NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Aviation Engineering Division
Washington, DC 20594

September 11, 2000

AIRWORTHINESS GROUP CHAIRMAN'S FACTUAL REPORT

A. ACCIDENT: DCA00MA005

Location:	Mina, South Dakota (SD)
Date:	October 25, 1999
Time:	1213 Central Daylight Time (CDT)
Aircraft:	Sunjet Aviation, Inc., Learjet, Inc. Model 35, N47BA

B. AIRWORTHINESS GROUP

Chairman: Kevin M. Pudwill
National Transportation Safety Board
Washington, DC

Member: Victoria Anderson
Federal Aviation Administration
Washington, DC

Member: James B. Tidball
Bombardier Aerospace Learjet
Wichita, KS

Member: Michael A. Cummins
Honeywell, Inc.
Phoenix, AZ

Member: Gary Hannah, P.E.
B/E Aerospace, Inc.
Lenexa, KS

Member: Tony Vecchio
Sunjet Aviation, Inc.
Sanford, FL

C. SUMMARY

On October 25, 1999, at approximately 1213 CDT, a Learjet Model 35-060, N47BA, operated by Sunjet Aviation, Inc., crashed near Mina, SD. The pilot, copilot, and all four passengers onboard received fatal injuries and the aircraft was destroyed.

The Airworthiness Group was established on October 25, 1999 and was responsible for documenting the aircraft wreckage distribution, damage to the airframe, aircraft systems, and powerplants.

Members of the Airworthiness Group reconvened between November 30th and December 2, 1999, at the Learjet, Inc. facility in Wichita, Kansas, to perform teardowns of the significant Oxygen and Pressurization system components recovered on scene. Refer to Section 5.0 "Oxygen /Pressurization System Component Teardowns" for further details.

Members of the Airworthiness Group reconvened, in Aberdeen, SD, on June 13, 2000, to review additional wreckage recovered from the crash site during the spring of 2000. Refer to Section 6.0 "Additional Wreckage /Examination" for further details.

Functional tests of an exemplar Flow Control Valve (air conditioning system) were performed to determine the performance of the valve, assuming various mechanical failure modes. Refer to Section 7.0 "Flow Control Valve Testing (Mechanical Failure Modes)".

Testing of exemplar crew oxygen mask connections was performed by B/E Aerospace (Puritan-Bennett Aero Systems Co.), at their facility in Lenexa, Kansas, during December 1999 and January 2000. The testing was designed to determine the failure modes of crew oxygen mask connections, when the mask connectors are forcefully separated from their mating oxygen outlet valves. This testing was performed following the recovery of both crew oxygen outlet valves, with their respective crew mask oxygen (hose) connectors missing. Refer to Section 8.0 "Crew Oxygen Mask Connector Testing (Structural Failure Modes)" for further details.

Computer simulations were performed by Honeywell, Inc. throughout the investigation, that were intended to model the performance of the Environmental Control System (ECS).[1] The testing was designed to provide a better understanding of the cabin rate of climb (during ascent) assuming 1) the air conditioning system (i.e. bleed air to the cabin) was selected off at takeoff, and 2) a loss of bleed air to the cabin occurred at flight altitudes at /or above 25,000 feet.[2] Refer to Section 9.0 "Computer Simulations, Pressurization System" for further details.

Following this accident, the Federal Aviation Administration (FAA) initiated a Special Certification Review (SCR) tasked to investigate the design and certification of the Learjet Model 35 Oxygen & Pressurization systems. The objectives of the SCR were to determine 1) if the Oxygen and Pressurization systems were properly certificated, and 2) whether or not any unsafe design features existed within the systems. Refer to Section 10.0 "FAA, Special Certification Review" for further details.

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[1] Refers to those systems used to supply regulated (temperature controlled) bleed air pressure to the cabin for pressurization and heating (i.e. pneumatic, air-conditioning systems) as well as the pressurization system, used to maintain the desired differential pressure across the cabin, by controlling the position of the outflow valve.

[2] Last transmission from N47BA occurred at approximately 23,200 feet, while climbing at 2400 - 2500 feet per minute (fpm).

At the request of the Safety Board, Learjet performed a Flight Test of a Model 35 aircraft to 1) capture Cockpit Voice Recorder (CVR) audio, and 2) validate the pressurization system performance during an ascent similar to that of the accident flight, assuming the air conditioning system (i.e. bleed air) was selected off at takeoff. Refer to Section 11.0 "Flight Test, Learjet 35" for further details.

D. DETAILS OF THE INVESTIGATION

1.0 Wreckage Distribution

The accident site was located 2 miles east and 2 ½ miles south of Mina, SD, at the following geographic coordinates: 45 degrees, 25 minutes North Latitude; 98 degrees, 45 minutes West Longitude. The local ground elevation at the crash site was estimated to be 1300 feet (mean sea level), based upon published survey data for the Aberdeen, SD regional airport, located several miles to the east.

The accident site was characterized by a crater that measured 42 feet and 4 inches long, oriented east to west, by 21 feet and 7 inches wide, oriented north to south. The crater measured 8 feet and 6 inches at its deepest point, approximately 7 feet south of the crater's northern wall. The local terrain was relatively flat. A marsh, extending from north to south, was located approximately 80 feet due east of the crater.

The airplane was found destroyed and in a nose down attitude, i.e. with its upper surfaces oriented towards a magnetic heading of approximately 190 degrees. The main airframe wreckage was located in or nearby the impact crater. The majority of all other wreckage was found within a radius of approximately 75 feet. However, additional wreckage was recovered at distances up to 150 feet away. Essentially all wreckage found outside of the crater, was located to the east of the crater.

A debris field of smaller wreckage including; instrument panel components, the flight manual, seat cushions, life vests, and personal effects, extended outward from the impact crater in a north - northeasterly direction. The debris field formed a conical shape of approximately 35 degrees and extended from the crater to the nearby marsh.

Refer to Attachment I for a diagram(s) of the aircraft wreckage distribution.

2.0 Structures

Refer to Attachment II for configuration drawings of the Learjet Model 35, including structural station identification drawings of the major airframe components (i.e. fuselage, wing, empennage, nacelles etc).

2.1 Fuselage

The primary structure of the fuselage from Sta. 36.75 to Sta. 603.06 (i.e., nose to tail), and the tailcone was crushed rearward and destroyed.

The cockpit windscreen was shattered inward and missing. However, remnants of the windscreen remained attached around the perimeter of the opening. Numerous pieces of plexiglass from the windscreen were also discovered along the northern perimeter of the crater while others were discovered imbedded in the southeast wall of the crater.

The windscreen center column "bird splitter" was broken away from its mounting at the base of the glare-shield and near the fuselage crown.

The cabin window frames were destroyed along with the remaining fuselage. The plexiglass windows were broken out and their debris scattered throughout the wreckage.

The main cabin door upper and lower clamshell sections and the framework surrounding the entry door, between fuselage Sta. 221.59 and 245.59, were broken out and fragmented. The upper and lower door sections were crushed rearward and fragmented, yet retained their respective hinges. The door (pressure) seals remained attached to the fragmented sections of the door frame structure that were recovered. The seals were found to be soft and pliable, and displayed no flat spots. Seal fractures coincided with the respective frame and /or door section fractures. The exterior cabin door handle was broken away from the door and dented. The handle was found in the closed and locked position. The door hydraulic cylinder "snubber" was separated from the door assembly.

The rear pressure bulkhead, i.e. Frame 22 at fuselage Sta. 421.42, was pushed rearward and destroyed. Only small pieces of the bulkhead could be identified in the wreckage due to the severity of the breakup.

The divan seat floorboard, forward of fuselage Sta. 368.68, was bent inward (i.e. upward) convexly, and broken into numerous sections not easily recognized in the wreckage. No sections of the baggage compartment floorboard were recognized in the recovered wreckage.

2.2 Wings

2.2.1 Left Wing

The outboard section of the left wing was severed longitudinally (i.e. chord-wise) at wing station (WS) 181.10. The section outboard of this fracture plane was crushed rearward and torn open. This outer section of the wing was found near the northeast rim of the impact crater. Inboard of WS 181.10, the wing was crushed rearward, broken open and fragmented from the leading edge surfaces aft to spanwise spar number (No.) 5. The structure aft of spar No. 7 was heavily damaged. The lower surface of the left wing, inboard of wing station 125.00, was crushed inward (i.e. upward) and bent aft from spar No. 2 to spar No. 8.

The trailing edge of the left wing tip fuel tank (i.e. tip tank) extended vertically from the ground near the eastern edge of the crater. The tip tank was separated from the left wing at WS 205.14. The forward 83 inches of the tip tank were crushed rearward, broken open, and fragmented aft to station (Sta.) 113.

The left aileron remained attached to its hinge attachments at spar No. 8. However, spar No. 8 was found torn away from the main wing structure between WS 181.10 and 125.00. The aileron was found bent and buckled. The trim tab remained attached to the aileron.

The left spoiler remained attached to its hinge attachments along the wing rear spar. The spoiler was found bent upward at mid-span.

The left flap was separated at its hinges, bent upward and crushed forward near the inboard trailing edge. The flap tracks, hinges and jackscrews were found separated from their wing attachments.

