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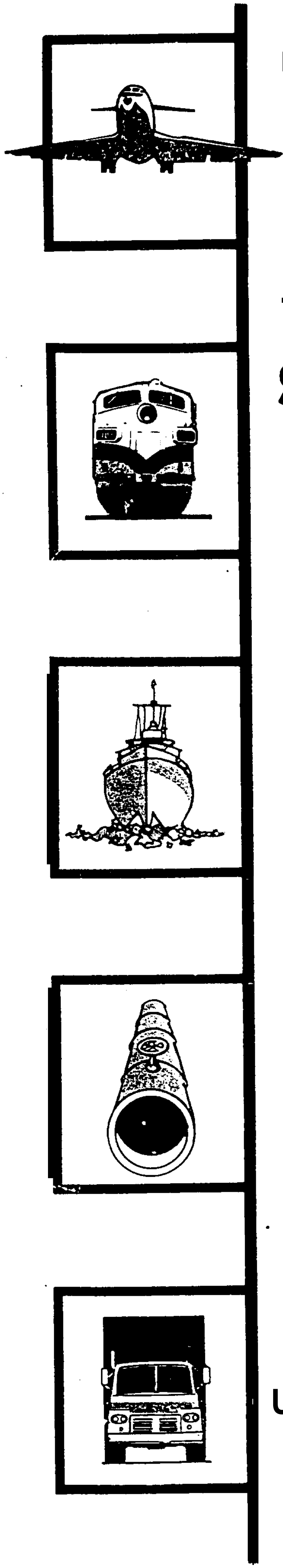

NATIONAL TRANSPORTATION **SAFETY** BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

ZANTOP INTERNATIONAL AIRLINES, INC.,
LOCKHEED L-l 88A ELECTRA
CHALKHILL, PENNSYLVANIA
MAY 30, 1984

NTSB/AAR-85/04

UNITED STATES GOVERNMENT

SEE ALSO: NTSB Reporter - July '85, p.12

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16. Abstract

On May 30, 1984, Zantop International Airlines, Inc., Flight 931, a Lockheed Electra L-188 (N5523) was a regularly scheduled cargo flight from Baltimore-Washington International Airport to Willow Run Airport, Ypsilanti, Michigan. There were three flightcrew members and a non-revenue passenger on board.

The airplane departed Baltimore-Washington International Airport at 0110 end climbed to flight level 220. The cockpit voice recorder indicated that the flightcrew experienced gyro problems during the climb to cruising altitude and that it had subsequently selected the No.1 vertical gyro to drive both approach horizons since there was an indication of a malfunction in the No. 2 vertical gyro system. By 0136:32, Flight 931 was level at flight level 220. At 0143:09, Cleveland Air Route Traffic Control Center cleared Flight 931 to Dryer VOR. Conversations on the cockpit voice recorder at 0144:11, include a comment which, although not clear, appeared to be "altitude" followed by the statements, "What's happening here," "You got it," end "No." The airplane entered a right descending spiral es the indicated airspeed increased from 205 knots to about 317 knots. There was a sound similar to structural failure during inflight breakup on the cockpit voice recorder at 0144:24.9. The airplane wreckage was scattered over an area 2 miles long by 1 mile wide.

17. Key Words Vertical gyro; amplifier malfunction; structural failure; conflicting pitch and roll data; inadequate instrument scan. Vertical guidance; Pitch attitude; control-loss of; roll; gyro system; attitude control-loss of	18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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The National Transportation Safety Board determines that the probable cause of the accident was the airplane's entry into an unusual attitude and the inability of the flightcrew to analyze the flight condition before there was a complete loss of control. Although the precise reason for the loss of control was not identified, an undetermined failure of a component in the No. 2 vertical gyro system, perhaps involving the amplifier and associated circuitry, probably contributed to the cause of the accident by incorrectly processing data to the copilot's approach horizon. The inflight structural failure of the airplane was due to overload.

CONTENTS

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

Adopted: March 19, 1985

ZANTOP INTERNATIONAL AIRLINES, INC.
LOCKHEED L-188 ELECTRA, N5523
CHALKHILL, PENNSYLVANIA
MAY 30, 1984

SYNOPSIS

On May 30, 1984, Zantop International Airlines, Inc., Flight 931, a Lockheed Electra L-188 (N5523) was a regularly scheduled cargo flight from Baltimore-Washington International Airport to Willow Run Airport, Ypsilanti, Michigan. There were three flightcrew members and a non-revenue passenger on board.

The airplane departed Baltimore-Washington International Airport at 0110 and climbed to flight level 220. The cockpit voice recorder indicated that the flightcrew experienced gyro problems during the climb to cruising altitude and that it had subsequently selected the No.1 vertical gyro to drive both approach horizons since there was an indication of a malfunction in the No. 2 vertical gyro system. By 0136:32, Flight 931 was level at flight level 220. At 0143:09, Cleveland Air Route Traffic Control Center cleared Flight 931 to Dryer VOR. Conversations on the cockpit voice recorder at 0144:11, include a comment which, although not clear, appeared to be "altitude" followed by the statements, "What's happening here," "You got it," and "No." The airplane entered a right descending spiral as the indicated airspeed increased from 205 knots to about 317 knots. There, was a sound similar to structural failure during inflight breakup on the cockpit voice recorder at 0144:24.9. The airplane wreckage was scattered over an area 2 miles long by 1 mile wide.

The National Transportation Safety Board determines that the probable cause of the accident was the airplane's entry into an unusual attitude and the inability of the flightcrew to analyze the flight condition before there was a complete loss of control. Although the precise reason for the loss of control was not identified, an undetermined failure of a component in the No. 2 vertical gyro system, perhaps involving the amplifier and associated circuitry, probably contributed to the cause of the accident by incorrectly processing data to the copilot's approach horizon. The inflight structural failure of the airplane was due to overload.

1. FACTUAL INFORMATION

1.1 History of the Flight

On May 30, 1984, Zantop International Airlines, Inc., Flight 931, a Lockheed L-188 Electra (N5523), was a regularly scheduled cargo flight from Baltimore-Washington International (BWI) Airport to Willow Run Airport, Ypsilanti, Michigan. The flightcrew, consisting of a captain, first officer, and flight engineer, had flown from Detroit, Michigan, on the day of the accident as passengers and had arrived at Baltimore, Maryland, about 1818. 1/ They checked into a motel until they were alerted for Flight 931 about 2300.

The flightcrew reported to the airport about 0010 for predeparture preparations. The first officer prepared the flight plan and reviewed the dispatch information as the captain was briefed on a hazardous materials shipment. The flight engineer supervised the refueling of the airplane and completed the predeparture inspection. An instrument flight plan was filed for flight level (FL) 220 (22,000 feet). 2/ The weather forecast for the en route portion of the flight in Pennsylvania was, in part, ceilings 2,000 feet to 3,000 feet broken, 10,000 feet broken to overcast, light rainshowers; freezing level 12,000 feet, winds aloft from the southwest at 60 knots.

Zantop ground personnel began to load the airplane at 2300. The loading was completed at 0040. All cargo was bulk loaded and tied down on the right side of the airplane for the full length of the cargo compartment. The night shift supervisor inspected the loading distribution for security at 0050. There was one non-revenue passenger onboard for the flight to Ypsilanti.

Flight 931 departed the gate at 0105 and took off on runway 28 at 0110. At 0111:42, Flight 931 contacted Baltimore departure control and was cleared to 13,000 feet. At 0112:54, the captain, who was not flying the airplane, instructed the first officer to stop the climb and level the airplane. He stated, "Level it off for just a second, I want to. check this radar; I got the antenna full up, it looks like it is still painting the ground." At 0113:34, the climb was continued.

At 0115:58, the captain said ". . .get your airspeed down to about 190 and we'll climb up through this faster." At 0116:20, Flight 931 contacted Washington Air Traffic Control Center (ARTCC) and reported climbing through 8,300 feet. At 0116:34, Washington ARTCC cleared Flight 931 to climb to FL 220.

At 0116:44, the captain stated, "Climbing out like we are now, where you are getting bounced around and you don't know what you might hit, the last thing in the world you want to do is to have your airspeed high." Throughout the climb, the captain and first officer discussed aircraft and air traffic control subjects, including an apparent adjustment problem with the airplane's airborne radar set. At 0127:03, the captain said "Out of 18,000, 992." At 0128:57, Washington ARTCC instructed Flight 931 to contact Cleveland ARTCC. Flight 931 contacted Cleveland ARTCC at 0129:18 and verified FL 220 as the assigned altitude.

At 0132:24, the first officer said, "*Kept turning---that's at. . ." and the captain responded at 0132:35, "Gyro's screwed up ---*." The conversation about the gyro continued until 0136:07 and included a request by the first officer for the flight engineer to "switch it over to No. 1." This was an apparent command to switch the Wilcox switching unit to drive the approach horizons from the No. 1 vertical gyro. Once they had switched to No. 1, the gyro problem appeared resolved, since the first officer and flight engineer commented that "its level now" and that it was "better."

At 0136:32, the first officer called for the cruise checklist and the three cockpit crewmembers began a conversation about indications on the No. 2 engine. The indications were that the horsepower was low while the temperature was high. The

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1/ All times herein are eastern daylight time based on the 24-hour clock.
2/ All altitudes are mean sea level unless otherwise noted.

conversation continued until 0138:33. At 0138:40, Cleveland ARTCC asked Flight 931 about the cloud tops in the area, and at 0139:02, the first officer transmitted that they had climbed through the tops of the clouds at 14,000 feet or 15,000 feet.

Aside from a request by the flight engineer at 0141:27, for engine times and temperatures, there was no cockpit conversation between 0139:02 and 0144:11, although the cockpit voice recorder did indicate the sounds of paper pages being turned.

At 0143:09, Cleveland ARTCC cleared Flight 931 direct to the Dryer VOR and provided a new radio frequency. The first officer responded at 0143:17, "One twenty-five one direct Dryer, Zantop 931, good night." At 0143:29, the first officer contacted Cleveland ARTCC on the new frequency and stated, "Zantop 931's with you flight level 220, we are going direct Dryer." This was the last transmission from Flight 931.

At 0144:11, a comment was made by an unknown crewmember which may have been "altitude". The tape of the CVR was not clear that the word was actually "altitude." However, the CVR investigation group came to a consensus that altitude was possibly the comment. At 0144:13.3, the first officer said, "What's happening here," followed by the sound of increasing wind noise at 0144:15. At 0144:15.2, the first officer asked, "You got it?" and the captain answered at 0144:18.1, "No." At 0144:21.1, the sound of the landing gear warning horn started, followed at 0144:22.7 by the sound of the overspeed warning clacker. The overspeed warning clacker continued until the end of the cockpit voice recorder tape. The cockpit voice recorder indicated a sound similar to structural failure during inflight breakup at 0144:24.9. At 0144:30, the cockpit voice recorder tape stopped.

The air traffic controller who was controlling Flight 931 stated that no other aircraft had gone through his area in the 10 minutes preceding the accident. At 0145:03, when he noted that the transponder data block of Flight 931 had disappeared, he attempted to contact Flight 931.

Numerous persons in the area of the accident reported ‘loud, unusual noises" which they attributed to an airplane in trouble. Witnesses reported a “terrific rumble and vibration,” while witnesses close to the accident site described continuing noises after the initial "boom." The noises were described as "different" engine noises, shrill, like an object traveling, "arc welding,” and "crackle." There was general agreement that the noises lasted 45 seconds to 1 1/2 minutes.

The airplane came apart in flight. The wreckage scattered over an area about 2 miles long by 1 mile wide and oriented northeast by southwest on a line through Chalkhill, Pennsylvania. (See appendix F.) Falling wreckage damaged some houses; however, most of the wreckage fell in uninhabited, wooded areas.

The three crewmembers and the non-revenue passenger died in the accident. The accident occurred during the hours of darkness at coordinates 35°48'35" north latitude and 79°37'32" west longitude. There was no moonlight at the time of the accident.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others	Total
Fatal	3	1	0	4
Serious	0	0	0	0
Minor/None	0	0	0	0
Other	0	0	0	0
Total	3	1	0	4

1.3 **Damage to Airplane**

The airplane was destroyed.

1.4 **Other Damage**

Some private residences, the Chalkhill Post Office, and the parking lot of the post office were damaged by sections of **the** airplane.

1.5 **Personnel Information**

The flightcrew was certificated and qualified for the flight and had received the required training. (See appendix **B.)**

1.6 **Aircraft Information**

The airplane, a Lockheed L-188 Electra, N5523, **(S/N1034)** was operated by Zantop International Airlines, Inc; and it had been maintained in accordance with applicable regulations. The takeoff gross weight was 85,827 pounds, which included 12,508 pounds of cargo and 14,000 pounds of jet fuel. The maximum allowable takeoff gross weight was 113,000 pounds. The center of gravity was within the prescribed limits. (See appendix C.)

The airplane was powered by four Allison **501-D13** turbopropeller engines and four Aeroproducts Model No. **A6441FN-606** propellers. A review of the airplane records indicated compliance with all applicable airworthiness directives (AD) and Lockheed Service Bulletins. Additionally, there were no outstanding minimum equipment list discrepancies or deferred maintenance items. The airplane logbook pages for flights through May 26, 1984, were available at Zantop International% main maintenance base. A review of the logbook revealed no significant maintenance deficiencies or trends of maintenance deficiencies.

A first officer who had flown with the captain of Flight 931 in N5523 one week before the accident stated that the autopilot "tripped **off"** several times during the flight. On one occasion, a **500-foot-per-minute (fpm)** descent resulted. He said that the autopilot switch tripping was indicated only by an annunicator light on the captain's instrument panel. He said that other pilots had reported to him unwanted altitude-hold disconnects. There were no logbook entries which related to any autopilot difficulties.

The flightcrew who operated N5523 for 2 **1/2** days before the accident said they had encountered no serious problems with the airplane. They said that the radar antenna apparently was out of adjustment, the No. 2 engine instruments were slightly different from the other three, and there had been two momentary **"jerks"** in the pitch axis of the autopilot. The first officer characterized the jerks as **"very** minor."

1.7 **Meteorological Information**

The 2300, May 29, surface weather map showed a flat **1016-millibar** low over the eastern edge of Lake Huron and a frontal system lying along the Atlantic Coast from Massachusetts through the Delmarva Peninsula with a weak low on the front over southeastern Virginia. Surface conditions over western Pennsylvania were characterized by overcast skies and light westerly winds with areas of fog and haze. Stations in eastern Pennsylvania reported moderate steady rain and drizzle.

The following are the surface observations at Morgantown, West Virginia, the nearest reporting station to the accident site:

> Time--0100; type--record special; ceiling--measured 1,900 feet broken, 8,000 feet overcast; visibility--7 miles; temperature--46°F; dewpoint--42° F; wind--260° 4 knots; altimeter--30.14 inches.
>
> Time--0158; type--record special; clouds--2,000 feet scattered, ceiling--measured 3,600 feet overcast; visibility--7 miles; temperature--45° F; dewpoint--42° F; wind--240° 5 knots; altimeter--30.13 inches.

The 0100 infrared photograph from the Geostationary Operational Environmental Satellite (GOES) showed an area of higher clouds with the potential for convective activity east of a line extending approximately north-northeast, south-southwest through the vicinity of Cumberland, Maryland. West of this line, the clouds were predominantly low with a line of high clouds north-northeast south-southwest in the vicinity of the accident site. Based upon the infrared temperature scale, the higher cloud tops were probably in the vicinity of 25,000 feet.

