The planet gear carrier was intact; however, the corner of two of the three mounting lugs exhibited material loss with a rough eroded appearance. The planetary carrier was not disassembled. Most of the oil barrier was consumed in a manner consistent with heat distress and melting. The ring gear and ratchet assembly was intact and the ratchets appeared to be undamaged.

The clutch output shaft assembly appeared to be undamaged but exhibited a black sooty coating (Photo 35). Before disassembly, the output shaft was free to rotate in both directions; however, there was no corresponding rotation of the planetary assembly or audible ratcheting of the pawls. After removal of the clutch, the pawls were found in the dis-engaged position, undamaged, and were coated with a hard brittle material, which restrained the pawl motion (Photo 36). Once the hard brittle material was removed the pawls were free to move. A spring was removed from one pawl and was compared to a new exemplar spring. The removed spring had a permanent set at an increased radius of curvature. The output shaft bearing could be rotated; however, it was rough and had excessive play.

D.4.3 Air Turbine Starter Valve Air Filter Assembly (ATSV-AF)

The ATSV-AF assembly on the accident airplane was P/N 11-10579; S/N 6628 and filter element was P/N 21-10930, the Lot Number (00??) could not be determined. Although the ATSV-AF housing component of the assembly is marked with a serial number, the filter element component is controlled only with a lot number.

The assembly appeared to be externally undamaged (Photo 37). The lock wire was still intact and was removed prior to disassembly. Although the removal torque value was not measured, it was considered to be within the normal range.

When installed, the orientation of the assembly is vertical with the housing on the top and the fitting towards the bottom. The air flow enters the housing at the top and exits from the lower fitting. The element was found fractured from the fitting along a line just above the fitting braze joint (Photo 38). Most of the fractured surfaces of the filter element remaining on the fitting were smeared. About 70% of the metallic filter element material was missing. The remaining element material adhered to the inner wall of the housing (Photo 39). The remaining filter element material had a red-brown color whereas a new filter is silver in color. The upper cap of the element was still intact but separated from the element (Photo 40 & Photo 41). Some filter element material was still attached to the cap and was worn and rounded-off. The edges of the cap were also worn and was found resting in an inverted condition upon the lower fitting inner nipple and a fretting pattern on the flat surface was present, consistent with contact against the nipple (Photo 42). When the flat surface of the cap is in contact with the fitting nipple, the air flow can be restricted or stopped.

The ATSV-AF assembly was sent to the NTSB laboratory in Washington, DC for further analysis. See NTSB Laboratory Report Number 08-049 for details.

D.5 Engine Start Procedures

According to the AA engine start procedure manual MEL/CDL Maintenance Procedures Manual 80-2 (Attachment 1), when a manual engine start is to be done, the mechanic must use an approved specialized wrench, Boeing P/N DG16314-501 or AA P/N WRE9550 (Photo 43), to access and turn the wrenching flats on the upper end of the butterfly valve shaft. This manual override method directly turns the butterfly valve shaft (Photo 44) thus bypassing the manual override pin, ball valve and piston actuation system within the ATSV. Use of the approved butterfly override method using the specialized wrench requires that the entire forward lower nacelle cowl door be unlatched and opened because the wrench cannot fit through the small access panel (Photo 45).

The wrenching procedure is the only AA written authorized procedure. No instruction for depressing the manual override button with hand pressure is provided, nor any cautions or warnings prohibiting the use of unauthorized tools or procedures. The use of the wrenching procedure requires the mechanic to locate the tool, which is not part of his standard tool kit, open the cowl latches and door and perform the start sequence and close of the lower door once the engine has started and is running. The time to perform this task can take roughly 20 minutes and according to AA ground personnel, an ATSV manual override button technique is used to expedite the start process, although no written AA procedure exists for this technique.

Although the Boeing manual TP-80MM-AAL (Attachment 2) allows the use of hand pressure to activate the manual override button, the manual override button technique presents its own problems and according to AA ground personnel this technique is modified because:

- The button is a very small diameter and if an unprotected finger or thumb is used to push it, continued holding for 40 seconds becomes very painful.
- The valve body becomes hot once starter pneumatic air flows through it. If an unprotected finger or thumb is used to push the button, it can become painfully hot to the mechanic near the end of the 30 to 40 second start sequence.
- The button must be depressed for approximately 40 seconds and if the button is inadvertently released during this time, then the start attempt must be abandoned and the engine allowed to spool-down and stop completely before another start attempt is made.
- If the mechanic attempts to re-engage the button before the engine has come to a complete stop, then a 'crash' engagement of the ATS clutch will occur requiring the immediate replacement of the ATS unit.

In order to alleviate these problems, a levering type tool can be used to actuate the manual override button by resting it against the open nacelle panel edge or ATS housing, using them as a fulcrum (Photo 46 & Photo 47). The use of a levering technique is not approved in either the Boeing or AA maintenance manuals.

The Boeing maintenance manual TP-80MM-AAL (Attachment 2) cautions to "use only hand pressure to depress override button. Use of a screwdriver 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. If undetected or uncorrected, this condition will result in significant damage to engine starter." Additionally, Boeing released AOL 9-2549, dated December 16, 1997 in an attempt to clarify manual start procedures and to inform operators of the possible damage to the ATSV manual override pin if anything other than hand pressure is used (Attachment 3).

D.6 List of Attachments

Attachment Number	Title
1	AA - MEL/CDL Maintenance Procedures Manual 80-2
2	Boeing - TP-80MM-AAL (excerpts 80-10-00 & 80-10-02)
3	Boeing - AOL 9-2549