Continuity of the aileron control cable was established between the aileron and the cable overload failure located just inboard of WS 53.00. The aileron trim tab push-pull tube remained attached to the aileron and trim tab.

2.2.2 Right Wing

The outboard section of the right wing was severed in a chord-wise direction between its wing to fuselage attachment points and WS 53.00. This section of the wing was found on the northwest edge of the crater. The wing was crushed rearward, from the leading edge surfaces aft to spar No. 5, i.e. approximately mid-chord along the wing. The wing section was bent upward, split laterally, and ripped open.

The inboard section of the right wing, from WS 53.00 inboard to WS 0.00, was broken and fragmented into several pieces.

The trailing edge of the right wing tip tank extended vertically from the ground, near the western edge of the crater. The tip tank was severed from the outer wing at WS 205.14. The forward 83 inches of the tip tank were crushed rearward, peeled open, and fragmented to Sta. 113. The tip tank trailing edge fin was partially severed and displaced laterally along its rivet line at Sta. 149.94.

The right aileron remained attached to its hinges along spar No. 8. The upper and lower aileron skins were bent upward and buckled. The aileron balance tab was found deflected downward approximately 45 degrees.

The right wing spoiler and wing structure, between WS 50.00 and 95.00, were bent, twisted, and mangled.

The right flap was separated from its hinge attachments, crushed inward and heavily damaged. The flap tracks and jackscrews were pulled away from their respective wing attachments.

Continuity of the aileron control cable was established between the aileron and the cable overload failure located just inboard of WS 53.00. The aileron balance tab push-pull tube remained attached to the aileron and balance tab.

2.3 Empennage

2.3.1 Vertical Stabilizer /Rudder

The vertical stabilizer front spar cap was broken out near the leading edge of the left horizontal stabilizer. The vertical stabilizer was severed longitudinally (i.e. fore to aft) between water line (WL) 65.00 and WL 95.00. The leading edges of the stabilizer were crushed rearward, torn open and fragmented.

The rudder was torn free from its hinges and actuator arm. It was bent to the right approximately 15 degrees at WL 72.56. The right surfaces of the rudder were severely buckled. The rudder trim tab was bent inward and upward at its base.

The rudder flight control cables exhibited overload failures just forward of fuselage Sta. 592.00, near the tail cone bellcrank assembly.

Fire damage was noted on the rear surfaces of a 24-inch section of the second spar (i.e. aft of the front spar), beginning at approximately WL 76.32. The fire damage extended upwards to a fracture plane approximately 24 inches beneath the horizontal stabilizer. However, no fire damage existed on the mating spar section immediately above the noted fracture. The damaged spar section with sooting was recovered from the bottom of the crater beneath the left engine. Note that the crater was found smoldering upon first arrival to the scene.

2.3.2 Horizontal Stabilizer /Elevators

The left horizontal stabilizer was crushed rearward and folded downward approximately 90 degrees. The left elevator was also bent downwards and torn open along its entire leading edge. The left elevator was found separated from its hinges.

The right horizontal stabilizer was separated from the vertical stabilizer at its root, i.e. body line (BL) 3.52. The lower surface of the stabilizer was torn open and bent inward (i.e. upward). The right elevator was separated from its hinges and the leading edges crushed rearward, between BL 4.50 and BL 50.20. The outboard section of the right elevator was separated from the remainder of the elevator at BL 50.20 and was fragmented into several sections.

The elevator flight control cables exhibited overload failures just forward of fuselage Sta. 592.00, near the tail cone bellcrank assembly. The elevator push-pull tubes, that extended through the vertical stabilizer, were bent and broken in several locations. Minor fire damage (i.e. sooting) was noted on localized sections of the push-pull tubes. The push-pull tubes with sooting damage were recovered from the bottom of the crater near the left engine.

2.4 Nacelles /Pylons

Both engine nacelles were pushed rearward and completely separated from the left and right pylons. The nacelle inlets were crushed inward from their leading edges aft to the fan section of each engine. The engines were torn free of their respective engine mounts and found resting in the bottom of the crater. The engine beams at fuselage station 443.23 and 473.00 were broken apart. The left engine mount was found basically intact. The right engine mount was severely damaged. The left engine cowling was found near the northeastern rim of the crater. The right engine cowling was broken apart and crushed inward, aft to nacelle station 218.00.

The right engine pylon was separated from the fuselage. Sooting was noted on the trailing edges (i.e. aft 8 inches) of the upper and lower surfaces. However, the pylon surfaces forward of this area showed no signs of fire damage. The pylon was recovered from the base of the crater directly beneath the left engine.

2.5 Landing Gear

2.5.1 Nose Landing Gear

The nose gear strut was found separated from its trunnion attachments in the forward wheel well. The nose wheel axle was fractured from the nose gear piston.

2.5.2 Left Main Landing Gear

The left main landing gear strut was found separated from its trunnion attachments and the retract cylinder. The wheels, brakes, and anti-skid unit were destroyed.

The inboard and outboard gear doors were found separated from their respective hinges and heavily damaged. The gear door actuators were torn free from each of the gear doors.

2.5.3 Right Main Landing Gear

The right main landing gear strut was found separated from its trunnion attachments and retract cylinder. The strut assembly was found approximately 10 feet northwest of the crater. The wheels, brakes, and anti-skid unit were destroyed.

The right inboard and outboard gear doors were found separated from their respective hinges and heavily damaged. The gear door actuators were torn free from their respective doors.

3.0 Power Plants

Two AlliedSignal (Honeywell), Model TFE731-2-2B turbofan engines powered the aircraft. Aircraft records indicate that engine S/N's P-74265 and P-74264 were installed at the left and right positions respectively.

3.1 On Scene Recovery

The right engine core and mainframe /inner case were found separated and inside the impact crater. One fan hub assembly was found adjacent to the right engine. After extraction of the right engine core and further excavation, the other fan hub assembly was recovered in the same area as the right engine core. The left engine core and separated mainframe assembly were buried beneath wreckage and dirt on the eastern edge of the impact crater.

The right engine core did not display any evidence of post impact fire or sooting. The left engine core displayed evidence of post impact fire damage to the fuel manifold hoses and sooting on the outer surfaces of the aft plenum, exhaust diffuser, and tailpipe.

The engine data plates were not recovered. Therefore, initial identification of the engine installation on the aircraft was based on mount fracture indications and the physical geometry of the engines.

The following pieces identified with the left engine were recovered:

1) Core Engine (heavily damaged).
2) Approximately 180 degrees of the Mainframe and Intermediate Housing.
3) Fan hub and associated assemblies (all but seven blades were separated at the platform or were found released from the hub).

The following pieces identified with the right engine were recovered:

1) Core Engine (heavily damaged).
2) Mainframe and Intermediate Housing (heavily damaged).
3) Fan hub and associated assemblies (all but five blades were separated at the platform or were found released from the hub).

The sections identified (above) were segregated and placed into separate TFE731 shipping containers. The remaining engine parts recovered from the wreckage were also placed into the same shipping containers, after separating components simply on a per engine basis. For example, two fuel control units were found and therefore one unit was placed in each shipping container. The inventory and initial description of the parts recovered is outlined below:

Parts of Unknown Association Placed in the Left Engine Box:

1) Oil /Fuel Cooler and Oil Temperature Regulator Assembly: No data plate.

2) Oil pump assembly: Nichols, P/N 3071949-11, Cage Code 99193, S/N 5-14057-364, A-Stamp 14 / 057, chip detector still in place, mounting flange fractured, no lines attached, magnesium body (older style).
3) Transfer Gear Box: No Residual oil observed, engine mono-pole installed, P/N 3070093-12 (x from –3), S/N P-562.
4) Upper Oil Cooler: AirResearch LA Repair Tag 9/3/82, Rotational and axial scoring on the inner diameter (ID) wall.
5) Lower Oil Coolers (2): The other oil cooler displayed rotational and axial scoring on ID.
6) Flow Divider: Service fittings in place, magnesium body, 394396-1-1, P-1076, bellows missing.
7) Accessory Gear Box: Fractured into multiple parts.
8) Pressurizing Valve: P/N 3075323-3.
9) Fuel Control: Separated from pump, P/N 3070800-8, S/N A5650T, Series 38, Mod 16,33,38, A-Stamp 07/459, Garrett Turbine Engine Company data plate, P3 limiter broken off, 120 PLA, no fuel observed.
10) Fuel Pump: Fuel wetting but insufficient to take sample, Vickers P/N 623138, S/N MX285879, Update record V and earlier, P17964.
11) Oil Temp Control Valve: P/N 158465-3 S1, S/N 12-3770.
12) Horizontal Drive Shaft.
13) Low Pressure Bleed Transfer (2).
14) Oil Tank
15) Tower Shaft Housing.
16) Surge Bleed Valve Controller.
17) Core Stator Splitter (multiple pieces, approximately 270 degrees).
18) Oil Filter and Oil Filter Caps.
19) Tower shaft strut.
20) Drain Mast.
21) L.P. Compressor Case Fragments (2).
22) L.P. Compressor Shroud Fragment.
23) Miscellaneous Components (4).
24) L.P. Stator Support Fragment and Vanes (2).
25) Fan Inlet Fragment.
26) Aft Fan Duct Fragments (3).
27) Accessory Gear Box: Multiple parts (3).
28) Main Frame: Fragments with other attachments.
29) Fan Containment Ring: Two fragments.
30) Fuel Control Computer: Case fractured open and missing top, P/N 2101142-1, S/N 21 1365, Series 6, Ref. Spec. PSC-74-211293, Selector in Normal.

