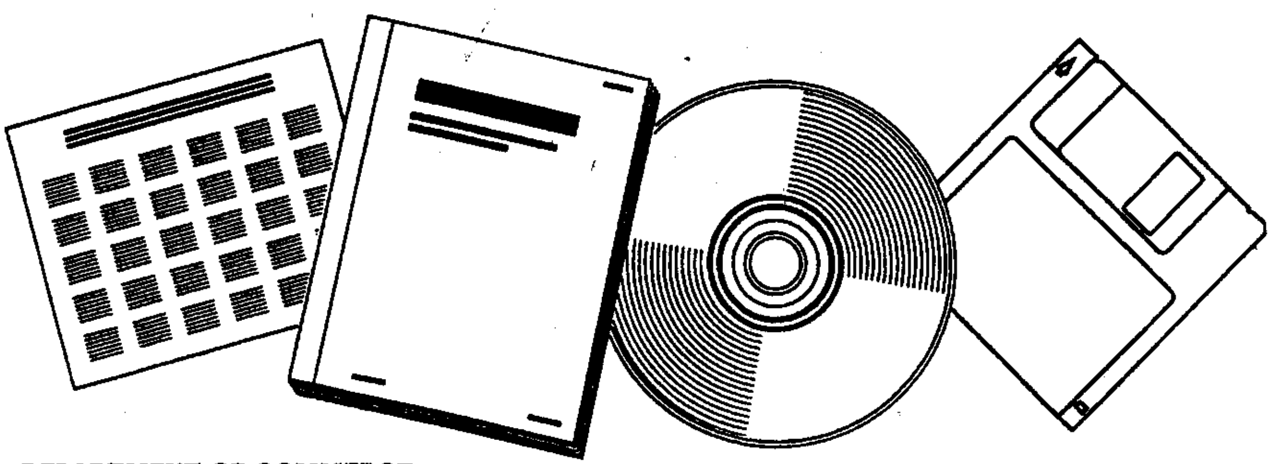
AIRCRAFT ACCIDENT REPORT. LAKE CENTRAL AIRLINES, INC. ALLISON PROP-JET CONVAIR 340 N73130, NEAR MARSEILLES, OHIO MARCH 5, 1967

NATIONAL TRANSPORTATION SAFETY BOARD,
WASHINGTON, D. C

26 FEB 1968



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Adopted: February 26, 1968

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DEPARTMENT OF TRANSPORTATION

WASHINGTON D.C. 20591

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SYNOPSIS

About 2007 e.s.t., on March 5, 1967, Allison Prop-Jet Convair 340, N73130, being operated as Lake Central Airlines, Inc., Flight 527, crashed near Marseilles, Ohio. The 38 persons aboard the aircraft received fatal injuries. The aircraft was destroyed.

Investigation revealed that all four blades of the right propeller separated in flight and the No. 2 blade penetrated the aircraft fuselage in line with the propeller plane. The penetrations destroyed the structural integrity of the fuselage to an extent that, together with the loads caused by a right yaw which accompanied the propeller separation, the fuselage failed along the line of penetrations and the aircraft crashed.

Examination of the internal mechanism of the right propeller revealed that the helical splines of the torque piston of the No. 3 blade pitch change unit were worn away and the torque cylinder was completely failed. The wear of the splines was due to an omission of nitriding for surface hardness during manufacture and the cylinder failure was caused by fatigue.

When the torque cylinder failed, propeller oil pressure maintaining the pitch position of the right propeller blades was lost. The blades moved toward low pitch at a rate too rapid for the propeller pitch lock to operate effectively. At a low blade angle the propeller oversped, causing the blades to separate in overstress.

The Safety Board determines that the probable cause of this accident was the failure of the right propeller due to omission of the torque piston nitriding process during manufacture, and the failure of manufacturing quality control to detect the omission.

1. INVESTIGATION

1.1 History of the Flight

On March 5, 1967, Lake Central Airlines Flight 527 was a scheduled passenger operation between Chicago, Illinois and Detroit, Michigan, with intermediate stops at Lafayette, Indiana, and Cincinnati, Columbus, and Toledo, Ohio. The aircraft utilized was Allison Prop-Jet Convair 340, N73130.

Flight 527 left Chicago at 1704 [1/] and progressed with no reported difficulty to Columbus where it arrived at 1935. It departed Columbus for Toledo 17 minutes later, operating on an Instrument Flight Rules (IFR) flight plan and clearance in instrument weather conditions.

About 2005 the flight was cleared from its assigned cruising altitude of 10,000 feet to descend to 6,000 feet, and to report leaving 8,000 and 7,000 feet. Crew acknowledgement of the clearance and a report that the flight was leaving 10,000 feet was the last transmission from the aircraft. At 2007 the radar target of the aircraft, which was being observed by Cleveland ARTCC (Air Route Traffic Control Center), disappeared from the controller's radar scope.