Harald Reichel
Aerospace Engineer - Powerplants

Photo 1 – Engine start assembly schematic

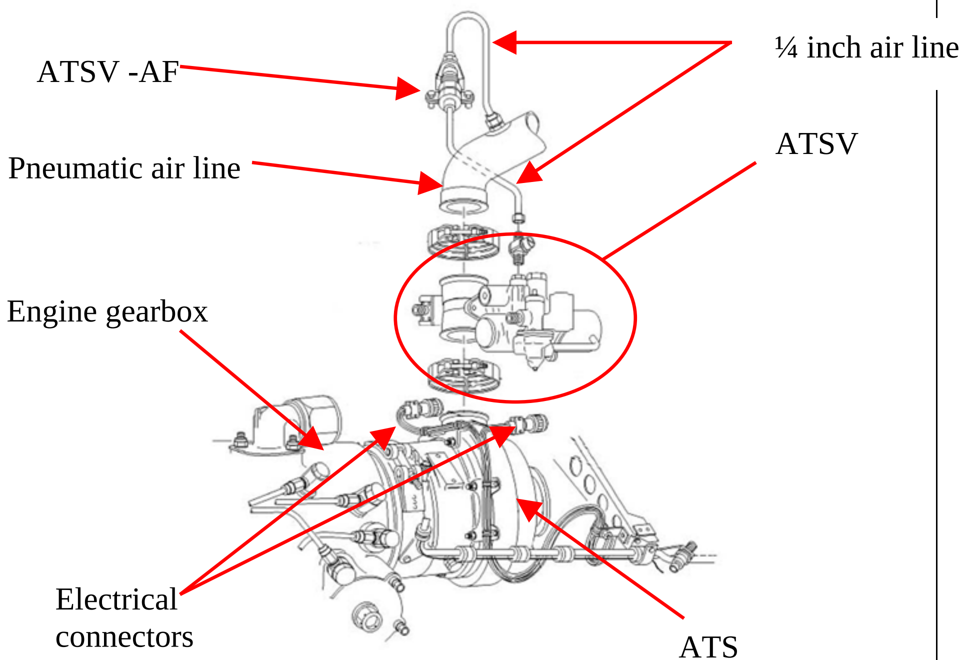


Photo 2 – Starter pneumatic line schematic

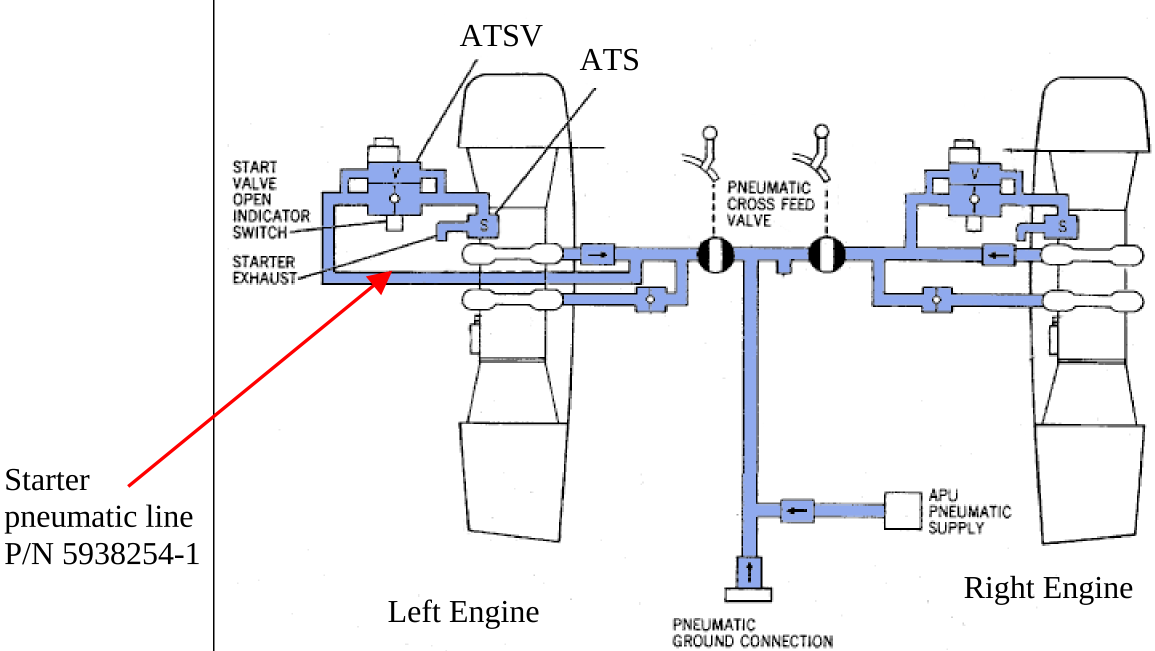


Photo 3 – Engine start switch and annunciator light overhead panel

Photo No: P2080117.tif

Photo 4 – Exemplar ATSV (for illustration only) – top/side view

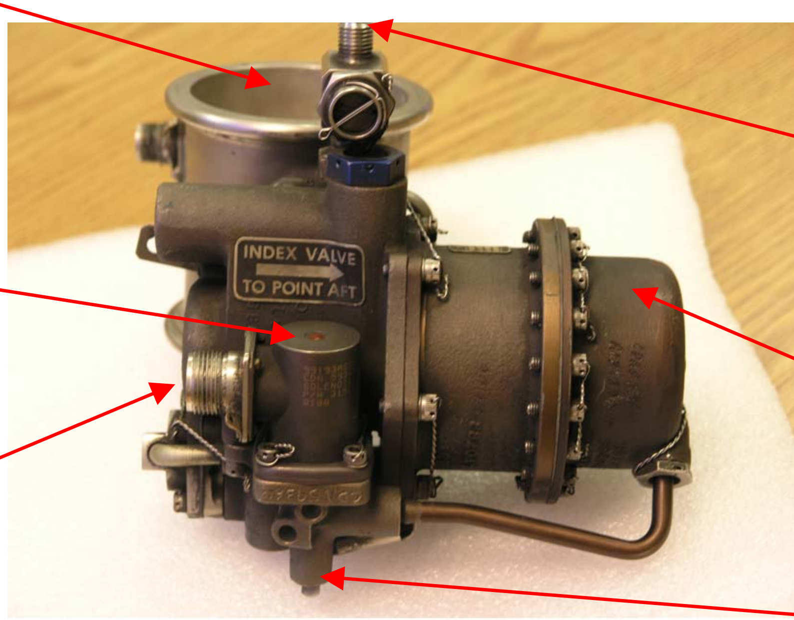


Photo No: P2125792.tif