<u>Parts of Unknown Association Placed in Right Engine Box:</u>

1) Oil /Fuel Cooler and Oil Temperature Regulator Assembly: Separated into two pieces. P/N 159610-8, S/N None. No residual fluids noted.
2) Oil pump assembly: Broken mount flange, broken input shaft, chip detector still in place, no lines attached, no data plate, magnesium body (older style).

3) Transfer Gear Box: Residual oil, engine mono-pole installed, P/N 3070093-12, S/N P-359.
4) Upper Oil Cooler.
5) Lower Oil Coolers (2). One had rotational and axial scoring that lined up with scoring observed on the oil cooler placed in left engine box. This oil cooler was later moved to the left engine container and a small cooler piece was placed in the right box.
6) Flow Divider: Service T's in place, magnesium body, no data plate, P/N 394396-?
7) Accessory Gear Box: Fractured into multiple parts.
8) Pressurizing Valve: P/N 3075323-3.
9) Fuel Control: P/N 3070800-21, S/N A3466PTC, Series 2, Mod 44, Garrett /AlliedSignal data plate, 120 degrees PLA, P3 limiter was installed.
10) Fuel Pump: Residual fuel, sample taken, pump badly fractured.
11) Surge Bleed Valve.
12) Horizontal Drive Shaft.
13) Low Pressure Bleed Transfer (2).
14) Oil Tank
15) Surge Bleed Valve Controller.
16) Spinner Fragments (2) and Spinner Support.
17) Scupper Panel.
18) Oil Filter and Oil Filter Caps.
19) Tower shaft strut.
20) Fan Blades: Total of 15 blade pieces (majority appear to be unique blades).
21) Miscellaneous Tubing
22) Additional Accessory Gear Box Pieces
23) Oil Temperature Control: P/N 158465-3, S/N 96-186.
24) Ignitor Leads
25) Intermediate Case Fragments (9).
26) Fan Containment Ring: Distorted but still intact.
27) Miscellaneous Parts.
28) Fuel Control Computer: P/N 2101142-? (-1 over-stamped either as a - 4 double strike or -44), S/N 116-947, Series 2, Ref. Spec. PSC-74-211293, Selector in Normal.

The engine shipping containers were sealed and banded on Saturday October 30, 1999, in the presence of an FAA representative. The engines were later shipped to Honeywell, in Phoenix, Arizona, for teardown and further examination.

3.2 Engine Teardowns

The engines teardowns were conducted at the Honeywell Product Safety and Integrity Investigation Laboratory in Phoenix, Arizona between December 14th and December 16th, 1999. The teardown inspections of engine S/N's P-74264 and P-74265 were witnessed by members of the Airworthiness Group and were conducted under the surveillance of the NTSB and a representative of the local FAA Flight Standards District Office (FSDO).

Honeywell, Inc. Teardown Report No. 21-11090, indicates that these inspections revealed that the type and degree of damage observed on engine S/N P-74264 was indicative of engine rotation at the time of impact. Furthermore, that the type and degree of damage observed on engine S/N P-74265 was indicative of engine rotation and operation at the time of impact. The report also indicates that no pre-accident condition was found on either engine that would have interfered with normal operation.

Refer to Honeywell, Inc. Teardown Report No. 21-11090, dated May 12, 2000 (Attachment III) for further details.

4.0 Aircraft Systems

4.1 General

All electrical wiring, transducers, and electromechanical devices recovered from the accident site were examined for fire damage. No fire damage was noted on any airplane wiring, cables, or electrical components. Nor was there any fire damage noted on any avionics or other electrical devices recovered from the airplane.

The following sections describe the condition of the aircraft systems as recovered on scene. Refer to Section 5.0 "Oxygen /ECS Component Teardowns" for more detailed information regarding these systems.

4.2 Oxygen System

Oxygen system components and fragmented portions of the oxygen distribution lines were found throughout the airplane wreckage. The following items from the oxygen system were retained for further testing.

4.2.1 Oxygen Bottle /Regulator /Relief Valve

The oxygen bottle, manufacturer part number (P/N) 3AA1800 (dated August 1971), was found intact, however damaged with a large dent running longitudinally the length of the cylinder. The regulator cap was missing, however; the shutoff and pressure regulator valve assembly (i.e. regulator) remained intact. The fittings for the oxygen distribution line, pressure gauge (cockpit), relief valve, and servicing valve were sheared off at the regulator assembly. Markings on the bottle indicated that the last hydrostatic test of the bottle was performed in June 1995, at Overland Aviation Service Company, St. Louis, Missouri.

No determination could be made on scene regarding the position of the oxygen bottle regulator /shutoff valve. Refer to Section 5.1.1 for further details.

Note: The oxygen source reportedly used by Sunjet Aviation, Inc. to service N47BA, was tested by Liquid Technology Corporation of Orlando, Florida, at the request of the FAA on October 28, 1999. The oxygen source(s) was found to be > 99.8% pure oxygen. Refer to Attachment IV for further details.

The oxygen bottle (thermal) relief valve [Ozone Industries, Inc., P/N AN6245A4, serial number (S/N) 17465] was recovered separately. The adjustment nut safety wire was found intact. Both army-navy (AN) standard fittings were broken at their jam nuts. The valve body showed a small nick on the face of its outlet.

4.2.2 Crew Distribution System

Both flight crew oxygen outlet (quick disconnect) valves were recovered. The valves were found plugged with dirt /debris. One quick disconnect valve was found with its dust cover still attached, however damaged. When cleaned out, the quick disconnect retainer pins[3] were found in place. However, no pieces of the mating crew oxygen mask hose connectors[4] were found in either valve.

Portions of one of the crew oxygen mask regulators was recovered in the wreckage. A section of the oxygen selector (valve) that rotates on the face of the regulator, remained attached to the regulator and was marked with three positions (i.e. Normal, 100%, Emergency). However, the position of the selector could not be determined.

One crew mask oxygen hose assembly pressure indicator[5] was found separated from its hose connections.

A short section of a flight crew oxygen mask hose assembly, measuring approximately nine inches in length, was found with a crimped ferrule on one end. The hose was torn open approximately five inches above the crimped fitting. Although a rubber microphone attachment band was located one and one-half inches above the crimp, the mask assembly microphone wire was not attached.

A longer section of a flight crew oxygen mask hose, measuring approximately twenty-two inches in length, was found severed at both ends with no further breaks or

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[3] Two stainless steel retainer pins (.078" diameter) located 180 degrees from one another, that protrude inward from the valve retainer assembly (inner bore) approximately .070", to interlock with and retain the crew oxygen mask hose connector. The retainer assembly is manufactured from brass rod, nickel plated (0.3 mils).

[4] An aluminum fitting, attached to the crew oxygen mask hose assembly with a crimped ferrule, designed to mate with the quick disconnect valve. The fitting is comprised of a probe and an outer connector (sleeve). When inserted into the quick disconnect valve (against spring pressure), and rotated approximately 1/4 turn clockwise, two slotted openings in the outer sleeve of the connector interlock with the quick disconnect valve retainer assembly. The spring pressure of the valve prevents removal (i.e. counter-clockwise rotation) of the connector without first depressing the connector inward. Once inserted, the probe allows the flow of oxygen to the crew mask.

[5] A spring loaded piston that displays a colored indicator based upon the oxygen system pressure sensed. A red indicator is visible when oxygen pressure is below nominal operating pressure and the piston is held in its normal position by the spring. When oxygen pressure reaches approximately 70 PSIG the piston overcomes the force of its spring, causing the piston to travel and reveal a green indicator.

damage. Neither end matched up with the shorter section of crew oxygen hose described above. A short segment of microphone wire remained attached through a rubber microphone attachment band, approximately nine inches from one of the severed ends. The microphone wire was severed approximately four inches short of a second microphone attachment band.

4.2.3 Passenger Distribution System

The passenger oxygen distribution system shutoff valve (PASS OXY) and aneroid bypass shutoff valve (PASS MASK) were both recovered and found plugged with dirt /debris. Note: These valves are manually operated and are physically located beside the captain's armrest. Further note that these valves are identical with the exception of their operating knob, which is marked as identified above. Although the valve bodies were found intact, the operating knobs for each valve were missing. The P/N tags for each valve were also missing. Therefore, no determination could be made regarding the installation (identity) of these valves.

One of the passenger oxygen actuator lanyard valves was found separated from its cabin ceiling compartment door, installation location unknown. The pneumatic door latch (integral to each lanyard valve assembly) was found in the extended (latched) position, with impact damage noted on the exposed end of the latch. Note that, when pressurized, these door latches are retracted (against spring pressure) to release (open) the ceiling compartment door, allowing the passenger masks to fall from their overhead compartment. When oxygen pressure upstream of the valve(s) is removed (or depleted) the latch springs will forcibly extend each latch once again.