The following are the 1915 winds aloft at Pittsburgh from the surface to 25,000 feet:

Altitude (feet above sea level)	Direction (° true)	Speed (knots)
1,181	300	5
2,130	290	14
3,050	281	10
3,970	267	8
4,890	248	11
5,890	241	18
6,867	241	23
7,824	234	25
8,791	229	30
9,755	225	36
10,851	227	35
11,880	226	40
12,909	224	40
13,693	220	43
15,076	218	47
16,189	217	50
17,234	217	60
18,273	213	78
19,353	205	90
20,411	203	96
21,429	205	101
22,433	206	103
23,436	209	100
25,456	208	104

Area Forecasts--The following area forecast, quoted in part, was issued by the National Weather Service Advisory Unit of the National Weather Service on May 29, 1984, at 1940, and was valid beginning at 2000:

Turbulence valid until May 30, 0800.

From Caribou (ME) to St. Johns (N.B.) to Nantucket (RI) to Parkersburg (WV) to Findlay (OH) to Quebec (Que) to Caribou (ME). Occasional moderate turbulence below 10,000 feet due to strong low level winds. Conditions improving southwestern portions by 0200, continuing elsewhere beyond 0800.

Pennsylvania:

2,000 to 3,000 feet broken 10,000 feet broken to overcast. Occasional ceilings below 1,000 feet overcast, visibilities below 3 miles in light rain and fog with mountains obscured in clouds and precipitation. Isolated embedded thunderstorms with light rain showers eastern quarter. Tops layered to 20,000 feet. Cumculnimbus tops to 30,000 feet. Outlook: IFR due to ceiling and rain showers northeastern quarter until 1200. Otherwise marginal VFR due to ceiling throughout.

At 1942, May 29, the following correction to the area forecast was issued.

Icing and freezing level valid until May 30, 0800.

Lake Erie, Ohio, West Virginia, Pennsylvania, correction.

From 80 miles northeast of Marquette (MI) to Buffalo (NY) to Beckley (WV) to Covington (KY) to Chicago (IL) to Green Bay (WI) to 80 miles northeast of Marquette (MI).

Occasional moderate rime/mixed icing in clouds and in precipitation above the freezing level to 12,000 feet. Conditions continuing beyond 0800.

At 2000 the following correction to the area forecast was issued.

Turbulence valid until May 30, 0800

From Toronto (Ont.) to Buffalo (NY) to Bristol (TN) to Montgomery (AL) to Memphis (TN) to Fort Wayne (IN) to Toronto.

Occasional moderate turbulence 15,000 to 25,000 feet associated with wind shear in upper trough. Conditions moving slowly eastward and contouring beyond 0800.

There were no SIGMETs, convective SIGMETs or AIRMETs valid for southwestern Pennsylvania at the time of the accident.

1.6 Aids to Navigation

Not applicable.

1.9 Communications

There were no known communication problems.

1.10 Aerodrome Information

Not applicable.

1.11 Flight Recorders

The airplane was equipped with a Fairchild A-100 cockpit voice recorder (CVR), serial No. 1063. The exterior recorder case was damaged slightly in the accident; however, the tape transport survived and the quality of the recording was excellent. The entire 32 minutes of the recording were transcribed in the Safety Board's Audio Laboratory. (See appendix D.)

The last 5 minutes of the CVR tape was examined to determine if there were any electrical system abnormalities during this time period. The 400 Hz aircraft a.c. power signature was printed on a Honeywell visacorder which showed amplitude versus time. There were no disturbances found until after the cockpit area microphone (CAM) picked up sounds associated with structural failure at 01:44:24.9.

The overspeed warning clacker which started at 01:44:22.7 and continued until the end of the tape was identified by measuring the frequency of the sounds it produced. The measured frequency was between 6.8 Hz and 7.0 Hz. The design frequency of the overspeed warning clacker is about 7 Hz.

The airplane was equipped with a Fairchild Model 5426 flight data recorder (FDR), serial No. 1349. The FDR was removed from the airplane and taken to the Safety Board's FDR laboratory in Washington, D.C., for examination and readout. (See appendix E.) The recorder was damaged mechanically in the accident, and it was cut open to remove the foil magazine. Although the foil magazine was warped, a large portion of the foil medium, including the accident flight record, was removed successfully from the magazine. The parameter and binary traces, except the magnetic heading trace, were recorded in the prescribed manner. The magnetic heading trace was static at all times and was positioned below the north/south binary trace.

1.12 Wreckage and Impact Information

Fuselage.--The fuselage broke apart in flight, and the damage from fuselage station (FS) 200 aft to FS 1117 was extensive. (See figure 1.) The main sections of the fuselage which were recovered were the nose and cockpit section from FS 42 to FS 200; the left forward fuselage section encompassing the four static ports and a portion of the forward entrance door frame; the left aft fuselage section (FS 796 to FS 1117) which included a portion of the cabin floor and the main cargo door assembly; and the right fuselage section from FS 540 to FS 695, including the bottom fuselage from FS 540 to FS 715, which was fragmented into small pieces and unidentifiable sections.

The main cargo door was closed and locked. The fuselage skin and associated support structure from the main cargo door aft to FS 1117 was folded in the forward and upward direction.

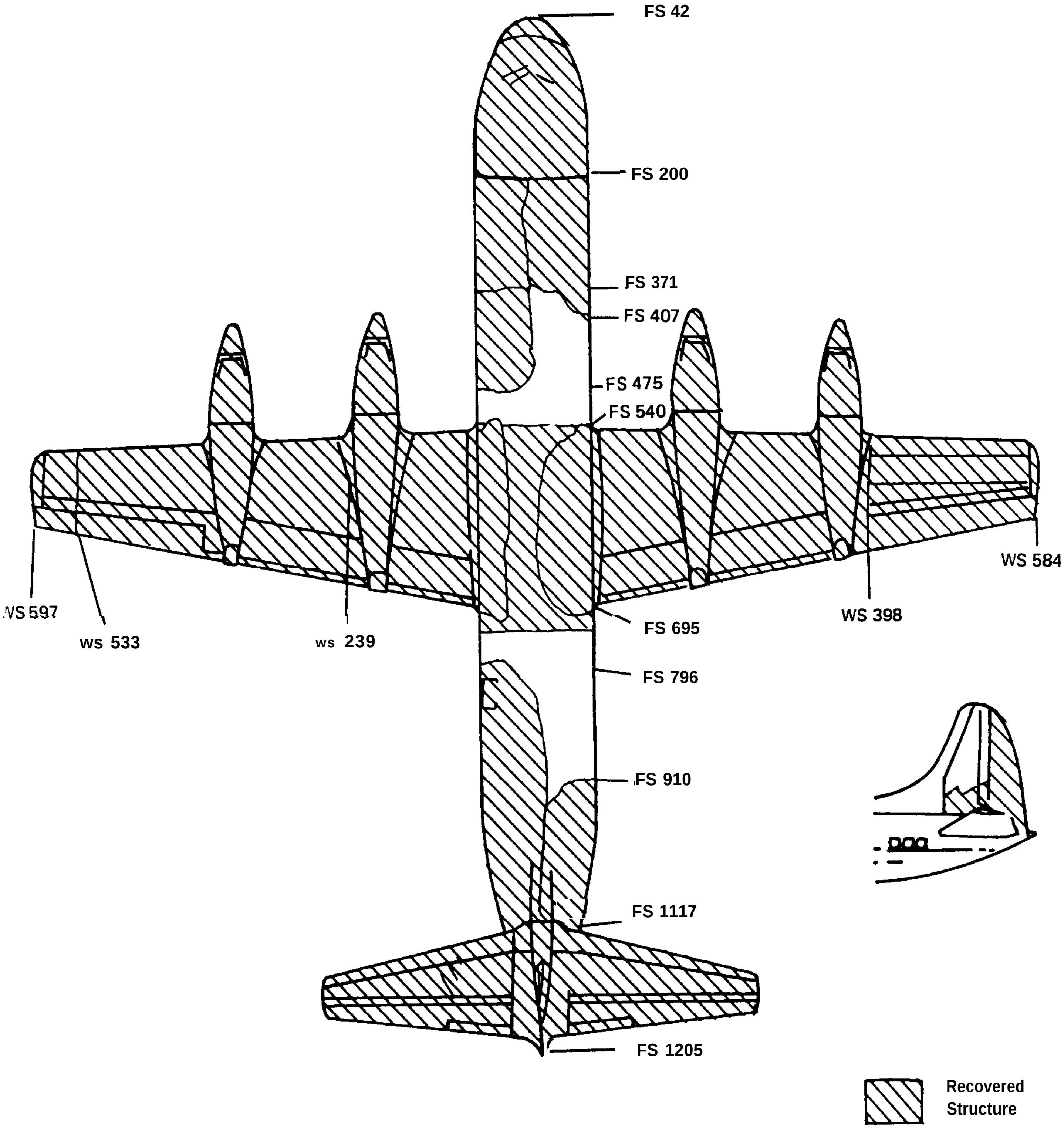

Figure 1.--Airplane diagram

The right fuselage section from FS 540 to FS 695 included the right wing inboard panel, the No. 3 and No. 4 engine nacelles, the left wing inboard panel, and the No. 2 engine, propeller assembly, and nacelle. The bottom fuselage structure was joined to the right and left wing inboard panels.

Empennage.--The right horizontal stabilizer was attached to the fuselage, but the elevator assembly had separated. The rudder and elevator boost packs were intact and attached to the fuselage. The stabilizer was bent upward at a point 5 feet inboard from the tip. The left horizontal stabilizer separated from the fuselage. The elevator assembly separated from the stabilizer. Pieces of the left and right elevators were recovered.

The vertical stabilizer was damaged severely and only two pieces were recovered. A 2-foot by 2-foot section of the stabilizer center left side remained attached to the fuselage. Another piece was attached to the right side of the rudder assembly, and the rudder assembly separated from the vertical stabilizer. The trim tab was intact and attached.

Wings.--The tip of the left wing separated at wing station (WS) 533 outboard to WS 597. The left wing outboard panel section from WS 239 to WS 533 and the trailing edge flap and aileron separated along with the No. 1 engine and nacelle. The left wing outboard upper extended surface panels between WS 329 and WS 221 exhibited severe compression buckling. Sections of the aileron assembly were recovered. The outboard tip of the left aileron was attached to the tip of the left wing outboard panel. The flap assembly was found near the wing structure. It had separated from the wing structure at ground impact.

The right wing inboard panel from WS 398 inboard to the fuselage, including the nacelles for engines No. 3 and 4, remained attached to part of the right fuselage. The area of WS 398 showed indications of inflight fire and heat damage; there was no evidence of ground fire. The leading edge of the right wing from WS 1398 inboard to WS 65 was damaged severely when it struck trees. ' The right outboard panel had disintegrated and separated at WS 398. Most pieces of the right wing were located and identified within the ground impact area.

The inboard end of the first beam web in the right wing and the inboard end of the rear beam web from WS 398 outboard to WS 422 were bent aft. The outboard wing panel front beam web and rear beam web fractures mated with the front and rear beam web fractures at the fire and heat damaged area. There was no evidence of fire or heat damage in the area of the outboard wing panel beam web fractures.

Most sections of the aileron were identified. The right wing flap assembly remained intact and attached to the right wing structure. The flap was in the retracted position. The nose landing gear assembly was retracted and was pushed upward into the cockpit structure. The left main landing gear assembly separated from the airplane at ground impact. The right main landing gear assembly was retracted within the No. 3 engine nacelle.

Propellers.--None of the propeller assemblies or engine power sections bore any evidence of pre-breakup or in-flight fire patterns, nor was there any evidence of ground fire in the areas adjacent to the propellers or the engine power sections. All of the propeller blades which remained attached to their respective propellers were positioned at different angles. All propeller assemblies separated from their respective engine power sections. The No. 2 propeller was found beneath the No. 2 engine nacelle. The other propellers were between 600 feet and 2,400 feet from their respective engine power sections.

Blade Nos. 2, 3, and 4 remained attached to the hub of propeller No. 1. Blade Nos. 2 and 4 remained attached to the hub of propeller No. 2. Blade Nos. 2, 3, 4 remained attached to the hub of propeller No. 3. Blade Nos. 2 and 4 remained attached to the hub of propeller No. 4. The "as found" blade angles for the four propellers ranged from about 50° to 72°, while the blade impact angles ranged between about 50° to 74°.

Damage to the four propellers consisted primarily of broken preload bearings, preload shims, blade bearing outer races and bent and distorted propeller blade hub sockets. All of the torque cylinders and fixed splines that were removed from the four propellers were intact and were not damaged except for the No. 2 blade fixed spline on the No. 4 propeller. The four master gears were intact and undamaged except for the three gear teeth that were integral to the No. 4 propeller's master gear.

Engines.--The Nos. 1 and 2 engine power sections remained in their respective nacelles; the No. 1 nacelle remained secured to the wing section, while the No. 2 nacelle was attached to the wing section by electrical wires only. The Nos. 3 and 4 engine power sections were separated from their respective nacelles and were buried almost totally in a horizontal attitude; the craters in which these engine power sections were found were not axially or laterally displaced.

The vertical split line flanges of the Nos. 1 and 2 engine power sections were not separated. The No. 3 engine power section was partially opened at the compressor diffuser assembly/combustion chamber outer casing/turbine inlet casing vertical split line flanges. The No. 4 engine power section was opened at the compressor diffuser assembly/outer combustion chamber casing vertical split line flanges; additionally, the turbine inlet casing/turbine rear bearing support vertical split line flanges were opened partially.

The combustion casings of the No. 3 and 4 engine power sections were forced radially inward to where the casings contacted the turbine coupling shaft. All of the reduction gear power section struts and the the torquemeter assemblies were found.

Fuel System.--The No. 1 fuel tank was intact, except for a rectangular-shaped tear-out section in the dome end cap of the tank. The No. 2 fuel tank was almost completely crushed and partially buried, and was broken open just inboard of the No. 2 engine's inboard mount. The No. 3 fuel tank was almost totally intact. The No. 4 fuel tank had separated just outboard of the No. 4 engine nacelle and generally was fragmented; about 80 percent of the tank was recovered. The fuel tanks were damaged by fire at the front wing beam and on the lower panels of the No. 4 fuel tank at the inboard side of the wing separation area.

Nearly all of the fuel valves and the fuel boost pumps were recovered generally intact. Most of the fuel valves and the fuel boost pumps were in their installed positions or were retained to broken sections of wing spar caps. None of the recovered fuel valves or the fuel boost pumps showed any evidence of fire or overheat damage.

Airplane Systems.--The continuity of the flight control system could not be established because of extensive inflight breakup and ground impact. The engine controls for each pilot station were separated from each other and from the mechanical activation controls for the engine and propeller systems. The two transformer rectifier units, the emergency a.c. rotary inverter, and the lead acid battery were located in the proper area under the cockpit. The lead acid battery was shattered, and the battery cells were scattered around the cockpit areas. The forward load center at FS 175 was damaged severely. The Nos. 1 and 2 directional gyros were mounted in this area; however, both gyros were detached from their mounts and damaged severely by the impact.

The Wilcox 732A switching unit was mounted behind the first officer's station. The unit was damaged heavily, precluding a continuity check of the switching function. However, the vertical gyro switch was found in the "Capt and Pilot on VG No. 1" position. The compass and VHF NAV switches were in the NORMAL position. There was no evidence that safety wire had been installed on the three switches.