Photo 5 – Exemplar ATSV (for illustration only) - bottom view

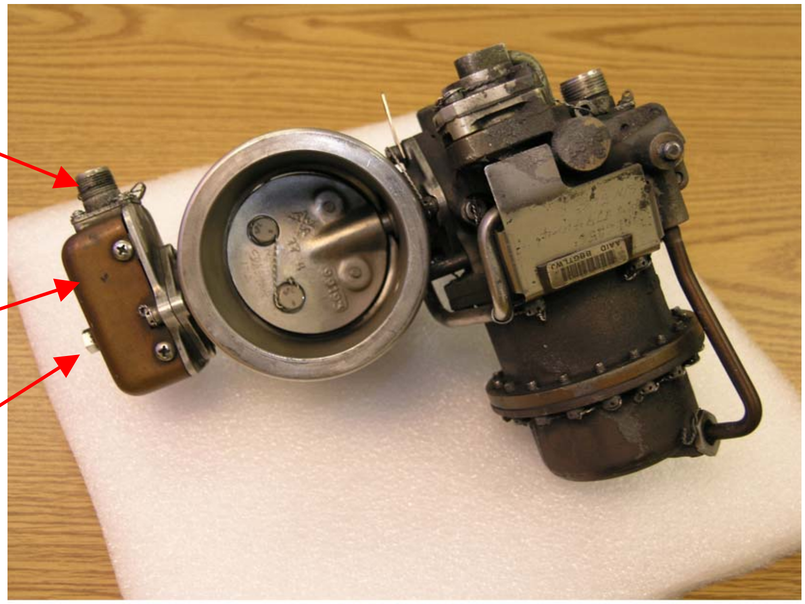


Photo No: P2125781.tif

Photo 6 – Simplified ATSV operation schematic

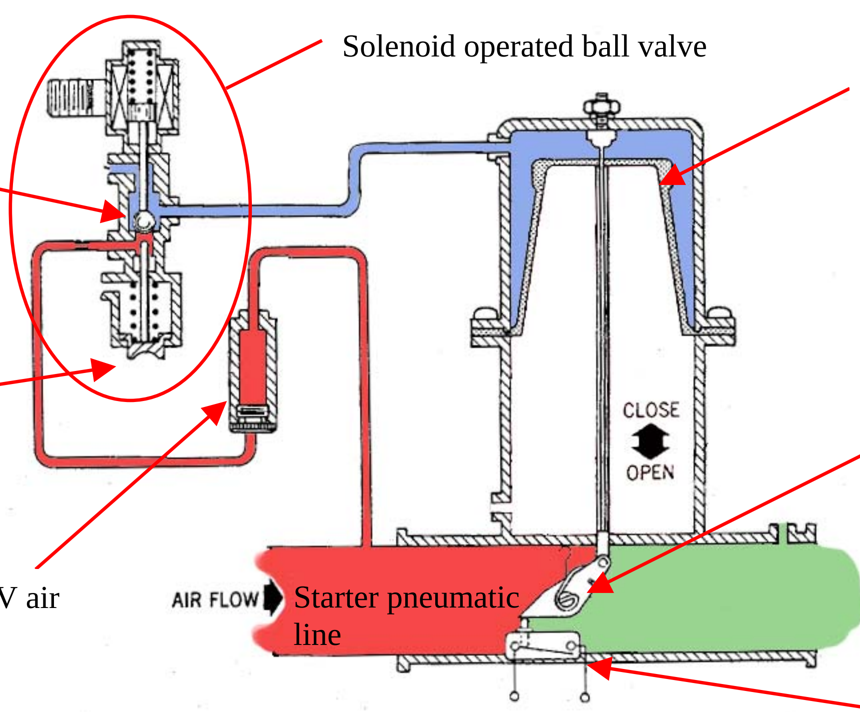


Photo 7 – Access panel for manual override start (For illustrative purposes only)

Photo No: P2080115.tif

Photo 8 - Access panel for manual override start (For illustrative purposes only)

Photo No: P2080114.tif

Photo 9 – ATSV-AF assembly – New exemplar (for illustration only)