Two additional lanyard valves were recovered on scene. However, no determination could be made regarding the position of the poppet valves[6] that supply oxygen to the passenger masks.

Several pieces of passenger oxygen masks, orange in color, were recovered. It was estimated that there were four separate masks all together. However, none of the torn pieces were able to be matched up to form any one single mask. Several miscellaneous sections of passenger oxygen mask hoses were also recovered.

4.3 Environmental Control Systems (ECS)

The pneumatic (i.e. bleed air), air conditioning, and pressurization systems, were found severely damaged and fragmented. The following items represent the ECS components that were recovered and retained for further examination and testing. Note: Many of the components listed below were missing substantial sections of their respective assemblies.

[6] The flow of oxygen to an individual passenger mask is initiated by pulling a lanyard /pin free from the passenger oxygen actuator lanyard valve assembly. When the lanyard /pin is pulled free, a normally closed poppet valve opens to supply a constant flow of oxygen at approximately 4 liters per minute to the respective mask.

4.3.1 Pneumatic System

The left and right (L & R) Bleed Air Shutoff /Regulator Valves (Mod Valves).

The L & R Engine Bleed Air Check Valves.

The Bleed Air Manifold /miscellaneous pneumatic distribution lines.

The L & R Nacelle Anti-Ice Shutoff Valves.

The Wing /Horizontal Stabilizer Anti-Ice Shutoff Valve.

The Windshield Anti-Ice Shutoff Valve.

Temperature Sensor (P2300-112CPI 590 degrees F, 8055) and bleed air tube.

4.3.2 Air Conditioning System

The Cabin Air Flow Control Valve.

The Hot Air Bypass Valve (H- Valve).

The Ram Air Heat Exchanger.

The Ram Air Check Valve.

Air Distribution System Check Valve (1 of 2).

4.3.3 Pressurization System

The Cabin Altitude Controller (i.e. a sub-component of Pressurization Module).

Cabin Altitude Limiter.

Pressurization limiter (P/N 146228).

A Differential Pressure Relief Valve.

Portions of the Safety Valve housing and surrounding structure at frame 22 (i.e. rear pressure bulkhead). The aluminum ducting that remained attached was crushed inward. Numerous fragmented pieces of the valve housing were found imbedded around the installation on the forward side of the bulkhead. Approximately one-half of the valve circumference was missing.

A portion of a diaphragm, believed to be from either the Outflow or Safety Valve.

4.4 Cockpit Instruments

The cockpit was destroyed along with the instrument panel. Several instruments were recovered and examined. The following is a list of the instrumentation that was onboard the airplane, whether or not it was recovered, and the indications noted.

Instrument	Left Side	Right Side	Indication
N1	Recovered	Recovered	Both destroyed
ITT	Recovered	Recovered	Both destroyed
N2	Recovered	Recovered	Both destroyed
Oil Temperature	Recovered	Recovered	Both destroyed
Oil Pressure	Recovered (single indicator)		Undetermined
Fuel Flow	Recovered (single indicator)		Destroyed
Hydraulic Pressure	Recovered (single indicator)		Destroyed
Emergency Air	Recovered (single indicator)		Destroyed
Oxygen Press. Indicator	Recovered (single indicator)		< 0 PSI
Ram Air Temperature	Recovered (single indicator)		Destroyed
Standby Gyro	Recovered (single indicator)		Destroyed
Altitude Alerter	Recovered (single indicator)		FL 390
Attitude Indicator	Recovered	Not Recovered	Undetermined
Airspeed indicator faces	Recovered	Recovered	Undetermined
Vertical Speed Indicator	One face plate-recovered		Destroyed
Radio Magnetic Indicator	One indicator-recovered		Destroyed
Audio panels	Recovered	Recovered	Destroyed
Communication panel	Channel 2 -recovered		Destroyed
Turn coordinator	One-recovered		Destroyed
Cabin Altitude Controller	Recovered		Destroyed
Throttles	Single quadrant recovered		Destroyed
Fuel qty indicator	Recovered (single indicator /selector)		Destroyed
Emergency brake valve	Recovered		Destroyed
Yaw Damper control panel	Recovered		Destroyed
Drag chute handle	Recovered		Broken
GPS control panel	Recovered		Destroyed
Autopilot control face	Recovered		Destroyed
Avionics switch panel	Captain's side-recovered		Destroyed
Altimiter	One-recovered		29.92 in Hg

4.5 Fuel System

The fuel system consists of five fuel tanks. Two tanks are located in each wing, i.e. one main and one wing tip tank. An additional body (fuselage) tank is located aft of the rear pressure bulkhead. Both wing tip tanks were recovered at opposite ends of the impact crater. The fuselage fuel tank was broken open and fragmented. Parts of the tank were located approximately 60 feet from the eastern edge of the crater on a 070 degree heading. Smaller pieces of bladder and tank supporting structure were located in the crater and in a debris field extending east of the crater. Fuel lines, connectors, and pumps were recovered from the accident site.

4.6 Hydraulic System

Hydraulic lines, fittings, transmitters and reservoirs were recovered from the accident site. The system was highly fragmented. Hydraulic fluid was observed in several line fittings and pumps. The hydraulic accumulator was recovered and examined. However, it had been broken out and was empty of fluid.

4.7 Crew Restraints and Seat Belts

The airplane was equipped with two, five-point, quick-release harnesses for the pilots, and several single-buckle (bayonet type) seat belts for 8 passengers. The quick-release buckles for each of the pilot seats were found with bayonets installed at two of the five buckle ports. One of the quick-release buckle bayonets retained a 10 inch long section of belt webbing that was torn and frayed at one end. Only one of the passenger safety belts recovered was found buckled. Several of the belts showed tears and fraying of the webbing.

4.8 Miscellaneous Systems

A nitrogen bottle for the emergency gear extension and brake systems was located and recovered from the debris field east of the crater. The bottle was broken out and discharged.

Two engine fire extinguisher bottles were recovered from the crater. Both bottles were broken out and punctured. The explosive (squib) caps were separated from the bottles and were heavily damage. The caps were isolated and treated as hazardous material for proper disposal.

Two hand-held fire extinguishers and a life raft were recovered from the accident site. The two fire extinguishers were destroyed. The life raft inflation cylinder was dented and its charge expended.

A cockpit voice recorder (CVR) was recovered from the bottom, northwest wall of the crater. The outer casing was cracked and broken open in several locations. The inner (structural) casing was found cracked laterally across the center of its upper surface. Internal components of the CVR were jarred loose. The CVR was retained for further examination and readout by the Recorders Division of the Safety Board.

5.0 Oxygen /ECS Component Teardowns

The following teardowns of the Oxygen system and ECS components were conducted November 30th through December 2, 1999, at the Learjet, Inc. facility in Wichita, Kansas.

5.1 Oxygen System

The aircraft oxygen system provides oxygen for the flight crew and passengers. The system consists of a single oxygen cylinder, a pressure regulator /shutoff valve, an oxygen pressure gauge, an overboard discharge relief valve and indicator, crew mask quick disconnect valves, crew masks, a manual passenger shutoff valve, an oxygen aneroid valve, an oxygen aneroid bypass shutoff valve, passenger oxygen actuator lanyard valves, and passenger masks. Refer to Figure 3-8 of the Learjet 35 /36 Pilot's Manual (Attachment V) for a schematic of the oxygen system.

Oxygen is available to the crew at all times when the pressure regulator /shutoff valve is open. Oxygen is available to the passengers automatically above 14,000 ± 750 feet cabin altitude, or manually at any cabin altitude, by opening the normally closed oxygen aneroid bypass shutoff valve, located on the pilot's sidewall.

5.1.1 Oxygen Cylinder, Regulator /Shutoff Valve

The Oxygen cylinder has a storage capacity of 38 cubic feet at 1800 pounds per square inch gauge (PSIG). Oxygen pressure for the crew and passenger distribution systems are reduced to 70 PSIG (nominal), via a pressure regulator /shutoff valve, Puritan-Bennett P/N 172170-03, mounted directly on the cylinder. The oxygen cylinder /regulator is located in the nose cone of the airplane and is inaccessible to the flight crew during flight.[7]

Note: The ON /OFF markings on an undamaged regulator cap indicate the position of the regulator when aligned with a fixed index mark at the base of the regulator. The regulator cap is also marked with arrows (adjacent to its ON /OFF markings) that indicate the direction of rotation required to operate the valve. For example; "← OFF", "ON →".

Normal Operation of the regulator /shutoff valve (regulator) requires that the regulator knob (cap) be rotated approximately one-quarter turn clockwise (CW) to close the valve, and that the cap be rotated one-quarter turn counter-clockwise (CCW) to open the valve.

Note: Oxygen cylinder pressure is indicated on the Oxygen Pressure gauge, located in the cockpit, regardless of the position of the regulator valve.