At times variously estimated as between 2005 and 2010, persons in the vicinity of Marseilles, Ohio, heard sounds from an aircraft. Some of the descriptions of sounds were: "like an engine revving up," "like a car stuck on ice" and "like a sports car on a drag strip." It was reported that a few seconds later there was an explosion like sound and after another short interval the sound of a heavy impact. It was soon determined that an aircraft had

1/ All times are eastern standard based on the 24-hour clock.

crashed and by about 2100 it was established that the aircraft was Lake Central Flight 527 and that all 38 persons, 3 crew and 35 passengers, aboard had been killed. The crash location was 2 miles southwest of Marseilles at north latitude 40°41'25" and west longitude 38°21'58".

Witnesses reported that weather conditions at the time and place of the crash consisted of a low overcast with poor visibility in rain, freezing rain, and snow. Because of these weather conditions none of the witnesses saw the aircraft before it crashed.

1.2 Injuries to Personnel

Injuries	Crew	Passengers	Others
Fatal	3	35	0
Nonfatal	0	0	0
None	0	0	

1.3 Damage to the Aircraft

The aircraft was destroyed.

1.4 Other Damage

None.

1.5 Crew Information

Captain John W. Horn, age 45, held airline transport pilot certificate No. 314457 with C-46, DC-3, CV (Convair) 240/340/440 and Allison Prop-Jet CV 340 ratings. He satisfactorily completed a CV 340 flight proficiency check September 10, 1966, an Allison Prop-Jet CV 340 flight proficiency check August 24, 1966, an Allison Prop-Jet CV 340 line check September 9, 1966, and an en route check March 1, 1967. He held a first-class medical certificate with no limitations issued November 29, 1966.

Captain Horn had accumulated a total of 22,425 flying hours, of which 403 were in the Allison Prop-Jet CV 340. During the 90-day period preceding the accident, a part of which period he was on vacation, Captain Horn flew 151 hours. He was off duty 85 hours before Flight 527 and his duty time in connection with the flight was about 6 hours.

First Officer Roger P. Skillman, age 33, held airline transport pilot certificate No. 1222045, with a DC-3 rating and commercial privileges, airplane multi and single-engine land. He satisfactorily completed an Allison Prop-Jet CV 340 flight proficiency check December 17, 1966, and an Allison Prop-Jet CV 340 line check October 28, 1966. He held a first-class medical certificate with no limitations issued September 26, 1966.

First Officer Skillman had accumulated a total of 4,166 flying hours, of which 250 were in the Allison Prop-Jet CV 340. He was off duty 80 hours before Flight 527 and his duty time in connection with the flight was about 6 hours.

Flight Attendant Barbara Littman, age 23, was employed by Lake Central Airlines August 3, 1965. Her last recurrent training was satisfactorily completed November 1, 1966.

1.6 Aircraft Information

The aircraft was manufactured by the Consolidated Vultee Aircraft Corporation November 3, 1952, as a Convair-Liner 340-31. It was converted to an Allison Prop-Jet Convair 340 in accordance with Supplemental Type Certificate No. SA-4-1100 by Pacific Airmotive, Inc., with a completion date of September 13, 1966. The conversion included installation of Allison Division of General Motors Model 501-D13D engines with Allison Division Aero Products Model A6441 FN-606A propellers. Lake Central Airlines, Inc., became the owner and operator of the aircraft September 15, 1966.

At the time of the accident the basic airframe of the aircraft had accumulated 16,216 flight hours. Engine and propeller operational histories were as follows:

Position	Engines Date of Manufacture	Serial No.	Total Hours	Hours Since Overhaul
1	March 30, 1966	CAE 501594	1055	N/A (new)
2	March 30, 1966	CAE 501593	1055	N/A
	Propellers			
1	August 12, 1966	P-987	372	N/A (new) 2/
2	July 29, 1966	P-984	1055	N/A

Computations showed that at departure from Columbus, Ohio, the gross takeoff weight of N73130 was 50,626 pounds, the maximum allowable gross take-off weight was 53,200 pounds and the center of gravity of the aircraft was within limitations. N73130 was last serviced with 560 gallons of kerosene at Cincinnati, Ohio, which brought the total fuel load to 10,120 pounds.

During the intermediate stops of Flight 527 the flight crew made no request for maintenance on the aircraft and none was performed.

1.7 Meteorological Conditions

At the time of the accident a cold front with waves extended southwestward from southwestern Pennsylvania through central Arkansas and beyond.

2/ Overhaul time for the propellers at the time of the accident was 2500 hours.

Associated with the front, widespread areas of Ohio, including the accident location, were dominated by 300 to 500 foot overcast ceilings and 2 to 5 mile visibilities accompanied by freezing rain or freezing drizzle and snow.

Weather was no factor in the accident.

1.8 Aids to Navigation

Not involved.

1.9 Communications

Communications were normal.

1.10 Aerodrome and Ground Facilities

Not involved.

1.11 Flight Recorders

The aircraft was equipped with a United Control Corporation Model F-542 flight recorder. The unit was recovered and it was determined that it had functioned normally. The recording medium had not received any mechanical damage in the crash.