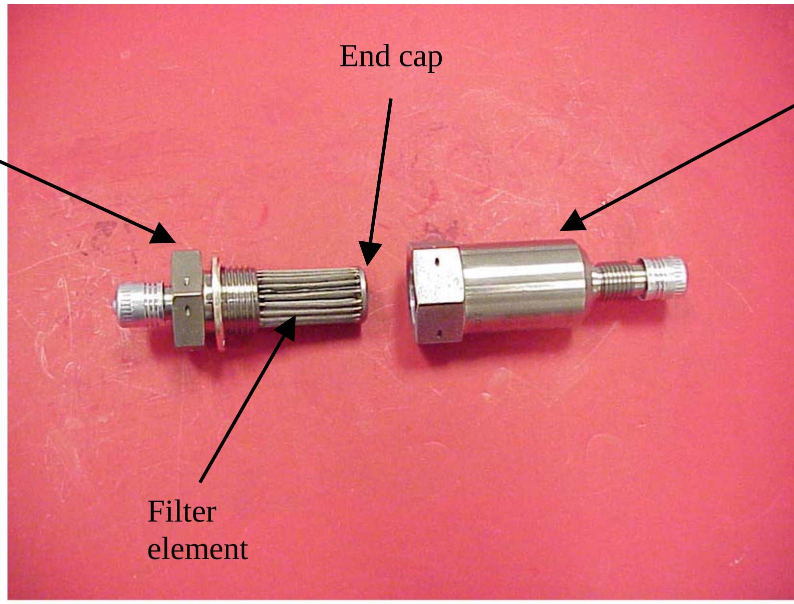


Photo No: MVC-034L.tif

Photo 10 – ATSV-AF location

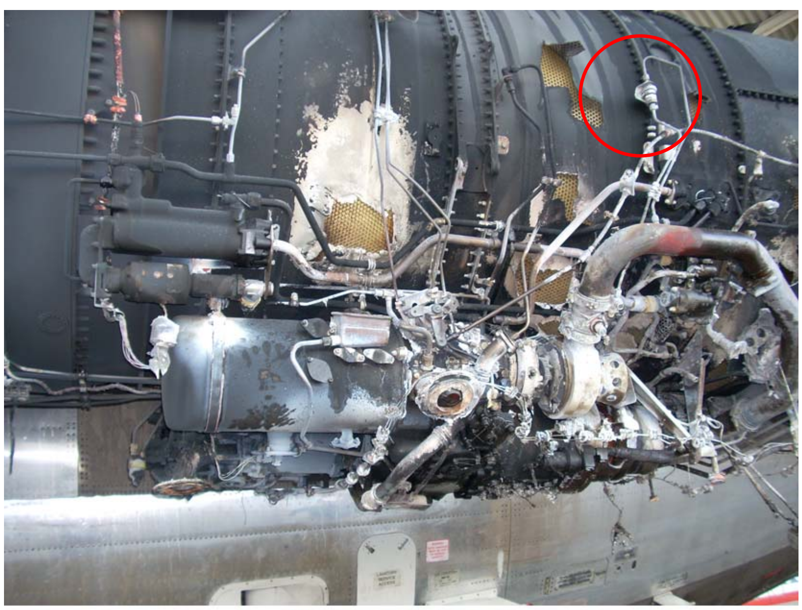


Photo No: DSCN0005.tif

Photo 11 – Starter pneumatic line P/N 5938254-1 in nacelle

Photo No: P9290061.tif

Photo 12 – Wiring harness damage

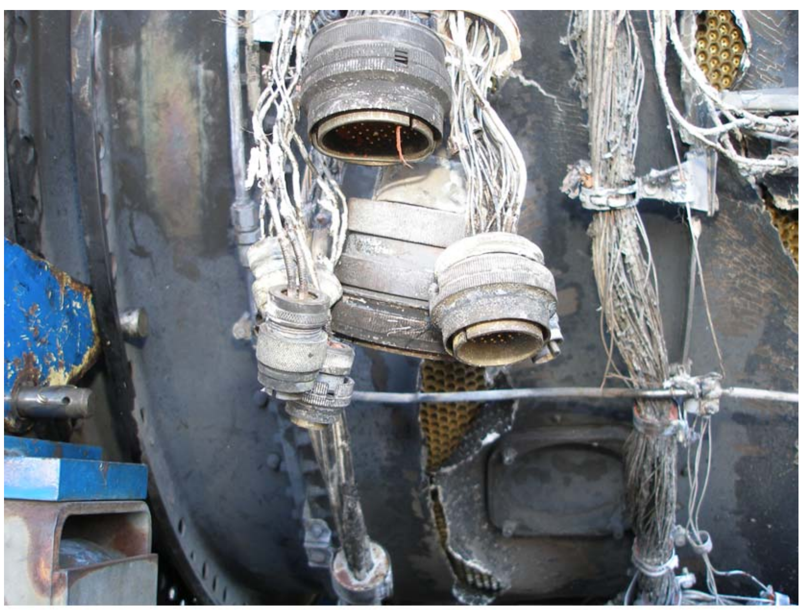


Photo No: PA010168.tif

Photo 13 – Engine start system – in situ

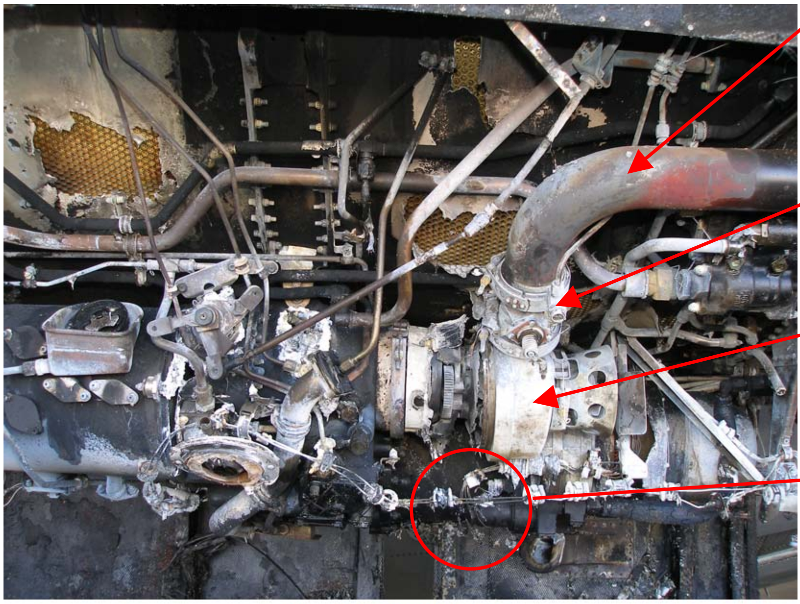


Photo No: P9290070.tif

Photo 14 – ATSV and ATS details in-situ

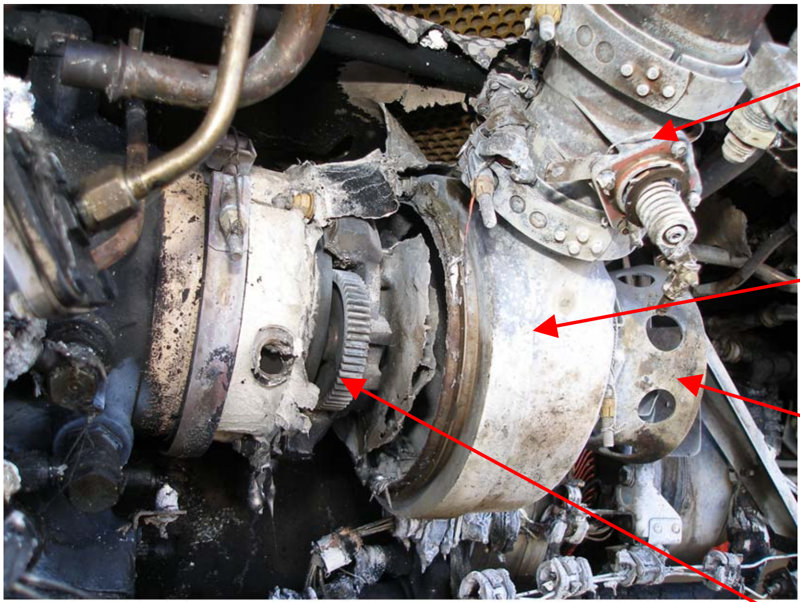


Photo No: P9290069.tif

Photo 15 – ATSV - removed from engine

Photo No: IMG_3656.tif

Photo 16 – ATSV manual override button – found in debris

Photo No: CHIO7MA310-8495.tif

Engine gearbox

Photo 17 – ATS in-situ - details

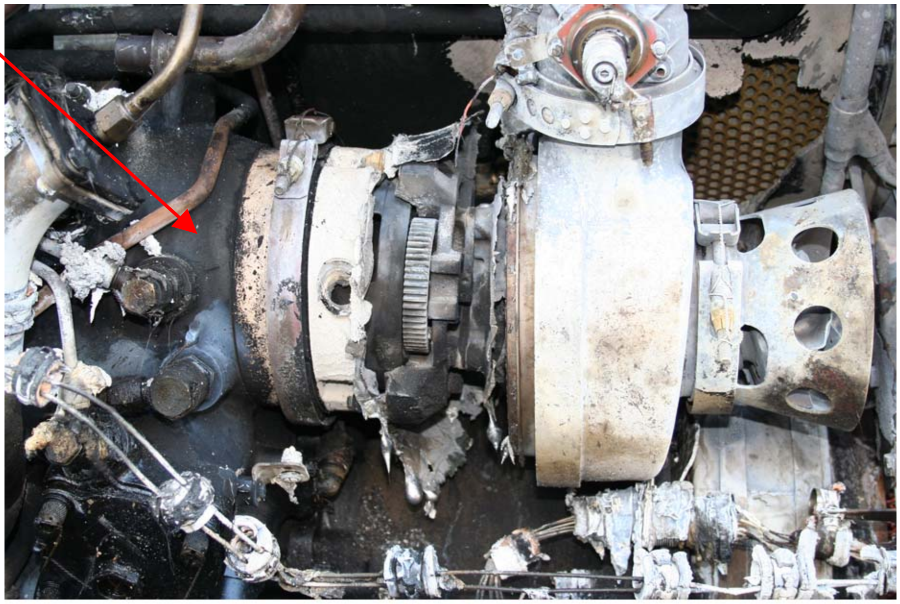


Photo No: IMG_3626.tif

Photo 18 – ATS in-situ - details