All four fittings /lines normally attached to the neck of the cylinder (i.e. service, distribution, pressure gage, and relief lines) between the regulator /shutoff valve and

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[7] The setting of the oxygen bottle regulator is inspected through an access panel door on the right side of the fuselage nose during pre-flight inspections. However, due to the installation (orientation) of the bottle, only the "← OFF" markings on the regulator cap are visible when the regulator is actually in the open (ON) position. When the regulator is in the open position, the ON markings on the regulator cap are aligned with the fixed index on the collar, however these markings are beyond the normal view of the pilot from the access panel door. Refer to the photo shown in Attachment VI.

the bottle were found sheared off near the surface of the regulator and /or completely missing.

The regulator valve was verified in the open position by comparing the remaining portions of the damaged regulator assembly with an exemplar oxygen regulator /shutoff valve.

The regulator valve was independently verified in the open position by pressurizing the cylinder with nitrogen, to approximately 350 PSIG, following the installation of a new fitting at the service port, and plugging the pressure gage and relief line ports. The regulator valve supplied nitrogen through its distribution line (port) upon pressurization.

Note: Although the cylinder was dented (i.e. remaining volume approximately 2/3 that of an undamaged cylinder) no leakage was noted from the cylinder other than through the distribution line that was left open during pressurization.

5.1.2 Crew Oxygen Mask Quick Disconnect Valves

Both crew oxygen mask quick disconnect valves were recovered. An elbow fitting remained attached to the valve body on each of the valves, however the oxygen supply lines to each valve had been sheared off.

One disconnect valve was found with one of its two ports capped and therefore identified as the valve installed at the copilot's station.[8]

Examination of the pilot's quick disconnect valve revealed that the valve was in good overall condition. Minor scratches were noted on the face of the valve and internally, near one of the retainer pins. The retainer pins, that interlock with the crew oxygen mask connector, were found intact. However, one of the retainer pins was bent slightly.

The copilot's quick disconnect valve was examined and also found in good overall condition. Minor scoring and gouges were noted on the inner walls of the valve, that penetrated the nickel plating of the retainer assembly and gouged the (brass) base metal beneath. The internal scoring was predominately noted midway between the two retainer pins and was inline with the bore of the valve. Minor scoring was also noted immediately adjacent to each of the retainer pins. During recovery, the valve dust cover, that is spring loaded closed when a crew mask is not plugged in, remained attached to the valve and was found in its closed position. The dust cover assembly broke away from the valve when it was initially opened.

[8] The flight crew oxygen distribution system extends from the cylinder (in the nose compartment), along the left hand side of the cockpit, to the pilot's quick disconnect valve, through the valve, then on to the copilot's station (through the cockpit overhead), where oxygen flow is terminated at the discharge port of the copilot's valve.

5.1.3 Crew Masks /Regulators

Portions of two different crew mask regulators were recovered, both manufactured by Puritan-Bennett. One regulator was identified as a ZMR series diluter-demand regulator, mask P/N 174118.[9] The second regulator was identified as a Rogers regulator, however no P/N (identification) was recovered. The ZMR series regulator was a two position regulator (i.e. Normal, 100% positions). The Rogers regulator, later identified as P/N 112145A, was a three position regulator (i.e. Normal, 100%, Emergency positions). The Rogers regulator is mounted on Learjet P/N 6600214-3 crew oxygen masks.

No determination could be made regarding the position of the ZMR series mask regulator from the section of the mask recovered.

The Rogers regulator was disassembled by B/E Aerospace, at their facility in Lenexa, Kansas, on August 30, 2000. Approximately 70% of the regulator selector (knob), including its pointer was missing. Examination of the disassembled regulator (selector) revealed that the regulator was in the Emergency position at the time of impact. However, rotational scoring was noted external to the regulator assembly and on the lower surfaces of the selector knob. Note: Positioning of the selector from its center position (i.e. 100%) to the Emergency position requires approximately 15 - 20 degrees clockwise rotation.

The ZMR series (diluter-demand) mask (P/N 174118), provides oxygen (diluted with cabin air) upon demand, when the selector lever (located on the side of regulator) is positioned to the Normal position. When the lever is positioned to the 100% position, the mask provides 100% oxygen upon demand, regardless of cabin altitude.

The P/N 6600214-3 mask (with P/N 112145A regulator), functions similarly in the Normal and 100% positions. However, this regulator design also incorporates a dilution aneroid that will progressively shutoff the diluter (cabin) port upon rising cabin altitudes, thereby supplying 100% oxygen at cabin altitudes above 33,000 feet. When the regulator selector is positioned to the Emergency position, the regulator supplies 100% oxygen, regardless of altitude, at a positive pressure. Note: This series mask will also supply automatic positive pressure breathing (@ > 130 liters per minute) at cabin altitudes above 39,000 feet, regardless of the regulator selected mode.

Refer to Attachment VII for the Learjet 35 /36 Airplane Flight Manual (AFM) Oxygen Duration tables for both the ZMR and 6600214 series crew masks onboard.

[9] Corresponds to a ZMR 147 mask assembly, effective for Learjet Models 35-001 through 35-014. According to the Learjet Model 35 /36 Illustrated Parts Catalog (IPC), the ZMR 159 mask is approved for S/N 35-060 (N47BA). Note: Both the ZMR 147 and 159 mask assemblies incorporate regulator P/N 172004-00.

One crew oxygen mask microphone connector was initially recovered and found plugged into the oxygen-microphone (OXY-MIC) position of its crew microphone panel.[10] The opposite microphone panel was later recovered (Refer to Section 6.0) and found with connectors in both the microphone (MIC) and OXY-MIC plug-ins. The position of the OXY-MIC (ON /OFF) toggle switch, located on the microphone panel, could not be determined.

Several sections of crew mask oxygen hoses were recovered, including one oxygen pressure indicator, however neither of the crew mask oxygen line connectors were initially recovered. Note: One crew mask oxygen line connector was later recovered. Refer to Section 6.0 "Additional Wreckage Examination" for further details.

5.1.4 Manual Passenger Shutoff Valve & Oxygen Aneroid Bypass Shutoff Valve

The manual passenger shutoff valve and oxygen aneroid bypass shutoff valve, identified as G.W. Dahl Co. Inc., Bristol, R.I., Model GT, were found intact with the exception of their respective operating knobs, that were not recovered. No determination could be made regarding the installation of these valves onboard N47BA, due to the missing knobs and missing identification labels that distinguish their installation.

One valve actuator shaft was bent and the supply and discharge lines on both valves sheared off. No additional external damage was noted to either of the valves. Each of the valves was packed with dirt /debris. No determination could be made regarding the position of the manually operated valves by visual examination.

The supply and discharge ports of both valves were cleaned. Shop air (approximately 100 PSIG) was supplied to each of the valves independently. One valve was found to be in the open position and the other (i.e. valve with the bent actuator shaft) was found to be closed. These positions were each independently confirmed by rotating the actuator shafts of each valve in the open and closed directions. Note: Normal operation of these valves requires approximately two complete turns of the valve actuator shaft.

Note: Normal oxygen system configuration is with the Manual Passenger Shutoff Valve normally open and the Oxygen Aneroid Bypass Shutoff Valve normally closed.

Note: The Passenger Oxygen Aneroid Valve[11] was recovered several days later and sent to the Safety Board for examination. Although the valve body (housing) was

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[10] Located at each pilot's station side panel. Each crew oxygen mask microphone connector should normally be plugged into its respective panel. In order to operate the mask microphone, the OXY-MIC switch must be positioned to the ON position and the microphone keyed, using the microphone switch on the outboard horn of the control wheel.

[11] At 14,000 ± 750 feet (cabin altitude) an internal aneroid closes a normally open switch that applies DC power to command the Passenger Oxygen Aneroid Valve open, bypassing the normally closed Oxygen Aneroid Bypass

intact, the electrical connector pins were bent and /or missing. Since the operation of this valve does not effect the crew oxygen distribution system, no further testing of the valve was warranted.

5.1.5 Passenger Oxygen Actuator Lanyard Valves

Three of five cabin Oxygen Actuator Lanyard Valves (Puritan-Bennett P/N Z623) were initially recovered and examined. Five such valve assemblies are normally installed in the cabin overhead of the Learjet Model 35. Note: The remaining two valve assemblies were later recovered and examined by the Airworthiness Group during the additional wreckage examinations conducted on June 13, 2000. Refer to Section 6.0.

No lanyards or lanyard pins were recovered with the initial valve assemblies. One oxygen mask poppet valve housing (i.e. lanyard pin receptacle) was found intact, all remaining housings (i.e. 3 per each valve assembly) were destroyed during the crash.

The latches of each valve assembly, that retract against spring pressure when the valve body is pressurized and release the respective overhead oxygen doors, were found heavily damaged and retained in their retracted positions by the deformed latch housings.

No determination could be made regarding whether or not these valve assemblies were pressurized at the time of impact. Similar findings were noted with the two remaining valve assemblies recovered later. Refer to Section 6.0.

5.2 Pneumatic System

The airplane pneumatic system uses bleed air extracted from the engine compressor sections. The pneumatic system includes controls for the regulation and distribution of low pressure (L.P.) air from the fourth stage axial compressor and high pressure (H.P.) air from the centrifugal compressor.