A readout of the recording medium showed that about 14 minutes after lift-off from Columbus the aircraft had descended from 10,000 feet to 8,000 feet and was on a magnetic heading of 322 degrees, with an indicated airspeed of 254 knots. The recorder readout showed that at this time the aircraft veered sharply to the right of heading nearly 40 degrees and immediately veered back to the left about 55 degrees. Electrical power to the recorder was then abruptly terminated.

The aircraft was equipped with a United Control Corporation Cockpit Voice Recorder. The unit was recovered and the recording medium was found undamaged.

Playback of the recording tape revealed that substantial portions of the crew conversation and radio transmissions were unreadable, but there was sufficient intelligence to determine that operation of the flight proceeded normally until after descent began from 10,000 feet. At 2006:05 electrical power to the recorder was abruptly terminated. Two and one-half seconds before this a sound could be heard on the CAM (cockpit area microphone) channel which began as a low pitched hum and increased rapidly in pitch until it abruptly stopped with the power failure. The sound was similar to that of an air raid siren during its first seconds of operation.

1.12 Wreckage

Investigation revealed that the aircraft crashed in an upright, near-level attitude on a magnetic heading of approximately 360 degrees. When the aircraft struck the ground, that portion of the fuselage ahead of fuselage station (F.S.) 193 was completely separated except for the control cables and the main electrical wiring bundle. Evidence showed that the separated forward fuselage section broke free on impact and slid about 90 feet ahead of the main body of the aircraft.

Examination of the main wreckage revealed that a large portion of the fuselage structure, interior equipment, and furnishings from between F.S. 193 and F.S. 340, a length of about 12 feet, and the right propeller were missing. The missing structure, interior equipment and furnishings were found in numerous pieces along a ground path 1/2 mile wide and 1-1/2 miles long on a magnetic bearing of 135 degrees from the main wreckage site. The four propeller blades of the right propeller were detached and found at separate locations ranging from 2,000 to 2,300 feet southeast of the main wreckage. The main reduction drive gear of the right propeller was recovered 2,200 feet south of the wreckage site. The right propeller feathering reservoir, feathering motor and master gear were found 2,000 feet north of the wreckage site and the No. 3 torque piston was located about 300 feet west of the main wreckage. The right propeller hub containing the other three torque unit assemblies was recovered 2,800 feet north of the main wreckage.

The majority of pieces of fuselage structure missing from the main wreckage were recovered and a mockup of the forward fuselage area was constructed. This revealed a vertical line of structural separation at F.S. 216 which is located in line with the propeller planes. On the right side of the fuselage [3] the mating edges of the fuselage skin pieces and stringers along the line of separation from horizontal stringer (H.S.) 9 to H.S. 17 were rolled inward and upward, with heavy scuff marks on pieces of the ice shield from the same area. From H.S. 17 to H.S. 21 on the same side of the aircraft, the mating edges of fuselage stringer and skin pieces were rolled outward and upward with heavy scuff marks on the inside of the fuselage skin. In this area the line of separation was sharp and narrow with slight burrs pointing outward and upward. The characteristics of the line were those of a cutting penetration by a sharp object. Between H.S. 9 and H.S. 17 the penetration was from outside to inside and upward, and between H.S. 17 and H.S. 21 it was from inside to outside and upward. Structure on either side of the separation line from F.S. 193 and F.S. 340 was torn away in large pieces along random lines.

3/ Left and right are looking forward from behind the aircraft.

On the left side of the aircraft between H.S. 17 and H.S. 22 at F.S. 212 the fuselage skin and stringers were broken in an irregular pattern by an object moving from inside to outside. From F.S. 193 to F.S. 340 the fuselage skin was torn away in the same manner as that on the right side of the fuselage.

Examination of equipment and structure from the interior of the fuselage revealed that the upper cargo bin inside bulkhead was crushed inward (to the left) at a point 27 inches above the cabin floor line.

The top cover of the liquor kit, which was positioned on the buffet serving counter about level with H.S. 19 on the left side of the fuselage, was buckled in (to the left) and there was a semicircular impact imprint in it. The imprint matched the curvature of the side of the butt end of a propeller blade.

A bundle of 26 electrical wires, containing the power source wires for the cockpit voice and flight data recorders, which is routed below the cabin floor close to H.S. 9 on the right side of the aircraft, was cut at a location near F.S. 216. A second bundle of three electrical power feed cables which power the 28V DC essential bus and which is routed through the same area, was also cut near F.S. 216. The aircraft control cables, however, which are routed just below the above described electrical wiring bundles, had not been touched by the cutting medium but were broken by overstress.

An examination of the four blades of the right propeller revealed that all were failed in the blade root section, at the same location and in the same manner. The failures were determined by visual and metallurgical examinations to have been tensile overload type separations.

Examination of the No. 2 blade disclosed it was heavily scuffed on the thrust side in the area of the tip, and there were black deposits impregnated in the scuff marks. Laboratory examination of the deposit material revealed that it was of the same composition as the faying strip used between the ice shield and fuselage skin of the aircraft.