ATS Turbine rotor – contained within exhaust shroud

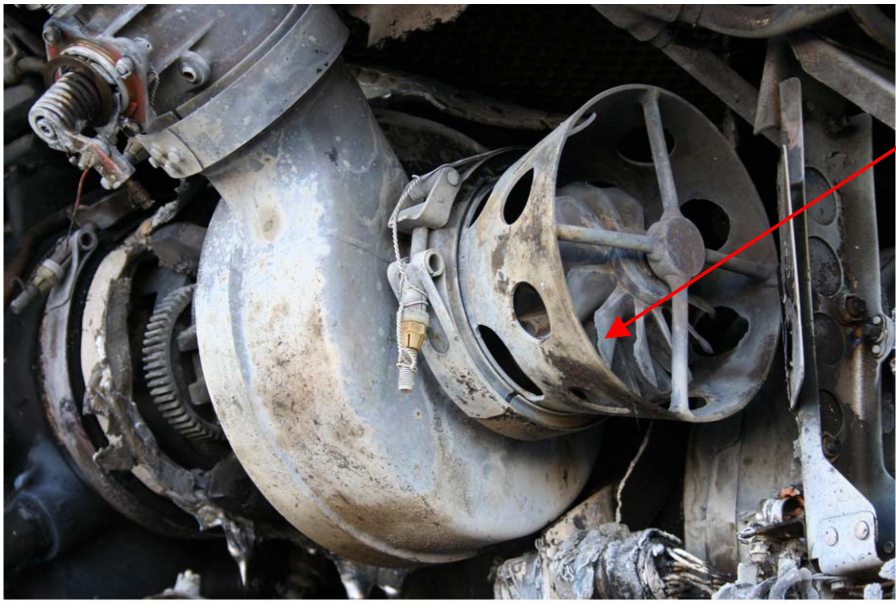


Photo No: IMG_3625.tif

Photo 19 – ATSV parts

Photo No: DCAO7MA310-8464.tif

Photo 20 – ATSV butterfly plate

Photo No: DCAO7MA310-8510.tif

Photo 21 – Water flow pattern - normal

Photo No: DCAO7MA310-8508.tif

Photo 22 – Butterfly plate return spring

Photo No: DCAO7MA310-8483.tif

Photo 23 – ATSV Solenoid

Photo No: DCAO7MA310-8560.tif

Photo 24 – ATSV solenoid plunger rod

Photo No: DCAO7MA310-8571.tif

Photo 25 – Photomicrograph of tip of solenoid plunger rod

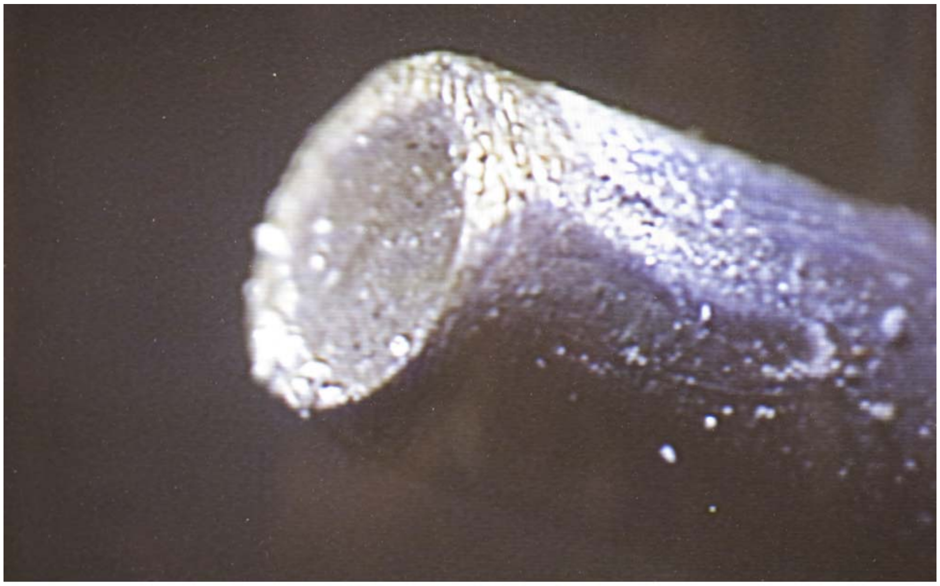


Photo No: DCAO7MA310-8589.tif

Photo 26 – ATSV manual override button - bent

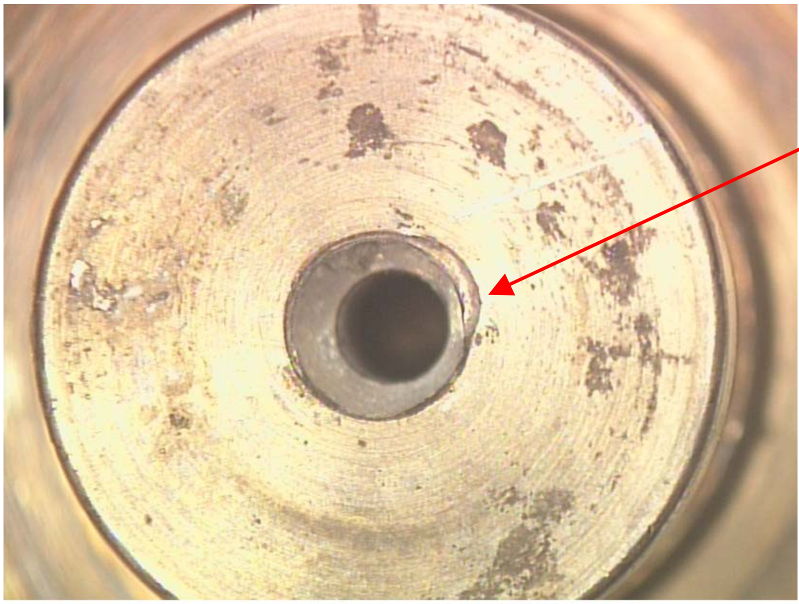
Photo No: AA image002.tif

Photo 27 – Detail of buckling and mushroom deformation of rod end

'Mushroom' type deformation of rod end

Photo No: AA image013.tif