The airplane's power generation and distribution systems and some components of the autopilot system were located in the electrical load center at FS 502. The components from the load center were found scattered within 200 feet of the cockpit area. The Nos. 1 and 2 vertical gyros were mounted normally in the electrical load center. Both gyros were found about 600 yards west of the cockpit area. Both gyros were detached from the airplane structure. The No. 1 vertical gyro case was crushed and damaged severely. The roll gimbal assembly was broken in five places, and all internal mounting studs were broken. The unit could not be tested functionally.

Electrical wiring near No. 4 engine.--The electrical wiring in the inboard wing section outboard of the No. 4 engine received intense local external heat damage in the vicinity of the engine fire wall d&connects. Only two firewall connectors were attached to the inboard portion of the wing structure. The wiring was ripped from the connectors that had separated with the No. 4 engine. An inspection of the firewall connectors and wiring at the point of separation from the airplane structure indicated that the wire ends had frayed.

Other Components.--All major components of the hydraulic system were located and inspected. The aileron, rudder, and elevator booster assemblies were located and inspected; no preimpact discrepancies were noted. All four fire bottles were found intact; each was charged fully. All eight fire control units were located and the associated fire loop wiring for each quick engine change were intact with no signs of deterioration. The following relevant instrument readings were recorded:

	Captain	First Officer
Horizontal situation indicator	Heading 140°	
Radio magnetic direction indicator	Course 100° Compass heading 310° No. 2 needle - VOR and indicating 240°	Compass heading 70° No. 2 needle indicating 38°
Airspeed indicator	225 knots - Barber pole indicated 215 knots.	Needle broken Barber pole 290 knots.
Drumpointer altimeter	14,800 ft; 29.92 in. hg.	
Kollsman altimeter	3,500 ft; 29.92 in. hg.	3,150 ft; 29.96 inhg.
Artificial horizon		10° left bank, full up pitch

1.13 Medical and Pathological Information

There was no evidence of preexisting medical conditions which affected the flightcrew. All occupants received fatal multiple injuries. Post-mortem and toxicological examinations were conducted and disclosed no evidence of alcohol or drugs.

1.14 Fire

There was an inflight fire in the right wing just outboard of the No. 4 engine nacelle. The fire primarily was between the front spar and the rear spar. The right wing separated at the point where the fire damage was observed. There was no evidence of fire on the piece of the wing which separated. There was no ground fire in the area where the piece of right wing, which had been exposed to inflight fire, was found.

1.15 survival Aspects

The accident was not survivable.

1.16 Tests and Research

1.16.1 Powerplants

The powerplants and propellers were disassembled and examined by the Safety Board at the Burbank Division of Aviall, Inc., Burbank, California, and the Hamilton Standard Group of United Technologies Corp., Long Beach, California, respectively. The examination of the components was conducted to the extent necessary to determine if any pre-impact breakup-associated damage or failure was present. None of the propeller components showed evidence of abnormal operating conditions. None of the blades which remained attached to their respective propeller assemblies exhibited impact or strike marks on the leading or trailing edges.

The thrust bearing retaining nut locks installed in the reduction gear front housings of the four engines were in their installed positions and appeared to be properly installed. The bearings installed on the compressor extension shaft assemblies, and the compressor side gears and their ball bearing assemblies that were installed in the Nos. 2, 3, and 4 air inlet housings were intact and were not damaged. Some degree of roughness was felt while rotating the bearings installed on the No. 2 compressor extension shaft and the compressor side gear. The No. 3 compressor extension shaft and compressor side gear bearings rotated freely. The No. 4 compressor side gear bearing rotated freely; however, the compressor extension shaft bearing could not be rotated. The bearings which exhibited rotational roughness or could not be rotated were contaminated with impact associated debris.

The No. 1 engine power section front and rear turbine bearings were intact, undamaged, and rotated freely. The compressor front bearing and the turbine rear bearings that were installed in the Nos. 2 and 4 engine power sections were intact, undamaged, and rotated freely. The No. 3 power section front compressor bearing inner race was in good condition; however, the outer race and bearing rollers were not recovered.

Fresh, clean deposits of an aluminum-type material were found uniformly distributed on the leading faces of the turbine inlet temperature thermocouples installed in the four engines.

A pattern of static-type compressor blade tip contact impressions was embedded into the compressor case rotor path of the Nos. 2, 3, and 4 engine power sec tions. Compressor rotor blade tip rotational contact marks also were visible on a majority of the compressor case rotor paths of the Nos. 2, 3, and 4 engine power sections.

None of the components of the four engines showed any evidence of being subjected to dynamic loading conditions, such as repeated multidirectional contacts or repetitive opposite direction contact marks between adjacent components. Three selected engine mounts were disassembled and found to be in normal condition except for some engine discrepancies associated with inflight separation and impact. None of the mount cushions showed any evidence of being subjected to repetitive compressive bottoming-out type loadings.

The No. 1 and 4 front spar mounted, manually actuated, normal and emergency fuel shutoff valves were intact, were in their installed positions, and were not damaged. The motor-actuated fuel cross feed valve and the fuel scavenger pump were intact and remained in their installed positions.

A functional test of the Nos. 1 and 4 fuel tank float-actuated vent valves using a pneumatic test fixture showed that the No. 1 fuel tank float actuated vent valve unseated at less than 1 psi, which is within specified limits, while the No. 4 fuel tank float-actuated vent valve unseated at 5 1/2 psi, which is outside of specified limits. It was noted that the negative pressure port was clogged with mud from ground impact.

1.16.2 Metallurgical Examination

The metallurgical examination of the airplane was performed by a Safety Board metallurgist at the accident site and in Safety Board's Metallurgical Laboratory.

Fuselage and Empennage Structure.--Fractures of the primary fittings for the fuselage and empennage structure were all typical of gross overstress separations. None of the components showed indications of inflight exterior penetrations or major impact from other parts of the airplane. Interior portions of the fuselage sections appeared clean with no evidence of explosions or penetrations from the inside.

Left Wing.--The left wing section from the tip to just outboard of the No. 2 engine was found in two pieces at the Chalkhill Post Office. The inboard break in the wing was oriented chordwise, having characteristics typical of tension along the lower skin and irregular compression features along the upper skin. Detailed visual examination of this break disclosed areas indicative of fatigue cracking emanating from five fastener holes in the lower skin.

Three of the fastener holes were in the area located about 19, 20, and 21 inches forward of the rear spar. The holes appeared to be about 3/16 inch in diameter and were associated with the attachment of a repair plate to the lower skin surface. Cracking extended from both sides of the 19- and 20-inch positioned holes having a maximum extension ranging from 1/16 inch to 5/16 inch from the hole edge. An approximate 1/8-inch-long fatigue crack emanated aft from the hole positioned 21 inches forward of the rear spar.

The other two fastener holes exhibiting fatigue progression were at the positions about 37 and 45 1/2 inches forward of the rear spar. A representative of Zantop Airlines indicated these holes were used to secure a skate angle of the skin for attachment of the No. 2 nacelle to the wing. Extension of fatigue was about 1/16 inch aft and 1/2 inch forward from the hole edges at the 37-inch position about 1/2 inch aft and 1/8 inch forward at the 45 1/2-inch position. All of the remaining fractures on the inboard break exhibited features typical of gross overload separations. The amount of fatigue cracking found at this location was small with respect to the net section of the wing.

The left wing tip was separated chordwise from the left wing section and also was located at the post office. This break was irregular and jagged, typical of compressive overstress along both the upper and lower wing skin surfaces. The proximity of the left wing tip to the left wing section indicates that the tip probably separated during ground impact. No fatigue or other type of progressive cracking was found on the left wing tip break.

Right Wing.--The right wing tip had separated just outboard of the No. 4 engine nacelle. The inboard break showed evidence of fire damage. This fire damage was primarily between the front and rear spar locations in the form of fibrous "broomstraw" fractures and heavy soot. Fibrous fractures in aluminum alloys indicate the material was heated between 900° to 1,200' prior to being stressed. Both the upper and lower wing skins in this location were jagged, with spanwise splitting; the most irregularity was in the lower skin. When first viewed on June 3, 1984, tree branches covered the fractures that had not been burned. The surrounding ground area showed no evidence of a ground fire. The front and rear spar breaks were representative of overstress.

A section of the wing plank in the area of the right wing inboard fibrous break was removed for laboratory examination. Metallographic examination of a longitudinal section at one of the transverse breaks as well as hardness measurements (DPH 112 or 122) confirmed that the fibrous fractures were produced in part by grain boundary melting at temperatures exceeding 900° F.

Pieces of the outboard right wing tip section mating to the inboard section which had been damaged by fire were recovered in pieces. There was no evidence of fire or heat distress on any of the recovered outboard pieces.

The outboard front and rear spar web sections on the outer right wing fragmented section were longitudinally split adjacent to the inboard separation, and the web sections on the inboard side were deformed permanently aft relative to the upper and lower extremities of the spar caps. Numerous longitudinal splits of upper and lower wing skins also contributed to fragmenting these planks. The largest wing plank section recovered was part of the lower skin and numerous sections were missing. The aileron was fragmented into three almost equal size spanwise pieces, there being considerable damage to the inboard piece. All fractures on these components, however, were typical of gross overload separations.

The deformed inboard front spar section and a portion of the rib at wing station 431 adjacent to the lower skin were removed in the field and sent to the laboratory for more detailed examination. Bench binocular examination of the longitudinal breaks of the web section disclosed what appeared to be mechanical smearing on the fractures. This smearing, however, was not continuous along the fracture, and sporatic areas of an original, undamaged fracture were found. Examination of the undamaged separations disclosed no evidence a preexisting crack. All fracture areas were typical of overstress breaks.

A piece was removed from the wing station 431 rib. This piece contained rib diagonal separations representative of, those found on most of the ribs between wing stations 398 and 516. Examination of the rib diagonals disclosed deformations indicative of bending overstress, as if the diagonals were moving outboard relative to the bottom rib channel.

1.16.3 Autopilot-Vertical Gyro Examination

The Safety Board examined the components of the Bendix PB-20 autopilot system at the Bendix West Coast Support Operations Facility. The autopilot components were damaged severely, and most could not be tested functionally.

Vertical Gyro No. 2.--The unit was installed on N5523 on April 11, 1984. At that time the time since overhaul was 1,151.8 hours (specified time between overhaul is 3,000 hours). High pressure air was used to remove the cover off the gyro. The three internal mounting studs were broken. The E-l and E-4 slip ring assemblies were broken and associated brushes were bent. Terminal board TB-4 was broken and the gyro motor brake was broken. The resistance of the bank torquer was measured and the value was within specification. The pitch torquer could not be measured due to broken slip rings. There is no other major physical damage to the unit. Subsequent to the initial inspection of the gyro, an attempt was made to operate the unit. This operation required replacing the mounting studs, replacing the E-l and E-4 slip rings, repairing terminal board TB-4, and repairing brush block E-l (a wire was soldered directly onto the brush). A continuity check of the unit revealed no short circuits. Power was applied to the unit, the gyro motor ran, and the gyro erected normally. An electrical check of the gyro signals revealed that no gyro warning flag voltage was present (the absence of an electrical signal would cause a warning flag to be displayed on the horizon indicator); however, the 70-second time delay for routing the flag voltage to the indicator did operate. In addition, there was no pitch attitude signal for the horizon indicator, no roll signal for the autopilot, and no vertisyn (up elevator compensation for turning maneuver) signal for the autopilot. All other signals (horizon indicator roll signal, autopilot pitch signal, pitch and roll signals, and autopilot interlock signal) were present. During subsequent troubleshooting of the gyro, several wires in the gyro pigtail electrical cable were found open as a result of broken wires. The cable was replaced and all signals normally supplied by the gyro were restored. After the unit had operated for about 7 minutes, the gyro drifted about 15° noseup in the pitch axis. The drift exceeded the capability of the torquer to keep the gyro level. The roll axis remained level. No determination could be made as to whether this anomaly existed before the accident or was a result of impact damage.

The following components were connected to a power source and tested: control surface position transmitters, elevator position transmitter, aileron position transmitter, rudder position transmitter, dynamic vertical sensor, and pitch trim servo.

The following components were damaged so severely that no test was possible: directional gyros, rate control unit, air data sensor, flux gate transmitter, autopilot computer amplifier, and the power junction box.

1.16.4 Flight Instrument Teardown and Examination

The Safety Board tore down the flight instruments and examined them at the ‘facility of Rockwell International Collins Division. The following results were obtained:

Steering Computer.--The unit was crushed and distorted severely and the cover had to be cut and pried away from the chassis. The chassis, on which all modules were mounted, was badly distorted. All of the magnetic amplifier modules and the power supply module were found intact, with only dents and scratches on the covers. The major computer components were found intact. Some of the interconnect wiring was damaged as a result of the unit’s cover being crushed against the chassis. No functional test of the unit was possible.

Instrument Amplifier.--The unit suffered heavy damage and was severely crushed. The cover had to be cut away to reveal the internal components. The chassis was distorted badly as a result of the unit's being crushed. The three servo amplifier module mountings conformed to the distorted shape of the chassis; however, the components of amplifiers remained intact. The flag amplifier module remained intact. One corner of the power supply module was crushed and conformed to the shape of the chassis. Some of the interconnect wiring was ripped from the chassis connectors, and some wires were chafed as a result of the unit cover's being crushed into the chassis. No functional testing of the unit was possible.

The unit was crushed and deformed which necessitated cutting the case away from the chassis. All three servo amplifier modules were crushed in conformance with the shape of the distorted chassis. Most major components of each module remained intact; however, some component leads were broken and the components shifted from their normal mounting. The flag amplifier module remained intact. The power supply module was crushed in conformance to the shape of the chassis.

First Officer's Approach Horizon.--The instrument front glass was shattered and the bezel broken. The case was crushed severely and had to be cut away. The two castings which form the chassis were broken and cracked in several places. The servo motors used to drive the bank and pitch displays mechanically remained in their mounting positions; however, the motors were dented and scratched. The servo motors remained connected, through mechanical linkages, to the bank display mask and the pitch bar. The display was frozen indicating a 10° left bank and full-up pitch condition. The steering flag was in view in the lower right corner of the instrument. All other flags were destroyed. The trim knob, used to adjust the relative position of the pitch bar, was set to a mid-range (12 o'clock) position.

1.16.5 Airplane Performance

National Track Analysis Program (NTAP) radar data was obtained from the Cleveland ARTCC. The radar data provided position and altitude information every 12 seconds. The last 8 minutes of the radar data were analyzed. Secondary radar returns (transponder-generated) indicated that the airplane was flown at a constant west-northwest heading until about 0144:08. There was a secondary radar return at 0144:08, at which point the radar data indicated the start of a right turn. The right turn increased between 0144:08 and the next secondary radar return at 0144:20. In this period, the CVR recorded the conversations between the captain and the first officer which included the question "you got it?" and the sounds of increasing wind noise. The indicated airspeed, which had been constant between 205 knots and 210 knots, increased to 225 knots in about 4 seconds and then to 317 knots in the next 10 seconds. In the last 21 seconds of the FDR operation, altitude data changed from about 2,700 feet (pressure altitude) to about 15,300 feet. The FDR recorded g trace values which increased from 1.0 g to 4.5 g when the recorder ceased operating.

About 0144:20, the last secondary radar return was recorded. Primary radar data were obtained for the next 3 minutes. Primary radar data are recorded when a radar impluse is reflected off a physical object and the location of that object is observed on the radarscope. Twenty separate primary radar returns were recorded between 0144:20 and 0147:56. (See appendix G.) The scatter pattern of the primary radar returns ran southwest-northeast.