Bleed air from both the L.P. and H.P. engine compressors is provided to a bleed air shutoff /regulator valve (Mod Valve) on each engine. When open, these valves regulate the flow of bleed air from the L.P. and H.P. compressors, to a common manifold that supplies the pneumatic systems. This regulated bleed air is used for cabin pressurization and heating, anti-icing systems (i.e. engine nacelle, wing /stabilizer, and windshield), the pressurization system jet (vacuum) pump, and pressurization of the hydraulic reservoir.

Control of pneumatic bleed air is accomplished with the left and right BLEED AIR switches, located on the copilot's lower right switch panel. When the associated BLEED AIR switch is placed in its OFF position, a shutoff solenoid on the respective Mod Valve is energized and the normally (spring loaded) open Secondary Pressure Shutoff Butterfly

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Shutoff Valve, and thereby supply oxygen to the passenger oxygen distribution system.

Valve of the Mod Valve is closed using bleed air pressure. When the associated BLEED AIR switch is placed in its ON position, the respective shutoff solenoid is de-energized and the Mod Valve (butterfly valve) modulates to regulate a downstream pressure of 27 - 35 PSIG. [Note: Description of operation provided by Learjet, Inc.]

Bleed air check valves, located downstream of each Mod Valve allow flow in one direction and prevent the loss of bleed air during single engine operation. A bleed air manifold serves as a collection /distribution point for regulated bleed air from either engine. From the manifold, bleed air is distributed to the cabin for pressurization and heating via the Flow Control Valve (Refer to Section 5.3). Likewise, the bleed air manifold also supplies the various other pneumatic systems previously identified.

5.2.1 Bleed Air Shutoff /Regulator Valves (Mod Valves)

One Mod Valve was found with its H.P., L.P., and secondary valve body sections present. Although the secondary section of the valve was heavily damaged, the Secondary Pressure Shutoff Butterfly Valve (butterfly valve) was found basically intact, with the butterfly plate broken loose from its actuator shaft assembly. The Mod Valve shutoff solenoid was missing.

The secondary butterfly valve actuator arm was broken off and missing. However examination of the remaining portion of the actuator arm and the orientation of the butterfly spoon shaft, revealed that the valve was within approximately 15° of its fully closed position when compared with an exemplar Mod valve.

Note: Normal operation of the secondary butterfly valve requires a 90 degree rotation of the actuator shaft assembly, to transition from a fully open to fully closed position. The secondary butterfly valve is spring loaded open and requires engine bleed air pressure to close the valve.

The flow mixing poppet valve between the H.P. and L.P. stages of the second Mod Valve was missing. The Secondary Pressure Shutoff Butterfly Valve was missing except for the upper bearing chamber, which contains the valve spoon shaft and spring assembly. The position of the actuator arm and spoon shaft end position indicator (slot) indicated that the valve was near its closed position when compared with an exemplar Mod Valve.

No assembly data plates (i.e. serial numbers) were recovered on either Mod Valve and therefore no determination could be made regarding their installation on the left or right engine.

A functional test of the left engine Mod Valve[12] P/N 3213736-1-1, S/N P-247, removed and replaced by Sunjet Aviation, Inc. on October 23, 1999, and returned to

[12] The repairable tag for the removed Mod Valve indicated that the valve was removed due to a split in turbine temperatures at altitude and due to a cabin loss with reduced power settings.

Learjet, at the request of the Airworthiness Group, is attached for reference. The functional test of the Mod Valve revealed that the flow mixing poppet between the L.P. and H.P. stages did not operate (i.e. open) at low bleed air pressures. Refer to the attached Functional Test Data Sheet, dated December 1, 1999 (Attachment VIII) for further details.

5.2.2 Bleed Air Check Valves

Two complete Bleed Air Check valves (left and right engine) were found. The adjacent pneumatic distribution lines and valve assemblies were crushed around the flapper valves. The left engine check valve was found with one half of the check valve wedged in the closed position and the other half open. The right engine check valve was found with both halves of the flapper valve stuck in the partially open position. The valves were found installed properly and no obstructions were noted immediately downstream of either check valve. Note: These check valves are hinged at their mid-plane with a common hinge pin and require no springs.

5.2.3 Bleed Air Manifold /Distribution Lines

No ruptures, holes, or tearing were noted on the Bleed Air Manifold or any of the pneumatic system distribution lines recovered. However, the distribution lines were difficult to inspect due to the extent that they were crushed and mangled.

A 47 PSIG pressure switch (S153, P/N 6600243-1) was found installed on a section of ducting upstream of the flow control valve. The pressure switch noted is referenced in Airplane Modification Kit (AMK) 76-7 "Relocation of Cabin Air Distribution Flow Control Valve", Figure 2. Although this configuration is not as delivered, the aircraft records indicate that FAA approved AMK 76-7 was installed on N47BA on July 20, 1977.

5.2.4 Anti-Ice Shutoff Valves (L & R Nacelle, Wing /H. Stabilizer, Windshield)

The left and right Nacelle Anti-Ice Shutoff Valves (solenoid operated) were found intact. The position of the valves at impact could not be determined. Note: These valves are spring loaded closed.

Likewise no determination could be make regarding the position of the Wing /Horizontal Stabilizer Anti-Ice Shutoff Valve.

The Windshield Anti-Ice Shutoff Valve[13] (motor operated) was found in the closed position and with its actuator shaft locked (i.e not free to rotate). The valve

[13] Used to provide an alternate bleed-air source for emergency pressurization, when the IN NORMAL /OUT DEFOG knob, located below the instrument panel to the left of the pedestal, is pushed inward. The shutoff valve is controlled by either of two switches mounted on the anti-ice control panel, located on the left side of the instrument panel [i.e. by positioning the Windshield (WSHLD) HEAT AUTO /MAN switch to AUTO or by placing the same switch in MAN (manual) and using the ON /OFF switch to open /close the shutoff valve].

assembly was broken at its actuator arm, near its attachment to the butterfly valve. The valve position was determined by comparison of the valve Open /Closed indicator (flag) and actuator arm with that of an exemplar shutoff valve. Refer to Attachment IX for a photo of the Windshield Anti-Ice Shutoff Valve recovered.

5.3 Air-Conditioning System

The air conditioning system regulates the the volumetric flow rate and temperature of bleed air entering the cabin and cockpit areas. The primary system components include system switches, the flow control valve, hot air bypass valve, ram-air heat exchanger, and distribution ducts /check valves.

The flow control valve is a solenoid controlled, pneumatically operated valve, that is located in the tail cone, downstream of the pneumatic system bleed air manifold. Its primary function is to regulate the flow rate of conditioned bleed air entering the cabin, reducing fluctuations in cabin pressurization caused by changes in engine power.

The flow control valve is controlled by the CABIN AIR switch, located on the Pressurization Module. Refer to Attachment XV for a complete description of operation of the Flow Control Valve (page 2) and a schematic of the valve (Figure 1, page 17).

5.3.1 Flow Control Valve

The Flow Control Valve upper actuator housing and servo mechanism were missing. The actuator diaphragm was torn around its entire perimeter. However, no pre-existing ruptures were noted in the remaining diaphragm, and the diaphragm was found to be pliable. The valve main spring was in place and fully relieved due to the missing upper valve housing. The butterfly valve was found in the fully closed position. The end of the actuator shaft, attached to the main spring assembly, was slightly bent. The valve was free to operate about its full range of motion. The actuator was in its retracted (spring loaded closed) valve position when the lower actuator housing was destroyed. The lower housing of the actuator was found crushed inward into the actuator diaphragm /spring cup assembly. Refer to the photos of the Flow Control Valve recovered in Attachment X.

Note: Normal travel of the butterfly valve actuator shaft and linkage assembly is approximately 5/8 inch, as determined by using an exemplar flow control valve. When the valve is in its open position, the actuator diaphragm /spring cup assembly is displaced upward and away from the valve, clear of the lower housing of the valve body that was found crushed inward. (Refer to Attachment X). By cycling the exemplar flow control valve, the Airworthiness Group observed that the diaphragm and butterfly valve assembly takes approximately 1.5 – 2.0 seconds to travel from the fully open to fully closed position, with its inlet duct at ambient pressure. Note however, when in service, the closing force of the valve main spring is opposed by a an inlet pressure of 35 PSIG (nominal) upstream of the valve.

The inlet flange to the flow control valve was found still attached to the bleed air manifold. The removal of the V-Band attachment clamp revealed that the gasket was fragmented and brittle. Once the clamp was disassembled the gasket fell apart. Another gasket removed from the same manifold was found to be in a pliable condition and less brittle.

Note: Learjet was unable to provide any reliability data related to the Flow Control Valve (i.e. failure modes, history, etc.).

5.3.2 Hot Air Bypass Valve

The Hot Air Bypass Valve (H–Valve)[14] vane was found intact and frozen in an intermediate position. No obstructions were noted.

5.3.3 RAM Air Heat Exchanger

The Ram Air Heat Exchange was destroyed (i.e. crushed).

5.3.4 RAM Air Check Valve

The Ram Air Check Valve was examined and found to operate properly.