Photo 28 – Ball valve housing manual override button sleeve



Score mark consistent with contact against manual override button ridge

Photo No: AA image019.tif

Photo 29 – Manual override button within sectioned ball valve housing

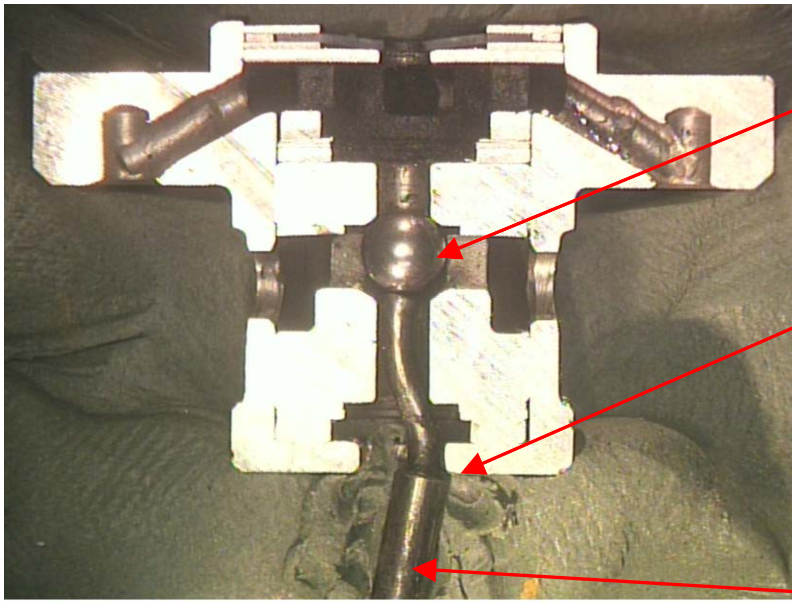


Photo No: auntitled000.tif

Photo 30 – Air turbine starter (ATS)

Photo No: DCAO7MA310-8591.tif

Photo 31 – Turbine rotor comparison

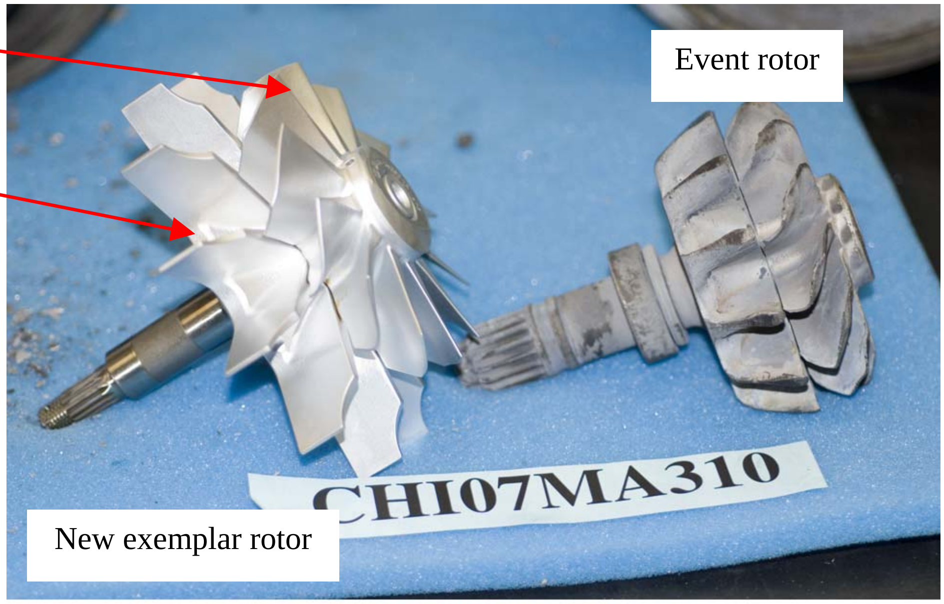


Photo No: DCAO7MA310-8659.tif

Photo 32 - Inlet/exhaust scroll housing

Photo No: DCAO7MA310-8639.tif

Photo 33 – Turbine inlet scroll

Photo No: DCAO7MA310-8626.tif

Photo 34 – Planetary gearbox

Photo No: DCAO7MA310-8645.tif

Photo 35 – ATS output shaft with clutch pawl carrier

Photo No: DCAO7MA310-8697.tif

Photo 36 – Clutch pawls

Photo No: DCAO7MA310-8708.tif

Photo 37 – Air turbine starter valve air filter (ATSV-AF)