1.17 Additional Information

1.17.1 Approach Horizon

The approach horizon is the primary attitude and steering instrument. (See figure 2.) It shows whether the wings are level or in a bank, and the position of the nose relative to the horizon. The vertical needle, or steering pointer, will point in the direction to which the airplane should be turned. The bank pointer and the horizon bar operate together. The bank pointer indicates the amount of bank in 10°, 20°, 30°, and 45° graduations at the top of the horizon disc. The horizon bar indicates the roll or bank attitude in a forward view presentation. The horizon bar is not sensitive to pitch and will always pivot about the center of the instrument. The pitch bar is the miniature airplane viewed from behind. It moves vertically above and below the centerline of the instrument to indicate changes in airplane pitch attitude. The steering pointer extends vertically from the center of the instrument. The position of the pointer is an indication to a pilot of the turn that should be made. For example, a right deflection of the pointer is an indication to make a right turn.

1.17.2 Vertical Gyro Operation

The two vertical gyros installed in the accident airplane were not originally manufactured under their current part numbers. Bendix Service Bulletin No. 6110-27-A, issued on November 7, 1961, and revised December 4, 1962, described a modification to the unit. When originally manufactured, the unit contained a vertical circuit monitor, which monitored the ability of the gyro to remain erect. If the vertical monitor detected precession of the gyro of more than 7 1/2° for a period of 110 to 220 seconds, a gyro warning flag would be displayed on the horizon indicator and the autopilot would disengage. This feature was removed in compliance with Service Bulletin No. 6110-27-A. The gyro on N5523 was modified before Zantop acquired the airplane.

The captain and first officer each had an approach horizon which was the primary display of the airplane's roll and pitch attitudes. The instrument panel-mounted indicators consisted of a pictorial display (a mask which moves in the roll axis and a pitch bar which moves vertically in the pitch axis), a series of mechanical synchros and servo motors to operate the moveable display, and instrument lights. The indicator did not contain the gyroscope used for attitude referencing. Two remotely mounted vertical gyroscopes supplied the attitude references for the indicators as well as for the weather radar and autopilot. A vertical gyro assembly consists basically of a precisely controlled electric motor operating as a stable gyroscope, a synchro transmitter which provided reference signals to the attitude indicator (the No. 2 vertical gyro additionally provided reference signals for the autopilot and weather radar system), and associated electronics. An instrument amplifier was used with each attitude indicator to process reference signals from the vertical gyro and the resultant display position signals from the indicator. Each amplifier also provided signals necessary to drive mechanically the attitude indicator display.

The Wilcox 732A switching unit allowed the flightcrew to select the source of vertical gyro information which drove the approach horizons for the captain and first officer. (See figure 3.) Under normal flight operations, the No. 1 vertical gyro drove the captain's approach horizon and the No. 2 vertical gyro drove the first officer's approach horizon. Additionally, the No. 2 vertical gyro provided stabilization for the airborne radar and the attitude reference signals for the autopilot.

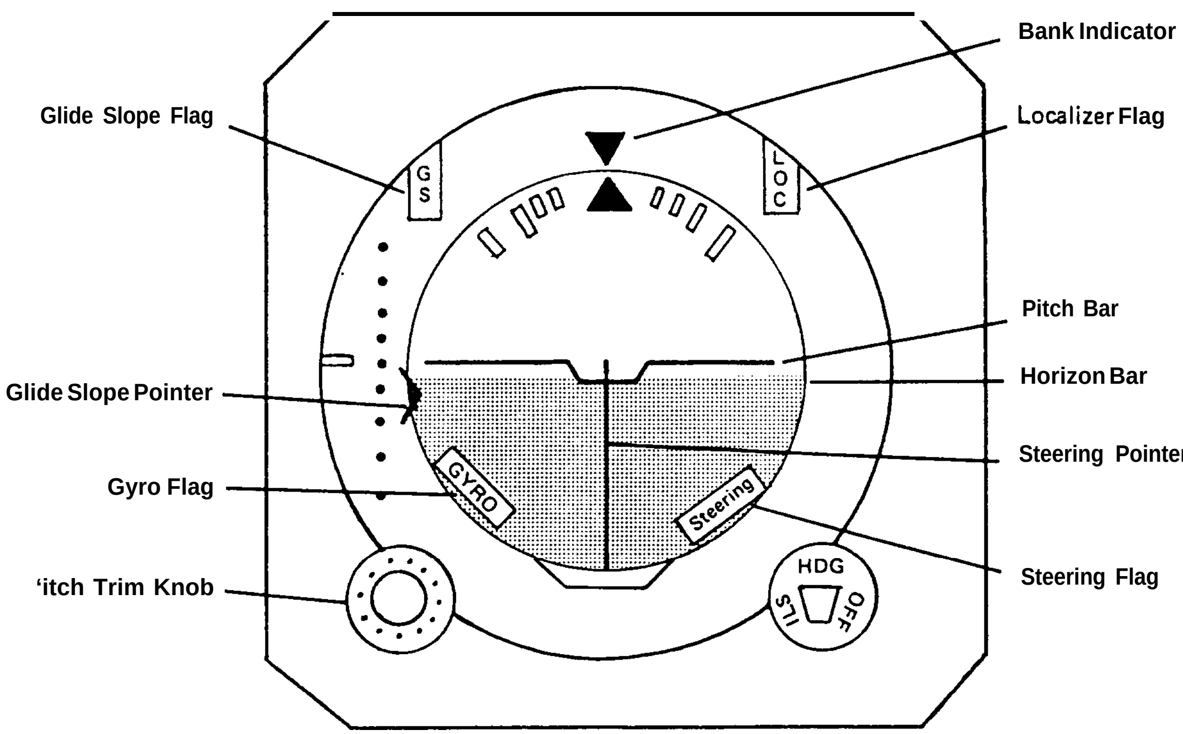

Figure 2.--Approach horizon.

The Zantop L-188 Flight Manual states that the switches on the switching unit were to be safe-tied to the normal position. Aside from the normal position, the flightcrew could select "Capt. & Pilot on VG No. 1" or "Capt & Pilot on VG NO. 2" in the event of a vertical gyro failure. The manual states, "Their (switch positions) is to restore the normal operation, within certain limitations of the Course Indicator and the Approach Horizon in the'event of failure of the vertical gyro, compass, or VHF NAV system."

A gyro failure is indicated by the appearance of a warning flag labeled "GYRO" on the face of the affected approach horizon and the illumination of an annunciator labeled "Horizon Failure." The manual also notes that the GYRO flag can appear without the "Horizon Failure" annunicator illuminating. In that case, a failure in the gyro amplifier or associated circuits is indicated, and the vertical gyro still functions normally. The manual states, "Under these circumstances, switching to the other Vertical Gyro will not restore operation of the approach horizon."

If the problem with the approach horizon as noted by the flightcrew was the result of a malfunction of the vertical gyro, the flightcrew would see the gyro and horizon failure indications. Use of the approach horizon would be regained by selecting a different position on the switching unit. With the vertical gyro switch moved from the normal position to the "Capt & Pilot on V.G. No. 1" position, the No. 2 vertical gyro would no longer drive the first officer's approach horizon. The No. 1 vertical gyro would provide signals to both approach horizons.

Upon switching positions, the signal from the No. 1 vertical gyro would go directly to the amplifier of the first officer's approach horizon where the signal would be processed to produce a mechanical indication in the face of the instrument. The capture of the first officer's approach horizon by the No. 1 vertical gyro would be nearly instantaneous upon switching. The warning flags and indicators would disappear, and both approach horizons would be identical. However, the No. 2 vertical gyro would continue to provide stabilization for the airborne radar and the attitude reference signals for the autopilot regardless of the position of the switching unit.

There is no written procedure in the Zantop L-188 manual which describes how to identify a malfunctioning approach horizon/vertical gyro if the instrument indications are obviously incorrect but no gyro or horizon failure warning appears. However, identification of unusual attitudes and instrument nonagreement situations was covered in Zantop flight training on the L-188 flight manual and in all other phases of flight instruction.

1.17.3 L-188 h-flight Structural-Failure Accident History

The Lockheed Electra L-188 was certificated by the Civil Aeronautics Administration in 1958. There were two fatal accidents as a result of inflight structural failures in the 18 months after August 1958. The first accident involved a L-188 near Buffalo, Texas, where the probable cause of the accident was the structural failure of the left wing from forces generated by undampened propeller "whirl mode." (See appendix H.) The second accident occurred March 17, 1960, near Cannelton, Indiana. The cause of the accident was the separation of the right wing due to flutter induced by oscillations of the outboard engine nacelles.

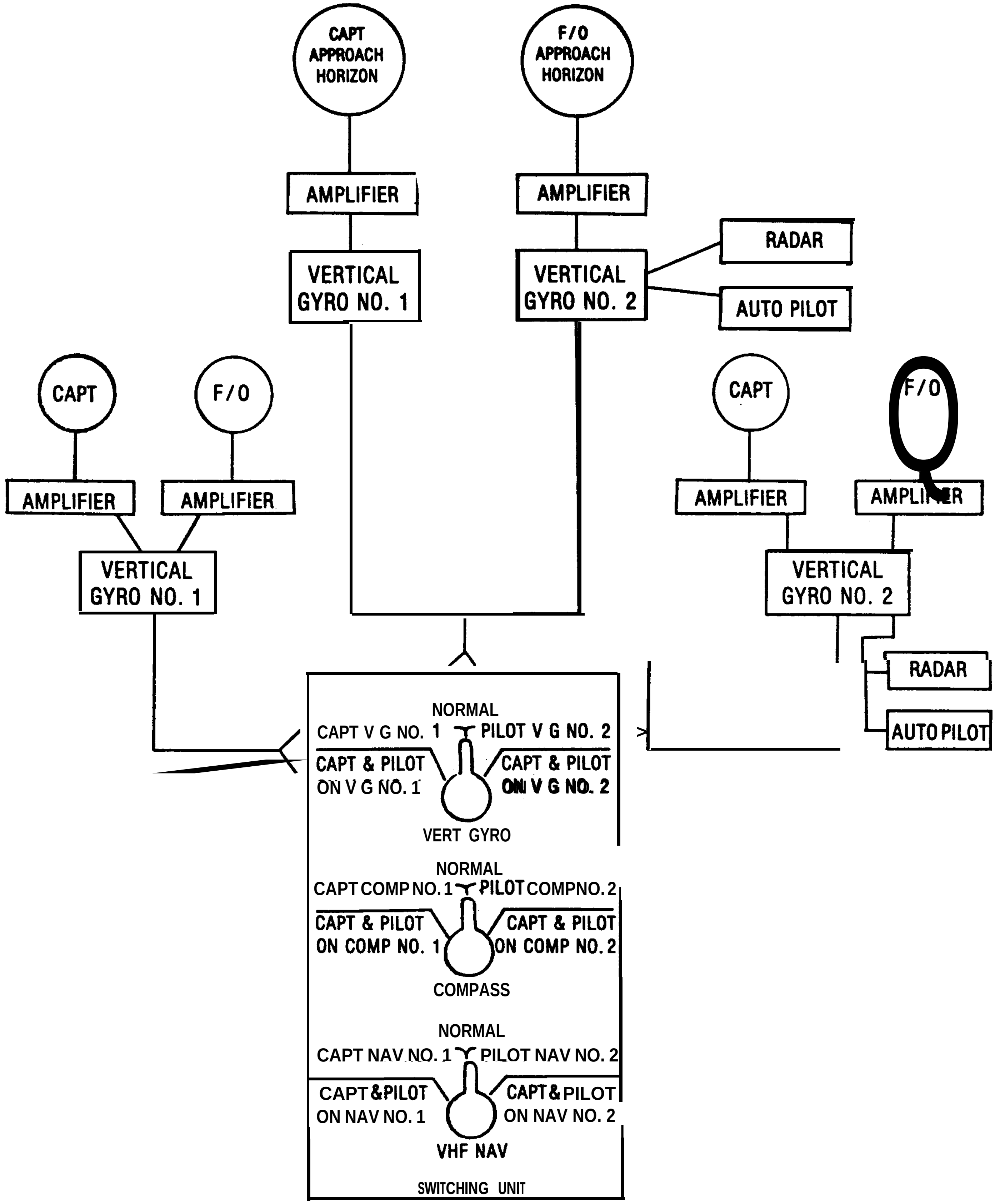

Figure 3. Wilcox Switching Unit

As a result of these accidents, detailed studies were conducted of the damage patterns present in "whirl mode" associated structural failures. In general, "whirl mode" evidence was found in the powerplant support structures which revealed signs of cycling in the form of damage caused by repeated bottoming of the front mounts, curved scratches on one of the swirl straighteners, and repeated interference of fracture surfaces. The evidence, particularly the curved scratches on the swirl straightener, was indicative of the propellers having oscillated violently for a short period of time before overall displacement which accompanied the disintegration of the powerplant structure.

On May 3, 1968, a Lockheed Electra L-188 encountered an area of severe thunderstorms near Dawson, Texas. The flightcrew lost control of the airplane and a structural failure occurred during the recovery attempt from the unusual attitude. As part of the investigation of this accident, the Safety Board requested the National Aeronautics and Space Administration to perform simulator tests using FDR data from the accident airplane. The objective of the simulator test was to determine whether the airplane could be maneuvered to produce the variations of flight parameters exhibited on the FDR tape. The simulator tests indicated that "a rational re-creation of the terminal flight recorder indications of altitude, airspeed, and total heading change could be produced by maneuvering the simulated airplane to maintain an approximation of the normal acceleration values recorded in the accident aircraft, and by rolling, at a moderate rate, from a moderately banked, right climbing turn to a right-bank of approximately 105°."

On November 18, 1979, a Transamerica L-188 crashed at Salt Lake City, Utah, when its flightcrew lost control of the airplane after a failure in the airplane's electrical system. The flightcrew had requested no-gyro vectors to visual flight conditions. During the descent, the airplane attained a high rate of speed which resulted in structural damage and an inflight separation. The Safety Board concluded that "the flightcrew could not resolve the instrument anomalies to determine proper aircraft attitude reference, and became disoriented and lost control of the aircraft."

As a result of this accident, on March 13, 1980, the Safety Board forwarded Safety Recommendation A-80-19 to the Federal Aviation Administration (FAA). The safety recommendation stated:

> Amend 14 CFR 121.305(j) to extend its application to all large turboprop aircraft to require an additional attitude-indicating instrument, for bank and pitch, operating from a source of power independent of the normal electrical generating system as is now required on all large turbojet aircraft.

The FAA rejected the safety recommendation on June 11, 1980, "due to the lack of flight control or electrical problems associated with this type of aircraft." The Safety Board continues to carry the recommendation in an "Open" status. However, as a result of the FAA's inaction, the recommendation response is classified "unacceptable action." The Safety Board continues to believe that the safety recommendation addresses an important safety issue, especially in view of the facts of this accident investigation.

1.17.4 Human Performance Data

Zantop's pilot and training personnel were interviewed to obtain background information on the flightcrew. The flightcrew were characterized as very competent.

A former Zantop first officer, who is now an FAA Operations Inspector, stated that the captain often read books and newspapers while en route. He would turn the cockpit overhead lights "full bright" to facilitate reading. However, she said, "He didn't get so wrapped up in reading that he couldn't drop it." She had flown with the first officer when he was a flight engineer and had also flown with him off-duty in private airplanes. She characterized him as an excellent pilot. She believed the first officer would have flown the airplane manually rather than have engaged the autopilot. She said, "Besides, those autopilot's don't work on most of the airplanes." She estimated that she had flown 3,000 hours with Zantop, yet used the autopilot only 200 of those hours. She said, "fishtailing" and "porpoising" were the most likely autopilot malfunctions.