The propeller torque unit assembly serves as a means of converting propeller hydraulic oil pressure into mechanical rotating or twisting movements to control blade pitch. There is a separate torque unit for each blade. A master gear ties together and coordinates the functions of the individual units to maintain precisely the same pitch of all propeller blades. It also provides redundancy for the system, in that if one torque unit were to fail the function of the failed unit would be transferred to and performed by the others.

The torque unit consists of three basic parts: the fixed spline, the torque piston, and the torque piston cylinder. The fixed spline is bolted to the propeller hub and has external helical splines which mate with internal splines on the torque piston skirt. Incorporated on the torque piston skirt are external helical splines which mate with splines on the inside of the torque cylinder. Through these splines, linear movement of the torque piston rotates the torque cylinder and propeller blade attached to it to the desired blade angles. An increase in propeller oil pressure moves the piston outward to increase blade angle and, conversely, a decrease in oil pressure permits the normal aerodynamic twisting moments of the propeller blades toward low pitch to decrease the blade angle.

One of the safety devices incorporated into the propeller system, which is pertinent to this accident, is the propeller pitch lock. This is a revolution sensitive mechanical device which functions to arrest propeller blade pitch-change if the propeller revolutions per minute (r.p.m.) increase to 1055, as opposed to the normal r.p.m. which remains essentially constant at 1020 r.p.m.

Examination of the No. 3 torque unit of the right propeller revealed that the internal and external helical splines of the torque piston were worn away to the extent that the piston could not function, and was, in effect, a free piston. Subsequent metallurgical examination showed the wear was due to a lack of nitriding of the splines for surface hardening. In addition, the examination disclosed that the torque piston cylinder had failed. Visual and laboratory examinations showed that the failure was a fatigue fracture which had originated on the inside of the cylinder wall and then progressed around the entire circumference of the wall until a sudden and total separation of the cylinder occurred.

An X-ray of the pitch lock and master gear assembly of the right propeller, made before the unit was disassembled, revealed that the pitch lock piston block-out lug was against the master gear lock block-out cam, a position which corresponded to a propeller blade angle of 21.5 degrees. This compares to a normal blade angle, for the operating conditions last reflected by the flight recorder for Flight 527, of 49 degrees. The pitch lock piston gear teeth were badly damaged over an arc of about 120 degrees and the mating teeth on the master gear were damaged in a similar manner.

The master gear assembly of the right propeller had separated from the hub as a result of overload failures of the master gear assembly-to-hub retaining bolts.

1.12-A Manufacturing and Related Information

On or about February 27, 1967, a propeller from an Allegheny Airlines Prop-Jet Convair was received for repair at the Allison facility with the complaint that it failed to reverse. On March 2, the propeller was disassembled and found to contain two torque pistons with badly worn helical splines. The next day, metallurgical examination determined that the splines on both pistons had not been nitrided for surface hardening during manufacture. The propeller had accumulated 454 hours in service since new.

As soon as the defective torque pistons were found, the possibility that others might be in service was realized. An immediate search of heat treat (nitriding for hardness) and final inspection records was made to isolate any other torque pistons which could have missed the nitriding process. By comparing dates that certain torque pistons went through the nitriding process, when they received final inspection, and their serial numbers, with the serial numbers on the defective pistons, a group of 234 suspect torque pistons was established. It was determined that the pistons in the group were processed in several lots between February and June 1966.

When the serial numbers of the suspect pistons were isolated, it was possible from assembly records to identify the propellers in which they were installed and, from the propeller serial numbers, to identify the operators possessing them.

When the suspect torque pistons were isolated and operators possessing them were known, it was decided to instruct the operators to perform a special check of the oil in the affected propellers for metal contamination. It was reasoned that, since the propellers were equipped with magnetic drain plugs designed to pick up metal particles to show abnormal wear of internal parts, such an inspection would also reveal metal particles from the wear of a soft (non-nitrided) torque piston. On March 3, all of the affected operators were telephoned and asked to perform the oil inspection. They were asked to check the magnetic drain plug and the propeller regulator filter for any metal particles, to drain the oil and look at it for metal contamination discoloration and to filter the oil through a suitable type filter to separate and reveal any metal particles in the oil. Only in the latter respect was the special oil check different from a regular oil check for metal contamination during routine propeller maintenance. In the rapid sequence of events the oil from the Allegheny propeller had not been checked for metal. On March 4, telegrams confirming the special check instructions were sent to all of the involved operators.

When Lake Central Airlines personnel received the special oil check instructions and identifying information as to propellers involved, they determined that the four Prop-Jet Convairs, which were then in the Lake Central fleet, were subject to the inspection. Maintenance personnel were advised of the inspection and a form was prepared to follow and record the check.

On March 4, the oil inspection was performed on N73130. No metal particles were found when the oil was filtered through a double paint strainer, and there were no particles on the propeller regulator filter. The oil was green, with no sign of grayishness indicative of metal contamination. The magnetic plug had a fine line of carbon-like material on it but no metal. The same material had been seen before on magnetic plugs during routine propeller oil changes and it was a normal finding. An Allison technical representative assigned to Lake Central who, the day before, participated in the special oil inspection on another Lake Central Prop-Jet, aircraft No. 125, considered it a normal condition. It was also the general view of other Allison personnel that the material did not represent metal particles expected from the oil inspection if there were a defective piston. It was also noted that subsequent events proved there was no defective piston in the propellers of aircraft 125.