5.3.5 Cabin Air Distribution Check Valves

One of two Air Distribution Check Valves was recovered and removed from its crushed duct, i.e. Frame 22 (Rear Pressure Bulkhead) installation. The valve was complete and in its normal position. Note: The flapper valve consists of two halves, hinged together at their mid-plane. Although, the ducting was flattened at the valve installation, no damage was noted to the flapper valve itself and no evidence indicating that the valve would not have operated properly before the duct was crushed.

5.4 Pressurization System

Cabin pressurization is provided by conditioned air entering the cabin through the air distribution ducts (i.e. via the bleed air /air conditioning systems) and controlled by modulating the amount of air exhausted from the cabin. The major components of the pressurization system are the cabin air exhaust (outflow) valve, cabin safety valve, differential pressure relief valve, cabin altitude limiters, pressurization jet pump (vacuum regulator), and pressurization module (with its associated controls described below). During flight, the pressurization system is completely independent of the electrical system.

[14] The position of the H-Valve determines how much bleed air passes through (or bypasses) the RAM Air Heat Exchanger.

Normal pressurization is controlled with the Altitude Controller and RATE Selector, located on the pressurization module. Prior to takeoff, the pressurization module AUTO /MAN switch is set to AUTO, the Cabin Air switch to NORM, the Airplane Altitude Selector knob (part of the Altitude Controller) set to cruise altitude and the IN NORMAL /OUT DEFOG knob pushed in. After takeoff, the RATE Selector may be adjusted to obtain a recommended rate of cabin pressurization of 600 ± 50 feet per minute. The rate is monitored by the Cabin Rate-of-Climb indicator and may be varied with the RATE Selector. Cabin altitude is monitored with the Cabin Altimeter. The Cabin Altimeter also includes a differential pressure (PSID) scale.

In the event of a loss of normal pressurization, windshield anti-ice (defog) air can be routed into the cabin as an emergency source of pressurization. This is accomplished by pushing the IN NORMAL /OUT DEFOG knob (full in), setting the Windshield Heat switch to AUTO and the CABIN AIR switch OFF. Pressurization will then be maintained automatically. If however, pressurization is not maintained in the AUTO position, cabin altitude can be maintained by manually controlling the Outflow Valve using the manual UP /DN switch (Cherry Picker), located on the Pressurization Module.

Refer to Learjet Maintenance Manual Chapter 21-30-00, Figure 3 (Attachment XI) for a diagram of the Learjet Model 35 Pressurization System Control Schematic, effective for S/N 35-060 (N47BA).

5.4.1 Cabin Altitude Controller

The Cabin Altitude Controller, comprised of a selector dial with a window and pointer, that displays the cabin altitude setting in relation to aircraft altitude, was recovered. The display assembly was found crushed. However, the selector dial and underlying cabin /aircraft altitude dial (i.e. scales) remained together. The display was cleaned and indicated that the aircraft altitude was set to approximately 36,000 feet.

Note: The Cabin Altitude Controller is mounted on the Pressurization Module, on the lower section of the instrument panel, directly forward of the co-pilot.

5.4.2 Cabin Altitude Limiter

The Outflow Valve Cabin Altitude Limiter,[15] (located in the Pressurization Module) was disassembled and indicated that the valve stem and ball valve assembly moved freely after cleaning. No damage was noted to the upper surface of the aneroid bellows (capsule).

The Safety Valve Cabin Altitude Limiter was not recovered.

5.4.3 Differential Pressure Relief Valve

[15] The Cabin Altitude Limiter senses decreasing cabin pressure. At 11,000 ± 1,000 feet, an expanding capsule opens the normally closed ball valve, and admits cabin pressure to the control chamber of the Outflow Valve, to move the Outflow Valve toward its closed position, in an attempt to maintain cabin pressure.

One Differential Pressure Relief Valve was recovered on scene. The valve was disassembled and its internal metering valve found to move freely. The valve diaphragm was torn around its entire perimeter. The housing was destroyed. However, the valve spring was present.

Note: Two Differential Pressure Relief Valves are installed on the aircraft. The Outflow Valve Differential Pressure Relief Valve[16] is located in the Pressurization Module, and is connected to the control chamber of the Outflow Valve. The second relief valve is connected to the control chamber of the Safety Valve and is similar in all respects.

No determination could be made regarding the identification of this relief valve.

6.0 Additional Wreckage /Examination

The Airworthiness Group reconvened in Aberdeen, SD, on June 13, 2000, to review additional wreckage recovered from the crash site in the spring of 2000. Approximately 45 boxes consisting of approximately 1,000 pounds of aircraft debris /dirt was examined. Four boxes contained individually bagged debris in 10-inch zip lock bags. Each bag was marked with numbered tags labeled "Edmunds County, SD" dated between 4/4/2000 and 4/6/2000. A description of the noteworthy components /pieces that were identified is listed below:

1) One main landing gear retract actuator, observed to be in its retracted position.

2) Pieces of a cassette tape (ribbon) in bags numbered 41 and 114. The cassette ribbon was delivered to the Recorders Division of the Safety Board for analysis.

3) Two oxygen lanyard valves and one lanyard string (unattached). No determination could be made regarding the position of the door latch mechanism at impact.

4) The oxygen bottle overboard discharge indicator (body) with two small fragments of green material, believed to be pieces of the indicator. Note: The (green) discharge indicator provides the pilot with a visual indication (during pre-flight inspection) that there has not been an overpressure condition in the oxygen cylinder.

5) Tagged item No. 209, identified as a Bleed Air Shutoff /Regulator valve secondary butterfly valve (plate), with portions of its outer seat. No determination could be made regarding the position of the valve at impact, based upon this section alone.

6) The cockpit Oxygen pressure gauge. The indicator viewing glass was broken. However, the needle remained attached and read just below zero. The Oxygen

[16] Limits the normal operating cabin differential pressure to 8.9 PSID (Learjet 35-060).

pressure gauge was retained for further examination[17] by the Materials Laboratory of the Safety Board.

Note: According to Sunjet Aviation, Inc. the Oxygen pressure gauge was noted in the green band (i.e. 1550 - 1850 PSIG) during pre-flight checks on October 25, 1999. (Refer to Attachment XII). According to the aircraft records, the oxygen system was last serviced (by Sunjet Aviation) on September 3, 1999. (Refer to the Maintenance Records Group Chairman's Factual Report). Refer to Attachment XIII for a flight manifest (log), that indicates N47BA was flown approximately 103 flight hours (90 cycles) between the last time the oxygen system was known to have been serviced and the accident flight.

7) Four independent fittings and portions of the back-plate of the Pressurization Module, with S (static) and CP (control pressure) ports.

8) Tagged item No. 261, with a P/N 130406-1, S/N 253127[18] data plate from an Outflow Valve. Several additional fragments were identified, that are believed to be from either the Outflow or Safety valve. A portion of the Outflow valve gasket and its corresponding bulkhead (i.e. Frame 5) were also found.

9) One crew microphone jack panel was found with jacks in both the microphone (MIC) and oxygen-microphone (OXY-MIC) plug-ins. The position of the OXY-MIC (ON /OFF) toggle switch could not be determined.

10) Two short crew oxygen mask hose sections with compression ferrules were recovered, along with one additional ferrule, one connector (bayonet fitting), and one oxygen outlet cover. The oxygen outlet valve cover was found crushed and torn away from its spring assembly retaining pin. One of the connector locking tangs was broken and missing. The opposite locking tang was found bent inward approximately 30 degrees with scoring on its outer surface. The connector nozzle (probe) was broken away from the connector at its base.

7.0 Flow Control Valve Testing (Mechanical Failure Modes)

Functional tests of an exemplar Flow Control Valve (P/N 6608067-5) were performed at the Learjet, Inc. facility in Wichita, Kansas, on February 4, 2000. The test plan was developed to evaluate the performance of the valve, assuming 1) the loss of the Venturi Throat Pressure Sense Line, and 2) the effects of damage to the Actuator diaphragm.

[17] Examination by the Materials Laboratory on 8/11/2000 revealed one prominent, and one or more less prominent, needle slaps (marks) on the face of the oxygen pressure gauge. The marks were readily apparent under magnification (>7.5x), once the needle had been rotated slightly from its position as found. The needle marks were detected below scale (i.e. < 0 PSI). The oxygen gauge needle was found to rotate freely against its movement (coil). Refer to Attachment XIV, photographs of the oxygen gauge.

[18] According to aircraft records, this Outflow Valve was installed on January 27, 1986.

The functional tests revealed that when the Venturi Throat Pressure Sense Line was removed (simulating a leak to atmosphere), the Flow Control Valve fully closed when sensing a back pressure[19] of 0.5 PSIG. Note: A closed Flow Control Valve prevents the supply of bleed air flow to the cabin during normal operation of the pressurization system.