She said it was routine for the flight engineer to switch the Wilcox switching unit to other gyros when one of the attitude instruments provided erratic information.

1.18 New Investigative Techniques

None.

ANALYSIS

2.1 General

The flightcrew was properly certificated and each member had received the training and off-duty time prescribed by FAA regulations. There was no evidence that medical or psychological factors adversely affected the flightcrew's performance.

The weather forecast available to the flightcrew was substantially correct. The airplane was likely between layers of clouds at FL 220. The lower level, as stated in the CVR transcript, was about 14,000 feet when Flight 931 climbed to cruise altitude. The actual ceiling near Chalkhill, Pennsylvania, probably was about 9,000 feet. The base of the upper clouds near the accident site may have been as low as FL 220, with the cloud tops about FL 250. There was a potential for moderate or greater turbulence between 16,000 feet and FL 190; however, there should not have been significant turbulence at FL 220, and this conclusion was supported by an analysis of the g trace on the FDR. The wind near FL 220 was about 206° at 103 knots.

The airplane was certificated, equipped, and maintained in accordance with applicable regulations and procedures. The examination of the airplane's maintenance records did not reveal a history of logbook entries which indicated powerplant, structural, flight instrument, autopilot, or systems deficiencies related to inflight structural failure or loss of airplane control while inflight. The observations of the FAA inspector concerning the "fishtailing" and "porpoising" characteristics of the autopilot were not safety issues and were not considered to be factors in the accident. The weight and balance and center of gravity of the cargo load and the airplane were within limits.

2.2 Inflight Structural Failure and Fire

The airplane structure and components were analyzed to determine if the inflight separation was caused by a component or structural failure under normal airloads, or after the airplane was exposed to excessive loads.

The examination of the break in the left wing outboard of the No. 2 engine did disclose some small areas of fatigue. However, the fatigue was not considered significant to the ultimate separation of the wing. Examination of all parts of the left wing indicated clearly that the separation of the wing resulted from a gross overstress and not from the failure of a single member due to fatigue or from loads imposed by normal operating conditions.

Examination of the right wing showed that the outboard wing section just outboard of the No. 4 engine separated in flight and that inflight fire erupted after this separation. The longitudinal splitting of the web section and aft bending of the front and rear spar web sections suggested that the right wing tip folded aft while under internal pressure. The outboard wing most likely was damaged by centrifugal loading that moved fuel rapidly outboard toward the wing tip. This movement would cause an overpressure in the wing outer section, which would break rib members, fragment wing planking, and longitudinally split the spar web sections from the spar caps. The wing section could then fold aft, separating the spar web sections from the spars. A violent roll and/or yaw appeared to be the probable movement which indicated separation of the right wing outboard section.

None of the four engines or propellers showed any evidence of pre-inflight separation or damage. None of the engines was operating at impact as revealed by the examination of the engines and propellers. The inflight breakup of the airplane severed the fuel supply and later caused the engines to flame out. The engine mounts of each engine were examined to detect signs of a "whirl mode." None of the engines or the mounts showed any evidence of having been subjected to dynamic loading conditions such as repetitive multidirectional contacts, opposite directed contact marks, or repetitive compressive bottoming out.

The fire in the right wing outboard of the No. 4 engine started after the outboard right wing tip separated. There was no sign of fire or heat distress on any of the outboard pieces. It is likely that ruptured fuel lines and electrical wires caused the inflight fire. However, the fire was extinguished at or before impact, since there was no ground fire.

In summary, excessive aerodynamic loads were imposed on the airplane, ultimately causing the breakup of its structure. The left wing probably separated first from excessive positive upload, followed by a violent roll and yaw which overpressurized the right wing tip tank. The violent movement could have separated the right wing engines and outboard wing section. After the right wing section separated, the stub end of the wing caught on fire at the separation. The fire burned itself out or nearly out before ground impact.

2.3 Operational Interpretation of Flight Instruments

The elimination of the possibility of inflight separation under normal operating conditions led the Board to focus its analysis on flightcrew actions which could have resulted in the excessive aerodynamic loads. The meterological and flight conditions mandated that the flightcrew derive attitude information exclusively from cockpit flight instruments, since there probably was no defined horizon visible. It was possible that the flightcrew had some ground reference, but the lower cloud layers would have made ground reference and the horizon indistinct. Consequently, the Safety Board examined and tested all flight instruments and components to the extent possible to determine if false or contradictory flight instrument information was being presented to the flightcrew.

There was no information in the airplane records to indicate that flight or attitude instruments had malfunctioned frequently in the past. Additionally, flightcrews who had operated N5523 previously had not experienced instrument problems, except for problems with the airborne weather radar and the autopilot. Conversations on the CVR indicated that the crew of Flight 931 experienced difficulties with the tilt of the weather radar and the approach horizon on the first officer's instrument panel. At 0112:54, the captain indicated that even though the radar antenna had been set to the full up position, it actually ended up aimed at the ground. At 0120:28, he indicated again that he could not control the tilt of the radar.

At 0132:24, the first officer states, "* Kept turnin'-- that's ah," and the captain said, "Gyros ah screwed up ---." There was additional conversation, and at 0132:41 the first officer stated, "Wings level now," and "Chuck, could you switch it over to No. 1." The first officer then confirmed that the attitude information had improved. The "switch" the first officer requested was to reposition the vertical gyro switch in the Wilcox switching unit from the normal position to the No. 1 position, which resulted in the first officer's approach horizon being powered from the No. 1 vertical gyro. This action was confirmed by the position of the gyro switch in the unit after the accident. Consequently, it is apparent that some malfunction or abnormality of the No. 2 vertical gyro system was recognized by the flightcrew, and the physical indication of the problem was noted primarily in the first officer's approach horizon. Although there was no indication in the CVR conversation that the "Gyro" or the "Horizon Failure" warnings were visible when the captain concluded that the gyro was malfunctioning, the comment "Gyros ah screwed up---" is indicative of pitch and roll irregularities in the No. 2 vertical gyro, since the flightcrew immediately switched to the No. 1 vertical gyro. There was no postaccident evidence to indicate there was a malfunction in the vertical gyro (indicated by a "Horizon Failure" warning), or in the amplifier and associated circuits (indicated by the "Gyro" flag on the face of the first officer's approach horizon). Nevertheless, it is concluded that a malfunction in the No. 2 vertical gyro system had been identified by the flightcrew which caused the first officer to select the No. 1 vertical gyro at 0137:07 and that the malfunction could have been in the gyro itself, in the amplifier, or in both components. The Safety Board could not determine whether the selection of the No. 1 vertical gyro corrected the malfunction, since impact damage to the affected instruments and components precluded conclusive tests and analysis.

Had the problem been with the No. 2 vertical gyro, the selection of the No. 1 vertical gyro at 0137:07 would have provided the flightcrew with accurate indications. However, if the problem was with the amplifier or associated circuits of the No. 2 vertical gyro, selection of the No. 1 vertical gyro would not have eliminated the false indications, since pitch and roll signals from the No. 1 vertical gyro would have been processed through the defective amplifier. Furthermore, a malfunctioning amplifier or associated circuits would cause the "Gyro" warning flag to appear only if there was a power interruption in the vertical gyro sytem. A malfunction not related to a power source would not trigger an actual warning, as such, but the indications on the affected approach horizon and other pitch and roll instruments would be inconsistent. In other words, the first officer's approach horizon would receive inaccurate inputs regardless of which vertical gyro was selected. The Safety Board believes that this may have been the situation on Flight 931, and that the captain's approach horizon likely was the only accurate pitch and roll data available to the flightcrew.

Examination and testing of other flight instruments and autopilot components were not conclusive because impact damage precluded meaningful tests. The No. 1 vertical gyro could not be tested. The examination of the No. 2 vertical gyro did reveal that seven reference signals, including the "Gyro" warning flag voltage reference signal, were inoperative. Additionally, several wires in the gyro "pigtail" electrical cable were broken, and a metallurgical examination of the wires proved inconclusive. Therefore, the possibility remains that no preimpact malfunction was present in the No. 2 vertical gyro, and that the deficiency which manifested itself in the first officer's approach horizon stemmed from the amplifier and the associated circuits.

Given the lack of evidence concerning the preimpact status and reliability of the airplane flight instruments, the Safety Board, relying on CVR/FDR information, analyzed the sequence of events based on three scenarios, (1) that the first officer was flying the airplane with the autopilot engaged, (2) that he was flying the airplane manually, receiving incorrect pitch and roll data all the while; and (3) that the first officer was flying the airplane manually but misinterpreted the pitch and roll data after 0144:11.

Autopilot.--After the Wilcox switching unit was switched to the No. 1 vertical gyro, both approach horizons were driven by the same vertical gyro. However, the airborne radar and the autopilot remained driven by the No. 2 vertical gyro. If the No. 2 gyro had been precessing or otherwise malfunctioning, the erroneous signals would have continued to be supplied to the autopilot even after the switching unit had been switched. The first officer may have engaged the autopilot after leveling the airplane at FL 220 and switching to the No. 1 gyro. As long as the airplane was not turned, the No. 2 vertical gyro would have sent signals to the autopilot indicating small pitch and roll changes, and the airplane would have remained generally in the wings-level attitude first established by the first officer. From 0135:45 until 0143:09, the airplane remained at a constant altitude and the heading should not have varied. However, at 0143:09, the first officer started a right turn when Cleveland ARTCC cleared Flight 931 after the vertical gyros were switched to the Dryer VOR. This change of course was the first major course change after the vertical gyros were switched and would have caused signals for large pitch and roll changes to be transmitted to the autopilot.

At this point, however, if the No. 2 vertical gyro itself was malfunctioning, incorrect signals would have been transmitted to the autopilot computer as the computer attempted to bank the airplane to achieve the commanded heading. Concurrent with the change of heading, the first officer changed communications and navigation radio frequencies, necessitating that he look away from the flight instruments. If the computer had no roll reference signal from the vertical gyro because of a malfunction in the No. 2 vertical gyro, the autopilot would have been capable of deflecting the flight controls to the deflection limits because the vertical gyro roll reference signal also limited the bank angle the autopilot can command. Under such conditions, the airplane could be put into an unusual attitude rapidly. Based on this scenario, the exclamation at 0144:11 and the confusion which followed can be explained if the No. 2 vertical gyro provided faulty roll signals to the autopilot which, in turn, resulted in the rapid development of an unusual attitude. The CVR indicated that between 0144:11 and 0144:18.5 the flightcrew appeared not to take control of the airplane during which time the airspeed increased to where recovery may have been impossible. The inability to recognize the developing unusual attitude may have resulted from (1) the lack of outside visual cues, (2) brief doubt about the validity of the first officer's approach horizon because of the earlier vertical gyro problem or (3) the malfunction in the vertical gyro system may have also affected the first officer's approach horizon.

While this scenario is considered to be a feasible explanation for this accident, the consensus of opinion of Zantop pilots was that the first officer would not have used the autopilot. They stated that he preferred to fly the airplane manually and usually did so because the autopilots on the L-188 Electra frequently porpoised or fishtailed.

In summary, since most of the autopilot components were damaged too badly to test and since the components which were tested exhibited no malfunction, it is likely that if the upset of the airplane occurred while the autopilot was engaged it was started by invalid pitch and roll commands from the No. 2 vertical gyro and not from an autopilot malfunction. The evidence is insufficient to permit the drawing of a conclusion that the autopilot was engaged at 0144:11, or that the autopilot malfunctioned, either independently or in concert with inaccurate signals from the No. 2 vertical gyro. However, based on the impressions of other Zantop pilots, it is likely that the autopilot was not engaged by the first officer.

Flying Airplane Manually.--With the autopilot not in use, the selection of the No. 1 vertical gyro at 0135:45 would have provided correct pitch and roll data to the first officer's approach horizon unless the No. 2 vertical gyro amplifier had malfunctioned. If, however, the No.2 vertical gyro amplifier was malfunctioning, at 0143:09, when the first officer started a turn to the Dryer VOR, his approach horizon would have started receiving incorrect data. The airplane should have been turned soon after 0143:09 and should have been established on course by 0143:35, or shortly thereafter. It is apparent from the lack of conversation or concern before 0144:11, when someone said "(altitude)," 3/ that no problems had been recognized by the flightcrew. Moreover, the airspeed, altitude, and g trace data from the FDR showed no deviations until about 0144:11 when the altitude and airspeed data reflect positive changes. About 0144:14, the g trace on the FDR showed an abrupt change to 1.17 g.

Since the onset of the right bank was as much as a minute after the airplane was turned to a new heading, it is likely that the first officer had looked away from the flight instruments after turning to the Dryer VOR. During that time, he probably had changed communication radio frequencies, made two radio transmissions, and changed navigation radio frequencies. The flightcrew's attention was directed back to the flight instruments at 0144:11 as the airplane entered a right bank and the airspeed indicator started to show increased airspeed. At that point, the flightcrew may have received conflicting pitch and roll information from the two approach horizons. Most likely, the first officer's approach horizon differed significantly from the captain's display, and probably gave information which conflicted drastically from what was received from the other flight instruments. The Safety Board believes that the confusion which was evident in the conversations on the CVR after 0144:11 may have been caused by a conflict between information presented on the approach horizons and the other flight instruments.

At 0144:11, when the flightcrew first was alerted to a problem, there was no control input which indicated that the problem had been analyzed. The first control movement was about 0144:14, when a 1.17 g was evident. However, the developing right bank and rate of descent was not corrected at 0144:14. Instead, the flight condition appeared to worsen as the rate of descent increased rapidly. There was no heading information on the FDR, but the indication from the g trace and the airspeed data indicated that the increasing airspeed was matched by increasing positive g forces.

3/ Although the CVR group believed that the word may have been "altitude," the comment "attitude" not only would have been consistent with the situation but also would be similar in sound. Consequently, it is possible that the word "altitude" on the CVR recording could have been "attitude."

The Safety Board can only hypothesize but it is possible that the first officer attempted to stabilize the airplane by first attempting to level the wings. If his approach horizon was incorrect, he could have applied the wrong control inputs as he reacted to the information before him. Had his approach horizon indicated a climbing left turn, it would have caused him to correct the airplane's altitude to the right and compound the actual problem. This scenario would explain the rapid deterioration of the flightpath after 0144:18.1. The CVR indicates that someone had recognized the rapidly increasing airspeed by 0144:21.1 and retarded the throttles. The activation of the landing gear warning horn confirmed that this action occurred, even though by then the airspeed had reached about 237 knots.

The third scenario considered by the Safety Board involved the first officer flying the airplane manually, selecting the No. 1 vertical gyro at 0137:07, eliminating the discrepancy in the first officer's approach horizon, and the flightcrew's receiving correct pitch and roll data after 0137:07.