On March 8, following the crash of Flight 527, the Federal Aviation Administration (FAA), acting on information obtained from the accident investigation, issued an Airworthiness Directive (A.D.). The directive called for an immediate removal of all propellers from service in which torque pistons in the suspect range were installed. It required that the propellers be disassembled and the torque pistons physically checked for hardness to assure they were not defective.

When the various actions to find and remove the defective torque pistons from service or potential service had been completed, 10 torque pistons had been found which had not been nitrided. Of the 10, 2 were found by the oil check, 2 were found by a hardness check after the oil check had been performed, with negative results, 2 were discovered in new propellers by the hardness check, 3 were found during propeller maintenance after service difficulty and 1 under the circumstances hereinbefore described relating to Flight 527.

The manufacture of propeller torque pistons involves 79 separate operations, of which 12 to 14 were associated with the process of nitriding the splines for surface hardening. After several steps of preparation, the nitriding is accomplished by placing the parts in a nitriding furnace for 48 hours at a temperature of 975 degrees, F.

As part of the overall nitriding process after the heat treat phase, a sample is checked in the laboratory for case and core hardness, and a depth check is made of a white layer formed by the nitriding. The entire lot of parts is then cleaned of the white layer, stripped of certain bronze plating, stress relieved and additionally cleaned. The parts then move to inspection.

During the above-described operations the lot of parts is accompanied by a Process Control Instruction Travel Card. This card lists the steps to be performed in the overall process and makes provision for, among other things, the total number of parts processed, the date each step was accomplished and identification of the operator involved.

In the final inspection phase each of the torque pistons is given a dimensional inspection, the inner and outer splines are inspected for surface hardness and the part is magnafluxed. Each part is stamped by the inspector involved with his inspection identification, for each of the three inspections. After the dimensional inspection the part is serialized. In the inspection phase, Inspection and Quality Routing cards accompany the parts, giving detailed instructions for the inspections. Final Inspection Records are used to identify the parts involved, the inspections performed, the dates of the inspections and the inspector involved. The number of parts in a specific lot can be determined from the Inspection and Quality Routing card and checked for accuracy by a physical count of the number of parts inspected.

Preceding the Lake Central accident and at the time the defective torque pistons would have been manufactured, the splines were checked for surface hardness by means of a file check. The check was made by applying a file of Rockwell hardness 89 (RC 89) across the spline surface. If the surface was not of proper hardness the file would mark it and one would be able to feel the file drag, but there was no difference in appearance between nitrided and non-nitrided parts. An Allison Inspector who had been engaged in inspection work more than 15 years and had done some file checking for 7 years, reported that he had found "soft" parts by using the file check, but never a torque piston. The work area was adequate, well lighted and not open to all personnel.

In describing his work, the particular inspector involved said it was his habit to perform his inspections, which were both the file and magnaflux checks, on all of the parts in a lot and to then put his inspection stamp on the entire lot. The areas for uninspected, inspected, and rejected parts are within his work area but clearly separated from each other. With respect to the defective torque pistons, he could not offer any reasonable explanation as to how they could have been soft and, if inspected, could have been checked as satisfactory for surface hardness.

While it was clear that the 10 torque pistons had missed the nitriding process, extensive efforts by Allison failed to determine exactly how this omission occurred or how it escaped detection in the inspection phase. One possibility lies in the circumstances associated with the movement of 10 torque pistons from the production flow to the laboratory in connection with a statistical study. The study was to determine the "growth" of the parts during nitriding. In the laboratory each of the 10 parts was marked with numerals 1 and 2 at distinct locations on the spline end. These markings distinguished the 10 pistons from any others. Each of the 10 defective pistons was found to have these distinguishing marks.

As a result of the sequence of events and findings after March 2, a number of changes or modifications were made in the areas of quality assurance and manufacturing procedures. One, was to serialize the torque pistons prior to the nitriding process. This provides a better basis for strict accountability of each part in the production steps and in any necessary actions whereby parts were moved out of the normal flow.

Another change was to put colored medallions in each container of parts to show the status in the production process, and to mark the medallions to show the precise step in the process such as "carbonize", "stress relief", "etc."

A procedure to use the Rockwell hardness tester at the heat treat and final inspections was adopted. The Rockwell machine can be used on the spline end of the piston only; therefore, it is to be used in conjunction with the file check. Associated with this procedural modification, the use of a logbook was adopted in which the specific Rockwell value is recorded for each part by serial number.

Several modifications or design changes were made to the 606A propeller as a result of the accident investigation findings and related test work. [4/] One was the incorporation of an increase pitch flow restrictor in the increase pitch oil supply line of each torque piston assembly. The restrictor was designed to restrict a loss of oil to a rate which would prevent a decrease of propeller blade pitch change rate in excess of 9 degrees per second. Tests showed this rate was well within the capability of the pitch lock to control.