The functional tests also revealed that relatively small areas of damage to the Actuator diaphragm [i.e. 0.040" diameter hole, (0.00125 square inches)] caused the Flow Control Valve to operate sluggishly and outlet flow to vary significantly with changes in inlet pressure.[20] Likewise, with a back pressure of 8.4 PSIG, the flow of bleed air through the valve was reduced significantly from its nominal flow rate of 12 ± 1 lb_m /minute. Testing revealed that diaphragm damage equivalent to 0.052" diameter (.00212 square inches) prevented the valve from operating at any inlet pressure and further disabled the Max Flow[21] function of the valve.

Refer to "6608067-5 Flow Control Valve Evaluation" (Attachment XV) for further details, including a description of the Flow Control Valve operation (page 2) and a schematic of the valve (Figure 1, page 17).

8.0 Crew Oxygen Mask Connector Testing (Structural Failure Modes)

Testing of exemplar crew oxygen mask connections was performed by B/E Aerospace (Puritan-Bennett Aero Systems Co.), at their facility in Lenexa, Kansas, during December 1999 and January 2000. The testing was performed in accordance with B/E Aerospace Investigation Plan No. 3500-99-44 and was designed to determine the structural failure modes of crew oxygen mask connections, when the mask connectors are forcefully separated from their mating oxygen outlet valves (receptacles).

Four separate tests were performed; a tensile test, shear test, bending test, and vibration test. In the shear and bending tests, the connector initially deformed and then broke away from the oxygen outlet valves after breaking into several pieces. Post test examination of the oxygen outlet valves revealed essentially no damage. In the shear test, a small scratch was observed on the lip of the valve and in the bending test, minor scuffs were noted on the surface of the valve near one of its retainer pins. In each case, the damage was superficial.

During the shear and bending tests, one of the two bayonet tangs on the connector broke away while the opposite was bent, yet remained attached to the connector. Likewise, the connector nozzle (probe) broke completely away from the connector at its base in each test.

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[19] Normal operation of the cabin pressurization system (outflow valve) maintains a positive differential pressure across the fuselage, not to exceed 8.7 PSIG maximum (35-060), thereby exerting a back pressure (equal in magnitude to the cabin differential pressure) downstream of the Flow Control Valve. [Description of pressurization system operation provided by Learjet, Inc.]

[20] Designed to operate with an inlet pressure between 7 and 85 PSIG. (Refer to Attachment XV, Figure 1). A nominal inlet pressure of 35 PSIG is supplied to the Flow Control Valve by one or both engine Mod Valves.

[21] When the Cabin Air Switch (located on the Pressurization Module) is placed in the MAX position (35-060), the Max Flow solenoid is energized, thereby causing the Flow Control Valve to open fully, allowing full (unregulated) bleed air flow to the cabin. [Refer to Attachment XV, description of operation (page 2)].

The connector remained securely installed during the vibration and tensile tests and subsequent examination revealed no observable damage to the connector or the oxygen outlet valve during either of these tests.

Refer to B/E Aerospace, Inc. Document No. 3500-00-04, Rev. A00 (Attachment XVI) for further details, including photos of each test setup and the associated components following testing.

9.0 Computer Simulations, Pressurization System

Honeywell, Inc. performed two computer simulations that were intended to model the performance of the ECS. The testing was designed to provide a better understanding of the cabin rate of climb (during ascent) assuming 1) the air conditioning system (i.e. cabin air) was selected off at takeoff, and 2) a loss of cabin air occurred at altitudes at /or above 25,000 feet.

The first simulation predicted that the cabin altitude would lag slightly behind the flight altitude of the aircraft as it continued its climb. The cabin reached an altitude of 10,000 feet as the aircraft passed through a flight altitude of 10,600 feet. Refer to Lear 35 Analysis, "Predicted Cabin Pressurization Effects with Zero Inflow" (Attachment XVII) for further details.

The second simulation considered the loss of cabin air at altitudes of 25,000 feet, 30,000 feet, 35,000 feet, and 40,000 feet. The results predicted that the cabin altitude would ascend to 9,500 feet in approximately 24 - 44 seconds, depending on the cabin altitude at the time of ECS inflow valve closure. The simulation further predicted that the cabin would ascend to 25,000 feet in approximately 2 1/2 minutes and approach the aircraft flight altitude in 4 - 5 minutes. Refer to Lear 35 Analysis, "Predicted Cabin Pressure Effects Due to Inflow Valve Closure During Ascent" (Attachment XVIII) for further details. The supporting calculations used to determine the effective leakage flow areas for each simulation have also been included.

Note: The aircraft ascent profile utilized by Honeywell, Inc., during each simulation, was based upon Radar data for N47BA, obtained from the FAA following the accident flight. During each simulation a cabin leakage rate of 115 standard cubic feet per minute (SCFM) was modeled at a cabin differential pressure equal to 8.0 PSID and 28 SCFM at 0.5 PSID.

10.0 FAA, Special Certification Review

Following the accident involving N47BA, the FAA initiated a Special Certification Review (SCR) of the Learjet Model 35 pressurization and oxygen systems. The objectives of the SCR were to determine 1) whether the noted systems were properly certificated, and 2) whether any unsafe design features existed.

The SCR team did not identify any unsafe conditions associated with the oxygen and pressurization system modifications as certificated on the accident aircraft. However, the team did uncover a number of Learjet accidents that appear to have been caused by crew incapacitation due to hypoxia. The SCR also found that it is probable that crews are not donning their oxygen masks when necessary to preclude the effects of hypoxia.

Several SCR team recommendations were made specific to the Learjet Model 35. Additional recommendations were made applicable to all airplanes, certificated for pressurized flight above 25,000 feet, in accordance with Title 14 code of federal regulations (CFR) Part 23 and Part 25.

Refer to "FAA Special Certification Review Team Report on: Learjet Model 35 /36 Pressurization and Oxygen Systems", dated February 25, 2000 (Attachment XIX) for further details related to the findings and recommendations of the SCR.

11.0 <u>Flight Test, Learjet 35</u>

At the request of the Safety Board, Learjet performed a Flight Test of a Model 35 aircraft to 1) capture CVR audio, and 2) validate the performance of the pressurization system, during an ascent similar to that of the accident flight. The test of the pressurization system was performed assuming the air conditioning system (i.e. cabin air) was selected off at takeoff.[22]

The Flight Test revealed that during the initial take off (climb) with cabin air secured, the cabin altitude lagged the flight altitude by approximately 3500 feet. The cabin altitude warning[23] activated at a cabin altitude of 10,000 feet while the aircraft was passing through a flight altitude of 13,500 feet mean sea level (MSL). Refer to Test Procedure No. 2 of the Flight Test referenced below for further details.

Cabin leakage checks were conducted on the Flight Test airplane, Learjet Model 35-036, in accordance with Learjet Model 35 Maintenance Manual (MM) Chapter 21-30-00, prior to the flight tests described herein. [Refer to MM Chapter 21-30-00 (Attachment XX) for a description of the cabin leakage /pressurization checks also effective for Model 35-060 prior to the accident]. The cabin leakage rate on the test airplane was determined to be 106.22 SCFM.

Refer to Bombardier Aerospace (Learjet) Flight Test Report No. 5428, dated June 23, 2000 (Attachment XXI) for further details.

[redacted]

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Aerospace Engineer

[22] Cabin Air Switch (located on the Pressurization Module) placed in the "OFF" position.

[23] Aural warning sounds at 10,000 ± 500 feet (cabin altitude) and clears at > 7500 feet.

ATTACHMENTS

I.	Aircraft Wreckage Distribution.
II.	Configuration Drawings, Learjet Model 35.
III.	Honeywell, Inc. (Engine) Teardown Report No. 21-11090.
IV.	Liquid Technology Corporation, Oxygen (Source) Tests.
V.	Learjet 35 /36 Pilot's Manual, Figure 3-8, Schematic of Oxygen System.
VI.	Digital Photograph, Oxygen Bottle Regulator /Pre-flight Inspection.
VII.	Learjet 35 /36 AFM, Oxygen Duration Tables (ZMR, 6600214 Crew Masks).
VIII.	Mod Valve (P/N 3213736-1-1, S/N P-247), Functional Test.
IX.	Photograph, Windshield Anti-Ice Shutoff Valve.
X.	Photographs, Flow Control Valve (with Exemplar, Open, Closed).
XI.	Learjet 35 MM Chapter 21-30-00, Figure 3, Pressurization System Schematic.
XII.	Sunjet Aviation, Inc. Statement, Oxygen System Pressure at Takeoff.
XIII.	A/C Flight Log Information Sheet, N47BA (8/11/99 - 10/23/99).
XIV.	Photographs, Oxygen Pressure Gauge (Needle Slaps).
XV.	Flow Control Valve Evaluation (Mechanical Failure Modes).
XVI.	B/E Aerospace, Inc. Document No. 3500-00-04, Rev. A00.
XVII.	Learjet 35 Analysis, Predicted Cabin Pressurization Effects with Zero Inflow.
XVIII.	Learjet 35 Analysis, Predicted Cabin Pressure Effects Due to Inflow Valve Closure.
XIX.	FAA _ SCR, Learjet Model 35 /36 Pressurization and Oxygen Systems.
XX.	Learjet 35 MM Chapter 21-30-00, Cabin Leakage /Pressurization Checks.
XXI.	Bombardier Aerospace (Learjet) Flight Test Report No. 5428.