After 0139:02, there virtually was no conversation in the cockpit between crewmembers. The flight engineer was making engine log entries, as witnessed by his request at 0141:27 for "times and temps." It appeared that someone, presumably the captain, was reading, since the sound of pages being turned was recorded on the CVR at 0142:43. The first officer was involved in flying the airplane and in making radio transmissions. At 0143:09, Cleveland ARTCC cleared the flight direct to Dryer VOR and assigned a new frequency. The first officer switched frequencies and transmitted, "Good evening Cleveland, Zantop nine thirty-one's with you flight level two two zero, we are going direct Dryer." Since there had been insufficient time to tune in Dryer VOR and since he probably did not know the frequency without reference to the chart, he then would have diverted his attention from the flight instruments to the map and the radio tuner heads before focusing on the flight instruments again. About 36 seconds elapsed between the radio conversation and the comment of ("altitude") at 01:44:11. If the airplane was not trimmed properly after the turn to Dryer VOR at 0143:29, it was possible that a right descending turn started during the 36-second period when the first officer's attention was diverted to look up radio frequencies and tune the navigation radio. At 0144:11, when some crewmember noted the altitude of the airplane, the obscure nighttime horizon and the previous experience with the gyro malfunction may have resulted in the confusion reflected by the conversations on the CVR tape, and allowed an unusual attitude to develop before initial corrective action was taken. For whatever reason, the corrective action was inadequate to regain control over the airplane and may have, in fact, aggravated the spiral if only backpressure was applied to halt the rate of descent.

This third scenario assumes inattention and an inadequate instrument scan by the captain and first officer, and the lack of proper response when the developing unusual attitude developed. As with the other possible scenarios, however, there was insufficient evidence to conclude that these events reflect the development of the accident.

In summary, the Safety Board believes that there is sufficient evidence to conclude that a malfunction occurred in the No. 2 vertical gyro system and that the flightcrew used the No. 1 vertical gyro to drive the approach horizons. About 0144:11, the airplane started an uncommanded right, descending turn which was not corrected by the flightcrew. The most likely reason why the flightcrew was unable to react properly was a failure in the first officer's attitude indication system which gave him an incorrect indication of the pitch and roll condition of the airplane. Although a positive conclusion cannot be reached, the failure or malfunction probably was in the amplifier or associated circuits of the No. 2 vertical gyro. There was no evidence which indicated whether the autopilot was used in the flight.

The flightcrew should have recognized that a malfunction of the No. 2 vertical gyro would disable the autopilot. They appear to have concluded there was a problem in the No. 2 vertical gyro since they had physical evidence of the gyro problem and shifted the first officer's approach horizon to the No. 1 vertical gyro. However, it is not clear they recognized that the failure could have been in the amplifier since they do not appear to have reached the conclusion. However, they should have anticipated that, in the event of instrument conflicts, the captain's approach horizon would be the reliable pitch and roll display. Consequently, they should have assumed that the captain's approach horizon was the only reliable pitch and roll display in the cockpit.

2.4 Human Performance

Reaction Time.--Although it was evident that there was an initial period of confusion at 0144:11, nevertheless, the flightcrew did have a discrete period in which to react to the unusual attitude. Therefore, the issue of whether the reaction time of the flightcrew was appropriate for an attentive, professional flightcrew is important to the accident. Unfortunately, the majority of information on human reaction time is derived from laboratory studies which necessarily take place under artificial, controlled conditions. Laboratory studies typically require simple responses to anticipated stimuli under circumstances that do not resemble situations encountered by pilots during actual operations. Consequently, data derived from laboratory studies usually "are not applicable to unalerted responses or situations in which an operator must make a decision before responding." 4/ However, laboratory studies have been able to isolate the processes involved in reaction time, and this information is useful in analyzing this accident. Reaction time encompasses sensing time, decision time, and response time. 5/ Sensing time is the time required for a pilot to detect a stimulus or "signal," attend to the signal, and most importantly, interpret the signal. Decision time is the time required for the pilot to choose between alternative courses of action, and it increases in proportion to the complexity of the decision to be made. Response time is the time required for the pilot to make a flight control movement or activate an aircraft system.

In operational situations, sensing time can be quite lengthy. A factor that significantly increases detection time under operational conditions is an unexpected signal. "Response to an un-anticipated or weak signal that is partially masked may take upwards of a minute, if it is detected at all. Even strong signals may not be noticed if the operator is attending very closely to his other duties." 6/ The complexity of signals is the primary factor that increases interpretation time for a pilot. Sensory signals presented to the crew of Flight 931 during the unusual attitude situation they encountered may have increased interpretation time to a degree that precluded their effecting a recovery.

Simulator studies have produced data on reaction times under conditions that more closely approximate actual operations. In one such study, reseachers recorded the time required for pilots to initiate power reduction after experiencing the malfunction of a primary flight control. The average time was 2.7 seconds (standard deviation

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4/ Van Cott, H.P., and Kinkade, R.G., Editors. Human Engineering Guide to Equipment Design, Revised Edition, McGraw-Hill Company, 1972, p. 229.
5/ Morgan, C.T., et. al, Editors. Human Engineering Guide to Equipment Design, McGraw Hill Book Company, Inc., 1963, p. 227.
6/ Van Cott, op. cit. p. 299.

0.83 seconds). 7/ In another study, researchers used a helicopter simulator and measured the response completion times of pilots experiencing unannounced, total engine failure. In this ease, the time averaged 3.08 seconds (standard deviation 0.94 seconds). It was concluded that: "On the basis of the available data, a realistic expectation for the time taken by a pilot to respond to an emergency (even one of primary importance) is about three seconds. Given the special conditions pertaining in a simulator exercise, when pilots traditionally expect emergencies, this estimate is probably low rather than high." 8/

An unidentified crewmember on Flight 931 detected an altitude or attitude deviation and brought it to the attention of the others, "*(altitude)*," in a span of approximately 3 seconds. Considering the fact that the deviation was not expected, this detection time perhaps was short, and it indicates that at least one crewmember was attentive to the altitude of the airplane. However, the time taken by the crew to interpret their situation, decide on corrective action, and attempt to execute a recovery is another matter.

Behavorial Factors.--The Safety Board could not determine conclusively that the captain was reading at the onset of the accident sequence. Coworkers established that it was his habit to read in flight with the cockpit thunderstorm lights set on bright. On the CVR transcript, the captain made a comment about lighting that may have referred to adjusting cockpit lights for reading: "Well, you know I don't think these lights are going to do us a # bit of good tonight." If the captain was reading, regardless of the nature of the material, he would have been distracted to some degree from monitoring the flight instruments. The Safety Board recognizes that operational material is read by flightcrew members during a flight. However, reading of nonoperational material is not a good practice because it detracts from the pilot's primary duty, and therefore should not be tolerated in an airplane cockpit. Although an unidentified crewmember made a rapid reaction to the emergency situation, it is possible that the captain was inattentive to the flight instruments and that his inattention was a factor in the accident.

Unusual Attitude Recovery.--Several factors may have affected adversely the crew's ability to recover successfully from the unusual attitude that they experienced. Under visual conditions, outside references can reduce interpretation and decision times dramatically. In the case of Flight 931, however, the crew was flying at night, with no moonlight, on top of cloud cover that impaired if not eliminated most ground references, and perhaps with interior lights set at a level that further obscured any remaining outside references. Although detection of the unusual attitude may have been by means of proprioceptive ("seat-of-the-pants") cues or vestibular cues, the crew had to rely on instruments almost exclusively to interpret the unusual attitude and to effect a recovery.

By referencing flight instruments alone, an unusual attitude may be detected by the concurrent changes on several instruments: attitude indicator, airspeed indicator, altimeter, vertical speed indicator, and (often) heading indicator. The interrelationship of these indications is both relatively complex and critical to interpreting the spatial orientation of the aircraft. The instrument of primary importance to interpreting spatial orientation is the approach horizon, often referred to as an attitude direction indicator (ADI). The flight performance instruments are used to verify the existence and nature of

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'Ii-Green, R.G., and Skinner, R.J. (1981), An Experiment to Measure Response Times of Pilots to a Locked Elevator Condition at Rotation Speed. In: Report on the accident to BAe HS 748 G-BEKF at Sumburgh Airport, Shetland Islands, on 31 July 1979. Department of Trade Aircraft Accident Report No. 1/81. London: HMSO

8/ Chappelow, J.W., An Investigation of the Time Taken to Respond to Double Engine Failure, The Royal Air Force Institute of Aviation Medicine.

an unusual attitude; that is, they are used as a crosscheck to ensure that the approach horizon has not malfunctioned. However, it is likely that the first reaction could be to information displayed on the approach horizon and the airspeed indicators, especially if the unusual attitude that was developing indicated an increasing rate of descent.

On airplanes equipped with two approach horizons, such as the Electra, checking the other pilot's approach horizon usually will also provide verification. Extreme confusion can result when the two approach horizons conflict, as they did in the Transamerica Airlines Electra accident in 1979, or in the less likely situation that they agree but are both presenting erroneous information. In the Transamerica case, a third attitude indicator would have enabled the crew to determine which of the pilot's approach horizons was correct.

If an approach horizon was presenting erroneous information, and the crew or autopilot flew the airplane into an unusual attitude, it would have been almost impossible for the crew to recover from the situation. Flying by "needle-ball-airspeed" is not feasible in the Electra, since small power changes result in large torque differentials and yaw excursions that can fully deflect the turn needle and the ball, even in level flight. If a third, standby, attitude indicator had been available to the crew of Flight 931, a conflict between this instrument and the two main approach horizons may still have caused confusion, but the crew would have had a better opportunity to resolve the conflict and recover the airplane. It is recognized that the rapid buildup of airspeed required the flightcrew to identify and resolve the problem quickly. In this accident, the practical usefulness of the third standby attitude indicator would have been minimal after the airspeed reached a critical level. However, the standby instrument would have provided more assistance than otherwise was available to the flightcrew. Consequently, the Safety Board continues to urge the FAA to reconsider safety recommendation A-80-19 and to require an additional attitude-indicating instrument on all large turboprop aircraft.

Another factor which would affect recognition time was the ease of interpretation of the approach horizon. Although the flightcrew was experienced in the airplane and was accustomed to the approach horizons in the L-188, this type instrument is more difficult to use in unusual or unexpected airplane attitudes. The approach horizons in N5523 had what is known as an "outside-in" presentation, where the pilot visualizes the airplane as if he were outside the airplane and viewing it from behind. Modern attitude indicators have adopted the alternative "inside-out" orientation where the miniature aircraft symbol is fixed in the center of the case with the wing tips at the 3 o'clock and 9 o'clock positions. With this display, the pilot visualizes his spatial orientation from inside the aircraft. When the actual aircraft climbs or descends, the horizon on the attitude sphere moves vertically, just as the earth's horizon appears to do when viewed from the cockpit. This display is preferred because of its relative ease of interpretation.

According to the FAA "Instrument Flying Handbook" under the subject of trends in attitude indicator design:

> The value of the attitude indicator is directly related to the readabililty of the instrument; that is, to the speed and ease with which you can get information from it to determine exact aircraft attitude.

> Although the older type attitude indicators are not difficult to interpret in normal flight attitudes, reference to other instruments to confirm the indications observed on the attitude indicator is recommended and particularly when abnormal flight attitudes are experienced. The greater the divergence of the miniature aircraft from the horizon line, the more difficult exact interpretation becomes, yet the extreme attitude is the condition requiring immediate and accurate visual information.

The Safety Board must assume that the flightcrew was proficient in the use of the approach horizons in N5523. However, the unexpected flight attitude that was encountered at 0144:11 certainly required visual confirmation from the other cockpit instruments to provide an accurate interpretation. The few seconds required to make the confirmation may have been significant in reducing the ability of the flightcrew to correct the airplane's flightpath. It is possible that a more rapid assessment of the flight attitude would have been possible if the approach horizon had been easier to interpret. In any case, a third, standby attitude indicator would have been easier to interpret under "abnormal flight attitudes" since these instruments use the inside-out spatial orientation.

3. CONCLUSIONS

3.1 Findings

1. The flightcrew was certified properly, and each crewmember had received the training and off-duty time prescribed by Federal regulations.

2. The airplane was maintained and equipped in accordance with Federal regulations. There was no history of maintenance deficiencies which would have caused an inflight structural failure.

3. The engines were operating when the inflight breakup started and flamed out as the fuel system was destroyed.

4. The engines, the engine mounts, and the nacelle structure had not been subjected to "whirl mode effect."

5. There were no indications of structural failures other than those caused by excessive aerodynamic loads, fuel tank overpressure, and the ground impact.

6. The fire in the right wing was caused by the inflight breakup and did not start until after the right wing tip separated.

7. The flightcrew assumed that the No. 2 vertical gyro had malfunctioned.

8. The amplifier or associated circuits of the No. 2 vertical gyro was probably the source of the malfunction.

9. The first officer's approach horizon may have displayed incorrect pitch and roll information after the turn to the Dryer VOR.

10. The flightcrew may have received conflicting pitch and roll information from the two approach horizons as they attempted to recover from an unusual attitude.

11. The flightcrew was unable to recover from the unusual attitude because of conflicting or incorrect pitch and roll data, an inability to interpret the attitude display, or a combination of these factors.

12. The prompt reaction to the developing unusual attitude by a crewmember indicates one crewmember was abreast of flight instrument indications. However, the flightcrew did not conduct an ensuing scan of the flight instruments adequate to discover the onset of the unusual attitude.

13. The flightcrew had to rely almost exclusively on flight instruments to interpret the unusual attitude and to effect a recovery.

14. The actions of the flightcrew to recover from the unusual attitude may have aggravated the situation if they maneuvered the airplane in response to the incorrect approach horizon data on the first officer's instrument.

15. The flightcrew overstressed the airplane in an attempt to recover from the unusual attitude.

16. The airplane was not equipped, nor was it required to be equipped, with an independently powered standby attitude indicator.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the airplane's entry into an unusual attitude and the inability of the flightcrew to analyze the flight condition before there was a complete loss of control. Although the precise reason for the loss of control was not identified, an undetermined failure of a component in the No. 2 vertical gyro system, perhaps involving the amplifier and associated circuitry, probably contributed to the cause of the accident by incorrectly processing data to the co-pilot's approach horizon. The inflight structural failure of the airplane was due to overload.

4. RECOMMENDATIONS

As a result of this accident, the Safety Board reiterated Safety Recommendation A-80-19 to the Federal Aviation Administration, as follows:

> Amend 14 CFR 121.305(j) to extend its application to all large turboprop aircraft to require an additional attitude-indicating instrument, for bank and pitch, operating from a source of power independent of the normal electrical generating system as is now required on all large turbojet aircraft.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JIM BURNETT
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ G. H. PATRICK BURSLEY
Member

March 19, 1985

5. APPENDIXES

APPENDIX A

INVESTIGATION AND DEPOSITION PROCEEDING

1. Investigation

The National Transportation Safety Board was notified of the accident about 0230 e.d.t., on May 30, 1984, and immediately dispatched an investigative team to the scene from its Washington, D.C., headquarters. Investigative groups were formed for operations, air traffic control, structures, systems, powerplants, airplane performance, cockpit. voice recorder, and flight data recorder. Human performance, airplane performance, and meterological specialists participated in the investigation.

Parties to the investigation were the Federal Aviation Administration, Zantop International Airlines, Inc., the Bendix Corporation, Allison Division of General Motors, Hamilton Standard Propellers, and Aviall Turbine Service Division.

2. Deposition Proceeding

Two one-day deposition proceedings were conducted; one in Ypsilanti, Michigan, and the other at Burbank, California.

APPENDIX B

PERSONNEL INFORMATION

Captain John J. Bolton, Jr.