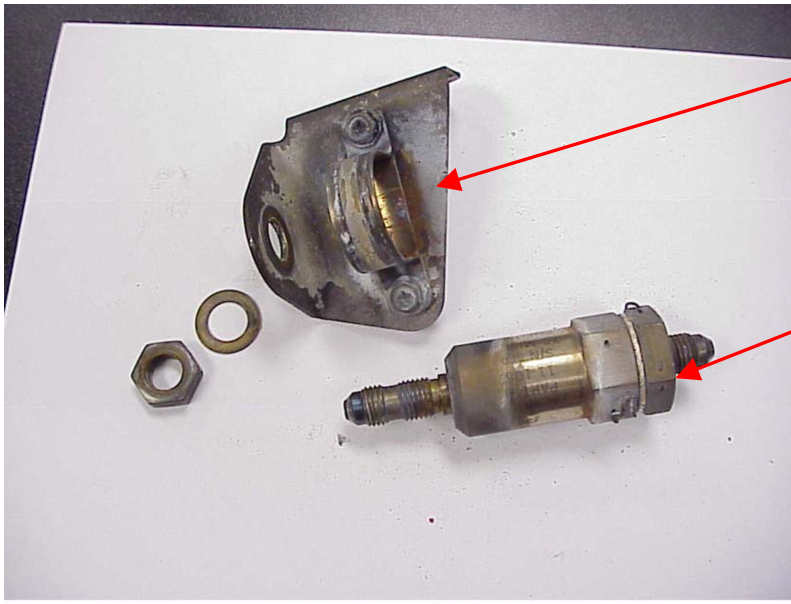


Photo No: PTI-MVC-012L.tif

Photo 38 – ATSV-AF dis-assembled – filter element missing

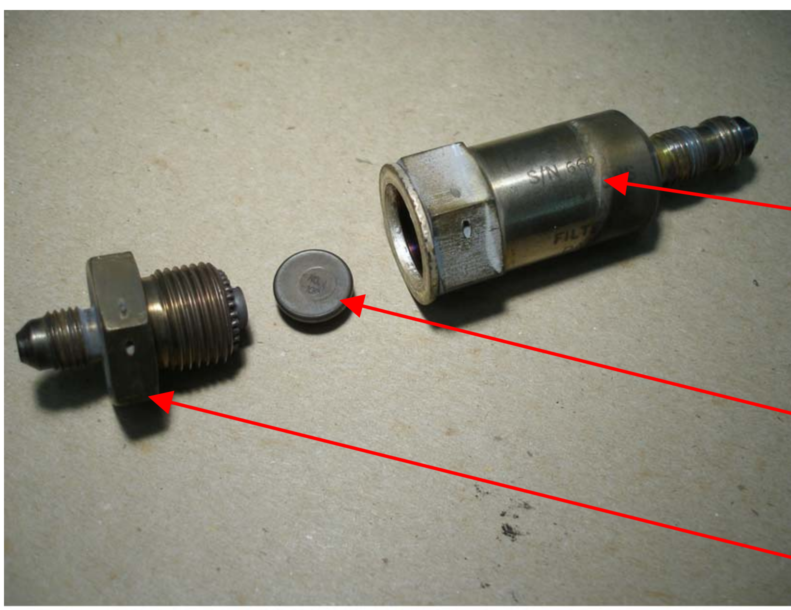


Photo No: P2250015.tif

Photo 39 – ATSV-AF housing – internal view

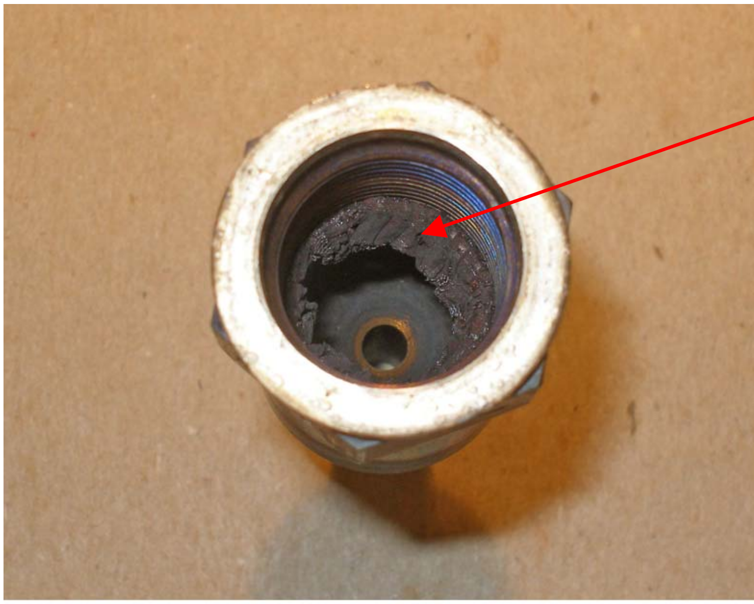


Photo No: P2250034a.tif

Photo 40 - ATSV-AF end cap – bottom view

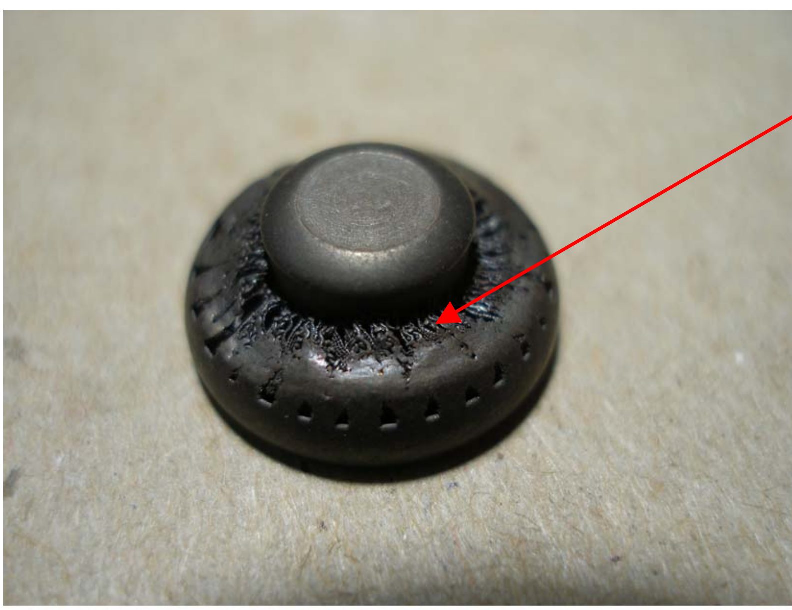


Photo No: P2250020.tif

Photo 41 - ATSV-AF end cap – top view

Photo No: P2250021.tif

Fretting marks consistent with contact against fitting nipple

Photo 42 - ATSV-AF top of fitting

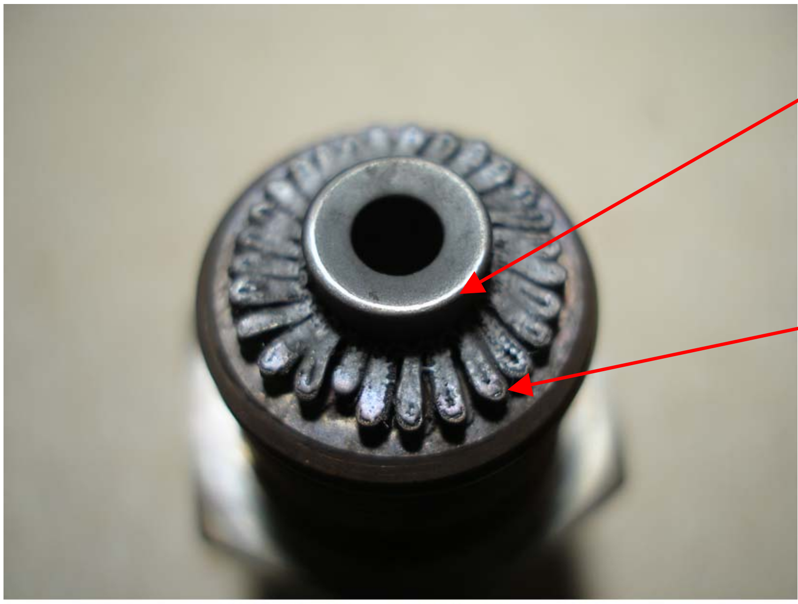


Photo No: P2250027.tif

Fretting marks consistent with contact against cap top

Remains of filter media and braze material