Also, the torque cylinder was redesigned to increase its fatigue life from finite to infinite life under all types of failure situations.

As a matter of further assurance, the pitch lock housing-to-hub retaining bolts were changed from bolts with an ultimate tensile strength of 175,000 pounds per square inch (p.s.i.) to ones with a value of 220,000 p.s.i. In addition, the number of bolts was increased from 8 to 16.

4/ See Section 1.15, Tests and Research.

The installation of the increase pitch flow restrictors and the installation of the retaining bolts were made the subject of an FAA Airworthiness Directive with a compliance date of November 1, 1967. While the newly designed torque piston cylinder was considered a product improvement item, Allison furnished them to all affected operators for installation during compliance with the Airworthiness Directive.

Part 145 of the Federal Aviation Regulations (FAR) governs Certificated Repair Stations, and was applicable to Allison since it was certificated as a repair station. Under Section .63(a) of the Part it states that such repair station ". . . shall report to the Administrator within 72 hours after it discovers any serious defect in, or other recurring unairworthy condition of, an aircraft, powerplant, propeller, or any component of any of them . . ." Section .63(b) states that "in any case where the filing of a report under .63(a) might prejudice the repair station, it shall refer the matter to the Administrator for a determination as to whether it must be reported. If the defect or malfunction could result in an imminent hazard to flight the repair station shall use the most expeditious method it can to inform the Administrator."

The first notification to the FAA in connection with the aforestated regulatory requirements was made in the form of a telephone call to the FAA Regional office in Kansas City, Missouri, about 1700 on March 7. This was followed by a Malfunctioning and Defects Report, dated March 9, to the local FAA office. On March 3, from the examination of the Allegheny propeller, Allison personnel were aware of the two improperly heat treated torque pistons which had caused a readily detectable malfunction. However, at this time they did not consider the condition an unairworthy one or an imminent hazard to flight. When there was sufficient information available from the Lake Central accident investigation, this, together with the Allegheny propeller information, prompted the telephone call of March 7 in which Allison recommended physical examination of the suspect propellers. The next day the Airworthiness Directive requiring this action was issued by the FAA. The FAA Engineering District office first learned of the torque piston problem on March 8, when it saw the AD. The Allison Division of General Motors holds, among others, Production Certificates for the manufacture of engines and propellers used on the Prop-Jet Convair and other aircraft. FAR Part 21.139 states that an applicant for a Production Certificate must show that he has established and can maintain a quality control system so that each product will meet the design provision of the certificate. FAR Part 21.165 makes it the responsibility of the manufacturer for determining that each completed product is in a condition for safe operation.

In practice, before a Production Certificate is issued, the FAA reviews an applicant's quality control plan and inspects his facility to determine if the plan and facility meet the regulatory requirements. After the issuance of a Production Certificate, FAA Manufacturing Inspectors maintain general surveillance over the operations and facilities of a certificate holder for continued adherence to the regulatory requirements. The FAA Engineering and Manufacturing District office is responsible for manufacturing surveillance under Production and Repair Station Certificates, participation in inspections for type certificates and the work associated with the issuance of Airworthiness Certificates for original aircraft. For this work the office is staffed with three Manufacturing Inspectors, and its area of responsibility includes Indiana and parts of two other states. There were 35 manufacturers in its area. Allison is the largest but some of the others have several hundred employees.

In practice, manufacturing surveillance is accomplished by dividing the production and quality control areas into manufacturing control areas and inspecting in each area for compliance with the approved production specification data. In the case of Allison there are 51 such control areas with respect to engines and propellers, 22 of which were strictly propeller areas. The FAA office is required to inspect each area at least once each year. About 150-man hours per year are spent in the Allison plants.

Inspectors from the Engineering and Manufacturing District office made regular and frequent visits to Allison in connection with their various functions. The records reflect that, a number of recommendations were made by the inspectors over a two-year period preceding the Lake Central accident, but none was directly related to production and quality control changes made by Allison based on the torque piston experience.

1.13 Fire

There was no fire involved in the accident.

1.14 Survival Aspects

The accident was nonsurvivable.

1.15 <u>Tests and Research</u>

The Allison Chief Project Engineer for the 606A propeller reported that when the splines of the torque piston were sufficiently worn away, the piston would move as a free piston to the outer limit of the torque cylinder. He stated that calculations showed that as a result of this movement, a certain amount of imbalance would be created and the operating oil pressure would increase about 33 percent. The piston, having moved to and retained by the cylinder end cap, would increase the cylinder wall load from about 2,400 pounds to about 44,000 pounds with a resultant increase in stress up to 99,000 p.s.i.

A test was run to determine the fatigue strength of the torque cylinder. In the test a cyclic load of 1100 to 2800 p.s.i. was used to simulate the operating pressure load of a torque cylinder with a failed piston. Two cylinders were tested. The first failed at 62,400 cycles and the other at 67,000 cycles. These results indicated a torque cylinder could operate with a failed piston up to about 500 hours before it failed. The test failures and the failure from the accident aircraft were similar.