Captain Bolton, 37, was hired by Zantop International Airlines, Inc., on April 16, 1973. He held Airline Transport Pilot Certificate No. 2026499 with type ratings in the Convair - 600-640, Lockheed L-188 and commercial privileges for airplane single engine land. He qualified in the L-188 on February 21, 1978. He had a total of 10,047 flight hours, 7,173 of which were in the L-188, and 5,000 of which were as pilot-in-command. His most recent proficiency check was completed May 21, 1984. His most recent first-class medical certificate was issued April 27, 1984, with no limitations. He also held Flight Engineer Certificate No. 2235729, issued May 21, 1973, with a rating for reciprocating engine, and a Mechanic Certificate No. 2161862, issued April 29, 1972, with an airframe and powerplant rating.

First Officer John D. Figarra

First Officer John D. Figarra, 37, was employed by Zantop International Airlines, Inc., on May 21, 1979. He held Commercial Pilot Certificate No. 1798457 with ratings for airplane, single and multiengine land, instruments, issued August 26, 1972. He held Flight Engineer Certificate No. 16336029, issued June 19, 1979, with a reciprocating engine rating, and Mechanic Certificate No. 1724695, issued November 3, 1966, with airframe and powerplant rating. He was upgraded to first officer on the L-188 on December 8, 1983. He had recorded about 3, 534 hours of total flight time, 2,558 of which were in the L-188. He had flown 260 hours as first officer. His first-class medical certificate was issued May 7, 1984, with the limitation, “Holder shall wear correcting lenses while exercising the privileges of his/her airman certificate.”

Flight Engineer Charles R. Embry

Mr. Embry, 57, was employed by Zantop International Airlines, Inc,. on August 16, 1973. He held Flight Engineer Certificate No. 1842162, issued January 24, 1978, with ratings for reciprocating engine powered and turbopropeller powered. He had recorded about 17,587 hours of flight time, 4,779 of which were‘in the L-188. His most recent proficiency check was completed May 20, 1984. His second-class medical certificate was issued March 9, 1984, with the limitation, “Must have available glasses for near vision.” He had been granted a Statement of Demonstrated Ability on January 26, 1967, for defective color vision.

APPENDIX C

AIRPLANE INFORMATION

Lockheed Electra L-188, N5523

The airplane, manufacturer's serial number 1034, was certificated on March 11, 1959, and was purchased by Zantop International Airlines, Inc., on December 28, 1977. The airplane had 28,989 total hours and 33,879 cycles when acquired by Zantop. At the time of the accident, the airplane had recorded about 35,668 total hours and 38,353 cycles.

The most recent routine check was completed May 13, 1984. The last service check and phase check were completed March 20, 1984, and October 3, 1983, respectively.

Powerplants

Engine	No. 1	No. 2	No. 3	No. 4
Serial Number	500519	500625	501706	500793
Date Installed	3-18-84	3-l 8-84	3-l 8-84	2-21-84
Compressor TSO (hours)	8,546	6,255	7,455	5,894
Turbine TSO (hours)	150	4,228	8,683	6,135
Gearbox TSO (hours)	4,564	5,862	13,350	12,082

Propellers	No. 1	No. 2	No. 3	No. 4
Serial Number	P809	P689	P253	P291
Date Installed	9-4-82	4-4-84	12-11-83	2-21-84
TSO (hours)	1,497	3,278	435	3,774

APPENDIX D

TRANSCRIPT OF COCKPIT VOICE RECORDER

TRANSCRIPT OF A FAIRCHILD A-100 COCKPIT VOICE RECORDER
S/N 1063, REMOVED FROM THE LOCKHEED ELECTRA L-188A.WHICH
WAS INVOLVED IN AN ACCIDENT AT CHALKHILL, PENNSYLVANIA OR MAY 30, 1984

LEGEND

CAN	Cockpit area microphone voice or sound source
RDO	Radio transmission from accident aircraft
-1	Voice identified as Captain
-2	Voice identified as First Officer
-3	Flight Engineer
-?	Voice unidentified
DEP	Baltimore Departure Control
WCTR	Washington Air Traffic Control
CCTR	Cleveland Air Traffic Control
*	Unintelligible word
#	Nonpertlnent word
%	Break la continuity
()	Questionable Text
(( ))	Editorial Insertion
---	Pause

Note: Only the air traffic control transmissions that pertain to Zantop flight 931 were transcribed. All times are exprersed in eastern daylight savings time.

INTRA-COCKPIT

TIME 6 SOURCE	CONTENT
01:20:10 CAM-1	I said it's possible
01:20:13 CAM- 1	If we don't switch to another frequency by the time ah we're up there ah ---
01:20:19 CAM-2	That's what we filed for filed for , twenty two unless (you want lower) *
01:20:28 CAM-1	I don't know what to say about this radar --- there it is zero (I don't know what the # it's *)
01:20:40 CAM-2	I think you got the ground there at zero
CAM-1	Sure the # looks like it
01:20:46 CAM-2	There a lake or something out there
CAM-1	I think they wrote it up last week
01:20:53 CAM-1	This is a finicky bugger when it comes to radar
01:21:32 CAM-2	What's after ah this Martinsburg or whatever
CAM-1	Ah ---

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT

c

INTRA-COCKPIT

TIME & SOURCE	CONTENT
01:21:43 CAM-2	J something
01:21:45 CAM-1	J forty three to Dryer * Cleveland Victor twenty six tripe 1'11 get you direct Carleton --- over Cleveland you should be able to get direct Carleton direct Willow Hun --
01:22:03 CAM-2	Cumin' back
CAM-1	J forty three
01:24:57 CAM-?	* *
01:27:03 CAM-1	Out of eighteen nine nine two

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
01:26:28 RDO-3	Arinc Zantop nine thirty one
01:26:32 ARINC	Zantop niner three one San Francisco go ahead
01:26:34	Yeah nine thirty one was out of Baltimore Washington International at zero five hundred slash one one ah fourteen thousand pounds of fuel on board
ARINC	(Arinc six zero roger)

INTRA-COCKPIT

TIME & SOURCE	CONTENT
01:29:00 CAM-2	Do you want to verify that ---
CAM-1	sorry
CAM-2	One twenty four four is in
01:29:03 CAM-1	Is that for us?
CAM-2	One twenty four four is in
01:29:08 CAM-2	I just wondered, do you want me to verify that that's ah ---
CAM-1	Oh --- yeah

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
01:28:57 WCTR	Zantop nine thirty one Cleveland one one two four point four
RDO-2	One twenty four four Zantop nine thirty one
01:29:18 RDO-2	Cleveland Zantop nine thirty one is with you, ah, verify we're suppose to, ah, we're cleared to flight level two two zero
01:29:27 CCTR	Zantop nine thirty one roger, I show you climbing to flight level two two zero
01:29:31 RDO-2	Nine thirty one thank you

INTRA-COCKPIT

TIME 6 SOURCE	CONTENT
01:32:24 CAM-2	*, kept turnin' --- that's ah
01:32:35 CAM-1	Gyro's ah screwed up --- *
01:32:37 CAM-2	Yeah I keep turnin' it was the other way ---
01:32:40 CAM-1	Yeah
01:32:41 CAM-2	Wings level now
01:35:45 CAM-2	Chuck could you switch it over to number one
01:35:48 CAM-3	Yeah
01:36:01 CAM-2	Yeah it's level now
01:36:04 CAM-3	letter
01:36:05 CAM-2	Yeah
01:36:07 CAM-3	Okay

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT

INTRA-COCKPIT

TIME & SOURCE	CONTENT
01:36:32 CAM-2	Cruise
01:38:06 CAM-2	Might be just ah ---
01:38:13 CAM-2	Horse power reads low on number two
01:38:18 CAM-2	Horse power readin' low ---
CAM-1	Yeah
01:38:20 CAM-2	Temperature's readin' high and the fuel flow is normal
01:38:26 CAM-2	Are you set ---
01:38:27 CAM-1	They already changed the ah --- anti-ice valve
01:38:30 CAM-3	Ah wait a minute

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
01:36:41 RUO	((Sound of static on radio))
01:37:42 RDO	((Sound of static on radio))
01:38:23 CCTR	Eight six hotel alpha go ahead

INTRA-COCKPIT TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	CONTENT
01:38:33 CAM-3	Reset the fuel flow to around eighty --- and you get a hot temp		
		01:38:36 CCTR	Ah negative
		01:38:38 CCTR	Stand by just a minute
		01:38:40 CCTR	Zantop nine thirty one ah can you tell what the tops, ah, were in that area
01:38:42 x4-3	Might be just the horse power calibration (ya know)		
01:38:47 CAM-2	Did be say tops is this area, is that what he said?		
		01:38:48 RDO-2	(Stand by)
01:38:50 CAM-1	It's clear above and below		
		01:38:52 CCTK	Say again
		01:38:54 RDO-2	We're in the clear right now sir, --- we went through the tops ah ---
01:38:59 CAM-2	What do you figure ---		
JAM- I	I don't know		
3AM-2	About ah--seventeen fifteen		

INTRA-COCKPIT TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATIONS TIME & SOURCE	CONTENT
01:39:02 CAM-1	Yeah	01:39:02 RDO-2	Oh on climbout, we were through the tops at somewheres around fourteen or fifteen thousand
		01:39:07 CCTR	Roger thank you
		01:39:09 CCTR	And November eighty six hotel alpha did you hear that?
		01:39:15 CCTK	An aircraft, ah, climbing out of Baltimore said that he ah climbed out of the tops at ah about fourteen thousand
		01:39:28 CCTR	Welcome
01:41:27 CAM-3	Times and temps (please)		
01:42:43 CAM	((Sound similar to a paper pages being turned))		
		01:43:09 CCTK	Zantop nine thirty one cleared direct Dryer, contact Cleveland Center on ah one two five point one
		01:43:17 HDO-2	One twenty five one direct Dryer Zantop nine thirty one good night

INTRA-COCKPIT

TIME & SOURCE	CONTENT
01:44:11 CAM-?	* (altitude) *
01:44:13.3 CM-2	What's happening here
01:44:15 CAM	((Sound of increasing wind noise))
01:44:15.2 CAM-2	You got it
01:44:18.1 CAM-1	No
01:44:21.1 CAM	((Sound of landing gear warning horn starts))
01:44:22.7 CAM	((Sound of overspeed warning clacker starts and continues to end of tape))

AIR-GROUND COMMUNICATIONS

TIME & SOURCE	CONTENT
01:43:21 CCTR	Good night
01:43:29 RDO-2	Good evening Cleveland, Zantop nine thirty one'6 with you flight level two two zero, we are going direct Dryer
01:43:35 CCTK	Zantop nine thirty one roger

INTRA-COCKPIT		AIR-GROUND COMMUNICATIONS	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
01:44:24.9 CAM	('(Sound similar to structural failure during inflight breakup))		
01:44:26.5 CAM-?	We're dead.		
01:44:27.2 CAM	((Sound of landing gear warning horn stops))		
01:44:30	((End of tape))		

APPENDIX H

WHIRL MODE

A propeller behaves much like a gyroscope in that it will tend to remain in its plane of rotation even though it be loosely mounted. It will stay in this plane unless it is disturbed by a strong external force. When this *occurs,* the propeller reacts in the same manner as a gyro, that is, the reaction is 90 degrees out of phase with the applied force. Possible *forces* which could act on the propeller in this manner include sudden aircraft maneuvers. atmospheric turbulence and gusts, sudden power changes, etc. When such a force is applied to the propeller, it reacts in the following manner: If it is displaced upward by some force, the structural stiffness of the mounting *system* resists the movement and applies a nose-down pitching moment. When viewed from the rear, this moment will cause the propeller disk to turn to the left due to gyroscopic precession. The yaw stiffness of the structure in this direction acts in a like manner and causes the propeller disk to pitch down. The structural resistance in this direction causes the propeller disk to yaw to the right where the yaw stiffness in that direction causes the propeller disk to pitch up, thus completing a cycle. This phenomenon has been termed the "whirl mode", and its direction of rotation is opposite to that of the propeller. Tests and analyses pertaining to the ability of an overspeeding propeller to cause and sustain the "whirl mode" proved conclusively that this could not occur within the speed range of the airplane at any overspeed as long as the engine and nacelle were undamaged. In a normal undamaged airplane, the "whirl mode" can operate only within the limits of flexibility of the engine mounts and is damped out very quickly. If some structural element of the powerplant. the powerplant mounting system, or the nacelle is in a damaged or weakened condition, and results in a loss of *stiffness* in the propeller shaft mounting system, the whirl mode will not damp out rapidly at high airplane speed.

Powerplant installation damage does not significantly change the conditions under which the whirl mode may be initiated. but it makes the phenomenon, which in itself is not hazardous, potentially dangerous in three ways. First, the greater flexibility of a weakened installation can allow the whirl mode more freedom and consequently it can become more violent. Normally, system stiffness increases rapidly as powerplant deflections approach the mount limits. In a damaged installation, this characteristic may be altered.

WHIRL MODE (cont'd)

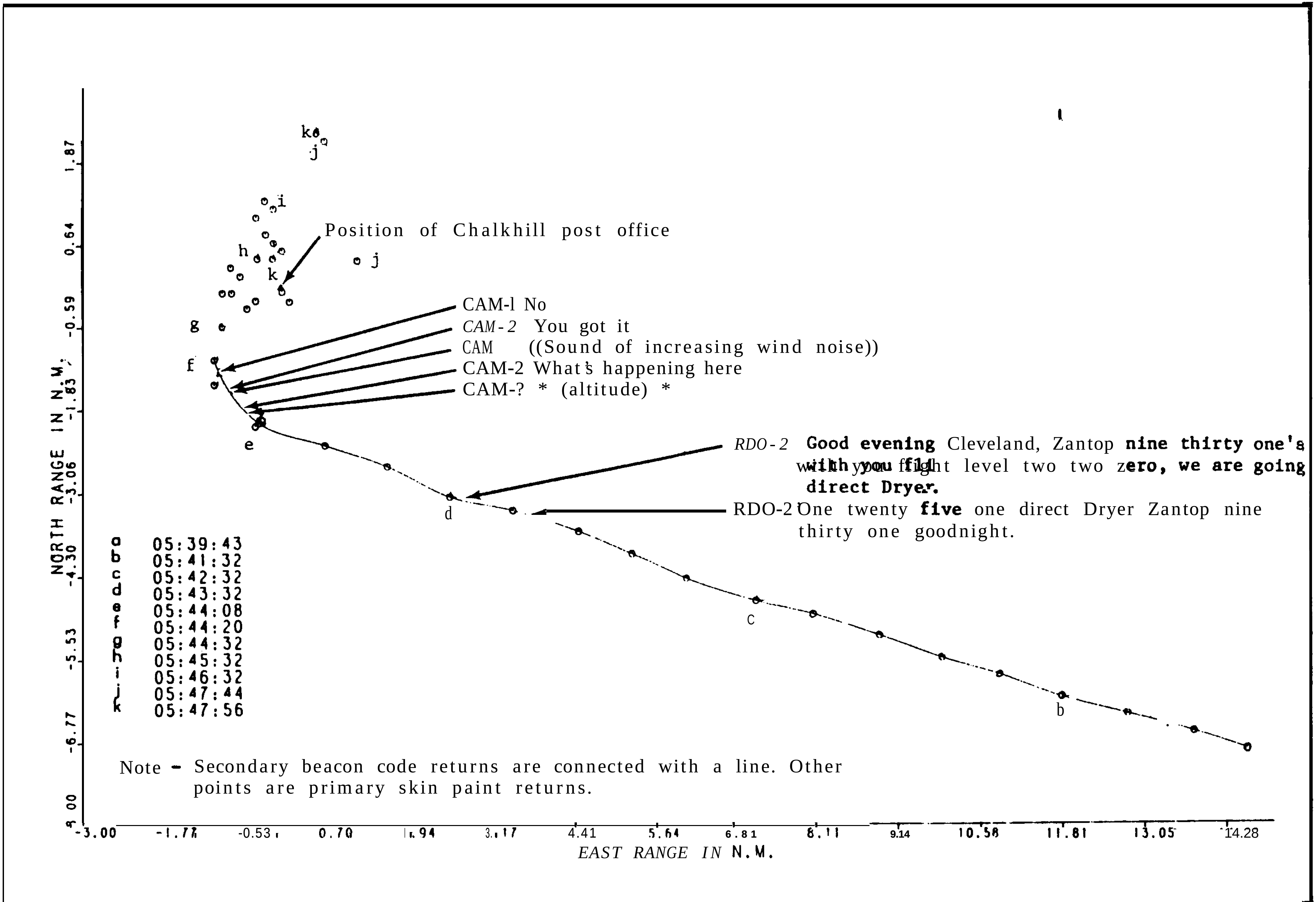
Second, in a weakened installation, the strength level is reduced. This, in combination with the increased violence of the whirl mode, can result in further damage which, as it progresses, further reduces structural stiffness. Third, and most important, is a condition where the frequency of the whirl mode in a damaged and overly flexible structure reduces from its natural value (which is well above the fundamental natural frequency of the wing) to lower values approaching the wing natural frequencies.