Photo 43 – Specialized ATSV butterfly shaft tool

Photo No: PICT0768.tif

Photo 44 - Exemplar ATSV (for illustration only) – butterfly manual override wrench flats detail

Photo No: P2125796.tif

Photo 45 – Specialized ATSV butterfly shaft tool used on exemplar aircraft – Note: cowl door must be opened for access

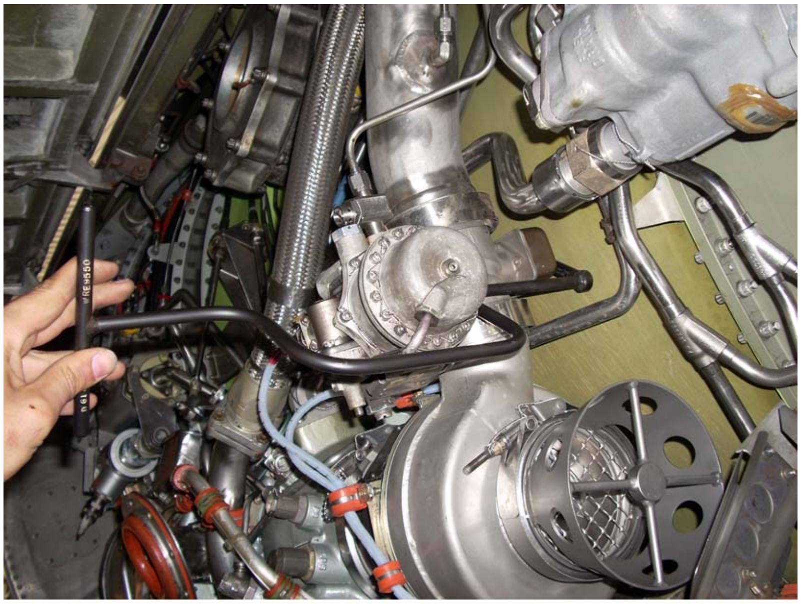
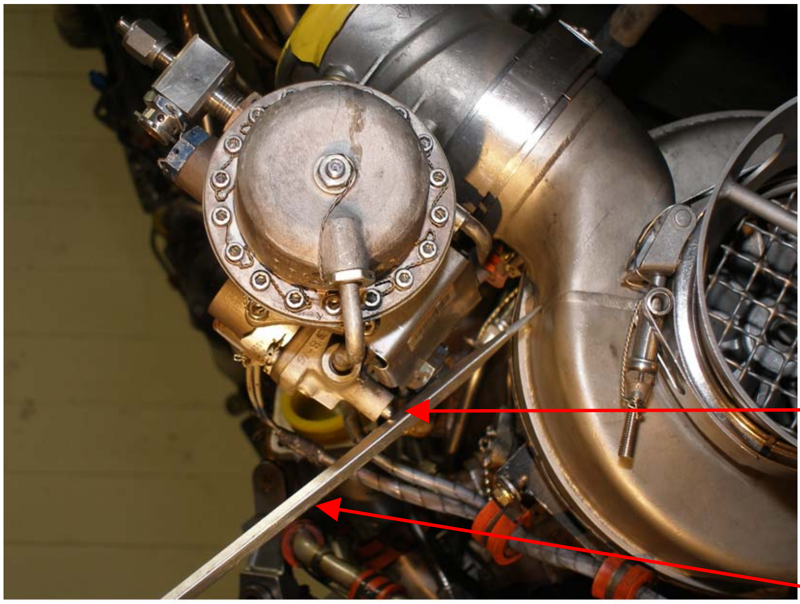


Photo No: DSCN0049.tif

Photo 46 – Lever used to assist manual override button activation (For illustrative purposes only)



Note: Cowl door is open.

Manual override button

Screwdriver

Photo No: P2080092.tif

Photo 47 - Lever used to assist manual override button activation (For illustrative purposes only) – alternative levering method

Photo No: P2080119.tif

Note: Cowl door is closed