Another test was made to determine the approximate rate of propeller pitch decrease which would occur if there were a sudden and total loss of oil pressure on the torque piston. A diesel rig driving a propeller instrumented to measure pitch rate change of the blades was used, with a provision to simulate a sudden loss of oil pressure under operating conditions. The test indicated the blades would pitch down at a rate of about 130 degrees per second.

With the above test information, digital computer program studies were run to relate the failure to the flight conditions of Flight 527 and to determine the dynamic effect on propeller r.p.m., pitch lock reaction and propeller blade structural strength. The results showed that it would take the propeller 0.10 second to increase to 1055 r.p.m., the pitch lock engage speed, and 0.084 second for the pitch lock to respond and lock the blade angle. In this time, however, the blade angle would have decreased from 49 degrees to 28 degrees. At 28 degrees the propeller r.p.m. would be 114 percent of normal operating r.p.m. but the r.p.m. would continue to increase to 196 percent. At 180 percent the design strength of the propeller blades would be exceeded.

During design and development of the propeller, the pitch lock was tested to a blade angle change rate of 40 degrees per second. This was considered the maximum rate which could result from any single primary failure, which was the failure design criterion for the propeller.

2. ANALYSIS AND CONCLUSIONS

2.1 Analysis

Based on the evidence obtained during the investigation and Public Hearing in connection with this accident the Safety Board concludes that the crew of Flight 527 were well qualified and that preparations for the flight were made in a routine manner. The flight progressed with no difficulty and at 2006 was over the vicinity of Marseilles, Ohio, descending in instrument weather conditions at 8,000 feet on a magnetic heading of 322 degrees, with an indicated airspeed of 254 knots. At this time, with no warning to the crew the right propeller oversped and its blades separated. The No. 2 blade penetrated the aircraft fuselage, destroying its structural integrity to the extent that, coupled with the force of violent right yaw created by the propeller separation, the fuselage failed causing the aircraft to crash.

The Board concludes that no malfunction or failure other than that associated with the right propeller was causative in the accident.

Clear physical evidence, hereinbefore described, shows that the No. 2 propeller blade penetrated the lower right side of the aircraft fuselage in line with the propeller plane. An analysis of the damage, its nature and locations, shows the blade pierced the structure, tip end first, while moving on a tangent to the propeller arc and rotating clockwise end over end. Due to the rotation, after the initial penetration the blade had rotated enough that its tip end cut through the upper right side of the fuselage from inside to outside. The rotating blade then continued through the interior of the fuselage on an upward slant and penetrated the upper left side of the fuselage, butt-end first, from inside to outside. The cutting and breaking of the penetrations destroyed about 50 percent of the structural integrity of the fuselage. The loss of integrity under the force of a violent right yaw created by the propeller separation caused the fuselage to separate along the lines of penetrations. The aircraft then fell with the two sections of fuselage joined only by the control cables and one electrical wiring bundle.

Metallurgical examination revealed that the helical splines of the No. 3 torque piston of the right propeller were worn away because the part had not been nitrided for surface hardening during manufacture. The torque cylinder had failed in fatigue with a sudden and total separation. This information, together with functional and test data on the propeller, provided the basis from which an analysis of the sequence of failure events was reconstructed. In the sequence, when the torque piston splines were sufficiently worn, probably several hundred hours before the failure of the cylinder, the piston moved as a free piston to the outer limit of the cylinder. Stress loads were thereby imposed at the junction of the piston and splined area in the order of 88,000 p.s.i., which exceeded the design finite fatigue life of the part. Unfortunately, the cylinder failure was a sudden and total separation, as compared to the more characteristic fatigue failure of a gradual breakthrough of the cylinder wall which could well have resulted in a detectable warning oil leak before total separation.

When the cylinder failed in the manner it did, there was an immediate and total loss of oil pressure controlling the propeller blade pitch at about 49 degrees for the existing flight conditions of the aircraft. Under the aerodynamic twisting moments the blades moved toward low pitch at an estimated rate of 130 degrees per second. The propeller pitch lock was unable to arrest the pitch change before the blades reached the low pitch stop and oversped, causing the blades to fail in overstress. As nearly as can be determined, the time element between the cylinder failure and propeller blade separation was a matter of 1 to 2 seconds.

While it is definite that the torque piston from the Lake Central aircraft along with 9 others missed the nitriding process during manufacture, the evidence is insufficient for the Board to determine with specificity how the omission occurred and how it escaped detection. The Board is of the opinion, however, that both were directly associated with the movement of 10 torque pistons from the production flow to the laboratory and back into the production system. It is inconceivable to the Board that this was not involved when 10 torque pistons were taken to the laboratory, given distinguishing marks and thereafter 10 torque pistons so marked were found defective. Because the parts missed the nitriding process it is not difficult to understand that they missed the case and core hardness check, since this was an integral step in the nitriding process. It is much more difficult to deduce how the nitriding omission was not detected at final inspection. While the Board is aware of possible explanations it finds that none is adequately supported or compatible with the available evidence to the exclusion of another.