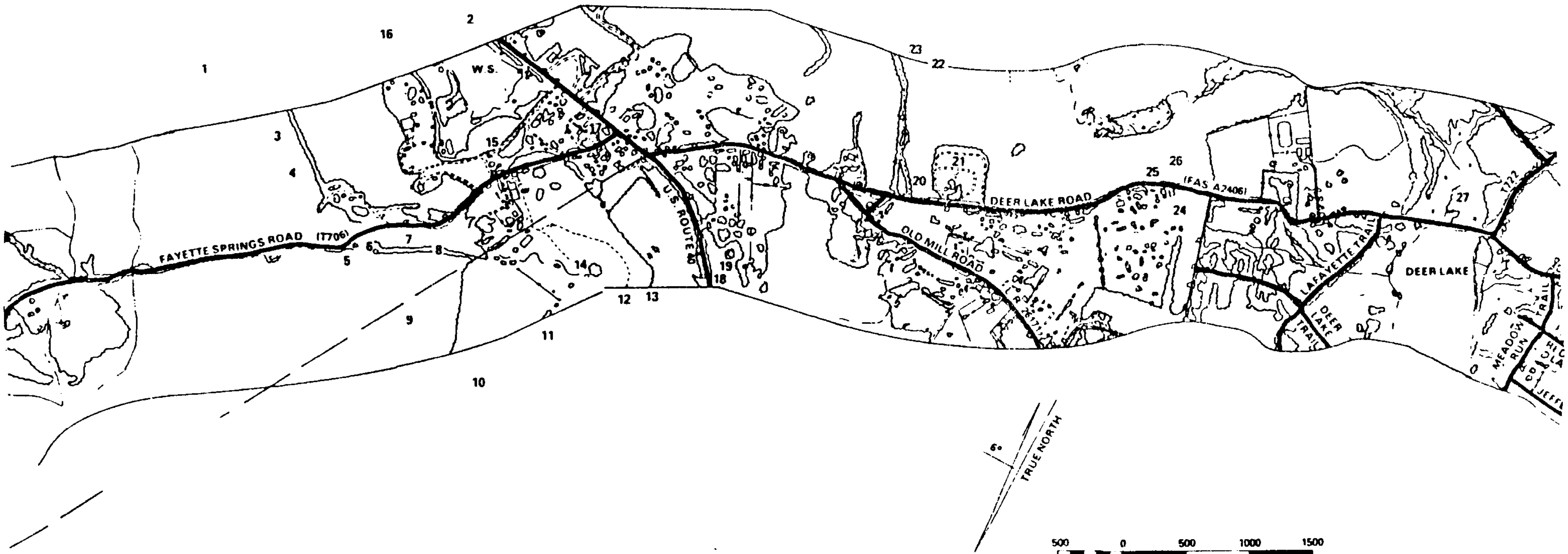
As the whirl mode progresses in a damaged installation, its natural frequency can reduce to a point where it could drive the wing in both up and down bending and torsional oscillations which could, in turn. both reinforce and perpetuate the whirl mode. The three oscillations, whirl mode, wing bending, and wing torsion, would then be coupled at the same frequency. This is a form of induced flutter. It is forced to occur at a lower indicated airspeed than that at which flutter in the classical sense can develop. A situation of this sort can quickly become disastrous through oscillatory divergency. As damping diminishes, each oscillation of the wing becomes greater than the previous one until, finally, structural capabilities are exceeded and structural damage occurs. (The whirl mode can develop at any nacelle position; however, its ability to produce wing oscillations is greater at the outboard positions.)

In the early 1960's, a detailed examination of the pre-LEAP wreckage provided evidence that the whirl mode had been present in the outboard nacelle areas. Examination of the Lord mounts revealed that they had been bottomed out repeatedly. Additional evidence in the area of the structural failures in the powerplant area confirmed repeated cyclic motions prior to complete failure. The number of cycles involved indicated a time period spanning a number of seconds.

The investigation clearly showed that propeller whirl mode can occur with reduced powerplant installation stiffness, at relatively high airplane speeds, and that forces generated by the whirl mode can cause further damage and ● dditibnal reduction in system stiffness. There is evidence that the whirl mode can reach a vibratory magnitude and frequency which, coupled with the wing natural frequency, can force severe wing oscillations.

RADAR DATA


Position of Chalkhill post office
CAM-l No
CAM-2 You got it
CAM ((Sound of increasing wind noise))
CAM-2 What's happening here
CAM-? * (altitude) *
RDO-2 Good evening Cleveland, Zantop nine thirty one's with you flight level two two zero, we are going direct Dryer.
RDO-2 One twenty five one direct Dryer Zantop nine thirty one goodnight.
a 05:39:43
b 05:41:32
c 05:42:32
d 05:43:32
e 05:44:08
f 05:44:20
g 05:44:32
h 05:45:32
i 05:46:32
j 05:47:44
k 05:47:56
Note - Secondary beacon code returns are connected with a line. Other points are primary skin paint returns.
NORTH RANGE IN N.M.
1.87
0.64
-0.59
-1.83
-3.06
-4.30
-5.53
-6.77
EAST RANGE IN N.M.
-3.00
-0.53
0.70
4.41
5.64
6.81
8.11
9.14
10.58
11.81
13.05
14.28



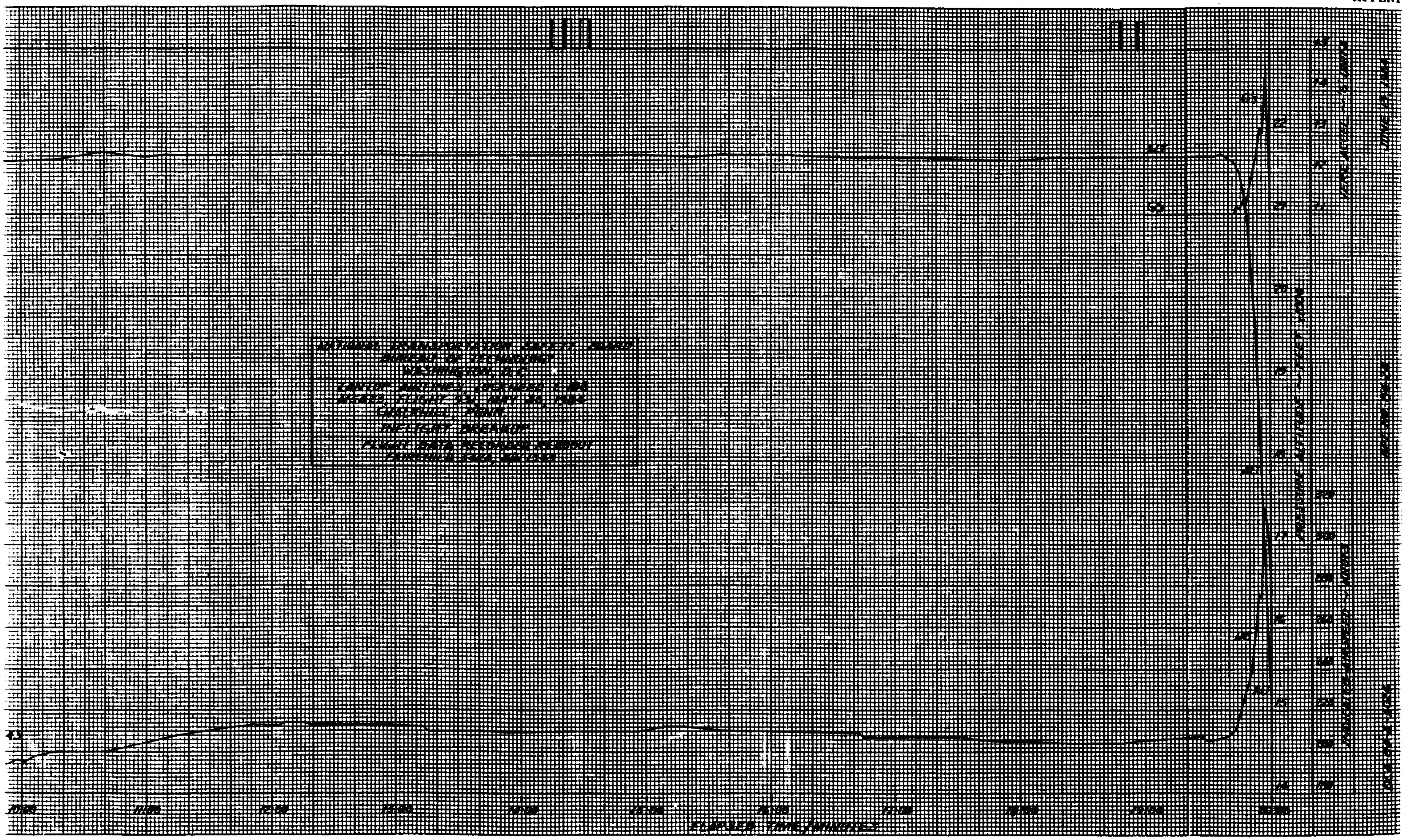
LEGEND

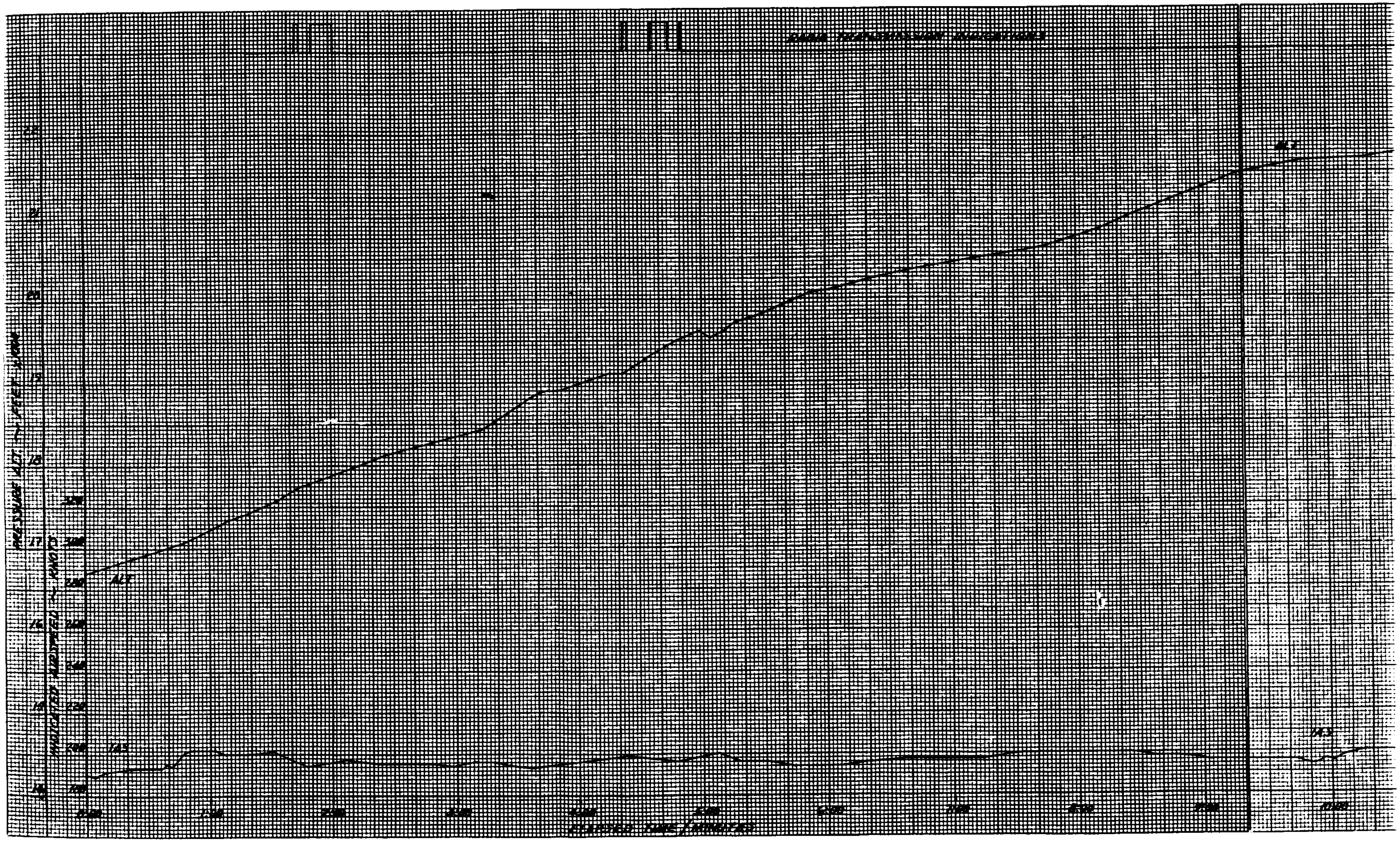
1. No. 4 propeller and reduction gear box assembly
2. Oil cooler door and actuator assembly
3. Right wing, fuselage center section, left wing inboard panel, No 2 propeller, No. 2 engine, left main and right main gear
4. No. 1 propeller and reduction gear box assembly
5. Motorcycle
6. Aft right side of fuselage, FS 910 to 1205
7. Body
6. Cockpit section, nose gear, and left forward entrance door
9. No. 3 propeller and reduction gear box assembly
10. No. 3 engine power section
11. No. 3 propeller spinner
12. No. 3 propeller outer thrust member
13. No 1 blade camber member from No 3 propeller
14. Left fuselage section
15. Right horizontal stabilizer
16. No 4 engine
17. Left wing section, No 1 engine power section and left wing tip
16. Stone house
19. No 2 propeller outer thrust member
20. No 3 blade camber member from No 2 propeller
21. Aft fuselage section
22. Rudder and section of vertical stabilizer
23. Left horizontal stab&liter
24. Section of bottom fuselage skin
25. Left fuselage section
26. Large section of floor structure
27. Section of fuselage (in lake)

APPENDIX F

WRECKAGE DIAGRAM

NATIONAL TRANSPORTATION SAFETY BOARD
ZANTOP INTERNATIONAL AIRLINES, INC
LOCKHEED L 188. N5623
CHALKHILL, PENNSYLVANIA




PRESSURE ALT. ~ FEET x1000
INDICATED AIRSPEED ~ KNOTS
ELAPSED TIME / MINUTES
ALT
IAS