When the defective torque pistons were manufactured between February and June, 1966, Allison had an established quality control system. It utilized full time personnel furnished with suitable working conditions, tools and equipment to perform their duties and the personnel were qualified and given satisfactory instructions. The system provided redundancy to assure the requisite quality of parts in that (1) responsibility was placed on each manufacturing unit to perform according to specifications with quality inspection checks in the form of sampling during the manufacturing process and (2) a 100 percent final inspection was utilized as a backup check at the completion of the manufacturing process. These quality control provisions could be expected to assure the requisite quality of parts and to satisfy the requirement of a satisfactory quality control system. In addition, the system, as well as the facilities, were inspected and deemed satisfactory by FAA teams in connection with the issuance of production certificates on two occasions, first in 1956 when production of the 501-D13D engines and A6441 FN-606A propellers was started and again, as required when the Allison facilities were moved from Vandalia, Ohio, to Indianapolis, Indiana, in 1960. During this period the system did, in fact, produce torque pistons of requisite quality for the 606A propeller.

It would have been difficult to anticipate that personnel breakdowns could occur in such a way that the previously mentioned elements of redundancy in the quality control system would be circumvented as in this instance. With the benefit of hindsight, however, it can be seen that procedures in the quality control system should have provided for a stricter accountability of parts in the production processes and particularly under circumstances wherein the normal production flow was interrupted and parts were handled for special purposes out of the normal sequence. This is evident in that the 10 torque pistons missed major steps in the nitriding process and the omission went undetected.

The evidence shows that the FAA has a responsibility to conduct surveillance over the manufacturing operations of Allison, to check for continued adherence to the regulatory requirements of the manufacturer's Production Certificate, and to check its products at various production areas for conformity to design specifications. 5/ The surveillance

5/ Sections 601, 603, and 605 of the Federal Aviation Act of 1958, as amended (49USC 1421, 1423, 1425).

responsibility, however, has been interpreted by the FAA as not requiring a detailed quality control surveillance program, or a sharing in the manufacturer's responsibility for determining that each completed product is in a condition for safe operation. 6/ The Board believes that while it was possible for the FAA Manufacturing Inspectors to have detected the weakness in Allison's quality control system, as a practical matter, it is unlikely under the existing procedures, that the surveillance would have detected a weakness which was not apparent to full time, responsible Allison personnel and which weakness involved personnel errors in the execution of the system rather than a deficiency in the system itself.

As a final consideration the Board believes that the special oil check was performed by Lake Central maintenance personnel in accordance with the intent of the Allison instruction, but the check failed to serve its intended purpose. There is no satisfactory explanation for the failure because general and past experience would indicate an oil check to be a suitable method for detecting metal contamination. Without intending to rely on events after the fact, the Board does believe that the effectiveness of the oil check could have been evaluated more thoroughly before it was used. The fact that Allison did not consider the defective torque piston an unairworthy condition and did not notify the FAA, indicates to the Board that the seriousness of the overall problem was underestimated.

6/ Section 21.139 of the Federal Aviation Regulations (14 CFR 21.139).

2.2 Conclusions

(a) Findings

1. The crew of Flight 527 were properly certificated and qualified for the flight.
2. The aircraft was properly certificated and maintained but at the initiation of Flight 527 it was unairworthy due to a defective torque piston in the right propeller.
3. Flight preparation was routine and the flight progressed with no apparent difficulty until it was near Marseilles, Ohio, at 2006.
4. Loads on the torque cylinder caused by the failed torque piston of the No. 3 blade of the right propeller exceeded the finite fatigue life of the cylinder and it failed in fatigue.
5. The loss of oil pressure in the right propeller due to the failed torque cylinder caused the propeller pitch to decrease at a rate which exceeded the propeller pitch lock capability.
6. The right propeller oversped, causing the blades to separate in overstress.

7. The No. 2 propeller blade of the right propeller penetrated the fuselage, destroying the structural integrity to the extent that together with the force of a right yaw attending the propeller separation, the fuselage failed along the line of the propeller penetrations.
8. The torque piston of the No. 3 blade had not been nitrided for surface hardening of the helical splines during manufacture.
9. The omission of the nitriding process was not detected by inspection.
10. The omission of the nitriding process was associated with the movement of 10 torque pistons from the normal production flow to the Allison laboratory and return to the production process.
11. The Allison quality control system lacked the accountability necessary to assure the requisite quality of the individual parts.
12. The metal contamination oil check to isolate defective torque pistons did not serve the intended purpose.
13. Allison underestimated the seriousness of the defective torque piston problem.

(b) Probable Cause

The Safety Board determines that the probable cause of this accident was the failure of the right propeller due to omission of the torque piston nitriding process during manufacture, and the failure of manufacturing quality control to detect the omission.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD:

/s/ OSCAR M. LAUREL
Member

/s/ JOHN H. REED
Member

/s/ LOUIS M. THAYER
Member

/s/ FRANCIS H. McADAMS
Member

Joseph J. O'Connell, Jr., Chairman, did not take part in the adoption of this report.

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